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FINAL REPORT

on

# THE NASA SUBORBITAL PROGRAM: A STATUS REVIEW

by

Ron Teeter and Bob Reynolds

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Approved by:

R R Teeter

R. R. Teeter, Project Manager

N H Fischer

N. H. Fischer, Section Manager
Space Systems and Applications Section

BATTELLE
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

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# 1.0 INTRODUCTION

The NASA suborbital program is an extremely valuable and productive element in the overall NASA science program. It has provided NASA with a highly flexible, low-cost means for performing high quality research in many scientific fields, for supporting a broad spectrum of research programs both within and outside of NASA, and for stimulating international scientific cooperation. Its research programs range from studies of cosmologically important astrophysical objects to the study of the Earth's energy budget; it plays an essential role in the study of the Earth's stratosphere and ionosphere, plays an important role in studies of the Earth's weather, and provides essential support capabilities for NASA orbital programs.

## 1.1 Objective and Scope

The objective of this report is to review the status of the NASA suborbital program and to assess its importance to the astrophysical and geophysical programs within NASA and to the scientific community as a whole. The report provides a summary of the entire program; a more detailed breakdown of some aspects of the program is presented in an appendix.

The scope of the report includes a survey of past scientific and developmental accomplishments, an examination of the trends in program costs, and an analysis of current and future program roles. The technical disciplines examined will be primarily those of astronomy/astrophysics/solar physics and magnetospheric/ionospheric/atmospheric physics. Meterological studies and Earth and ocean observation programs will be excluded.

## 1.2 Program Overview

The suborbital program provides NASA with an inexpensive, responsive means for acquiring scientific data, supporting its orbital programs, and fulfilling its charter to conduct scientific investigations of the terrestrial environment. The program may be conveniently broken down into three components--the sounding rocket program, the balloon program, and the airborne program.

### 1.2.1 Types of Platforms

The airborne program operates aircraft from ground level to approximately 22 km (70,000 ft); the primary vehicles in the NASA fleet are the Kuiper Observatory (C-141), a Lear Jet, two Convair 990s, a U-2, an ER-2, and several WB-57Fs. Major research areas are tropospheric chemistry and dynamics, atmospheric aerosols, troposphere/stratosphere exchange processes, and the role of thunderstorms in the global electric circuit. Important opportunities in infrared (IR) astronomy are provided by the Kuiper Observatory. Program benefits include the ability to observe objects above most of the atmospheric water vapor (IR astronomy), to perform extended manned observations, and to conduct in situ measurements in the troposphere and lower stratosphere.

The balloon program enables scientific instrumentation to be carried up to an altitude of $\sim$45 km (140,000 ft), allowing in situ studies to be performed throughout the stratosphere, a region containing most of the Earth's ozone. Balloons in astronomy provide an opportunity to perform IR observations with greater sensitivity because of the higher observation altitudes than obtainable using aircraft instrumentation; moreover, they provide an opportunity to perform extended observations in the areas of hard X-ray, $\gamma$-ray, and high-energy cosmic ray astronomy. In atmospheric research, balloons provide an opportunity to collect data on an extended time scale, using both in situ measurements and remote sensing techniques. Ballons are capable of lifting payloads weighing as much as 7500 lbs (3400 kg).

Sounding rockets provide access to altitudes of several 100's of kilometers and are the only means of obtaining in situ measurements in the altitude region above balloon float altitudes ($\sim$45 km) and below orbital altitudes ($\sim$200 km). Sounding rockets were the first to indicate the potential importance of high energy astrophysics, with observation of solar ultraviolet (UV) and X-ray emission. Sounding rockets provide the primary tool for obtaining information on the lower ionosphere, which is vital for understanding the impact of solar and terrestrial influences on communications. The limitation of sounding rockets for astronomy is their observing time, usually no more than 10 minutes.

### 1.2.2 Science Fields

1.2.2.1 Astronomy/Astrophysics. This discipline has undergone dramatic development in the last 20 years, in large part because of the suborbital program. The subjects of study in this field include the Sun and planets, stars, tenuous clouds of gas and dust between the stars, magnetic fields associated with normal stars, neutron stars, and galaxies, and galaxies themselves. Information on physical processes occurring in these sources arrives at the Earth in the form of electromagnetic radiation (photons) and high energy subatomic particles (cosmic rays). Astronomers have been able to learn a great deal about celestial objects by the examination of this radiation as it contains information on the temperature, density, chemical composition, presence of magnetic fields, and large- and small-scale motions in the emitting region.

However, before a signal can reach the Earth's surface, it must pass through the atmosphere, and the atmosphere blocks the cosmic rays and all electromagnetic radiation except that in the visual and radio regions (Figure 1-1). Information contained in cosmic rays and most of the electromagnetic spectrum could not be obtained until instrumentation was carried above the Earth's surface and this was first done from suborbital platforms and then satellites.

Electromagnetic radiation is usually discussed as being in one of several categories, distinguished by the energy of the radiation. In order of decreasing energy, there is $\gamma$-ray, X-ray (frequently divided into hard-(high energy) and soft-(low energy) X-rays), ultraviolet (UV), visual, infrared (IR), millimeter, and radio radiation. Thermal sources, i.e., sources emitting electromagnetic radiation characterized by the temperature of the source, emit most of their energy into one of these energy regions, with the higher temperature objects emitting in the higher energy regimes. Stars are

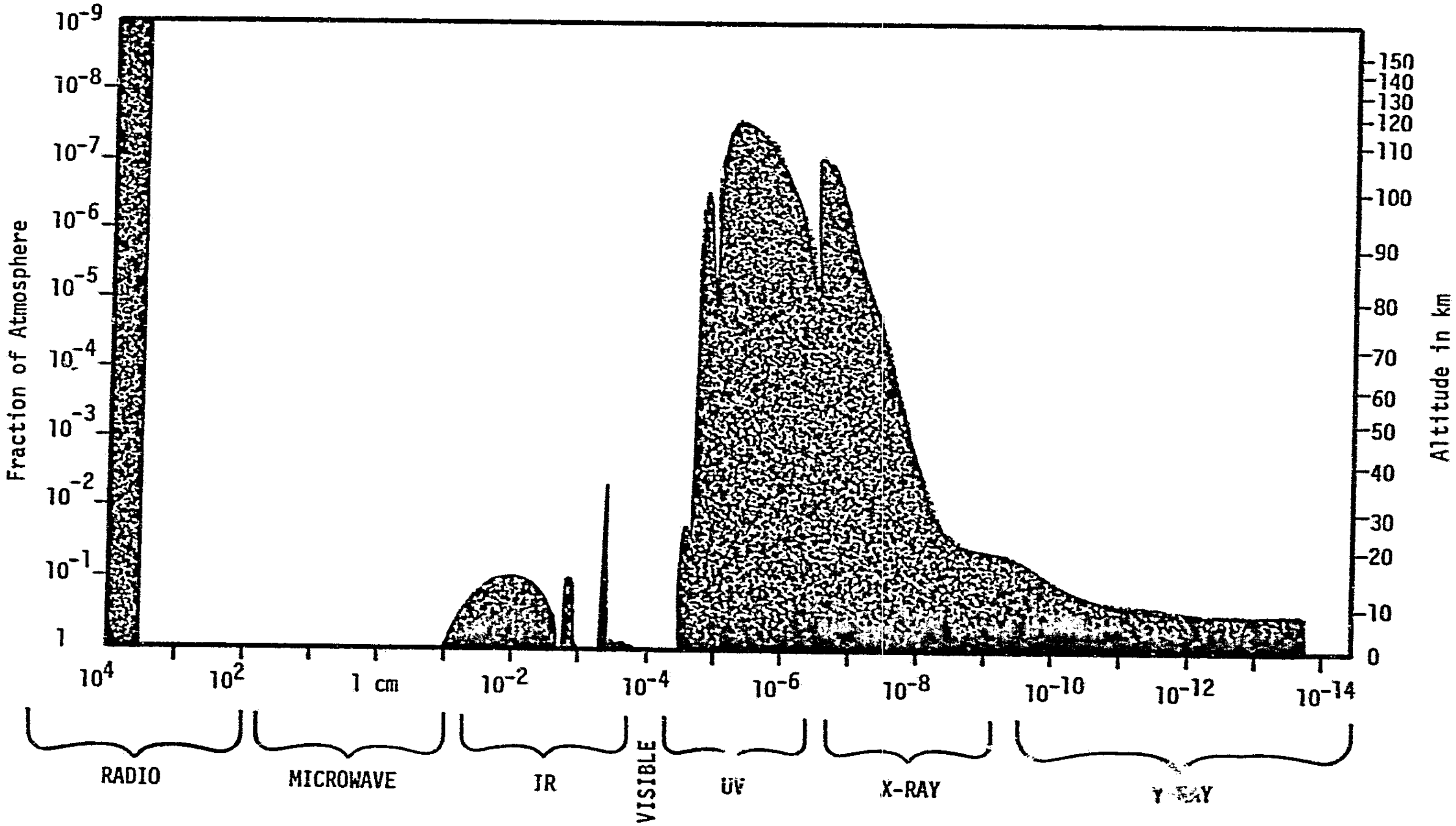


FIGURE 1-1. ATTENUATION OF RADIATION IN THE EARTH'S ATMOSPHERE
(1% TRANSMISSION CONTOUR)

the paradigm thermal sources. Non-thermal sources, such as synchrotron sources, emit electromagnetic radiation with a different type of energy distribution. Such sources are in general more complex and the radiation signature depends on parameters other than the temperature in the emitting region. In synchrotron sources the energy of the emitting particles and the strength of the magnetic field are the important parameters. Radio pulsars are synchrotron sources. A matrix linking the photon energy regimes, the characteristic thermal temperatures, and typical astronomical sources is presented in Table 1-1.

Cosmic rays are extremely energetic charged particles seen almost exclusively in the Earth's magnetosphere and upper atmosphere. Cosmic ray energies can exceed the greatest energies obtainable with manmade accelerators by many orders of magnitude, and the objective of cosmic ray astronomy is to explain the origin and history of these particles. Understanding the acceleration mechanism generating cosmic rays might lead to an improved picture of high energy astrophysical processes and a determination of the source location will have significant cosmological implications.

Because of the attenuation introduced by the Earth's atmosphere, the objective of the NASA programs for astronomy is to get the astronomical instrumentation above enough of the atmosphere to permit useful observations to be made. Orbiting instrumentation does this best, but only at great cost and the accompanying lack of flexibility. The suborbital programs have played an extremely valuable role in collecting data, in guiding instrument development, and in supporting orbiting platform missions. Moreover, some types of studies can be performed more effectively and at much lower cost from suborbital platforms than from orbiting systems.

One subfield important for its astronomical studies as well as its connection with geophysical phenomena is solar physics. The study of the Sun through the entire range of the electromagnetic spectrum has contributed numerous important findings. Suborbital platforms are particularly well-suited for studying such transient phenomena as the solar corona during solar eclipses and particle fluxes associated with solar flare activity.

The matrix of Table 1-2 identifies the essential involvement of the suborbital programs in the various areas of astronomical research. Of the

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TABLE 1-1. CHARACTERISTIC TEMPERATURE AND TYPES OF SOURCES IN DIFFERENT SPECTRAL REGIMES

| Spectral Region (Photon Energy) | Characteristic Source Temperature ($^{o}K$) | Type of Objects Observed |
|---|---|---|
| γ-Ray (>1 MEV) | $10^9$ | γ-ray bursts, interstellar synchroton, solar flares |
| Hard X-Ray (20 KeV-1MeV) | $10^7$-$10^9$ | Solar flares, active galaxies |
| Soft X-ray (100 eV-20 KeV) | $10^6$ | Pulsars, accretion discs around black holes, solar corona |
| [illegible] | $10^5$ | Solar chromosphere, central stars of planetary nebulae |
| Visible | $10^3$-$10^4$ | Stars |
| IR | 100 | Cool stars, planetary atmospheres, pre-main sequence stars |
| Millimeter | 10 | Cold interstellar clouds |
| Radio | 1 | Cosmic background |

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astronomy fields listed in this table, only IR astronomy can be effectively conducted from the ground, and that is only possible in the small IR windows at suitable observation sites such as Hawaii. The rationale for suborbital program involvement in these areas is briefly stated in the following paragraphs.

TABLE 1-2. PRIMARY SUBORBITAL PROGRAM CONTRIBUTORS TO VARIOUS FIELDS OF ASTRONOMICAL STUDY

| Field | Suborbital Program | Driving Factors |
|---|---|---|
| Cosmic Ray | Balloon | High Altitude, Massive Detectors |
| γ-ray | Balloon | High Altitude, Massive Detectors |
| X-ray (hard) | Balloon | High Altitude, Massive Detectors |
| X-ray (soft) | Sounding Rockets | Highest Altitude |
| UV | Sounding Rockets | Highest Altitude |
| IR | Airborne, Balloon | Above Water Vapor |
| Millimeter | Balloon | Above Water Vapor |

γ-ray Astronomy

γ-ray radiation is degraded by ionization, pair production, and photodissociation processes occurring with atoms and molecules in the upper atmosphere. Although roughly half of the signal has been attenuated by the time the radiation reaches maximum balloon float altitudes, nearly all of the signal has been lost at maximum aircraft cruise altitudes. Sounding rockets are not effective for conducting research on γ-ray sources because the sources are intrinsically faint and because γ-ray detectors are very massive. Balloons can operate at altitudes where there has been an acceptably small amount of attenuation and are capable of lifting the large detectors required to study most sources, and so suborbital γ-ray studies are conducted almost entirely from balloons.

X-ray Astronomy

The X-ray region of the energy spectrum lies between the γ-ray and UV regions. Hard X-rays, those with photon energies from 20 KeV to 1 MeV, present detection problems similar to those encountered in γ-ray observations; balloon borne instruments can be used effectively. Soft X-rays, those with energies from 100 eV to 20 KeV, can only be observed from sounding rockets.

UV Astronomy

In contrast to the γ-ray radiation which penetrates to balloon altitudes, most UV radiation is absorbed before it gets to that altitude range. Consequently, sounding rockets provide the only suitable platform for conducting suborbital research over most of the UV range and observations are limited by the necessarily brief time associated with a rocket flight. Over the limited useful range of balloon altitudes, however, some testing of UV detectors can be conducted.

IR Astronomy

The major source of opacity in the IR is water vapor, most of which is confined to the troposphere. Since instrumentation in each of the suborbital programs operates above the troposphere, useful observations can be made from any of the platforms. In practice, the limited observing time available on a given sounding rocket flight has resulted in the majority of IR work being done from airborne and balloon platforms.

The Kuiper Airborne Observatory (KAO), operating at 40,000 ft (13 km) is above 95 percent of the water vapor, the 130,000-140,000 ft float altitude places for balloons place that instrumentation above most of Earth's atmosphere. Both programs are capable of carrying large instrumentation and have the lifting capacity to use cryogenically cooled detectors. Extended time on station, up to 7 hours on KAO and up to days on balloons, are also obtainable.

The airborne program has the advantage of using manned instrumentation, allowing greater flexibility in the observing schedule and in the observations taken and low marginal cost for conducting observations. Balloons have the advantage of greater time on station, less atmospheric background, and less atmospheric line contamination.

1.2.2.2 Plasma Physics. The presence of plasmas in and above the Earth's atmosphere provides an extremely valuable research opportunity for the field of plasma physics. Plasmas play a major role in the Earth's environment from about 50 km to 75,000 km. These plasmas have a direct impact on communications and may play a role in controlling the Earth's weather and climate.

As subjects of study to plasma physicists, these plasmas possess properties which cannot be duplicated in the laboratory. They may possess relatively low volumetric charges, as in the mesospheric plasma, or be highly charged, as for the ionospheric and magnetospheric plasmas; they may be high-density collision-dominated, as for the ionospheric and mesospheric plasmas, or low-density and collisionless, as for the magnetospheric plasma. Laboratory plasmas are physically confined and this introduces boundary effects which seriously disturb the large-scale plasma properties; in contrast, plasmas surrounding the Earth are magnetic-field contained and will perhaps provide insights on containment mechanisms for controlled nuclear fusion. Access to these plasmas using sounding rockets therefore allows the in situ acquisition of plasma data that cannot be acquired in the laboratory.

These plasmas are astrophysically important because they are accessible space plasmas with signatures also seen in astrophysical sources. An understanding of the local conditions associated with specific plasma properties therefore provides insight into local conditions in some astrophysical sources.

Studies of these plasmas also promise to provide valuable insight into the Earth's global electrical current, its effect on the neutral atmosphere, and its effect on the Earth's weather.

1.2.2.3 Atmospheric Physics. The state of the Earth's atmosphere is controlled by the distribution and flux of energy arriving from the Sun, the release of chemical and particulate material from the Earth's surface, and processes occurring at the air-ocean interface. There are two broad study areas in atmospheric physics--atmospheric processes, the study of the short-term (hours to months) behavior of the atmosphere, and climate, the study of the long-term atmospheric state. A primary objective of current atmospheric research is to determine the way in which energy inputs from the Sun and energy and chemical inputs from the Earth affect atmospheric processes and establish climate trends.

Suborbital platforms provide much of the data needed to understand the role and importance of various atmospheric constituents and atmospheric processes. NASA has been primarily concerned with developing an understanding of the atmospheric energy budget, which requires an understanding of processes by which solar electromagnetic radiation is absorbed, how this energy source influences and is influenced by molecular abundances and chemical processes, how the presence of particulates and aerosols affect the atmospheric chemistry, and how energy sources from the Earth's surface lead to the weather patterns produced in the troposphere.

The NASA atmospheric research program has been divided into an upper atmospheric research program, concerned with the altitude regime from roughly 15-50 km, and the tropospheric program, covering altitudes up to 15 km. Both remote-sensed and in situ measurements are taken, but NASA has emphasized the development of remote sensing instrumentation to support atmospheric research from satellites. Balloons and aircraft are used in both programs.

Upper Atmospheric Research

The upper atmospheric research program consists primarily of stratospheric research work covering the altitude regime of 15-50 km, an altitude regime extremely important because it contains most of the atmospheric ozone. Most of this regime is accessible by balloon and the balloons use both in situ and remote sensing instrumentation. Although balloons are the most heavily used platforms, some research is carried on from airplanes, particularly in studying the troposphere/stratosphere transition.

The atmosphere from 80-90 km has aroused increasing interest because of its potentially important electrodynamic properties and has provided a new area for research from sounding rockets.

Troposphere Research

The troposphere program is concerned with the chemical and dynamical properties of the troposphere, the atmospheric region from 0-15 km, the region containing most of the atmospheric $CO_2$. The emphasis for the NASA program has been on developing instruments suitable for assessing global tropospheric chemical properties and, in this study, airborne platforms play the major role.

Severe Storm Studies

The study of processes occurring in association with severe storm systems is an important function of the NASA atmospheric sciences effort. The primary platform used in this effort is balloons, with a reliance on sounding rockets to monitor the phenomena occurring above the storm cell, and aircraft to observe within the storm. The severe storm program involves the combined efforts of the atmospheric and plasma physics research activities.

### 1.2.3 Program Objectives

The suborbital program performs a number of functions. It supports a wide variety of research activities, provides many forms of support for NASA orbital programs, and supports the business of conducting scientific effort in several ways. To facilitate the discussion of specific program objectives, a classification of objectives into (1) research (1.2.3.1), (2) development (1.2.3.2), and (3) general support (1.2.3.3) categories will be made.

1.2.3.1 Research Objectives. The research objectives involve activities in five general areas:

(1) Continuing studies.

Suborbital platforms represent the only means for obtaining some types of data; examples are the sounding rockets for in situ lower ionospheric studies, balloons for in situ upper stratospheric study, and manned, broad-band IR astronomical observations in the airborne program. Moreover, the sub-orbital program provides an opportunity to employ additional instrumentation to complement other programs; examples are IR telescopes on balloons, X-ray and UV telescopes on sounding rockets.

The study of solar eclipses and solar flares has yielded important information on physical processes occurring on the Sun, while studies of the response of the Earth's atmosphere have provided insight into the nature of the Sun-Earth interaction.

(2) Search for new phenomena.

The suborbital program provides a reasonably inexpensive means to introduce new types of instrumentation to look for new phenomena. Based on the results obtained, this activity provides a guide for directions of development of more expensive, specialized instrumentation. The classic example for such a development is the field of high energy astrophysics, in which the early sounding rocket and balloon data indicated there was a large variety of highly active, highly energetic, cosmologically important astro-nomical sources that were undetectable to ground-based instrumentation.

(3) Scientific support of other research programs.

The suborbital program supports a variety of NASA research programs. Calibration and ground truth* support of satellite instrumentation are often essential to obtaining usable data from satellites. In plasma physics, sounding rockets provide vertical profiles that complement the geographical coverage provided by satellites. In general, high energy astrophysical sources are time varying so that there are no "standard" references. Cali-bration for the manned Skylab missions and the Orbiting Astronomical Observatories (OAO's) of the 1970s was provided by sounding rockets and will be needed for future science platforms such as AXAF as well. Provision of

*In situ sampling to verify remote sensing measurements.

photometric standards in the IR will be a project to be accomplished by the airborne and balloon programs, to support future IR orbiting detectors (e.g., those on IRAS).

(4) Time-critical studies.

The study of transient phenomena, for example, comets, eclipses, or solar flares, may not justify the expense of an orbital program yet may represent a source of useful scientific data. For observing transient phenomena, the relatively small expense involved in acquiring suborbital data is important.

The occurrence of an event that requires a rapid introduction of instrumentation for its study represents another use of the suborbital platforms. The relative simplicity and consequent short development time for the suborbital flights is important. Airborne observations can occur almost immediately; sounding rocket development times as short as a month have occurred to place a new instrument into operation.

1.2.3.2 Development Objectives. The development objectives fall into two general areas:

(1) Development and testing of scientific instruments and detectors.

The suborbital platforms provide a relatively inexpensive means of developing and testing new ideas for improving the quality of currently acquired data as well as for opening up new areas for data acquisition. This function has been extremely important in the past and will continue as such in the future; the history of instrument and detector development has been one of increasing complexity with the attendant need to verify design concepts and establish reliability.

The suborbital program has performed the development and testing function for most of the NASA orbital programs. Instrument concepts for the Cosmic Background Explorer (COBE), International Ultraviolet Explorer (IUE), and Voyager were developed and tested within the balloon and sounding rocket programs. All of the instruments on the Gamma Ray Observatory (GRO) have grown from design concepts tested in the balloon program. One of the limitations of satellite programs has been that the large expense of placing instrumentation in orbit requires relatively old (8-10 years) technology and instrument designs of high reliability be used.

Hardware testing within the suborbital program has been facilitated by the ability to refly instrumentation. For sounding rockets, parachute recovery systems have allowed land recovery of science payloads and support hardware for many years. Recent developments at the Wallops Flight Center have enabled even very delicate sounding rocket payloads to be captured by airplane so that recovery over water can also be achieved. Balloon hardware is nominally returned by a parachute recovery system and reflown.

(2) Enhancement of support capabilities.

Collection of useful scientific data and the development and testing of new hardware are primary objectives in the suborbital program. Enhancement of the support capabilities within the program is therefore a major responsibility.

Providing better support for the science has been an ongoing activity, ranging from the introduction of new carriers and new payload support interfaces to the development of new techniques to get the data into the hands of the investigators. Such activity will remain of great importance in the future as the detector technology places greater demands on data acquisition capabilities.

An area of continual development is that of attitude control systems (ACS). Significant progress in the sounding rocket ACS selection has been made in the last 15 years. Of special importance to astronomy has been the development of fine pointing ACS's and the development of a ground-based interactive ACS for use in both solar and stellar observations. For experiments requiring orientation with respect to the local magnetic field lines, the development of attitude control driven by the local field has been very important.

In the balloon program, an ongoing low-level effort has been maintained to make long duration ballooning a scientifically useful option. Development of support for multiple sensor atmospheric research payloads is enabling more data to be gathered on each balloon flight. The drive to provide geographic flexibility in launch facilities has also been of great value in the atmospheric and magnetospheric physics areas. The concept of portable launch facilities in both the sounding rocket and balloon programs has gained in popularity with investigators in the past several years. In the future, such flexibility will be in demand if sufficient funding can be made available to support it.

1.2.3.3 General Science Support. The suborbital program offers NASA an opportunity to provide general science support in two ways:

(1) Graduate research and education.

The low-cost, relative simplicity, and short development times provide established researchers with a means for introducing graduate students to space research. In a suborbital project, a graduate student can reasonably expect to participate in all phases of a project--from instrument design through data reduction and analysis--during his period of graduate work.

(2) Continuity in science areas.

NASA orbital programs are sufficiently costly to be seriously limited* by government and NASA budgetary constraints. Moreover, the scope and size of such programs demand long lead times once funds become available.

Funding constraints and program delays make it impossible to provide continuous availability of orbital facilities in all established fields of study. For any particular technical discipline, e.g., X-ray astronomy, orbital facilities may be available for several years and then absent for an equal or longer period while emphasis shifts to other needs. During this period useful research can be done from suborbital platforms. This has the important effects of providing an opportunity for investigators to remain active in a field when orbital data is not being acquired and helping to assure the development and success of the next orbital program.

(3) Support international cooperation.

The suborbital program provides a low cost way for foreign countries to gain access to the special research capabilities which the program can offer. Each of the three types of platforms have been used extensively by foreign nations. A summary of this collaboration is provided in Table 1-3.

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*Both in terms of the pace with which orbital programs can proceed and the extent to which complementary or equally important programs can be simultaneously funded.

The suborbital program itself benefits by this cooperation as it greatly extends the geographic coverage it can offer to its investigators. Many phenomena, such as solar eclipses, plasma wave instabilities, and aurora, can only be observed in certain locales; without international cooperation many of these locales would be inaccessible.

TABLE 1-3. NUMBER OF FOREIGN COUNTRIES PARTICIPATING IN THE NASA SUBORBITAL PROGRAM DURING THE PERIOD 1960-1981

| | |
|---|---|
| Sounding Rocket | 19 |
| Balloon | 8 |
| Airborne | 11 |

## 1.2.4 Importance to Affected Science Areas

The impact of the suborbital program on the many science fields it affects has been significant. In many cases, suborbital observations have pointed the way for future orbital instrumentation; in other cases, the suborbital observations have been and will continue to be the only source of data.

Much of the intense activity in astronomy in the last 20 years can be directly attributed to the availability of satellite data; these data and the types of instruments used to collect it grew out of early sounding rocket and balloon flights. As in the past, the suborbital program will continue to play an essential role in collecting data when orbital instrumentation is not available and in developing new instrumentation ideas when satellite programs are in progress.

As with astronomy, the fields of atmospheric and space plasma physics research has relied heavily on the NASA suborbital program and will continue to do so in the future. Suborbital observations have been used to calibrate orbital instrumentation, such as the Nimbus VII satellite, and will provide a similar service for the proposed Upper Atmospheric Research Satellite (UARS). Such activities will be essential to future work on the global electric circuit and on establishing global weather and climate models. Suborbital platforms will continue to provide the unique service of allowing investigators to probe specific regions of the atmosphere, ionosphere, and magnetosphere with high spatial and temporal resolution to obtain data that are essential to understanding the chemistry and dynamics of the Earth's atmosphere.

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2. A Review of NASA International Programs, NASA Headquarters/Staff of the International Affairs Division, January 1982.

## 2.0 THE SOUNDING ROCKET PROGRAM

The sounding rocket research program can be traced to the post-World War II era of research with German V-2 rockets. In its early stages it formed the foundation for the U.S. space program, encompassing such luminaries as Werner von Braun and James van Allen. As the art of rocketry matured, the twofold role of rockets as military weapons and as research instruments emerged. Scientific research from sounding rockets in the late 40's and 50's kept a non-military cadre of rocket experts which would one day form the civilian space program.

Although NASA was formed in part in response to the Russian move into space with orbiting instruments, one of its first acts was to establish the NASA sounding rocket program and embark on a program of scientific research. A continuous record of flights in this program has been maintained, starting with the first test of an Arcon rocket by Carl Medrow of the Goddard Space Flight Center (GSFC) on May 14, 1959. Since that time, there have been 2233 flights (as of September 30, 1981) performing such diverse activities as monitoring the solar corona, studying auroral activity with in situ instrumentation, measuring electric currents associated with thunderstorms, investigating galaxy morphology in the UV, and performing experiments on materials processing in near zero-g environments. Sounding rockets have allowed NASA to conduct a research program greater in content, depth, and diversity than would have been possible had NASA pursued only orbital programs.

### 2.1 Capabilities and Limitations

Sounding rockets provide the altitude link between the lower altitude capabilities of the airborne and balloon programs and orbital instrumentation. They are essential research tools in the study of the Earth's upper atmosphere and have been instrumental in the development of the field of high energy astronomy/astrophysics. While the public attention has been captured by the orbital programs, a considerable amount of important science has been obtained in this program.

## 2.1.1 Capabilities

The capabilities of sounding rockets will be demonstrated in the discussion of significant scientific accomplishments, in the satisfaction of program objectives, and in the future role of the sounding rocket program. In this section, these capabilities will be categorized and discussed.

Perhaps the most descriptive statement relating to sounding rocket capabilities is that it is (relatively) simple to organize and conduct research programs on sounding rockets. In orbital programs, hundreds of people are involved in spending millions of dollars over years of time to plan and build a single spacecraft. Such an effort is well invested, as such instrumentation will yield months or years of data. In sounding rockets, a few tens of people spend thousands of dollars over months to plan the experiment, build and fly the insrumentation, and analyze the data. This aspect of sounding rocket research provides several significant advantages.

Most important is the flexibility introduced by the short development times and low cost. Instrument testing is an effective use for a flight, so sounding rockets serve as a test beds for new design ideas and new technology; where a satellite package is based on conservative hardware and design ideas, a sounding rocket payload frequently carries new ideas and new technology; where an instrument failure may be a catastrophe on a satellite, it can be a learning experience on sounding rockets. Because of this, sounding rockets have been used by NASA to test and verify instrumentation to be used on satellites such as the International Ultraviolet Explorer (IUE) and Voyager.

Lower costs and enhanced instrument testing capabilities have been facilitated by recovery and reflight of the science payloads--the scientific instruments, telemetry package, and attitude control system. Moreover, a minimal investment in development of new rockets is made; instead, motors from surplus DoD missiles have been acquired and fitted to satisfy sounding rocket requirements. These have included the Nike and Terrier motors, which have been used as boosters, and the Minuteman (Aries) and Hawk (Orion).

Besides serving a testing role, sounding rockets represent a significant source of scientific data. In plasma and neutral atmosphere research, sounding rockets play an essential role since they are the only means of obtaining in situ data from 45 km, the maximum balloon altitude, up to about 200 km, the lower limit for orbital instrumentation. In addition, sounding rockets can be targeted to study specific regions, for example where auroral activity is occurring or regions in which plasma waves are being observed. By collecting data near apogee and by using parachutes to retard descent rates, data can be collected with high spatial and temporal resolution. The "snapshot" vertical profiles obtainable from sounding rockets are extremely useful for studying atmospheric interaction processes.

In astronomy/astrophysics sounding rocket instrumentation has played more of a pioneering and testing role which is superseded in a given application when orbital instrumentation becomes available. Sounding rockets were the first platforms to indicate the existence of X-ray emission from objects such as the Sun, stars, and galaxies. Data acquired in these sounding rocket flights were used to guide the development of orbital instrumentation such as the very successful Orbiting Astronomical Observatory (OAO) Satellites. In studies which must be conducted during solar eclipses, sounding rockets have the advantage of much longer observing times than satellite instrumentation, which would pass through the region of totality in seconds (in fact this has never occurred) so that sounding rockets will continue to play an important role in gathering data associated with eclipse events.

### 2.1.2 Limitations

The primary limitation of the sounding rocket experiment is the necessarily short duration for data acquisition. For astronomical payloads, observing times of less than 10 minutes limit observations to relatively bright sources. Data acquisition in atmospheric studies can be extended to about 1 hour by deploying a high altitude parachute near apogee.

Atmospheric studies from sounding rockets (or indeed any suborbital platform) give only a localized sampling of a coupled, global phenomenon. This limitation is ameliorated somewhat by the capability to launch either from a geographically diverse set of established launch sites or from temporary launch sites using portable support equipment.

## 2.2 Program History

The sounding rocket program in its current form began immediately after World War II with the use of captured German V-2 rockets and the cooperation of German rocket scientists. The V-2 capability to loft a 2000 lb payload to 160 km made it possible for scientists to immediately begin probing the Earth's upper atmosphere, ionosphere, and lower magnetosphere. The first U.S. V-2 flight was made on April 16, 1946, and before the end of 1946 the solar ultraviolet spectrum had been photographed for the first time.

Aerobee rockets, developed to replace the V-2's and provide greater reliability, enabled payloads of a few tens of pounds to be lofted to altitudes of 500 km. This scientific activity, by exerting pressure for enhanced rocket performance--greater payload weights, higher altitudes, greater reliability--maintained an active civilian community in rocket research which eventually led to the formation of NASA and the establishment of a significant civilian space program.

The NASA sounding rocket program was initiated immediately after the formation of NASA. The initial flight was a test of the Arcon rocket on May 14, 1959. The first successful flight with a science payload was the launch of a Nike Asp on August 17, 1959, to study properties of the Earth's ionosphere. The number of flights increased each year until FY 1965 during which 207 flights were flown.

After 1965, the number of flights per year declined. This was due, not to the decline in demand for sounding rocket services, which has always greatly exceeded the available resources, but instead to the erosion of purchasing power by the combined effects of inflation and constant funding level.

The response within the program to monetary restrictions has been to minimize program costs by reflying science and support hardware, refurbishing and reflying liquid fuel rockets, adapting surplus military rocket motors, and providing carrier and support capabilities to accommodate larger, multiple experiment payloads. Development efforts were directed toward providing improved telemetry support, allowing more complex, in some cases remote-controlled, on board activities, and providing more accurate, more responsive attitude control. In short, the development emphasis has been to accommodate more science on each flight to offset, somewhat, the negative effect of decreased purchasing power.

A summary of the program evolution is presented in Table 2-1. An example of the type of effort involved in a typical sounding rocket flight today is the flight of a Nike-Orion out of Wallops Flight Center (WFC) on June 23, 1982. This flight, which used two DoD surplus motors, lofted four experiments: an X-ray monitor to study the deposition of high-energy particles in the upper atmosphere, a set of detectors to measure the ionospheric and mesospheric electric fields, a Gerdien probe to measure atmospheric conductivity, and a two-axis magnetometer to determine aspect.

The launch was coordinated with a satellite passing overhead and the operation of a high power transmitter in Annapolis, Maryland; the launch occurred in the required window. During the flight, X-ray data were obtained over 5 energy ranges, booms were deployed for electric field measurements, and Gerdien probe data were obtained. A high altitude parachute was deployed to float the payload back to aircraft altitude, a process which allowed more than an hour of electric field and conductivity data to be collected. The descent of the payload was terminated by an aircraft retrieval at 12,000 ft. All of the science and support hardware was recovered; it was the second flight of the science package, the third for the telemetry. The equipment was ready, with minor modifications to improve the science instrumentation, to be flown in Peru in 1983. At the termination of the flight, the science team was given a digital data tape and was able to begin data analysis less than 24 hours after the flight.

### 2.2.1 Trends in Key Parameters

An understanding of the directions of development, amount of activity, and general health of the sounding rocket program can be best obtained by examining trends in key aspects of the program. In this section, trends in the following areas will be presented and discussed:

(1) Launch activity, including breakdown by discipline
(2) Types of rockets flown and reliability
(3) Launch sites used

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TABLE 2-1. TRENDS IN SOUNDING ROCKET CAPABILITIES

| | 1960 | 1965 | 1970 | 1980 |
|---|---|---|---|---|
| Payload Capability (weight to 150 miles) | 150 | 200 | 450 | 2600 |
| Data Reduction Times | Months | Weeks | Days | Hours |
| Attitude Control Systems | | Startrackers | STRAP III, Solar Pointer | STRAP V, remote control, magnetic field orientation |
| Pointing | Spin only, 0.1 RPS | 3°, 15' limit cycle, 5 targets | 10' w.o. trkr., 1' w. trkr., 15' limit cycle 7 targets, 2" solar | 3' w.o trkr., 1' w. trkr., 8" limit cycle 20 targets, 0.5" solar |
| Science Capability: | | | | |
| Astronomy-telescope size | 10 cm Brightest sources | 30 cm | 40 cm | 90 cm 20th mag. star |
| Geophysical | Single instrument | | | Multiple instrument |

(4) Science support
(5) Mission parameters
(6) Costs.

Launch Activity

A primary indicator of activity in the sounding rocket program is the number of launches occurring each year. These data are presented in graphical form in Figure 2-1. Activity rose to peak levels, in the mid and late 1960s, of over 150 launches per year. In the 1970s it steadily declined to its present level of about 50 launches per year. This decline was caused by the combined effects of high monetary inflation rates, budgetary limitations, and increased costs (due to need for increasingly large, heavy, and sophisticated experiment packages). These effects will be discussed further later.

A breakdown of flight activity into discipline, grouped into 3-year sets, is presented in Figure 2-2 and shown as percentages in Figure 2-3. The preponderence of flights devoted to atmospheric and magnetospheric studies is expected. During the 1970's, astronomical flights took a larger portion of the flights, reflecting the value of the capability to do astronomy from sounding rockets.

Types of Rockets Flown and Reliability

The trend in sounding rocket usage has been to employ rockets permitting larger, heavier science payloads with heavier, more sophisticated support hardware. This is most easily seen by comparing the rockets flown in the 1960-61 flights listed in Table 2-2, and those flown in 1980-81, listed in Table 2-3. Performance curves for some of these rockets are presented in Figure 2-4.

Over the years, a very large number of rockets, with mixtures of boosters to enhance performance, have been flown in the sounding rocket program. In many cases, these choices have been guided by the availability of surplus or outdated military missiles, which may be acquired at a reasonable

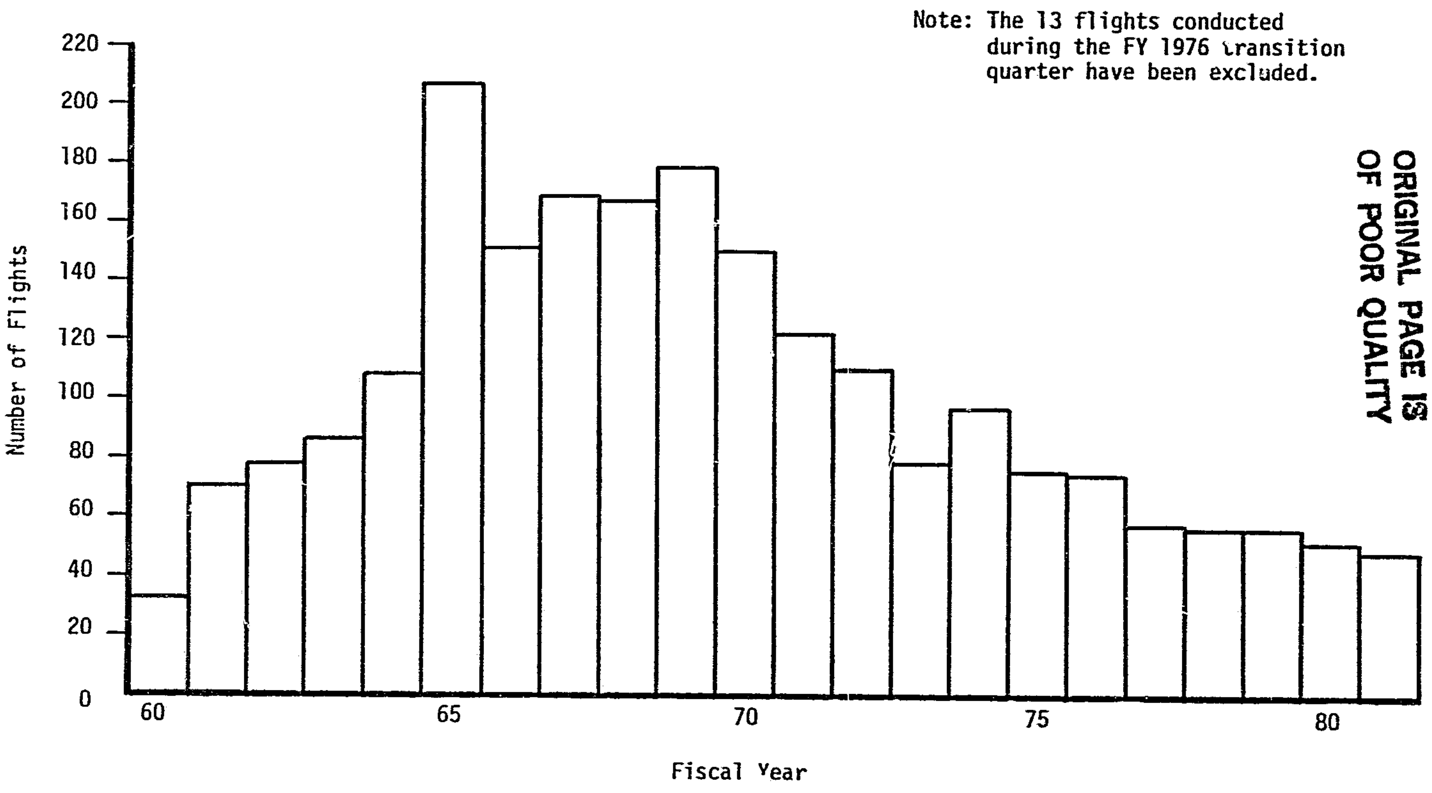


FIGURE 2-1. SOUNDING ROCKET FLIGHT HISTORY

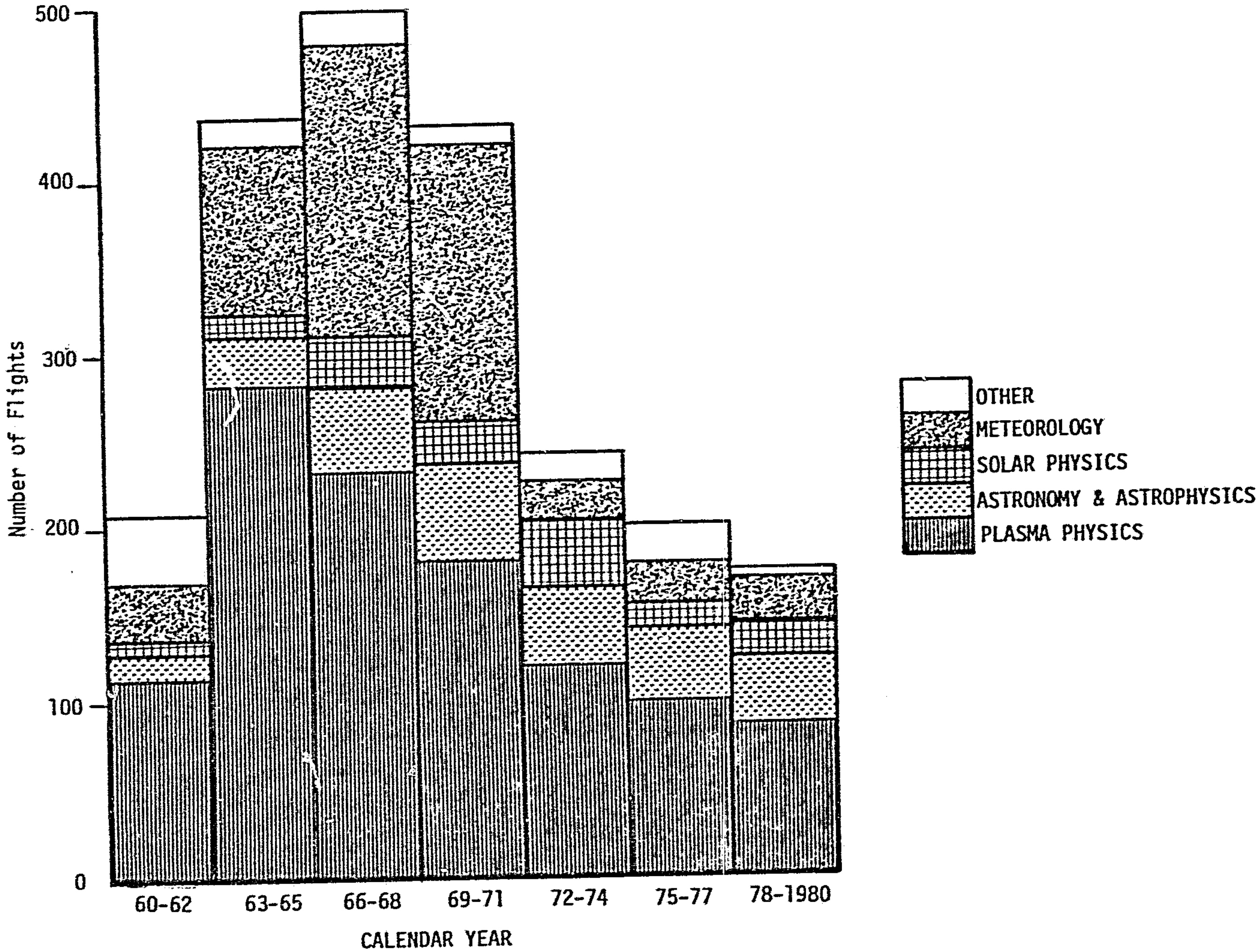


FIGURE 2-2. SOUNDING ROCKET FLIGHTS BROKEN DOWN BY DISCIPLINE

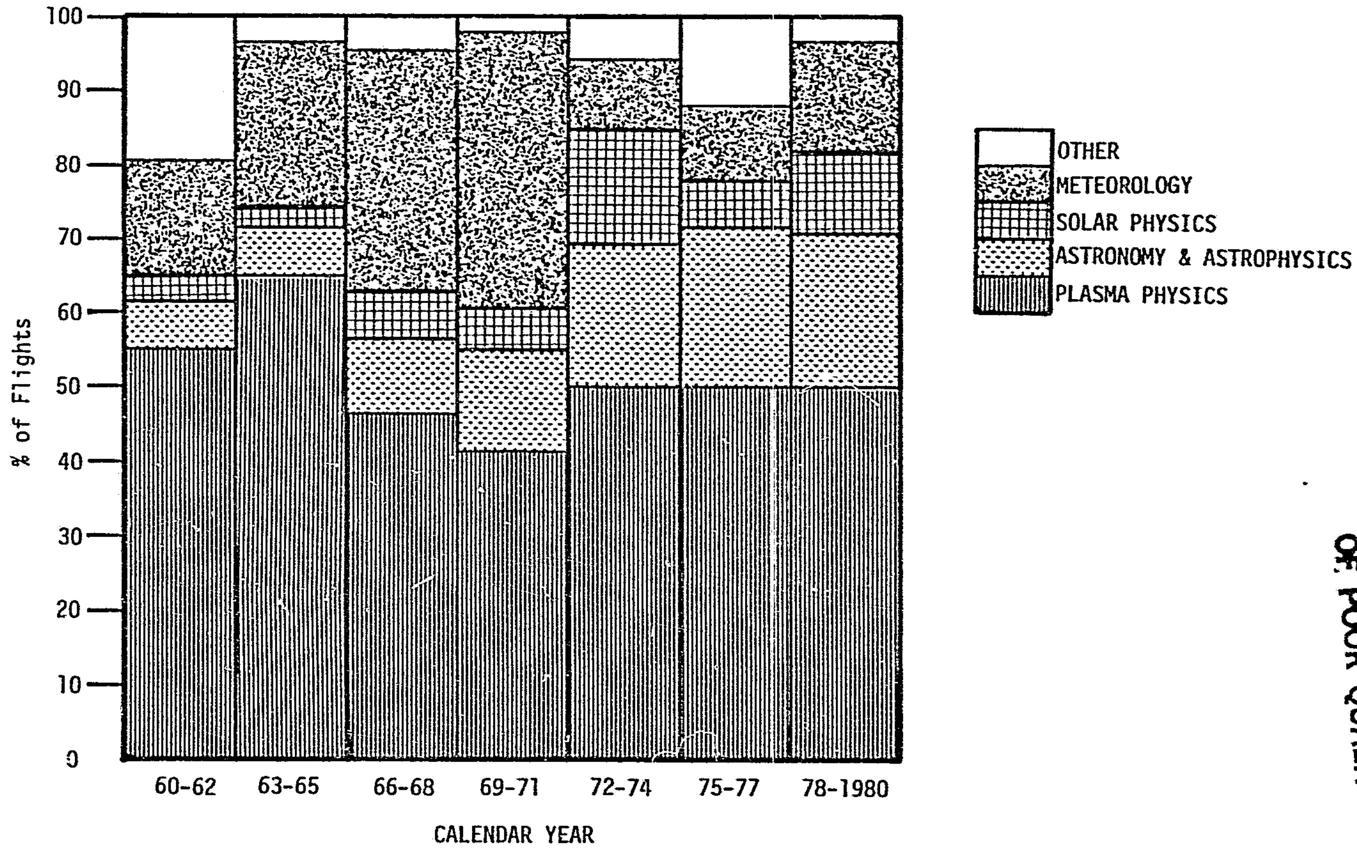


FIGURE 2-3. PERCENTAGE OF SOUNDING ROCKET FLIGHTS BY DISCIPLINE

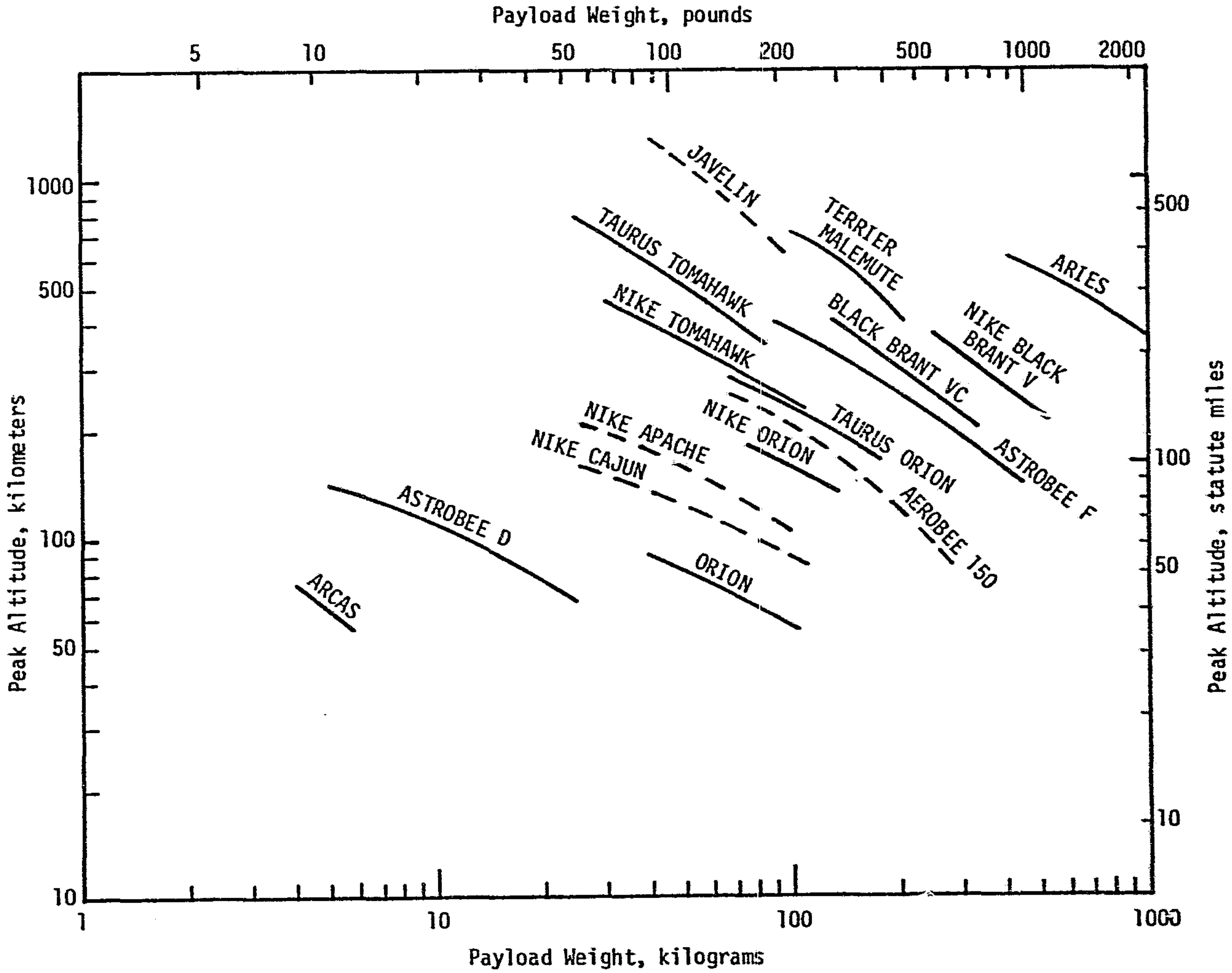


FIGURE 2-4. PERFORMANCE CURVES FOR SOUNDING ROCKETS. SOLID LINES FOR ROCKETS FLOWN IN 1980-81, DASHED LINES FOR ROCKETS FLOWN IN 1960-61.

price without investing in extensive development projects. The exception to this has been the Black Brant, which was developed with sounding rocket funding and is in demand for use in sounding rocket programs in other countries.

TABLE 2-2. SOUNDING ROCKETS FLOWN IN THE YEARS 1960 AND 1961

| |
|---|
| Aerobee 100 |
| Aerobee 150/150A |
| Aerobee 300 |
| Argo D-8 |
| Iris |
| Javelin |
| Nike Apache |
| Nike Asp |
| Nike Cajun |
| Skylark |

TABLE 2-3. SOUNDING ROCKETS FLOWN IN THE YEARS 1980 AND 1981

| |
|---|
| Arcas |
| Aries |
| Astrobee D |
| Astrobee F |
| Black Brant VC |
| Nike Black Brant V |
| Nike Orion |
| Nike Tomahawk |
| Orion |
| Taurus Orion |
| Taurus Tomahawk |
| Terrier Malemute |

The resourcefulness of this program management approach is reflected in the large variety of rockets that have been flown. The complete list is presented in Table 2-4, with additional information on the number of launches and percentage of successes. The overall rocket success rate has been about 95 percent; with a similar success rate in science payload operation, nearly 90 percent of the sounding rocket flights meet or exceed the minimum science requirements.

## Launch Sites Used

The ability to launch sounding rockets from a variety of established and temporary launch sites, allowing data to be acquired at many geographical or geomagnetic localities, is an important asset to the program, offsetting the necessarily localized aspect of individual rocket missions. The first major display of geographic flexibility was conducted in the 1965 shipboard campaign on the USS Croatan and, in fact, much of the mobile equipment being used today to support mobile launch operations was acquired for this campaign.

Geographic flexibility allows scientific data to be acquired for localized events, such as solar eclipses, as well as to allow study of phenomena from unique locations. The study of the interaction between the Earth's atmosphere and charged particles trapped in the Earth's magnetic field must be conducted near the magnetic poles, from locations such as Ft. Churchill or Poker Flat; on the other hand, plasma wave instabilities are best studied near the magnetic equator. The planned campaign for ionospheric studies at the geomagnetic equator, to be conducted in 1983 in Peru, will be conducted using temporary launch facilities.

Table 2-5 shows the history of this flexibility. Four established rocket ranges, Wallops Flight Center (WFC), White Sands Missile Range (WSMR), Fort Churchill Rocket Range (CRR), and Poker Flat Rocket Range (PFRR) are distinguished from other launch sites. Some of these other sites, e.g. those in Sweden, are maintained launch facilities but others require support from the mobile launch equipment to conduct operations.

An appreciation of the diversity in launch sites can be gained by observing the number of different sites that have been used in the course of

TABLE 2-4. LAUNCH HISTORY BY ROCKET TYPE WITH RELIABILITY BROKEN OUT

| | | Success | Partial Success | Failure | No Report | % Success | Total |
|---|---|---|---|---|---|---|---|
| ARIES | | 5 | | 1 | | 83.3 | 6 |
| AEROBEE | 100 | 13 | | 1 | | 92.9 | 14 |
| | 150/150A | 277 | 12 | 16 | 1 | 94.8 | 306 |
| | 170 | 90 | 1 | 4 | | 95.8 | 95 |
| | 200 | 49 | | 3 | | 94.2 | 52 |
| | 300/300A | 11 | | 0 | | 100. | 11 |
| | 350 | 11 | 1 | 1 | | 92.3 | 13 |
| ARCAS | | 158 | 4 | 7 | | 95.9 | 169 |
| ARCON | | 0 | | 6 | | 0. | 6 |
| ARGO D-8 | | 6 | 1 | 0 | | 100. | 7 |
| ASTROBEE | 1500 | 5 | | 1 | | 83.3 | 6 |
| | D | 17 | | 1 | | 94.4 | 18 |
| | F | 40 | | 1 | | 97.6 | 41 |
| BLACK BRANT | IIIB | 2 | | 0 | | 100. | 2 |
| | IV | 8 | | 0 | | 100. | 8 |
| | VC | 45 | 3 | 1 | | 98.0 | 49 |
| | IX | 1 | | 0 | | 100. | 1 |
| BULLPUP CAJUN | | 0 | | 1 | | 0.0 | 1 |
| ORION | | 11 | | 0 | | 100. | 11 |
| IRIS | | 2 | 1 | 1 | | 75. | 4 |
| JAVELIN | | 61 | | 3 | | 95.3 | 64 |
| NIKE | APACHE | 513 | 12 | 26 | | 95.3 | 551 |
| | ASP | 17 | | 10 | | 63.0 | 27 |
| | BLACK BRANT V | 32 | | 0 | | 100. | 32 |
| | CAJUN | 412 | 4 | 12 | | 97.2 | 428 |
| | JAVELIN | 2 | | 0 | | 100. | 2 |
| | MALEMUTE | 2 | | 0 | | 100. | 2 |
| | ORION | 17 | | 0 | | 100. | 17 |
| | TOMAHAWK | 202 | 2 | 7 | 1 | 96.7 | 212 |
| SKYLARK | | 4 | | 0 | | 100. | 4 |
| SPECIAL PROJECTS | | 34 | 1 | 4 | | 89.7 | 39 |
| TERRIER MALEMUTE | | 7 | | 3 | | 70.0 | 10 |
| TAURUS | ORION | 19 | | 0 | | 100. | 19 |
| | TOMAHAWK | 5 | | 0 | | 100. | 5 |
| Unknown | | 1 | | 0 | | 100. | 1 |

*% success = (success + partial success)/(success + partial success + failure).

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TABLE 2-5. LAUNCH HISTORY BY FIRING SITE FOR THE MOST HEAVILY USED SITES (PERCENTAGE IN PARENTHESES)

| | Wallops Flight Center | White Sands Missile Range | Fort Churchill Rocket Range | Poker Flat Rocket Range | Other |
|---|---|---|---|---|---|
| 1959 | 12 (75.0) | | 4 (25.0) | | |
| 1960 | 37 (61.7) | | 22 (36.7) | | 1 (1.7) |
| 1961 | 55 (78.6) | | 9 (12.9) | | 6 (8.6) |
| 1962 | 59 (75.6) | 5 ( 6.4) | 4 ( 5.1) | | 10 (12.8) |
| 1963 | 51 (54.8) | 11 (11.8) | 16 (17.2) | | 15 (16.1) |
| 1964 | 63 (41.4) | 21 (13.8) | 28 (18.4) | | 40 (26.3) |
| 1965 | 54 (28.3) | 22 (11.5) | 34 (17.8) | | 81 (42.4) |
| 1966 | 53 (33.3) | 29 (18.2) | 33 (20.8) | | 44 (27.7) |
| 1967 | 39 (24.1) | 33 (20.4) | 23 (14.2) | | 67 (41.4) |
| 1968 | 54 (31.0) | 42 (24.1) | 37 (21.3) | | 41 (23.6) |
| 1969 | 46 (36.8) | 34 (27.2) | 17 (13.6) | 1 (.8) | 27 (21.6) |
| 1970 | 63 (38.0) | 31 (18.7) | 26 (15.7) | 5 (3.0) | 41 (24.7) |
| 1971 | 27 (19.2) | 34 (24.1) | 12 (8.5) | 5 (3.6) | 63 (44.7) |
| 1972 | 12 (14.3) | 33 (39.3) | 11 (13.1) | 9 (10.7) | 19 (22.6) |
| 1973 | 13 (16.1) | 33 (40.7) | 4 (4.9) | 8 (9.9) | 23 (28.4) |
| 1974 | 19 (24.7) | 32 (41.6) | 7 (9.1) | 5 (6.5) | 14 (18.2) |
| 1975 | 15 (18.1) | 28 (33.7) | 6 (7.2) | 7 (8.4) | 27 (32.5) |
| 1976 | 13 (20.6) | 25 (39.7) | 5 (7.9) | 11 (17.5) | 9 (14.3) |
| 1977 | [illegible] (11.3) | 24 (45.3) | 5 (9.4) | 4 (7.6) | 14 (26.4) |
| 1978 | 9 (15.0) | 22 (36.7) | 4 (6.7) | 16 (26.7) | 9 (15.0) |
| 1979 | 17 (26.6) | 26 (40.6) | 2 (3.1) | 8 (12.5) | 11 (17.2) |
| 1980 | 6 (11.5) | 21 (40.4) | 1 (1.9) | 4 (7.7) | 20 (38.5) |
| 1981 | 11 (36.7) | 10 (33.3) | 3 (10.0) | 2 (6.7) | 4 (13.3) |
| Total | 734 (32.9) | 516 (23.1) | 313 (14.0) | 85 (3.8) | 586 (26.2) |

the program's history. This list is presented in Table 2-6, along with the number of launches that have occurred from each site.

Science Support

Key elements of science support have occurred in the areas of attitude control systems (ACS), data availability, and payload recovery.

ACS development has been extensive, as was shown in Table 2-1. While attitude control systems become capable of providing much finer pointing accuracy and stability, they have become more frequently used. Coarse guidance, which was first provided by rate integrating gyroscopes can now be provided by timed restraint gyroscopes, similar to those used in larger rockets such as the Delta. Star trackers are used for fine guidance in the STRAP series of attitude control systems; a solar tracker is used on the SPARCS system. In 1981, a magnetic ACS was flown and will be extremely useful for experiments requiring aspect with respect to the local magnetic field. Figure 2-5 provides a history of the inertially stabilized flights, excluding SPARCS. Ground interaction to control attitude is a feature which is now supported within both the STRAP and SPARCS ACS packages.[1]

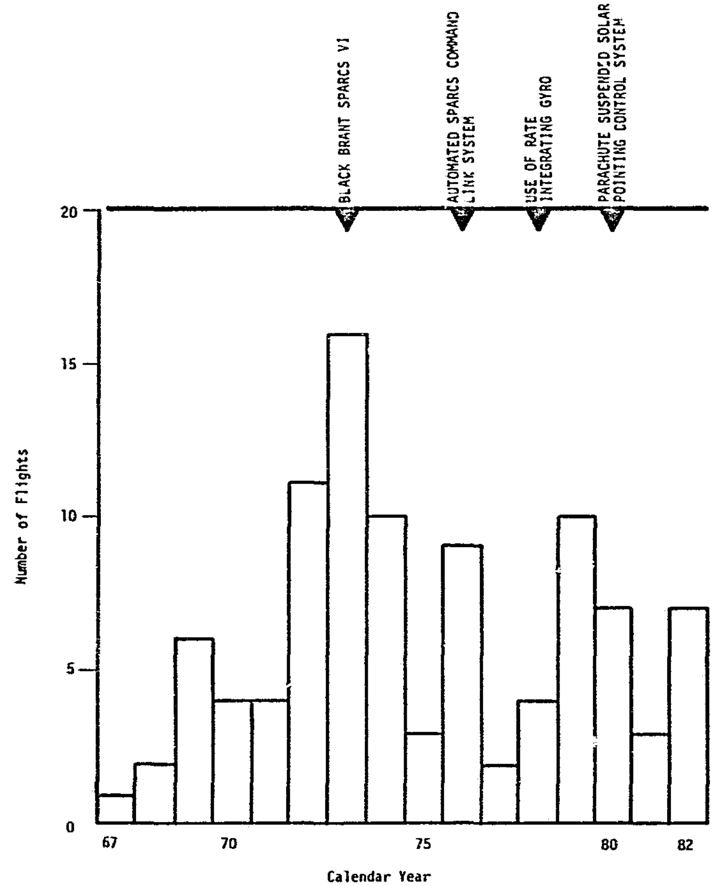
In the mid-60s, pulsed code modulated (PCM) telemetry systems were developed, allowing direct acquisition of digital data during this time, equipment was also developed to transmit in the P band, allowing higher data rates, use of antennae with reduced aerodynamic profile, and transmittal of signals with less interference. Current flight systems are modularized, accommodating analog or digital user input over a wide range of data rates, and provide a standard interface to the science package. The standard telemetry system has been adapted for use in the SPARTAN program and will be used with some other attached payloads.

On the ground, quick-look, microprocessor-driven receivers with a data processing capability provide the experimenter an ability to obtain real-time data analysis and evaluation.

The silver cell battery, the standard power source on sounding rockets, provided the technology to provide battery power for payloads in the SPARTAN program.

TABLE 2-6. NUMBER OF LAUNCHES GROUPED BY FIRING SITE

| | | |
|---|---|---|
| 1. | Antigua (ANT) | 8 |
| 2. | Argentina (ARG) | 2 |
| 3. | Ascension Island (ASC) | 12 |
| 4. | Australia (AUS) | 21 |
| 5. | Barter Island, Alaska (BI) | 3 |
| 6. | Brazil (BRAZ) | 45 |
| 7. | Chikuni, Canada (CHIKUNI) | 2 |
| 8. | Eglin AFB, Fla. (EGL) | 6 |
| 9. | Fort Churchill, Canada (FC, CRR) | 313 |
| 10. | Fox Main, Hall Beach, NWT, Canada (FM) | 8 |
| 11. | French Guiana (Kourou) (FGU) | 23 |
| 12. | Ft. Greely, Alaska (FGR) | 3 |
| 13. | Greece (GREECE) | 7 |
| 14. | Greenland (GRN) | 9 |
| 15. | Hawaii (HAWAII) | 13 |
| 16. | India (IND) | 52 |
| 17. | Italy (ITALY) | 3 |
| 18. | Kenya (San Marco) (KENYA) | 8 |
| 19. | Kerguelen Islands (KI) | 5 |
| 20. | Keweenaw, Michigan (KE) | 2 |
| 21. | New Zealand (NZ) | 7 |
| 22. | Cape Perry, NWT, Canada (NWT) | 3 |
| 23. | Norway (NOR) | 69 |
| 24. | Pakistan (PAK) | 16 |
| 25. | Panama (PN) | 2 |
| 26. | Peru (PERU) | 19 |
| 27. | Pacific Missile Range (PMR) | 8 |
| 28. | Poker Flat Rocket Range, Alaska (PFRR) | 85 |
| 29. | Primrose Lake, Canada (PL) | 2 |
| 30. | Pt. Barrow, Alaska (PB) | 73 |
| 31. | Puerto Rico (PR) | 9 |
| 32. | Red Lake, Canada (RED LAKE) | 5 |
| 33. | Resolute Bay, NWT, Canada (RB) | 7 |
| 34. | Ship (SHIP) | 47 |
| 35. | Siple Station, Antarctica (SIP) | 11 |
| 36. | Spain (SP) | 10 |
| 37. | Surinam (SUR) | 4 |
| 38. | Sweden (SWE) | 61 |
| 39. | Wallops Flight Center (WFC) | 734 |
| 40. | White Sands Missile Range (WSMR) | 516 |




IGURE 2-5a. HISTORY OF INERTIALLY POINTED SOUNDING ROCKET FLIGHTS (SPARCS)

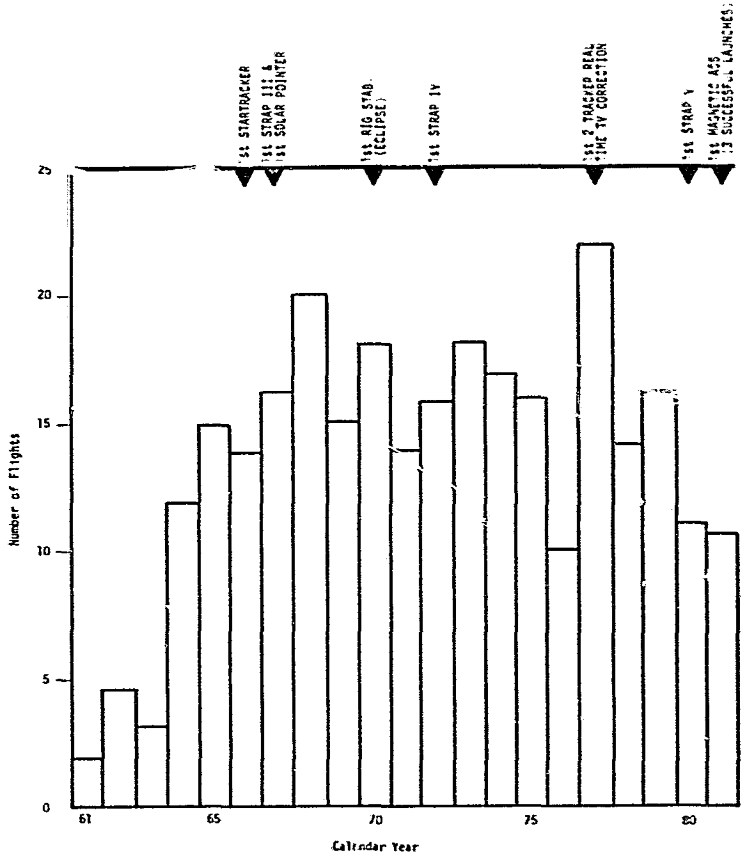



FIGURE 2-5b. HISTORY OF INERTIALLY POINTED SOUNDING ROCKET FLIGHTS (STRAP)

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Data reduction techniques have undergone a major alteration since the program inception. In 1960, most data were extracted from analog output and reduced by hand. Today, the need to translate the analog telemetry tapes to a digital format can present a major block in the data reduction process. Wallops flights from WFC can now make a digital tape as the data are received, enabling investigators to begin examining their data as soon as they can get onto a computer.

Finally, the Wallops capability to achieve airborne retrieval of science payloads makes sounding rocket flights over water a possibility for science payloads which should not be exposed to water.

## Mission Parameters

Two of the key parameters that define sounding rocket missions are peak altitude and payload weight. A history of peak altitudes achieved in past sounding rocket missions is depicted in Figure 2-6, which shows average peak altitude by fiscal year. The ability of rockets to achieve high altitudes in general has not been a problem in the NASA program. In fact, average mission peak altitudes were higher in the early 1960's than they are now. They have remained relatively constant for the last 15 years.

The constant average altitude of missions belies the fact that rockets and performance capabilities have grown substantially over the past 20 years. Rocketeers have used this capability to accommodate significant increases in payload size and weight. This trend is shown in Figure 2-7, which is a record of average payload weight by fiscal year. Average rocket payload weights are now four times what they were in the 1960s. This weight growth has allowed increasingly sophisticated experiment packages, significant improvements in flight support systems (attitude control, power, data handling, telemetry, etc.), and the incorporation of payload recovery systems that have had a favorable impact on program costs. Also, it has served to soften the impact of declining launch rates. Even though the launch rate has declined to less than a third of what it once was, the total weight of payloads launched each year is as high now as it ever was. As shown in Figure 2-8, total payload weight (annual) increased through the 1960s and has remained relatively constant since then.

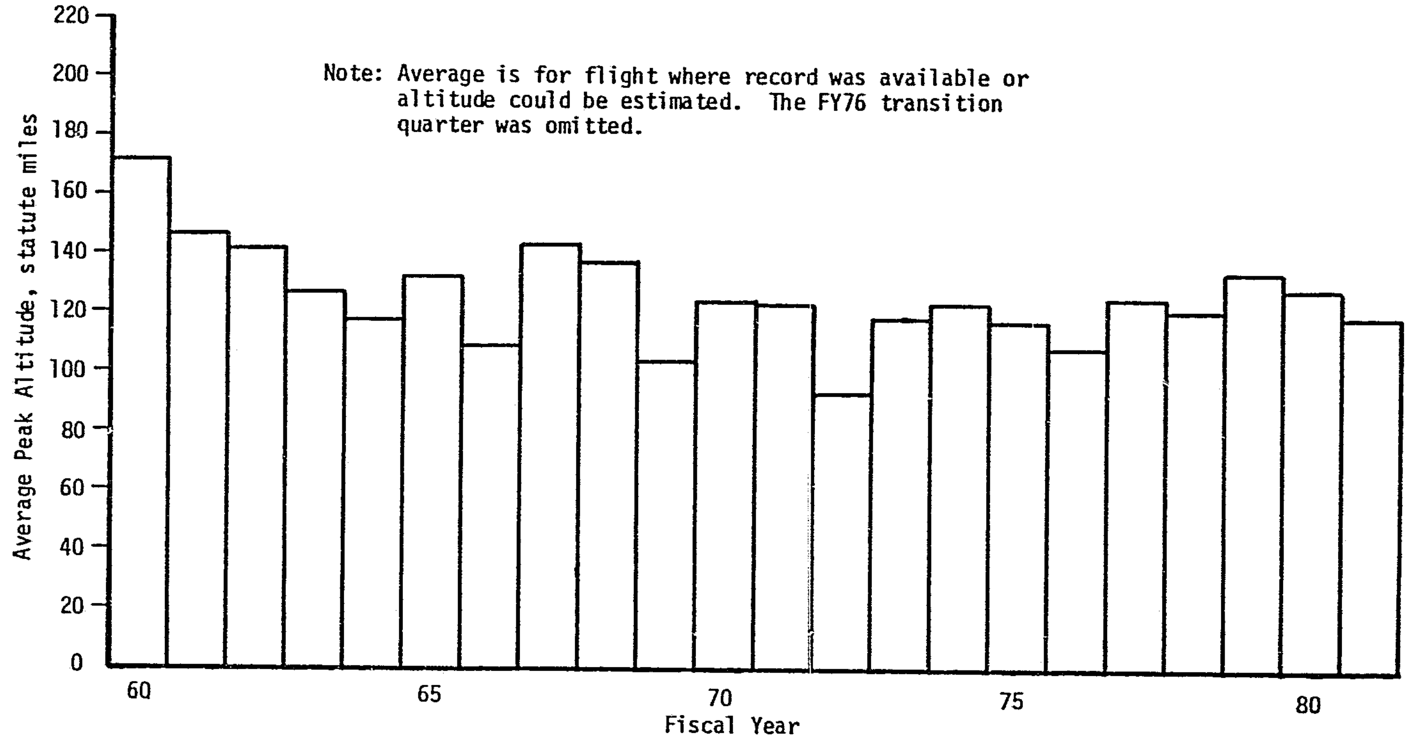


FIGURE 2-6. SOUNDING ROCKET AVERAGE PEAK ALTITUDE HISTORY

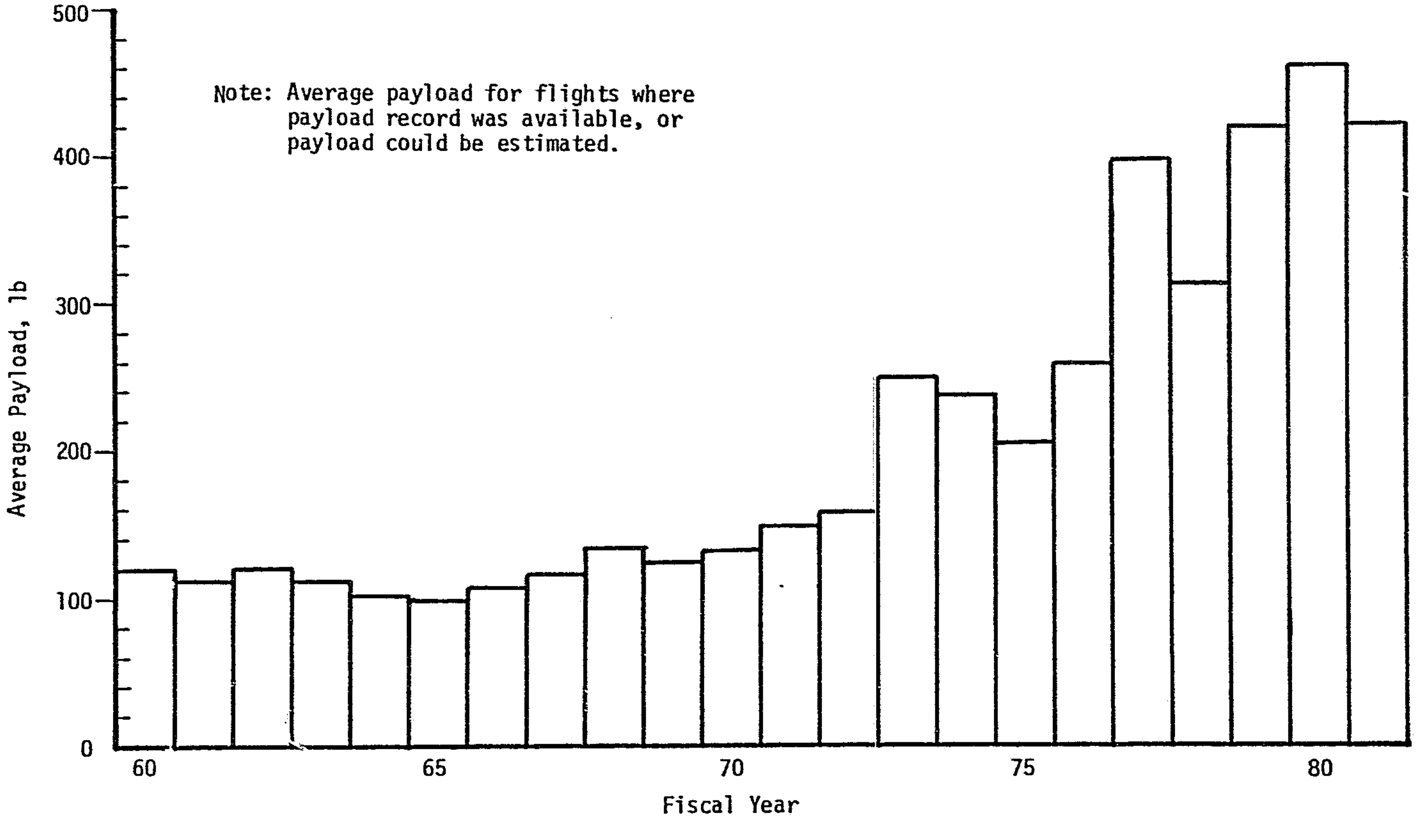


FIGURE 2-7. GROWTH IN AVERAGE WEIGHT OF SOUNDING ROCKET PAYLOADS

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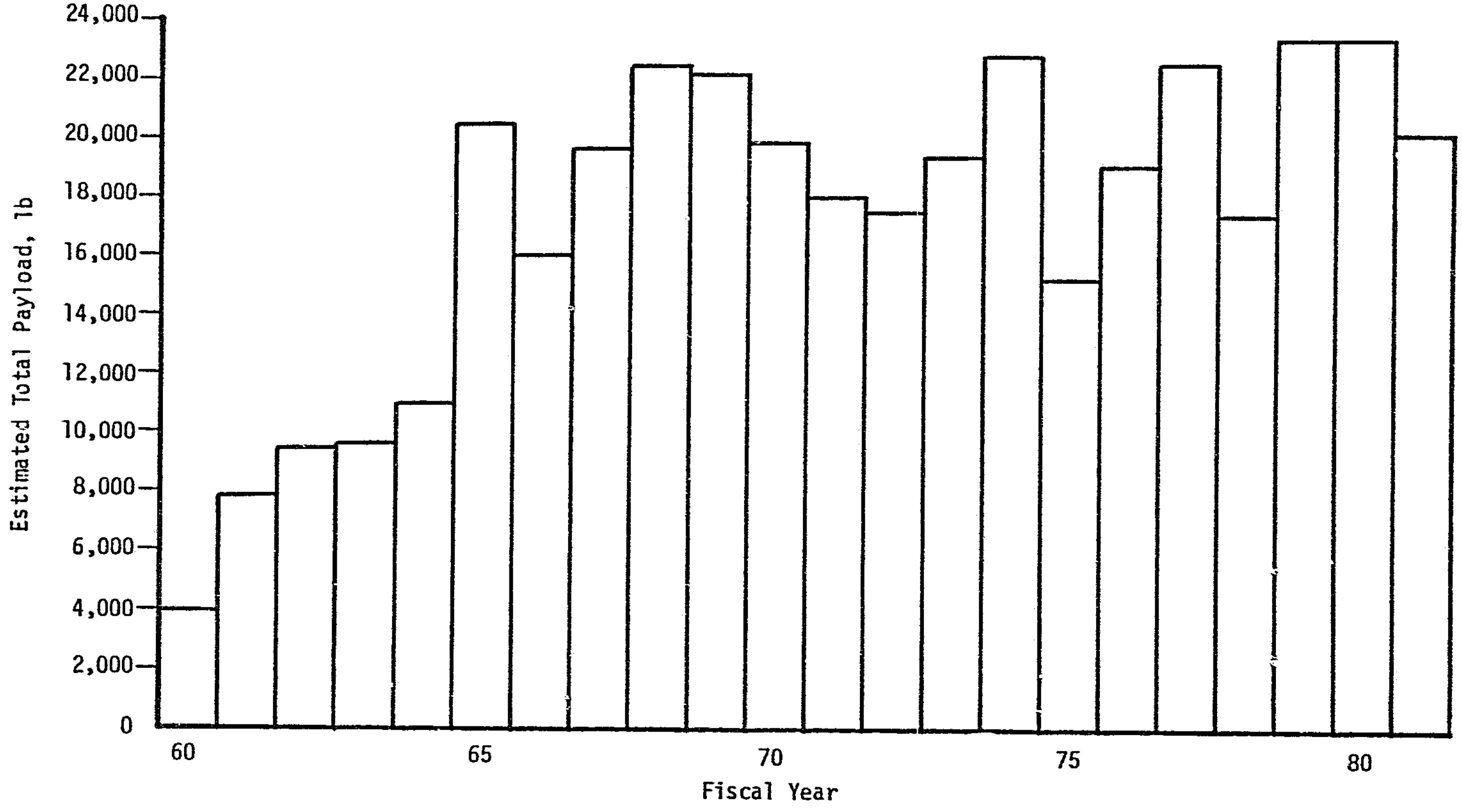


FIGURE 2-8. ESTIMATED ANNUAL TOTAL PAYLOAD WEIGHT CARRIED BY SOUNDING ROCKETS

## Costs

The budget history for the sounding rocket program is provided in Table 2-7. Costs shown include the rockets, experiments, operations program support, etc., but exclude the cost of civil service manpower. The years shown are fiscal years. The FY 1976 transition quarter which moved the start of fiscal year 1977 from July 1, 1976, to October 1, 1976, has been omitted. Funding for this quarter was $6.2 M for the period 1965-1981. These data are presented graphically in Figure 2-9. To translate this funding into purchasing power, the allocation is devalued by the NASA inflation factor since 1965 and presented in terms of constant $1965.

Figure 2-9 demonstrates that even though the actual sounding rocket budget has been increasing, the buying power of the program has been cut to less than half its 1960 value. If the history of cost-per-flight is examined (Figure 2-10), they are seen to increase substantially. Even the inflation adjusted costs (lower curve) increase somewhat. However, when it is remembered that over this time period flight rates were cut by a factor of three while payload weights increased by a factor of four, the historical increase in the inflation adjusted cost-per-flight is remarkably modest. The result is that the cost per pound of mission payload calculated in constant $1965 (Figure 2-11) has been cut in half since 1965. This may be contrasted with the cost per pound of orbiting spacecraft which has remained relatively constant in constant year dollars. One of the reasons for the favorable trend in sounding rockets $/pound payload costs no doubt is the advent and increasing use of reliable payload recovery systems that allow the recovery and reflight of costly payload hardware.

The significant reduction in cost-per-pound payload (as measured in constant $1965) is surprising and says something very positive about the program. As was shown in Table 2-1, a 1980 launch requires much elaborate support, is capable of obtaining much more science, and requires larger rockets than a flight in the 1960's. In short, the sounding rocket program is providing far more for the money invested today that it did 15 years ago, an unusual trend that came about by pursuing programs to reduce costs, keeping administrative overhead to a minimum, and maintaining a sharp focus on the scientific objectives.

TABLE 2-7. SOUNDING ROCKET FUNDING HISTORY

| Fiscal Year | Funding, $M |
|---|---|
| 1959 | 5.0 |
| 1960 | 9.7 |
| 1961 | 8.2 |
| 1962 | 12.1 |
| 1963 | 17.2 |
| 1964 | 17.1 |
| 1965 | 16.0 |
| 1966 | 18.5 |
| 1967 | 19.7 |
| 1968 | 19.8 |
| 1969 | 19.1 |
| 1970 | 18.2 |
| 1971 | 18.7 |
| 1972 | 18.2 |
| 1973 | 20.0 |
| 1974 | 18.0 |
| 1975 | 19.4 |
| 1976 | 20.0 |
| 1977 | 20.6 |
| 1978 | 19.6 |
| 1979 | 21.8 |
| 1980 | 21.5 |
| 1981 | 22.8 |

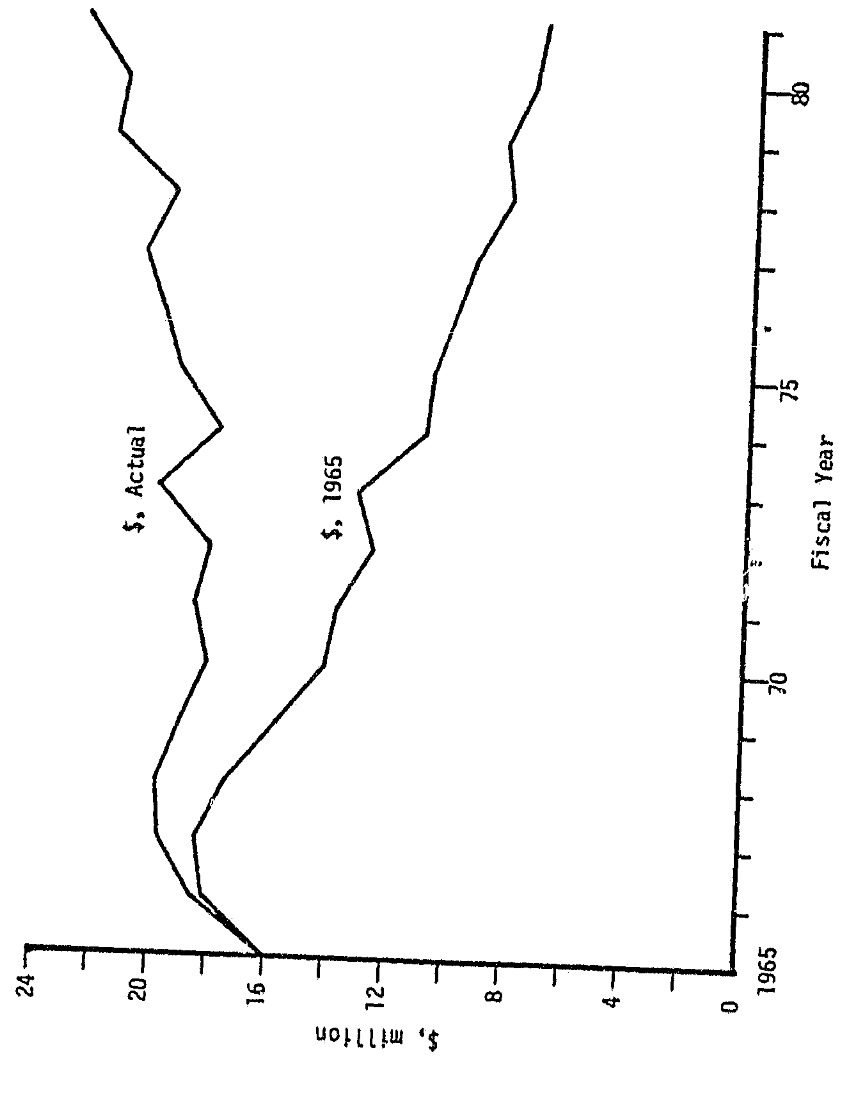


FIGURE 2-9. SOUNDING ROCKET PROGRAM COSTS

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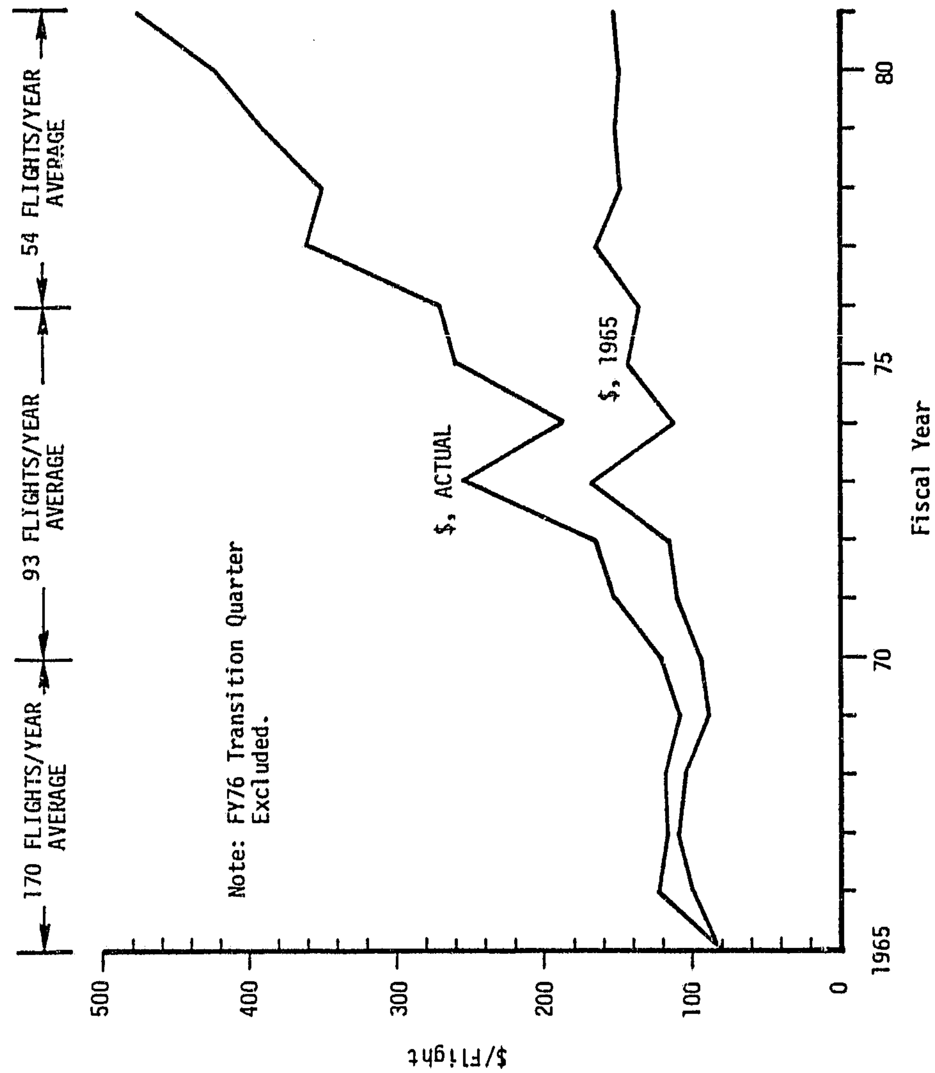


FIGURE 2-10. SOUNDING ROCKET COST PER FLIGHT TREND

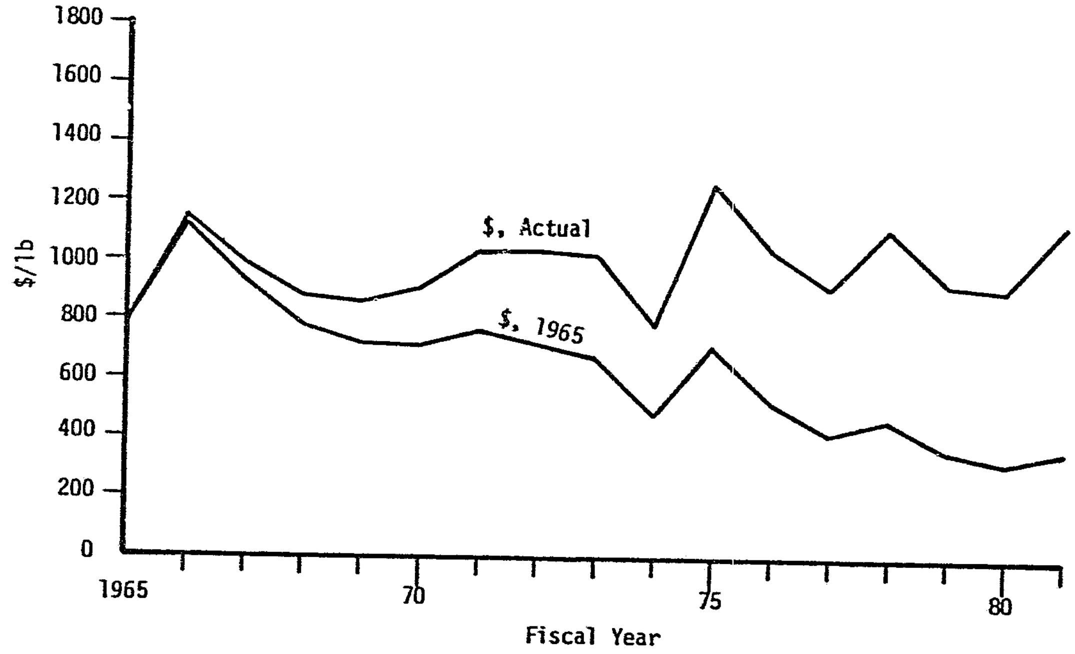


FIGURE 2-11. SOUNDING ROCKET MISSION PAYLOAD COST PER POUND TREND

The efficiency with which the sounding rocket program has functioned has probably had the positive effect of making the funding levels tolerable. However, the combination of increasing lead time for hardware procurement and tightness of money in the program are beginning to have a negative impact on flexibility in the program, and this is a trend that should be reversed.

### 2.2.2 Accomplishments

In this section, significant accomplishments within the sounding rocket program will be discussed from three perspectives--significant scientific results, advances in hardware and data analysis, and satisfaction of program objectives.

2.2.2.1 Significant Scientific Results. Significant scientific accomplishments will be discussed by science field.

#### UV Astronomy

The very earliest sounding rocket UV observations of the Sun and other bright sources gave the first indication that very interesting phenomena were occurring in astronomical objects which were completely masked by the Earth's atmosphere. From these early flights, the term "rocket ultraviolet" was coined to refer to the region from 500-2500 Å.

In more recent research on the Sun, sounding rockets have measured mass outflow rates through coronal holes, have determined the solar boron abundance, and determined solar UV emission line widths. Such results provide important information on coronal structure and dynamics and on mechanisms for coronal heating. The connection between supersonic jets in the corona and the acceleration of the solar wind is being investigated.

In non-solar work, direct imaging of galaxies in the UV is being used to gain new insights into galactic structure and evolution.[2] UV observations of the central regions of spiral and barred-spiral galaxies remove the dominating luminosity that the old stars in that region have in visible light and reveal regions of active star formation. Sounding rocket instruments were used to obtain the first UV spectra of quasars and, in work that is important for understanding mass loss in stars, to obtain the first observational evidence of stellar winds.

X-ray Astronomy

The first observation of X-rays from a celestial source occurred in sounding rocket observations of the Sun. This observation was anticipated since the Sun was expected to be a weak X-ray source. An observation that was unexpected and had a major impact on the field of astronomy was the identification of Sco X-1, the first non-solar X-ray source, in 1962. This observation essentially gave birth to the field of X-ray astronomy.

In the following years, significant work continued from sounding rockets. A large number of X-ray sources were catalogued in the next 10 years and provided the foundation and basis for embarking on X-ray satellite programs. In 1976, the first X-ray polarimeters were flown on sounding rockets and began to provide evidence for magnetic fields associated with pulsars. The first such object investigated was the pulsar at the center of the Crab nebula.

Earth/Sun Interface

Three significant observations using UV detectors have important bearing on the Sun's influence on the Earth. In 1975, the first accurate measurements of the solar energy flux in the 50-575 A region were made; this wavelength region contributes the major flux of ionizing radiation affecting the upper atmosphere. Shortly thereafter, variability in one of the solar UV helium emission lines, a line which has a major influence on the state of the upper atmosphere, was detected. In 1977 observations were performed which determined the free-free cross section of an electron in the neighborhood of atomic oxygen. This cross section, throught to be a major source of energy deposition in the upper atmosphere, could not be determined in the laboratory.

In the fields of atmospheric/magnetospheric physics there are many significant scientific results. From the upper stratosphere, at altitude 40 km, to the lower magnetosphere, at altitude 200 km, sounding rockets are the only means of placing instrumentation in situ. Among the significant results coming from studies of this region by sounding rockets are:

- Detection of radiation by van Allen which led him to hypothesize the existence of the radiation belts that become known as the van Allen Belts
- High spatial and temporal resolution studies of the auroral streamer regions
- Possible detection of large electric fields in the mesosphere, a region previously considered passive in the global electric circuit(3)
- Discovery and analysis of wave-like instabilities in the ionosphere at low geomagnetic latitudes.

2.2.2.2 Significant Hardware Advances. The hardware requirements for obtaining astronomical, solar, and geophysical observations are sufficiently distinct that each will be discussed individually.

In astronomical work, the limited observation time is the key factor. To acquire data from faint sources, it is necessary to increase the collecting area, improve the detection threshold, or do both. Larger sounding rockets--not just for performance but also of larger diameter--make it possible to loft a 90 cm telescope, giving a factor of 80 increase in the collection area of telescopes flown in 1960. Further, these telescopes are flown higher, reducing the atmospheric background and increasing the observation time. All of these factors have enhanced the instrument sensitivity. Further enhancement has occurred by applying new detector technologies to sounding rocket telescopes. Signal enhancement using microchannel plates, charge coupled detectors, and diode arrays have provided sounding rockets with sufficiently sensitive detectors that useful data can be collected in the absence of orbiting instrumentation.

Perhaps the most significant recent development in solar investigations from sounding rockets is the interactive ACS. This system enables high resolution studies of those areas of particular interest to be selected "at the telescope".

The significant hardware development in geophysical studies has been the development of multiple instrument payloads.

2.2.2.3 Contribution to Achieving Program Objectives. The objectives of the suborbital program were presented in Section 1.2.3. In this section, the way in which the sounding rocket program has satisfied these objectives will be discussed.

Continuing Research

An active program of continuing research has been conducted in both the astophysical and geophysical fields. There is an ongoing program in UV astronomy, focusing on galaxies as well as objects within the Galaxy. Plans are being made by several investigators to resume X-ray studies from sounding rockets. An active program of research is being conducted in atmospheric studies.

Ongoing research programs in astronomy include studies of solar flares and active regions, the solar wind and solar coronal structures, direct image studies of galaxies in the UV, UV spectroscopy of galactic and extragalactic sources, and studies of the properties of diffuse and discrete X-ray sources. In atmospheric studies, programs to study the aurorae, magnetospheric properties, mesospheric electric fields, and vertical atmospheric structure above balloon float altitudes are continuing.

Search for New Phenomena

Significant and unexpected results have been obtained from sounding rockets in the past--the discovery of the X-ray source Sco X-1 being an excellent example, the discovery of large mesospheric E fields, and the indication of the van Allen Belts being other cases in point. The first observational evidence for "stellar winds" was acquired from sounding rocket UV spectroscopy. Further studies of the transfer of energy from the magnetosphere through the ionosphere and mesosphere will undoubtedly reveal the presence of unanticipated processes. In astronomy, polarimetry studies in the X-ray may provide an improved understanding of the physical phenomena associated with pulsars.

## Support for Other Programs

Support of other NASA programs has come about in several ways. A function of major importance in sounding rockets has been the support of orbital instrumentation. This has been accomplished by providing a test bed for instrument development, by providing experienced science personnel to serve as investigators on satellites, by providing instrument calibration,[4] and by establishing standard reference sources.

The involvement of sounding rocket personnel in satellite projects is illustrated in Table 2-8. The development and testing of most of the instrumentation on these satellites occurred on sounding rockets. The calibration support of Skylab by sounding rockets considerably enhanced the value of the data which were acquired.[5]

## Time Critical Studies

A particularly productive research program has been associated with solar eclipse occurrences. Such programs not only benefit by the relatively small expense of sounding rocket flights, but also require the use of transportable launch facilities. A series of flights to study the upper atmospheric response to a solar eclipse were launched in 1963 from Fort Churchill in 1966 from Brazil and aboard ship off the coast of Greece. Other eclipse-related programs have been conducted from Kenya, New Zeland, and, in 1970, a major program from Wallops Island.

Comets have also been the subject of sequences of rocket flights. Comet Kahoutek was observed in the UV in January 1974, and another series of comet flights were conducted in March 1976, to observe Comet West. The decision to go for flights to study Comet West was made 59 days prior to launch, after it had been determined that the comet would be of sufficient interest to the scientific community to merit the investment.

A very useful feature of sounding rocket research of auroral phenomena is the ability of the investigator to hold his firing until the conditions of interest are occurring in the region which the payload will traverse. When such conditions occur, he can place his instrumentation in the

TABLE 2-8. SOUNDING ROCKET PROGRAM INVESTIGATORS ON SATELLITES

| | Number of Sounding Rocket Investigators Serving as PI's | Number of Sounding Rocket Investigators on All Instruments | Number of Investigators on All Instruments | Percent of PI's which were Sounding Rocket Investigators |
|---|---|---|---|---|
| SMM | 3 | 9 (2 foreign) | 46 (13 foreign) | 33 |
| Heao-1 | 3 | 24 | 36 | 75 |
| Heao-2 | 5 | | 20 (10 foreign) | 100 |
| Heao-C | 0 | 0 | 0 | 0 |
| ISEE-1 | 7 | 17 | 75 (30 foreign) | 50 |
| ISEE-2 (ESA) | 3 | 7 | 50 (25 foreign) | 38 |
| ISEE-3 | 4 | 11 | 67 (21 foreign) | 26 |
| Skylab 2 | 6 | 21 (4 foreign) | 70 (13 foreign) | 47 |
| DE-A | 4 | 12 | 37 (6 foreign) | 50 |
| DE-B | 7 | 23 | 46 (1 foreign) | 54 |

region within several minutes. Such a capability has also proven useful in the study of phenomena related to solar flare activity.

## Development and Testing of Scientific Instruments and Detectors

The primary thrust for instrument and detector development in astronomy has occurred in the fields of UV and X-ray astronomy. Sounding rockets were first used to extend normal incidence optics and detectors to wavelengths below 900 Å, allowing the first stellar spectroscopy to be conducted in that wavelength region. More recently, microchannel plates have been tested and used to perform direct imaging of galaxies in the UV. In the soft X-ray region, imaging, grazing-incidence telescopes were first flown on sounding rockets. Array detectors, charge coupled detectors, and diode array detectors are currently being tested. Each of these development programs had as the goal placing instrumentation on orbit--in the case of the microchannel plates and array detectors, use on the Space Telescope is planned.

Instrument and detector developments for geophysical and geochemical studies have tended to focus on the adaptation of existing technology rather than pushing for new technology. A case in point is the current work being done to produce a payload/sensor design that will verify the reality of the large horizontal mesospheric electric currents that are apparently being observed.

## Enhancement of Support Capabilities

Support trends in the areas of rocket performance and reliability, attitude control system development, geographic flexibility, data availability, and payload retrieval were discussed in Section 2.2.1. These areas cover the essential support features required by investigators and significant progress has been made in all areas in recent years. Especially notable advances have occurred in attitude control and pointing, both for astronomical and geophysical studies. An ongoing effort remains to minimize program expenses by acquiring and adapting surplus rocket engines for use in the program.

## Graduate Research and Education

The relatively brief time from project inception to flight makes the sounding rocket program well suited to providing research opportunities to graduate students. To date about 350 advanced degrees have been granted as a result of these research opportunities.

## Continuity in Science Areas

For sounding rockets, continuity in affected science fields is only an issue for astronomy. The sounding rocket program has contributed to continuity in two ways. First, by serving as a test bed for future orbital instrumentation it stimulates the need for successive generations of satellites--there will always be something new and exciting to fly next time. Second, the development process itself yields scientific results as a by-product and provides an incentive for people to maintain contacts with the program.

The process of investigators transferring from satellites back to sounding rockets has been occurring in the X-ray astronomy field. New detector technologies will have a considerable impact on future satellites and that the design and development of new instruments on sounding rockets will provide an important contribution to the field.

## Support of International Cooperation

The sounding rocket program has had an active involvement with other countries, providing them with a capability for acquiring data in and above the atmosphere while greatly increasing the geographic flexibility that the program can offer. The countries which have been involved in the program are shown in Table 2-9. The number of launches shown for each country reflect launches of large sounding rockets such as contained in the compendium; a much larger number of small meteorological rockets have also been flown.

In some cases, the launches have occurred during campaigns, for example, the eclipse launches in Greece in 1966 and the 1975 campaign in Peru to study ionospheric and magnetospheric properties at the magnetic equator, but in many cases the cooperation reflects a long-term working relationship.

TABLE 2-9. NUMBER OF INTERNATIONALLY SPONSORED SOUNDING ROCKET LAUNCHES GROUPED BY CO-SPONSORING COUNTRY OR ORGANIZATION

| | |
|---|---|
| Argentina | 19 |
| Australia | 25 |
| Brazil | 75 |
| Canada | 205 |
| Denmark | 6 |
| ESA | 1 |
| France | 41 |
| Germany | 54 |
| Greece | 7 |
| India | 54 |
| Israel | 4 |
| Italy | 49 |
| Netherlands | 5 |
| New Zealand | 10 |
| Norway | 94 |
| Peru | 19 |
| Spain | 10 |
| Sweden | 58 |
| Switerzerland | 2 |
| United Kingdom | 28 |

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4. Brothers, J. R. Skylab ATM Calibration Rocket Project, Final Report to NASA Marshall Space Flight Center, April 30, 1974.

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# 3.0 THE BALLOON PROGRAM

Scientific ballooning provides an opportunity to attack a wide variety of research problems in the fields of astronomy and atmospheric studies. Some factors which enhance the usefulness of balloons for conducting research are traits found throughout the suborbital program--a relatively low cost to fly, short development times, and geographic flexibility. However, there are also unique factors which give balloons special capabilities. Balloons are able to operate above enough of the Earth's atmosphere to collect $\gamma$-ray and high energy cosmic ray data; moreover, they can carry the large, heavy detectors these fields require for the extended observing times needed to gather the low-flux data from these characteristically faint sources. Astronomical investigations in the IR provide data with minimal atmospheric interference, so that spectroscopic information can be gathered to provide information on the physical state and chemical composition of astronomical IR sources. For atmospheric research, balloons are the only means for in situ placement of instrumentation. Balloons can probe the entire stratosphere with high spatial and temporal resolution while introducing minimal disturbance in the local conditions. The NASA balloon program complements activities in the sounding rocket and airborne programs, operating above aircraft altitude to a maximum float altitude of about 140,000 ft.

Unlike the sounding rocket and airborne programs, the NASA balloon program is conducted in concert with other government agencies. The most active of these has been the National Science Foundation (NSF) through its support of the National Center for Atmospheric Research (NCAR) and the NCAR parent organization, the University Committee for Atmospheric Research (UCAR). Through September 1982, NCAR operated the National Scientific Balloon Facility (NSBF) in Palestine, Texas, which supported about half of the NASA balloon launches. Other agencies supporting balloon programs are the Environmental Protection Agency (EPA) and the Department of Energy (DOE).

The NSBF is the principal site worldwide for large volume scientific balloon launches and much of the reliable data on the balloon program comes from the records of NSBF. This data has been relied upon heavily in providing input for balloon trend analyses in this report. Operation and funding of the NSBF was transferred from NSF to NASA as of October 1, 1982.

Balloons

Most balloons used in scientific research up to this time have been "zero-pressure" balloons, balloons which maintain pressure equilibrium with the surrounding atmosphere and must therefore have an open vent to the atmosphere. The zero pressure balloon has two components--a load bearing network of reinforced fibre strips (load tapes) to which the payload is attached, and a set of thin plastic panels (gores) connected to these strips to form the gas bag (usually containing helium). Because the balloon maintains pressure equilibrium with the atmosphere, these gores experience minimal stress and can be made of lightweight material. Balloons of this type have been built to reach a float volume of 70,000,000 cubic feet and are able to carry as much as 7,500 lbs of science payload; 3,000 lbs of payload can be carried to an altitude of 140,000 ft.

The principal limitation of zero pressure balloons is flight duration. At launch the balloon is only partially inflated so that as it gains altitude and the atmospheric pressure decreases, the helium in the balloon expands until the balloon becomes fully inflated. As the ascent continues some helium is vented to prevent overpressuring. At sunset, the atmosphere and the balloon both experience a temperature decrease. The atmophere, consisting primarily of heavy molecules--$N_2$ and $O_2$--in contrast to the balloon gas bag containing helium, leads to the balloon experiencing a loss of volume and a consequent decrease in bouyancy. The balloon will sink to the altitude at which bouyancy halts the fall, but this nightly altitude change can be tens of thousands of feet, and in some cases can cause the balloon to drop all the way to the Earth's surface. The altitude fluctuation can be moderated by dropping ballast at night and venting helium during the day, but carrying enough ballast to remain aloft more than a few days severely limits the allowable scientific payloads.

An alternative to the zero-pressure balloon is the "super-pressure" balloon, a sealed balloon which maintains a pressure excess over its surroundings. These balloons, which maintain density equilibrium with their surroundings, are sealed, and therefore are capable of indefinitely long float durations. However, construction, handling, and launch of these balloons require special techniques that presently limit the size of the balloon that practically can be manufactured and used. A maximum science payload weight of about 500 lbs can be carried by current super-pressure balloons. Since the balloon maintains a pressure excess over the surrounding atmosphere, the gas bag must be strong enough (and therefore heavier than zero pressure balloon gores) to withstand the stress; small perforations in the gas bag, which always occur when handling and launching large zero pressure balloons, cannot be tolerated and, at this time, the engineering problems associated with providing superpressure balloons of several millions of cubic feet appear formidable. As such large balloons come closer to realization, other problems in long term ballooning--power sources, command, control, and thermal control--will have to be addressed.

An experimental program on a hybrid balloon system, called "Sky Anchor", has been on-going at a low level of effort for many years. This system employs two balloons, a large zero-pressure balloon to provide loft and a smaller superpressure balloon to moderate the nightly altitude loss.

## Importance to Science Fields--Overview

Two broad fields--astronomy/astrophysics and atmospheric physics--are affected by the balloon program. In astronomy, the principal areas influenced are cosmic ray, $\gamma$-ray, hard-X-ray, and IR astronomy. In atmospheric physics both IR remote sensors and in situ sampling instruments are used and the area of primary interest is atmospheric chemistry.

Within the scientific community, an active balloon program is regarded as essential to the well-being of the science fields. Much of the instrument development for any of the affected orbital astronomy programs comes from the balloon program, and balloons play a continuing role in obtaining scientific data to complement satellite data when available and in place of it when satellites are not available. Balloons provide the only means of obtaining samples of the stratospheric constituents in the 70,000-140,000 foot altitude range.

## 3.1 Capabilities and Limitation

Balloons provide the altitude link between the airborne instrumentation and typical sounding rocket altitudes. They serve as probes from the lower stratosphere up to the lower mesosphere, covering a critical region in the Sun-Earth interface.

Balloons possess unique capabilities for conducting research in IR, $\gamma$-ray, and cosmic ray astronomy and atmospheric chemistry. In conducting these programs, balloons can serve in a support role for orbital instrumentation or instead be the primary research vehicle.

On the negative side, the fact that the balloon program has encountered some cost growth over the past several years is a concern. The situation may become even more critical in the near future when NASA must assume management of the National Scientific Balloon Facility. The pressure to channel funds into needed research activities has made and will continue in the future to make it difficult to justify the significant investment required to bring superpressure balloons to an operational status for scientific ballooning.

### 3.1.1 Capabilities

Balloons offer an opportunity to conduct research in a way that is relatively simple and inexpensive. Historically, the balloon science team has been responsible for providing and integrating the entire scientific payload--instruments, telemetry, attitude control. The balloon program provides the balloon, helium, recovery system, and launch facilities. Typical balloon costs have recently been in the range of \$15K-\$60K, typical science development in the vicinity of \$500K. However, reflying the science packages reduces the cost per flight to the \$150K-200K range. This relatively low cost encourages the use of new technology and makes instrument testing a valuable feature in the program. Such testing not only makes balloons more valuable in this research capacity, but also makes an essential contribution to orbiting programs. All of the instruments to be flown on the Cosmic Background Explorer (COBE) and on the Gamma Ray Observatory (GRO) have been tested and proved in the balloon program.

The relatively small expense involved in funding balloon projects makes them ideal vehicles in which to introduce and test new technology and new design concepts. Balloon instrumentation may be very nearly the state of the art. In contrast, greatly more expensive satellite programs must work with dated technology using a conservative design approach. The recently flown Solar Maximum Mission (SMM) accepted instrument proposals in 1972, selected instruments in 1975, and flew in 1980, nearly 10 years after the involved experimenters proposed their instruments. Similarly, the GRO instrument proposals were written in 1977, for launch now scheduled for 1988.

In atmospheric physics, balloons are capable of obtaining vertical samples throughout the stratosphere in a benign thermal and stress load environment. The breakdown of ozone by fluorocarbons emitted on the Earth's surface occurs in this altitude regime; an understanding of the chemical processes and process sensitivities driving this breakdown is best obtained by chemically analyzing small volume samples, so that balloons provide an especially appropriate tool for this work. Balloons also provide a test bed for remote sensing instruments that will be used on satellites and provide calibration for these instruments once they are flown. NASA has emphasized the development of remote sensing capabilities in its balloon program to support its long-range objective of obtaining global atmospheric data from satellites.

In astronomy, balloons operate at an altitude which make them well-suited for studying objects in the IR, hard X-ray, and $\gamma$-ray regions of the electromagnetic spectrum. High-energy cosmic-rays also may be studied at balloon altitudes. Balloons are capable of lifting the large, heavy equipment which is required for these studies and, the extended float duration provides an opportunity for studying faint sources.

### 3.1.2 Limitations

Although zero-pressure balloons are capable of providing hours to several days of observation time on each flight, the restriction on flight duration is perceived by the scientific community as the principal program limitation. Flight duration is a controlling factor in $\gamma$-ray and cosmic ray studies, in which sources are faint.[1] In $\gamma$-ray work at balloon altitudes, the atmospheric diffuse background, arising primarily from interactions between the atmosphere and cosmic rays, is about 10 times the cosmic diffuse background. In cosmic ray work, the limited float time prevents study for directional anisotropy.

Flight duration is not just controlled by the use of zero-pressure balloons, but also by the lack of international agreements on the crossing of balloons over national boundaries--balloons cannot cross into Mexico, for instance.[1] Also, flights which are in danger of flying over the ocean are terminated so that the science payload will not be lost. To circumvent these geographical restrictions, flights during the Spring and Autumn turnaround, during which the upper atmospheric winds change direction and are temporarily quiet, are in demand. However, the duration of turnaround is unpredictable and the demand for launches can exceed the support which can be provided by the launch facilities.

Superpressure balloons have performed flights of several months (in the Southern hemisphere, where there will be no crossing of national boundaries) but at this time the payload weight which these balloons can carry is small (~500 lbs) compared to the science equipment which needs to be flown (~5000 lbs).

In X-ray astronomy, the atmospheric opacity increases with decreasing photon energy. At balloon float altitudes, useful data at energies less than 20 KeV is almost impossible to collect, making balloons suitable for studying high-energy X-ray sources but unsuitable for soft X-ray sources. The atmosphere remains opaque until the near-UV is reached. Balloons can extend observations somewhat further into the near-UV than ground-based instrumentation, but such observations are primarily useful for testing instruments and detectors.

The primary limitation in atmospheric research is that the sampling volume is localized whereas in many cases data are needed on a global scale.

## 3.2 Program History

Balloons have a long and colorful history, providing man with his first opportunity to leave the Earth's surface for any significant amount of time. The early balloon experimenters were men with wide-ranging scientific curiosity; on the earliest flights, scientific data such as air temperature and pressure were recorded.

Scientific ballooning as a government funded operation began before World War II. After World War II interest was maintained and capabilities increased with the introduction of stronger, lighter weight balloon materials. One of the earliest projects of the modern era of scientific ballooning was in the area of optical astronomy--the Stratoscope Project conducted by Martin Schwarzschild. Although the Earth's atmosphere does not strongly absorb visible light, small scale turbulence and temperature and density variations in the atmosphere make any astronomical image appear "fuzzy" when viewed under high magnification. Schwarzschild, who had an ongoing interest in stellar structure and evolution, was interested in obtaining high resolution pictures of the nearest star--the Sun. Images of the Sun to look for small scale structure in the solar photosphere (solar granules) could only be obtained by getting above most of the atmosphere, which Schwarzschild accomplished using balloons.

In 1960, a balloon engineering group was formed which led to the creation of the NSBF, located in Palestine, Texas. The NSBF, which performed its first launch in 1962 and became operational August 1963, has since become the leading balloon facility in the world. From its inception, the NSBF has served various organizations interested in launching large balloons. To date it has been run by the University Council for Atmospheric Research (UCAR) as the management arm for the National Center for Atmospheric Research (NCAR), an organization funded by the National Science Foundation (NSF).

NASA has been the most frequent user of the NSBF, contributing about 50 percent of the NSBF launches. NASA's balloon program is extensive, its NSBF activity representing only about half of the NASA total. Control of NSBF is being transferred from NSF to NASA in FY 1983. NASA is assuming management and support of the facility.

Prior to 1976, the NASA balloon program was directed and managed out of NASA Headquarters. In 1976, management was delegated to the Wallops Flight Center. Balloon researchers have been funded for building their scientific payload and incorporating supporting flight systems (e.g., power, pointing, computing, etc.). With the experiment ready for flight, NASA has bought the balloon, helium, parachute, and other required hardware. For NSBF launches, the NSBF has supplied the launch, tracking, telemetry, and recovery crews.

Today, with the exit of the NSF from support of the NSBF, scientific ballooning in the U.S. is at a crossroads. The NASA Balloon Program has been funding-limited for many years and must now expand to support NSBF.

### 3.2.1 Trends in Key Parameters

The scope of the balloon program has changed dramatically in the last 20 years. Single instrument gondolas have been replaced by multiple sensor systems; more collaboration between investigators is producing more science on each flight; stratospheric research is becoming more important. A mid-60s launch typically would involve a balloon volume of a million cubic feet lifting a man-sized payload of a few hundred pounds; today a typical flight uses a 20 million cubic foot balloon to lift a pickup truck-sized payload weighing several thousands of pounds.

There are several parameters whose trends reflect the increasing utility of the program:

(1) Flight activity

(2) Mission parameters

(3) Launch site usage

(4) Costs.

In the discussion of trends it is important to note that information available on the NASA balloon program for the time prior to 1976 is incomplete and inconsistent. Hence, long term trend information was taken from NSBF sources; such trend charts will be labelled as NSBF data. As noted earlier NSBF data does not reflect only NASA launches, and there are many NASA launches not performed by NSBF.

Since 1976, data on the NASA balloon program has been maintained and this data has been used where possible to discuss the NASA program itself.

## Flight Activity

A record of launches supported by the NSBF has been maintained since 1963. This record is summarized in Figure 3-1; from 1977 to the present the NASA contribution to this flight total is shown.

The NASA launches have been recorded since 1976. Figure 3-2 presents this information for this period.

Balloon reliability is an important consideration. In the last two years it has exceeded 80 percent. The NSBF launch failure and success breakout is shown in Figure 3-3.

Breakout of launches into scientific fields has been accomplished for both the NSBF history--Figure 3-4--and NASA launches since 1976--Figure 3-5.

## Mission Parameters

In the period from 1963 to 1980, the average NSBF payload weight increased by a factor of six (Figure 3-6). Since 1977, NASA balloon payload weights have increased 40 percent as shown in Figure 3-7. These increases contributed to a tremendous improvement in the level of scientific instrumentation brought to balloon research projects.

In 1963 a payload was typically small enough that the investigator could carry it to the launch platform. Today, a typical payload requires elaborate mechanical contrivances for successful launch; a cosmic ray payload being prepared for flight at GSFC is a cylinder-shaped payload nearly 20 ft high and 20 ft across.

In 1976, a precipitous increase in the failure rate of heavy lift balloons was experienced. A task force of scientific and engineering balloon personnel was convened to determine the source of the problem. Out of this task force came recommendations to adopt more conservative procedures in heavy lift operations and failures were reduced to a tolerable level.

Balloons are difficult to categorize--each balloon seems unique. Parameters which reflect balloon capabilities are balloon volume, float

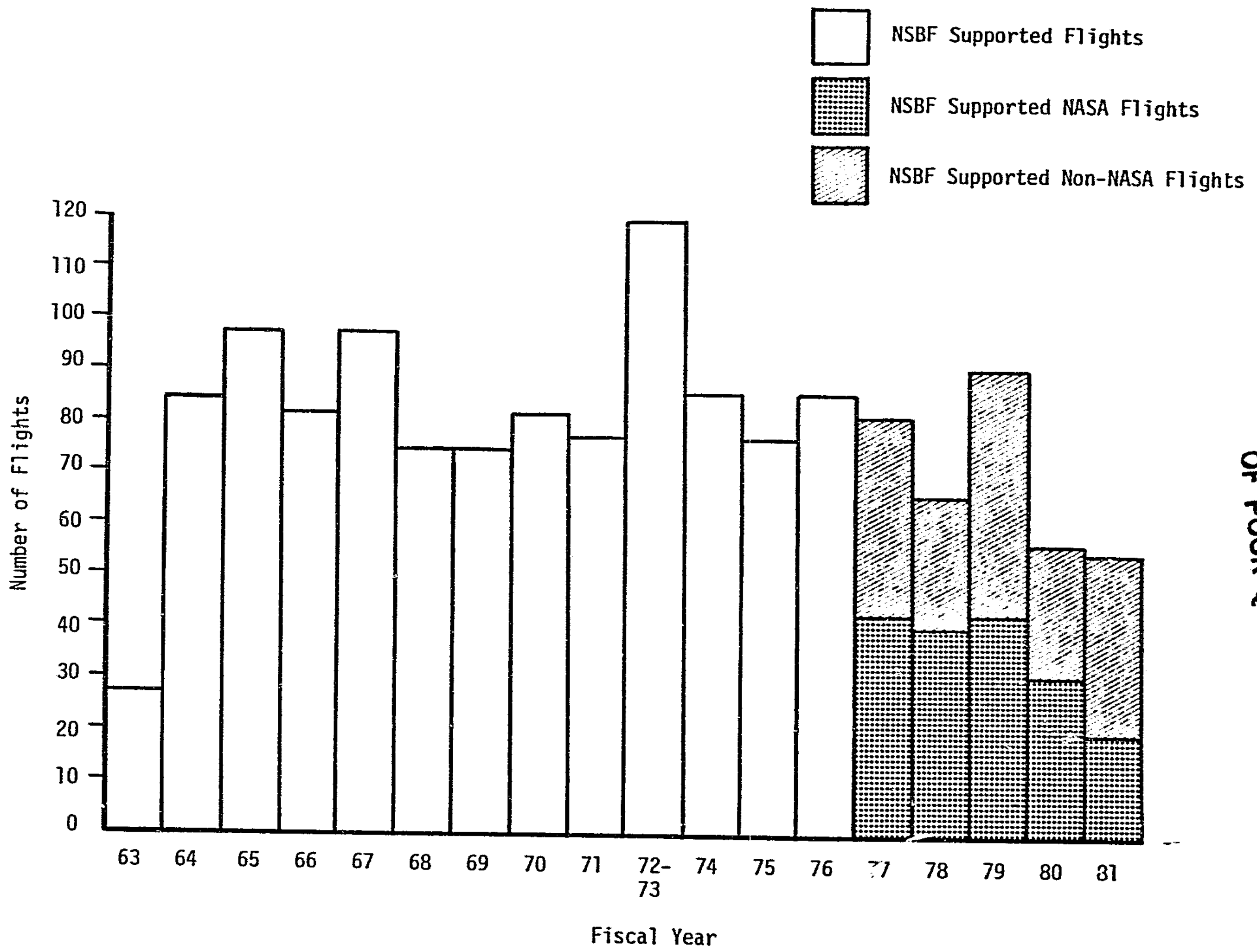


FIGURE 3-1. NSBF BALLOON FLIGHT HISTORY (INCLUDES REMOTE SITE OPERATIONS)

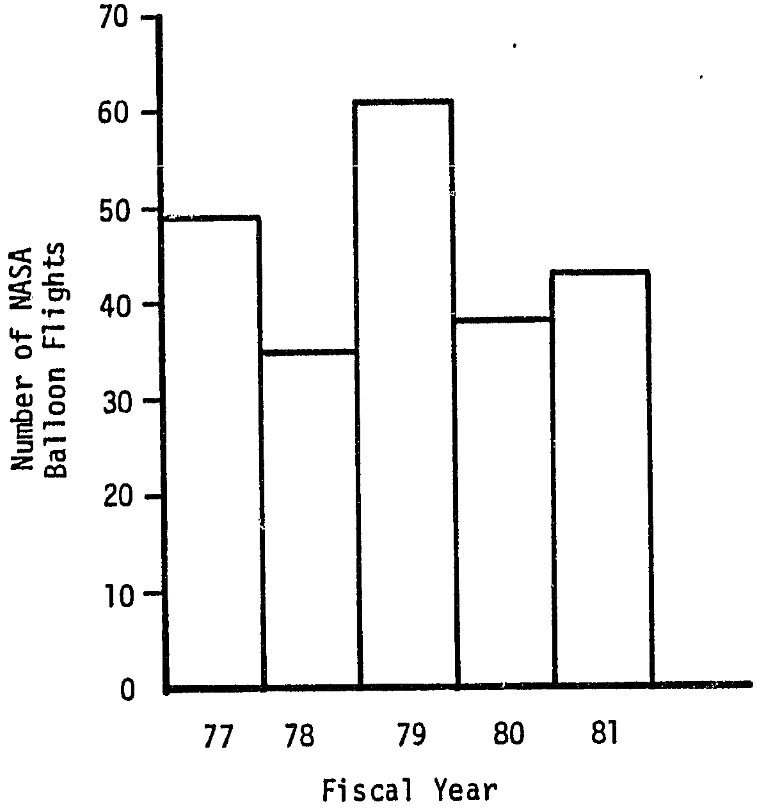


FIGURE 3-2. FY 1977-1981 NASA BALLOON LAUNCH RECORD

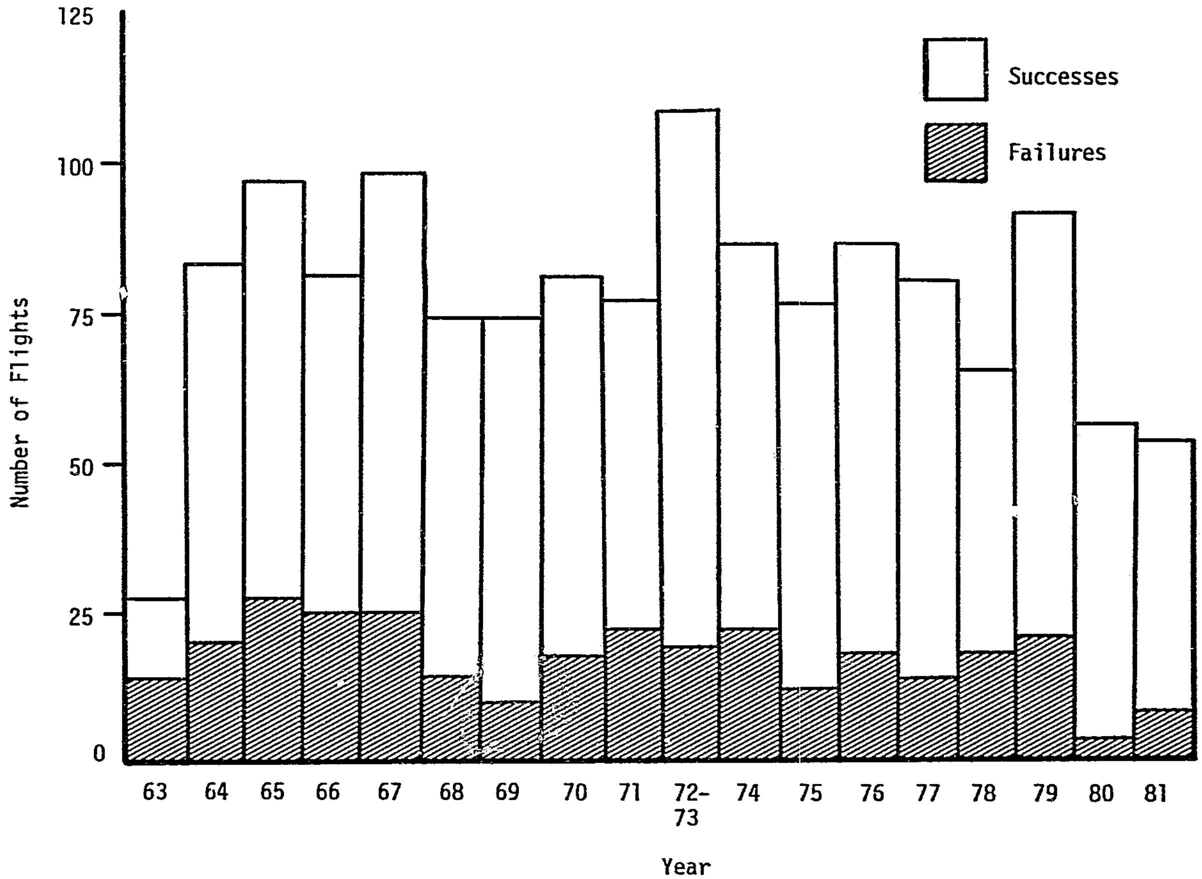


FIGURE 3-3. NSBF BALLOON RELIABILITY RECORD

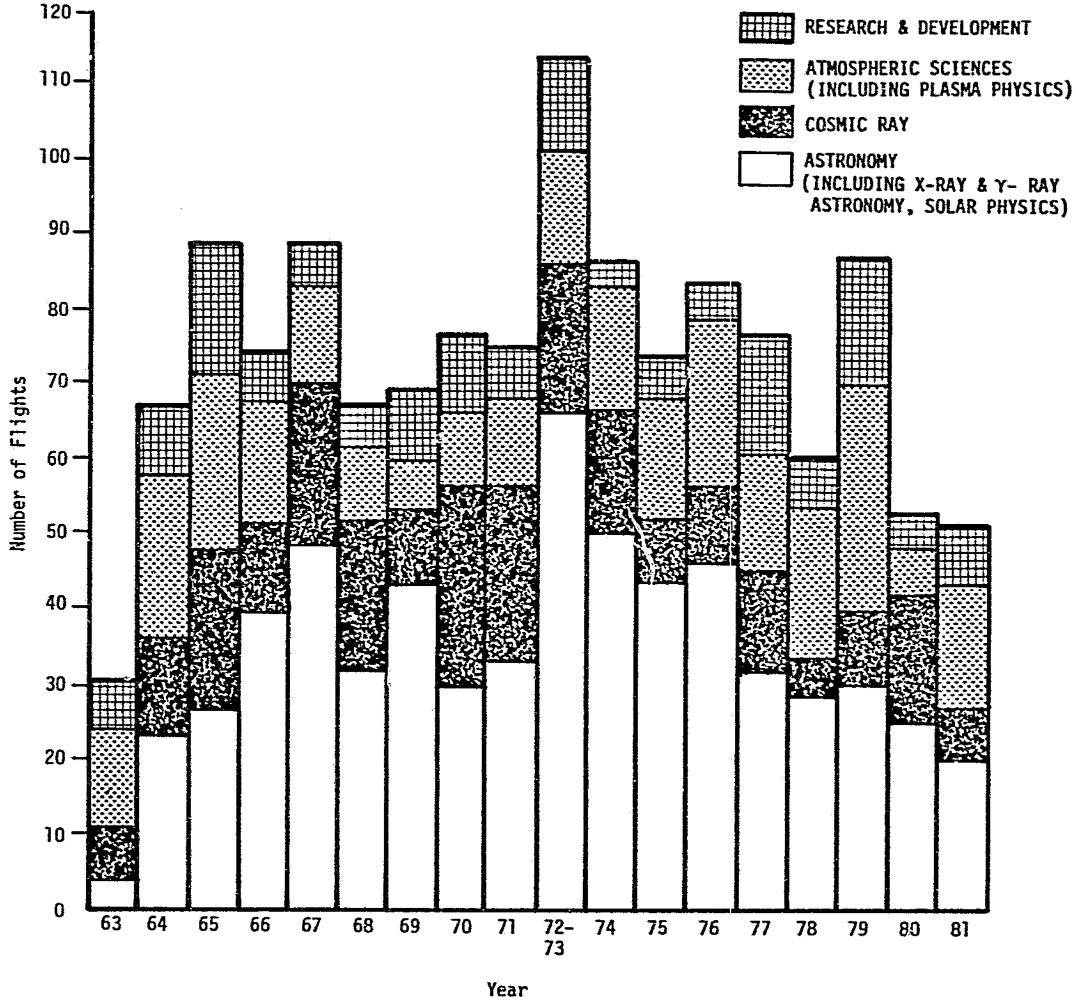


FIGURE 3-4. NSBF BALLOON LAUNCHERS BROKEN DOWN BY DISCIPLINE

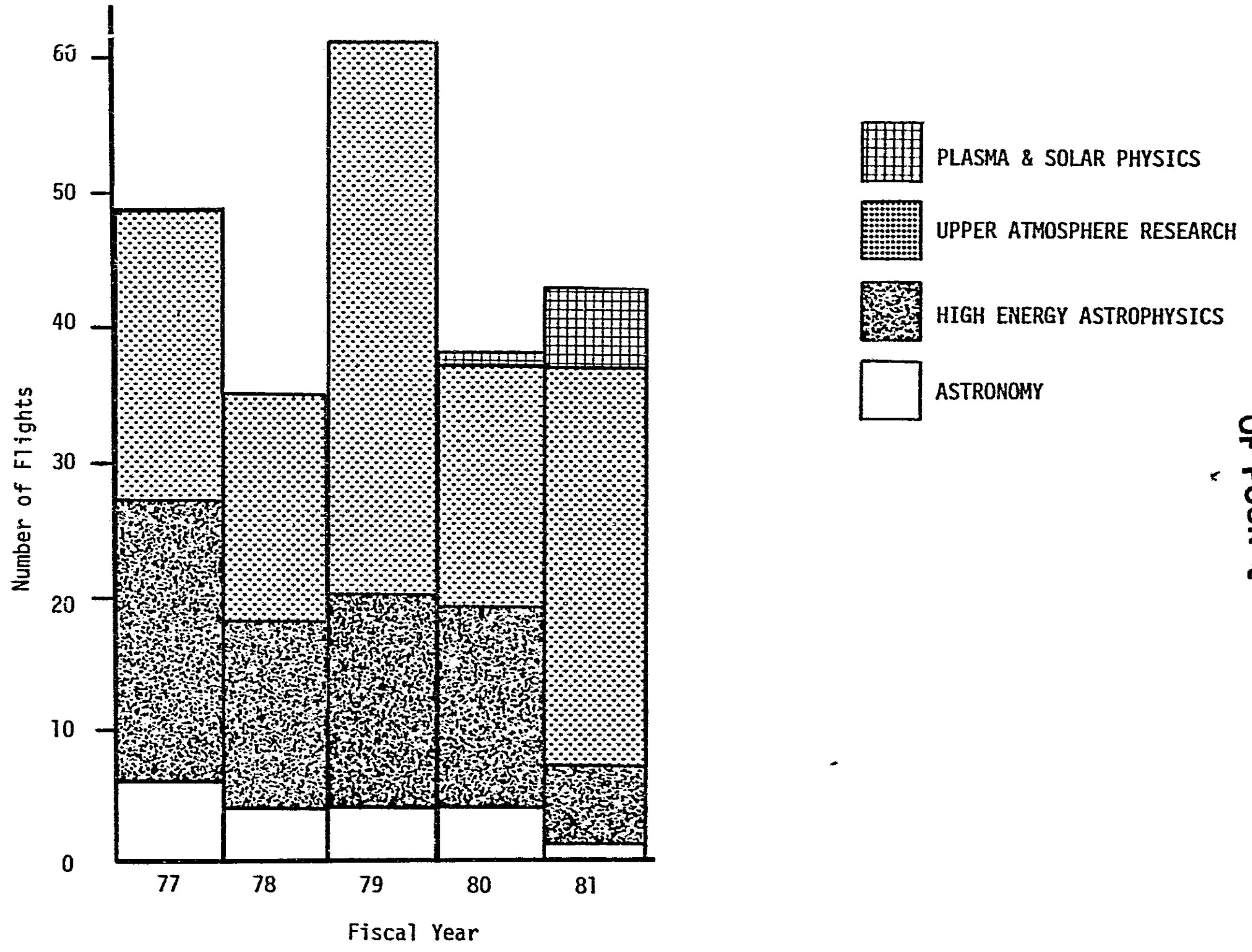


FIGURE 3-5. NASA BALLOON PROGRAM SUMMARY BY DISCIPLINE

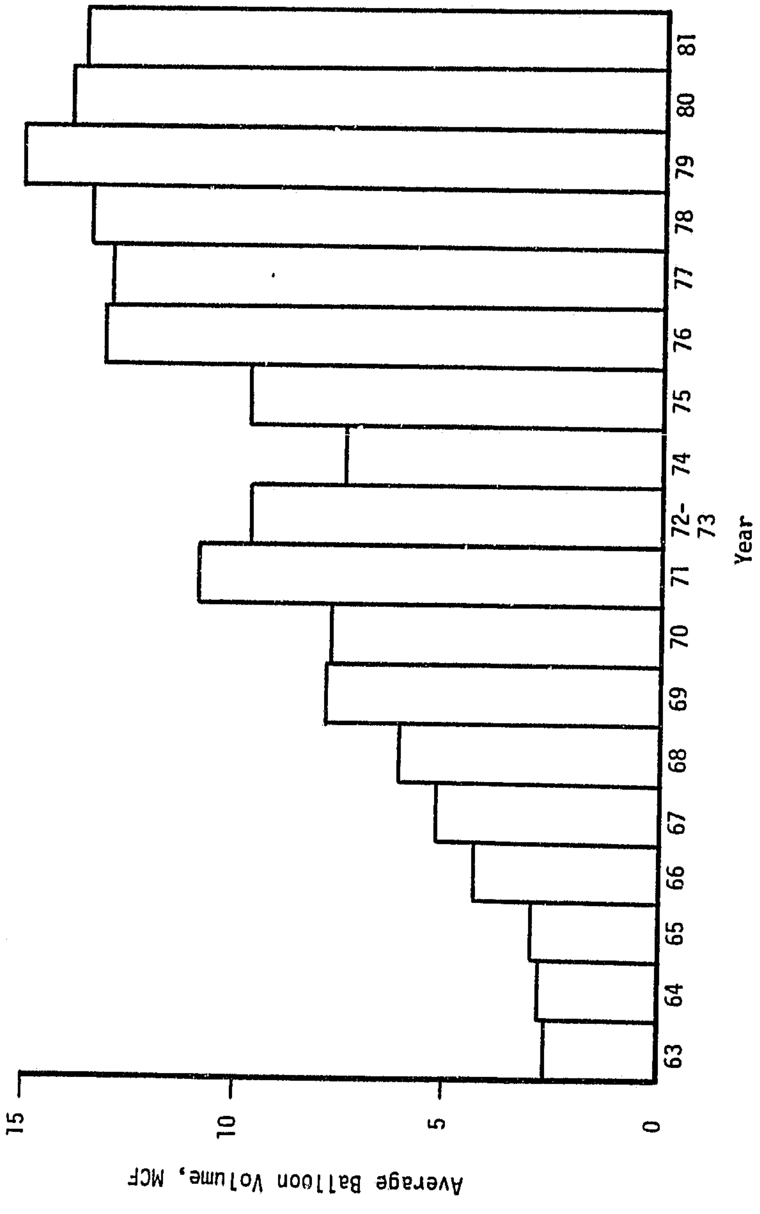


FIGURE 3-6. NSBF PAYLOAD WEIGHT TRENDS

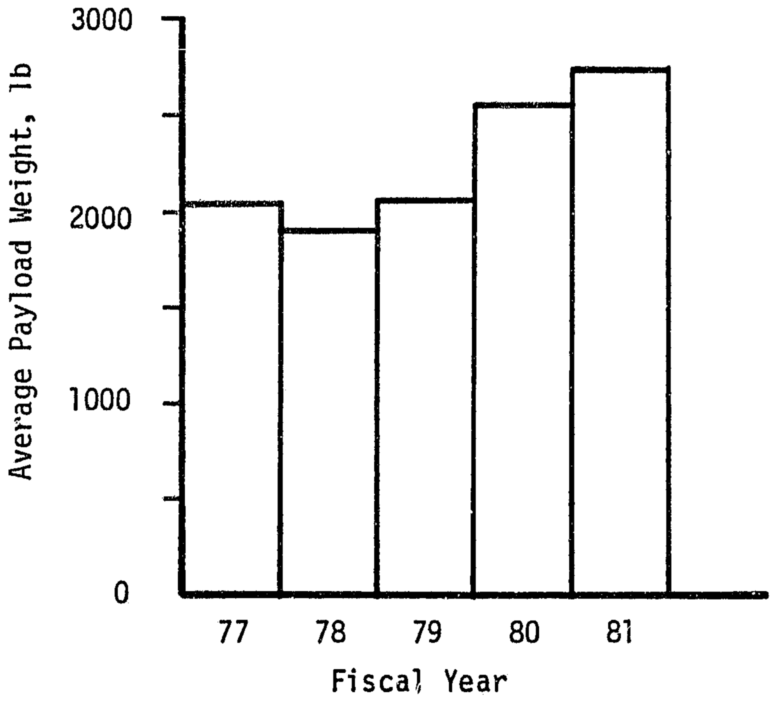


FIGURE 3-7. FY 1977-1981 NASA BALLOON PAYLOAD WEIGHT TRENDS

altitude, and float time. From 1963 to 1976, NSBF balloons experienced a steady increase in average balloon volume (Figure 3-8), a trend that has leveled off since that time. The average volume of NASA balloons launched since 1976 has remained relatively constant (Figure 3-9). This leveling off reflects a satisfaction within the science community in the service being provided by balloons. Although cosmic ray, $\gamma$-ray, hard X-ray, and IR astronomers would like to obtain higher float altitudes, this is not perceived to be as important as obtaining longer flight duration. However, in the soft X-ray and UV astronomy areas, an increase in float altitude would enhance the balloon research capability.

NASA Balloon average float altitudes and float times (flight duration) are shown in Figures 3-10 and 3-11. Both parameters have remained relatively constant since 1976.

## Launch Site Usage

Geographic flexibility in ballooning has been emphasized since balloon sampling must occur in varied regions. Figure 3-12 shows the selection of NASA balloon launch sites.

Although Palestine has been the most heavily used site in the U.S., obtaining long duration flights from this location requires launching during a brief period at spring or autumn turn-around, when the high altitude winds reverse their direction. During the switch, there is usually a dead period of a few days to a couple of weeks. Long duration launches at other times are in danger of crossing coastal boundaries or into Mexican air-space and are aborted.

To provide an opportunity for long duration ballooning at other times of the year, summer launches are being tried from Greenville, South Carolina. The summer winds move east to west so that balloons can remain in flight for several days before leaving U.S. airspace.

In 1981, 27 NASA balloons were launched at Palestine; 29 were launched at remote sites including Laramie, Wyoming, Holloman AFB, New Mexico, and Gimli, Canada. Two overseas campaigns were conducted--one from Barking Sands, Hawaii and one from Alice Springs, Australia.

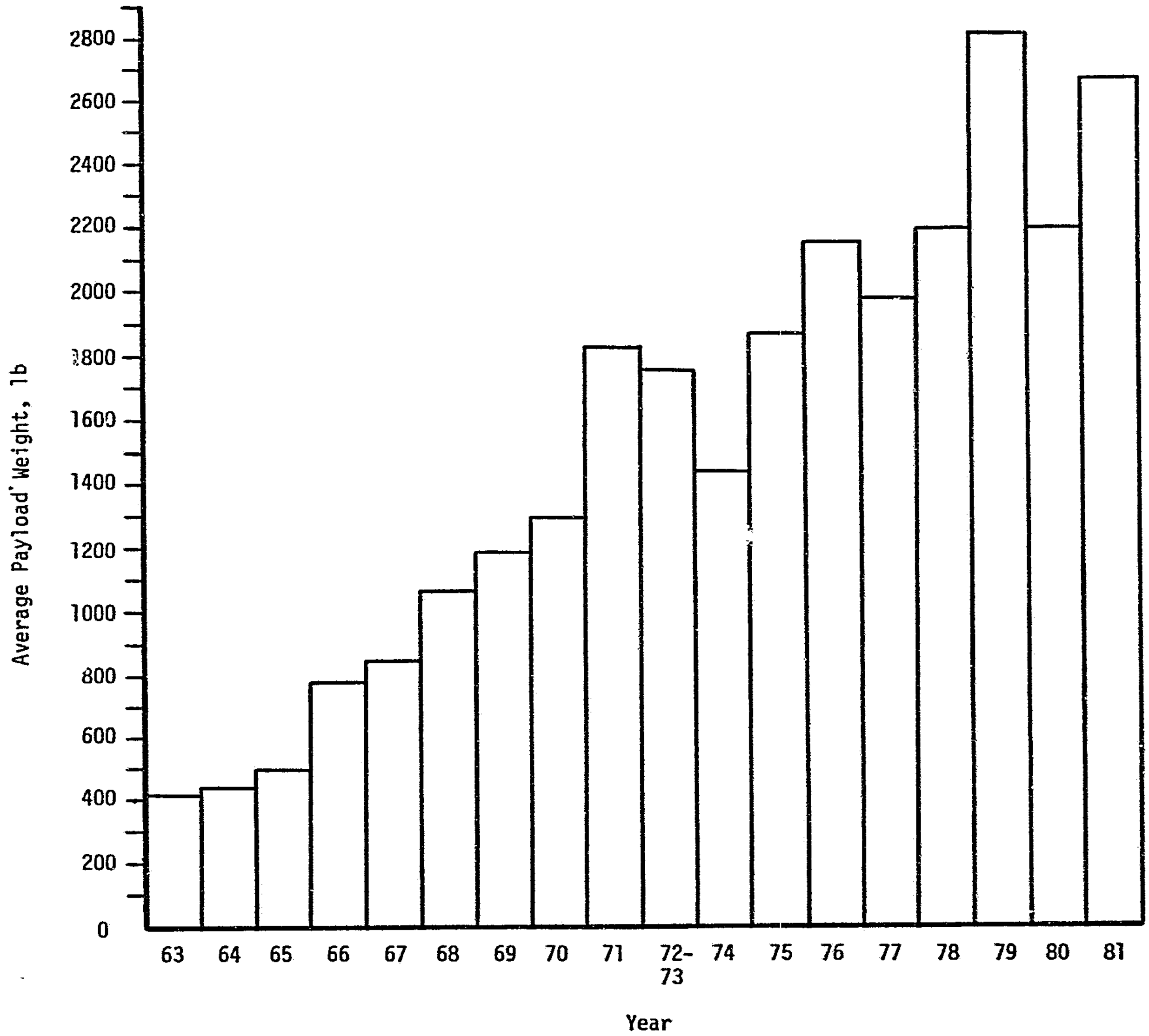


FIGURE 3-8. NSBF BALLOON VOLUME TRENDS

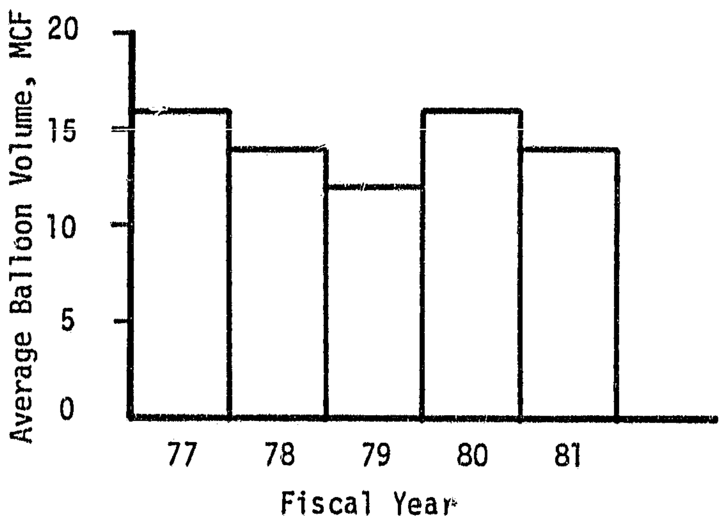


FIGURE 3-9. FY 1977-1981 NASA BALLOON VOLUME TRENDS

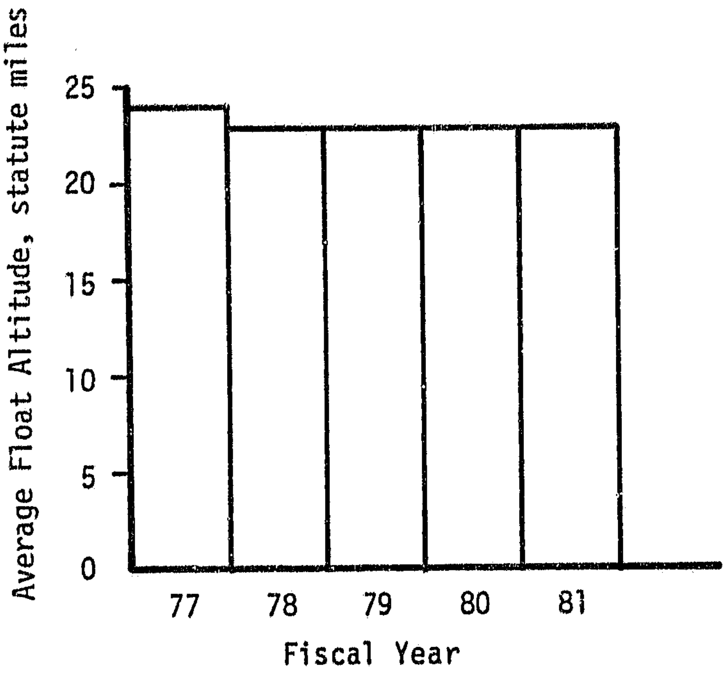


FIGURE 3-10. FY 1977-1981 NASA BALLOON FLOAT ALTITUDES

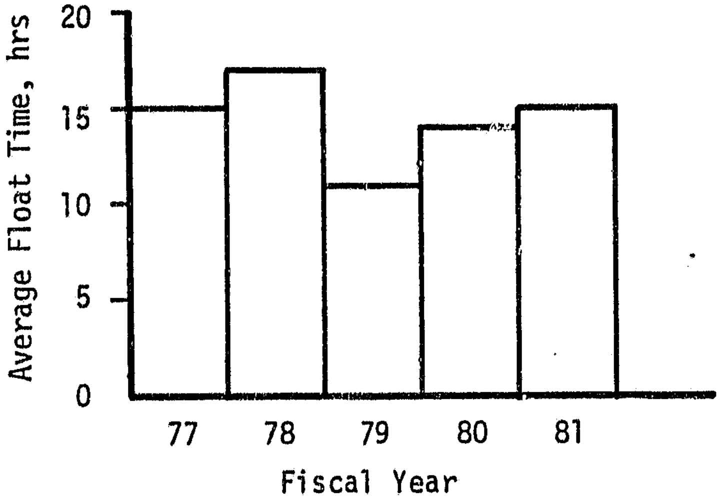


FIGURE 3-11. FY 1977-1981 NASA BALLOON FLOAT TIMES

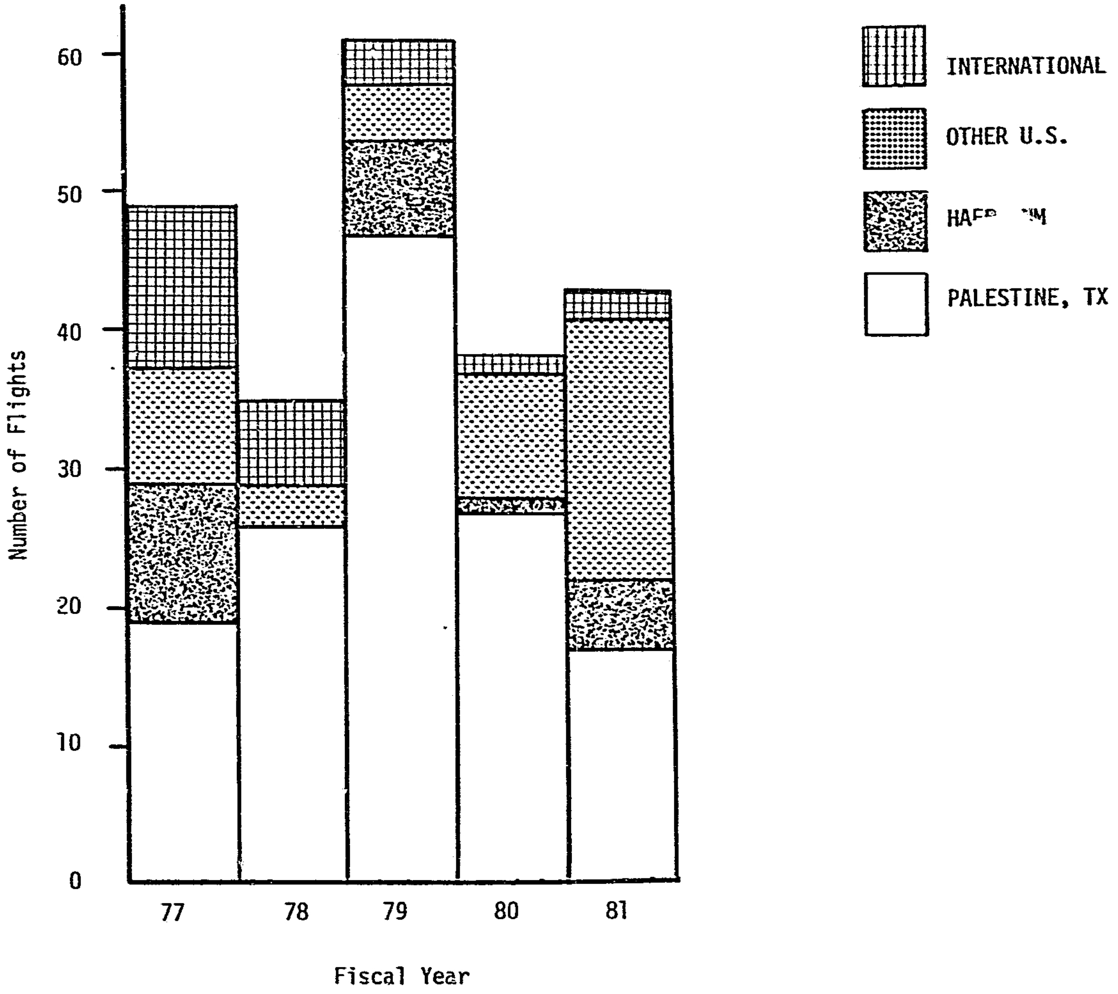


FIGURE 3-12. NASA BALLOON PROGRAM LAUNCH SITE USAGE

Costs

The NASA balloon budget line item covers the cost of the balloon, helium, supporting equipment, and some use of facilities and special services charges. The cost of the science packages, payload support equipment, and integration are carried under the SR&T budgets of the NASA divisions involved. This discussion primarily deals with the direct balloon procurement and use costs represented by the balloon budget line item.

Figure 3-13 summarizes NASA balloon line item costs for the FY 1977-FY 1981 time period. Both the actual costs, and cost converted to constant $1977 are presented to show the impact of inflation. Looking at the $1977 costs (inflation adjusted costs) it may be concluded that the buying power of the balloon budget has remained approximately level or even decreased slightly since 1977.

Figure 3-14 presents the average cost per flight of NASA balloons launched since 1977. This data was obtained by dividing the fiscal year budget by the number of flights flown in that year. Since some flights flown in a given year may be funded by money from a different FY budget, some inaccuracy is present in individual data points. However, the overall trend is accurate. The average cost of balloons launched in 1981 increased nearly 50 percent when compared to those launched in 1977. However, in terms of constant $1977, cost per flight has increased only slightly, if at all.

The balloon cost per pound of payload delivered aloft is shown in Figure 3-15. The two curves plotted (cost per pound in $ actual and $1977) roughly parallel the cost per flight curves. Cost per pound in 1981 is significantly higher than that for 1977. However, cost per pound in constant $1977 increased only slightly.

Although balloon costs expressed in constant year dollars have not increased significantly, a number of factors have put upward pressure on those costs. In the mid-1970s it became desirable to institute more formal management of the balloon program, which until that time had been managed by a single program manager at NASA Headquarters. A program office with a staff of

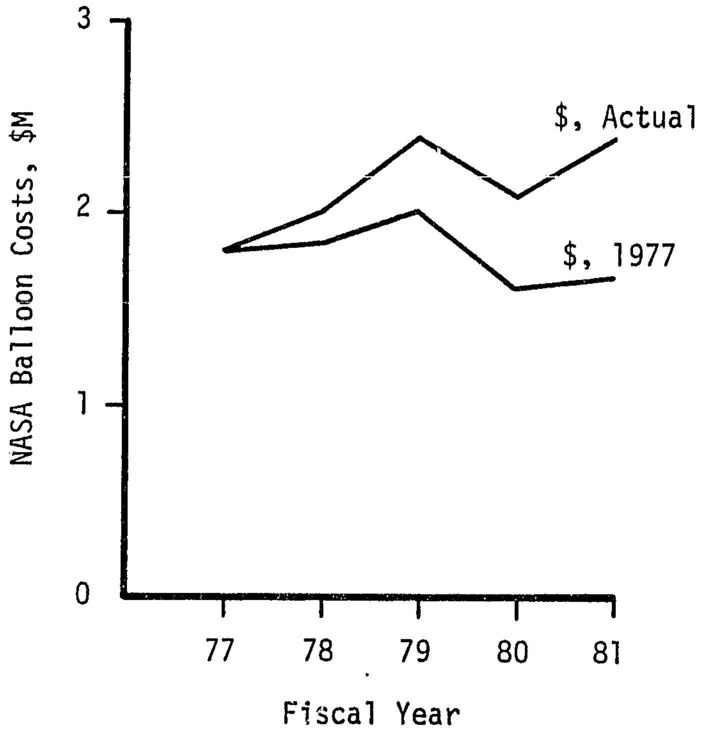


FIGURE 3-13. FY 1977-1981 NASA BALLOON COSTS

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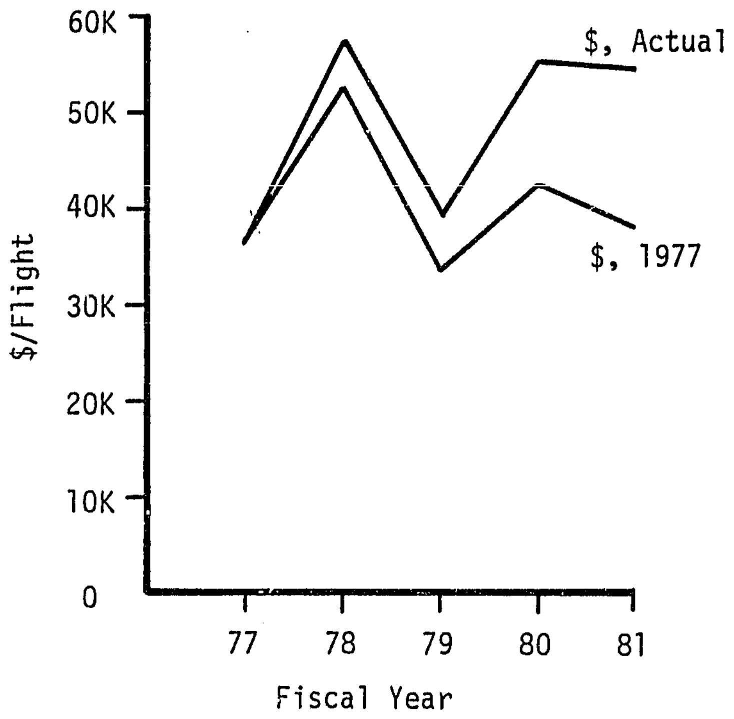


FIGURE 3-14. FY 1977-1981 NASA BALLOON COST PER FLIGHT

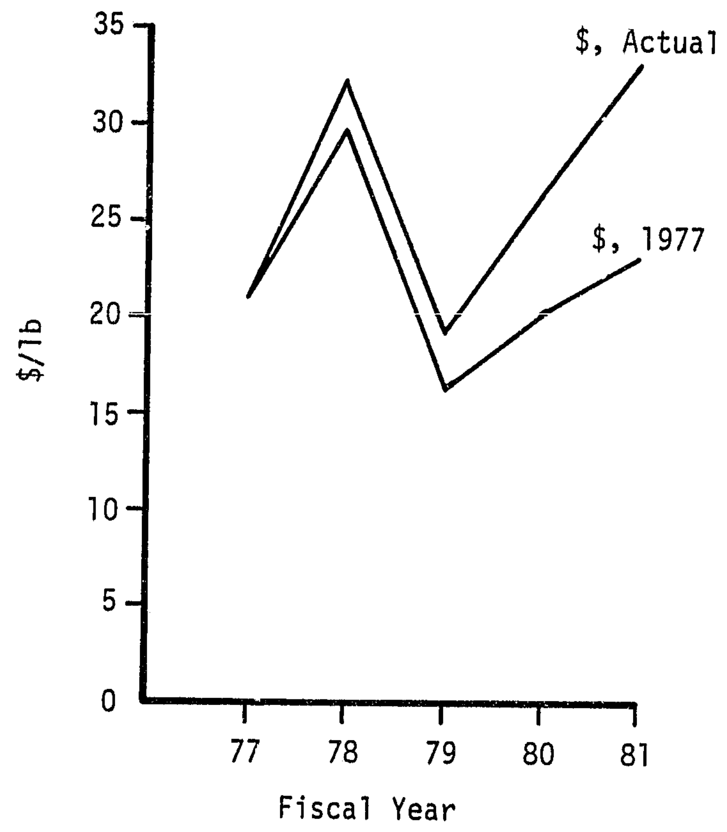


FIGURE 3-15. FY 1977-1981 NASA BALLOON COST PER POUND PAYLOAD

six persons (including the program manager) was established at the Wallops Flight Center (WFC).* About the same time, reliability problems were encountered with heavy-lift balloons (a moratorium on heavy-lift flights was in effect in 1978), and stricter, more formal reliability and quality assurance measures were implemented. A number of test flights were conducted to investigate the failures that had occurred and testing in general in the program increased substantially. Quality control provisions implemented at the balloon contractors' facilities increased balloon production costs. Balloon production costs were also adversely affected by the emergence of one dominant supplier and the weakness of competitors. This situation has begun to improve recently as stronger competition between suppliers is beginning to occur.

NASA participation in NSBF balloon operations costs has increased leading up to the transfer of NSBF from the NSF to NASA. NASA used to pay only for the balloons, helium, and any special services needed, e.g. the additional cost of offsite operations (both domestic and international) including all travel and other NSBF staff expenses. In 1980 and 1981 NASA participation increased to include larger incremental costs associated with NASA support. Finally in recent years increasing support for improvements in balloons has been provided.

The average cost per flight range of \$30K-\$50K reflected in Figure 3-14 is in agreement with data obtained from the NSBF and listed in Table 3-1. This table also shows that a downturn in balloon cost is now occurring. This downturn in part is due to an improving competitive situation between candidate balloon suppliers.

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*The staff increase does not affect the budget directly as it is civil service manpower not charged to the budget. However, the increased attention to management and reporting had some affect on contract costs.

TABLE 3-1. NSBF SAMPLE BALLOON COST TRENDS

| Year | Volume (MCF) | Cost ($ Actual) |
|---|---|---|
| 1967 | 5.250 | $ 4,193 |
| 1975 | 5.200 | 5,084 |
| 1981 | 5.048 | 13,382 |
| 1973 | 11.600 | 6,927 |
| 1976 | 11.600 | 12,108 |
| 1979 | 10.700 | 21,502 |
| 1980 | 11.600 | 16,700 |
| 1981 | 11.600 | 16,700 |
| 1972 | 15.500 | 9,800 |
| 1976 | 15.300 | 16,742 |
| 1977 | 15.500 | 19,500 |
| 1979 | 15.300 | 29,530 |
| 1981 | 15.900 | 25,807 |
| 1982 | 15.600 | 19,543 |
| 1975 | 20.300 | 19,886 |
| 1976 | 20.111 | 24,011 |
| 1978 | 20.111 | 29,813 |
| 1979 | 20.500 | 37,623 |
| 1981 | 20.500 | 31,156 |
| 1975 | 30.000 | 32,201 |
| 1977 | 31.650 | 37,402 |
| 1979 | 31.160 | 47,315 |
| 1980 | 31.150 | 55,593 |
| 1982 | 30.250 | 38,490 |

## 3.2.2 Accomplishments

In this section, balloon program accomplishments will be discussed from the standpoint of significant scientific accomplishments as well as in the context of satisfaction of program objectives.

3.2.2.1 Significant Scientific Results. Significant scientific accomplishments will be discussed by science field.

### Cosmic Ray Astronomy

Balloons have been essential to the development of high-energy cosmic ray astronomy. Cosmic rays, which are charged particles--electrons, protons, atomic nuclei, and the anti-matter correspondents--interact both with the magnetosphere as they approach the Earth and with the Earth's atmosphere. Low-energy cosmic rays are deflected by the magnetosphere and are not observed from balloons. High-energy cosmic rays enter the atmosphere and are thermalized--ground based detectors provide very little information, but at balloon altitudes the atmosphere has had only a minimal effect.

The sources and energizing mechanisms of cosmic rays are a puzzle--the Sun is a known source of low-energy cosmic rays--but for galactic cosmic rays the sources and accelerating mechanisms--supernovae, interstellar shock waves, large scale magnetic fields are current candidates--can only be indicated indirectly at this time. The existence of discrete sources or anisotropy in the background can only be conjectured.

Early studies of cosmic rays were concerned primarily with establishing their chemical composition and energy distribution. Current studies are addressing issues of more cosmological concern, attempting to obtain a consistent picture of cosmic ray sources and acceleration mechanisms. Isotope and chemical composition studies are helping to resolve the question of what fraction of cosmic ray nuclei originated from nucleosynthetic processes in stars and supernovae and what fraction are nuclear collision fragments, information that can also be used to obtain estimates of cosmic ray life-times.[2] Results of these studies may have broad cosmological implications; depending on the location of cosmic ray sources--near the solar system, galactic, or intergalactic--the amount of material in cosmic rays may be sufficient to close the universe.

Balloons have provided most of our information on the energy dependence of cosmic rays. New studies are being conducted on the energy dependence of the chemical composition. The first observation of ultraheavy nuclei, those nuclei above iron--were obtained from balloons as were the first observations of anti-matter components. Balloons offer an ongoing capability for observing the extremely high energy transitions which may produce new insights into fundamental particles and nuclear processes.

## γ-Ray Astronomy

Certainly one of the most productive fields of balloon research has been γ-ray astronomy. The types of sources seen, the types of instruments used, and the types of data acquired have not only produced valuable science, but spurred the initiation of the next major NASA science satellite--the Gamma Ray Observatory.

γ-rays are the extremely energetic photons produced either by transitions in or reactions between atomic nuclei, by the interaction of extremely energetic charged particles with a magnetic field, or by the annihilation reaction between matter and anti-matter. The very high energy of these photons makes them the most effective radiation to study in the observation of high energy sources.

γ-ray sources which also exhibit pulsed radiation in the radio region were discovered from balloons; both the Crab and Vela pulsars have been studied.[3] Extragalactic γ-ray sources in the Seyfert Galaxy NGC 4151 and in Centaurus A have been observed. A diffuse γ-ray background has been detected; a possible and unexpected excess of radiation in the 1-10 MeV energy range may provide new information on the Galactic magnetic field and the cosmic rays which it contains. γ-ray bursts, a phenomenon not yet understood, have been observed from balloons.

In a rather novel role, γ-ray detectors have been used to obtain information on the chemical composition of the surface of Mercury by studying the γ-ray radiation emitted by the surface in response to cosmic ray bombardment. Such a technique could be applied to any body lacking an atmosphere.

The γ-ray emission associated with solar flare activity was the subject of study during the last solar maximum. A new temperature component of the flare material was discovered, one that could not be detected at low spectral resolution.

Recently, a major step forward in obtaining high resolution γ-ray spectra has been taken with the flying of germanium detectors. These detectors are capable of much better resolution than previous ones (NaI crystals) and have now been applied to both solar and galactic/extra-galactic work.

## IR Astronomy

The field of IR astronomy is of interest in both the balloon and airborne programs. Balloons, because they operate at higher altitudes, have to contend with less atmospheric interference, and are better suited for studying faint sources and for obtaining IR spectra. Most of the balloon work falls into these categories. Other activities have involved obtaining all-sky surveys and producing low-resolution mapping of particular regions. Cooled detectors are used on balloons to reduce the thermal detector noise but balloons are not well-suited to cooling the entire instrument; instead, the large lifting capacity of balloons has been used to carry large enough telescopes to effectively enhance the signal to noise ratio of the incoming data.

Balloons have provided the first detection of numerous molecular lines in the Sun, in planetary atmospheres, and in interstellar "molecular clouds".[3] Using various atmospheric windows and atmospheric emission line, the temperature and chemical composition of planetary atmospheres have been studied. Jupiter's atmosphere, for example, has been observed from an altitude where the pressure is 0.01 atm down to an altitude where the pressure is 5 atm. Since the exposed surfaces of moons and planets in the solar system radiate in the IR and far IR, studies of the temperature and thermal properties of these surfaces have been performed from balloon. Balloon observations of the Jovian moons first revealed the presence of internal heat sources.

Beyond the solar system, studies of early star development in molecular clouds and HII regions is advancing our understanding of the early stages of stellar evolution. All the catalogues of sources in the far infrared have been compiled in the balloon program, and initial investigations of the spectrum and anisotropy in the 3°K cosmic background radiation were first made from balloons. Studies in the far IR have provided new information on the distribution of dust and new stars in and near the galactic plane.

Studies of the Sun in the IR provide information on the photosphere/chromosphere transition region and provide input to improved models of the solar atmosphere.

## UV Astronomy

Some work in the ultraviolet region of the spectrum can be conducted from balloons. Ozone, which exists mostly below the altitude of 25 km, is the dominant absorber down to 1900 Å, so that some work can be conducted in the near UV (1900-3000Å). Since there is considerable variability in the atmospheric opacity in this region, UV studies of stellar sources on balloons are most useful in studying small wavelength regions--most notably performing high resolution spectroscopy. These studies have produced new information on a number of hot, emission line sources such as Be and shell stars, contact binaries (where mass transfer is occurring), and chromospheric regions in F and A stars.(3)

## X-Ray Astronomy

High energy X-rays are not blocked before they reach balloon altitudes, so that useful observations can be performed here.

Significant observations from balloons have been:(2)

(1) Identification of the continuum in the Crab Nebula as non-thermal

(2) Detection of a diffuse component in the high energy X-ray region
(3) First observation of an X-ray flare
(4) Observation of the long term variability in Cyg X-1.

## Atmospheric Sciences

Atmospheric studies have become an increasingly important part of the balloon program. This interest has arisen in part because the capability to understand, model, and perhaps influence weather and climate patterns is closer to being a realizable goal. However, a more urgent concern in this activity is the realization that the Earth's energy budget is in delicate balance, and that man is capable of (and in fact is) disturbing this balance, perhaps irreversibly.

The ozone depletion problem has been a topic of extensive research effort for balloons. Ozone exists almost entirely in the stratosphere and is the dominant opacity to UV radiation in the energy range 1900-3000Å. If ozone breakdown is caused by fluorocarbon emissions at the Earth's surface, more of this radiation will get to the Earth's surface, an event that will be inimical to many forms of life on the Earth.

Balloon measurements of atmospheric properties use both in situ and remote sensing techniques. In the NASA program, the emphasis has been on the development of remote sensors, since these instruments can serve as precursors to satellite instrumentation. In situ measurements are most useful for detecting rare species and determining chemical reaction kinetics; using such techniques, scientists first discovered the free radicals involved with ozone breakdown and led to the conslusion that ozone breakdown, which had not been though to be a problem, was in fact a problem of considerable magnitude. Remote sensors are essentially the same as those used for IR astronomy, the difference being that the large fluxes eliminate the need to use telescopes and cryogens. Recent development of emission line detectors will faciliate studies of the diurnal dependence of chemical states.

A series of studies beginning in 1970 revealed unexpectically large amounts of $N_2O$, NO, and $NO_2$ in the ozone layer of the stratosphere and led to the conclusion that the ozone content in the stratosphere must be decreasing. Subsequent studies, in which balloons played an essential role, were able to attribute these elevated oxide concentrations to the emission of fluorocarbons from the Earth's surface. More recent balloon observations using IR spectrometers have detected nitric acid, $HNO_3$, providing further evidence that stratospheric ozone is being chemically degraded.

3.2.2.2 Significant Hardware Advances. The role of ballons as test vehicles for satellite instrumentation is an important one; the capability of allowing greater lifting weights by balloons has facilitated this activity. This is fortunate, as the instrument development role will continue to increase in importance in the future. Early in the program life, any observations were notable and the primary goal was to get some instrumentation into the air. Now, the most easily obtained data has been collected, and obtaining new, groundbreaking information will more and more frequently require new types of instruments, larger collection areas, and more sophisticated observational techniques.

In hard X-ray astronomy, higher resolution instruments are being developed to reduce the resolution from degrees to arc minutes. Germanium detectors are presently being tested to advance the capability for performing high resolution $\gamma$-ray and X-ray spectroscopy. The development of electronic readout of spark/chamber data, replacing photographic readout, was accomplished on balloons. In the future, increased detection areas may be obtained by employing arrays of spark chambers, a development program which would undoubtedly be performed on balloons.

Cosmic ray study requirements have been primarily responsible for the pressure to lift larger payloads. In cosmic ray work, the emphasis has been on the development of new technology as well as on scaling existing technology to larger instruments. The volume of the detector is a significant parameter in cosmic ray work and these volumes have continued to grow in the balloon program.

In IR astronomy, the greater lifting capacity in the research balloons has allowed large telescopes to be used, lessening the need to use cryogens to obtain useful data.

Significant advances are being obtained in the atmospheric work. A testing program is about to begin on an atmospheric emission line detector which will greatly enhance the capability for obtaining diurnal variations in the atmospheric chemical composition.

3.2.2.3 Contribution to Achieving Program Objectives. The suborbital program objectives have been satisfied in the balloon program.

Continuing Research

An active program of research has been continuing in the balloon program. In the γ-ray, hard X-ray field high resolution spectroscopy with enhanced spatial resolution is providing more detailed information on diffuse and discrete sources. Sky surveys are continuing in the IR field and will provide preliminary data and lists of significant sources for the COBE, IRAS, and SIRTF instrumentation. The large telescopes and long observing times allow important research to continue.

In atmospheric research, combined in situ and remote sensing detectors will continue to be used to investigate the time dependent chemical constituents in the stratosphere.

Search for New Phenomena

In conducting research, new and sometimes puzzling phenomena may appear at any time. In the balloon program, evidence for ozone breakdown in the atmosphere and γ-ray burst events of unknown origin beyond the solar system are examples of such events. The next generation of cosmic ray detectors, which will obtain new information on isotopic abundances and provide better directional resolution, might yield new, unexpected results.

Support for Other Programs

The support the Balloon Program provides for NASA orbital programs is of major importance. All of the instruments to be flown on GRO will be flown on balloons to test and verify designs. The high resolution germanium detectors will be ready for the next generation γ-ray satellite. All of the instruments and principle investigators on COBE have come from the balloon IR program. Balloons provided calibration of the SMM instruments since it did not carry its own calibration sources.

In atmospheric research, balloon instruments provided calibration support for satellite observations from the NIMBUS IV, VI, and VII satellites. The development of emission line IR spectrometers which is now in progress will provide new instrumentation for the proposed Upper Atmosphere Research Satellite. Such development also supported experiments on board the Voyager flights.

## Time Critical Studies

Time considerations enter in the need to get instruments into the field to observe transient events. The balloon program facilitates this by encouraging short duration experiment development and by allowing flexible launch times.

A good example of both capabilities is provided by a recently flown solar X-ray package. Go-ahead on the project was obtained in February 1980; the first launch occurred on November 1 of that year. Reflight from Greenville, South Carolina, was scheduled in May 1982, a time when the Sun was expected to be active. When the experiment was ready for launch, however, the Sun entered a quiet state and the launch was placed on hold. The report that a major active area was coming into view spurred preparations for launch, but a period of windy surface conditions prevented it from occuring (unfortunately a major flare event occurred during this time). When the surface winds died off, launch occurred within 24 hours, and 29 hours of useful data were obtained.

## Development and Testing of Scientific Instruments and Detectors

There is an ongoing program of testing and instrument developments using balloons. In part, this supports the requirement that proposed

C-2

satellite instrumentation be able to demonstrate a record of performance and reliability. The germanuim detectors currently being developed and tested in the balloon program promise to provide a significant advance in $\gamma$-ray spectroscopy. These detectors are being used for both solar and non-solar astrophysical sources and will be ready for use on a $\gamma$-ray satellite after GRO.

Programs are now being considered for development of a Compton telescope to observe in the 100 KeV to 30 MeV energy range and to develop a Dicke camera for normal incidence imaging of X-ray sources. In the future, testing of mercury iodide (HgI) detectors to perform X-ray spectroscopy might be instituted; such detectors require no cooling and so are well suited for satellite work.

Development of detector arrays using charge coupled detectors (CCD's) or diode arrays will become important.

## Enhancement of Support Capabilities

A rise in balloon failures of heavy lift balloon flights in 1976 prompted a moratorium on such flights while the source of failure could be determined. Out of this study came a more conservative approach to conducting such launches and improved mechanical support.

As balloon flight duration increases, or as higher data rates are introduced by more sophisticated instrumentation (e.g., matrix detectors), additional support of the science teams will be required. There are the obvious considerations of providing long-term tracking and data acquisition, long-life power sources, and long-term thermal control. Not so obvious may be the need to support efforts to provide more sophisticated capabilities for on-board data processing and selective transmission.

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2. Tesi, G., and R. E. Halpern. A Review of the History, Status, and Future Requirements of Scientific Ballooning, June 3-4, 1980, private communication.

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# 4.0 THE AIRBORNE PROGRAM

## 4.1 Introduction

The NASA Airborne Program provides a family of specially equipped aircraft as national facilities in support of research and development in a variety of scientific disciplines. Aircraft currently used include: a Lockheed C130, a Convair 990 ("Galileo Observatory"), a Lear Jet, a Lockheed U-2, a C141 ("Kuiper Airborne Observatory"--KAO), a Lockheed ER-2, and a General Dynamics WB-57F. The basic capabilities of these aircraft are summarized in Figures 4-1 to 4-7. Science payloads of up to 100,000 pounds can be carried to over 40,000 feet altitude. Lesser payloads of 1,000 to 3,000 pounds can be carried to altitudes exceeding 60,000 feet. Experiment durations ranging from 2-1/2 to 8 hours are achieved depending on the aircraft used.[1,2]

The C130 was one of the first aircraft used by NASA as a scientific research platform. In fact, its first use in 1955 predates NASA. This aircraft is still in service today and used primarily as an Earth observing vehicle.[1]

NASA's airborne astronomy program began in 1964 with the development and introduction of the Convair 990 ("Galileo I") observing platform. The NASA Ames Research Center (ARC) was assigned responsibility for operating this facility. The ability of this aircraft to operate at altitudes above more than 99 percent of the Earth's water vapor opened up the near infrared region of the spectrum for astronomical research.* However, since the astronomical instruments could not be operated open port, its usefulness for the infrared was limited to the shorter wavelengths. Nonetheless the payload carrying capability, endurance, and range of the aircraft made the Galileo a versatile and convenient tool for scientists conducting research.[3]

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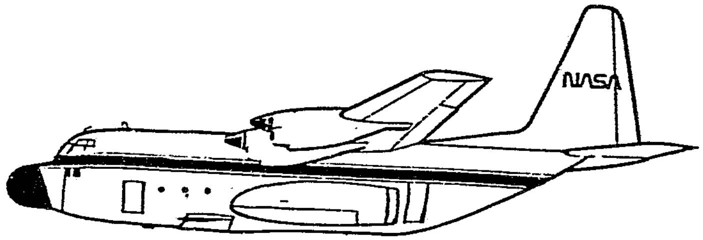
*Atmospheric water vapor absorbs most incoming infrared radiation. At ground level, only very limited infrared observations can be made at only a few mountaintop geographic locations.



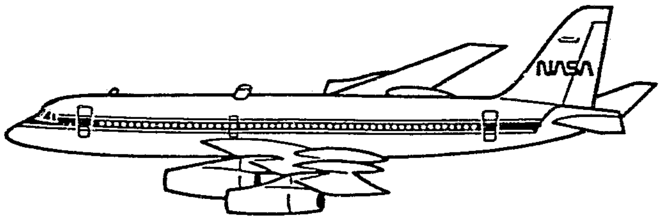

OPERATING ALTITUDE: . . . . . . 30K ft

ENDURANCE FOR RESEARCH:. . . . . 8 hr, Range: 2500 n.mi.
Payload: 20K lb

INVESTIGATOR ACCOMMODATION:. . . Up to eight systems crew

APPLICATIONS:. . . . . . . . . . Soil Moisture Studies
Agricultural Surveys
Meteorological Investigations
Satellite Sensor Development

FIGURE 4-1. C-130, LOCKHEED



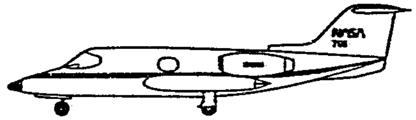

OPERATING ALTITUDE: . . . . . . 30-40K ft(Cruise), 41K ft(Max.)

ENDURANCE FOR RESEARCH:. . . . . 6.5 hr, Range: 3300 n.mi.
Payload: 20K lb

INVESTIGATOR ACCOMMODATION:. . . 10-25

APPLICATIONS:. . . . . . . . . . Environmental and Ecological Surveys
Meteorological Investigations
Radar Technology Studies
Astronomy

FIGURE 4-2. CV-990, CONVAIR



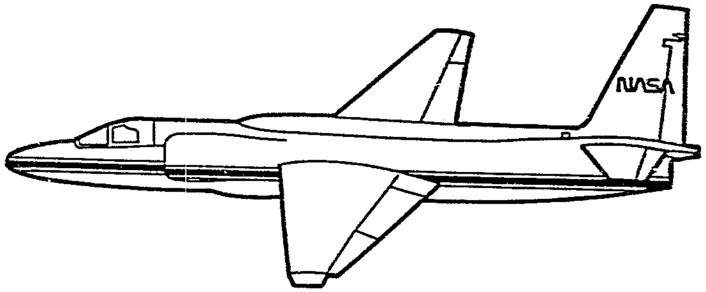

OPERATING ALTITUDE: . . . . . . 45K ft

ENDURANCE FOR RESEARCH:. . . . . 2.5 hr, Range: 1300 n.mi.
Payload: 1.2K lb

INVESTIGATOR ACCOMMODATION:. . . 2

APPLICATIONS:. . . . . . . . . . Astronomy
Instrument Development
Atmospheric Research

FIGURE 4-3. LEAR JET OBSERVATORY



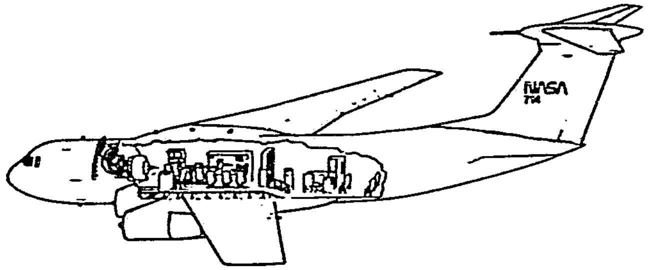

OPERATING ALTITUDE: . . . . . . 65K ft(Cruise), 70K ft (Max.)

ENDURANCE FOR RESEARCH:. . . . . 6.5 hr, Range: 2500 n.mi.
Payload: 750 lb Q-bay; 100 lb, Canoe; 300 lb, Wing Pods

INVESTIGATOR ACCOMMODATION:. . . None, Pilot only

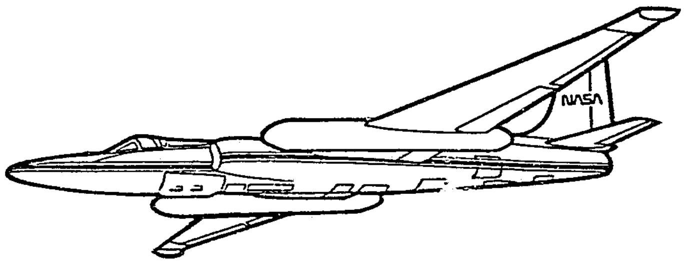
APPLICATIONS:. . . . . . . . . . Land Use Mapping
Satellite Sensor Development
Communications and Data Handling Exp.
Stratospheric Sampling
Disaster Surveys

FIGURE 4-4. U-2, LOCKHEED



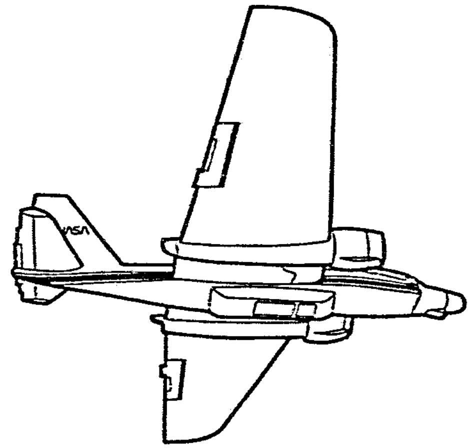

| | |
|---|---|
| OPERATING ALTITUDE: . . . . . . | 41-45K ft |
| ENDURANCE FOR RESEARCH:. . . . . | 7.5 hr, Range: 3300 n. mi.<br>Payload: 60-100K lb |
| INVESTIGATOR ACCOMMODATION:. . . | 5-7 |
| APPLICATIONS:. . . . . . . . . . | Astronomy<br>Satellite Ground Truth<br>Satellite Instrument Development |

FIGURE 4-5. KUIPER AIRBORNE OBSERVATORY




| | |
|---|---|
| OPERATING ALTITUDE: . . . . . . | 70K ft (Cruise) |
| ENDURANCE FOR RESEARCH:. . . . . | 8 hr, Range: 3000 n.mi.<br>Payload: 600 lb, Nose; 750 lb, Q-bay;<br>1500 lb, Wing Pods |
| INVESTIGATOR ACCOMMODATION:. . . | None, Pilot only |
| APPLICATIONS:. . . . . . . . . . | Satellite Sensor Development<br>Stratospheric Research<br>Astronomy<br>Satellite Ground Truth<br>Communication and Data Relay Research |

FIGURE 4-6. ER-2, LOCKHEED




| | |
|---|---|
| OPERATING ALTITUDE: . . . . . . | 60K ft(Cruise), 63K ft (Max.) |
| ENDURANCE FOR RESEARCH . . . . . | 7 hr, Range: 2800 n.mi.<br>Payload: 2800 lb |
| INVESTIGATOR ACCOMMODATION:. . . | Pilot plus trained SEO* |
| APPLICATIONS:. . . . . . . . . . | Satellite Sensor Development<br>Satellite Ground Truth<br>Land Use Survey<br>Agricultural Inventory Data<br>Stratospheric Research |

FIGURE 4-7. WB-57F, GENERAL DYNAMICS
*SEO--Scientific Equipment Operator

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OF POOR QUALITY

Early planetary observations aboard the Galileo were made by Dr. Gerard P. Kuiper of the University of Arizona. His research team conducted the first detailed near-infrared spectroscopic studies virtually free from the degradation of atmospheric water vapor absorption. They demonstrated that, contrary to previous findings, the atmosphere of Venus contains very little water. This activity led to the development and operation (beginning in 1968) of an "open port" infrared telescope (in order to extend the wavelength capability) aboard a NASA Ames Lear Jet aircraft. Dr. Frank Low, a colleague of Dr. Kuiper, led early Lear Jet research activities. He and his colleagues made the first measurements of far-infrared emission from another galaxy, measured the infrared luminosities of Jupiter and Saturn, and pressed forward with the development of new instrumentation.[3]

Tragically, in April 1973, the Galileo I and its entire crew were lost in a midair collision at Moffett Field. However, only 8 months later, its replacement, another Convair 990, named "Galileo II", first flew to observe Comet Kohoutek. In addition, the success of research efforts with the Convair 990 and Lear Jet had led NASA to embark on the development of a larger facility based on the Lockhead C141 "Starlifter" military cargo aircraft. Development began in 1969 and the first research mission for astronomy was flown in February 1974. On May 15, 1975, the C141 was dedicated as the "Kuiper Airborne Observatory" (KAO) in honor of Dr. Kuiper who had passed away in 1974.[1]

Since that time the KAO has become the mainstay of NASA's Airborne astronomy program. Use of the CV 990 Galileo II has diversified. Research on this aircraft and the C130 now emphasizes Earth observations, atmospheric studies, and airborne radar system development. In 1975, Ames acquired an additional CV 990. It has been used as a dedicated platform for USAF Project Macy.[1]

Due to the high demand for infrared astronomical studies using the Lear Jet, Ames leased a second Lear in 1970 and subsequently purchased it in 1974. From 1958 to 1975, the Lears served as forerunners to the KAO. Once the KAO became operational, the use of the Lears for astronomical studies declined, and in 1980 one of the aircraft was transferred to NSTL. However, the remaining aircraft is still in use to do the wide field infrared astronomy studies it is well equipped to perform, and it is frequently the choice of foreign investigators involved in international programs. In addition, a variety of other research disciplines now utilize the Lear Jet, and it is also used to economically maintain pilot training/currency for the larger jets.[1,3]

A desire for a higher altitude airborne research mission capability led NASA Ames to acquire a Lockheed U-2 aircraft in 1971, and a Lockheed ER-2 (Super U-2) in 1981. NASA/JSC acquired a high altitude General Dynamics WB-57F aircraft. These aircraft contribute significantly in land use, atmospheric research, satellite sensor development, satellite ground truth calibration, and other activities.

## 4.2 Capabilities and Limitations

Airborne platforms provide a capability to perform a variety of needed research activities at altitudes up to 70,000 ft (21 km). Compared to other modes of research in this regime (sounding rockets, balloons, remote land based, remote satellites), aircraft offer a number of advantages in many classes of activities. Aircraft are a relatively inexpensive means of conducting investigations of up to 7.5 hours duration (per mission), in which all equipment can be returned safely to the ground for analysis and possible reuse. Relatively high mission rates and rapid turnaround can be maintained if needed. For example, the KAO can conduct up to 80 infrared astronomy missions each year.[1,4]

The larger transport aircraft provide the capability to carry heavy payloads, support equipment, and a team of investigators to the mission destination. Thus, man-in-loop research operations can be conducted with real time response to results and equipment behavior. In many cases test flights can be conducted to test equipment and practice procedures. The ability to respond in real time is further aided by the existence of a good on-board computational capability. In addition, the aircraft can generally supply ample electrical power to operate experimental equipment.[3]

Aircraft offer a great deal of flexibility in mission operations. They can and have been operated from airfields over much of the world (host nations permitting), and provide good flexibility in mission scheduling. They also allow investigators considerable latitude in experiment design (at minimum complexity) due, once again, to their favorable weightlifting capability and the availability of support equipment and services. The KAO is operated as a fully guest investigator facility similar to ground observatories. Its on-board equipment complement gives investigators the capability to do infrared astronomical studies using photometry, spectroscopy, or interferometry. For these studies the investigator can rely on accurate instrument pointing (∿1 arc second) and high image resolution--provided by the KAO.[1,3]

High flight rate and repeat mission capabilities with identical supporting equipment make the airborne programs ideal for instrument development. They are also valuable in providing reliable ground truth, in situ measurements for satellite calibration purposes.[1]

The primary limitation for airborne platforms is their operating ceiling. The larger aircraft can operate no higher than 40,000-45,000 ft with the smaller aircraft reaching 60,000-70,000 ft. This permits astronomical observations in the longer wavelengths (with the infrared being the portion of the spectrum of primary interest), but precludes observation of shorter wavelength radiation, much of which is absorbed by the upper atmosphere. Even in the infrared, the sensitivity of observations is limited somewhat by the small amount of water vapor that is contained in the upper atmosphere above operating altitudes. In situ atmospheric studies are also obviously limited by the operating ceiling. Nonetheless the airborne platforms provide unique capabilities that should be and are used to the maximum extent that operational limitations permit.

## 4.3 Accomplishments

Review of present and past activities in NASA's airborne program reveals that they have contributed significantly to the satisfaction of NASA program objectives in the areas of research, development, and general support defined in Section 1.2.3. The following discussion summarizes examples of program achievements. It is not a complete listing and intended only to characterize the scope and significance of the airborne program.

## 4.3.1 Significant Scientific Results

4.3.1.1 Atmospheric Sciences. At this juncture aircraft are being used primarily in an exploratory mode in the atmospheric sciences. The scientific community is just beginning to gather enough information about atmospheric processes to define investigations needed to understand those processes. Research aircraft have been, and continue to be one of the main sources of data in this effort which also demands significant contributions from ground based, balloon, sounding rocket, and satellite systems. While the main thrusts are in instrument development and ground truth support of satellite systems, significant scientific results are also being obtained.

In the mid 1970's the National Climate Program was established by Congressional Mandate. The National Oceanic and Atmospheric Administration was assigned the lead role in the program; NASA was given the task of determining the Earth's Radiation Budget. The Climate program consists of four main activities: (1) the assembly of global climate data sets, (2) studies of atmospheric processes, (3) atmospheric modeling, and (4) satellite observations and measurement of global atmospheric properties and the radiation budget. NASA research aircraft play an important role in ongoing process studies by conducting in situ sampling and analyses. This information allows the construction of atmospheric process models that enable NASA to interpret satellite data.

In 1980, NASA began a joint effort with the Environmental Protection Agency (EPA) directed toward the study of tropospheric air quality. Since then, participation of the EPA has waned, but NASA is committing to a growing interest in the troposphere and its problems. At this stage the program is almost entirely suborbital. NASA airborne platforms are being used to increase the understanding of the troposphere and develop instrumentation needed to study it so that an effective satellite program can be defined and designed.

NASA's Severe Storm Program now uses the Convair 990 Galileo II, equipped with a doppler lidar (laser) system to conduct wind field measurements in the vicinity of storms. Understanding the mechanisms of storms and local weather conditions requires detailed measurements of the associated state variable (e.g., wind) fields. The lidar equipped CV 990 provides a potent tool for high resolution measurement of vector wind fields over large areas--a 10 km x 10 km map is produced in approximately 80 seconds. Analysis and modeling of hurricane life cycles was notably advanced by tropospheric surveys along the projected path of a tropical storm, and of the high energy circulation just prior to and after two landfall events in a fully developed hurricane.[5-11]

The use of multi-instrumental, high altitude remote sensing aircraft is essential for studies of clouds. The WB-57F was equipped and used to: (1) examine cloud tops with high resolution infrared and other wavelength instrumentation to improve interpretations of satellite observations; (2) use remote sensors and other instrumentation, some active (e.g., lidar) to assess the promise and feasibility of new types of satellite measurements, and (3) develop methods to use remote sensors to investigate cloud top processes and their interactions with their surroundings. The WB-57F has been used to study five different storm systems over the past 3 years. Now, it is being retired and the instrumentation is being transferred to the newer, high-flying ER-2.[6,7]

The U-2 is being utilized in the Optical Lightning Detection Experiment (OLDE) in which storm clouds are overflown to observe topside lightning discharges. Results show that the intensity of lightning-generated optical emissions radiating from cloud tops are typically one order of magnitude or more greater than was previously predicted. One benefit derivable from the study of severe storm electricity is better understanding of the relationship between lightning activity and storm dynamics.[8]

Using the CV 990, measurements of atmospheric OH concentration were made, for the first time, by a resonance fluorescence technique. High concentrations were observed at high altitudes over urban areas. The role of this molecule in atmospheric chemistry remains to be determined.[11]

The roles of cloud fields and atmospheric aerosols in the total radiation budgets of geographical regions critical to development of the Indian summer monsoon were defined by CV 990 measurements of radiation fluxes, and the associated microphysical properties of clouds and aerosols. Soil derived aerosols having optical properties characteristic of arid and semiarid regions appear to be a significant component of the total aerosol burden, at altitude up to at least 5 km. A data base was established for the atmospheric trace gas carbon monoxide (CO). CO concentration profiles with altitude and latitude, in the context of a maturing monsoon circulation, provide information on large scale atmospheric convection processes.[9-11]

4.3.1.2 Astronomy/Astrophysics. Research in astronomy, particularly infrared astronomy has been the longest running (since 1964) and a very productive effort in NASA's Airborne Program. Today the primary astronomy facility operated under the Airborne Program is the KAO; for experiments not requiring the capabilities of the KAO, the Lear Jet Observatory is also available. Both facilities contain telescopes designed especially for observations in infrared spectral regions. Occasionally, the Airborne Program has supported highly specialized astronomical observations from NASA U-2 and CV 990 aircraft.[2,4]

From initial pioneering efforts over 15 years ago, the Airborne Program has grown and matured to produce many important scientific discoveries. The program made possible the first observations of luminous far-infrared emissions from other galaxies and provided an important series of infrared observations of our galactic center. Such observations have also been tools for the study of the interstellar gas and dust within our galaxy, bringing new information to bear on stellar birth and mass loss processes. Within our solar system, the airborne facilities have made possible the discovery of internal energy sources in Jupiter, Saturn, and Neptune, the discovery of rings around Uranus, and the discovery of water in the atmosphere of Jupiter and sulfuric acid in the clouds of Venus.[3]

The KAO has made significant contributions to the study of a wide range of astrophysical problems. In many cases, the KAO observations have discovered and studied previously unknown and unsuspected phenomena. In other cases the full significance and value of the airborne work is realized only when it is combined with, or used to extend and augment, observations at ultraviolet, optical, radio, or near-infrared wavelengths. Some of the discoveries made from the airborne observatories, and some of the scientific areas where airborne observations have been particularly important, are highlighted below.[3]

1. Galactic Nuclei and Extragalactic Astronomy

- First measurements of the infrared luminosities of the peculiar Seyfert galaxies which are more than 100 times that of our own Galaxy, and greater than the luminosities of many quasars.[3] It is difficult to understand how the likely energy sources could support such high luminosities if they persist over the lifetime of the galaxies.
- First detailed far-infrared studies of H II regions in external galaxies. Results suggest that massive stars in our nearest extragalactic neighbor, the Large Magellanic Cloud, form in regions of lower dust density than is seen to occur in our Galaxy.
- Detection at far-infrared wavelengths of nearly two dozen spiral galaxies which have luminosities in the range between 0.1 and 100 times that of our Galaxy, and exploration of a possible association between far-infrared and molecular emission in these galaxies by coordinated far-infrared and radio observations.
- Determination of the luminosity, excitation conditions, and dust distribution in the innermost regions of our own Galaxy, which cannot be observed optically, but can be studied in great detail at all infrared wavelengths.[3]

2. Star Formation and Evolution

- Determination of the luminosities of protostellar objects--stars in the earliest observable stages--by measurements of their far-infrared energy distributions.
- Determination of the luminosity, energy balance, composition, and structure of regions of active star formation, such as the Orion Nebula and the Omega Nebula, by mapping the distribution of far-infrared line and continuum radiation across them.

- Discovery of spectral emission features produced by dust grains in the interface between H II regions surrounding hot, young stars and the molecular clouds out of which the stars formed.
- Discovery of far-infrared emission arising from cool, extended circumstellar dust shells associated with low-mass,[3] premain sequence stars such as T Tauri stars. These shells may be the remnants of the clouds within which the stars have recently formed.
- First identification of SiO, and of infrared bands of the polyatomic molecular species HCN, $C_3$, and $SiC_2$ in the photospheres of carbon stars. These data are of primary importance for understanding the atmospheric structure of these stars.
- Determination of luminosities and mass loss rates for rapidly evolving, highly variable, dust embedded post-main sequence stars by combining far-infrared measurements with simultaneous ground-based near-infrared and radio observations
- Precise observations of the apparent increase in the Sun's diameter as seen in the infrared, compared to its apparent diameter in the visible. This measurement can be used to model the inhomogeneous nature of the solar chromosphere.

3. <u>The Interstellar Medium</u>

- Observation of a previously unobserved warm, neutral atomic phase of the interstellar medium, first detection of the far-infrared lines of neutral and singly ionized carbon in the interstellar medium. The emission in these lines is a major cooling mechanism for the gas in many cool interstellar clouds.
- Determination of the properties of a hot, shocked region of the Orion Molecular Cloud by observations of emission from highly excited CO, OH, and $H_2$ molecules at wavelengths not accessible from the ground.

- Determination of luminosities and gas and dust properties for many planetary and pre-planetary nebulae.
- Determination of the physical conditions and atomic abundances in H II regions by the detection and detailed study of infrared emission lines from ions of oxygen, nitrogen, sulfur, and argon.[3]
- Determination of the structure of warm molecular cloud cores and the optical properties of dust grains embedded in them by interpretation of airborne observations of their thermal emission.
- First detection of thermal emission from dust in cold, isolated interstellar clouds ("Bok globules"), and from dust in reflection nebulae.
- Discovery of spectral absorption features attributed to much larger than expected abundances of hydrocarbon grains in dense molecular clouds.[3]

4. <u>Planetary Astronomy</u>

- Discovery of the rings of Uranus, revolutionizing concepts of ring formation and dynamics.
- Demonstration that the giant planets Jupiter, Saturn, and Neptune have internal heat sources, which implies that their interior regions are still evolving.
- Discovery of $H_2O$, $PH_3$, and $GeH_4$ in the atmosphere of Jupiter, and $PH_3$ in the atmosphere of Saturn; these molecules are important tracers of atmospheric chemistry and dynamics.
- Measurement of the extent of water frost coverage on the surfaces of the outer three Galilean satellites of Jupiter.
- Discovery of sulfuric acid droplets as the major aerosol constituent in the clouds of Venus.[3,12]

### 4.3.2 Significant Hardware Advances

Over the life of the Airborne Program, research capabilities have increased steadily with the acquisition of aircraft that could carry larger payloads (KAO--C141), fly higher (U2, ER2), or provide for more economical operations (Lear Jet).* Equally important has been the development of supporting equipment that provide users with the assistance and flexibility needed to conduct successful research operations. This includes on-board power supply, environmental control, platform stabilization, command and control, imaging, data recording, computing, and communications. In the use of the larger aircraft, a crew of scientific investigators is carried for manned experimentation. The KAO carries a 91 cm "open-port" infrared telescope system for infrared sensor development and infrared astronomical research. The telescope is carried on a floating stabilized mount located in a cavity just ahead of the left wing of the aircraft. The external port to the cavity is open during observation periods. Pointing precision of $\leq 1$ arc second is provided.[1,3]

### 4.3.3 Satisfaction of Program Objectives

4.3.3.1 Continuing Research. The Airborne Program contributes significantly to the satisfaction of NASA research objectives in the fields of infrared astronomy and atmospheric sciences. It also contributes to NASA efforts in various Earth observational programs (land use, agriculture, pollution monitoring, etc.) not covered in this report. In infrared astronomy, airborne observatories continue to be used extensively to study infrared sources using a wide variety of sensors and observational equipment. Frequently, photometric and spectroscopic measurements from the KAO are focused on the same object; in combination with a variety of observations in

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*The Lear Jet was not originally acquired for reasons of economy, but it is much more economical to use in appropriate applications.

other spectral bands this capability yields a better picture of the phenomena and systems under study.[2,3]

Sources studied regularly with photometry include central regions of very luminous galaxies, regions of intensive star formation, "dark" clouds which have not yet condensed into stars, nebulae ejected by stars in the last stages of their evolution, and all major planets and their moons. Spectroscopic studies are conducted to obtain an understanding of the composition excitation, chemistry, and dynamics of astrophysical systems. Phenomena studied spectroscopically include the nuclei of galaxies, the outer layers of cool stars, interstellar gas, interstellar dust clouds, circumstellar clouds associated both with forming and with evolving stars, and planetary atmospheres and surfaces.[2,3]

In atmospheric research the Airborne Program is an integral part of national and international efforts to create a new level of understanding of the atmosphere and atmospheric processes. New observation and measurement techniques and instruments are being used on board airborne platforms to study atmospheric dynamics, chemistry, electrification, and evolution. Data obtained are providing key inputs to global atmospheric modeling and climate studies as well as providing insight into phenomena such as storm and lightning dynamics and the atmospheric impact of volcanic eruptions. The ability of aircraft to provide deterministic wide-ranging geographic coverage of the troposphere is essential to current NASA atmospheric studies.

4.3.3.2 Search for New Phenomena. Research conducted on airborne platforms has produced a number of important discoveries. These include:[3,8,11]

- The discovery of rings around the planet Uranus
- Discovery of a number of planetary atmospheric constituents
- Discovery that Jupiter, Saturn, and Neptune have internal heat sources
- Determination of radiative mechanisms of interstellar gas and dust clouds
- Spectroscopic identification of numerous elements and isotopes in infrared sources

- Determination of the luminosities of bodies thought to be protostars
- Discovery of far-infrared galaxies that emit only a fraction of their energy as visible light but are powerful as $10^{12}$ Suns and 100 times more luminous than the entire Milky Way
- First reported remote detection of Clear Air Turbulence from Infrared Observations of water vapor
- Discovery that lightning generated optical emissions are at least an order of magnitude greater than previously predicted.

Continuing investigations in infrared astronomy and the growing capability to perform atmospheric studies should provide additional scientific advances and discoveries.

4.3.3.3 Support for Other Programs. One of the principal roles of the airborne program is to provide ground truth support of satellite systems. For example, in 1979 eight flights were conducted for the purpose of calibrating the Nimbus 7 satellite. Similar operations have been conducted for numerous other satellites, including SEASAT, LANDSAT, MAGSAT, HCMM, GOES, SMS, AEM, SAGE, and TIROS. The Lear Jet and CV990 were used as part of the "Assess" Program to simulate Shuttle Spacelab operations. The CV990 played an important role in the development of experiments for the Shuttle STS-2 and STS-3 missions including underflight of STS-2 to obtain correlative data.[10-15]

NASA's research aircraft are very useful for observing chemical releases from rockets and satellites. They can carry the needed viewing equipment above most cloud cover--high enough for the task to be performed. For example, low light level TV cameras were carried aloft to view the results of barium releases from the West German Firewheel satellite.

Planetary astronomical observations from the KAO complemented Pioneer and Voyager missions findings with regard to two Jupiter's moons, Galileo and Titan. KAO discoveries concerning the surface composition of Galileo, helped explain features observed by Voyager. The existence and structure of particulate matter in Titan's atmosphere were jointly measured by KAO and Pioneer.[4-12]

The third Shuttle mission (STS-3) saw the successful use of the KAO infrared observing capability in a unique application. During the atmospheric reentry of the Shuttle at the conclusion of its mission, the KAO underflew the Shuttle and obtained an infrared photographic record of the aerodynamic heating experienced by the Shuttle at the maximum heating portion of the trajectory. This KAO mission (known as Project IRIS, for Infrared Imagery of Shuttle) provided NASA engineers with the first overall record of the actual heating experienced by the Shuttle during reentry.(15)

4.3.3.4 Time Critical Studies. Scientifically equipped Aircraft are an ideal tool to respond to appropriate short lead time requirements. Satellite or even rocket or balloon missions require the procurement, assembly, and test of flight systems equipment, an addition to the acquisition, preparation and integration of the scientific instrumentation package. Aircraft provide a flight ready airborne platform, needing only appropriate instrument complements to proceed with a scientific mission. This capability has been used in a number of ways. Missions were conducted to assess the atmospheric effects of recent volcanic eruptions, including the eruption of Mount Saint Helens in Washington State. Observations were made of the passage of the Comets Ikeya Seki, and Kohoutek. The use of the KAO in Project IRIS discussed above (in 4.3.3.3) is another example of the responsiveness of airborne platforms.

4.3.3.5 Support of International Cooperation. Airborne platforms frequently are involved in cooperative international research efforts. An example is underflight and observation of chemical releases from West German's Firewheel satellite.

Foreign investigators have contributed instruments to and participated in research flights conducted for meteor observation, cloud motion wind estimates, survey of stratospheric trace constituents infrared steller observations, solar eclipse studies, and other studies. A total of 17 international airborne programs have been conducted involving 12 foreign nations.(16)

4.3.3.6 Instrumentation/Detector Development. The development of instruments and detectors for satellite applications is one of the major thrusts of the airborne program. Research aircraft are ideally suited to the task, always returning instrumentation undamaged and often allowing real time man-in-loop operation/adjustment of experiment. In NASA's present atmospheric program the primary purpose of many flights is the development and test remote sensing instrumentation and concepts for future satellites. Achievements in this endeavor thus far include: the development of a satellite radar system for oceanographic research, the first application of microwaves to remote sensing of surface atmospheric pressure, the first Doppler-Lidar measurements of horizontal wind fields, the development of a clear air turbulence (CAT) remote sensor, and the development of various instruments to remotely and locally determine quantities of various atmospheric constituents. Sophisticated photometers and spectrometers now in use on the KAO can be considered as prototypes of instruments to be developed for use on facilities such as the planned Shuttle Infrared Telescope Facility (SIRTF). Monolithic infrared detector arrays will almost certainly be used on the KAO prior to their use in space.

4.3.3.7 Enhancement of Support Capibilities. The Airborne program has witnessed a steady improvement in capabilities through the introduction of new aircraft and the improvement of on-board facilities. The Lear Jet provided for the first time, a 31 cm open port telescope. Then, with the KAO, a 91 cm telescope became available. The sensitivity of instrumentation used for broadband photometry from the KAO has increased by an order of magnitude over the life of the observatory.[1-3]

The U2 and WB57F aircraft were acquired to provide airborne research operations at higher altitudes. In 1981, the ER-2 (Super U2) extended the altitude limit even further to 70,000 ft (13 miles). One benefit this provides is an improved capability for topside observation and study of storm cells. The most interesting storms reach the highest altitudes and, where the U2 cannot get quite high enough to overfly these storms, the ER-2 can.

Airborne platforms provide the greatest geographical flexibility of all astronomical and atmospheric research tools. In most instances, aircraft can go where an event of interest is occurring; often the experimenter can go with his instrument to do hands-on research. In 1981, the KAO operated from Japan to observe a solar eclipse. On-board equipment was checked out and the mission practiced in flight. The first far-infrared observation of a total eclipse of the sun was obtained on this mission.(14)

4.3.3.8 Support of New Researchers. The airborne program provides an effective means of training new scientists who will play an important role in future space missions. The existence of these platforms and the associated supporting equipment and services allow the investigator to concentrate on his experiment with minimal concern about the flight system. The KAO is operated as an investigator facility much the same as ground observatories. The number of advanced degrees earned based on airborne research is not large (15 in astronomy) when compared to the sounding rocket and balloon programs, but the payoff has been significant in terms of key personnel additions to the scientific community, such as the current Technical Direction of the United Kingdom Infrared Telescope Facility (UKIRT).(2-4)

4.3.3.9 Continuity in Science Areas. Although the airborne program often carries a significant instrument development emphasis, it also remains the primary mechanism for accomplishing many scientific tasks. The atmospheric (tropospheric) instrument development effort itself generates investigative scientific requirements that only airborne experimentation can satisfy. There is a need to understand the troposphere better before effective satellite programs and systems can be defined/designed. At present these investigations are almost entirely suborbital, mainly relying on research aircraft. This activity is likely to continue relatively unchanged for four to five years--the only orbital instrumentation planned for introduction in that time period is one instrument on the Spacelab II mission.

Research aircraft are likely to continue to be used for atmospheric studies indefinitely, due to the unique degree of operational flexibility they provide. Atmospheric properties vary greatly with location and time. Aircraft can be operated in most geographic locations and can remain in a vicinity of interest to record time variations of desired properties.

In the field of astronomy, airborne platforms, particularly the KAO have been a mainstay of NASA's infrared astronomy program. As noted earlier, most infrared astronomy cannot be done from the ground, and orbital facilities have not been available. Research aircraft and balloons are needed.

The KAO is responsible for establishing the viability of several new areas of infrared astronomy, such as submillimeter heterodyne spectroscopy. Infrared spectroscopy was pioneered from the KAO. The planned Infrared Astronomy Satellite (IRAS) will perform an all sky survey in the infrared, but IRAS will not be equipped to do spectroscopy so the KAO will be used to perform that and other complementary functions. A vigorous airborne program will continue to stimulate scientific and technical ideas which will have a major impact on future space observing activities.[2]

## 4.4 Trend and Cost Analyses

Airborne platforms have been heavily used for a variety of NASA applications. Figure 4-8 summarizes the research flight history of the KAO since its introduction in 1974. In the 1976-1981 time period, an average of 72 research flights per year were flown. Demand for the KAO remains strong (about double capacity). In FY 1981 the KAO average cost per flight was $65K including aircraft operations ($25K), experiments ($16K), and research support ($24K).[1,17]

Current usage of NASA's other airborne platforms on atmospheric programs is summarized in Table 4-1. The Convair 990 "Galileo II" flew a total of 29 research flights in FY 1981. The average cost per flight was $65K, including aircraft operations ($40K), and research support ($25K). NASA's other Convair 990 (used for USAF Project MACY) flew 58 research flights in FY 1981. Its average cost per flight was $49K, including aircraft operations ($42K), and mission support ($7K).[1,17]

NASA's Lear Jet flew 72 research flights in FY 1981. The average cost per flight for this aircraft was $4.9K, including aircraft operations ($2.8K), grants ($0.7K), research support ($0.5K), and reimbursable allocation ($0.8K). FY 1981 airborne platform cost data are summarized in Table 4-2.[1,17]

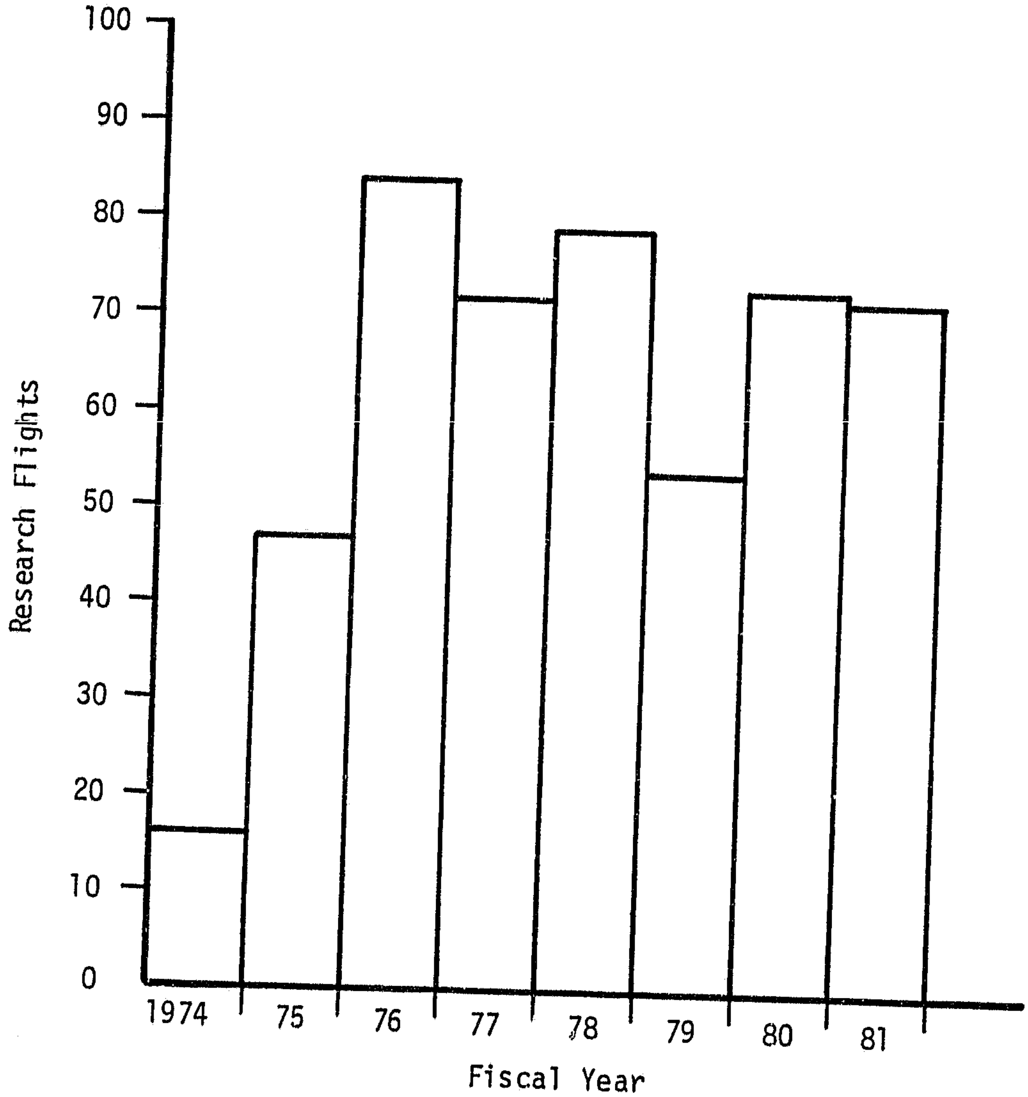


FIGURE 4-8. KAO RESEARCH FLIGHT HISTORY

TABLE 4-1. USAGE OF NASA AIRBORNE PLATFORMS IN ATMOSPHERIC PROGRAMS (Flight Hours)

| | Severe Storms | Climate | Troposphere |
|---|---|---|---|
| CV 990 | 80(a) | | 30-50(b) |
| U-2 | 80(a) | 60-80 | |
| ER-2 | 80(a) | | |
| Electra | | | 50(b) |

(a)User would like to increase to 100 hours.
(b)User expects increase to 200-300 hours in the future.

TABLE 4-2. FY 1981 AIRBORNE PLATFORM COST COMPARISON ($K PER FLIGHT))

| A/C | Flight Operations | Experiments/ Grants | Research Support | Other | Total |
|---|---|---|---|---|---|
| KAO | 25 | 16 | 24 | -- | 65 |
| CV 990 Galileo II | 40 | -- | 25 | -- | 65 |
| CV 990 Project MACY | 42 | -- | 7 | -- | 49 |
| Lear Jet | 2.8 | 0.7 | 0.6 | 0.8 | 4.9 |

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# 5.0 FUTURE OF NASA'S SUBORBITAL PROGRAMS

NASA's suborbital platforms have been an integral part of NASA research programs in the astronomical, atmospheric, and Earth sciences. Their demonstrated qualities of low cost, high flexibility, short lead time, and the capability to provide quality research have often placed them at the forefront of NASA research efforts. Their proven usefulness should guarantee their continuation with strong funding support. Unfortunately, they have performed their tasks over the past two decades with a certain degree of anonymity and their accomplishments and value to NASA are less well understood than they should be and need to be (both inside and outside the agency).

To many, suborbital platforms represent only an intermediate step to the "real" objective--on-orbit satellite systems; and, indeed, this <u>is</u> <u>one</u> of their functions. Those closer to these programs recognize the shallowness of this viewpoint and appreciate the role that these programs play in basic research, instrument/experiment development, investigator development, and support of orbital systems. The lack of universal understanding of the importance of these programs has contributed to a budget history that has significantly lagged inflation and eroded budgetary buying power. To ensure that the viability of these programs is not jeopardized, NASA must endeavor to provide adequate future funding.

The major future thrusts, and potential problem areas for the sounding rocket, balloon, and airborne programs are summarized in the following paragraphs.

## 5.1 Future Status of the Sounding Rocket Program

The future role of the sounding rocket program will depend on the science which will be done in the program, governed by the interests of the investigators, new discoveries, and new technology developments, and the ability of the program to support the scientific work. Up to this time, the program has been able to provide adequate support for the scientists; however, with a continuing deterioration of support dollars and new demands on the available resources, from the SPARTAN program, for instance, will eventually have a significant impact on the science obtained from sounding rockets.

## Scientific Role

The history of the sounding rocket program in astronomy has been one of pioneering discoveries, instrument development, and, with the replacement of a sounding rocket capability by orbiting instrumentation, a development of new capabilities. Sounding rockets carried the first UV spectrometers, with sensitivity in the near UV. When OAO was placed in orbit, its spectrometers covered this same spectral range; subsequent development on sounding rockets extended the spectral range to below the Lyman limit. Copernicus was able to cover this range also, but only for bright sources and sounding rockets developed off-set guidance so that they could study faint sources. The IUE was able to study faint sources also, so that the role of sounding rockets in obtaining stellar UV spectra was effectively eliminated. Sounding rocket investigators then began a program to study galaxies in the UV using direct imaging and developed micro-channel plate technology to enhance the signals. The present capability will be unsurpassed by Space Telescope so once again the program will have to develop a new capability to remain in the field. Current possibilities include developing a UV polarimetry program for stars and non-stellar sources and extending the wavelength range to the extreme ultraviolet.

Future development on sounding rockets in astronomy will be primarily directed towards detector development, on-board data reduction, and communications. The use of CCD and diode array detectors will make fainter sources accessible and serve to verify designs for orbital instrumentation. Equally important for future orbital instrumentation will be the on-board processing which will be developed to reduce the large data transmission rate requirements that array detectors would require to transmit raw data. Array detector and microchannel plate technology now being tested in the sounding rocket program will be used on AXAF and the Extreme Ultraviolet Explorer (EUVE).

In contrast to the development thrust in astronomy which will employ new technology, research in the atmospheric sciences will emphasize modified designs using existing technology. An example of this is the new design developed by Maynard at GSFC to verify the existence of horizontal mesospheric E fields.

## Science Support

A crisis in the program may be the looming in the area of science support. Up to this time, the program management has been able to deal with shrinking purchasing power by introducing effective methods for reducing costs-retrieval and reuse of the payload support hardware as well as the science payload being one of the most significant.

Hardware reserves have dropped since the early 70's, when a significant inventory was maintained; today there is virtually no reserve hardware. Such a tight sutiation has reduced program flexibility and had a negative impact on the willingness both of the scientists and the program managers to try new and riskier ideas for instrumentation. Equipment in the machine shops has not been extensively replaced or improved, requiring more involvement in outside work or more costly procedures within the shops to produce necessary hardware. Fewer vendors are producing support hardware and these vendors, to reduce the cost of operations, are carrying a smaller inventory; these effects combine to produce a less favorable unit cost and lead to back order times of typically 1 to 3 years.

With the current funding picture, significant support developments are not expected, and this assessment includes new motor capabilities as well as new support capabilities.

## SPARTAN Program

The Shuttle Pointed Autonomous Research Tool for Astronomy (SPARTAN) is a concept for flying sounding rocket paylods aboard the space shuttle by developing small experiment carriers which become detached from the Shuttle Orbiter and are later retrieved (during the same Shuttle flight) and reused.

The SPARTAN will be deployed with the Remote Manipulator System (RMS), and then commence operations as a free-flying spacecraft. It will have its own power, programming, attitude control, pointing, and data handling and storage systems. RF links from the SPARTAN to the orbiter will not be used, so all experiment and housekeeping data must be stored aboard the SPARTAN. The experiment, and most supporting subsystems that will comprise the SPARTAN will come directly from sounding rocket systems.[1]

Figure 5-1[1] illustrates the relationship between sounding rocket hardware and SPARTAN. The SPARTAN package would be rectangular weighing about 1000 pounds. It will be able to operate for up to 40 hours while detached from the orbiter. The first SPARTAN experiment is one that has been flown numerous times aboard NASA sounding rockets. It will perform x-ray astronomy observations in the energy range of 0.5-15 Kev.[1]

The objective of the SPARTAN program is to provide an inexpensive means of extending sounding rocket astronomy observation times from 8-10 minutes to 40 hours. The goal is to accomplish this at a mission cost equivalent to two or three larger sounding rockets. How well this goal is achieved is critical, because the cost of SPARTAN is currently planned to be borne by the sounding rocket budget.

## 5.2 Future Status of the Balloon Program

The balloon program will continue to provide a service compatible with its primary capabilities. It will remain the major resource capability for studying the Earth's atmosphere in the altitude range of 60,000 to 140,000 ft. Instrument development will play a progressively greater role in the research programs, and important contributions will be made in the various areas of astronomy.

Major projects in $\gamma$-rays, cosmic ray, and IR astronomy will produce new information in the next few years. Detector development and testing, coupled with greater directional discrimination will produce data with greater spectral resolution than will be possible on GRO with a comparable spatial resolution. The larger cosmic ray detectors will produce new information on isotopic abundances in heavy nuclei cosmic rays.

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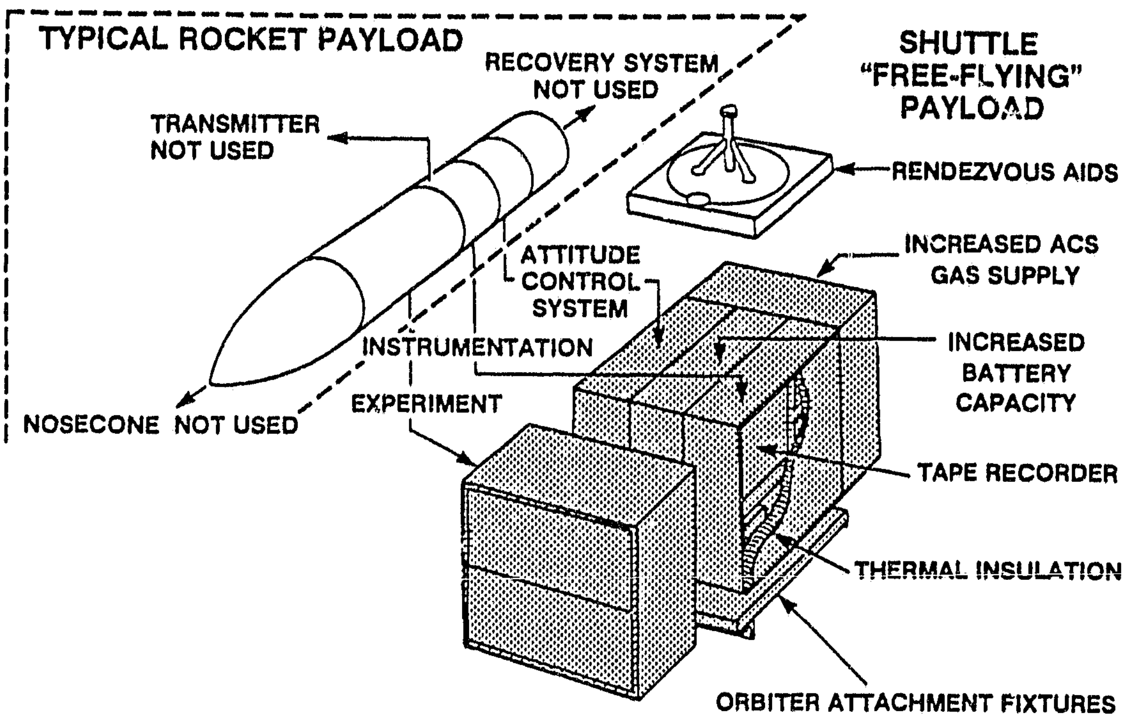


FIGURE 5-1. SPARTAN RELATIONSHIP TO SOUNDING ROCKET PAYLOADS

A major decision will have to be made in the near future concerning the fate of long duration ballooning (with large balloons). Such a capability would have considerable value for the science fields, but it will be achieved only with a significant investment in development. Long-term issues of thermal control, data transmission, balloon location, and balloon reliability must be addressed. A significant investment in the resolution of engineering problems associated with launching large super pressure balloons would have to be made. In considering such a move, NASA must determine whether the cost per flight can be kept to a reasonable level, how the result may impact zero-pressure ballooning, and whether the capability can be used adequately with the current lack of air-space agreements in the Northern Hemisphere.

## 5.3 Future Status of the Airborne Program

The demand for airborne research flights is expected to continue strong for the next several years. In the atmospheric sciences, a continuing and growing need exists for aircraft to perform research operations studying severe storms, climatology, and the troposphere. In fact, the demand for tropospheric studies may increase significantly. Aircraft will be used to assist in the development of tropospheric models, in the continued study of chemical, electrical and dynamic processes, and the development of experiments and instrumentation for orbital programs.

In addition to generalized studies of lower atmospheric properties and processes, more specific studies of important phenomena (e.g., storms) will be undertaken as needed. For example, polar stratospheric clouds recently discovered by the Nimbus satellite may be the subject of an airborne study. Also, the recently introduced ER-2 will be used to perform topside studies of taller storm clouds than could previously be observed.

In astronomy, the emphasis will remain in the infrared regime. The primary research tool will be the Kuiper Airborne Observatory (KAO). The type of work performed will be affected by the launch of the Infrared Astronomy Satellite (IRAS). IRAS will perform an all sky survey in the IR. IRAS is characterized by large band width, but pointing not as good as the KAO. IRAS will do photometry, but little spectroscopy. The KAO will continue to provide more accurate pointing where needed, more complex instrumentation and a spectroscopy capability. The IRAS will be able to see farther because it will be out of the atmosphere and its instruments will be cryogenically cooled. However, the KAO will be used to learn how to interpret IRAS observations.

The KAO will continue to be used extensively for instrument development. These efforts will include photometers , spectrometers, and interferometers. The photometer work is concerned with the development of detector arrays. The KAO instrument development effort will provide the basis for future orbiting infrared instruments such as the Shuttle Infrared Telescope Facility (SIRTF) and the Large Deployable Reflector (LDR).

As with the other suborbital programs, the Airborne Program has been hurt by budget limitations. When the effect of inflation is considered, the buying power of the Airborne budget has been cut in half just since 1974.

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