CONSOLIDATED SPACE TEST CENTER

CAPABILITY TO SUPPORT

SMALL SATELLITES

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ABSTRACT

No analysis of small satellite programs is complete without thorough consideration of the operational concept that will support them. It is not uncommon today that a space system's lifecycle cost will show that operating costs exceeded development and production costs. This is particularly true for programs that hope to reduce spacecraft expense by transferring, to the ground, as much of the on-board processing requirements as operationally feasible. Facility, hardware, software, maintenance, manning, training, communications, on-orbit operations and launch costs all factor into the total operations spending and must be prudently considered.

The Consolidated Space Test Center (STC) located in Sunnyvale, California addresses these factors with an important strength - experience. Over 25 years of satellite operations history has prepared the STC for the tremendous challenge of economically operating "one-of-a-kind" spacecraft prototypes or a large constellation of spacecraft for a user community increasingly constrained by limited funding. The STC will meet this challenge through flexibility and adaptation. Today, STC operated spacecraft are supported through UHF, VHF, L-Band, and Unified S-Band links. A world-wide network of permanent ground stations is being continually upgraded and supplemented by transportable assets capable of remotely located operations. In addition to these telemetry, tracking and commanding systems, the STC is driving to develop a mission data reduction and processing capability. These cost efficient systems form the vanguard to an STC ability aimed at meeting user requirements at all levels of resource commitment and effort.

INTRODUCTION

One of the most important issues confronting the Small Satellite program community is the question "How will the Small Satellite mission be accomplished on-orbit?". No aspect of the Small Satellite's conceptual development stands independent from this fundamental operational decision. A hypothetical Small Satellite's orbit is significantly influenced by the operational decision as to how and where a user will access spacecraft telemetry. Complexity of the satellite's onboard software is completely tied to a tradeoff with how much software and generic support capability will be provided ground operators. Even the simple operational determination of the satellite's desired lifetime waterfalls into reliability, spacecraft size, hardware, software, orbit and other developmental compartments.

Despite the clear relationship between operations and satellite design, there are a surprising number of instances where a spacecraft system was constructed with little attention paid to operational issues. Spacecraft are designed incompatible with existing satellite networks necessitating costly network or spacecraft modifications late in the development timelines. On-orbit support costs exceed program budgets over time as satellite's past their mission usefulness are supported only because they are still operating.

One of the Small Satellite program's most important challenges will be to recognize the intrinsic value of answering operational questions in detail and subsequently incorporating those answers into their system designs early. This paper is intended to address specific operational area candidates for this early incorporation and to apprise the community of an organization committed to supporting Small Satellite development with operational expertise unmatched anywhere in the world -- the Consolidated Space Test Center.

THE CONSOLIDATED SPACE TEST CENTER

For over 25 years the Consolidated Space Test Center (CSTC) has operated numerous national space programs with scientific, civilian, and military objectives. Recently, the CSTC has even supported the satellites of foreign nations -- a testament to the Center's widely recognized expertise. What began as a distinct research and development effort now includes operations that routinely provide on-orbit support to space assets implicitly relied on by operating commands of the armed forces. In fact, as space systems and spacecraft achieved reliability and standardization, spending on research and development efforts declined in favor of mission systems.

Today, in an era of dynamic and demanding future spacecraft requirements, the relative importance of strong research and development programs is tremendously increasing. This reemphasis was an important contributor to the formation of the Unified Space Command and the division of routine mission operations and research and development operations between two principle space centers. The recently commissioned Consolidated Space Operations Center in Colorado Springs will operate established and routine support satellite constellations with communication, navigation and weather missions. The CSTC, located in Sunnyvale, California will serve as a redundant node for these operations but more importantly, as an asset of the Air Force System Command's Space Division, will become the focus of all military sponsored space research and development operations and orbital safety initiatives. The CSTC is executing a concerted program to enhance its resources supporting this specific charter.

Both Centers make use of the Air Force Satellite Control Network, a globally dispersed array of tracking stations. Spacecraft are commanded from these stations, telemetry is retrieved, and the tracking data they produce is used for ephemeris determination and prediction. This support is provided for satellites and the NASA STS Orbiter flights and represents numerous programs. Scheduling of these resources and resolution of schedule conflicts for R&D programs is a service provided by the CSTC. Additional Network assets are the radiometric calibration facility at Camp Parks, California, and the Timing System at Sunnyvale for universal range timing data.

SMALL SATELLITES AND THE SPACE TEST CENTER

The Space Test Center is well equipped for support of space R&D, and will become increasingly so as the planned improvements are implemented. The Center's greatest assets are its experienced crews of controllers and analysts, who have supported space missions launched on expendable rockets, deployed by the Orbiter, or flown as sortie missions on the Orbiter. They have supported multiple deployments and tests of ballistic systems. These crews, along with program office operations people and contractor support, operate out of secure Mission Control Centers at Sunnyvale. The Consolidated Space Operations Center's coming on line will allow dedication of Mission Control Center resources at Sunnyvale to R&D support. These Mission Control Centers will continue to have full access to the Satellite Control Network and its scheduling operation. In addition, they provide access to NASA resources, such as the Tracking and Data Relay Satellite System, by the resident programs. Communication networks link the Control Centers to Air Force and NASA centers and to other test facilities, for both voice and data transmission. Each center is being equipped with dedicated processing equipment for mission support. These processors host the upgraded Command and Control Segment software which covers all generic aspects of normal operation.

To the operators in these Control Centers, the size of the satellite is, in itself, of no consequence. Standardized operational procedures are directly applicable to space vehicles of any size. The mission of the satellite dictates the nature of its operation. This bears on an important subpoint of this paper: the influence of operations on the life-cycle costs of a space program. The concept of deploying small satellites as a cost-saving measure must account for all cost elements. It is not unusual for the operating costs of on-orbit spacecraft to equal or exceed the initial development costs. At present, the Air Force and NASA are, by necessity, focusing on launch capability, and program planners commonly use the cost per pound to orbit as a preliminary yardstick of program cost. Reduction of this cost element has been the subject of intensive study by both agencies; and of course, reduction of payload weight is as legitimate an approach as is reduction of the price per pound for lifting the payload. Estimates of life-cycle costs are, however, a basic tenet of the system engineering which produces space systems. Major cost elements in operations must be identified, and the program shaped wherever possible to keep these costs at affordable levels.

PRE-LAUNCH AND SPACE FLIGHT ACTIVITIES

To develop a clear understanding of the costs of operating a space vehicle, it is appropriate to step through the various activities which the program office and the Space Test Center undertake leading up to the operation, and those which comprise the flight itself after deployment. These activities are typical for a small satellite tasked with gathering scientific data, but apply at least in part to many other mission profiles as well. (It should be noted, however, that they do not apply to deployments of large numbers of vehicles over a short period of time. Consolidated Space Test Center studies of SDI and other large-scale deployment control requirements shows that a major network upgrade is needed for these cases.) The activities are depicted in Figures 1 and 2. The following text follows the sequence of these figures.

Once a program concept has been formed, early mission planning is essential, for orderly cataloging of the vehicle design and support requirements, and for estimating program costs. This planning is embodied in an Operations Concept. The operational community can provide consultative services at this stage which can lead to substantial cost savings, although some design and mission tradeoffs may be indicated. The Operations Concept is a living document which develops along with the program.

Mission simulations should be performed early, particularly if the data-taking process is strongly influenced by orbit parameters and launch time. The Space Test Center can assist in this, and make preliminary runs to aid in the orbit selection and to assure that the likelihood of collision with other spacecraft or with orbiting debris is insignificant.

Mission Control Center activation takes place well in advance of the launch date, so that flight software and procedures can be well polished and the necessary crew training accomplished. The latter usually involves familiarizing Air Force and Mission Control Center personnel with the mission and vehicle, and program crew members with Consolidated Space Test Center and network operations.

Software preparation entails the development and test of mission unique software, its interface with the Mission Control Center common user software, data base preparation, and formulation of operating procedures for its use. A resource use plan is generated, as is a search plan for initial acquisition of a vehicle deployed by an expendable.

Rehearsals are essential for all missions. They are held in a realistic environment, involve the network and the Control Center, and demonstrate flight readiness in all respects.

Prior to launch, communications checks are made between the mission vehicle and the network, to assure compatibility once the vehicle is in orbit. In some instances, these checks may first be conducted while the vehicle is still at the factory.

Pre-launch activities and the launch itself are monitored in the Mission Control Center, and vehicle and payload data taken during this phase are processed and analyzed in the Center. An updated collision avoidance run is made as a step in pre-launch processing.

Tests are conducted on the vehicle systems and payloads once orbit is attained. The length of time allotted to such tests varies from a few revolutions to weeks, depending on the mission's nature and on the program office's particular needs and intents. Following these checkouts, normal operations begin.

Drawing on mission-length pre-planning, an activity plan is composed daily, spelling out the specific resources -- tracking stations or relay satellite contacts -- needed each day. Command messages are composed and transmitted to the vehicle during contacts. Telemetry data is retrieved, processed, and analyzed. Tracking data is reduced, ephemerides determined and predicted, and advance planning undertaken. These are routine efforts but most programs have special activities as well, startracker acquisition routines for example. Assessment of vehicle health and management of its expendables also are part of the daily routine. Many spacecraft require stationkeeping or orbit adjustment, to overcome the effects of perturbations and so maintain an acceptable orbit. Planning these and executing them are Mission Control Center tasks.

Spacecraft reliability has increased greatly since early years of space flight. Occasionally, however, anomalous behavior develops. In some instances, it can be innocuous, but in others it can threaten termination of the mission. The Mission Control Center must be postured to deal promptly and effectively with these situations, and as will be seen, this can be a major element in operating costs.

Several space vehicles have achieved truly astonishing life periods, returning useful data after many years. Most, however, eventually run out of some expendable, or simply outlive their usefulness. They can at this point be shut down. The CSTC has conducted planning exercises for retrieving vehicles with the Orbiter, and this appears to have some potential advantages. Increasing concern within the community over the amount of debris in space has led to consideration of deboosting spent satellites into the ocean in untrafficed areas; the Space Test Center plans to have the software resources to plan and execute such deboosts safely. It is conceivable that retrieval or deboost may be mandatory at some time in the future.

OPERATION COSTS

Space operations costs are divisible into non-recurrent and recurrent costs. The major non-recurrent costs lie in implementation of new operational capabilities, which include hardware modifications and new software generation. Recurrent costs are principally those involved in program manning, software maintenance and hardware maintenance. The CSTC is not industrially funded; users flying spacecraft on the range are not charged by the number of contacts per day. The CSTC has a budget for sustaining operational efforts and improvements in common user equipment and software. Given adequate lead time, the CSTC will budget such items as new communications links, if they are backed by validated requirements.

Program planners can eliminate excessive non-recurrent costs by tailoring their missions to be compatible with existing network capabilities. This use of standardized communication, tracking, command, and telemetry systems often leads to an increase in actual spacecraft costs. However, what is lost to more expensive spacecraft hardware, is gained back in operations savings. For example, a program may have access to a non-standard command system which is inexpensive and readily available, but the cost of network hardware and software modifications to accommodate it can run many times the system procurement savings. By selecting a higher performance command system compatible with an existing network, hardware and software savings may outweigh the cost of the new command system. Consolidated Space Test Center personnel are available to consult with mission planners, and to infuse the Center's experience into the program concept at the outset.

CSTC space operations are run by computers. The common user software, hosted on IBM 370 Series processors, supports routine and special operations. Inevitably, however, all programs require some unique software suite. The sharp program manager will avoid costly duplication of existing routines by determining what existing software is available and compatible with his mission profile. Standard routines exist, for example, for ephemeris generation and for maneuver and orbit adjust planning. A star catalog is resident in the software, as are geopotential and geomagnetic models; and rendezvous software is planned. Unnecessary costs can be incurred in building up mission-related software, for use in development as well as in flight operations, if it is not compatible with Center software and processing equipment. Again, at a very early stage in a program, planners are advised to consult with the CSTC on the matter of mission unique software, and to avail themselves to existing routines and to the CSTC's experience in helping formulate specialized software packages.

The size of the Mission Control Center team depends on many factors. The team is composed of Air Force Mission Directors, CSTC Mission Controllers, and program-sponsored analysts for vehicle and payload support. Support requirements -- the number of contacts per day, the amount of vehicle analysis deemed necessary, and the nature of payload activity -- determine the number of crew members. A major factor in crew sizing lies in the satellite's reliability. The crew will have to contend with anomalies and if these are frequent and serious, work loads will increase. Increased workload translates to increased manning. Often, design specialists from the vehicle or payload contractor's facility are called into the Mission Control Center to aid in the process. Obviously, this is costly in itself; and during periods when anomalies are being resolved, the mission may be suspended, which raises the "price per bit" of mission data. Reliability shortcuts can be costly; inherent design features and adequate testing are sound investments, although they may appear to be tempting areas for economizing measures.

Standardization also plays into crew costs relative to training. If the Mission Control Team and analysts are familiar with the vehicle systems, retraining is confined to payload familiarization affecting software and procedures generation costs as well. This suggests that the Small Satellite Program, as an entity, could profit by considering a standardized spacecraft bus (or more than one). The economies in subsystem manufacture, and in vehicle testing, as well as in operation, could well be worth the difficulties which always accompany a standardization campaign. On a program-wide basis, the possibility of sharing Mission Control Centers and, to some extent, their crews, should also be investigated. Most of the Mission Control Centers today handle a number of spacecraft.

Developing and building a satellite of any size will always be an expensive proposition, by any standards. While many satellites may continue providing useful data for years, as alluded to earlier, most have to amortize the investment over a span of months. The possibility of alleviating this by retrieving a spent spacecraft is not a new thought: witness the WESTAR and PALAPA operation. The empty Orbiter payload bays on their return to Earth deserve attention. The difficulties are not to be minimized, but studies suggest an attractive offset in refurbishment versus build costs. From an overall Small Satellite Program point of view, envisioning an on-going series of missions over several years, reusable standardized spacecraft buses hold promise of significant economies. Whether these should be credited to operations might be subject to debate. In any event, the Consolidated Space Test Center planners are making retrieval a subject of study.

Other new developments may also reduce operational costs. The CSTC has a set of Expert Systems planned, which will be tested off-line in the operational environment. These, it is hoped, will reduce the manpower intensity associated with many routine tasks, and make the process of anomaly resolution more efficient. There is also a program at the Center for incorporating new technology into vehicle analyst workstations which should help keep crew sizes affordable. Both these developments require strong integration with the satellite design effort from its inception.

Data rates, and data-taking spans, present another area of interplay between satellite design and operations considerations. Use of the network tracking stations for low earth orbit vehicles restrict the amount and rate of data which can be recovered at any contact, and probably will require tape recorders on the satellite. Relay satellites such as the NASA TDRSS handle much higher rates, and provide long contact spans; but the mission satellite using this service requires high-grade stabilization and a pointing antenna of considerable size. Also, competition for TDRSS services may become keen in the future. CSTC planners are advocating an Air Force relay system at EHF, which could ameliorate these issues; but such a system is yet to be authorized. The CSTC is now studying the possibility of setting out inexpensive transportable ground stations, spaced so as to provide near-continuous coverage for spans of 30 to 40 minutes in low-inclination orbits. Development programs are under way to increase the data rates which the network links can handle, and to provide a computer facility capable of processing very high-rate mission data.

Lastly, a tradeoff must be addressed, particularly in Small Satellites, between vehicle autonomy and crew operations. A very simple vehicle may be an economy in manufacture and test, but may result in operations costs which exceed the savings. Clearly, autonomy carried past some point can offset any possible good. If the vehicle hardware reliability is actually reduced by a collection of fault sensors and the like, this may be negative progress. The behavior of autonomous systems on spacecraft can be a challenge to the operators' understanding as well, and this can lead to expensive delays in restoring mission operations after an anomaly.

SUMMARY

In summary, the cost elements in operations which should be considered by Small Satellite planners are the following:

a) design to existing operational capabilities to the greatest extent possible; use standardized subsystems wherever a choice exists;

b) tailor the mission to avoid large, complex software developments for flight support;

c) use available software routines and services where appropriate;

d) design software which may be used in operations support for compatibility with the Space Test Center software environment;

e) abstain from design and test shortcuts which could reduce vehicle operational reliability;

f) provide a good balance between vehicle autonomy and ground-controlled vehicle operations.

Consideration of the operational environment and consultation with Consolidated Space Test Center planners in the earliest phases of a program can lead to solid economies, and make for smooth operations from launch date on.

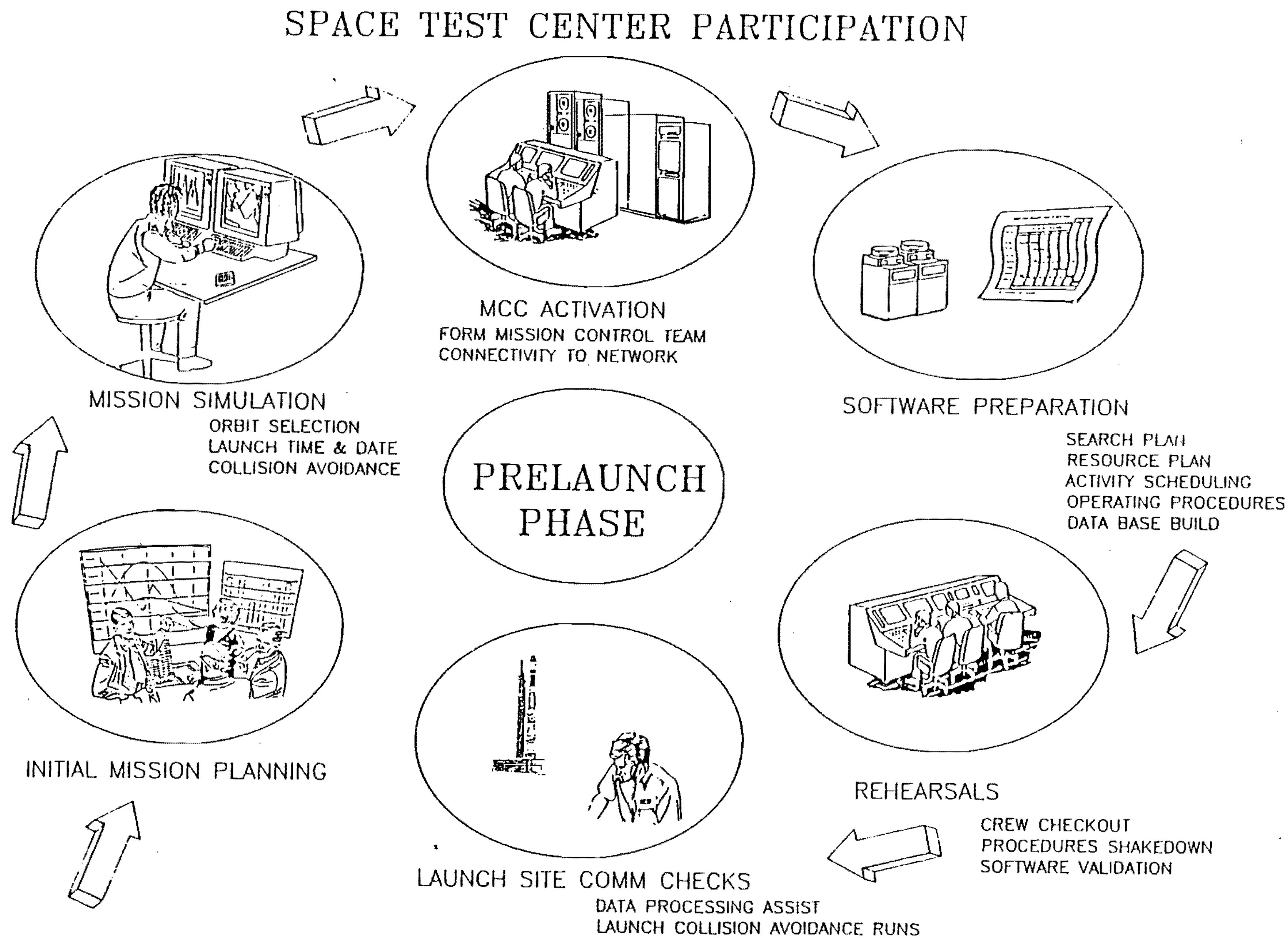

Figure 1. Space Operation Pre-Launch Activities

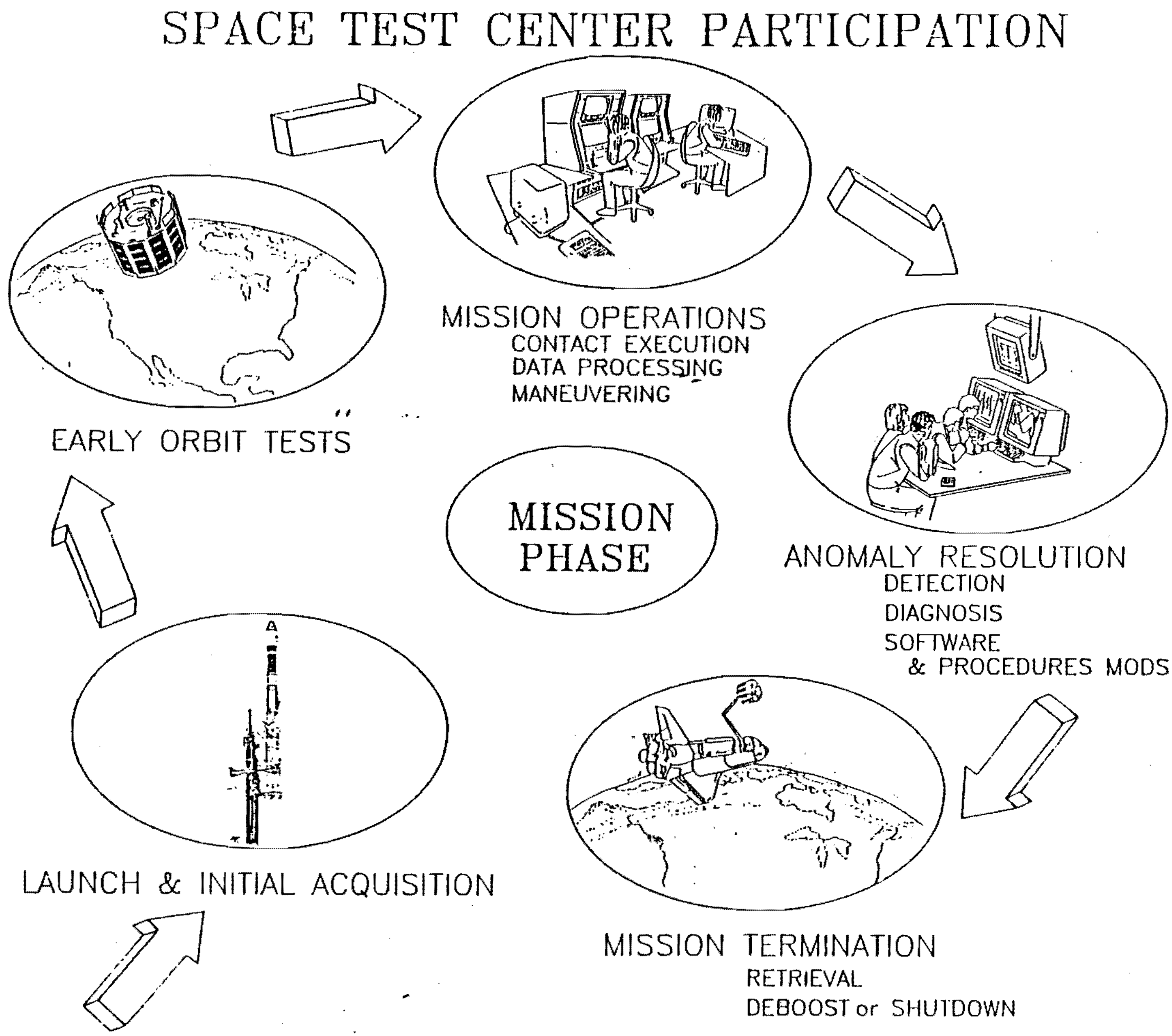

Figure 2. Space Operation Mission Activities