FOR OPA

SMALL APPLICATIONS TECHNOLOGY SATELLITE

SATS

INTERNAL STUDY REPORT

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INTERIM STUDY REPORT

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MAY 1970

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

130 pg

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This study and report was a team effort of Goddard Space Flight Center. Some of those who contributed are noted here.

Emil W. Hymowitz - Study Manager
Joseph H. Conn - Assistant Study Manager
Warren A. Hovis, Dr. - Study Scientist
J. Michael Balderston - System Engineer
William S. West, Dr. - Consultant

R. Falwell
R. Groves
W. Gruhl
R. Gunton
R. Hoffman
J. Lidston
E. Moyer
H. Norris
M. Schneebaum
J. Scobey
P. Villone

Applications Working Groups

Group	Chairman
Communications	S. Gubin
Navigation	C. Laughlin
Geodesy	F. Vonbun, Dr.
Meteorology	W. Bandeen
Earth Resources	W. Nordberg, Dr.

Note is made of informal contacts with personnel of the following organizations:

Aerojet General
Fairchild Hiller
Hughes Aircraft Company
Ithaco
Langley Research Center
Lewis Research Center
Lincoln Laboratories
LTV
Lockheed Missiles & Space
NASA Headquarters
North American
Northrop
RCA
SAMSO
TRW
University of Maryland

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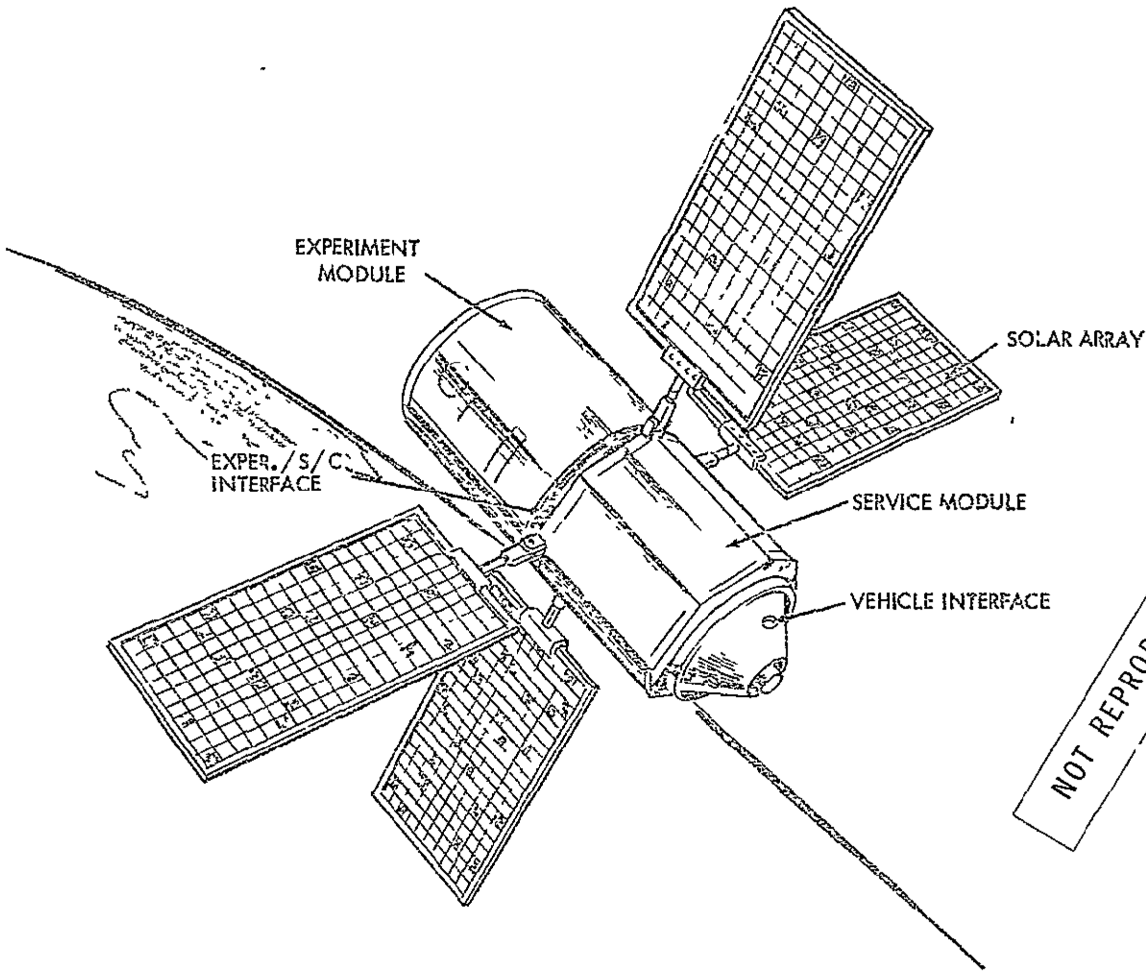
FOREWORD

This is an interim report of the Small Applications Technology Satellite (SATS) study being performed at the Goddard Space Flight Center. The study was requested by a letter of February 26, 1970, from the Deputy Associate Administrator for Space Science and Applications (Applications). This report represents the results of the study effort through April 1970. Because of the interim nature of this report, and the continuing evaluation and analysis of all facets of the SATS concept, the material presented is subject to change in the final report. As requested in the letter mentioned above, a final report will be forwarded in August/September 1970.



Frontispiece

SATS General Configuration Concept

SMALL APPLICATIONS TECHNOLOGY SATELLITE

SATS

INTERIM STUDY REPORT

1.0 INTRODUCTION AND STUDY SUMMARY

1.1 Introduction

The purpose of the SATS concept is to supplement and support the NASA Space Applications Program. It will DIRECTLY AID the progress of earth-oriented space applications by expediting the development of sensors, experiments, spacecraft technology and systems through orbital flight testing of components, subsystems and system parameters. A Small Applications Technology Satellite will expedite the launch of applications instrumentation, enable spacecraft technological experiments to be performed and permit in situ measurements necessary for the development of systems parameters. Inherent in the SATS concept is the standardized, low cost spacecraft that can be "called-up" and launched in a short time.

The purpose of this study is to develop the SATS program concept to the point where management can determine the program benefits to be derived. This information is required in support of the OSSA budgetary and planning function for FY 1972. This report covers an in-house effort conducted along the following guidelines:

1. Consider the rationale, objectives and justifications for a SATS program.

2. Review potential applications experiments and disciplines for SATS flights.

3. Review past and present spacecraft for applicability of available designs or hardware to SATS.

4. Analyze time and cost effectiveness of a SATS program relative to other programs.

5. Develop and present alternate SATS spacecraft concepts including a pilot spacecraft program.

6. Perform preliminary review of program management implementation.

7. Highlight areas for future study and program effort.

8. Identify and review potential problem and conflict areas.

The information and discussion presented in this interim report will be further detailed and supplemented in the final report.

1.2 Study Summary

This summary will highlight the principal results developed in the course of the study.

The SATS concept is rationalized as a key means of supplementing the Applications Programs. This is complementary to recent recommendations that NASA increase its efforts in this area.

The principal SATS objective is stated as providing a standardized spacecraft to permit early demonstration flights, for test and development of technology and experimentation, and to help in defining parameters of new systems.

The SATS program is justified because it provides an orbital test means to evaluate effects of unpredictable phenomena or those not reproducible on earth and to verify system concepts not otherwise possible. SATS provides direct support of applications system development by testing prototype instruments, including AAFE experiments, and by helping to define future systems.

A survey of potential future SATS experiments is discussed together with comments of the participating working groups. Parametric results of the survey analysis are presented from which data are made available for spacecraft requirements and the designs developed later in the report.

The spacecraft characteristics desired to meet stated program objectives are reviewed. Basically, this is to have a standard spacecraft. It was concluded decisively that to realize the goal of a standard spacecraft it would be necessary to define and control the interface with the experiment. This is achieved by specifying the mechanical-electrical interface between the spacecraft and a separate experiment module. It is also desired to make as much use as possible of existing hardware and spacecraft designs for ease of integration and to minimize development costs.

A number of existing spacecraft designs are reviewed and discussed with a view to using concepts or hardware applicable to SATS. Several available designs are considered applicable.

A mission and vehicle analysis is presented to illustrate the capabilities of the Scout and Delta vehicles for three principal SATS missions: low earth orbit, geosynchronous orbit and 12-hour highly elliptical orbit. The vehicle capabilities available lead to allowable Scout and Delta spacecraft weights of approximately 300 lbs. and 600 lbs., respectively.

Several SATS spacecraft design concepts are shown. The crucial requirement for a stabilized earth oriented spacecraft is met by using an attitude control system based upon a momentum bias system with single axis active control about the orbit normal to the local vertical. Two SATS/Scout spacecraft configurations are given both of which can meet these requirements. A single SATS/Delta spacecraft configuration is shown; a second is being developed. One configuration of a SATS/Delta Piggyback design is presented, and one for the Agena vehicle.

A discussion of unique SATS considerations of Reliability, Quality Assurance, and Testing addresses the differences of shorter lifetime, quick reaction, minimum cost and how these would be accommodated.

Cost estimates are given for SATS spacecraft types; and these are compared to existing programs on a payload delivery system cost basis ($/pound to orbit).

The Goddard approach to managing a SATS program is discussed together with an illustrative SATS Pilot Program. Manpower and funding requirements are estimated based on the illustrative program.

The principal conclusion given is that the SATS concept of a quick reaction program using standardized spacecraft may be feasible. Other conclusions are that SATS may, in fact, supplement the applications programs, that SATS cost compares favorably with other satellite programs, and that no significant new development appears to be required to synthesize SATS spacecraft designs from available, flight proven hardware.

A recommendation is made for continuing study during FY-1971 to be ready to support a prospective FY-1972 start.

An examination of potential problem areas draws attention to three possible trouble areas: They are. (1) the selection of experiments, how, by whom?, (2) the obtaining of flight approval for several flights in advance.(as in Explorers or Sounding Rockets PAD), and (3) the inclusion of nonstandard spacecraft in the SATS program—how best to phase in with SATS regular program.

2.0 RATIONALE

The status and future of the national effort in the practical use of earth-oriented satellites has been reviewed and documented over the past few years. The information below is taken from various task group efforts, studies and Congressional hearings. On the basis of recommendations and questions presented by these sources, a clear rationale is available for the SATS program.

2.1 Space Task Group Report to the President — September, 1969

This report was undertaken to provide the President with a recommended direction for the space program following Apollo.

The first recommendation:

> "Increase utilization of space capabilities for services to man, through an expanded space applications program."

The last recommendation:

> "Promote a sense of world community through a program which provides opportunity for broad international participation and cooperation."

2.2 Summer Study on Space Applications — National Academy of Sciences Report, 1969

In 1966, NASA requested the National Academy of Sciences to conduct a study on the probable future usefulness of satellites in practical earth-oriented applications. The study was to include ". . . the nature and scope of the research and development program believed necessary to provide the technology required to exploit these applications."

Thirteen technical panels were convened to study the following fields:

1. Forestry - Agriculture - Geography
2. Geology
3. Hydrology
4. Meteorology
5. Oceanography
6. Sensors and Data Systems
7. Points-to-Point Communications
8. Systems for Remote Sensing Information & Distribution
9. Point-to-Point Communications
10. Broadcasting
11. Navigation and Traffic Control
12. Economic Analysis
13. Geodesy and Cartography

The panels worked during the summers of 1967 and 1968 at Woods Hole, Massachusetts. The work of each panel was reported to a Central Review Committee (CRC), appointed by the Academy, which produced the overall report. The following overall conclusions and recommendations are excerpted from the CRC Report:

Conclusions —

"The benefits from space applications are expected to be large — larger than most study participants had originally believed, and certainly larger than the costs of achieving them. We are convinced, however, that an extensive, coherent, and selective program will be required to achieve these benefits."

"The Central Review Committee has taken particular note of the present NASA launching schedule for R&D test-bed satellites in support of space applications in 1970 and thereafter. The average interval between launches is more than a year for both geosynchronous orbits (ATS Program) and low-altitude polar orbits (Nimbus Program). Noting also that the program does not now provide for back-up launches, we must highlight several serious implications of this schedule."

"First, and of paramount importance, the possibility is that failure of any one launch in such a program can extend to as much as three years the interval between opportunities to obtain R&D results from space. .....We are convinced that a substantial increase in the present schedule of test-bed satellite launches — to at least double — is required if many important space applications are to be achieved within the next decade."

"Second, high-calibre scientists and engineers are not challenged by, or attracted to, a program the launch schedule of which can only be characterized as 'leisurely.' The kinds of scientists and engineers needed for space applications will be attracted by a vigorous program providing frequent opportunities to try new approaches...

"We are convinced that the present space applications program is too small by a factor of two or three, if we measure it in the light of the substantial opportunities that can be pursued effectively..... Additional funding..... would enable the nation to proceed toward critically needed investments in preparation for future operational applications systems. NASA would be able to carry certain work through the space-flight operational experimental phase, so that both the potentials and the problems of future systems could be thoroughly understood."

Recommendations —

"NASA should give greater emphasis in its future programs and activities to earth-satellite programs with promise of beneficial applications. ..... An expanded research and development program and prototype operations that will test out the technical capabilities and benefit potentials of possible practical applications."

Abstracts of the Central Review Committee's specific conclusions and recommendations on: R&D, International, Manned and Unmanned Flights, Meteorology/Earth-Resources Satellites, Communications and Navigation, Frequency Utilization and Orbital Spacing are included as Appendix D of this report.

2.3 Testimony Before Subcommittees of the Committee on Science and Astronautics of the House of Representatives

Information obtained from a reading of the Committee's proceedings* substantially reinforces the theme brought out in the paragraphs above. The point is continually developed that the RATE AND RATIO of NASA expenditures in support of useful and beneficial applications programs, as compared to other sectors of NASA involvement, is TOO SLOW AND TOO LOW.

2.4 Public Support of Applications Program

An attempt to define the public attitude today toward the expenditure of resources for space leads to several pointed questions:

(1) Is this program required for national/international considerations, such as diplomacy, leadership, national capability, etc.?

(2) How will the public directly benefit from the proposed program expenditures?

There can be little doubt that most other NASA programs originally benefitted from the early "catching up" justification of the manned effort. Today, however, each discipline is burdened with its own justification, and each program must uniquely identify its raison d'être. Of all the areas of NASA effort, applications can be most credibly justified on the basis that predicted accrued benefits, in dollars, will substantially exceed systems development and operational costs. This is being demonstrated today by operational communications and meteorological systems.

2.5 Summary

On the basis of the high level reports quoted above, on the basis of the record of Congressional interest in deriving economically beneficial

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*1. Hearings before the Subcommittee on Space Science and Applications-Ninety-First Congress; Dec. 16, 17, 18, 19, 1969 (No. 12); First Session

2. Hearings before the Subcommittee on Space Science and Applications-Ninety-First Congress, Oct. 16, 1969, (No. 9) First Session

3. Report for the Subcommittee on NASA Oversight-Ninetieth Congress-Second Session, Serial W Dec. 31, 1968

payoff from space as quickly as possible, and on the basis that applications is an area of space expenditure that is capable of being justified in in terms of greater dollar output than input, the SATS concept is rationalized as a key means to supplement NASA Applications Programs.

3.0 PROGRAM OBJECTIVES AND JUSTIFICATION

3.1 Program Objectives

The principal SATS program objective is to provide a STANDARDIZED SPACECRAFT to:

- Provide early demonstration of system practical value.
- Test technological concepts and devices.
- Test developmental applications experiments and sensors.
- Aid definition of parameters for future systems.

Ancillary objectives considered as necessary requirements of a successful SATS program are:

- A dedicated payload capability.
- A quick reaction capability.
- A relatively low cost budget.

The concept of a standardized spacecraft implies fixed design or designs, specified experiment-spacecraft interfaces, ease of manufacturing, and ease of experiment integration.

A dedicated payload capability is defined as readiness to integrate and launch a single experiment payload. Such a payload might be, in fact, one experiment or a set of several interrelated sensors or units taken as a single experiment.

A quick reaction capability is the ability to accept available experiment hardware, integrate it with a spacecraft and launch in a time period of approximately six months. This is a measure of the program time effectiveness.

A relatively low cost budget is one which compares favorably in overall costs with other satellite programs on a "per pound of delivered payload" basis. This is a measure of the program cost effectiveness.

3.2 Program Justifications

The SATS program can be justified principally for two reasons with an assist from other related considerations:

- PROVIDES ORBITAL TEST SERVICE
  - To evaluate effects of unpredictable phenomena or those not reproducible on earth
  - To verify system feasibility concepts not otherwise possible
- DIRECT SUPPORT OF APPLICATIONS SYSTEMS DEVELOPMENT
  - Test AAFE Experiments
  - Testing of engineering and prototype applications sensors
  - Aid in parametric definition of future systems

At present there are instances of experiment and sensor performance in orbit that cannot be readily explained. Obviously, what is required is the capability to fully instrument the subject equipment for an orbital test that can provide the necessary information regarding unpredicted performance. The recent anomalous behavior of IR radiative coolers is one example of a requirement for in situ testing.

It is not always possible to fully analyze system performance based on available knowledge of the effects of a choice of parameters. In some cases a part of the system must be exercised in an orbital test. Complete description of phenomena may not be available or a monitoring survey of the phenomena may be indicated. The present need for further data on radio frequency interference and multipath phenomena for design of the Data Relay Satellite is one example of a requirement for orbital measurement testing to define system parameters.

The early flight testing of developmental applications experiments, components, sensors, etc., can be expected to expedite systems development and enhance the worth of data finally returned from flights aboard observatory class spacecraft. Included here, of course, are the experiments now being developed by OSSA under the Advanced Applications Flight Experiments (AAFE) Program at Langley Research Center.

There are several related SATS program benefits that are significant:

- The program is cost effective.
- The SATS launch rate is flexible.
- Opportunities for international cooperation are increased.
- The applications programs are provided with an emergency quick reaction capability.

The SATS Program is compared on a payload delivery cost basis, in Section 5, with other programs of the observatory class. Paragraph 6.2 presents a pilot program for initiating SATS. It is quite flexible in terms of spacecraft launches per year. The program can handle a mix of the several types of spacecraft under consideration.

The availability of a SATS quick reaction capability permits the launching, within three to six months, of a back-up experiment should the initial launch prove unsuccessful or the experiment have a short life. Such an emergency capability could prevent a delay of one to two years in a typical observatory class program which does not normally schedule back-up flight spacecraft.

Recommendations were made both in the President's Space Task Group Study and the National Academy of Sciences "Summer Study" (Section 1) to the effect that there should be increased cooperation at the international level. This is a continuation of U.S. efforts in this area which have been highly successful as an adjunct of national policy. In addition, it is considered necessary to involve other countries in the burgeoning earth resources effort if it is ever to be acceptable as a world-wide system. The SATS program is ideally suited to provide opportunities for the foreign experimenter at relatively low cost. The spacecraft concepts which are proposed in this report lend themselves to a minimization of interface problems and integration effort.

3.3 Relationship of SATS to Observatory Programs

The most obvious means of increasing the pace of the Application's Programs is by increasing the launch rate of the observatory class spacecraft. However, this is not included in the present program plan.

through 1975 which includes Nimbus-E, F, ERTS-A, B (possibly through E, F), ATS-F, G, SMS-A, B and NAVSAT-A, B. These plans call for a launch spacing of 12 to 18 months with no back-ups scheduled. Experiments for approved applications programs have been selected, or will be selected in the near future. It may be noted that the next opportunity for flight aboard an applications spacecraft may be 1976 or later, based on the initiation of a study effort for such a program within the next two years. However, a FY-1972 SATS start could result in launches beginning in 1973.

The SATS program adds a new dimension to program planning by permitting a flexible launch rate (3 to 6 month centers), at relatively low cost, thus supplementing the observatory programs.

4.0 EXPERIMENT SURVEY

4.1 Background

Initially, it was considered necessary to canvass as broadly as possible in search of existing experiments of merit that could be flown on SATS. It was hoped that sufficient data on users would be developed for definition of mission and system parameters. To assist in the survey, the effort included consultation with the five Applications Programs Working Groups in meteorology, earth resources, communications, navigation and geodesy.

An attempt was made to obtain from the committees discrete candidate experiments applicable to SATS. It became apparent shortly that the committees were unable to respond well in this manner. In several instances, specific experiments were proposed; however, the most satisfactory committee responses resulted from informal discussions of types of missions and areas of experimentation. This information was incorporated into the experiment survey, in addition to data from the AAFE Program at Langley Research Center and informal proposals from Lewis Research Center and NASA Headquarters, OART. The survey effort is continuing.

The purpose of the experiment survey was twofold. First, to determine the extent of experimenter interest and need. Second, to compile experiment and mission parametric data for use in developing spacecraft system concepts. As will be described in the following section, the experimenter input by way of the various applications working groups resulted in an expression of interest and need. On the other hand, it was understandably short on experiment descriptive detail, since, in most cases, one was not describing a specific experiment on a specific spacecraft. While this information is useful, it is not adequate for systems design concepts. It was concluded that this problem could be overcome by making a statistical review of experiments that have been described fully for past, present and approved applications spacecraft. This information, as will be shown, is adequate for our purposes, and is probably more accurate and definitive than could possibly have been obtained from "proposed" experiments.

4.2 Illustrative Experiments

The list of experiments in Table A is generalized, and no data is offered on size, weight, power requirements, etc. Details of a few illustrative experiments are given in Appendix A. These are included only to give some idea of the capabilities of the SATS spacecraft and should not be taken as proposing any specific experiment.

In the course of meetings between the SATS study office and the various Applications Working Groups, it became obvious that the term "experiment" itself was a hindrance to effective communications. In most people's minds, satellite hardware in the applications area falls into three broad categories: operational, as typified by TOS and INTELSAT payloads, developmental, as typified by NIMBUS and ATS experiments; and what might be called prototype or flyable preprototype. Requests for data on possible experiments were interpreted either as (1) no details are available because the experiment has not yet been fully conceived, or (2) it would be improper for us to "propose" experiments because of the formal and proprietary nature of such a procedure. The fact that SATS was principally interested in flying the last of the three categories was subsequently accepted by the Working Groups. They were then quite responsive in developing appropriate areas where SATS could be useful, and in highlighting potential future experiments. One of the Working Groups summed it up appropriately following a discussion meeting with the Study Group as

"A Rationale for SATS:

> To provide a space environment platform for the quick test and evaluation of critical technological or scientific devices, components, or concepts that cannot be tested adequately and at a lesser cost by the usual means. e.g., in a laboratory, on aircraft, balloons, rockets, etc."

The statement of purpose above indicates the reason why a true list of future candidate experiments, other than AAFE, is difficult to prepare. The presently proposed schedule for SATS results in a first flight in the middle of CY 1973, and it is unrealistic to attempt to determine what will be "critical technological or scientific devices, components, or concepts" that far in the future.

While the primary purpose of SATS is as shown above, it should not be inferred that SATS will provide no capability for testing developmental or even operational sensors. The weight, power, and data service that is available to the SATS Experiment Module, as discussed in Section 5, is sufficient to handle the majority of applications sensors; this will be detailed below. However, once the SATS program were initiated and its capabilities made known to the applications community, it is anticipated that the number of prototype candidates would be large enough to fully occupy SATS for some time.

4.3 Parametric Results

The list in Table A gives an indication of the range of the potential experiments, but is of little help in developing spacecraft parameters. Since data on these illustrative future experiments were extremely limited, Figures 1 and 2 were prepared from data on past and present experiments, in particular those on ATS-1 through -5, -F, and -G; NIMBUS-1 through -4, -E, and -F, SMS-A and -B, ERTS-A and -B; and examples from the AAFE Program. Data from approximately 100 experiments were used.

The preliminary SATS/Scout design, as indicated, could accommodate 88% of the experiments as regards weight, and 91% as regards power. The corresponding figures for SATS/Delta are 100% and 95%.

The capabilities of the preliminary designs are discussed more fully in Section 5.

4.4 Dedicated Payload

In this report a dedicated payload is defined as a single experiment or a set of several closely related experiments considered as a whole. The experiment set may be necessary to perform a rigorous test of a principal device or it may be required to simultaneously and comparatively test the merits of several competing devices. There is also the flight test whose principal mission may be to perform a systematic

TABLE A. ILLUSTRATIVE EXPERIMENTS

COMMUNICATIONS

RFI Survey Experiments
Multipath Propagation
Lightweight Pointed Narrow Beam Antennas and Phased Arrays
Experimental Deployable Antennas
Millimeter Wave Propagation
Modulation and Coding Techniques
Millimeter Wave Multiple Beam Formation and Control
Satellite-to-Satellite Relay Tests
Advanced Spacecraft Communication Subsystems
Data Collection Techniques

GEODESY

Laser Reflectors
Radar Altimeter
Time and Frequency Standard Emissions
Relativity Experiment
Nano-G Accelerometer
Drag Free Satellite

NAVIGATION

Navigation and Air-Traffic Control Over Land Masses
Interferometer Position Location
Air Collision Avoidance
Search and Rescue

METEOROLOGY

Differential Doppler Techniques
Radio Occultation Experiment Techniques
Satellite Microwave Radiometer

METEOROLOGY (Continued)

Sea State Measurements
Ocean Surface Temperature
Surface Water/Ice Backscatter Albedo
Atmospheric Aerosol Data

EARTH RESOURCES

Radiative Cooler Performance
Low Sun Angle Earth Surface Observations
Ocean Surface Color Imagery
Multispectral Image Dissector
Wide Range Image Spectrometer
IR Long Wavelength Spectrometer
Radio Frequency Surface Reflectance
Microwave Imaging
Synthetic Aperture Radar
Optical Image Processing

ADVANCED RESEARCH AND TECHNOLOGY

Improved Attitude Control and Determination Techniques
UV/Microwave Horizon Sensor
Materials Degradation Experiments
Contamination Experiments
High Vacuum Techniques
Cryogenic Technology
Advanced Propulsion Techniques
Space Power Techniques
Vertical Sensor
Extendible Boom Technology
Large Aperture Antenna Technology
Gravity Gradient Techniques
Recoverable Payload Techniques
Remote Manipulator Technology

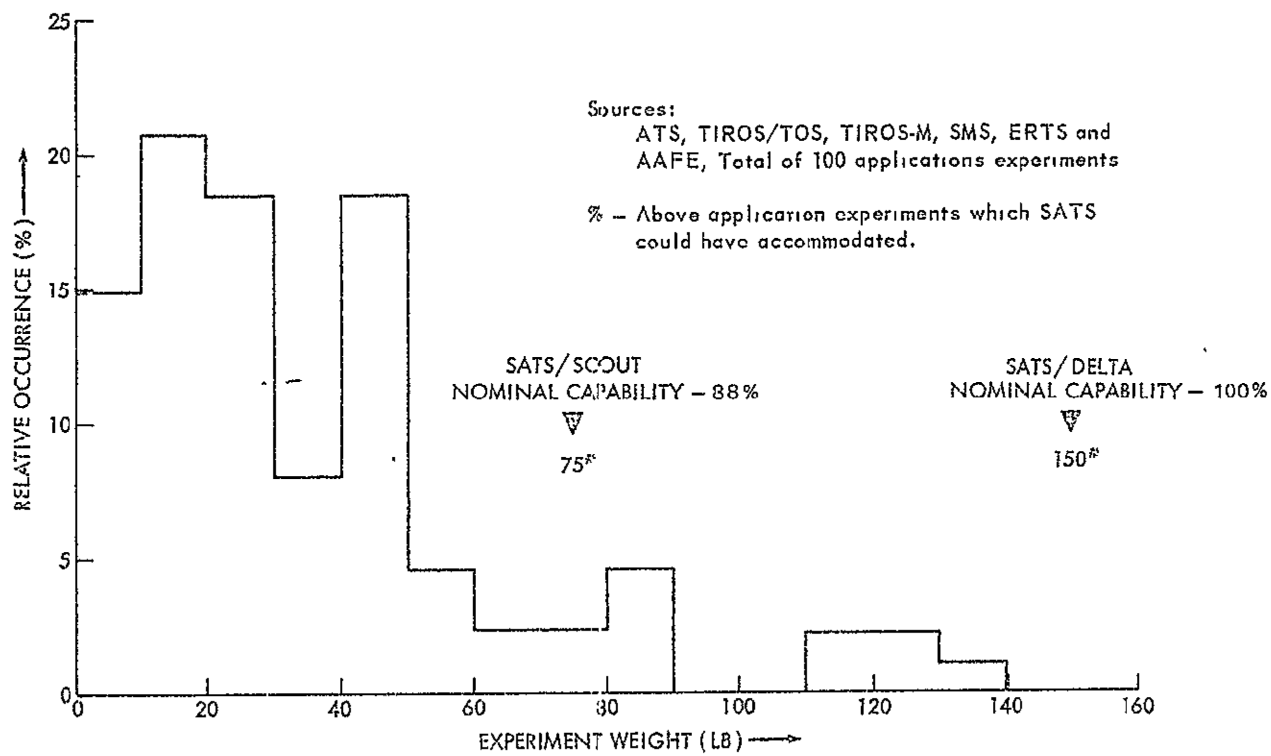


Figure 1. Applications Experiments Weight Distribution

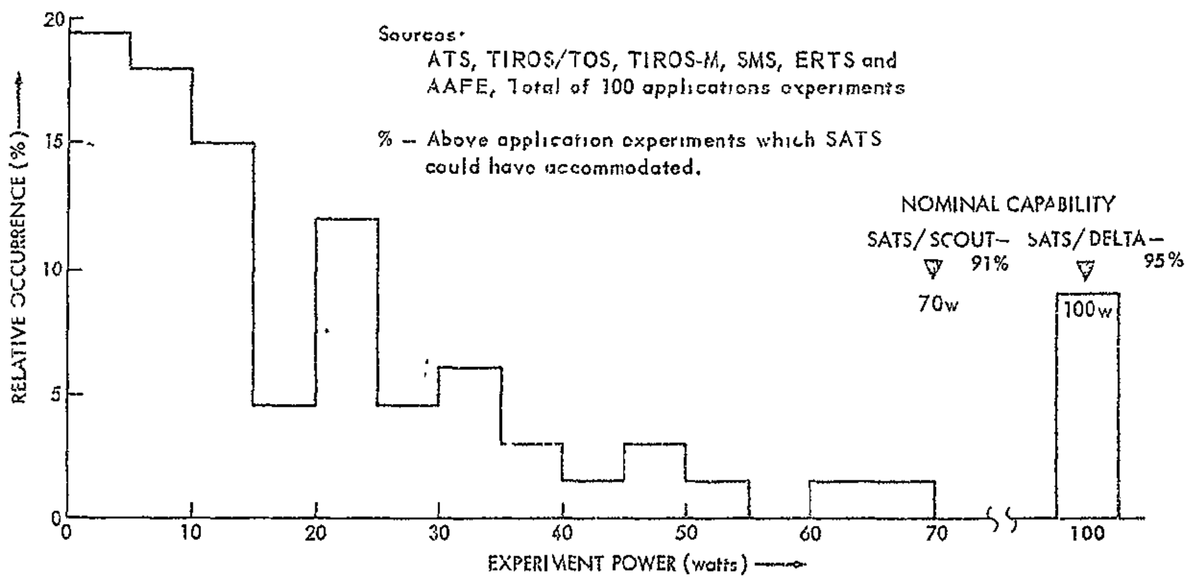


Figure 2. Applications Experiments Power Distribution

measurements survey. Other flights may be required to establish feasibility of system function or principle by a clear pragmatic demonstration mission.

The concept of dedicating a test-bed spacecraft to a single experiment, device or measurement survey is a reasonable and practical goal when assessed in terms of relative worth of ends to means. In most cases experiment development costs will be comparable to or greater than the basic SATS spacecraft costs (Section 5.6 and 5.7). In cases where one wishes to investigate system parameters by making survey measurements from SATS, the data will be required for the design of systems costing many times the cost of a SATS spacecraft. As before we speak only of flight tests where the information is not obtainable by any other means. Also, how does one estimate the value of necessary test data obtained in a timely manner? Its ultimate worth to a program may be judged in terms of the cost efficiency of an optimum development schedule and the payoff benefits from an earlier operational system.

The dedicated payload concept implies the desirability and capability of flying single experiment. However, this need not exclude the possibility of accommodating additional payload where feasible. One might designate a single experiment as prime and also make the flight available to another experiment on a non-interference basis, understanding that the schedule and mission constraints of the prime will govern.

5.0 PROGRAM AND SPACECRAFT CHARACTERISTICS

5.1 Desired Spacecraft Characteristics

5.1.1 Standard Spacecraft

The basic objective and outstanding characteristic of this program is a standard spacecraft for flight testing applications experiments and concepts. The standard spacecraft concept has been proposed for many years. Whether for lack of advanced planning, or the necessity of designing for particular missions, or the desire for a fully integrated spacecraft and experiments, most spacecraft subsystems and structures were modified for each succeeding launch of a spacecraft series. Many of the modifications were desirable but not really mandatory. The objective of a standard SATS does not permit constant spacecraft subsystem and system redevelopment. Advanced subsystems would be considered experiments and would be flown such that the spacecraft could operate independently from them. After flight qualification, and if required, modifications to the standard spacecraft could be performed on future models.

During this study, it was concluded that mission and experiment requirements create most design problems, particularly for a standard spacecraft. If these items can be well defined or controlled, then the concept of a standard spacecraft can be implemented.

The missions that were selected for study are: low orbits (300 nm. nominal) at inclinations of 0°, 30°, 52° and sun-synchronous, on Scout and Delta vehicles; geosynchronous orbits at 0°, 30°, and 50° inclinations on the Delta vehicle; and 12 hour simulated geosynchronous elliptical orbits (i.e. approx. 300 × 22000 nm) at 50° and 63.4° inclinations on the Delta. These mission parameters meet the majority of applications requirements. Further studies will determine if some of the inclinations might be eliminated and whether the 12 hour orbit for this kind of a test satellite is satisfactory for most missions and experiments. The conclusion is that because of varying vehicle capability and differing orbit requirements, several standard spacecraft will be required. The only significant change in any one spacecraft for different inclination requirements is the solar array size and aspect angle. The solar power can be readily adapted with proper modularization of a solar paddle system. Thermal considerations will be discussed later.

Another problem in implementing a standardized spacecraft is the need to meet changing experiment requirements. In the past. most spacecraft systems have been designed to meet particular experiment requirements. The experiment and subsystems were then integrated within a common structure. Any change in experiment volume, weight, power or data handling requirements from one launch to another required rearrangement, re-integration and general retest of the whole spacecraft. This always involved increased costs and time. The SATS design philosophy is to physically isolate the experiment and related hardware from the operational subsystems (e.g., transmitter, controls, power supply, etc.). This concept has been used on the SAS and OV-1 and 3, for example. The spacecraft would be integrated using major blocks of systems in modular form. These would include an experiment compartment or module, service module, solar array (paddles) and possibly an attitude control and propulsion module. The spacecraft design would develop an electrical, mechanical and thermal interface specification for integrating all experiments. The volume limits are theoretically the vehicle envelope; however, the spacecraft would provide specific mounting platforms and covered volumes or the experiment could provide its own experiment module to mate with the standard interface. It should be noted that the experiment weight is defined as everything above the primary experiment module/service module interface, including the experiment module itself.

The electrical interface will consist of a standard set of electrical connections for power, command and data transfer between the experiment module and the subsystem module. Power will be made available to the experiment via the main bus. Any special voltage or regulation requirements will be met by the experimenter. Connections will be available for a fixed number of commands to, and housekeeping points from, the experiment module. The main data connections will consist of a fixed number of points, the sampling and formatting of which will be variable within limits prior to launch. Any data storage or handling requirement in excess of that provided by the service subsystems will be taken care of by the experimenter. In special cases the above provisions can be modified where practical, as with communications experiments, in which portions of the standard spacecraft subsystems might be used directly by the experiment.

The primary mechanical interface would be at the top of the service module for all spacecraft. A secondary interface could be developed within the experiment module. This will be discussed more fully in Section 5.4.2.

A thermal design analysis indicates that the service module and experiment module can be thermally controlled using passive external coatings, multilayer insulation and heat pipes. To reduce internal temperature gradients, good heat transfer between mounting surfaces and components must exist. This can be achieved in part by blackening all internal surfaces and components and mounting the components to a platform. Additional discussion of the thermal design is given in Section 5.4.1.

To summarize, the SATS program will include a series of spacecraft, mission and vehicle dependent, with separate modules for the experiments, subsystems and solar array. This concept will provide:

1. Standard interface for experiments.
2. Standard environmental characteristics for experimenters.
3. Minimal spacecraft subsystem change between launches.
4. Ability to maintain a modest inventory of systems and subsystems.
5. Reduced integration time and effort.
6. Reduced complete spacecraft acceptance testing.

5.1.2 Other Characteristics

The other characteristics of the program and spacecraft that are necessary to meet the objectives are:

1. Random packaging
2. Use of available subsystems
3. Commonality of subsystems among SATS spacecraft where possible
4. Stabilized and earth oriented
5. Adaptable for external propulsion module
6. Limited orbital design life

7. Extensive test monitoring of experiment status

8. Special purpose, SATS exclusive, ground data reduction facility

These characteristics are desirable to keep costs at a minimum and realize quick reaction from experiment selection to data return. The following is a brief discussion of the above characteristics.

1. To implement the design requirements discussed in 5.1.1 and to maintain some packaging flexibility, the SATS spacecraft will adopt a random packaging concept. In many Explorer spacecraft the packaging goal has been efficiency of volume and weight for specific missions and experiments. This high density packaging is used for example on IMP's and S^3. The major disadvantage is that the spacecraft assembly, harness, balance, packaging, distribution, and integration, is highly dependent on the exact dimension (height) of each and every electronic card. These cards are shaped and stacked such that a design change, poor volume estimate by designers or experimenters, electrical interference or last minute modifications during integration and test phase can cause extensive rearranging of the subsystems. This is expensive and time-consuming. Although the SATS service module is basically a fixed design, there is some flexibility with random packaging and excess volume. This will result in quick response to an unforeseen change.

2. The development costs and initial design time will be reduced from previous spacecraft programs if available subsystems and hardware are used with a minimal amount of modification. A selection will be made based upon a review of existing subsystems. Initially the SATS program will not try to develop new subsystems for use in the service module. On later spacecraft updating or improvement might be incorporated; this would only be done if mandatory.

3. Along the same line of reasoning, it is desirable to have as much commonality as possible among subsystems of each of the spacecraft types. This will be limited only by unique mission requirements.

4. During the experiment survey, it was determined that some, if not most, experiments require three axis stabilization and earth

orientation. However, some experiments did not demand three axis control and would accept two axis control (spin stabilized). This divergence in control requirements creats a variation in control system design. A most desirable design feature of SATS would be to incorporate a control system that meets the most stringent requirements, but one that could be easily relaxed to allow the spacecraft to spin — all with a single design and set of equipment. A control system with this flexibility could be used in space on any single flight to obtain fine earth pointing, optional pointing, or spin scanning.

5. The capability of adding a propulsion module is a required feature of the structural design. Auxiliary propulsion is required for synchronous orbit insertion (i.e., kick motor), orbital trim to achieve fine sun synchronism or cancelling external drag forces. or for deboosting a recoverable package from orbit, if desired. The propulsion requirements are not completely defined at this point. Additional study will be performed.

6. The fact that SATS is a test-bed spacecraft, implies that a long lifetime is not required. Most experimenters indicate that, to test feasibility or operation of an experiment, life-times from a few hours or orbits to less than 6 months would be satisfactory. It is also desirable to have a short lifetime goal for other reasons. The orbital altitude can be set lower initially for better earth observation or geodetic measurements without decaying within the short lifetimes. Other mission parameters such as drift, inclination, and eccentricity are not critical. Redundancy and reliability criticality can be reduced. Quality control and assurance would be maintained at a high level, but reduced formally as regards some documentation.

7. The spacecraft basic design would incorporate a large number of housekeeping channels to monitor the test and engineering performance of the experiments. Being a test-bed spacecraft, a prime requirement is to determine the experiment status and examine its engineering and performance functions most critically. On most large spacecraft, because of the number of experiments and complex systems, the housekeeping channels are minimal for each experiment.

8. The quick-reaction capability envisioned as one of the essential ingredients of SATS rules out the use of the present routine

means for data reduction because of the expected delay of one to three months in processing data. There are two alternatives: 1) to set up a small independent SATS data reduction facility, or 2) to make the raw data (tapes) immediately available to each experimenter so that he can perform his own data reduction. Both alternatives will require real-time data transmission from the ground stations to GSFC.

In a single-experiment configuration, the easiest way to provide quick reaction for the experimenter would be to let him do his own data reduction. If the experimenter were at GSFC, he could be provided with the data almost immediately upon reception from the satellite. For non-GSFC experimenters, tapes could be shipped directly from the ground station to the experimenter; for backup, they would also be shipped (or played back over the data transmission link) to GSFC.

For missions with several experimenters, and conceivably for some single-experiment missions, the most efficient data reduction scheme would involve setting up a dedicated data reduction facility as indicated in Figure 3. This has been done previously. The IMP data reduction line is an example. In the interest of cost-effectiveness, the Ground Checkout Equipment, Control Center, and Data Reduction Facility could be combined in one location, and could share certain of the required hardware. This appears to be the most desirable way to provide quick reaction data reduction. It will also provide the greatest flexibility in accommodating different experiment configurations.

5.2 Existing Spacecraft Designs

During the study an investigation of about twenty different relatively small spacecraft was performed to determine if any could meet the general conditions and characteristics outlined in Section 5.1. If the complete spacecraft could not be used, were there any concepts, design parameters or subsystems that could be adapted to a SATS spacecraft? It was concluded from the investigation that many spacecraft had something to contribute but none fitted all the requirements. Two general designs, described in Section 5.4, evolved with variations that used hardware directly from existing spacecraft. It was felt that a new or modified structure for SATS would be necessary. However, on small spacecraft this is not an expensive development item.

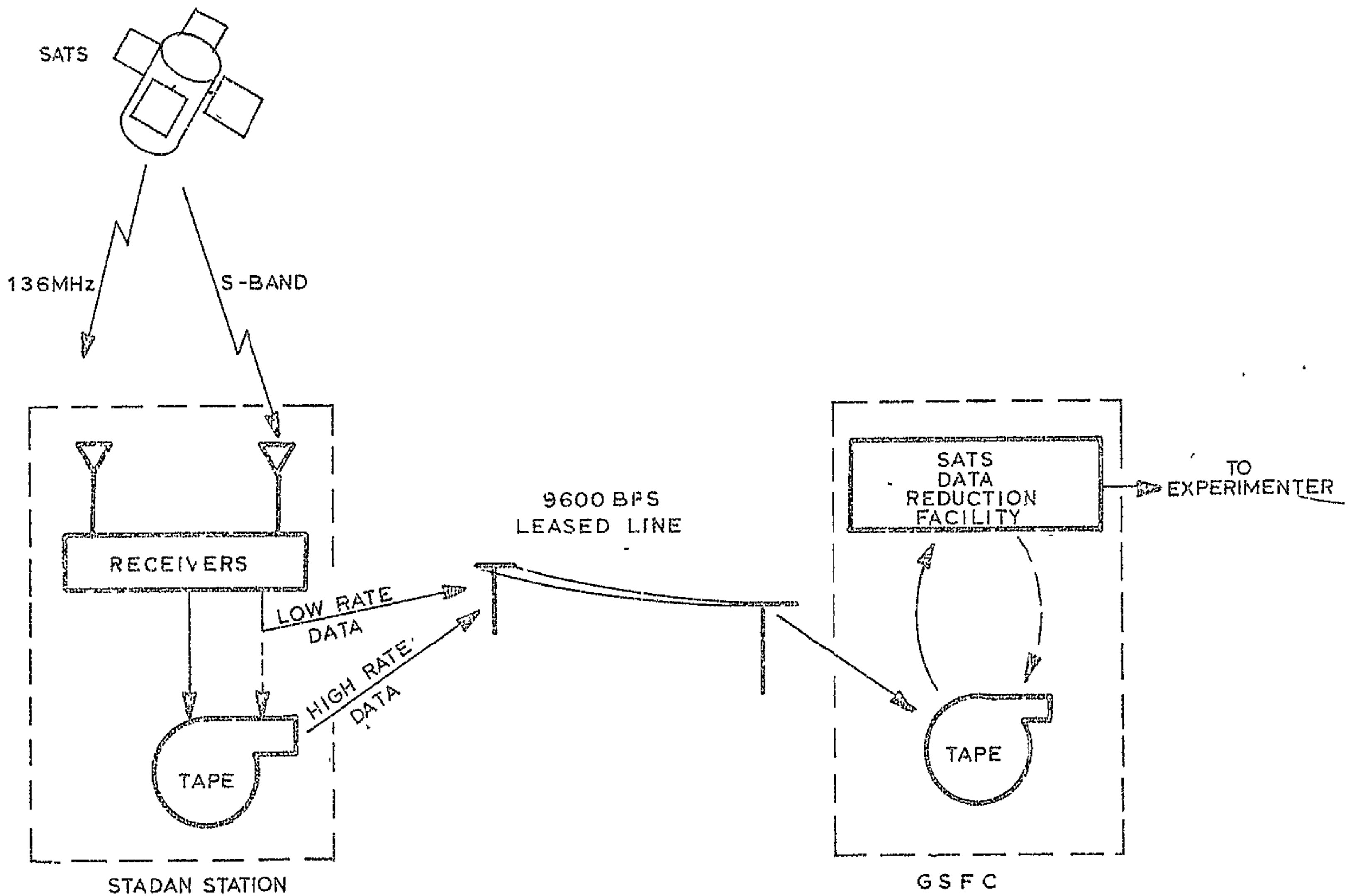


Figure 3. SATS Transmitted Data Flow

Table B is a summary of the pros, cons and conclusions about several spacecraft. The following discussion concerns their relavance to SATS.

5.2.1 Small Astronomy Satellite

This spacecraft is one of the best examples of the type of experiment modular design contemplated for SATS. It also contains a rather simple, single momentum wheel control system which slowly scans the heavens. It is a Scout sized spacecraft. The spacecraft is not directly adaptable to SATS. However, its modular concept will be used on SATS.

5.2.2 TIROS/TOS

These are meteorological satellites with limited attitude control. They are, however, mass produced, readily reproducible spacecraft. Managerially and technically approaches were developed to upgrade the spacecraft and subsystems as obsolescence or increased requirements made changes mandatory. The spacecraft has body mounted solar cells. This is a disadvantage on SATS, which should have solar paddles to allow for power flexibility without structural envelope changes. The TIROS/TOS major contribution is that there are many subsystems presently developed, flown and stocked that could be directly used by SATS.

5.2.3 TIROS-M/ITOS

The TIROS-M is an earth-oriented stabilized meteorological spacecraft. It is too large for the SATS concept, even for the Delta version. A smaller spacecraft with an improved momentum wheel control system (i.e., one motor and two roll sensors) is a possible candidate for the SATS/Delta spacecraft. The subsystems are usable on any SATS.

TABLE 8. APPLICABILITY OF OTHER SPACECRAFT TO SATS DESIGN CONCEPTS

PROGRAM	PRO	CON	CONCLUSIONS
SAS	EXPERIMENT MODULAR CONCEPT, SOME ACS CONTROL	NON-STANDARD SPACECRAFT	-SATS WILL ADOPT EXPERIMENT MODULE CONCEPT, SELECTED SUBSYSTEMS WOULD REQUIRE REDESIGN
TIROS/TOS	SIMPLE, QUICK REACTION, PRODUCTION REPRODUCIBLE S/C	LIMITED OR NO ACS, POWER LIMITED, NO SYNC ORBIT CAPABILITY	SELECTED FLIGHT PROVEN SUBSYSTEMS READILY AVAILABLE
TIROS-M	EARTH-ORIENTED SPACECRAFT USES TIROS/TOS IMPROVED SUBSYSTEMS	SPACECRAFT IS TOO LARGE AND HEAVY, NO SYNC ORBIT CAPABILITY	ATTITUDE CONTROL SYSTEM CONCEPT PRIME CANDIDATE FOR SATS, SPACECRAFT GENERALLY NOT ACCEPTABLE BECAUSE OF SIZE
INTELSAT-II	SYNCHRONOUS SPACECRAFT,	NO ACS, LIMITED POWER	CANDIDATE FOR SYNCHRONOUS SATELLITE - REQUIRES ACS INCORPORATION AND ADDITION OF SOLAR PADDLES
SMALL EXPLORERS	REFINED SMALL S/C TECHNOLOGY, USED SOLAR PADDLES & BOOMS	S/C'S TAILORED TO EXPERIMENTS, NO ACS IN GENERAL, HIGH DENSITY PACKAGING	IN GENERAL, NOT ACCEPTABLE TO SATS, SELECTED SUBSYSTEMS DESIGNS MAY BE EXPLOITED
S^3	FLEXIBLE DATA SYSTEM	HIGH DENSITY PACKAGING, POWER LIMITED-NO PADDLES, COMPLEX DATA HANDLING, NO ACS	NOT ADAPTABLE TO SATS REQUIREMENTS
LES SERIES	COMMUNICATIONS R&D S/C, SYNC SATELLITE, AUTOMATIC STATION KEEPING.	NON-STANDARD SPACECRAFT, INTEGRATED EXPERIMENTS	NOT ADAPTABLE TO SATS, TYPES OF EXPERIMENTS ARE SAME AS CONTEMPLATED FOR SATS
OV SERIES	EXPERIMENT MODULAR CONCEPT, PLANNED AS STANDARD S/C, FLEXIBLE STRUCTURES	LITTLE ACS-ONLY G G., STANDARDIZATION CONCEPT VIOLATED, LIMITED POWER	MODULAR EXPERIMENT CONCEPT ADOPTED ON SATS OV-1 AND 2 SPACECRAFT ARE NOT ADAPTABLE TO SATS OV-3 IS PRIME CANDIDATE WITH MODIFICATIONS FOR SATS
DELTA-PAC	FLOWN AS A DELTA PIGGYBACK S/C, PASSIVE ACS	LIMITED POWER, WAS SINGLE EXPERIMENTAL FLIGHT	CANDIDATE CONCEPT FOR DELTA PIGGYBACK WITH MODIFICATIONS TO POWER SUPPLY AND NEW SUBSYSTEMS (PROBABLY FROM THE SCOUT AND DELTA SPACECRAFT SYSTEMS).
P-11	DESIGNED AS STANDARD AGENA PIGGYBACK, PROPULSION CAPABILITY	FLIGHTS WERE NON-STANDARD WITH LARGE COST INCREASES, NO ACS DEVELOPED OR FLOWN EXCEPT AGENA VEHICLE, POWER LIMITED.	CANDIDATE FOR AGENA PIGGYBACK WITH ACS ADDITION, POWER SYSTEM MODIFICATION AND ENFORCED STANDARDIZATION

5.2.4 Intelsat-II

This is a medium size spacecraft with a kick motor and attendant hardware for synchronous orbit operations. It is spin-stabilized and does not have any appreciable attitude control system. Some of the satellite subsystems are adaptable to SATS synchronous designs. The amount of engineering and development to incorporate an ACS, modify structure, and add subsystems from other spacecraft makes this approach less than desirable.

5.2.5 Small Explorers

A number of past small explorers (e.g. S-3's, IMP's A-F, RAE, ARIEL-I & II, Air-Density, Injun, AE-A & B, and BE-A, B, C) were investigated to determine if there were any desirable features that could be adopted. Their primary contribution was that they had advanced the technology of many subsystem designs and concepts that can be obtained off-the-shelf today. Secondly, many of these spacecraft developed boom and solar paddle or array designs to a high degree. The major disadvantage was that most spacecraft were developed as a series of 2 or 3 spacecraft to fly particular types of experiments. The spacecraft was tailored to the experiments and the whole system was integrated into one envelope. Another disadvantage is that none of these spacecraft had developed a good ACS for small satellites.

5.2.6 Small Scientific Satellite

The Small Scientific Satellite (S^3) is a Scout launched small spacecraft currently being built at GSFC. This spacecraft has a highly complex and flexible data handling system. It has body mounted solar cells and no ACS system. This spacecraft is a classic example of a highly integrated, weight and volume efficient spacecraft. SATS does not need a highly complex and costly data system similar to that developed for S^3. The fabrication, checkout, testing and software problems associated with the S^3 spacecraft computer would negate the quick reaction capability desired for SATS. Because of the previously stated characteristics given for SATS, the S^3 does not contribute to the SATS concept.

5.2.7 LES Series

The LES series of experimental communications satellites built for the Air Force ranged from 80 lbs. for LES-1 to over 400 lbs. for LES-6. These satellites have contributed to space communications technology.

The spacecraft and subsystems were mostly tailor-made at Lincoln Laboratories for each individual mission. The LES spacecraft, in general, is not adaptable to SATS. The past experiments and some future planned communications and technological experiments are the types which could fly on SATS.

5.2.8 OV Series

The OV series of spacecraft, built for the Air Force, was planned as "standard" spacecraft (OV-1, -2, and -3). The OV-1 and -3 also included a modular compartment for the experiments. All three spacecraft were spin-stabilized. The OV-1 series is too small and power limited for the SATS program. The OV-2 series did not maintain its "standard" concept. The OV-3 modular concept and the flexibility of design is directly applicable to SATS. Furthermore, the ability to maintain a "standard" spacecraft for the required four launches was achieved to a greater extent than in any of the previous OV series.

The OV-3, with the possible incorporation of a GSFC ACS system and a STADAN compatible communication system, would be an acceptable candidate for SATS. This will be discussed in more detail in Section 5.4.

5.2.9 Piggybacks

A. <u>Delta-PAC</u>

The PAC spacecraft was flown attached to the second stage of the Delta, in 1969. It was stabilized using a gimbal damped momentum wheel with the long 2nd stage tank adding gravity gradient augmentation. The flight was primarily a test of the ACS. The design was power-limited for use by experiments. The magnetic dipole of the Delta 2nd stage requires compensation to reduce the magnetic disturbances. A similar concept was analyzed using a Scout-size spacecraft and the Scout 4th stage motor. Extreme differences in moments-of-inertia and inertia ratios between the Delta and Scout configurations make use of the same attitude control system impractical. The addition of long booms with tip masses to obtain a few orders of magnitude increase in inertias would theoretically make the design feasible; but it would add problems of boom mechanisms and boom deflection. It is recommended that the gimbal damped momentum wheel with gravity augmentation be used only in the Delta piggyback configuration.

B. P-11

The P-11 spacecraft, built for the Air Force, was designed to fly piggyback on the Agena vehicle. It can remain attached and use the vehicle's control system or it may be separated and spin-stabilized. No ACS has been developed or flown on P-11. The P-11 was initiated as a "standard" spacecraft; however, in 20 or more flights no two spacecraft have been the same. Starting with a standard structure, the contractor was permitted to change and modify wherever desirable to meet an experimenter's needs. No real restrictions were placed on the experiment envelope or on other experiment interfaces. The result was high cost (5 - 6 times advertised base price).

P-11 was considered for use on other vehicles. This approach, while attractive on the surface, is not recommended. The launch loads, load paths, structural configuration, and separation system, would be completely different on any other vehicle. The Scout and Delta vehicles produce some of the most severe vibration and acceleration loads of any vehicle. A modified P-11 structure and all subsystems would require requalification. It was stated previously that structures need not be a large development cost item. Therefore, it would be more efficient and economical to design a spacecraft structure along guidelines previously established by Scout and Delta and use subsystems that have already been qualified to these loads.

The P-11 spacecraft, if used on the Agena, is an acceptable piggyback candidate. If it were to be separated, an ACS would probably be necessary. A STADAN compatible communication system would be required. Strict control of the experiment interface by GSFC would be mandatory to keep down costs.

5.3 Vehicle Capability and Orbital Characteristics

5.3.1 Vehicle Performance

Two candidate boosters for SATS missions are the Scout and the Delta. The Scout vehicle provides modest low-altitude payload capability whereas the Delta can deliver larger spacecraft (possibly multiple spacecraft) into low-altitude orbits or approximately 600 lbs. into a synchronous equatorial orbit.

Scout performance is shown in Figures 4, 5, and 6. The first plot indicates the deliverable payload capabilities from the Wallops Station (WS) launch site into a 37.5° inclined orbit and from the Western Test Range (WTR) into a polar orbit. Notice that 250 lbs. can be placed into a 300 n. mi. polar orbit out of WTR and into a 430 n. mi. 37.5° orbit out of WS. Figures 5 and 6 show the effects of requiring other orbit inclinations at altitudes of 300, 500 and 700 n. mi. for the two launch sites. All curves assume the use of the 10 lb. standard Scout/Spacecraft adapter. The improved Scout, not shown, which will be ready before SATS first launch will increase the capability approximately 100 pounds for the 300 nm. polar orbit.

The Delta vehicle is available in a variety of configurations. Depicted in Figures 7 and 8 are the circular orbit capabilities of boosters available from mid-1971 onward. The DSV-3L is the long tank Thor with the Universal Boattail (UBT — for accommodating 3, 6 or 9 solid motor strapons for thrust augmentation) and an inertial guidance system. The second stage is the Improved Delta (ID) using Nitrogen Tetroxide (N_2O_4) and Aerozene 50 (A-50) as the bi-propellants. Available with these booster combinations is a Thiokol third stage, TE 364-3 or TE 364-4, which are used for high energy missions. As indicated in the figures, the two stage configuration is considered for low altitude circular orbit applications. Figure 7 shows the performance for launches from the Eastern Test Range (ETR) into circular, 28.5 degree inclined orbits and Figure 8 the performance from WTR into polar orbits. There is a significant increase in payload from the Scout launches, almost an order of magnitude for the 9 solid configuration. Associated with this increased performance is a large increase in booster costs.

The last booster performance curve in this section, Figure 9, shows the Delta capability into a synchronous transfer orbit. This configuration includes a third stage, the TE 364-3. In order to attain the synchronous equatorial orbit an apogee kick motor is required. Table C summarizes the apogee motor sizing and the resultant payload into the geostationary orbit.

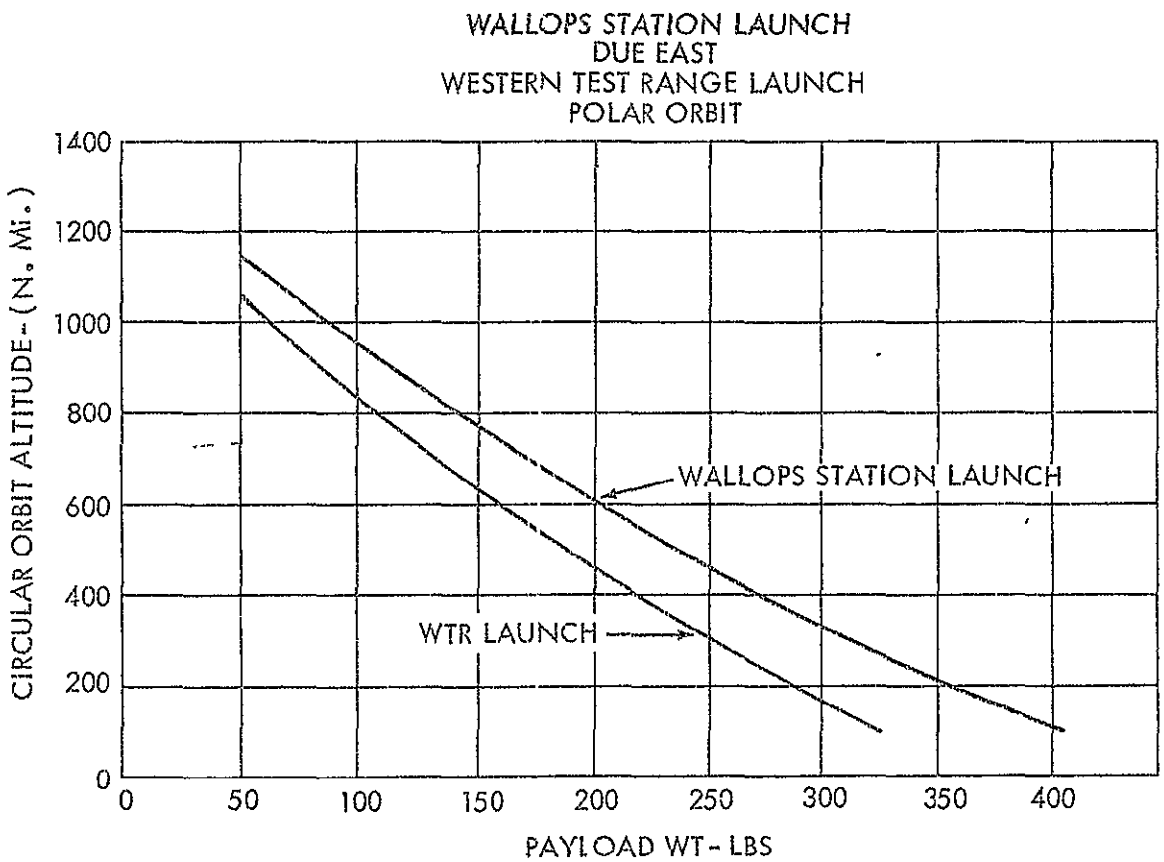


Figure 4. Circular Orbit Performance (Scout)

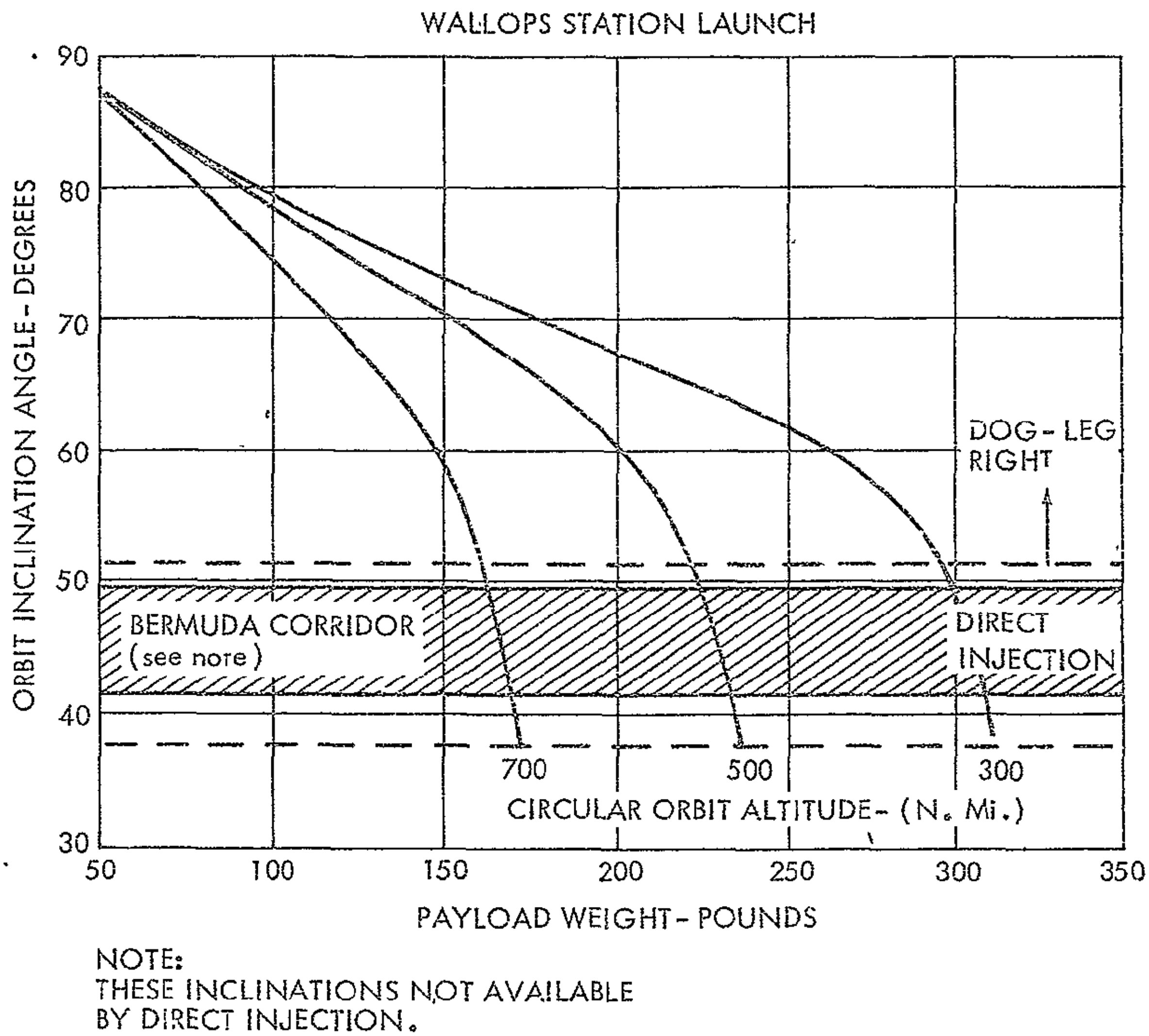


Figure 5. Effect Of Orbit Inclination On Payload Capability — Wallops Station (Scout)

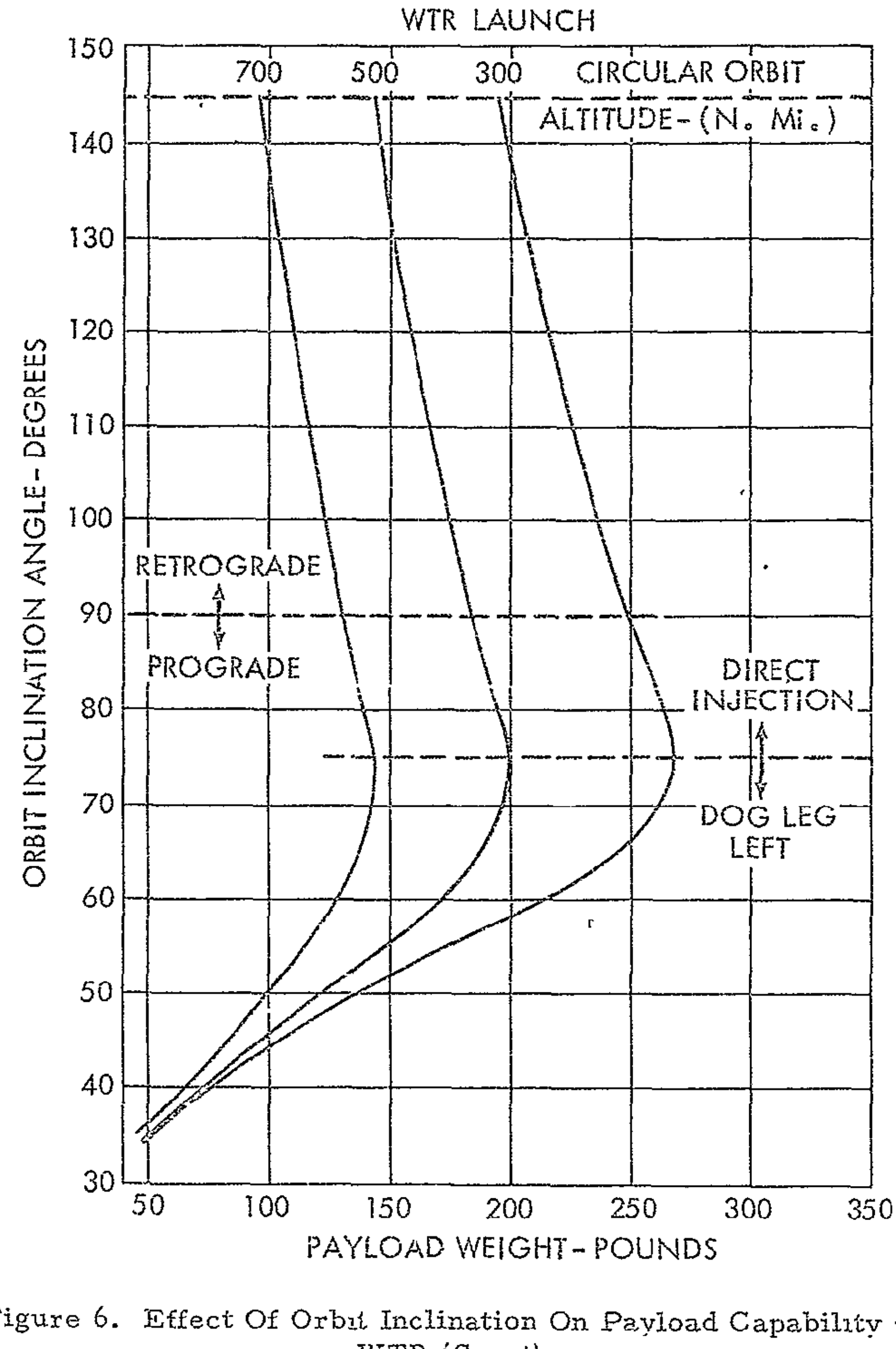


Figure 6. Effect Of Orbit Inclination On Payload Capability — WTR (Scout)

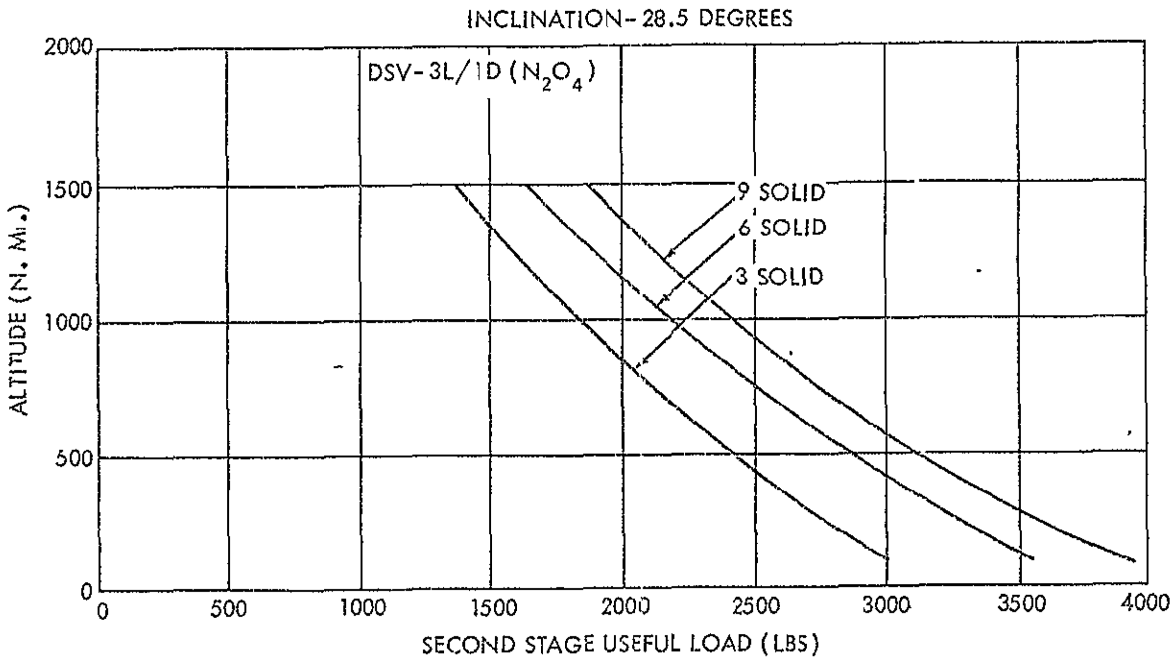


Figure 7. Delta Performance Circular — ETR

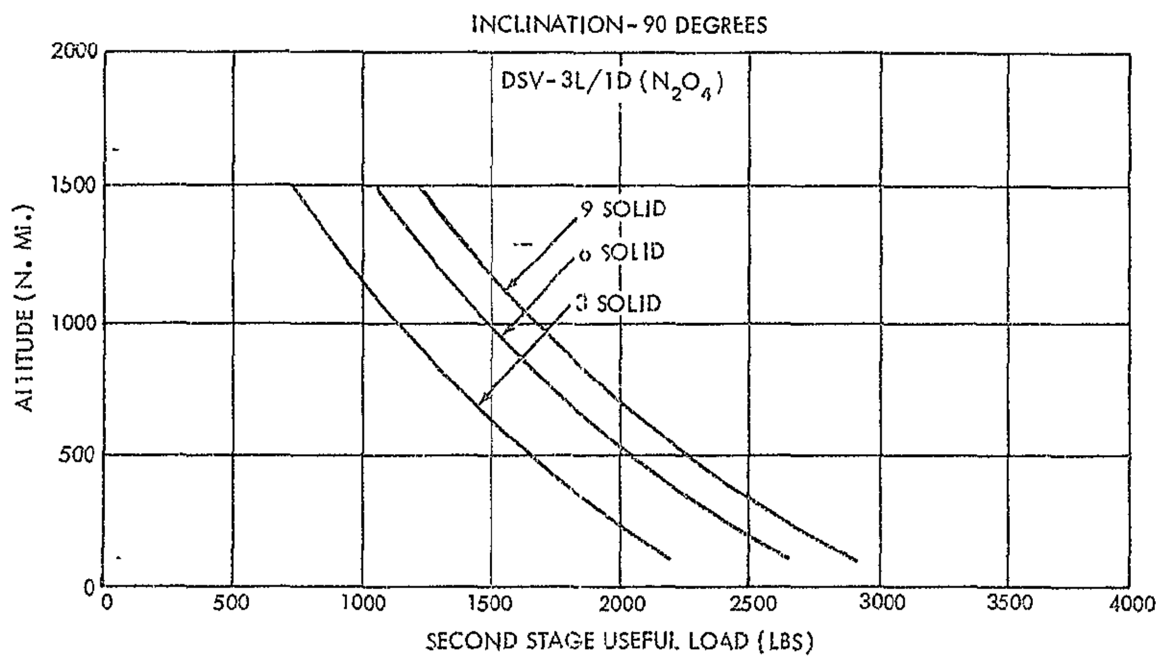


Figure 8. Delta Performance Circular Orbit — WTR

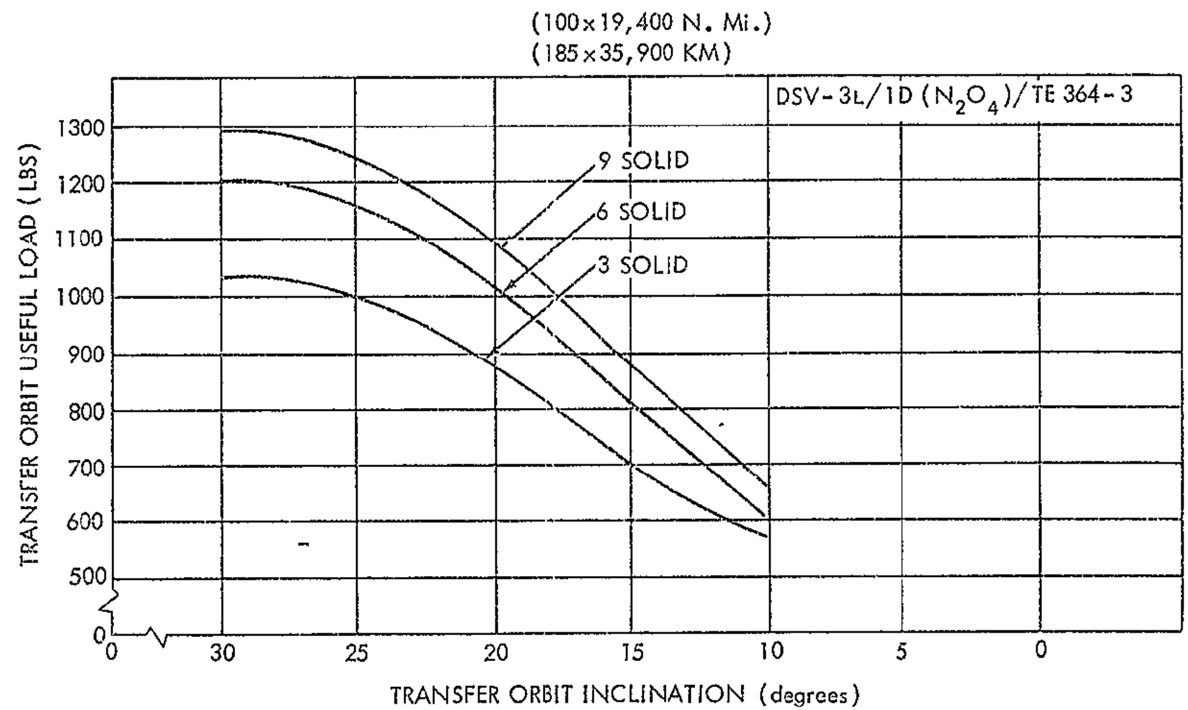


Figure 9. Delta Performance Synchronous Transfer Orbit

TABLE C. DELTA SYNCHRONOUS MISSION CAPABILITY

STANDARD FAIRING

DSV-3L/ID (N_2O_4)/TE 364-3

CONFIGURATION	VEHICLE USEFUL LOAD (LB)	TRANSFER ORBIT PAYLOAD (LB)	APOGEE MOTOR* TOTAL WT (LB)	APOGEE MOTOR BURNT WT (LB)	FINAL** PAYLOAD WT (LB)
9-Solid	1280	1230	627	62.7	602
6-Solid	1200	1050	585	58.5	565
3-Solid	1030	978	495	49.5	484

NOTES:

1. TRANSFER ORBIT IS 100 by 19,400 NM AT 28.5 DEG INCLINATION
2. ALL CONFIGURATIONS INCLUDE FAIRING (APPROXIMATELY 2M INTERNAL DIAMETER)
3. ALLOWANCE HAS BEEN MADE FOR ATTACH FITTING WT. 50 LB

*APOGEE MOTOR CHARACTERISTICS: SPECIFIC IMPULSE - 290 SEC
MASS FRACTION - 0.90

**DOES NOT INCLUDE BURNT MOTOR WEIGHT

5.3.2 Alternate Orbits

Orbits considered thus far for the SATS application have been essentially circular, either low altitude or high altitude earth synchronous. Elliptic orbits, however, can provide "simulated" operation for both high and low altitude experiments. Such orbits have as their major advantage a reduction in the booster requirements. In fact, under certain conditions, a multiple launch of one or more low altitude circular orbit spacecraft in addition to a "simulated" synchronous orbit satellite can be achieved by the same booster as used for a single synchronous equatorial (24 hr. circular) satellite. An apogee kick stage will not be required, thereby simplifying the spacecraft and reducing its cost. The next paragraphs will discuss some of the key characteristics and associated booster performance of these elliptic orbit configurations.

The first to be considered is the transfer orbit normally used for achieving a geostationary orbit. As indicated in Figure 9, the DSV-3L/ID (N_2O_4)/TE 364-3 with 9 solid strap-ons can deliver about 1300 lbs. into the transfer orbit. This orbit has a period of 10.6 hours and for almost two hours the spacecraft is very close to the synchronous orbit altitude. Since the SATS mission is to provide a test-bed for experiments and not operational capability, two hours of experiment operation every ten hours might be adequate. Notice that two synchronous type 600 lb. class spacecraft could be accommodated. Alternatively, it is possible to separate a payload while in the parking orbit prior to third stage firing, in which case both a low altitude circular orbit and an elliptic orbit could be achieved. The 100 n.mi. parking orbit normally associated with the transfer orbit may be too low, because of aerodynamic drag, in which case a higher parking orbit must be attained. Figure 10 shows the additional payload deliverable to the parking orbit as a function of the parking orbit altitude, assuming that a 600 lbs. useful payload is injected into the elliptic transfer orbit by an optimally configured third stage. The third stage weights are indicated in Figure 11.

Before discussing other possible elliptic orbits, a few additional characteristics of this synchronous transfer orbit should be noted. The subpoint (geographical) location of the apogee point will vary due to two factors. First the orbit period is not equal to nor is it an integral fraction of a sidereal day (approximately 24 hours); and the second is the oblateness of the earth which causes nodal and apsidal motion. The first primarily affects the longitude of the apogee subpoint. In the orbit discussed above, the longitude at the repetitive apogee (i.e., every

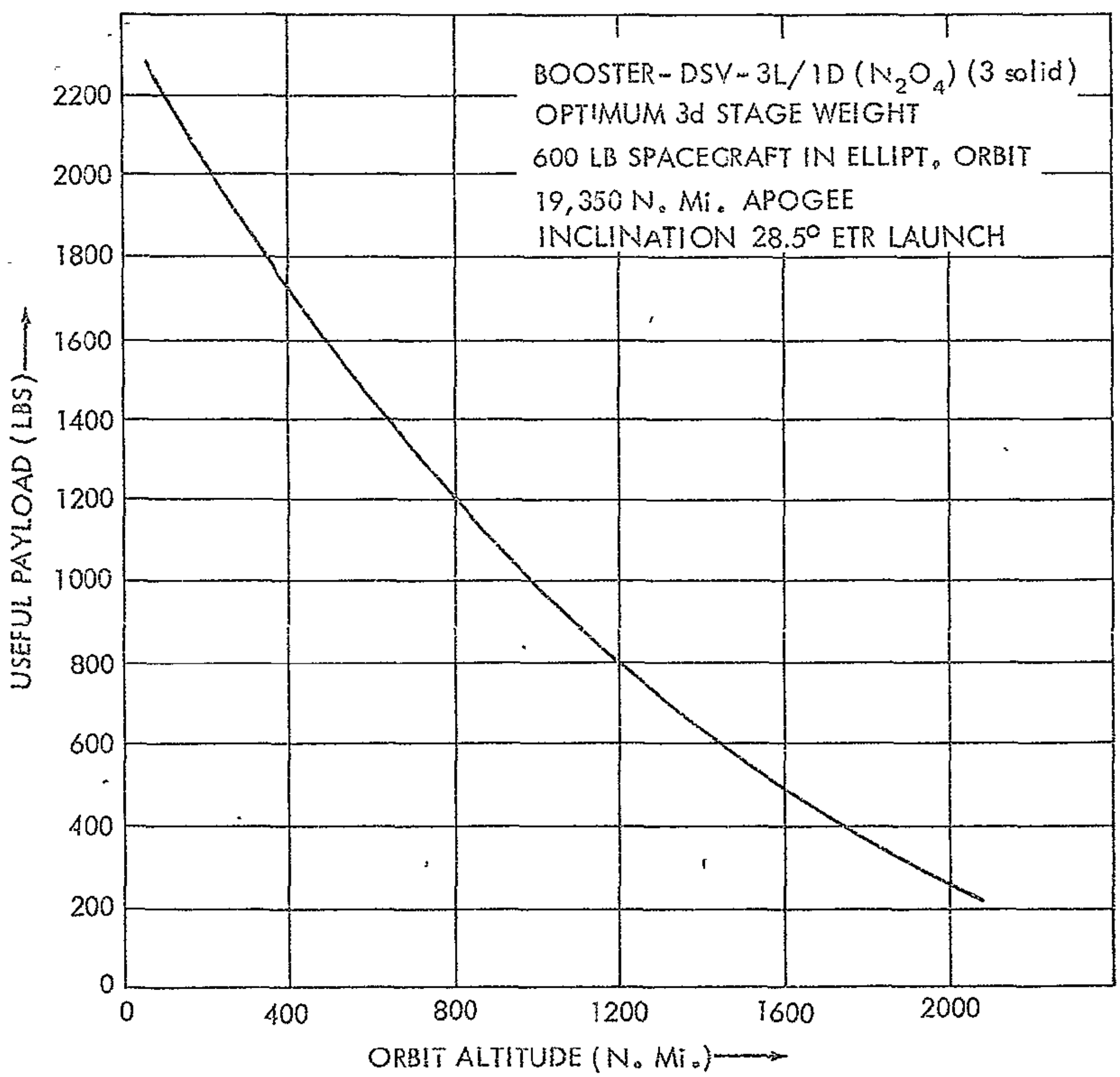


Figure 10. SATS payload Remaining In Circular Parking Orbit

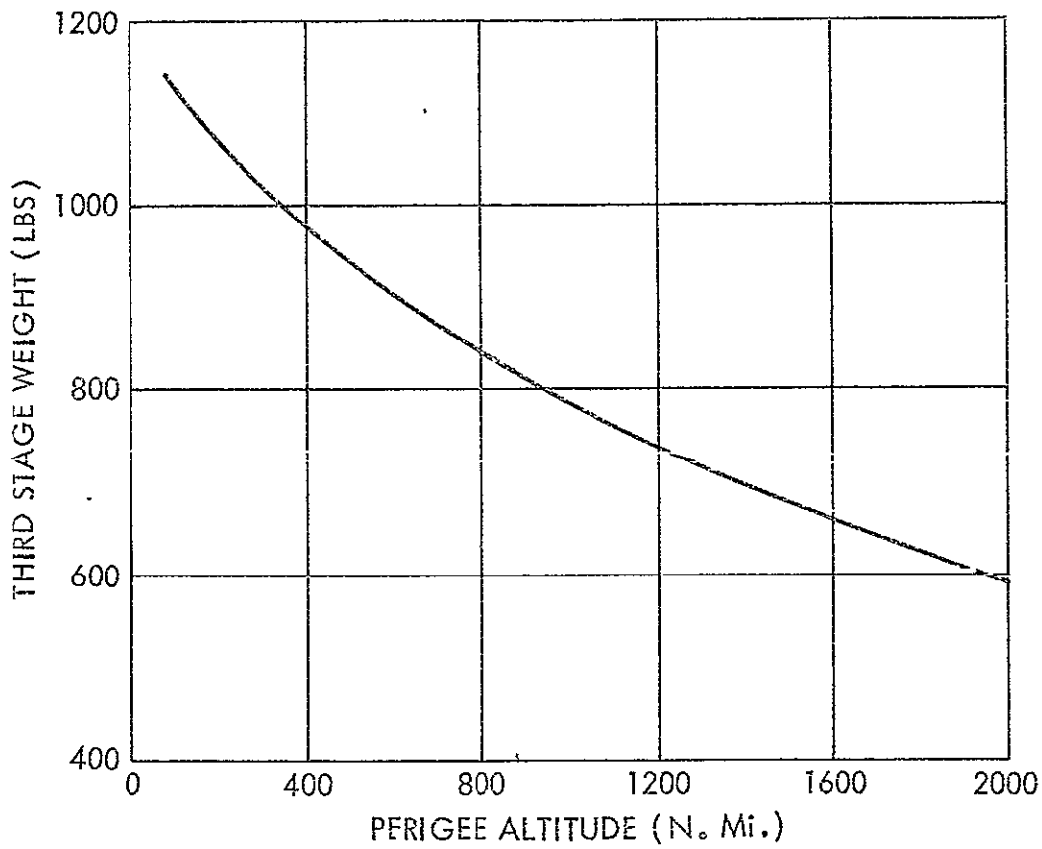


Figure 11. Optimum Third Stage Sizing

second apogee) will change by about 45 degrees. If this orbit is modified to approximately a "twelve-hour" orbit (a half of a sidereal day), the apogee longitude every other orbit would remain geographically fixed excluding the nodal and apsidal motion. As a result, the apogee point could be fixed to lie along a U.S. longitude once per day and between India and Japan once per day on alternate orbits. This alternate orbit has an apogee altitude of about 22,000 n.mi. The boster payload penalty would be modest since only about 200 ft/sec. additional velocity would be required. Recalling Figure 10, this would amount to less than a 60 lb. reduction in the low altitude payload.

Earth oblateness effect were neglected in discussing the "twelve-hour" orbit. The nodal motion for these high altitude elliptic orbits is small, less than .32°/day primarily affecting the longitude of the apogee subpoint. This is readily cancelled by adjusting the orbit period. On the other hand apsidal motion has a more significant effect because it changes the longitude and latitude of the apogee subpoint. This motion of the orbital semi-major axis is a function of the orbit inclination. The Russians have demonstrated in the Molniya communications satellites, which have "twelve-hour" orbits, that at an inclination of 63.4°, either posigrade or retrograde, the apsidal motion will be zero. Hence, the apogee subpoint can be made to recur at the same latitude every orbit. Depending on the injection point, or argument of perigee, a "twelve-hour" orbit, 63.4° inclination, could place apogee over the central U.S., or over Canada, or on the equator, and every day for several hours the satellite would remain near these points at altitudes close to synchronous altitude (19,300 n.mi.). In terms of booster requirements, achieving this orbit imposes some serious weight penalties. A range safety constraint from ETR of a 44° minimum azimuth limits direct injections to a maximum of 50° inclinations. Hence a "dog-leg" maneuver is required resulting in a significant loss of payload. From WTR, a direct injection into a retrograde orbit of 63.4° inclination is possible. However, again a payload penalty is involved due to the fact that the earth's rotational velocity must be removed. The results are shown in Figure 12. The optimum 3rd stage sizing is the same as before, Figure 11. More than 700 lbs. could be left in a 300 n.mi. circular orbit with 600 lbs. in the 63.4° elliptic orbit. If a "twelve-hour" orbit was required, an additional 60 lbs. would be lost from the low circular orbit. Therefore, the use of two 600 pound class SATS/Delta spacecraft or a SATS/Delta spacecraft and a piggyback, one each in a low and 12 hour orbit, is feasible.

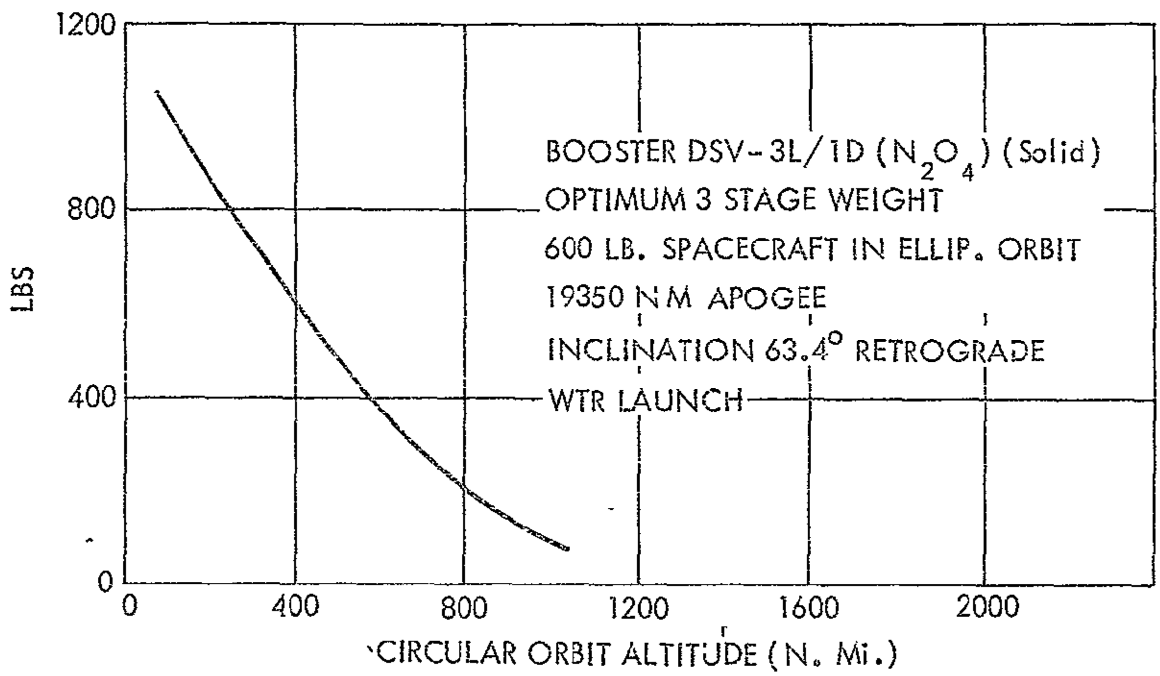


Figure 12. SATS Payload Remaining In Circular Parking Orbit

Consideration should be given to a direct injection from ETR into a "twelve-hour", 50° inclined orbit. The additional velocity required to achieve this orbit, rather than 28.5° orbit, is 400 ft./sec. This reduces the payload curves shown in Figure 10 by less than 210 lbs. including the 60 lbs. penalty for the "twelve-hour" orbit. The apse line only rotates at a rate of 0.18°/day in the orbital plane. The result is less than 5° longitude and 10° latitude variation during a 90 day mission. Figure 13 depicts the spacecraft track in the orbit plane, with time markers and corresponding altitudes. Notice that more than four hours are spent at altitudes higher than the synchronous altitude.

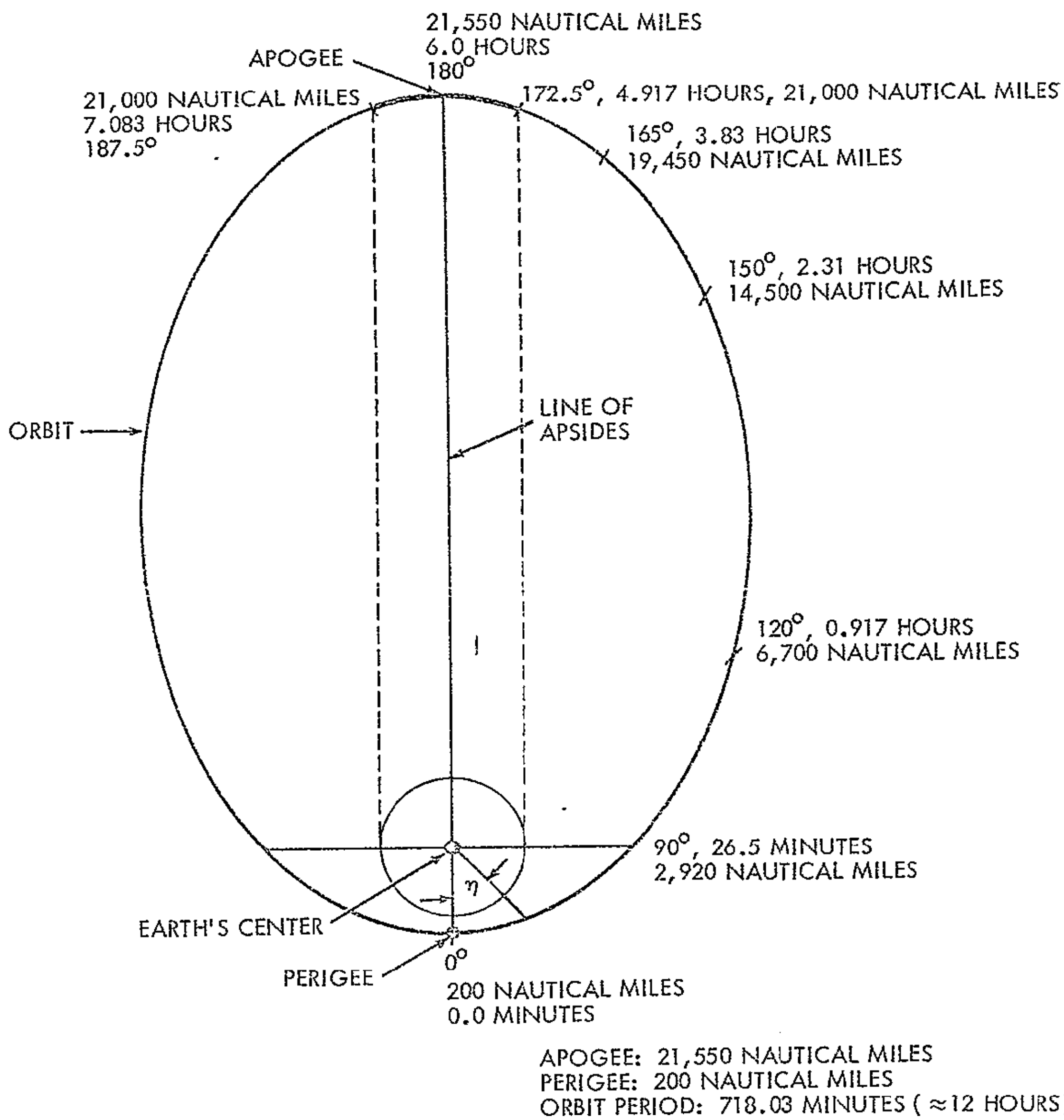


Figure 13. Spacecraft Track In Orbit Plane

5.4 SATS Spacecraft Design Concepts

5.4.1 Systems and Subsystems Discussion

The present effort has not included an in depth review of all the subsystems, or even identified all the specific blackboxes required for the various SATS configurations. Some general guidelines have been developed as to the overall parameters. The following paragraphs contain a brief summary of some of the subsystems. Table D also indicates some of the preliminary system parameters.

1. Telemetry Encoding. The present concept is to have 2 encoders, one low-sampling-rate, moderate precision (8 bits), to sample housekeeping (say, 64 channels) and feed a 136 MHz transmitter; the other high sampling rate, moderate precision, for the experiment, feeding an S-band transmitter. Input requirements for the experiment encoder will be developed during subsequent studies. Ideally, the encoder should be able to accommodate a moderate number of analog channels at a moderate sampling rate for each, or a single analog channel at a high sampling rate (e.g., video), or a few high rate serial digital signals. Flexible modular systems for varying data requirements will be examined.

2. Data Storage. Generally, we expect real-time readout, however, to provide flexibility to accommodate a wide range of experiments, data storage is provided. As with the experiment encoder, data storage requirements are not in final form during this phase of program study; however, a tape recorder is presently planned with a storage capacity is between 10^6 and 10^8 bits. It would have the capability of operating either in a burst mode (storing and playing back at the same bit rate) or full-orbit-coverage mode (to accommodate 2 orbits of data, 20:1 ratio or greater between playback and record rates). In either case, maximum output bit rate should be 150 Kbps.

3. Command System. The command receiver will be at 148 MHz, PCM/FSK/AM per GSFC standards (64 bps, 64 bits total per command including sync, parity, and spacecraft address). The exact number of commands to be provided has not been determined but approximately 64 commands should be adequate. These would be divided among programming, relay and experiment type commands.

TABLE D. PRELIMINARY SYSTEM PARAMETERS

	SATS/SCOUT	SATS/DELTA	DELTA/PIGGYBACK
TOTAL S/C WEIGHT	300 LBS.	600 LBS.	375 LBS.
EXPT. WEIGHT (nominal)	75 LBS.	150 LBS.	75 LBS.
S/C - EXPT. CONFIGURATION	SEPARATE MODULES	SEPARATE MODULES	INTEGRATED
STABILIZATION	MOMENTUM WHEEL, MAGNETIC TORQUING	MOMENTUM WHEEL, GAS TORQUING	MOMENTUM WHEEL
PROPULSION	NO	AS REQUIRED	NO
STABILITY	10 ARC-SEC/SEC	20 ARC-SEC/SEC	20 ARC-SEC/SEC
ATTITUDE DETERMINATION	<1°	<1°	<1°
POWER AVAILABLE: SPACECRAFT EXPT. (15% duty cycle)	 25 W 70 W	 40 ~ 50 W 100 W	 20 W 50 W
COMMAND SYSTEM	GSFC STANDARD	SAME	SAME
TELEMETRY: VHF TRACKING/HOUSEKEEPING S-BAND DATA	 0.25 W 1 MBPS	 1 W 5 MBPS	 0.25 W 1 MBPS
DATA STORAGE: LOW RATE HIGH RATE	 SOLID STATE/TAPE NONE	 SOLID STATE/TAPE TAPE	 NONE NONE

4. Programmer. To provide control for pyrotechnics during the launch and pre-operational phases of the mission, a moderate number of sequencing functions is required. The programmer (or sequencer) must also provide some command-like functions and act as a backup for some commands (e.g., S-band transmitter turnoff). The commands stated above include some number of programmer functions; the Command Decoder may be combined with the Programmer. Programmer timing may include control of delayed commands.

5. RF System. Two transmitters will be provided: a beacon, fed by the housekeeping encoder, with an output of 0.2 - 0.25 watt at 136 MHz; and an S-band transmitter with 1 watt output at 2300 MHz, fed by the experiment encoder and commanded (or programmed) on and off over station. The beacon will feed an omnidirectional antenna (dipoles, turnstile, etc.). The S-band transmitter may feed either an omni-antenna or one with moderate gain, depending on the mission. Link calculations in Appendix B indicate that the above is in the proper power range for the data rates and orbits presently envisioned.

6. Thermal System. A thermal design analysis indicates that the service module and experiment module can be thermally controlled using passive external coatings. A combination of thermal control coatings and multilayer insulation on the exterior of the spacecraft together with the internal power dissipation will maintain the components within their temperature limits. To reduce internal temperature gradients, good heat transfer between surfaces and components must exist. This can be achieved in part by blackening all internal surfaces and components and mounting the components to a platform. Since the spacecraft will be designed for the non-spinning condition, it appears at present that heat pipes should be used in the service module to insure adequate heat transfer between subsystems and across the experiment interface to maintain an acceptable overall temperature profile.

7. Power System. The power system has been studied in some depth because it affects the configuration and thermal designs. The primary source of power for SATS will be a solar array. A paddle configuration is preferred because of the need for the flexibility of available power. Provision must be made for peak loads which exceed the array output and for standby power in

shadow. The system configuration consists of the solar array feeding the main spacecraft power bus, to which is attached a shunt regulator, batteries with a charge regulator, a discharge regulator, and an under-voltage cutoff system.

As in the case of any power system design, certain environmental and performance parameter assumptions were made prior to the initiation of the design effort. These assumptions are listed below:

(a) three month life requirement, with a possible extension to six months;

(b) a regulated load bus operating at 28 v dc;

(c) 300 nautical mile polar orbit (noon, and noon ±45°);

(d) variable power requirements for spacecraft average load to a maximum of 30 watts (SATS/Scout);

(e) variable peak load power (on for 15% of orbit, daylight only) to a maximum of 80 watts;

(f) minimum weight for all power system components compatible with system reliability;

(g) electrical power to be provided by means of a conventional solar conversion, energy storage, power system.

Figure 14 shows one power system configuration capable of efficiently meeting the spacecraft load requirements. Such a configuration, commonly known as a Direct Energy Transfer (DET) System, has been used on several satellites. The lack of any series element between the solar array and the regulated load bus allows the system to supply the daytime load demands at almost 100% efficiency. A possible drawback is the lower efficiency—typically 85%—when the batteries must be discharged to supply spacecraft loads.

P. S. Electronics

The battery charger presently under consideration is a simple series dissipative type, although a pulse-with-modulated (PWM) charger could be used with possibly a small gain in transfer efficiency. The loss is considered 1/30 the charge power.

2-4

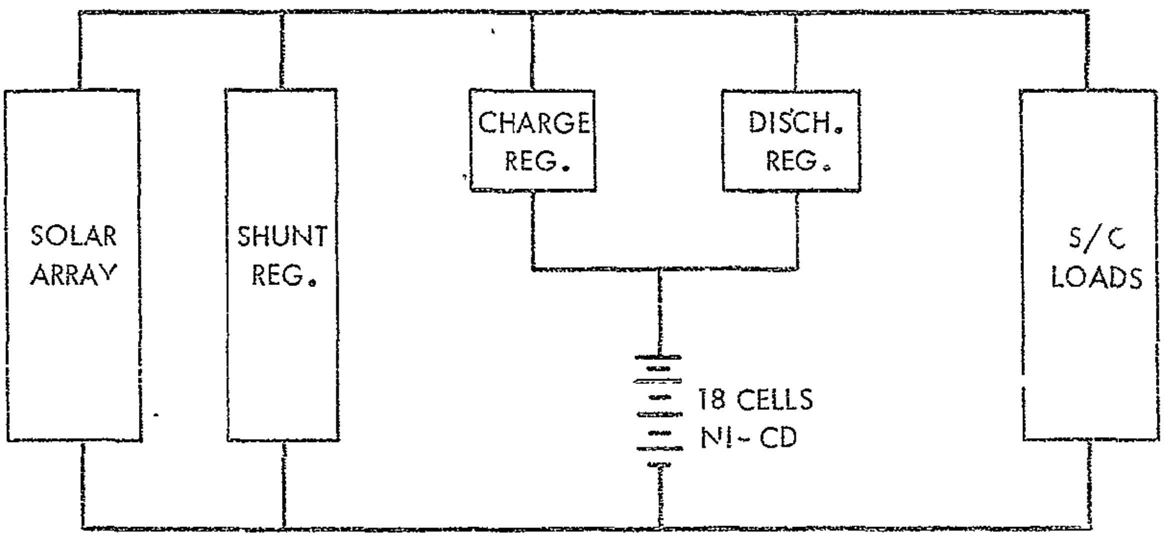


Figure 14. Direct Energy Transfer Power Subsystem

The discharge regulator will be a boost converter with a regulated 28 v dc output. It has been assigned a power transfer efficiency of 85%.

The shunt regulator in Figure 14 will actually be a partial shunt regulator. This approach will allow most of the unneeded power to remain in the array, thereby reducing the power dissipating requirement for the regulator shunt paths. This technique has previously been employed on several spacecraft.

Battery

The storage cell selected for this mission is a conventional nickel-cadmium (Ni-Cd) cell. An advantage of this type over others is its better cycle life under conditions of deep discharge. In addition, a Ni-Cd cell can tolerate a small amount of continuous overcharge, thereby reducing the complexity of the battery charge controller. Although the actual charge control method has not been selected, either a third-electrode cell (as flown on OAO) or a Cd-Cd coulometer (RAE) could be incorporated into the charge control system.

Solar Array

After the other power system components have been defined, and the day, night, and peak load profiles specified, the required solar array power output can be easily obtained.

The average daytime regulated bus demand (load power + battery recharge power) was calculated for various peak loads and day and night loads. Figure 15 summarizes these calculations. Three assumptions were made: 1) the peak load plus spacecraft day load is greater than the required array power; 2) the peak load occurs in the day only; and 3) the actual solar array power output is the same as the required array power at the time of the peak load.

Several array configurations are capable of supporting the estimated power required. It was initially assumed that the solar array will consist of solar cells mounted on deployable rigid paddles and that the spacecraft body would have its long axis along the earth spacecraft radius. Figure 16 shows the output for four different paddle orientations. The sun aspect angle would rotate around the spacecraft from the top to the bottom in the top views of the figure. Curve 4 gives less solar array ripple and has the highest output for the valleys of the curve.

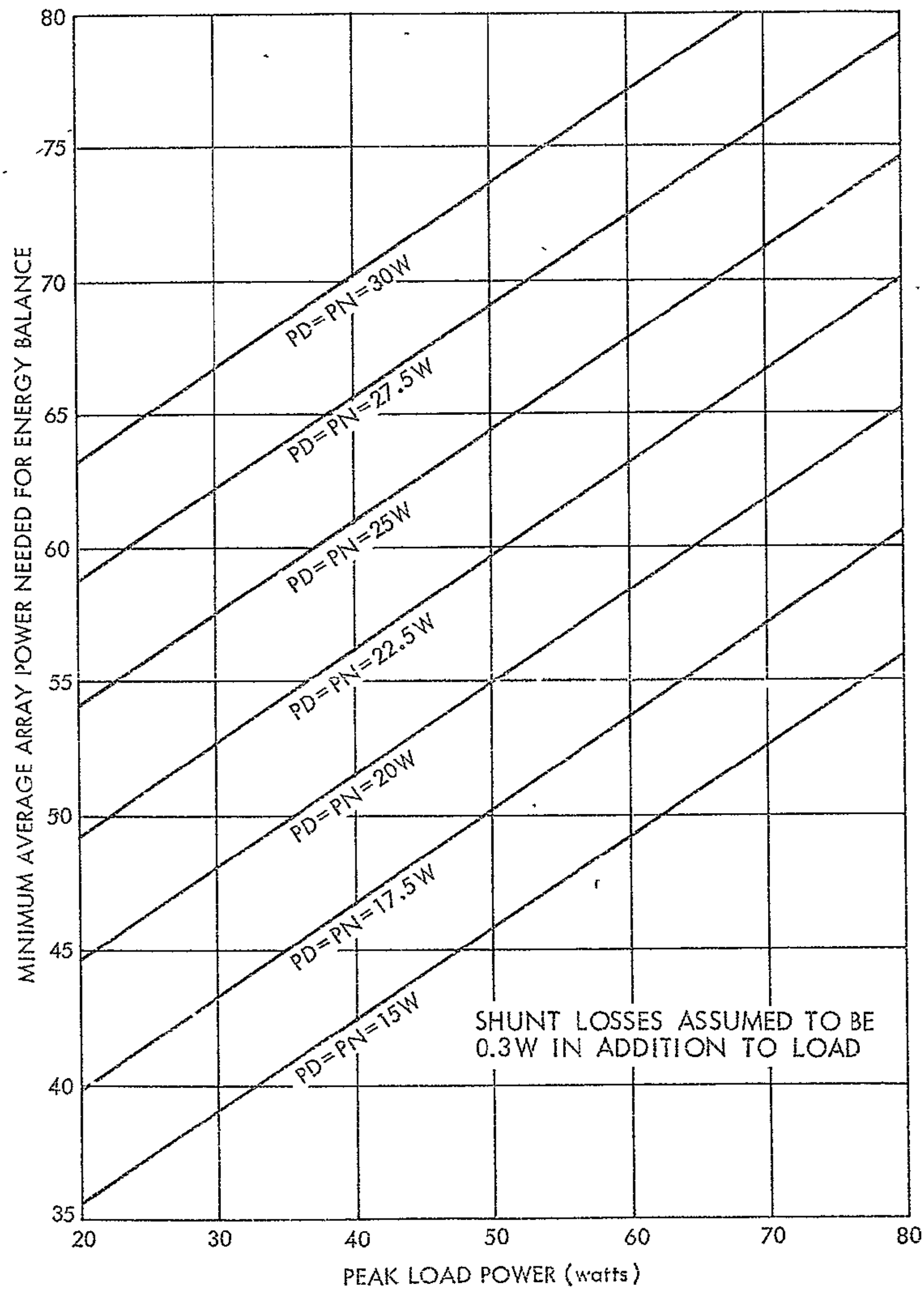


Figure 15. SATS Energy Balance — Noon Orbit

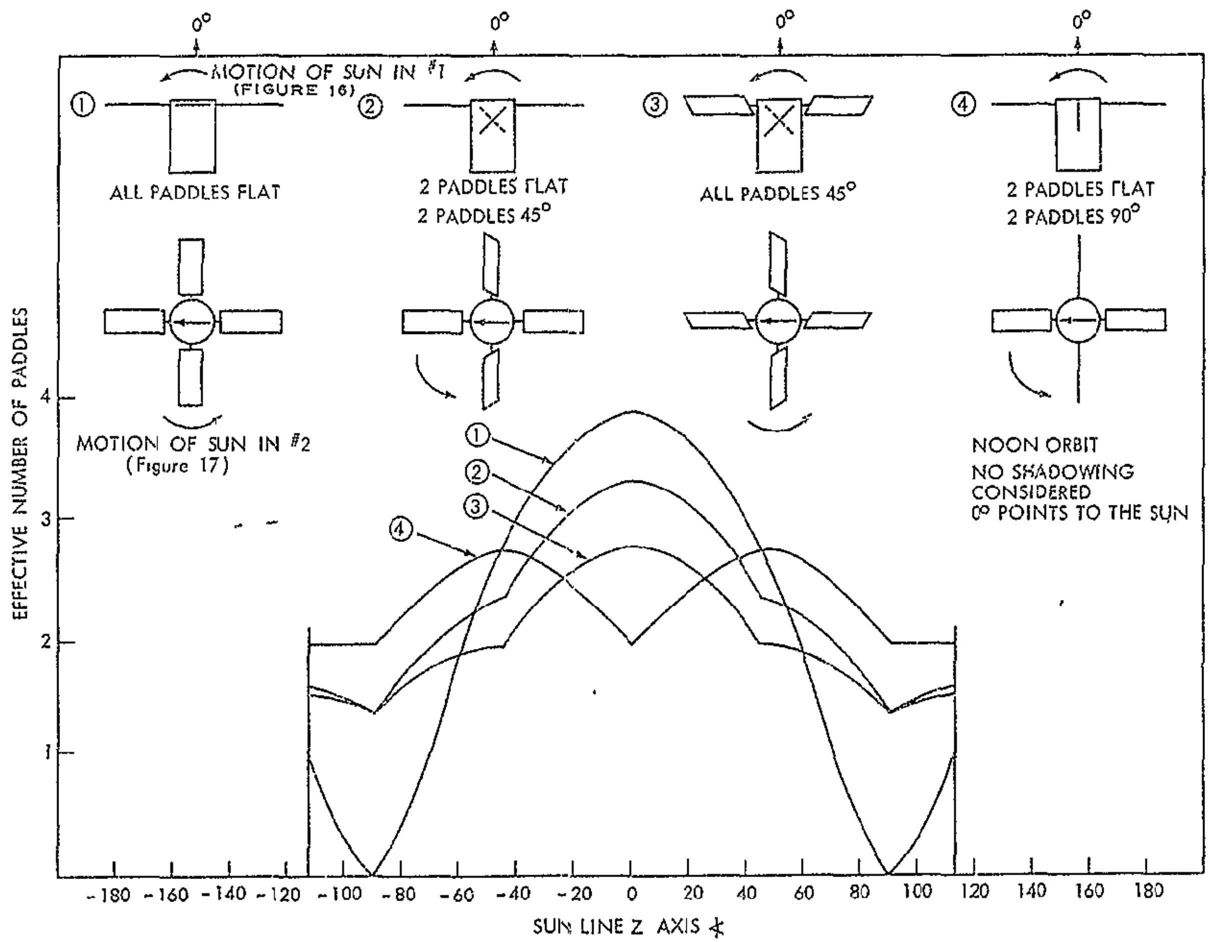


Figure 16. Solar Array Outputs #1 For Selected Configuration

It was also assumed that the long axis of the spacecraft body could be normal to the orbital plane. Figure 17 shows solar array outputs as a function of effective paddles.

In this configuration, the sun angle rotates about the body as shown in the lower views of Figure 16. Also included is a three paddle configuration for the same size paddle. The three paddle configuration has less variation output. If the paddle area were larger than used in this analysis, the three paddle design would be preferable. A point of interest here is that Figure 17 shows that there is no shadow effect from other paddles at polar orbits off of the earth-sun line, 30° or greater. If the paddles in these orbits can be oriented for optimum sun, then there is no need for cells on the back of the paddles and the weight can be reduced as well as almost doubling the available power.

The information upon which Figures 13 through 17 are based is continually being updated. Once final spacecraft designs are chosen upon, these figures will be revised to reflect the new data.

8. Attitude Control System. This system has been investigated in some depth because of its direct impact on the spacecraft configuration. It was necessary to determine the general type of ACS and alternative configurations that could be implemented readily.

The SATS concept includes three separate spacecraft configurations: 1) Scout launched; 2) Delta launched; and 3) Delta piggyback. In each concept, the objective of the ACS is to provide earth orientation with attitude error angles of 1° or less, and attitude error rates of .01°/sec or less, about each axis of a local vertical reference system. In addition, the ACS power, weight and volume requirements should be low.

The philosophy of the SATS program is that all systems should be configured around existing hardware with little or no modification. There should be no extensive hardware development program.

In the process of choosing a control system concept for SATS, three categories of attitude control systems were considered: fully active, three axis control, passive gravity gradient control: and momentum biased, semiactive control. The proposed control system concept falls into category three.

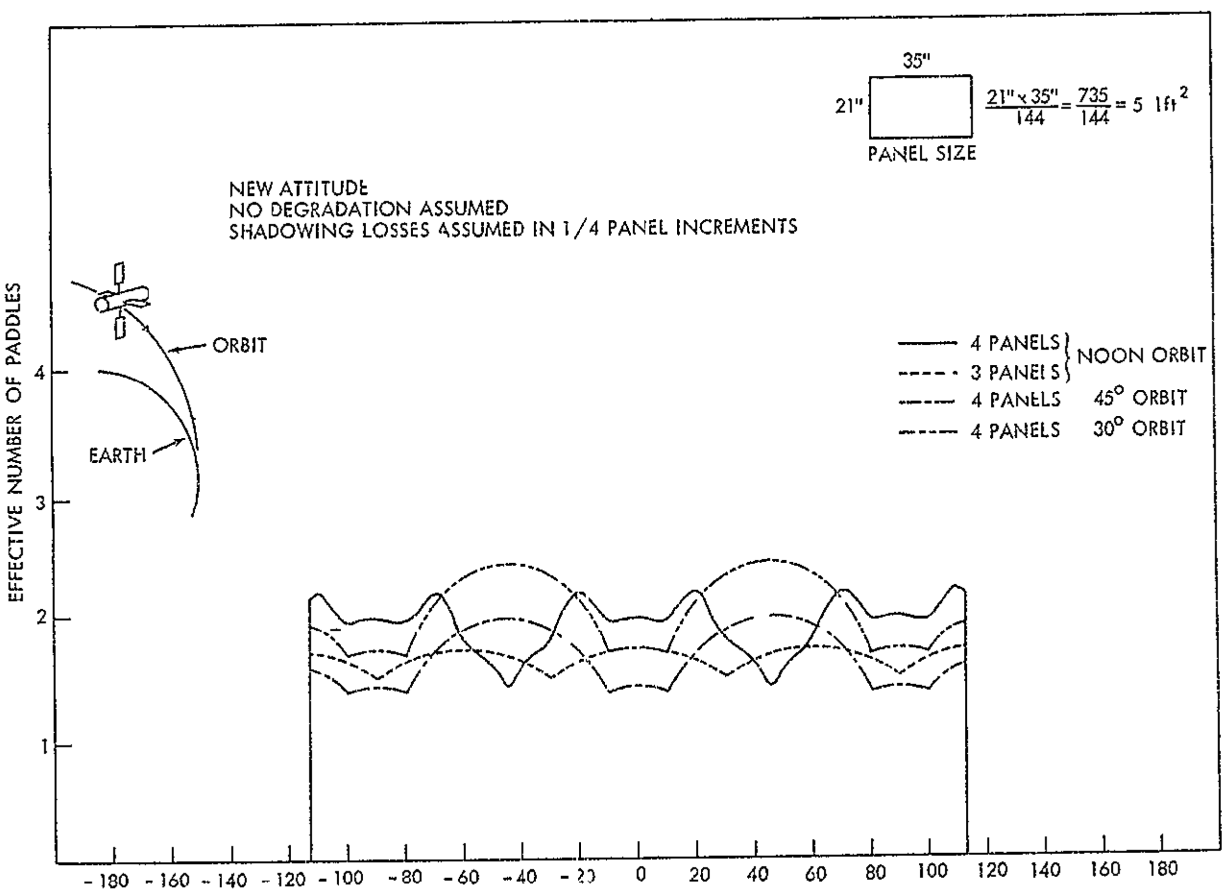


Figure 17. Solar Array Output #2 Including Shadowing

A fully active, three axis control system (i.e., active error sensing and active control torquing about all three axes) would introduce complexity, weight, and power problems not compatible with simple system concepts. It is highly unlikely that an existing three axis active system could be employed on the presently conceived SATS missions without either a major hardware redevelopment or major redefinition of project requirements. A separate control technique would be required for the synchronous SATS mission, due to the difficulty of sensing yaw altitude error signal.

While a good deal of work has been done in the area of three axis passive gravity gradient control (i.e., no error sensing and no active control torquing), this control concept has yet to be shown capable of achieving the pointing accuracies required for SATS. Significant problems still exist in understanding in-orbit boom dynamics; and the behavior of some gravity gradient control experiments is as yet unexplained. In addition, the ability of existing damping mechanisms to cope with spacecraft disturbances is questionable. Three axis gravity gradient control does not appear all capable of meeting SATS mission requirements.

While we could address each spacecraft concept separately, it will be seen that all of the proposed control system concepts are of the same basic type: a semi-active momentum bias system with single axis active control about the orbit normal to the local vertical. Alignment of system momentum to the orbit normal and momentum unloading is provided by some passive or open loop means (e.g., gravity gradient, mass expulsion, or magnetic torquing). With the possible exception of the gravity-gradient augmented system, initial acquisition will consist of an open loop orientation of the system momentum to the orbit normal with a closed loop single axis acquisition of the local vertical. This type of system should be capable of maintaining the desired attitude accuracy and stability by proper sizing of the momentum.

Two modes of hardware implementation are presently under consideration for configuration of this control system concept. Hardware for both modes is flight proven.

First to be considered is a single, large inertia, low speed momentum wheel and scanner system with a view field on one side of the spacecraft and an earth scan intercepting one side of the earth. Such a system has been successfully flown on TIROS-M and employs reflective optics for horizon scanning.

Second, by a pair of small, high speed (hermetically sealed) momentum wheels and scanners could be mounted internally, one on each side of the spacecraft. The earth sensors scans would each intercept a different side of the earth. The hardware for this system has been flown on both Nimbus-D and Delta-PAC, although not configured in this control concept. It employs refracting optics for horizon scanning at low altitudes.

It is desirable that on board, closed-loop control be employed to activate a magnetic torque generator. While the feasibility of such a closed-loop system requires further investigation, open loop, from the ground has already been flight demonstrated. The ground operation mode would always be available as an override. Finally, a dynamic system of the type under discussion is sensitive to gyroscopic nutation caused by a misalignment of the system momentum vector from the body rate vector. The system will incorporate a fluid damper to remove such nutational energy.

Achievement of the desired attitude accuracy will be a function of wheel momentum, disturbance torques, and attitude determination capability.

Orbit injection sequence and initial attitude acquisition for the low orbit, and 12 hour orbit will be performed as follows: the SATS spacecraft will be despun while on the last stage of the vehicle, so as to contain the nominal system momentum; separated from the vehicle's stage; the momentum wheel will then be activated, despinning the spacecraft body. Orientation of the system momentum may be determined by the scanner signal and spacecraft ephemeris information. The system momentum vector will be precessed to the orbit normal by use of the magnetic coil torquing system operated open loop from the ground. Once the wheel axis is aligned to the orbit normal, the active reaction wheel control loop will be closed to orient the body to the local vertical, thus completing earth acquisition. Open loop activation of the magnetic torquing system will depend on the nature and magnitude of disturbance torques. The injection sequence for the geosynchronous orbit is under study.

5.4.2 Configuration Concepts

The previous sections have developed the general design philosophy, characteristics and parameters. Figure 18 is a generalized representation of these concepts. The configuration includes five main elements:

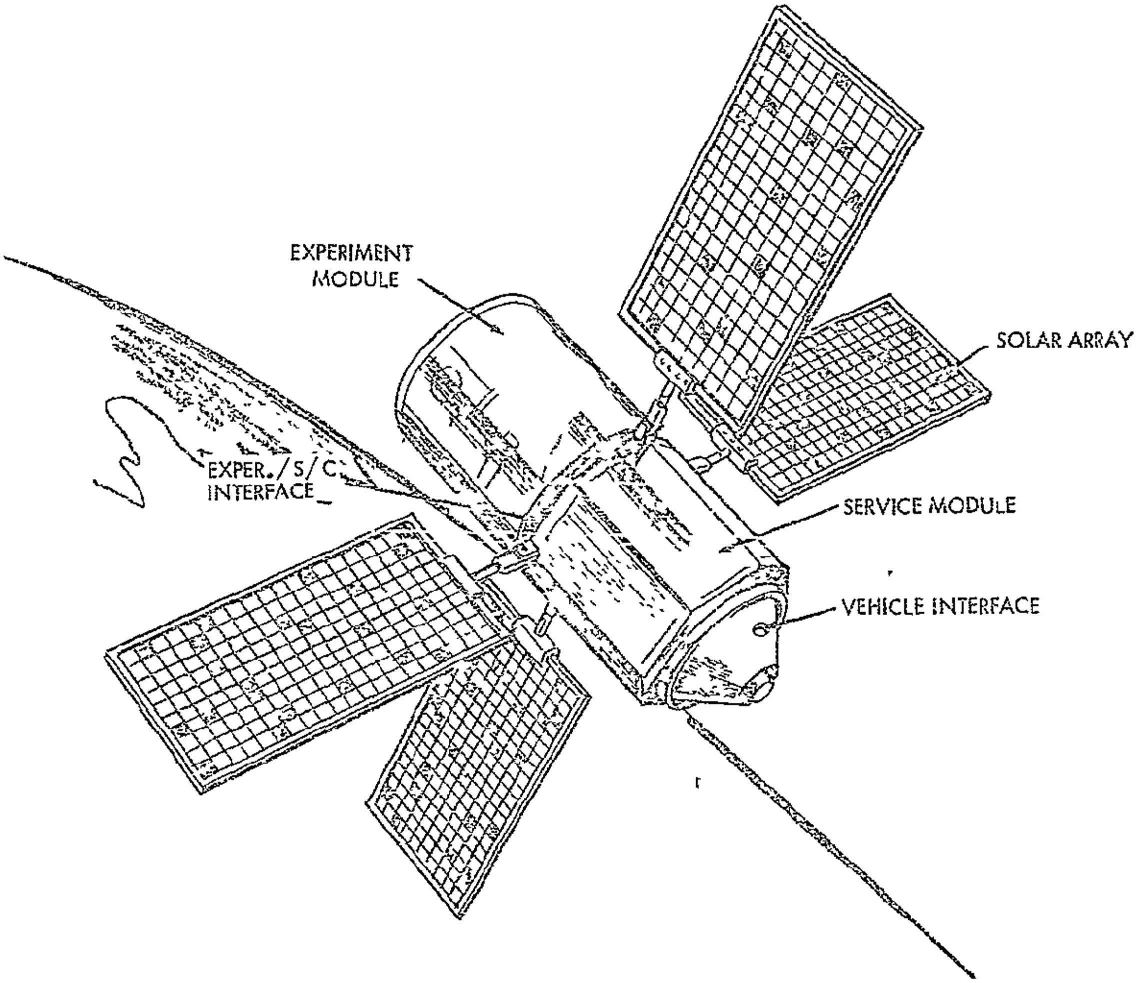


Figure 18. General Configuration

1. Service Module

2. Experiment Module

3. Solar Array

4. Experiment/Spacecraft Interface

5. Vehicle Interface

An auxiliary propulsion module could also be adapted at the vehicle interface. The height and diameter of the modules depend on the internal equipment requirements, the particular vehicle envelope and the folding designs for the paddles. The same design principle configuration can be used as the standard SATS spacecraft for both Scout and Delta vehicles.

Two preliminary configurations for each launch vehicle have been designed using different attitude control hardware, but having the same dynamic response principles. Each results in variations of the solar array, thermal design, look angles to earth and load paths during launch.

The first design developed for Scout, Figure 19, uses hardware derived from existing TIROS/TOS family designs, including a baseplate for package mounting and hexagonal or octagonal sides for the service module. A single motor momentum wheel with two roll earth scanners is mounted on the lower surface of the baseplate. Three holes through the wheel allow for spacecraft attachment to the launch vehicle using explosive bolts. The experiment module shown is a continuation of the service module sides and still fits within the Scout heat shield (Figure 20). The paddles are sized to provide 10 watts continuous spacecraft power, plus an additional 70 watts available for the experiment on a 15% duty cycle. The VHF antenna is shown on paddle tips and the S-band antenna on the service module side.

The spacecraft, after launch, is reoriented so the launch and rotating momentum wheel axis is normal to the orbital plane. The earth vector is normal to the momentum axis. The experiments would view the earth out the side of the experiment module. The control system will also include magnetic torquing. The momentum wheel speed can be varied to maintain a stable earth orientation or allow the body shell to rotate from a few degrees per minute to 10 rpm.

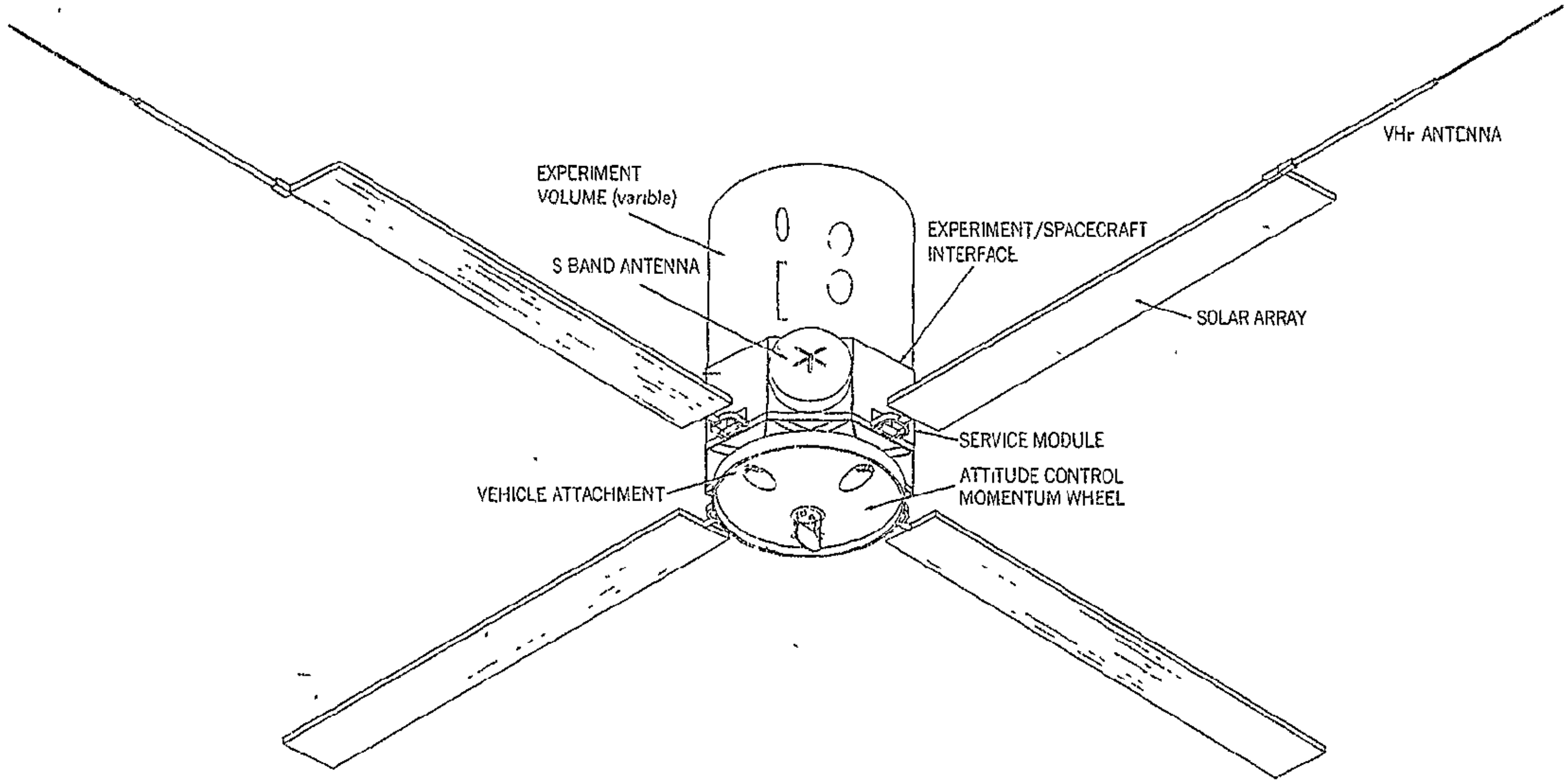


Figure 19. SATS/Scout Configuration #1

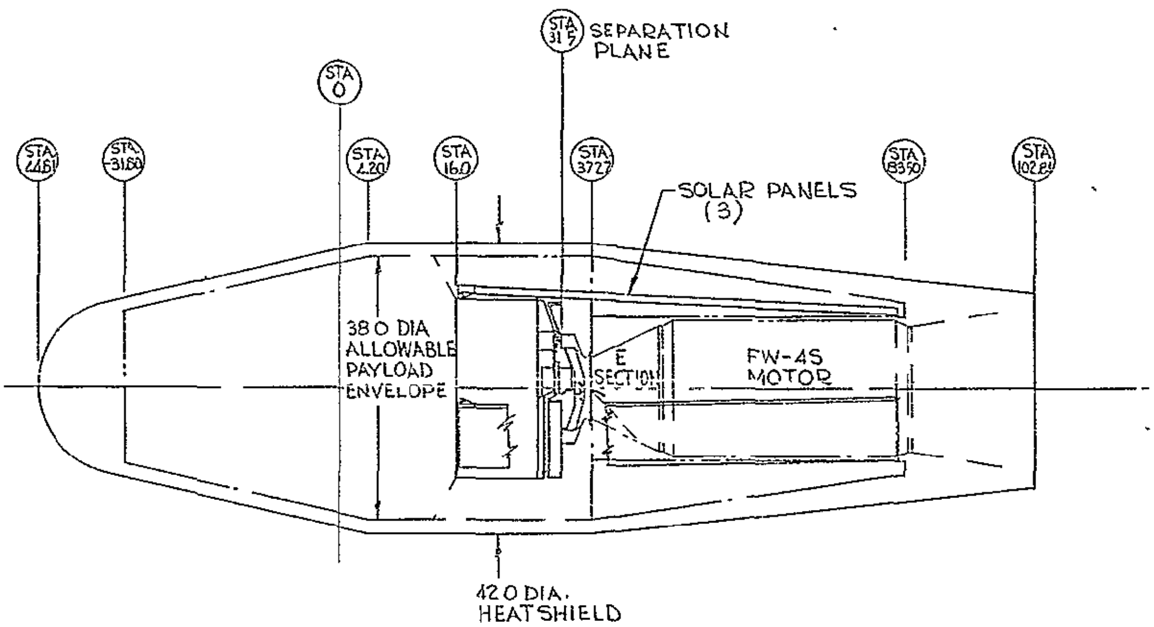


Figure 20. SATS/Scout Vehicle Envelope

The status of typical hardware that could be made available is listed in Table E. Most of this hardware is available with little or no change. A major item is the ACS, which can be used exactly as presently designed.

The first SATS/Delta configuration, taking advantage of the larger weight and volume allowances of the Delta vehicle, used 600 lbs. as a limiting weight. Figure 21 illustrates this design. Again the service module is the small section on the lower portion of the spacecraft. The baseplate (mounting platform) for the service module and selected subsystems were adapted from the TIROS-M design. The experiment volume is shown for completeness and would not necessarily be that configuration. The ACS and most other subsystems are the same as for SATS/Scout spacecraft #1. Variations would be necessary to accommodate geosynchronous requirements or a 12 hour elliptical orbit. Figure 22 shows the spacecraft within the Delta envelope and including an apogee kick motor module for geosynchronous orbit injection. This propulsion module would not be necessary for a 12 hour simulated synchronous orbit.

The second SATS/Scout configuration using the alternate ACS is shown in Figure 23. This spacecraft uses the general OV-3 design configuration (Figure 24) developed by Aerojet General, and incorporates two Bendix momentum wheel/earth scanner packages in the service module. These momentum wheels are part of the TRW-SAGS control system, the same as flown on Delta-PAC. They would not be gimbaled but would be rigidly mounted such that the momentum axis would be normal to the launch axis. After launch and reorientation of the momentum axis to the orbit normal, the top end of the experiment module would be earth oriented.

This configuration has the advantage of using a packaged control system without building special structural support as in the first configuration. The use of the Bendix wheels and integral scanners is questionable at geosynchronous altitude. Additional study will proceed in this area. It is desirable to use the same general control system hardware (momentum wheel and scanners) for both the Delta and Scout missions. It has been initially assumed however that for geosynchronous operations gas torquing rather than magnetic will be required.

The second Delta configuration has not been completed at this time. More information will be available in the final report.

TABLE E. HARDWARE SUMMARY

SUBSYSTEM	WEIGHT		AVAILABILITY
STRUCTURE	40.0		NEW
ATTITUDE CONTROL	36.8		
MOMENTUM WHEEL ASS'Y		29 6	NO CHANGE
PITCH CONTROL ELECT.		3.2	
DAMPER		4.0	
MAGNETIC COILS		1.3	
MAGNETIC BIAS SWITCH		1.4	
POWER	57.0		
SOLAR PADDLES		12.0	NO CHANGE
P.S. ELECTRONICS		11.0	MINOR PKG MODIFICATION
BATTERIES		30.0	
DC/DC CONVERTER		4.0	
COMMUNICATIONS & DATA	29.3		
VHF ANTENNAS		2.1	LITTLE OR NO CHANGE
DIPLEXER		0.5	
COMMAND RECEIVER		2.3	
BEACON		2.6	
S-BAND ANTENNA		0.9	
S-BAND TRANSMITTER		3.5	
COMMAND LOGIC		10.1	
PCM TELEMETRY		5.0	
TAPE RECORDER		5.0	TO BE DETERMINED
SPACECRAFT TOTAL	163.1		
EXPERIMENT	75.0		
TOTAL	238 1 lbs		

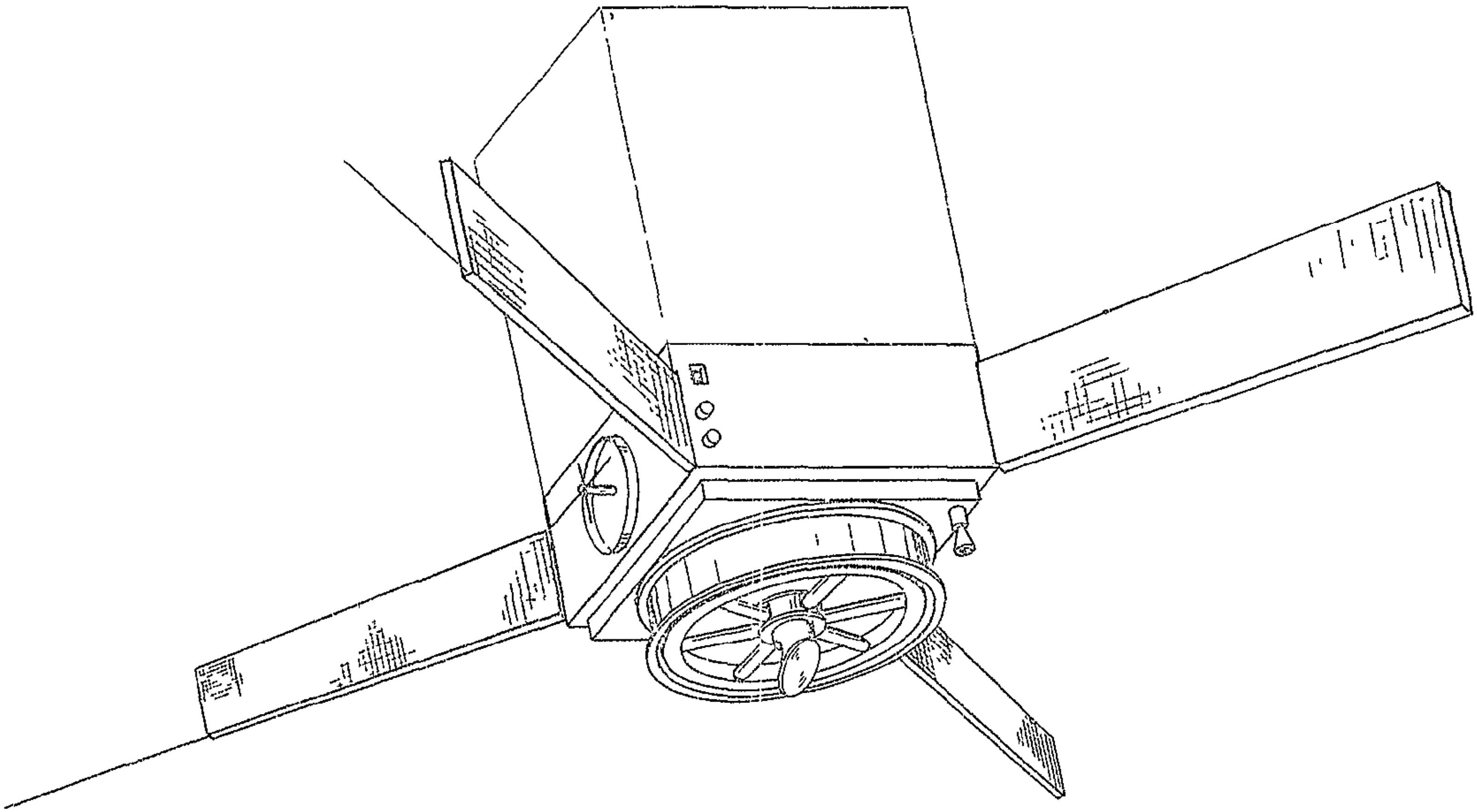


Figure 21. SATS/Delta Configuration #1

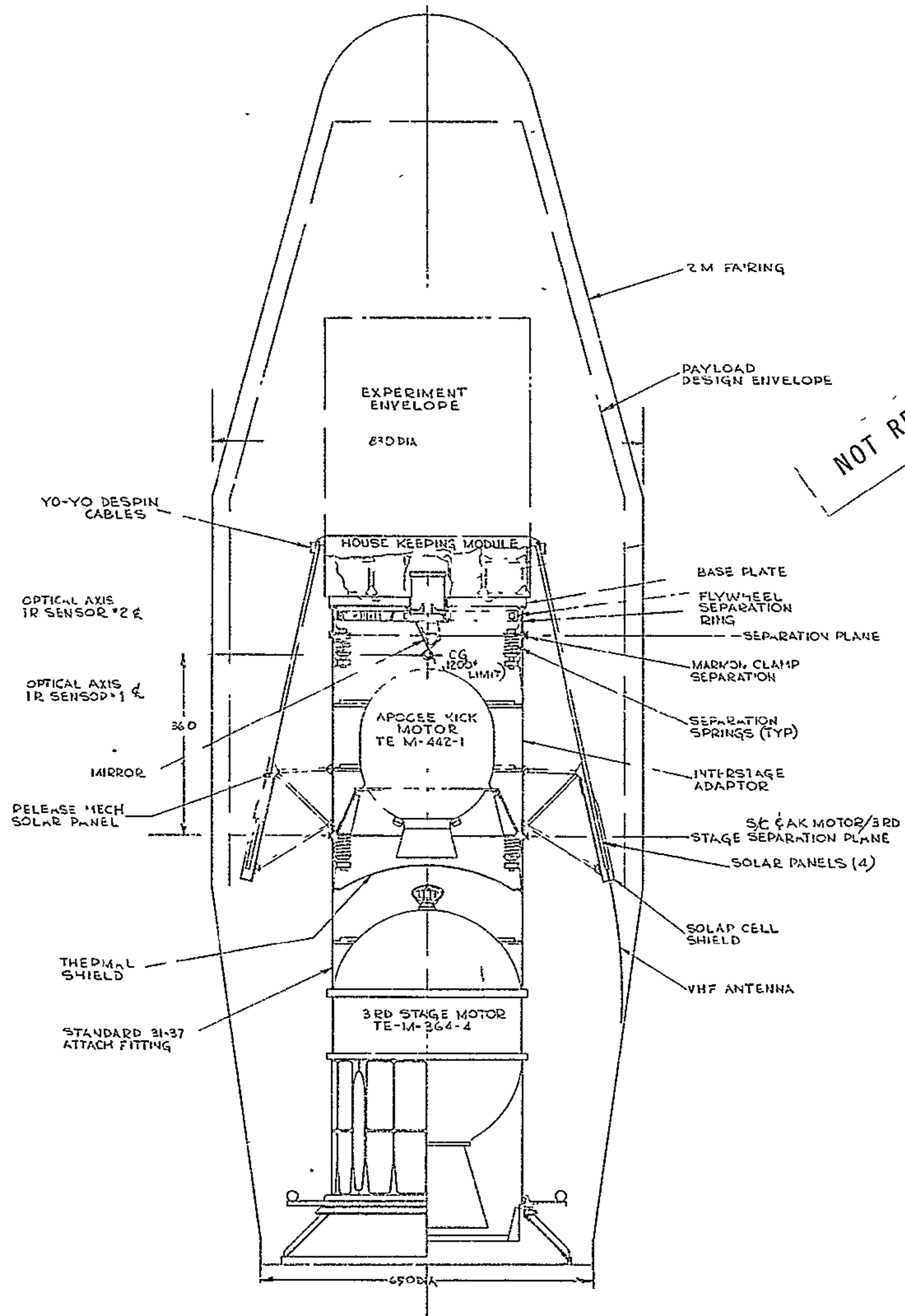


Figure 22. SATS/Delta Vehicle Envelope

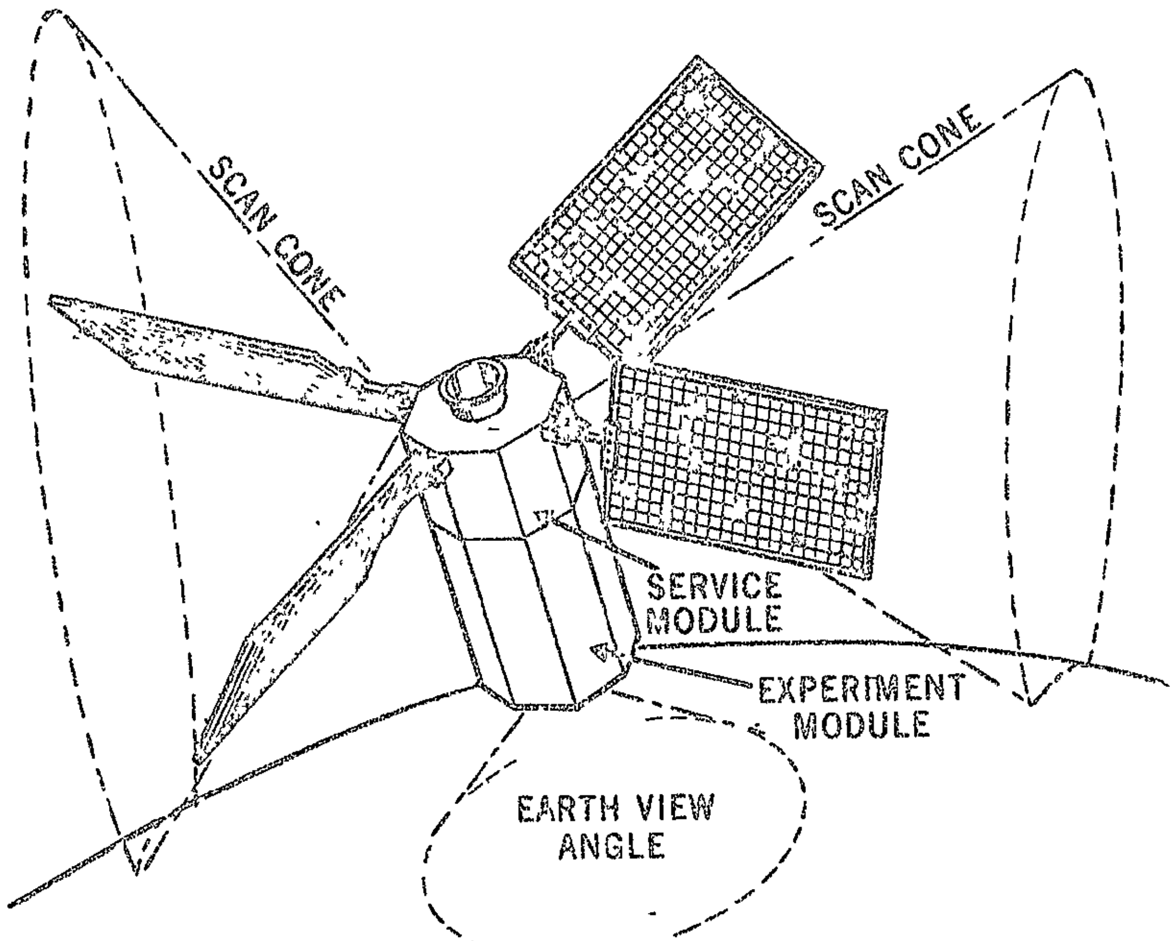
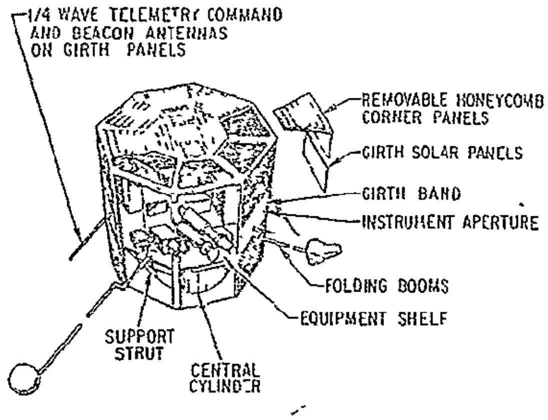
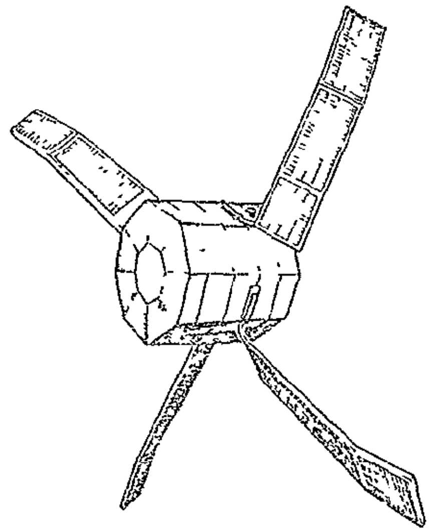
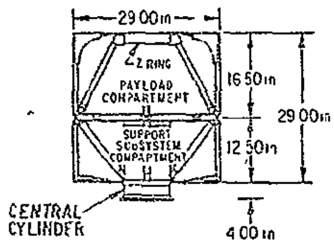


Figure 23. SATS/Scout Configuration #2

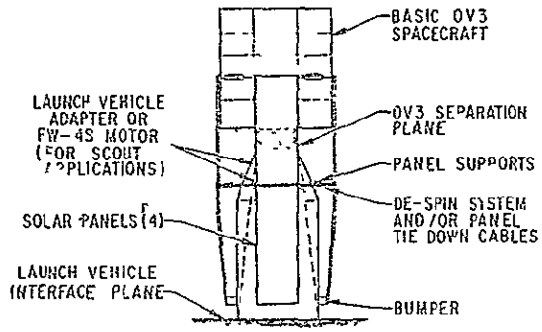




(c) ON-ORBIT DEPLOYED CONFIGURATION



OV3 Spacecraft Basic Configuration



(b) LAUNCH VEHICLE STOWED CONFIGURATION

OV3 Spacecraft Supplementary Solar Paddles

Figure 24. OV-3 Configuration

It was previously mentioned that the experiment module would have a primary interface with the top of the service module. One possible experiment module internal design (a secondary interface) is shown in Figure 25. If the experiment were composed of many packages, the vertical platform could be used in any of the spacecraft configurations. This secondary interface or platform would provide greater mounting surface and a thermal plate area to distribute heat within the module and between modules. If any experiment could not use this platform, then integrating to the primary interface would always be available. The external cover around the experiment module could be either a specific envelope supplied by the spacecraft or tailored by or for the experimenter.

The Delta piggyback spacecraft could be similar to Figure 26. A study performed by McDonnell Douglas Corporation, January 1970, titled Payload Experiment Package (PEP) discusses most of the Delta piggyback configurations that could be considered. One PEP mission not presented was the combination of a SATS/Delta spacecraft in a geosynchronous or 12 hour orbit with a piggyback in low orbit on the second stage. This launch assembly could be used for complementary mother-daughter missions. Another possible mission would be to launch two SATS/Delta and a piggyback all in low orbit phased some distance apart.

The P-11 piggyback for the Agena spacecraft is shown in Figure 27. The configuration for a separable spacecraft would require the use of the Bendix momentum wheels and scanners and additional solar array. This spacecraft, as previously mentioned, was designed to fly on the Agena vehicle and should be considered only in connection with the Agena. Because NASA has no planned Agena launches, the upgrading and use of the P-11 for SATS is questionable.

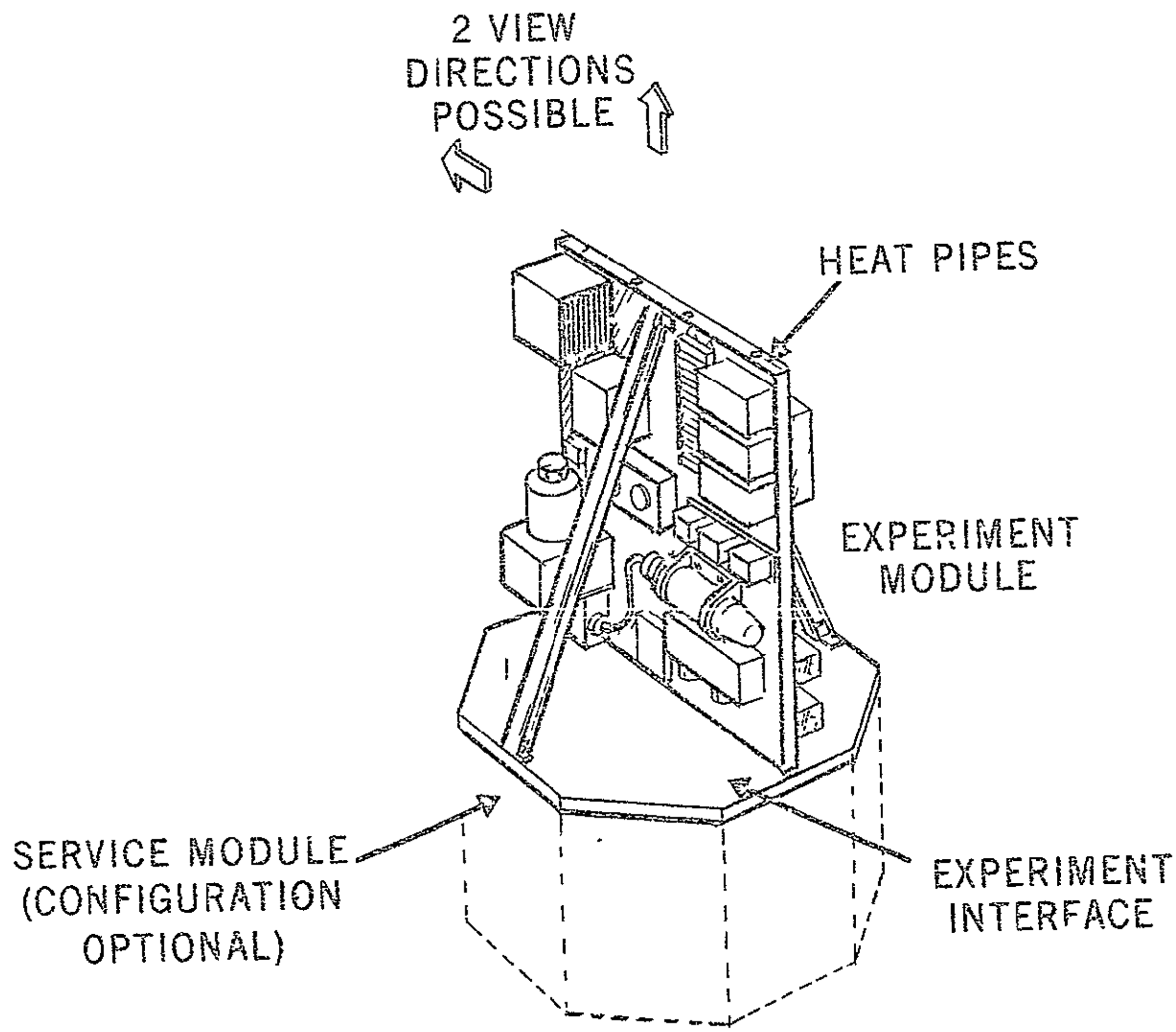


Figure 25. Preliminary Experiment Module Packaging Concept

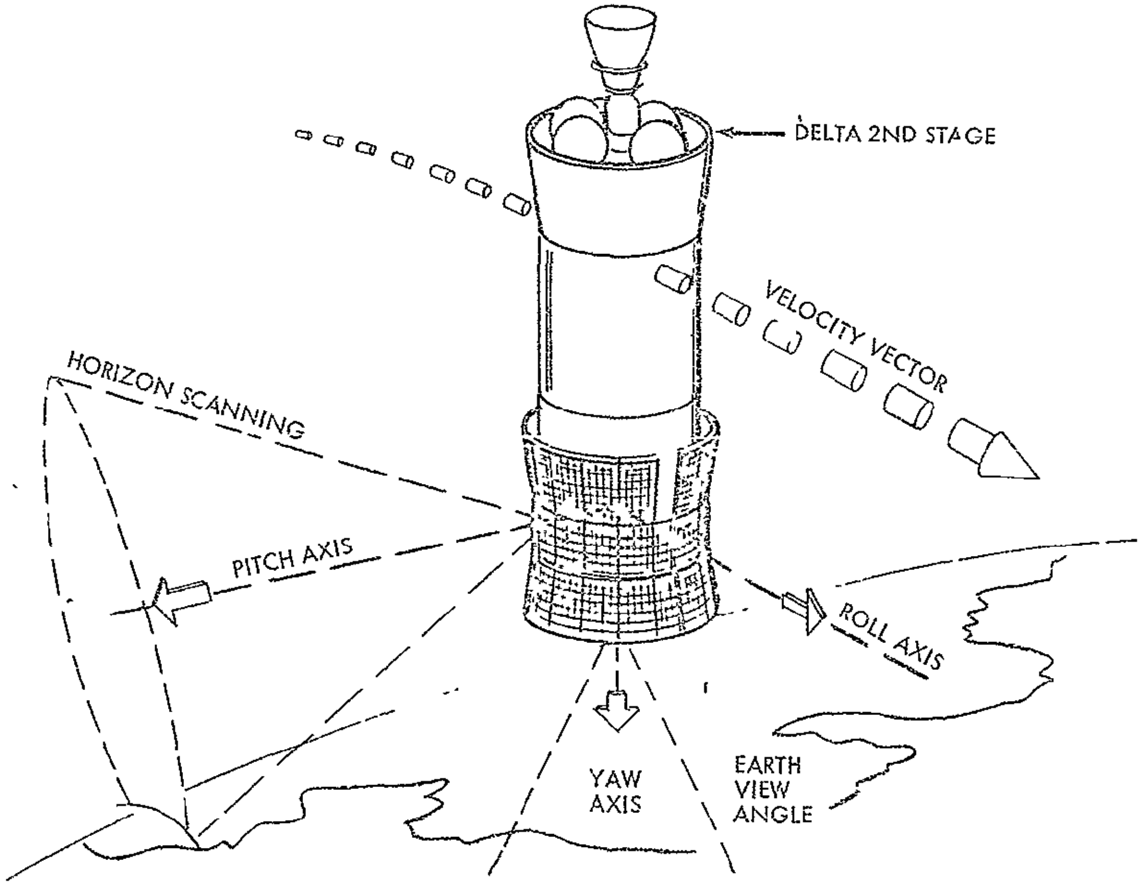


Figure 26. SATS-DELTA Piggyback Configuration

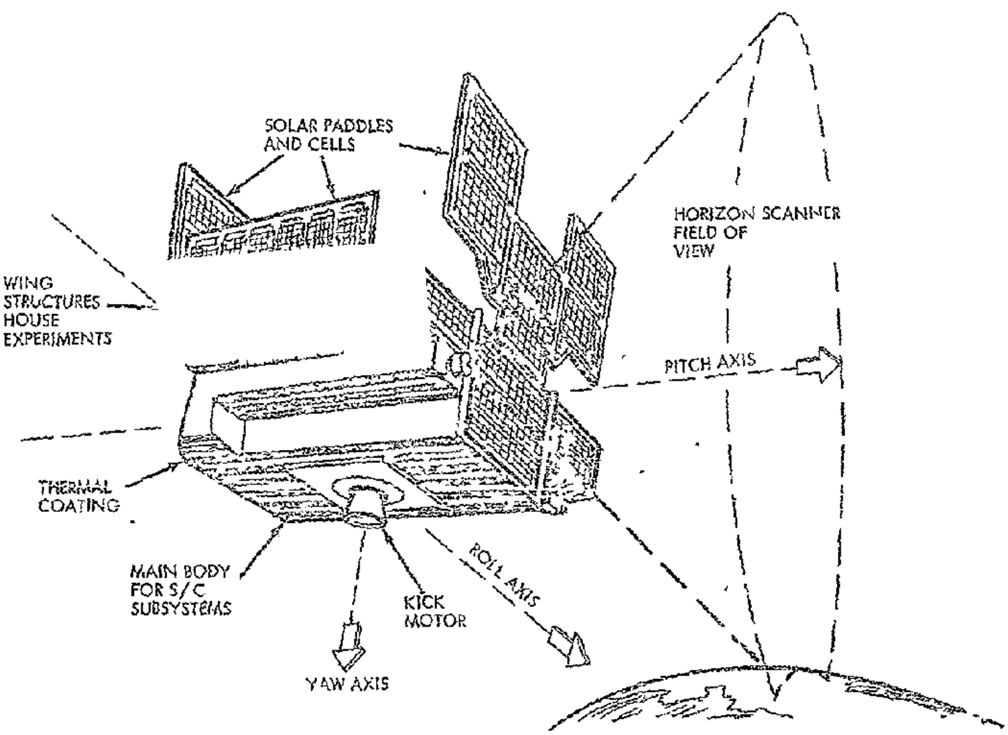


Figure 27. SATS/P-11 Application

5.5 Reliability, Quality Assurance, and Testing

The objectives of the SATS reliability, QA and testing program are to:

1. Prepare SATS to achieve a successful 90 day mission
2. Acquire high confidence that a particular spacecraft is, in fact, ready for flight
3. Consider minimum cost without sacrifice in reliability
4. Plan reliability, quality assurance and environmental testing interfaces to result in a short time (3 months) for integration and tests — quick reaction capability

These objectives are obviously interrelated. To achieve them, our basic approach includes an adequate program for the prototype spacecraft system with tight control of the configuration after prototype qualification. We are planning a lean but effective reliability and quality assurance program carefully tailored under the basic guidelines of the NASA reliability and quality assurance series of publications. Other specifications and standards pertaining to semiconductors, other electronic parts, mechanical parts, soldering, workmanship traceability, etc., will also be utilized. Proven and available high reliability parts, such as those listed in the GSFC Preferred Parts List (PPL) will be considered to assure that the design is inherently reliable.

The reliability and quality assurance programs for SATS will be closely monitored to assure compliance with established reliability and quality assurance requirements. Available DOD quality assurance personnel will be utilized to support NASA/GSFC with in-plant monitoring, inspection and witnessing of tests in accordance with existing NASA/DOD agreements.

The environmental test program is designed to further enhance the achievement of the above objectives. The design qualification phase will be sufficiently comprehensive to assure that the system design is indeed suitable to satisfactorily operate in the launch and space environments for a period of up to 180 days.

All mandatory environmental tests, and other tests as required for "design qualification" of SATS will be accomplished in accordance with the GSFC test specification S-320-G1, "General Test Specification for Spacecraft and Components." This phase of testing will be applicable to the first SATS made, which will be called a protoflight unit. For reasons of economy, we will fly the prototype spacecraft. This has been done before on other programs with excellent success, and is now common practice at GSFC.

Complete environmental testing of the protoflight unit in compliance with S-320-G-1 would require a large amount of testing time. This time can be considerably reduced, by introducing an engineering spacecraft model (w/dummy packages) and using this model to prove out (1) the structural integrity, (2) the thermal system design, and (3) the development of a comprehensive experiment/service module interface specification.

Following the successful flight of the protoflight SATS, subsequent spacecraft would be subjected to minimum necessary testing. In compliance with S-320-G-1, waivers from some mandatory testing would be sought, in order to tailor the environmental testing program to the needs of the project objectives (i.e., quick reaction time and economy of operation).

5.6 Estimated Spacecraft Costs

A preliminary estimate was made of the spacecraft costs. These are averages of rough estimates obtained from GSFC and outside sources. Costs are for the spacecraft only and do not include costs of the experiments, vehicles, ground operations. The two figures indicated are the costs of the initial spacecraft and that of each subsequent unit.

SATS/SCOUT	SATS/DELTA	DELTA/PIGGYBACK
\$2.6M - 2.0M	\$4.0M - 2.9M	\$2.7M - 2.0M

5.7 Payload Delivery System Cost Comparison

In order to put the SATS cost data into a perspective that would permit comparison with other applications spacecraft Table F was developed. Table F shows the experiment orbital delivery cost per pound. This was calculated by adding the spacecraft costs only and launch vehicle costs and dividing the total by the experiment weight. The actual cost and experiment weight data were used for ATS-1 through -5, NIMBUS-4, and TIROS-M; data for the other spacecraft are taken from POP-70-1, March 1970. The SATS experiment weight used for these calculations were 75 lbs., 150 lbs. and 75 lbs. for SATS/Scout, SATS/Delta, and Delta/Piggyback, respectively. The spacecraft costs were taken from Section 5.6.

TABLE F. DELIVERY SYSTEM COST COMPARISON
$/pound

Nimbus 4	$169K
Nimbus E&F	97K ea
ATS 1-5	151K ea
ATS F&G	147K ea
Tiros-M	133K
ERT A&B	80K ea
SATS/Scout	56K ea
SATS/Delta	60K ea
Delta/Piggyback	36K ea

The piggyback spacecraft is not charged with any vehicle costs. Also, there is no ground operations or experiment costs included for any of the spacecraft mentioned above.

It should be remembered that the SATS objectives do not include long life, world mapping or 100% duty cycles. Therefore, while SATS would appear to be economical for testing applications experiments and technology, it operates in a different regime for different purposes and thus may not be directly comparable with other spacecraft programs.

6.0 MANAGEMENT AND SCHEDULING

6.1 Management Approach

The approach to management of the SATS program activities includes the period prior to a FY 1972 new start, as well as the formal project direction following program initiation.

Until the new start, the existing study team will continue to review program, user, and hardware requirements for SATS. This will involve the use of civil service and contractor personnel. Small study contracts may be let to permit several outside teams, in addition to the Goddard team, to review the applicability of existing spacecraft systems and subsystems to the synthesis of SATS standard design concepts. Following review and selection of designs by Goddard, system and subsystem specifications would be prepared for use of in-house designers, assuming the first spacecraft were done in-house, or for use in a statement of work for the first spacecraft to be contracted. In either event, it is planned that follow-on spacecraft, after the first of each type, would be produced out-of-house. The preparation of adequate system and subsystem descriptive specifications during FY 1971 is a necessity if a FY 1972 new start is to result in a first flight within 18 to 24 months thereafter.

6.2 An Illustrative Pilot Program

A pilot program will be described in the final report. It will be discussed here only in outline, since its composition and options are still under active consideration. The preparation and planning of a pilot program for SATS operation permits the development and tradeoff of critical program parameters such as capability, schedule, and resources.

The pilot program will permit SATS to build up to a desired capability over a period of approximately two years. It will also confirm basic program parameters and allow their modification or adjustment as a result of what is learned during this period.

The three basic spacecraft design configurations described in Section 5.4 are all part of the pilot program. This will contribute to a balanced mix of spacecraft and missions adequate to prepare for probable future SATS operations.

The pilot program now under consideration envisions an FY 1972 new start and a phased-in follow-on program that could be initiated in FY 1973 or 1974. The following launch schedule, Table F, gives the number of launches by spacecraft type per calendar year. Shown in parentheses are launches associated with a follow-on program that can continue at any desired rate. The nature of this program lends itself to considerable flexibility in numbers of launches per year, without causing correspondingly severe impact on project management.

TABLE G. SPACECRAFT LAUNCHES

CALENDAR YEAR	1973	1974	1975	1976
SATS/SCOUT	2	2	(3)	(3)
SATS/DELTA	1	1	(2)	(2)
DELTA/PIGGYBACK	1	1	(1)	(1)
TOTAL SPACECRAFT	4	4	(6)	(6)

6.3 Resources

6.3.1 Manpower

The proposed FY 71 study effort will require approximately 10-12 man-years. A FY 1972 new start will, of course, require an increase in manpower that will depend on whether a first spacecraft design is done in or out-of-house. An in-house design effort is estimated to build up to about 100 man-years per year within two years of start-up. Civil service manpower requirements for an out-of-house program are estimated at 30 to 40 man-years per year following start-up. This level of manpower, is also representative of what will be required to run the program during its routine operational phase.

6.3.2 Funding

Total funds required for a FY 1972 new start flight program would depend on the mix of Scout, Delta and Piggyback spacecraft to be launched in a given period. If the pilot program described previously, consisting of 4 Scouts, 2 Deltas, and 2 Piggybacks launched over CY 1973 and 1974, is assumed, then the total cost for the spacecraft, project management, and ground operations would be on the order of $25M. The major cost is spread over FY 1972, 73 and 74 with some operations costs in FY 1975. The follow-on program yearly cost would be proportional to the number of launches per year and the time lag between the pilot program and the follow-on program.

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 Preliminary Conclusions

It is concluded that the SATS concept of a quick reaction program involving several types of standardized spacecraft for testing applications subsystems, components, parameters and principles may be feasible.

It is concluded that implementation of the SATS program may have significant impact on the stated objective of increasing the rate of progress of NASA applications programs.

It is concluded that a modest SATS program may be achieved at a cost that compares favorably with Explorer class programs.

It is concluded that no significant amount of new systems development is required to synthesize SATS spacecraft designs from existing, off-the-shelf, flight proven hardware.

7.2 Recommendation

It is recommended that continuing study/SRT effort be expended during FY 1971 to support a prospective FY 1972 new start.

8.0 POTENTIAL PROBLEM AREAS

In an analysis of a new procedure or concept, such as SATS, close attention must be given to both administrative and technical problems resulting from novel program requirements. The most significant areas requiring additional attention result from SATS' promise of QUICK REACTION. There are other areas of lesser significance, which will receive continued surveillance, but which are not seen as crucial.

8.1 Experiment Selection

A premise of the SATS program concept is that it can integrate and fly experiments within 3 to 6 months of the time such equipment is delivered to the spacecraft integrator. This premise can be completely negated if existing flight program experiment selection procedures are required. These procedures typically allow for competitive selection with design and development through several flight and spare models. Cognizance is also taken of a two to four year spacecraft development cycle. SATS, alternatively, would fly experimental or prototype hardware, based principally on (1) need to fly and (2) availability of hardware for integration. This type of test and development service may require a variation of existing selection methods or new ones. Several appropriate questions to ask now are:

(1) Should there be Announcements of Flight Opportunities (AFO)?

(2) If yes, should they be open AFO's, or periodic AFO's?

(3) If no, how should experiments be solicited?

(4) Should selection be by subcommittee, ad hoc committee, or appropriate HQ program or discipline office?

Since SATS may be viewed as a continuing level of effort program, experiments might be selected semi-annually approximately one year before beginning of spacecraft-experiment integration. Some experiments can be available for integration in less than a one-year period.

This situation points up the fact that the SATS project office will have to maintain close experimenter liaison for two or three spacecraft simultaneously, each on a different schedule.

8.2 Program Flights Approval

As in the above discussion, quick reaction may imply new or modified procedures for obtaining program approval of a number of flights sufficiently far in advance so as not to inhibit the quick turn around necessary between flights. For this purpose the study has been reviewing Program Approval Documents (PAD's) of OSSA programs with the assistance of the cognizant Program Manager. In particular, it has been noted that parts of both the Sounding Rockets PAD, 85-850-879, and the Explorers PAD, 85-850-850, have certain objectives, interfaces, and operational and management considerations which are analogous to the SATS program. Based on these precedents it should be possible to develop a SATS PAD which provides annual approval of several planned flights and incorporates the management flexibility to direct the necessary quick reaction.

8.3 The Non-Standard Spacecraft

It is expected that there will be some small percentage of experiment or mission requirements that cannot be accommodated by the three standard spacecraft designs. In such cases, a unique spacecraft must be designed and developed. The question posed by this situation is: How best to manage and phase such an element within the context of developing and operating a SATS capability? It is planned to fully address this question during the FY 1971 study continuation. Examples of possible unique spacecraft designs include: drag free, gravity gradient research, and remote maneuvering technology.

REFERENCES

A detailed list of the referenced documents will be included in the final report.

APPENDIX A

EXAMPLES OF ILLUSTRATIVE EXPERIMENTS

The following tables and figures are included as a small sample of illustrative SATS-type experiments. They are presented to more fully explain the objectives and characteristics of these experiments and their relationship to the SATS spacecraft.

TABLE A-1. RFI AND MULTIPATH SURVEILLANCE

OBJECTIVES:	1. COLLECT DATA ON RFI SOURCES IN THE VHF RANGE. 2. INVESTIGATE MULTIPATH PROBLEMS. 3. INVESTIGATE THE USE OF INTERFERENCE AND MULTIPATH REJECTION TECHNIQUES.
CHARACTERISTICS:	1. SWEPT-FREQUENCY, VARIABLE GAIN RECEIVER. 2. S-BAND DATA TRANSMISSION TO GROUND. 3. USE OF ANOTHER SATELLITE (e.g., ATS) AS RF SOURCE OR RECEIVER.
USERS:	TRACKING AND DATA RELAY SATELLITES — COMMUNICATIONS.
LAUNCH VEHICLE:	SCOUT
ORBIT:	300 NM
EXPERIMENT WEIGHT:	10 POUNDS
EXPERIMENT POWER:	5 WATTS

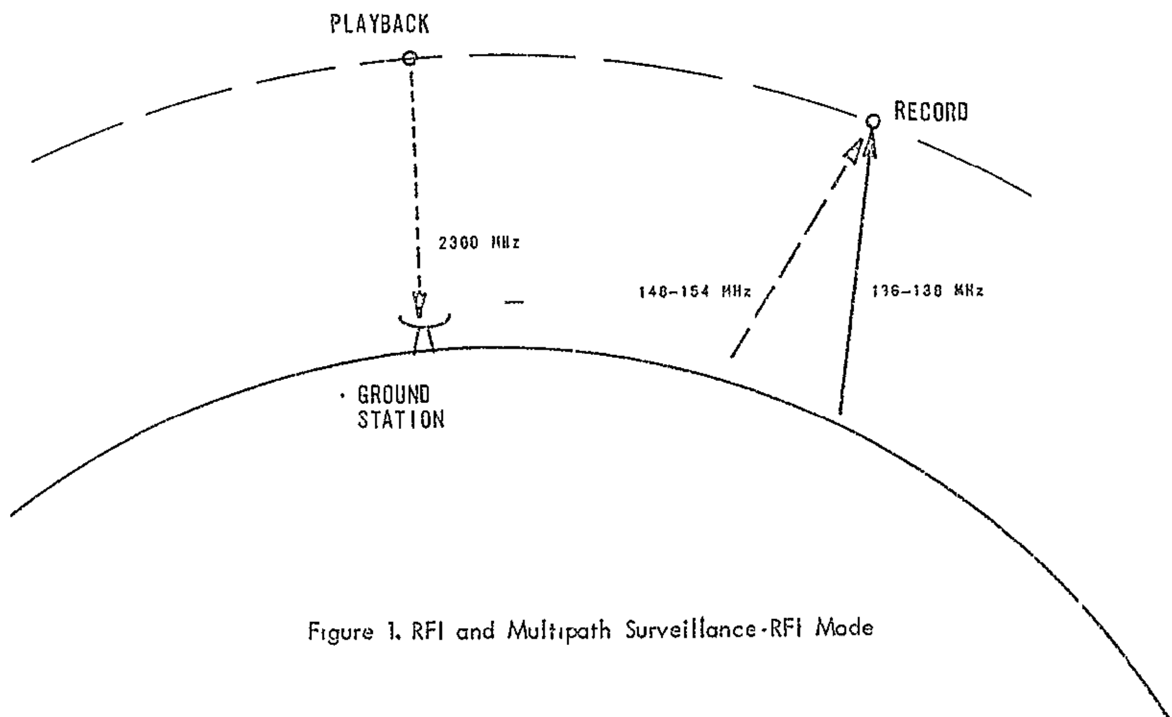


Figure 1. RFI and Multipath Surveillance-RFI Mode

Figure A-1. RFI and Multipath Surveillance RFI Mode

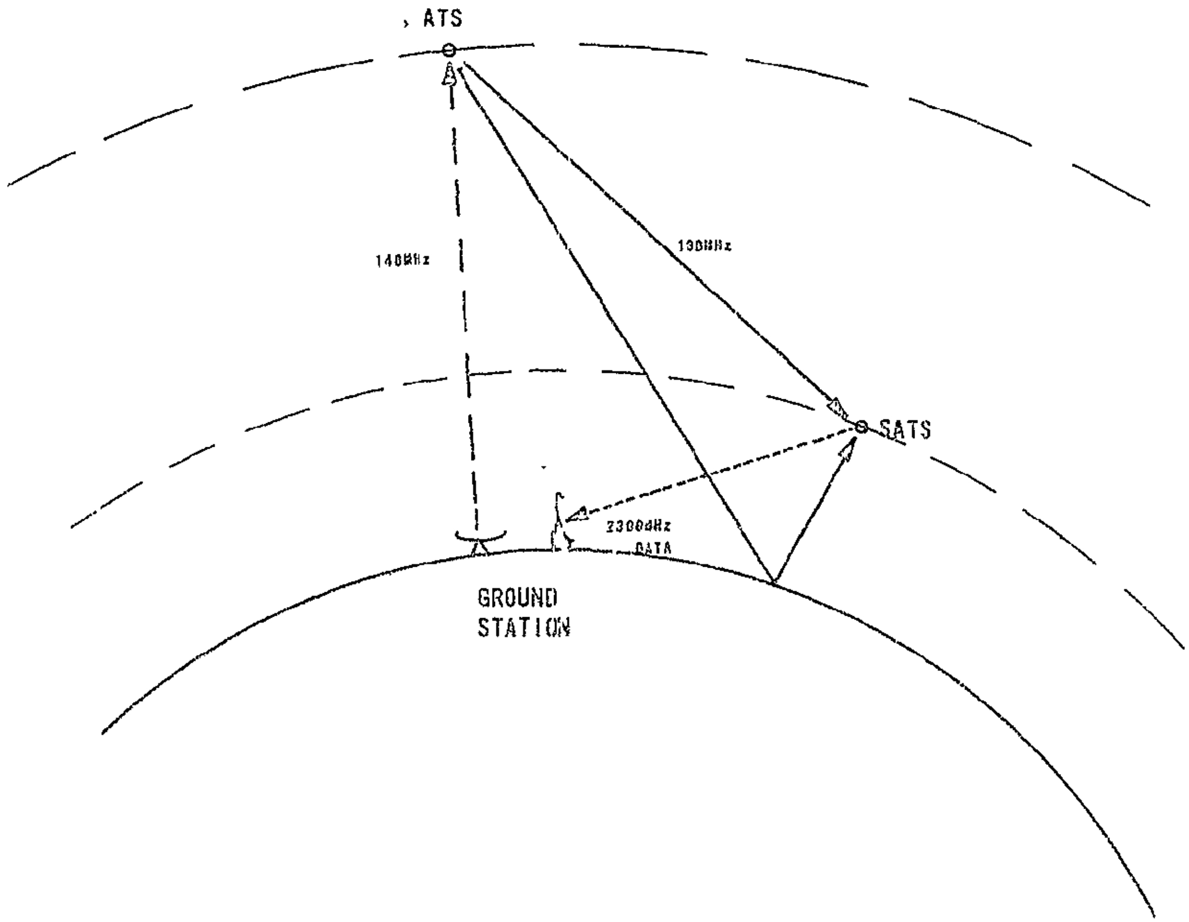


Figure A-2. RFI and Multipath Surveillance Multipath Mode

TABLE A-2. L-BAND AIRCRAFT COMMUNICATIONS

OBJECTIVES:	1. DEMONSTRATE ACCURACY OF AN ACTIVE RANGING SYSTEM USING SATELLITES IN PROVIDING AIRCRAFT POSITION. 2. DETERMINE GRADE OF SERVICE FOR VOICE AND DIGITAL LINKS BETWEEN GROUND AND AIRCRAFT VIA SATELLITE. 3. COLLECT DATA ON MULTIPATH EFFECTS AT L-BAND.
CHARACTERISTICS:	1. SYNCHRONOUS ORBIT 2. L-BAND TRANSPONDER WITH DIRECTIONAL ANTENNA (15 DB GAIN)
USERS:	NAVIGATION AND TRAFFIC CONTROL
LAUNCH VEHICLE:	DELTA
ORBIT:	SYNCHRONOUS
EXPERIMENT WEIGHT:	40 POUNDS
EXPERIMENT POWER:	80 WATTS
OPERATIONS:	USE OF AIRCRAFT IN COORDINATION WITH GROUND STATION AND SATELLITE.

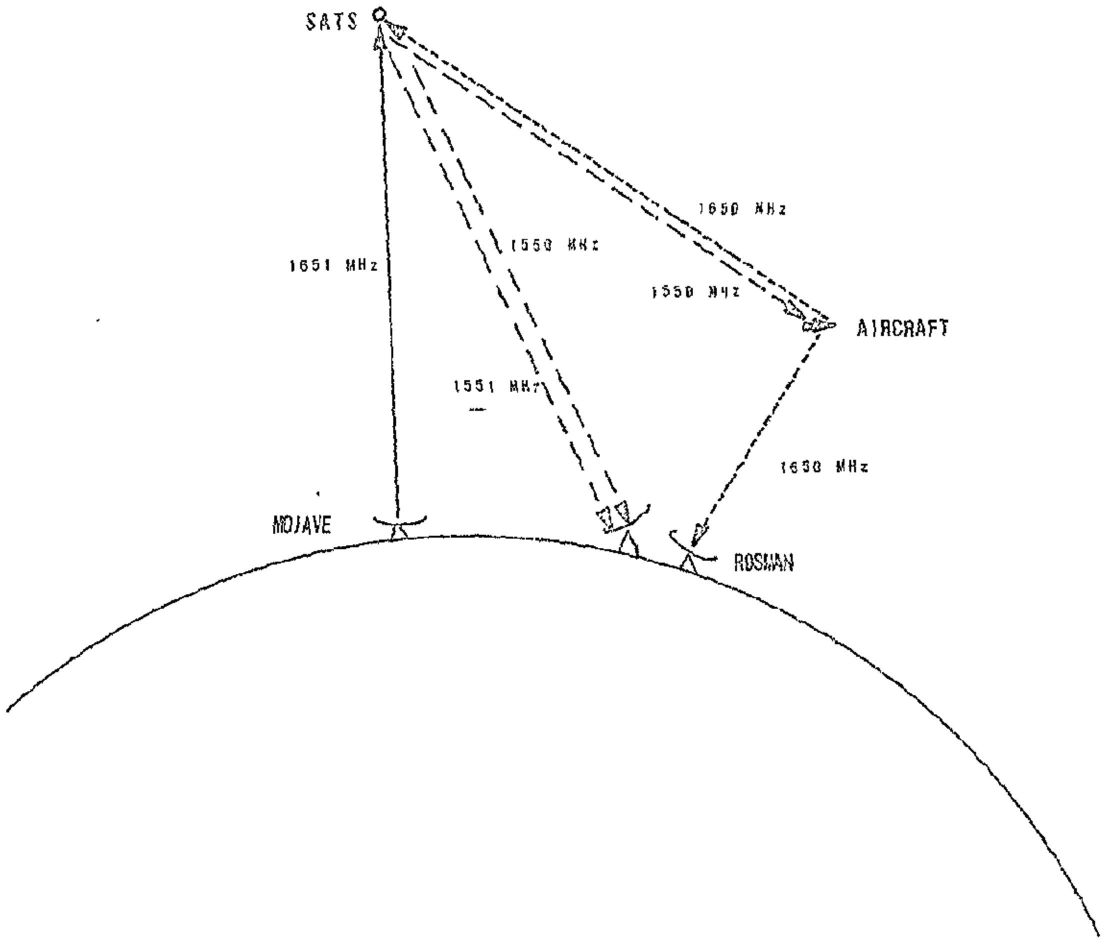


Figure A-3. L-Band Aircraft Communications Surveillance/Communications Mode

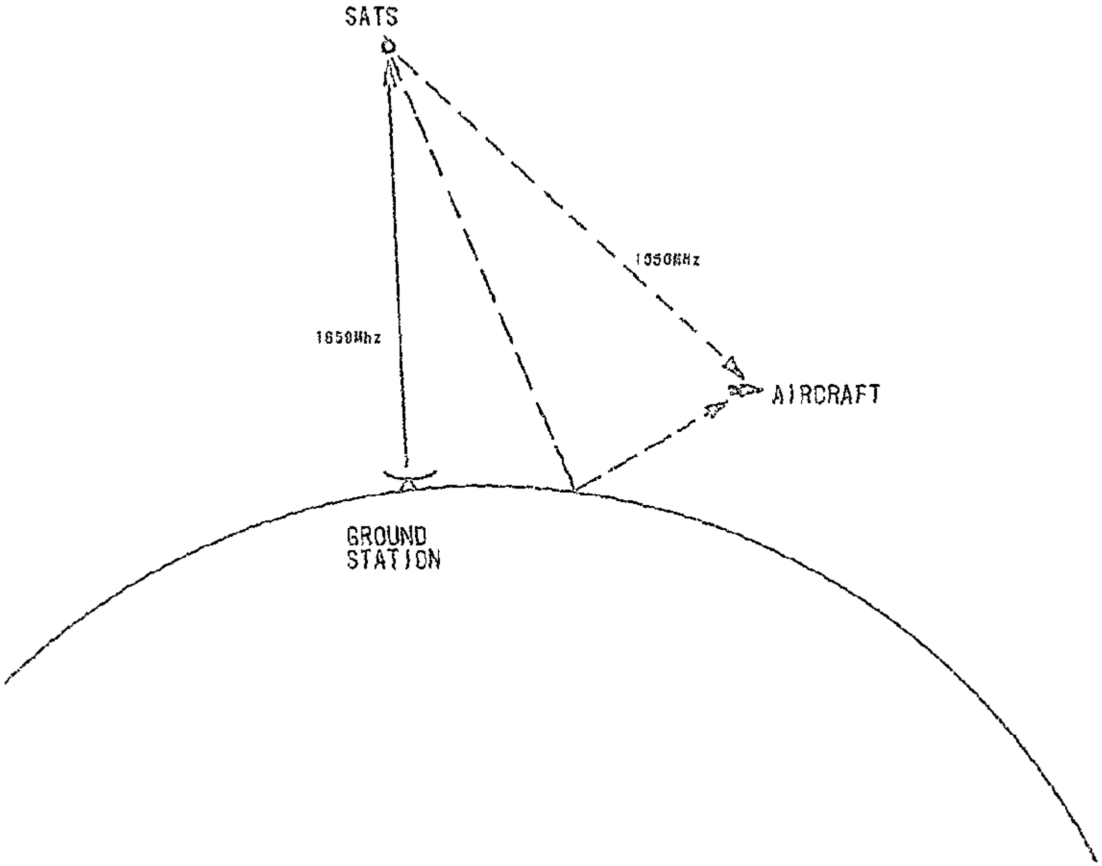


Figure A-4. L-Band Aircraft Communications Multipath Mode

TABLE A-3. RADIATIVE COOLER INSTRUMENTATION

OBJECTIVES:	1. INSTRUMENT A RADIATIVE COOLER TO DETERMINE CAUSES AND SOURCES OF CONTAMINATION/CONDENSATION. 2. TEST TECHNIQUES FOR COUNTERACTING THE CONTAMINATION
CHARACTERISTICS:	1. AVAILABLE RADIATIVE COOLER (ITOS OR NIMBUS-TYPE) 2. NEUTRAL PARTICLE MASS SPECTROMETER TO DETECT TYPES OF FOREIGN GASEOUS MATERIAL PRESENT. 3. TWO HIGH-SENSITIVITY PRESSURE GAGES AS USED ON AE-B TO DETERMINE AMOUNT OF GASEOUS MATERIAL.
USERS:	TECHNOLOGY, METEOROLOGY, EARTH RESOURCES
LAUNCH VEHICLE:	SCOUT
ORBIT:	300 NM
EXPERIMENT WEIGHT:	38 POUNDS
EXPERIMENT POWER:	18 WATTS

TABLE A-4. TIME/FREQUENCY STANDARD SATELLITE

OBJECTIVES:	1. DEVELOP PRECISE ATOMICALLY CONTROLLED WORLD-WIDE TIME AND FREQUENCY REFERENCES. 2. IMPROVE PRECISION OF SATELLITE TRACKING (RF and Laser) 3. MEASURE RELATIVISTIC EFFECTS.
CHARACTERISTICS:	1. SPACECRAFT ATOMIC CLOCK (CESIUM NOW, HYDROGEN MASER IN THE FUTURE). 2. CORNER REFLECTORS FOR LASER TRACKING.
USERS:	GEODESY, NAVIGATION, TECHNOLOGY
ORBIT:	1 - GEOSYNCHRONOUS; 2, 3 - HIGHLY ELLIPTICAL 24 HOUR
EXPERIMENT WEIGHT:	40 POUNDS, INCLUDING TRANSMITTER
EXPERIMENT POWER:	35 WATTS, INCLUDING TRANSMITTER
OPERATION:	TRANSMIT TIME CODES AND STANDARD FREQUENCIES MAKE GEODETIC MEASUREMENTS

TABLE A-5. MULTISPECTRAL IMAGE DISSECTOR

OBJECTIVE:	EVALUATE A HIGH-RESOLUTION, MULTISPECTRAL IMAGE DISSECTOR FOR USE AS AN EARTH RESOURCES SENSOR.
CHARACTERISTICS:	1. IMAGE DISSECTOR SYSTEM WITH SEPARATE APERTURES FOR SIMULTANEOUS IMAGING OF THREE SPECTRAL BANDS. 2. S-BAND DATA TRANSMISSION.
USERS:	EARTH RESOURCES
LAUNCH VEHICLE:	SCOUT
ORBIT:	300 NM
EXPERIMENT WEIGHT:	90 POUNDS
EXPERIMENT POWER:	30 WATTS
OPERATIONS:	VIDEO AND S-BAND TRANSMITTER COMMANDED ON AND OFF WHEN OVER STATION; BACKUP TIMER TO INSURE TURNOFF.

APPENDIX B

COMMUNICATIONS LINK CALCULATIONS

Since the SATS service module characteristics and experiment module data provisions have not been finalized, the link calculations below are shown only to indicate the possible data rates for some assumed configurations. Tables B-1 and B-2 were developed using a computer program for such calculations. The assumed parameters are listed at the top of each table. The energy-per-bit to noise-power-density ratio [ST/(N/B)] required corresponds to a bit-error rate of $\sim 10^{-5}$ for an uncoded PCM signal. The 1000 mile range shown on both tables corresponds to the maximum slant range from a 300 mile orbit, and the 26,000 miles corresponds to a geosynchronous orbit.

Table B-1 shows the capabilities of a 136 MHz (beacon) system. The spacecraft has a low-power transmitter and omnidirectional antenna, while the assumed ground station has a 30 foot dish antenna. From the 300 mile orbit the link capability exceeds the ground station capacity even under these assumptions. From synchronous orbit, there is enough available bit rate for full-time housekeeping, as well as the beacon function. Should a higher bit rate be desired from geosynchronous orbit, a higher transmitter power, a directional spacecraft antenna, or a larger ground station antenna could be used.

Table B-2 shows the capabilities of two different S-band systems. Both assume a one watt spacecraft transmitter and a 45 foot dish at the ground station. Capabilities are shown for spacecraft with an omnidirectional antenna, and with a moderate gain antenna, which might be a one foot dish or a planar array about 18 inches square. The 15 db gain corresponds to a little more than 20 degrees beamwidth, or enough to cover the earth including attitude errors from synchronous orbit. The results indicate that an omnidirectional spacecraft antenna should be sufficient for data requirements from the low orbit, while a moderate antenna gain is probably necessary for geosynchronous orbit. As with the VHF system, transmitter power and antenna gains may be altered from the figures shown, if required.

If Alaska and Rosman are used as the prime SATS ground stations, 85 foot dishes will be available, providing gains of 30 db and 53 db at VHF and S-band respectively. As the spacecraft and operations requirements become better defined, these, and other changes, will be incorporated into the link calculations.

TABLE B-I. VHF COMMUNICATIONS LINK

VHF Frequency	136 MHz
Transmitter Power	0.2 W
Transmitter Antenna Gain	-3 db
Receiver Antenna Gain	21 db
Required ST/(N/B)	11 db
Losses: Polarization	3 db
Sync & Pointing	1 db
PLL S/N	9 db
PLL BW	3 Hz
Margin	6 db
System Noise Temperature	1450 K

Range (Stat. mi.)	Bit Rate (bps)
1000	69 K
5000	2700
10,000	690
26,000	100

TABLE B-2. S-BAND COMMUNICATIONS LINK

S-Band Frequency	2300 MHz
Transmitter Power	1 W
Receiver Antenna Gain	48 db
Required ST (N/B)	11 db
Losses: Polarization	3 db
Sync & Pointing	1 db
PLL S/N	9 db
PLL BW	3 Hz
Margin	6 db
System Noise Temperature	300 K

Range (Stat. mi.)	Bit Rate (bps) -3 db xmtr. ant.	Bit Rate (bps) 15 db xmtr. ant.
1000	2.3 M	148 M
5000	94 k	5.9 M
10,000	23 K	1.48 M
26,000	3460	218 K

APPENDIX C

ABSTRACTED FROM THE NATIONAL ACADEMY OF SCIENCES, CENTRAL REVIEW COMMITTEE'S REPORT "USEFUL APPLICATIONS OF EARTH-ORIENTED SATELLITES", 1969

R & D APPLICATIONS

Conclusions

"It is likely that, in most space applications, it will be desirable for NASA to continue its technical program leadership beyond the research and engineering development stage into a phase of 'pilot' operation, taking responsibility for the total space-flight experimental system: . . . Potential user agencies, however, should participate actively in the planning and design of experimental programs . . . ."

Recommendation

"NASA should accept responsibility for organizing the required space-flight operational experiments in close cooperation with potential users, and for providing the necessary satellites and related ground equipments to execute this important phase in the development of space applications."

INTERNATIONAL

Conclusion

"In examining existing or suggested patterns for international space applications, the CRC has reached strong convictions on the importance of institutional arrangements that can be adapted easily and rapidly to functional requirements as they evolve with the technology. Imaginative organizational and political innovation may be as crucial as technical innovation in this sphere, especially where national systems interface with international ones."

Recommendation

"NASA, in cooperation with the Department of State, should continue to develop its international programs concerned with space applications . . . to ensure the development of a favorable climate for international acceptance and use of practical space applications, as they become technically feasible."

MANNED AND UNMANNED FLIGHTS

Conclusion

". . . the manned program has provided technological developments of importance to many aspects of space flight and the use of space. . . . Additionally, this program will provide significant opportunities to test sensors and to prove out techniques . . . . However, the use of manned vehicles per se does not, at present, appear necessary or desirable for the operation of the various space applications systems considered by this study."

Recommendation

"Manned programs must be justified in their own right; they cannot be justified in terms of space applications."

METEOROLOGY/EARTH-RESOURCES SATELLITES*

Conclusion

". . . Certain R&D programs give unusually great rewards; these are generally in areas of investigations that are on the steep part of the learning curve. Such an area is sensor-signature research — considered the single pacing element in earth-resources applications, and of value to other fields, such as oceanography and geology."

*Under this topic a number of conclusions are presented, each followed by an appropriate recommendation.

Recommendation

"Support of sensor-signature R&D should be increased, as we are convinced that a modest investment in this area will generate great advances in our capability to evaluate the use of satellites for beneficial purposes."

Conclusion

"We conclude that, in the near future, satellites can be flown with imaging sensors that can provide useful output data. ... A common approach involving forestry, agriculture, geography, hydrology, and possibly oceanography is feasible. ... An operational system for overall earth-resources information seems realizable within a decade if the results of R&D are favorable."

Recommendation

"NASA should promptly initiate a pilot program to provide pictorial information in familiar and immediately useable form. ... could be of the Global Land Use (GLU) type... The potential value of side-looking radar for geology ... should be explored. Planning ... should be started for the evolution within 10 to 12 years of a substantially broader system with more sophisticated sensors. A facility of critical size is necessary to sustain the data processing and R&D needed to develop the second-generation system."

Conclusion

"Direct quantitative inputs for mathematical models are needed in the interests of numerical weather prediction. ... Large, high-speed electronic computers are available ... ."

Recommendation

"NASA should continue to support and expand its space technology programs aimed at securing the quantitative, world-wide, general-circulation atmospheric information required by the meteorological community for mathematical models of the world weather system."

Conclusion

"The geosynchronous meteorological satellite ... (with) ... the constant surveillance of the weather of a large part of the globe permits observation of the growth of storms, measurement of winds ... developing mesoscale weather."

Recommendation

"NASA and ESSA should continue to exploit this usefulness, leading toward capability for full tests by 1971. To permit rapid video playback in near-real time for warning, ..."

Conclusion

"At present, more than 14,000 small data-collection platforms are operating around the world; the number is expected to reach 26,000 by 1975. Only restricted synoptic, real-time, data-collection service ... now exists. It is important that all the data be collected on a timely schedule, and a satellite system is substantially less costly than the conventional means of doing so."

Recommendation

"Develop and deploy operationally a data-collection relay satellite system, to provide for the interrogation and collection of data from large numbers and types of widely distributed data platforms ... and for the relaying of those data to specified data-processing centers."

Conclusion

"Real-time readout of imagery direct from satellites to ground (may not always be desired or required). The necessary on-board, wide-band, long-lived data storage and transmission equipment is beyond the present state-of-the-art."

Recommendation

"We recommend that an early determination be made of operational and cost advantages realizable from the on-going NASA Data Relay Satellite System Program ... ."

COMMUNICATIONS AND NAVIGATION

Conclusion

"Broadcast by satellites is technically feasible from low-power satellites with large ground stations for transmission and/or re-broadcast, to high-power satellites with direct broadcast into homes."

Recommendation

"Of all the uses we find for the different classes of broadcast satellites, two seem so easy technically, so reasonable economically, and so potentially desirable that we recommend consideration of their implementation by the proper authorities as a matter of high priority. One is a multi-channel distribution system for the use of network television transmission for both the private and public sectors of the industry. The other is a multi-channel system of the 'teleclub' type for educational, instructional, and informational television for developing countries, as well as for those audiences sparsely spread throughout the United States, who require and need programming suited to their special interests — e.g., physicians, lawyers, engineers, educators."

Conclusion

"A satellite system for navigation and traffic control over the North Atlantic would be likely to pay its way for shipping alone, provided all shipping were included. It would also provide for aircraft."

Recommendation

"Immediately undertake efforts to design a system, identify the necessary operating organizations, and start the necessary R&D for establishment of a North Atlantic satellite navigation and traffic-control system to provide en route traffic control of transoceanic aircraft, traffic control of surface vessels in confluence areas, and improved search and rescue operations at sea."

FREQUENCY UTILIZATION

Conclusion

"The increasing use of satellites will, we anticipate, necessitate very large allocations in the radio-frequency spectrum. To accomplish this, effective long-range plans for management of the RF spectrum must be formulated and implemented . . ."

Recommendation

"The U. S. Government should promptly identify or create the authority to manage the total U.S. use of the radio-frequency spectrum... The Government and other appropriate responsible groups should also work toward increasing effectiveness of international agencies that are responsible for reaching agreements in radio-frequency management."

Conclusion

"The availability of assignments in the radio-frequency spectrum will pace the entire scope of satellite applications."

Recommendations

"Immediate consideration should be given, . . . to initiating the frequency-allocation process in order to secure frequency assignments within the following bands:

"1) 108 MHz for FM broadcast

"2) 470-890 MHz for direct-to-home broadcast (possibly restricted to upper end of band)

"3) 2500 MHz band for educational TV and other TV services

"4) 12,000 MHz for distribution service

"5) Allocations in the 18-GHz and 35-GHz bands which may have important future uses."

ORBITAL SPACING

Conclusion

"Crowding of the geosynchronous orbit, causing radio-frequency interference, especially at continent-bisecting longitudes, may require international agreement for positions in the geosynchronous orbit."

APPENDIX D

MEMORANDA OF APPLICATIONS WORKING GROUPS

The memoranda below are suggestions and philosophies of the Application Working Groups as regards SATS. They should not be taken as indicating the complete inputs from the Working Groups, since, as mentioned in the text of the report, many inputs were obtained orally, in the course of meetings between the SATS Study Office and the individual Working Groups.

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : Mr. E. W. Hymowitz
SATS Study Manager

DATE: April 6, 1970

FROM : S. Gubin, Chairman
Communications Working Group

SUBJECT: SATS Experiments

I should like to suggest that the highly successful LES program is the Air Force's parallel to SATS, and, that you and Dr. Hovis should try to visit Boston to see what they have done in the Communications area. I should be glad to accompany you, if you wish, and to make arrangements for the visit.

There are numerous experiment possibilities for SATS some of which are as follows:

1. Measurement of Earth temperature from VHF information Millimeter Wave range with various spacial and bandwidth resolutions.

2. Transmissivity of frequencies, from VHF thru the optical range, considering the numerous impairments because of ionospheric and atmospheric effects on signal strength and despersion.

3. Experiments in multiple-beam formation and control in the Millimeter Wave region (small antennas suit SATS).

4. Tests of retrodirective antennas with limited scan angle. These require fewer radiating elements and transponders.

5. Time synchronization for aircraft having collision avoidance electronics on board.

6. Data acquisition from, and tracking of low orbiting satellites from synchronous stationary orbit, when each end of the link has a high gain aperture.

Subject: SATS Experiments

These are only a few examples of what can be done with SATS. The detailed information you need would become evident only after study. In effect, such data would become a critical part of any experiment proposal, and the effort to produce such data would be that needed for a proposal.

Samuel Gubin

Samuel Gubin by [illegible]
Chairman

SG:lac

cc: W.G. Stroud
D.G. Mazur
M.I. Schneebaum
Dr. W.A. Hovis
Dr. R.J. Coates
R.J. Darcey
R.H. Pickard
L.R. Stelter
W.P. Varson
C.P. Smith
Dr. W. Nordberg, Chm, Earth Resources W/G
Dr. F.O. Vonbun, Chm, Geodesy W/G
W.R. Bandeen. Chm, Meteorology W/G
C.R. Laughlin, Chm, Navigation Traffic Control W/G

Dr. F. O. VonLun, Chief
Mission & Trajectory Analysis Division

April 29, 1970

Mr. E. W. Hymowitz
SATS Study Manager

A Possible Small Applications Technology Satellite (Mini GEOS, Siry)

Your suggestions regarding the possible application of laser corner reflectors for long term geodetic measurements are useful and will be incorporated into the study.

There are other possibilities that come to mind in addition to a unique spacecraft, that may also have merit and should be considered.

1. Corner reflectors as payload becomes available on "standard" SATS.

2. A standard" SATS with geodetic/STADAN payload of laser corner reflectors and time/frequency reference emitters.

3. An experiment to test the feasibility of accurately determining spacecraft attitude and the motion of spacecraft booms through laser returns.

Please comment.

E. Hymowitz

cc: Dr. J. F. Clark, Code 100
Mr. J. T. Mengel, Code 500
Mr. C. A. Schroeder, Code 501
Mr. W. G. Stroud, Code 110
Chairmen, Applications Program Working Grou,
Mr. D. G. Mazur, Code 700
Mr. M. Schneebaum, Code 730

UNITED STATES GOVERNMENT

Memorandum

TO : Mr. E. W. Hymowitz
SATS Study Manager

DATE: April 24, 1970

FROM : Chairman, Space Applications Program Working
Group - Geodesy

SUBJECT: A Possible Small Applications Technology Satellite (Mini GEOS, Siry)

For geodetic purposes, spacecraft in low inclined orbits ($i \leq 20^{\circ}$) are needed for zonal harmonic determination.

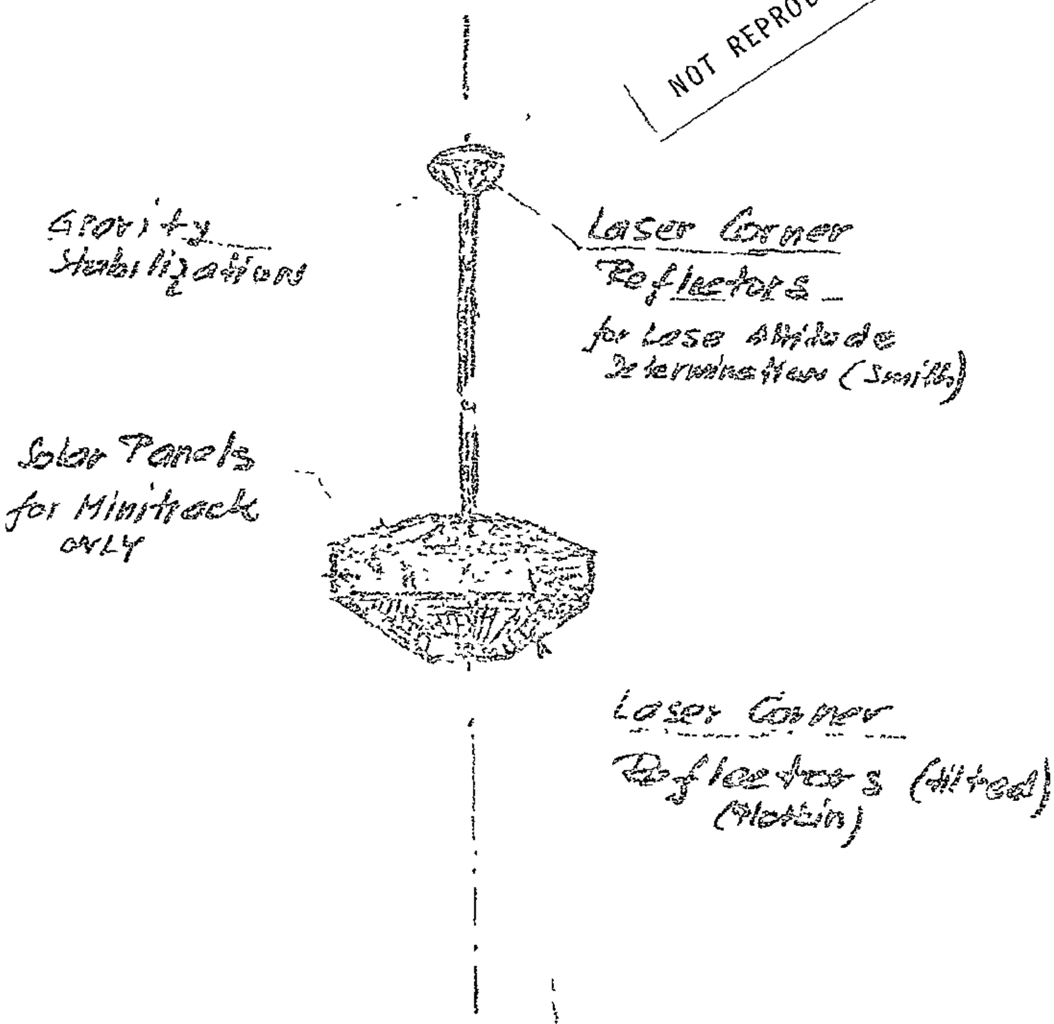
A "corner reflector only" (see Fig. 1) spacecraft would be not only cost effective (piggyback), but also a tool valuable for many years on an international basis. The Minitrack system, needing almost no power and no electronics, would be used for ease of firding. Many nations will have laser systems in operation over the next few years.

This is a spacecraft which meets SATS requirements, small, applications. . .

F. O. Vonbun, Chief
Mission & Trajectory Analysis Division
Tracking & Data Systems Directorate

cc: Dr. J. F. Clark, Code 100
Mr. J. T. Mengel, Code 500
Mr. C. A Schroeder, Code 501
Mr. W. G. Stroud, Code 110
Chairmen, Applications Program Working Group

550-26M-FOV:jmw



A SATS
A Corner Reflector Space Craft

Fig. 1

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : Mr. E. W. Hymowitz
SATS Study Manager

DATE: May 6, 1970

FROM : Chairman, Space Applications Program Working
Group - Geodesy

SUBJECT: A Possible Small Applications Technology Satellite (Mini GEOS, Siry)

Reference: Your memorandum dated April 29, 1970, same subject

I agree with 1, 2, and 3 of your memorandum.

I suggested that 1 be done on an international scale during the ISAGEX meeting in Paris, January 13, 1970.

Number 3 was suggested by Dr. Smith and is being studied for GEOS-C.

F. O. Vonbun, Chief
Mission & Trajectory Analysis Division
Tracking & Data Systems Directorate

cc: Dr. J. F. Clark, Code 100, w/ref
Mr. J. T. Mengel, Code 500, w/ref
Mr. C. A. Schroeder, Code 501, w/ref
Mr. W. G. Stroud, Code 110, w/ref
Chairmen, Applications Program Working Group, w/ref

550-30M:FOV:jmw

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : Emil W. Hymowitz
SATS Study Manager

DATE: March 27, 1970

FROM : W. R. Bandeen, Chairman
Meteorology Program Working Group

SUBJECT: SATS Study Support Requirements

REFERENCE : Memorandum from Mr. Hymowitz to Chairmen GSFC Applications Working Groups, same Subject, dated March 13, 1970

The Meteorology Program Working Group (METWG) has discussed the rationale for a SATS Program and the types of experiments that might purposefully be accommodated on a SATS during two recent meetings (on 17 and 23 March 1970). The following five persons, representing the SATS Project, briefed METWG (in response to an invitation) at the 23 March meeting:

Mr. E. Hymowitz, Study Manager
Mr. J. Conn, Assistant Study Manager
Dr. W. Hovis, Project Scientist
Mr. M. Balderston, Systems Engineer
Dr. W. West, Consultant

METWG members attending the 23 March meeting were Messrs. Bandeen Butler, Conrath, Gould, Ostrow, Schulman, and Shenk. Drs. Nordbe and Rasool attended the 17 March meeting but were unable to attend on 23 March. An executive session of METWG members concluded the 23 March meeting.

It became apparent at the end of the second meeting that it had not been possible to reach a clear, immutable position regarding the rationale and types of experiments applicable to SATS. We feel that considerably more time is needed to explore the many ramifications of a SATS Program in greater depth. However, the following information is advanced on a provisional basis to assist you in preparing your first report, due in the next few weeks.

The following statement was agreed to by the members of METWG:

<u>A Rationale for SATS:</u>

To provide a space environment platform for the quick test and evaluation of critical technological or scientific devices, components, or concepts that can not be tested adequately and at a lesser cost by the usual means, e.g., in a laboratory, on aircraft, balloons, rockets, etc.

This rationale is specifically intended to exclude the concept of a small satellite that might be dedicated to a single full-fledged experiment. We do not rule out the possibility that such a satellite might be highly desirable for the proper execution of a given experiment. If, for example, it were shown (and we do not conclude here that it has been) that a low-altitude, low-inclination satellite were needed to locate a fleet of constant level balloons and ocean buoys in the tropics every 100 minutes or so, a dedicated satellite would probably be required, along with on-board storage, a high systems reliability approach in design and fabrication, extensive ground data processing and other support facilities, etc. Such a satellite would in our opinion be properly categorized a (small) APPLICATIONS TECHNOLOGY SATELLITE, not a SMALL APPLICATIONS TECHNOLOGY SATELLITE (SATS) in the context of the rationale enunciated above.

The following four examples of types of experiments of meteorological interest that would be appropriate to a SATS test if a program were in existence today were suggested by METWG:

(1) Test of the Differential Doppler Concept - The differential doppler technique for tracking free-floating constant level balloons and buoys to determine winds and ocean currents has been proposed as the basis of a major experiment on Nimbus F and as the basis of the Platform Location and Data Collection sub-system to be carried on the polar-orbiting satellites in support of the Global Atmospheric Research Program (GARP). Obtaining samples of data under actual conditions of orbital velocities and realistic RFI conditions would aid in optimizing the design characteristics of the technique before a full-fledged experiment is orbited.

(2) Test of the Radio Occultation Concept - A multi-satellite scheme to sound the mass field of the Earth's atmosphere by means of the radio occultation principle (which has been successfully applied to Mariner spacecraft flying by Mars and Venus) has been proposed. However, there are several major problems confronting the successful execution of such an experiment, among them being (a) the difficulty of separating refractivity resulting from density, from refractivity caused by water vapor, (b) multipath transmissions occurring when critical refraction is encountered, (c) difficulty of separating the ionospheric

contribution to the phase shift from the neutral atmospheric effect, etc. An orbital test consisting of a "master" satellite and one "slave" satellite (e.g., a piggy-back satellite) will probably be needed to resolve the question of whether this technique is feasible or not.

(3) Test of Radiative Coolers, Optical Components, and Other Materials in the Space Environment - The performance of radiative coolers on the HRIR experiments flown on Nimbus II and III has been observed to degrade after a period of time. Similarly, it has been hypothesized that optical components, paints, and other materials have deteriorated on many radiometric instruments to explain the degradation observed in their data after several months in orbit. But the exact nature of these effects is not known. It would be advantageous to instrument a radiative cooler, selected optical elements, and other components and materials and monitor their behavior in orbit. If possible, it would be extremely valuable to recover the package from orbit for evaluation in the laboratory, although it is recognized that such sophistication might be beyond the scope of SATS.

(4) Test of Attitude Control and Determination Techniques - Advanced sensory systems (e.g., high-resolution scanning radiometers) being planned for Meteorological and Earth Resources satellites will require increased attitude control and determination capabilities (e.g., $\sim 0.02°$). It would be advantegeous to test such systems in orbit and, possibly, subsequently to optimize them before incorporating them into full-fledged missions.

We do not now have knowledge of data rates, size, weight, power etc. on these experiments. Certainly none of them is available for testing now. Near-Earth orbits ($\sim$1100-1700 km) would be required for the first two experiments. Sun-synchronous orbits ($i \sim 100°$) would be acceptable but not necessarily mandatory. The two satellites in the occultation experiment should be in the same orbit but separated in phase by about 70 degrees, with a station keeping capability on one satellite. Both near-Earth and geostationary orbits apply to the last two experiments.

3 ⊕

METWG will consider these and other aspects of SATS at forthcoming meetings and will be in communication with you concerning these further deliberations. I hope these initial thoughts will be of some value to you.

W. R. Bandeen

W. R. Bandeen
Assistant Chief
Laboratory for Meteorology
and Earth Sciences

cc: Dr. Pieper
Mr. Stroud
Dr. Hovis
Members, METWG
Chairmen, Applications Program Working Groups

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : Emil W. Hymowitz
SATS Program

DATE: April 27, 1970

FROM : Charles R. Laughlin
Applications Experiments Branch

SUBJECT: Submittal of Comments on Your SATS Program Presentation of 24 March 1970

Attached are copies of written responses received from Navigation Working Group Committee members to your presentation of March 24th. The members submitting responses were Messrs. Clark, Heffernan and Kampinsky. Further, I understand that Mr. Gould submitted his response directly to you.

Thank you for your presentation on SATS. Should you wish further dialogue with the NAVWG Committee we will be pleased to arrange it.

Charles R. Laughlin
Charles R. Laughlin
Applications Experiments Branch

Enclosures (3)

CRL:bam

cc: with enclosures
D. G. Mazur
Dr. J. F. Clark
W. G. Stroud
Dr. R. Stampfl

w/o enclosures
P. J. Heffernan
E. J. Habib
J. L. Baker
Dr. R. Rochelle
G. Clark
A. Kampinsky

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UNITED STATES GOVERNMENT

Memorandum

TO : C.R. Laughlin, Chairman
NAV/TC Working Group

DATE: March 25, 1970

FROM : P. J. Heffernan
Applications Experiments Branch

SUBJECT: March 24 meeting with SATS Project Personnel

The following comments are submitted in response to your request that Working Group members furnish written inputs to be forwarded for Mr. Hymowitz' attention. As is evident, the thoughts expressed below coincide to a large extent with those you expressed in the subject meeting.

The SATS Program are presently defined is aimed at providing a quick reaction, low cost spacecraft and launch capability to permit effective in-orbit testing and evaluation of special components, sensors, etc. intended for eventual flight use in major observatory ATS, or operational flight programs. As such, it is difficult to envision SATS program justification on the basis of meeting technology development requirements of the NAV/TC application and other areas of interest to the Working Group. What would appear to be more to the point is a program providing a low cost, quick reaction flight capability for the general class of current technology applications payloads which, unfortunately, can only at present be flown and demonstrated on the major OSSA "bus" type spacecraft, more often that not over the Project Manager's dead body. Obvious examples are the T&DRE package on Nimbus-E (largely a 1967 vintage GRARR transponder) and the L-band package on ATS-V. The key word missing from the SATS vocabulary as I see it is demonstration. As you have pointed out, the raw space technology required for such applications as air traffic surveillance, "emergency" broadcast services, data collection, etc. is really here today and needs testing on SATS like it needs a hole in the head. What is needed in each case is the capability of getting simple-minded limited capability system on the air in the earliest possible time frame and then let nature, with a little help from the NASA Public Information Office, take its course - in no time at all today's tongue tied users would be banging on the door for service.

Subject March 24 Meeting with SATS Project Personnel

I endorse your notion of an Applications Development Satellite (ADS) to meet this need. Basic spacecraft characteristics required include

- synchronous or near-synchronous orbits
- large earth-pointing antenna apertures or large solar arrays, but probably not both on a single spacecraft
- relatively loose attitude control requirements
- payload essentially a one-way or two-way frequency translating communications repeater

I apologize if the above words are not strikingly original - they do reflect my opinions on the SATS question from the point of view of the navigations and communications disciplines, and are forwarded for your use as you see fit.

P.J. Heffernan

PJH lac

cc: S. Gubin
R.H. Pickard

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UNITED STATES GOVERNMENT

Memorandum

TO : E. W. Hymowitz
Code 401

DATE: 26 March 1970

FROM . A. Kampinsky
Code 110

SUBJECT: SATS

This memo reiterates what I discussed around the table at the Navigation Applications Working Group meeting on 24 March.

(1) I consider that experiments that should be carried out on a spacecraft, are those that would reveal critical data of significance for a number of programs and which could be flown at the most propitious time for maximum benefit to designers.

(2) Suggested candidate experiments would be:

a) A multifrequency Multipath/Propagation experiment with significance to DRSS, Navsat/Traffic Control and Communications.

b) A multifrequency Radio Frequency Interference experiment with significance as in a).

c) Unfoldable Aperture Antennas, with significance to ERTS, DRSS, Nimbus for communications and microwave sensors.

(3) If the SATS proposals are believable, the cited experiments should be made available within a one-year period, preceded by the total experiments program plan for flight exercises. This would be part of the "quick reaction" concept of SATS.

(4) I would consider, as a factor of the rationale for SATS, the inherent quick reaction time to accomodate, combine, and to reshuffle experiments and the flexibility to reprogram the launch schedule so as to fly at that time when the experimental results may be considered as optimum. Also, the sequence of ordered series of flights are valuable to certain programs. -- Navigation/Traffic Control and ERTS

P.S. (5) There is no unique experiment or equipment realtive to the Navigation/Traffic Control functions that would require the SATS capabilities.

A Kampinsky
A. Kampinsky

UNITED STATES GOVERNMENT

Memorandum

TO : Mr. Charles R. Laughlin, Chairman
Navigation Applications Program Working Group

DATE: April 22, 1970

FROM : Head, Advanced Plans and Techniques Branch

SUBJECT: Potential Requirements for SATS (Small Applications Technology Satellites)

REFERENCE: Memorandum from Mr. Laughlin to Distribution dated March 18, 1970, Subject: Meeting to be Held Tuesday, March 24, 1970

The subject documents have been reviewed and the following comments are offered.

1. The general concept of a quick response, short lead time orbiting test bed is commendable and I feel should be supported. However, I do not see a direct application to the Navigation and Traffic Control discipline.

2. The concept of lowering spacecraft costs through reducing reliability programs, while technically commendable, is an undesirable approach. I make this comment from experiences with the TTS/TETR Project which was sold partially on the same type argument. The concept was lauded by all until a spacecraft failure occurred. From that time forward through all the ensuing failure committee activities, the concept was forgotten and almost all recommendations from said committees were directed toward increasing parts reliability and procedures. Therefore, I would recommend strongly against selling a program on that basis since I feel that the long term potential of such an approach results in more liabilities than assets.

George Q. Clark

831:GQC:slb
FILE. 051

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UNITED STATES GOVERNMENT

Memorandum

TO : Mr. E. W. Hymowitz
SATS Study Manager

DATE: March 26, 1970

FROM : Mr. W. I. Gould, Jr.
Member, Meteorology Working Group
Ersatz Member, Navigation Working Group

SUBJECT: SATS Presentation Comments

This is in response to your SATS presentations of 23 and 24 March. Your March 24th presentation, while it reflected a drastic revision of your Program Objectives along the lines recommended by the METWG, still reflects a "quick-and-dirty" approach to placing experimental equipment in orbit. Further, your minimal approach to reliability and quality assurance, while it may be salable at this point in time , will only serve to get you in trouble on the occasion of your first obital failure. While both of the above programmatic aspects are negative I feel they can be easily corrected by taking a different approach in your presentation - I submit the following for your consideration.

To avoid the "quick and dirty" categorization your approach could be - "While SATS is directed toward a minimal integration to launch time frame a typical schedule for a Scout launch would encompass programmatic elements shown in figure X" (this figure is a milestone chart depicting all major events encountered from receipt of experiment interface definition, thru integration, electrical check out, environmental test, shipping, launch site checkout, and launch). You can point out that since this is a typical schedule you would expect some variations based upon experimental payload requirements. Further, incorporation of a similar schedule for Delta should make this part of your presentation reasonably complete. With reference to the reliability and quality assurance problem, I feel that the spacecraft subsystems should use space qualified components independent of whether, the experiment is made of chewing gum, moth balls and string. Experiment failures are rather commonplace whereas spacecraft system failures are usually considered intolerable.

During your presentation on the 23rd you stated that you felt that the SATS program should not compete with or impact the on-going ATS and Nimbus programs. While I understand your rationale, I feel that the SATS could supplement the ATS and Nimbus capabilities by accommodating rejected category I experiments for which there were no satellite resources available. Further, it occurs to me that the SATS program could provide a vehicle by which phased procurement planning could be circumvented.

Subject: SATS Presentation Comments

As you may be aware, phased procurement planning has stretched the ATS F&G program to nearly twice the necessary program length. A Delta launched SATS could encompass satellites of OGO size and capability in near earth orbits to near NAVSAT capability in geostationary orbit while circumventing phased procurement planning and providing a means to enable a more timely exploitation of applications in space.

William J. Gould

WIG:lac

cc: Dr. J.F. Clark
W. Stroud
S. Gubin
M.T. Schneebaum
C.R. Laughlin
W.R. Bandeen

OPTIONAL FORM NO. 10
MAY 1962 EDITION
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UNITED STATES GOVERNMENT

Memorandum

TO : Members, GSFC Earth Resources Working Group DATE: April 27, 1970

FROM : Chairman, GSFC Earth Resources Working Group

SUBJECT: Minutes of the GSFC Earth Resources Working Group Meeting on April 16, 1970

The following agenda items were covered:

A. Discussion of SATS

B. Review of the outline for ERTS A and B follow-on missions.

The ERTS A and B follow-on outline had been discussed in the Working Group Meeting of February 11. Revisions to the outline were made in this meeting and the final version is being distributed under separate cover.

SATS System Description

Mr. Hymowitz and his staff lead the discussions on the Small Application Technology Satellite (SATS). The following are excerpts from his presentation:

SATS is being studied in response to Headquarters guidance which implies that the rate of Application missions is too low. SATS would be an "Orbital Experimental Laboratory". The objective is to observe, on a test basis, unpredictable phenomena which are unique to the orbital environment and not feasible to test outside that environment. Other objectives mentioned were opportunities for international cooperation, compression of the lead time between experiment selection and launch to about 6 to 12 months, and the possibility of an emergency launch capability in case of a major observatory failure.

Integration time will be 3 to 6 months. Three spacecraft versions are being considered: a low cost Scout launched spacecraft costing about 1 to 2 million dollars; a larger, more expensive Delta launched spacecraft and a piggyback spacecraft on a Delta launch vehicle. Spacecraft subsystem hardware will be based on existing structures and components. A reasonably "standard" spacecraft design for each of the two launch vehicles is anticipated. A package (PAC) already exists for the Delta piggyback configuration. The spacecraft is intended to be a fully instrumented test platform to permit extensive monitoring of all types of experiment performance functions. For the Scout version, a payload weight of 75 to 80 lbs. and peak power of 70 watts for about 15% of the orbit is being considered. A frequency of 4 Scout, 2 Delta, and 2 piggyback launches per year totaling about 26 experiments per year is anticipated. This compares with some 25 to 36 experiments per year at present in the total applications program.

SUBJECT: Minutes of the Earth Resources Working Group Meeting on April 16, 1970

Orbit inclination would be about 52° for Wallops Island Scout launches, equatorial for Delta ETR launches, or sun synchronous for both Scout and Delta WTR launches. Attitude control would be by momentum wheel, probably augmented by gravity gradient. Stabilization would be to one degree with a rate of 10" per second. Power would be from solar paddles. Housekeeping telemetry would be via STADAN beacon and video data rates, up to one megabit per second, could be transmitted via S-band on the Scout spacecraft; greater data storage is being considered at this time and all data transmission would be in real time. No orbit adjust system is being considered.

A report to Headquarters on the study is due by 1 May 1970. The first launch is expected by July, 1973.

Working Group's Consideration of SATS

The Working Group attempted to identify critical problems which are peculiar to Earth surface observation systems and which might be resolved through SATS. All these problems were judged to be in the areas of demonstrating the basic feasibility of certain observations and of sensor performance. Listed below are those problems in the Earth Resources area on which the Working Group felt that SATS might have some bearing. They are listed in order of priority as judged by the Working Group with regard to both, their significance and their relationship to SATS.

1. Performance of radiative coolers for infrared detectors in spacecraft environment. This problem is particularly urgent because the development of about six Earth observation sensors for Nimbus F&F, ERTS B, and ATS F rests on the assumption that such cooling can be achieved. Recent results conclude that experimental tests of coolers in orbit are required. In the Earth Observation program, the most useful function for SATS would be Observation missions, such tests would have to be conducted in the very near future.

2. Earth surface observations at low sun angles. Elevation of the sun above the horizon (sun angle) is a critical parameter in earth surface observations because it controls the detection of topographic effects and geologic structures on the returned imagery. However, there is little information available about the effect of varying sun angle on the geological interpretation of returned imagery. It is expected that the planned earth observatories will be in such orbits that low solar observations will not be obtained. Observation of the earth's surface with a single imaging sensor on a SATS, could provide valuable information on three aspects of the problem: (a) effect of varying sun angle on evaluation and applications of earth imagery; (b) recognition of unique applications of low-sun-angle imagery in geology and earth resources which might justify modification of future planned orbits; (c) collection of low-sun-angle imagery for geological applications which may not be duplicated with other planned spacecraft.

3. The degradation of optical materials (mirrors, gratings, filters, etc.) in the space environment is a continuing problem for Earth observations. Tests of contamination under various spacecraft conditions would be useful and SATS could provide a unique opportunity for such tests.