# JOINT OPERATIONS PLANNING FOR SPACE SURVEILLANCE MISSIONS ON THE MSX SATELLITE

Grant Stokes, Lincoln Laboratory, Massachusetts Institute of Technology
Andrew Good, Johns Hopkins University/Applied Physics Laboratory

**Abstract** - The Midcourse Space Experiment (MSX) satellite, sponsored by BMDO, is intended to gather broad-band phenomenology data on missiles, plumes, naturally occurring earthlimb backgrounds and deep space backgrounds. In addition the MSX will be used to conduct functional demonstrations of space-based space surveillance. The JHU/Applied Physics Laboratory (APL), located in Laurel, MD is the integrator and operator of the MSX satellite. APL will conduct all operations related to the MSX and is charged with the detailed operations planning required to implement all of the experiments run on the MSX except the space surveillance experiments. The non-surveillance operations are generally amenable to being defined months ahead of time and being scheduled on a monthly basis. Lincoln Laboratory, Massachusetts Institute of Technology (LL), located in Lexington, MA, is the provider of one of the principle MSX instruments, the Space-Based Visible (SBV) sensor, and the agency charged with implementing the space surveillance demonstrations on the MSX. The planning timelines for the space surveillance demonstrations are fundamentally different from those for the other experiments. They are generally amenable to being scheduled on a monthly basis, but the specific experiment sequence and pointing must be refined shortly before execution. This allocation of responsibilities to different organizations implies the need for a joint mission planning system for conducting space surveillance demonstrations. This paper details the iterative, joint planning system, based on passing responsibility for generating MSX commands for surveillance operations from APL to LL for specific scheduled operations. The joint planning system, including the generation of a budget for spacecraft resources to be used for surveillance events, has been successfully demonstrated during ground testing of the MSX and is being validated for MSX launch within the year. The planning system developed for the MSX forms a model possibly applicable to developing distributed mission planning systems for other multi-use satellites.

## INTRODUCTION

The Midcourse Space Experiment (MSX) is a satellite-based experiment sponsored by the Ballistic Missile Defense Organization (BMDO) to be flown in a low-earth orbit beginning in late 1994. MSX was initially conceived as the first extended duration, long wave infrared (LWIR) phenomenology measurement program sponsored by BMDO; however, these early objectives have evolved into a more comprehensive experiment. MSX is now a multi-year experiment designed to collect broad-band phenomenology data on missiles, plumes, naturally occurring earthlimb backgrounds and deep space backgrounds. In addition, MSX will be used to collect spacecraft contamination data, to integrate, validate, and transfer advanced technologies to current and future BMDO systems, and to conduct functional demonstrations of space-based space surveillance.

The Johns Hopkins University Applied Physics Laboratory (APL) is the integrator and operator of the MSX satellite. MSX will be launched from Vandenberg Air Force Base into a near-polar, low-earth, near sun-synchronous orbit. The MSX, shown in Figure 1, consists of the satellite superstructure, three primary optical sensors, contamination instrumentation and the spacecraft support subsystems. The optical axes of the three primary sensors (Space Infrared Imaging Telescope (SPIRIT III), Space-Based Visible (SBV) sensor, and Ultraviolet/Visible Imagers and Spectrographic Imagers (UVISI)) are parallel to one another and point in the +X direction. The support subsystems consist of the power subsystem, the thermal control
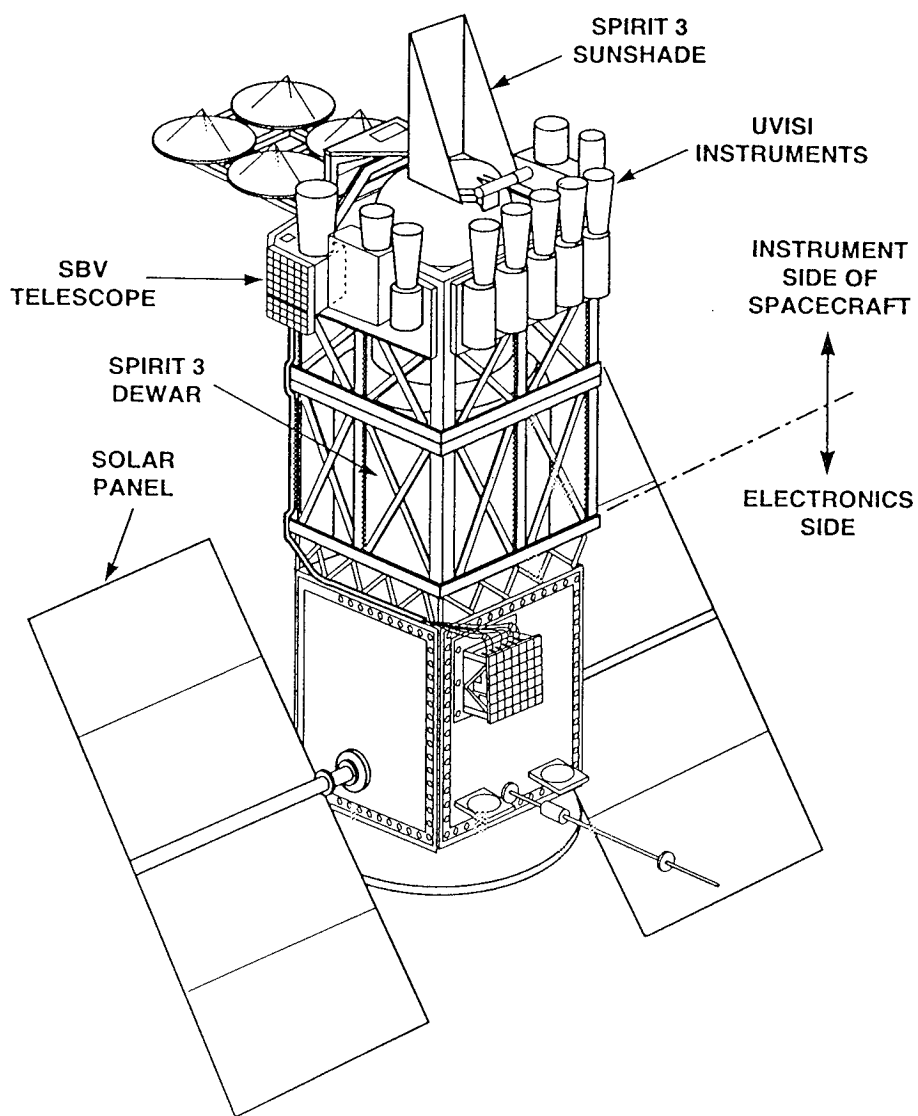
SPIRIT 3
SUNSHADE

UVISI
INSTRUMENTS

INSTRUMENT
SIDE OF
SPACECRAFT

SBV
TELESCOPE

SPIRIT 3
DEWAR

SOLAR
PANEL

ELECTRONICS
SIDE

*Figure 1. MSX satellite*

subsystem, the command and data handling subsystem and the attitude determination and control subsystem. In addition, MSX houses a Beacon Receiver and On-board Signal and Data Processor (OSDP).

The SPIRIT III sensor has been developed by the Utah State University Space Dynamics Laboratory (USU/SDL). It is a passive mid to very long wavelength infrared (M/VLWIR) sensor and is the primary instrument aboard MSX for collecting target and background phenomenological data. SPIRIT III consists of a telescope with a 35.5 cm diameter aperture, a six-channel interferometer, a six-band radiometer and a cryogenic dewar/heat exchanger. The lifetime for SPIRIT III operations, which will be limited by the cryogen supply, is currently projected to be 18-24 months.

The UVISI sensor has been developed by APL with a primary mission to collect data on celestial and atmospheric backgrounds. Other UVISI missions include target characterization in the UV regime and observation of contamination particulates in conjunction with the contamination instruments. The UVISI sensor consists of four imagers and five spectrographic imagers (SPIMs) covering a spectral range from far UV to near infrared. The imagers include wide and narrow field-of-view sensors in both the visible and UV ranges and also include filter wheels to select various passbands. UVISI also includes an image processing system which will be used for closed-loop tracking of targets and aurora.

The SBV sensor, developed by the Lincoln Laboratory, Massachusetts Institute of Technology (LL), is the primary visible wavelength sensor aboard MSX. It will be used to collect data on target signatures and background phenomenologies, but the primary mission of SBV will be to conduct functional demonstrations of space-based space surveillance. SBV incorporates a 15 cm, off-axis, all-reflective, reimaging telescope with a thermoelectrically-cooled CCD focal plane array. SBV also includes an image processing system, experiment control system, telemetry formatter, and a data buffer for temporary data storage.

The collective suite of MSX instruments and supporting subsystems provide a broad range of data collection potential; however, a significant number of operational constraints have been imposed by spacecraft and instrument designers in order to achieve safe operations and to maintain the desired mission life (five years overall including two years for SPIRIT III). These constraints include limitations on boresight pointing relative to the sun, moon, and earth, restrictions on warming of the SPIRIT III dewar and baffle, bounds on battery depth-of-discharge and temperature, and thermal and duty cycle limits for the on-board tape recorders. The combination of these operational constraints with the BMDO goal of 14 data collection events per day represent a significant challenge to the MSX flight operations system.

The MSX flight operations system consists of facilities at APL (Operations Planning Center (OPC), Mission Control Center (MCC), Mission Processing Center (MPC), Performance Assessment Center (PAC), and Attitude Processing Center (APC)), at LL (SBV Processing, Operations and Control Center (SPOCC), and at the USAF Test Support Complex (TSC) at Onizuka Air Force Base. This collection of facilities is referred to as the "extended" MSX Mission Operations Center (MOC). A BMDO-led Mission Planning Team (MPT) instructs the MOC on a monthly basis on the type, number, and priority of experiments to be conducted. The OPC/SPOCC then develop operations planning products (e.g., schedules, contact support plans, command loads) which are provided to the MCC and TSC for execution. Spacecraft science and housekeeping data are collected by the MCC and TSC and then processed by the MPC, APC, and PAC as well as disseminated to the MSX data community.

# SPACE SURVEILLANCE

Currently the United States maintains a world wide network of ground based sensors tasked with the acquisition of tracking data on all manmade objects in orbit around the earth. These sensors include a network of passive optical systems which are limited to a short duty cycle by poor weather and by daylight. Since foreign based sites are progressively more expensive and inconvenient to support, it is natural to ask whether ground based sensors could be supplemented or replaced by satellite based sensing systems. Satellite based sensors are not limited by daylight operation or poor weather and a single satellite borne sensor can sample the entire geosynchronous belt satellite population several times per day.

One of the missions of the MSX satellite is to demonstrate the feasibility of space-based space surveillance operations. One of the three principle MSX sensors, the SBV sensor has been specifically designed to provide visible-band satellite tracking data. The SBV consists of a six inch optical telescope with high off-axis rejection optics designed to acquire good quality satellite track data quite near the bright earth limb. In addition to the visible data from the SBV, track and optical signature data from the other MSX sensors is of interest to the space surveillance community. This is especially true for data from the SPIRIT III long-wave infrared sensor which promises the ability to detect satellites in the shadow of the earth.

The mission planning required to execute space surveillance activities is fundamentally different from that required to execute the other MSX missions. Normally space surveillance sensors are tasked on a day at a time basis by Space Command. In addition, Space Command provides special updates to the sensor tasking for special events, such as new launches, which require reactions on short time lines (minutes to hours). This operational tempo is significantly shorter than the normal MSX mission planning process which requires the operation to be well defined at the monthly planning level, which occurs as much as 10 weeks before the execution of the event on the spacecraft. If the routine MSX planning timeline were followed and space surveillance experiments were pre-planned, the ephemeris of many low altitude satellites targeted for observation will have changed enough to put them out of the sensor field of view by the experiment execution time. In addition, the normal MSX planning procedure contains no provision for generating observations in response to quick reaction experiments such as the launch of a new satellite.

The mission planning for the Space Surveillance experiments on the MSX satellite requires the ability to leave considerable flexibility in the experiment timing and attitude profile to be followed by the MSX in the experiment execution until late in the experiment planning process. Under "normal" circumstances the details of the operation, consisting of the list of satellites to be observed, the attitude profile for the MSX and the data acquisition times can be defined one to two days before the execution on the MSX. Special "quick reaction events", such as acquiring track data on a newly launched satellite in its transfer orbit to the geosynchronous belt, require reaction times on the order of hours.

## JOINT PLANNING PROCESS

The mission planning required to operate a satellite as complex as the MSX is a large task under any condition: however, it is complicated further by the breadth of the experimental missions to be conducted by the satellite. Most of the MSX experiments are amenable to a long-term planning process either because their targets are slowly changing (eg., naturally occurring earthlimb and deep space backgrounds) or because they are under the control of the experimenter (eg., dedicated missile shots). This long-term planning process allows time for the mission planners to communicate with the Principle Investigators to clarify the details of a specific experiment in the planning process. On the other hand the space surveillance experiments designed at Lincoln Laboratory, Massachuetts Institute of Technology require fundamental modifications late

in the planning process on timelines that admit little manual intervention. Thus, the MSX program was faced with a fundamental decision to either implement a highly automated and expensive general purpose planning system which would accommodate the complete set of diverse MSX experiments or to build a long-term planning system for the majority of the experiments and allow a link into the planning process from a more automated system dedicated to planning the space surveillance experiments. For reasons of economy and to minimize the complexity of the entire implementation, the second option was chosen. Since the expertise needed to fulfill the space surveillance mission planning function resides at Lincoln Laboratory, the center for surveillance experiment planning was located there in the SBV Processing, Operations and Control Center (SPOCC).

In order to simplify the planning procedures and to allow the parallel planning of experiments at APL and LL centers, the following three principles were adopted by the organizations involved:

I. The planning team at LL is responsible for complete operation of the MSX spacecraft and all its sensors during the time period scheduled for a surveillance experiment. Thus, the LL team will receive the MSX in a given standard configuration, known as parked mode, will generate all the command information for both the satellite and sensor sub-systems required to implement the data collection and will return the spacecraft to the standard parked mode upon completion of the event. The LL planning team is responsible for abiding by all spacecraft constraints and operating rules during the conduct of surveillance events

II. The long-term planning for the space surveillance events will consist of allocating time intervals and resource budgets to the space surveillance events. Thus, it has been agreed that the specific modes of satellite operation for surveillance experiments will be left to be filled in the day prior to conduct of the event. However, during the long-term planning process, the experiment will be scheduled during a specified time interval and the integrated effect on the MSX resources, such as battery depth-of-discharge (DOD) and changes to the spacecraft thermal state will be agreed on a "not to exceed" basis.

III. The final responsibility for safe spacecraft operations will belong to APL which will check all command information generated by LL. The check will be automated and will be conducted shortly before upload of the commands to the MSX.

These three principles enable the parallel planning of operations at the two centers by clearly separating the responsibilities of each planning center during each of the planning intervals necessary to operate the MSX. However, they also require an overlap of capability between the two planning sites because both must be able to generate command information for the entire satellite. This duplication was accepted as a cost of having a distributed planning system.

The planning system for the MSX goes through four phases of activity as shown in Figures 2 and 3 in order to generate a data collection event for the satellite. The phases and the interaction between the planning centers for surveillance events are described below:

Opportunity Analysis - The planning centers are given experiment priorities on a monthly basis by the BMDO run Mission Planning Team. The priorities are provided six weeks before the start of the month being planned. Once the priorities are received each planning center, the OPC at APL and the SPOCC at LL, analyzes the experiments for which they are responsible to determine feasible times for which data may be collected. For surveillance experiments, items such as target visibility, sun angle and proximity to the earth limb or earth shadow are considered and a list of feasible times is compiled. The opportunity list includes the start and duration of each feasible event start time, the event duration, the relative desirability of that particular feasible time compared with others on the list, an indication of the accuracy of the estimated event start time (eg., if the
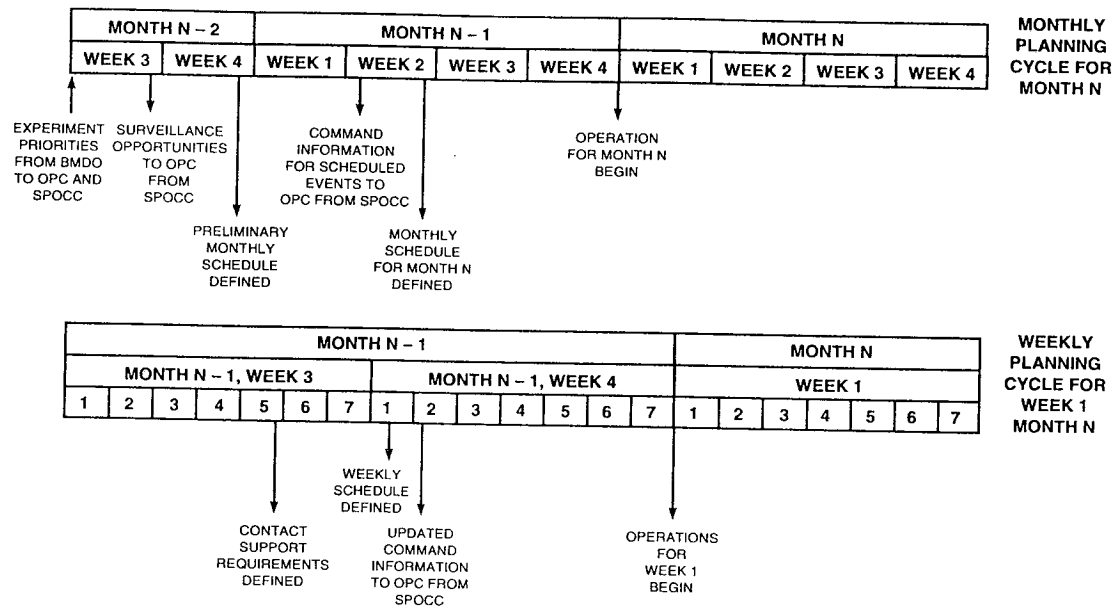
## Figure 2

| | MONTH N − 2 | | MONTH N − 1 | | | | MONTH N | | | | MONTHLY PLANNING CYCLE FOR MONTH N |
|---|---|---|---|---|---|---|---|---|---|---|---|
| WEEK 3 | WEEK 4 | WEEK 1 | WEEK 2 | WEEK 3 | WEEK 4 | WEEK 1 | WEEK 2 | WEEK 3 | WEEK 4 | | |

EXPERIMENT PRIORITIES FROM BMDO TO OPC AND SPOCC

SURVEILLANCE OPPORTUNITIES TO OPC FROM SPOCC

COMMAND INFORMATION FOR SCHEDULED EVENTS TO OPC FROM SPOCC

OPERATION FOR MONTH N BEGIN

PRELIMINARY MONTHLY SCHEDULE DEFINED

MONTHLY SCHEDULE FOR MONTH N DEFINED

| MONTH N − 1 | | | | | | | | | | | | | | MONTH N | | | | | | | WEEKLY PLANNING CYCLE FOR WEEK 1 MONTH N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MONTH N − 1, WEEK 3 | | | | | | | MONTH N − 1, WEEK 4 | | | | | | | WEEK 1 | | | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |

WEEKLY SCHEDULE DEFINED

CONTACT SUPPORT REQUIREMENTS DEFINED

UPDATED COMMAND INFORMATION TO OPC FROM SPOCC

OPERATIONS FOR WEEK 1 BEGIN

*Figure 2. Monthly and weekly planning cycles for MSX experiment*

## Figure 3

GROUND STATION CONTACT SCHEDULE FOR DAY D

| DAY D − 2 | DAY D − 1 | DAY D |
|---|---|---|

GMT 1600    0400    1600    0400    1600    0400    1600

DAILY CONTACT SUPPORT REQUIREMENTS FOR DAY D

FIRST HALF OF DAY D

DAILY SCHEDULE FOR DAY D DEFINED

OPERATIONS FOR DAY D BEGIN

EVENTS NOT AFFECTED BY CONTACT SCHEDULE

SECOND HALF OF DAY D

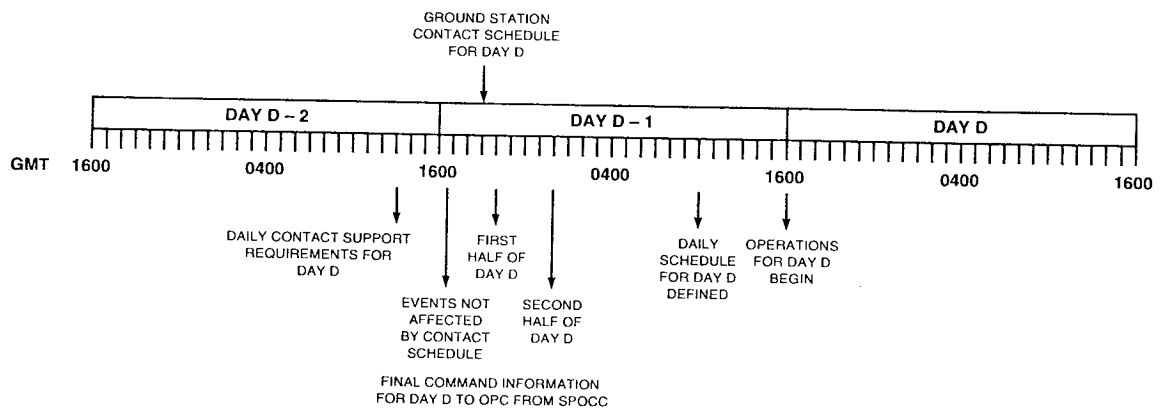FINAL COMMAND INFORMATION FOR DAY D TO OPC FROM SPOCC

*Figure 3. Daily planning cycle for MSX experiments*

243594-1

satellite to be observed has a low altitude, the time it becomes visible will not be precisely known 10 weeks in advance) and a pointer to an example set of command information for that type of event. The space surveillance opportunity list and the example command information sets are provided to the OPC for integration with the other experiments in the Monthly Planning Process.

Monthly Planning - The OPC combines the opportunity lists for each of the different types of experiments and constructs a schedule of data collection events to be conducted during the month. Since the MSX spacecraft is not designed for 100% duty cycle, the scheduling process must pay close attention to the use of spacecraft resources. In addition, the cryogenic SPIRIT III sensor is very sensitive to the thermal state and history of the MSX. In order to estimate the resources which will be used by the space surveillance events, the OPC analyzes the sample command information provided by the SPOCC for each event type and estimates the change in battery DOD and the thermal deltas for critical elements. These estimated resource expenditures now become a "not to exceed" budget for the conduct of the surveillance data collection event. The actual pointing and targets may be considerably different, but the integrated effect on the spacecraft resources may not be any larger than that defined during the monthly scheduling process. The OPC generates a monthly schedule for the MSX operations during the month and, after suitable iteration with BMDO and the SPOCC, the schedule is published and the SPOCC provides the OPC with preliminary command information for all of the space surveillance events as scheduled. The Weekly Planning process is then started for the first week of the planning month as shown in Figure 2.

Weekly Planning - Weekly planning is largely used by the OPC to update non-space surveillance experiments to reduce the amount of work needed at the daily planning level. In addition, the uplink and downlink requirements for the earth stations in the SGLS network are compiled and input into the scheduling process at the TSC. For surveillance experiments, the automated SPOCC planning system is re-run taking into account the updated ephemeridies for the intended targets (if known at the time) and the MSX, and an update of the event start times is provided to the OPC along with revised command information for each event to be executed during the planning week.

Daily Planning - The final mission planning occurs at the daily planning level, which occurs the day before the events are to be executed on the MSX, as shown in Figure 3. At that time the final uplink/downlink schedules are known, the orbital geometry of the MSX and the targets are available with sufficient accuracy and tasking lists are available from Space Command for tasked experiments. At that time the SPOCC generates final sets of command information for each event during the day and provides them to the OPC for analysis and inclusion in one of the three command upload creation cycles run during each day for the MSX. The SPOCC is responsible for generating command information that is compliant with all MSX constraints, operation rules and resource budgets determined during the scheduling process. The OPC conducts a final, automated analysis of the events as provided by the SPOCC and, if they are compliant with the agreed rules, incorporates them into the command load.

Quick Reaction Events - A number of space surveillance events require shorter timelines than provided by the daily planning process described above. These include events such as the launch of a new satellite, which is scheduled well in advance, but the specific launch time is not known with sufficient accuracy until after the launch. A series of special procedures have been developed to plan events requiring a very quick response from the planning system. The procedures require that an interrupt window be defined at the monthly planning level. The window defines a range of times during which normal MSX operations can be disrupted in order to collect data on a specific event if it happens. The ability to capture the event depends on the availability of suitable pre-scheduled ground station uplinks which may be used to uplink new commands to the MSX. Once a quick reaction event has been declared, the SPOCC will generate commands to observe the satellite based on tipoff information from Space Command (such as the time of launch in the case of a new launch) and will forward the new commands to APL for inclusion in an uplink which will

325

cancel the existing commands and replace them with those required to execute the quick reaction event observations. Preliminary timing tests run on the planning process indicate that the SPOCC can have the required command information ready for transmission to APL within 30 minutes of the launch and that APL can process the results in time to track a satellite in a transfer orbit to geosynchronous altitude. Final timing tests and procedure verification will take place after a period of operational experience with the MSX under the normal planning process.

## CONCLUSIONS

In order to accommodate the mission planning for a broad range of diverse experiments to be run on the MSX satellite, a distributed mission planning system has been defined and implemented. Under this model, the MSX mission planning is accomplished for all non-surveillance experiments using a long-term planning process at the APL OPC. Space surveillance experiments are planned by LL and carried in the APL planning schedule as event durations and resource utilization budgets without the details of the operation which are provided to the OPC during the final Daily Planning process in command ready form.

This system of distributed mission planning has been developed for a complex, multi-function/multi-mission spacecraft where the expertise needed to conduct mission planning for various mission types is distributed between two locations. The advantage of the process as defined is that the two planning centers can conduct the mission planning functions in parallel, each adding the details of the operation as they are available or according to the capabilities of each planning system. The event is held in the master schedule by budget allocations and schedule place holders until the final details are available. Having each planning center responsible for generating command information for the entire spacecraft for the events for which they are responsible simplifies the interaction between planning centers considerably since each can consider the other's events as "black boxes" until the final details are provided in a complete package. The disadvantage of this approach is that each planning center needs to understand and be capable of commanding every satellite function that will be needed to satisfy their events.

Given that many of the satellites launched currently are large multi-function payloads containing a broad range of instruments, collecting data for a diverse user set, the MSX planning system experience may yield broadly applicable lessons learned. The main requirement to implementing such a cooperative planning system has been a mutual understanding of each participant's mission requirements and a willingness on the part of all parties to consider all the alternatives and to negotiate a sensible approach to solving the mission planning puzzle.

# MULTI-MISSION OPERATIONS FROM THE HEADQUARTERS PERSPECTIVE

Guenter Strobel
NASA-HQ

Paper Not Available