# A Multimission Three-Axis Stabilized Spacecraft Flight Dynamics Ground Support System*

N93-24714
520-17
154740
p. 12

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## ABSTRACT

The Multimission Three-Axis Stabilized Spacecraft (MTASS) Flight Dynamics Support System (FDSS) has been developed in an effort to minimize the costs of ground support systems. Unlike single-purpose ground support systems, which attempt to reduce costs by reusing software specifically developed for previous missions, the multimission support system is an intermediate step in the progression to a fully generalized mission support system in which numerous missions may be served by one general system. The benefits of multimission attitude ground support systems extend not only to the software design and coding process, but to the entire system environment, from specification through testing, simulation, operations, and maintenance.

This paper reports the application of an MTASS FDSS to multiple scientific satellite missions. The satellites are the Upper Atmosphere Research Satellite (UARS), the Extreme Ultraviolet Explorer (EUVE), and the Solar Anomalous Magnetospheric Particle Explorer (SAMPEX). Both UARS and EUVE use the multimission modular spacecraft (MMS) concept. SAMPEX is part of the Small Explorer (SMEX) series and uses a much simpler set of attitude sensors. This paper centers on algorithm and design concepts for a multimission system and discusses flight experience from UARS.

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* This work was supported by the National Aeronautics and Space Administration (NASA)/Goddard Space Flight Center (GSFC), Greenbelt, Maryland, Contract NAS 5-31500.

# 1. INTRODUCTION

In 1987 the Upper Atmosphere Research Satellite (UARS) Attitude Ground Support System (AGSS) was being specified for Goddard Space Flight Center (GSFC). At this time the specifications support started for another mission, the Extreme Ultraviolet Explorer (EUVE). During the initial requirements analysis for EUVE, it was realized that UARS and EUVE were very similar in both hardware configuration and support requirements. The decision was made to generalize the UARS software specifications to include the EUVE support requirements.

Flight Dynamics Division (FDD) attitude support falls into three categories: attitude determination, attitude sensor calibration, and prediction of flight dynamics-related parameters that are used for mission and science planning. A typical AGSS is composed of many functions, but can be broken down into six areas: telemetry processing, data adjustment, attitude determination, sensor calibration, sensor monitoring, and planning aids prediction.

Data come into the system as spacecraft telemetry. The telemetry processing function unpacks and time tags the data and passes them to the next function, data adjustment. The data adjustment function corrects the data for known misalignments and biases and applies validation tests to reject bad data. The adjusted data are then ready for the attitude determination and sensor calibration functions.

There is usually more than one attitude determination function to support different levels of accuracy and response time. Also, there is a sensor calibration function for each calibration parameter being computed. The attitude determination and sensor calibration results are usually delivered to the spacecraft control center for uplink to the spacecraft in support of onboard attitude determination. The sensor monitoring function is an analysis aid that supports sensor performance evaluations.

The planning aids prediction function is a collection of functions for the production of mission and science planning aids. Some of these planning aids are mission-unique, but many are meant to meet similar requirements for a variety of missions. The common planning aids include guide star interference predictions, antenna contact times, spacecraft range predictions, and solar array position predictions.

The multimission concept is an intermediate step in the progression to a generalized mission support system in which numerous missions may be served by one general system. Multimission systems are useful when generalized systems are not available or cannot be fully achieved. The benefits of multimission systems extend not only to the software design and coding process but to the entire system environment, from specification through testing, training, operations, and maintenance.

The Multimission Three-Axis Stabilized Spacecraft (MTASS) Flight Dynamics Support System (FDSS), referred to as MTASS in the remainder of this paper, is an institutional system that provides key functions required for spacecraft attitude ground support (see Reference 1). The AGSS for a specific mission is composed of mission-specific functions in combination with MTASS.

# 2. SYSTEM DEVELOPMENT

This section deals with the specification and design aspects of the MTASS systems development process.

## 2.1 Specifications

In the requirements analysis and functional specifications phase, the inherent commonality of the UARS and EUVE modular attitude determination and control systems influenced our approach. Since the EUVE AGSS was regarded, to first order, as a subset of the UARS AGSS, the UARS requirements and functional specifications were generalized to include the EUVE requirements.

During the generalization of the UARS specifications, it became clear that, with minimal extra effort, the specifications could be generalized much further than simply necessary to support two missions. During every step of the specifications support, ways were investigated to generalize the system as far as possible. As an example, spacecraft attitude is usually represented as a set of roll, pitch, and yaw angles with respect to some reference coordinate system. The most straightforward approach to producing a two-spacecraft system would be to specify an "If UARS...if EUVE..." type of construction to define the coordinate system. This method is obviously a dead-end that does not allow for other mission definitions. Instead, the specifications allow the user to specify the transformation Euler sequence and the reference coordinate system. This approach makes the system configurable and usable for any mission. Through this approach to generalization, MTASS was born.

To go beyond the reuse seen in previous ground systems, it was recognized that reuse on the subsystem level was required. Each of the functions described above have traditionally been implemented as separate subsystems; however, each subsystem was coded to be mission-specific with, at best, reuse of low-level software units. The MTASS concept was to organize the generic and mission-specific functions into separate subsystems, thereby allowing reuse of higher-level functions and entire subsystems. MTASS specified only generic algorithms for a given subsystem and thereby built up generic subsystems. Those algorithms that were unavoidably mission-unique were segregated into separate subsystems.

## 2.2 Design Considerations

This section reviews MTASS design considerations and shows that the design is sensor-oriented, MTASS is table-driven, the files are sensor-oriented, and the design is extensible.

### 2.2.1 MTASS Design Is Sensor-Oriented

The traditional functional approach to the design of MTASS was supplemented successfully with sensor/actuator-oriented thinking and software partitioning. Although object-oriented design techniques were not employed, the design partitioning was conceived with sensors as the design objects within each major functional partition (i.e., subsystem). The sensor-oriented partitioning lies along the intermediate level in that each subsystem contains software packages for each type of sensor and actuator appropriate to the subsystem function.

For example, the data adjustment subsystem (DA) is a major functional partition that prepares the engineering data for attitude determination and other functions by applying calibration parameters (biases and misalignments), smoothing, and performing a few cross-sensor validation checks. The major portion of the DA is the application of calibration parameters. This function is partitioned by sensor type, resulting in a separate software package for the fine Sun sensor (FSS), the three-axis magnetometer (TAM)/magnetic torquer assembly (MTA), the inertial reference unit (IRU), etc.

Table 1 contains an entry for each of the MTASS subsystems. Each entry includes the subsystem function, operating mode, and selectable subfunctions.

### 2.2.2 MTASS Is Table-Driven

Each MTASS subsystem has user-supplied configuration parameters that specify which sensors are present on a particular spacecraft, in a particular telemetry format, or needed for a particular operational scenario. Using these parameters, subsystems can be configured to support any three-axis stabilized spacecraft that contains a subset of the currently supported hardware and for which the engineering data are supplied in the MTASS formats. The one restriction is that IRU data are required for attitude determination using the MTASS coarse and fine attitude determination subsystem (CFADS), which employs a differential correction least-squares fit and uses body rates from the IRU data to propagate. This restriction will be alleviated when a new single-frame attitude determination subsystem, which employs the QUEST algorithm, is completed.

## Table 1. MTASS Subsystems and Selectable Subfunctions (1 of 2)

| SUBSYSTEMS | FUNCTION |
|---|---|
| ATTITUDE DETERMINATION SYSTEM (ADS) EXECUTIVE (ADSEXEC) | • ALLOW SELECTION OF INTERACTIVE ADS SUBSYSTEMS: MISSION SPECIFIC TELEMETRY PROCESSOR (TP), DA, STARID, DS, CFADS, DADS (ALSO OPERATES IN BATCH MODE) |
| DATA ADJUSTMENT (DA) | • APPLY MISALIGNMENTS AND/OR BIASES TO:<br>(A) COARSE SUN SENSORS (UP TO 2 CSSs)<br>(B) EARTH SENSOR ASSEMBLIES (UP TO 2 ESAs)<br>(C) FIXED HEAD STAR TRACKERS (UP TO 2 FHSTs)<br>(D) FINE SUN SENSOR (UP TO 1 FSS)<br>(E) INERTIAL REFERENCE UNIT (UP TO 1 IRU)<br>(F) THREE-AXIS MAGNETOMETER (UP TO 2 TAMs, OPTIONALLY INCLUDING EFFECTS FROM MAGNETIC TORQUER ASSEMBLIES (MTAs))<br>• OPTIONALLY SMOOTH BODY RATES FROM IRU<br>• OPTIONALLY VALIDATE DATA USING DOT PRODUCT CHECKS |
| STAR IDENTIFICATION (STARID) | • USE TRIPLET, DOUBLET, SINGLE MATCH (STARID) HIERARCHY TO IDENTIFY STAR OBSERVATIONS FROM FHST AGAINST STAR CATALOG |
| COARSE/FINE ATTITUDE DETERMINATION (CFADS) | • DETERMINE SPACECRAFT ATTITUDE USING BATCH LEAST-SQUARES DIFFERENTIAL CORRECTION TECHNIQUE (NOTE: REQUIRES IRU)<br>• PRECISION OF ATTITUDE SOLUTION IS DETERMINED BY SELECTION OF SENSOR DATA ADJUSTED BY THE DA<br>• OPTIONALLY CALCULATE TAM BIASES<br>• OPTIONALLY WRITE ATTITUDES AT AN EPOCH TIME AND/OR A SPECIFIED DELTA TIME, AND/OR WRITE ATTITUDE RATES AT THE SPECIFIED DELTA TIME |
| DATA SEGMENTER (DS) | • DETERMINE OPTIMUM/SUITABLE TIMESPANS TO ENSURE IRU DATA ARE AVAILABLE AND LOCATE FHST OBSERVATIONS NEAR BATCH BOUNDARIES FOR BEST PRECISION IN CFADS |
| DEFINITIVE ATTITUDE DETERMINATION (DADS) | • USE ATTITUDE PROPAGATION AND CORRECTION TO FORCE MULTIPLE SEQUENTIAL BATCHES OF CONTINUOUS ATTITUDES TO MATCH AT BATCH BOUNDARIES FOR CONTINUOUS ATTITUDES |
| GRAPHICS USER INTERFACE (GUI) | • ALLOW SELECTION OF INTERACTIVE CALIBRATION AND ATTITUDE VALIDATION SUBSYSTEMS<br>• MAINTAIN AND REPORT CALIBRATION PARAMETERS FROM SENSOR CALIBRATION FILES<br>• MANUALLY LOG AND REPORT MESSAGES IN ACTIVITIES LOG FILE(S) |
| ATTITUDE VALIDATION (ATTVAL) | • COMPARE PAIRWISE THE OBC-COMPUTED ATTITUDE, THE PREDICTED ATTITUDE, AND THE GROUND-DETERMINED ATTITUDE<br>• EXAMINE ATTITUDES FROM INDIVIDUAL SOURCES |
| INERTIAL REFERENCE UNIT CALIBRATION (IRUCAL) | • CALIBRATE IRUs BY CONFIGURATION |
| FINE SUN SENSOR, EARTH SENSOR, FIXED-HEAD STAR TRACKER CALIBRATION (FEFCAL) | • CALIBRATE FSSs, ESAs, FHSTs |

## Table 1. MTASS Subsystems and Selectable Subfunctions (2 of 2)

| SUBSYSTEMS | FUNCTION |
|---|---|
| FINE SUN SENSOR FIELD OF VIEW CALIBRATION (FSSFOV) | • CALIBRATE FSS FIELD OF VIEW |
| THREE-AXIS MAGNETOMETER CALIBRATION (TAMCAL) | • CALIBRATE TAMS |
| BATCH MODE SUBSYSTEMS | • FOLLOWING SUBSYSTEMS ARE OPERATED IN BATCH MODE ONLY AND ARE INDIVIDUALLY SUBMITTED FOR EXECUTION |
| (UARS) STS ATTACHED MONITOR (UMON) | • GENERATE DISPLAY FOR CCTV DISTRIBUTION OF SPACECRAFT PARAMETERS INCLUDING ONBOARD ATTITUDE AND STS PARAMETERS DURING DEPLOYMENT FROM STS |
| ATTITUDE PREDICTION (ATTPRED) | • PREDICT ATTITUDES |
| HIGH-GAIN ANTENNA, TDRSS CONTACT PREDICTION (HGA) | • PREDICT POTENTIAL CONTACT TIMES BETWEEN HGA AND TDRSS |
| GUIDE STAR OCCULTATION PREDICTION (GSOC) | • PREDICT WHEN GUIDE STARS ARE OCCULTED BY THE EARTH, MOON, AND PLANETS |
| ORBIT VALIDATION (UTEP) | • CONVERT OBC-DETERMINED SPACECRAFT POSITION TO STANDARD CODE 500 EPHEMERIS FILE FORMAT FOR SUBSEQUENT COMPARISON WITH GROUND-DETERMINED AND PREDICTED ORBIT VECTORS USING INSTITUTIONAL SOFTWARE |
| CALIBRATION DELIVERY FORMATTING (CALFORM) | • SELECT AND CONVERT CALIBRATIONS FOR FORMATTING (ULTIMATE USE AS UPLOAD TO OBC) |
| PRODUCT DELIVERY FORMATTING (DELFORM) | • PACK DELIVERY RECORDS INTO STANDARD CODE 550 PRODUCT DELIVERY FORMAT |

### 2.2.3 MTASS Files Are Sensor-Oriented

Another crucial aspect of the MTASS design is the organization of the primary data interfaces. They are the engineering data sets data base (EDS), processed engineering data sets data base (PEDS), attitude history files (AHFs), and sensor calibration files (SCFs). Table 2 contains a functional description of each of the major file types unique to MTASS. MTASS also uses the institutional spacecraft ephemeris, solar/lunar/planetary (SLP) ephemeris, activities log, report data base, MMS star catalog, and tracking station geodetics file types.

The primary spacecraft data input to MTASS is through the EDS. The EDS is an MTASS-specific data base of spacecraft engineering data produced by a mission-specific telemetry processing (TP) subsystem. The EDS is a collection of engineering data sets tied together by an EDS directory data set.

Each individual engineering data set contains batches of engineering data corresponding to one sensor or actuator. Each batch is user definable, but nominally corresponds to the data processed in one session from one telemetry transmission. The user can delete and overwrite the oldest batches, add new batches, or concatenate data to the most recent batch. The directory data set contains summary information for each batch, including which sensors are in the batch.

The specific subset of engineering data sets included in a given EDS is definable by the user when that EDS is initialized. Further, the specific sub-subset of engineering data sets included in a given batch is definable at run time. Using these options, an EDS can be initialized that can contain data from only those sensors and actuators that are desired for a specific operational scenario using a specific spacecraft telemetry mode. Alternatively, an EDS can be initialized that can contain data from all of the sensors and actuators on a given spacecraft, and a given batch can contain data only for those sensors involved in a specific operational scenario.

## Table 2. MTASS Data Sets

| SUBSYSTEM | FUNCTION |
|---|---|
| ATTITUDE HISTORY FILE | • QUATERNIONS, EULER ANGLE RATES |
| ENGINEERING DATA SET (EDS) DIRECTORY FILE | • GENERAL DATA FOR EACH BATCH (HEADERS) |
| EDS FSS | • FSS ALPHA, BETA ANGLE COUNTS |
| EDS ESA | • ESA PITCH, ROLL ANGLES |
| EDS FHST | • FHST H AND V COUNTS AND INTENSITY |
| EDS TAM | • MAGNETIC FIELD VECTOR |
| EDS IRU | • IRU ACCUMULATED ANGLES |
| EDS ANALOG IRU | • ANALOG IRU RATE VECTOR |
| EDS CSS | • CSS PITCH, YAW ANGLES AND SOLAR PANEL ANGLES |
| EDS HGA | • HIGH-GAIN ANTENNA GIMBAL ANGLES |
| EDS MTA | • MAGNETIC TORQUER DIPOLE MOMENT VECTOR |
| EDS RWA | • ANGULAR MOMENTUM OF REACTION WHEELS |
| EDS THRUSTER FIRING | • THRUSTER FIRING COUNTS AND PULSE WIDTH |
| EDS THRUSTER TANKS | • THRUSTER TANK TEMPERATURES AND PRESSURE |
| EDS OBC EPHEMERIS | • OBC-DERIVED SPACECRAFT POSITION AND VELOCITY |
| PROCESSED ENGINEERING DATA SET (PEDS) DIRECTORY FILE | • GENERAL DATA FOR EACH BATCH (HEADERS) |
| PEDS FSS | • OBSERVED SUN UNIT VECTOR |
| PEDS ESA | • OBSERVED EARTH UNIT VECTOR |
| PEDS FHST | • OBSERVED STAR UNIT VECTOR, REFERENCE STAR UNIT VECTOR, AND STAR MAGNITUDE |
| PEDS TAM | • OBSERVED MAGNETIC FIELD VECTOR |
| PEDS IRU | • OBSERVED BODY ROTATION RATES |
| PEDS CSS | • SUN UNIT VECTOR AND SOLAR PANEL ANGLES |
| ESA SENSOR CALIBRATION FILE (SCF) | • ESA ALIGNMENT AND BIAS |
| FHST SCF | • FHST ALIGNMENT |
| FSS SCF | • FSS ALIGNMENT AND FOV CALIBRATION |
| IRU SCF | • IRU ALIGNMENT, SCALE FACTOR, AND BIAS |
| TAM SCF | • TAM ALIGNMENT, SCALE FACTOR, AND BIAS |
| HGA GIMBAL MASK FILE | • FILE DEFINING HGA MASK |

Most of the attitude determination-related engineering data contained in an EDS are processed by the DA, which produces the PEDS. The PEDS are organized like and contain the same selectivity as the EDS. One significant feature specific to the PEDS is the commonality of data representation. For each appropriate sensor type in the PEDS, the processed engineering data are represented as a vector. The PEDS are the most central data storage point for the MTASS. PEDS batches are created by the DA. Numerous subsystems obtain data from the PEDS, although a few use EDS data directly.

Each batch of PEDS data contains the complete set of calibration parameters applied to that data. The DA obtains these calibrations from the SCFs. One SCF exists for each type of sensor. Each SCF can contain the calibration parameters for up to 10 of that sensor type. For each sensor represented in an SCF, a complete history of calibrations can be maintained. Additionally, the current default set of calibration parameters for each sensor is marked for easy retrieval by the DA, and every past default set of parameters is identified as such.

When the DA retrieves a set of calibration parameters, the current default can be selected, or the user can select the desired set from a list of all sets for the specific sensor in question. A separate maintenance function also exists that allows the user to delete obsolete sets of calibration parameters and change the default set.

At several points in MTASS the spacecraft attitude is written to an AHF. The onboard computed (OBC) attitude can be written from the mission-specific TP, the coarse or fine attitude is written from the CFADS, and a definitive attitude series is written from the definitive attitude determination subsystem (DADS). Additionally, the CFADS can optionally write attitude rates with or without the accompanying attitudes.

The MTASS AHF was defined as a new standard file for storing attitude information. The attitude is stored as a quaternion in the geocentric inertial (GCI) frame. The attitude rates are stored as angular rates about each spacecraft body axis. The data on an AHF are stored in batches. Each batch has a set of header records, optionally followed by a series of attitude data records. The header records contain an optional epoch attitude quaternion and an optional epoch spacecraft orbit vector. The attitude data records in a given batch can contain attitude quaternions, attitude rates, or both.

The concept of generalized data structures was also applied to the definition of delivery file formats for planning aids. If the delivered product is the same for each mission, there is no need for a different software system. The FDD negotiated with other NASA/GSFC ground support elements for the acceptance of generalized file formats as standard FDD products. This standardization has been most successful for planning aids.

MTASS uses the well defined GSFC Code 500 standard ephemeris (EPHEM) file format for spacecraft position vectors, and the SLP ephemeris file for positions of the Sun, Moon, and planets.

As is traditional in GSFC Code 550 flight dynamics software, the FORTRAN NAMELIST technique is used for all user-definable configuration and control parameters. The NAMELIST files allow the user to override the hard-coded default values. These NAMELIST files are created or modified prior to the time of execution of MTASS. NAMELIST files can be set up for each operational scenario for each spacecraft to define each needed configuration. Most configuration and control parameter values can also be modified at execution time for those subsystems containing an interactive user interface.

### 2.2.4 MTASS Design Is Extensible

The list of sensors supported by MTASS can be extended through enhancement development efforts. The spacecraft hardware currently supported by MTASS was defined by the needs of UARS. The sensor-oriented design in MTASS, however, allows for the addition of other sensor and actuator types. Each appropriate subsystem would be modified to add a new software package to process data from the new hardware type, and corresponding configuration and control parameters would be added.

An alternative approach was employed for the Solar, Anomalous, and Magnetospheric Particle Explorer (SAMPEX) spacecraft. The SAMPEX hardware was similar, but different from that supported by MTASS. Consequently, the SAMPEX telemetry processor (TP) contained special processing to convert the SAMPEX digital Sun sensor (DSS) data to comply with the MTASS FSS EDS format. The SAMPEX coarse Sun sensor (CSS) arrays were processed to produce MTASS CSS EDS data. Finally, SAMPEX does not contain an IRU, so the SAMPEX TP calculates body rates to store in the MTASS IRU engineering data sets (which are needed by the CFADS to propagate attitudes). Finally, the SAMPEX attitude needs to be reported in a special

Sun-based reference frame, so the SAMPEX AGSS contains an attitude postprocessor that converts the MTASS attitudes from the AHF into the desired form. This SAMPEX AGSS is a good example of building a relatively small amount of extra processing in the front and back of the system in order to reuse entire MTASS subsystems.

## 3. FLIGHT EXPERIENCE WITH MTASS

At present, flight experience with MTASS consists primarily of experience with UARS, although some prelaunch spacecraft telemetry processing experience is now available from EUVE. Our discussions of MTASS flight experience are thus primarily directed to the UARS mission (see Reference 3).

UARS flight experience with MTASS can be divided roughly into nominal behavior and non-nominal behavior. Although the bulk of mission events to date fall into the class of nominal behavior, and although MTASS has performed in most respects like any other attitude support system created for the Mission Operations and Data Systems Directorate (MO&DSD), such non-nominal behavior as has been observed to date is reviewed here with the objective of identifying any features of this behavior that could be traced to the multisatellite character of MTASS. Our finding is that the non-nominal behavior was not attributable to the multisatellite character of MTASS.

Areas of nominal behavior with MTASS identified to date in the UARS mission experience include the following:

| **Phase** | **Behavior** |
|---|---|
| Prelaunch | Generating and transmitting FDF products<br>Prelaunch readiness testing |
| Launch to Release | Monitoring UARS attitude<br>Monitoring solar array release<br>Monitoring HGA deployment<br>Fine attitude determination |
| Early Mission | Monitoring UARS release<br>TAM bias determination<br>Observing solar array thermal snap<br>IRU bias determination<br>Monitoring ascent maneuvers<br>Monitoring yaw maneuver<br>Monitoring roll maneuver<br>Monitoring orbit adjust<br>Preliminary OBC validation |

An example of MTASS nominal behavior is found in the results of OBC validation. Ground solutions for roll, pitch, and yaw angles, including corrections for all known calibration errors, were determined from 911028.0150 to 911028.0328, with an estimated uncertainty of less than 10 arc-seconds in each of the angles. The root-mean-square differences of the OBC and the ground angles over this interval were found to be 8 arc-seconds in roll, 21 arc-seconds in pitch, and 5 arc-seconds in yaw. At all times the OBC knowledge was within the required 60 arc-seconds. The root-mean-square differences between ground solutions and the desired or target attitudes over this interval were 35 arc-seconds in roll, 41 arc-seconds in pitch, and 34 arc-seconds in yaw. The differences, which are a measure of the accuracy of OBC control, were at all times within the required 108 arc-seconds for pitch and yaw. The roll angle accuracy exceeded the requirement approximately 1 percent of the time and is related to the solar snap phenomenon. The good agreement of ground-determined attitudes, OBC-determined attitudes, and control attitudes provides an excellent example of the nominal performance of the combined MTASS and flight systems.

Areas of non-nominal behavior with MTASS identified to date in the UARS mission experience include the following:

| Phase | Behavior |
|---|---|
| Launch to Release | TP timing problem |
| Early Mission | FHST attitude propagation problem |

The telemetry processing problem consisted of errors in unpacking data when a UARS minute boundary was being crossed. The problem was traced to a requirement to handle data gaps of any length of time. A workaround was developed to remove the original calculation of the UARS minute counter and replace it with calculations dependent on the engineering minor frame counter.

The fixed-head star tracker (FHST) attitude propagation problem was manifested by several symptoms: the star clumps were spread out, the residuals were high, and the attitude solution did not match the OBC solution. The problem was traced to an erroneous counts-to-angles field-of-view (FOV) scale factor in the FHST.

Neither of the problems discussed above arose from the innovative multisatellite features of MTASS; they could have arisen in any system. On the whole, MTASS performance with UARS was as good as or better than experienced with previous ground systems.

# 4. BENEFITS

Multimission flight dynamics ground support systems like MTASS are being developed to achieve significant cost reduction. Unlike single-purpose ground systems, which achieve a much lower level of reuse and thus a lower level of cost saving, the multimission attitude support system is an intermediate step to a generalized system in which numerous missions are served by one general system. The benefits of multimission attitude ground support systems extend not only to the software design and coding process but to the entire system environment, from specification through testing, simulation, operations, and maintenance.

## 4.1 Benefits for Specifications

As described in Section 2.1, there were significant advantages to raising the level at which reuse occurred from low-level reuse to subsystem reuse. Thus, entire areas of functionality were generalized. The benefit is that specifications do not need to be reworked at such a fine level of detail for each new satellite. Additional benefits were realized by segregating mission-specific algorithms into separate subsystems.

## 4.2 Benefits for Software Design and Coding

The cost of software development from the software design phase through the acceptance testing phase is strongly related to the size of the system, where the cost for verbatim reused software is approximately 20 percent of the cost of newly developed software. The cost to develop AGSSs for EUVE and SAMPEX has been greatly reduced by reusing MTASS. Based on this success, the development of the Total Ozone Mapping

Spectrometer (TOMS) AGSS has begun and similarly plans to satisfy significant major functions with MTASS. Additionally, plans are being made to base the AGSSs for the International Solar-Terrestrial Physics (ISTP) Solar and Heliospheric Observatory (SOHO) and X-ray Timing Explorer (XTE) missions on MTASS. Using the relationship between software development cost and system size, the relative cost savings for EUVE and SAMPEX can be inferred from Table 3. This table shows total source lines of code (SLOC), new SLOC, and reused SLOC for UARS, EUVE, and SAMPEX. The reused SLOC for EUVE and SAMPEX is primarily reused from MTASS. The reuse for UARS is primarily existing utility packages.

**Table 3. System Size for AGSSs Using MTASS**

| MISSION | TOTAL SLOC (K) | NEW SLOC (K) | REUSED SLOC (K) |
|---|---|---|---|
| UARS | 335.4 | 294.8 | 40.6 |
| EUVE | 273.5 | 48.8 | 224.5 |
| SAMPEX | 176.1 | 24.1 | 152.0 |

Note: Size is measured in 1000 SLOC.

## 4.3 Benefits for Testing, Simulation, Operations, and Maintenance

UARS and EUVE combined *acceptance testing* provided a good example of test systems that could not only benefit from a high degree of commonality but could be operated in a single test environment. That is, from the beginning UARS and EUVE testing was conceived and implemented by a single acceptance testing process group. Personnel already familiar with the pattern of UARS tests readily adapted to requirements for EUVE-specific tests and readily applied the techniques and methods that had proved successful for UARS tests also to EUVE tests. Thus, methods of test evaluation and scoring, test tracking, and scheduling used for UARS could be adapted almost without change to EUVE.

In a manner similar to testing, the high requirements and software commonality for UARS and EUVE exhibited by MTASS supported the *simulation* phase. Thus, personnel already familiar with the setup and conduct of UARS mission simulations quickly adapted their methods and skills to the generation of EUVE simulations. On the other hand, the MTASS system, as adapted to UARS, or, alternatively, EUVE, with mission-specific job control language (JCL) and input data, tended to diverge with time, thus diluting some of the benefits observed during the earlier stages of the cycle.

Similarly, the entry of the mission-tailored systems into the *operations* phase tended to further dilute some of the benefits because of differences in the details of mission operations support; for example, differences in the single, Earth-pointing control mode of UARS and the multiple, survey and inertial-pointing modes of EUVE were reflected in the number and frequency of predictions required for the two missions. Moreover, the intensified effort and staffing peak required by the actual launch and deployment of UARS tended to compete with an ongoing demand for EUVE support and resulted ultimately in separate management arrangements for UARS and EUVE flight dynamics support.

The benefits accruing to *maintenance* from multisatellite systems like MTASS follow from the fact that corrections and enhancements originating from experience with one satellite, say UARS, usually apply to the other satellite, say EUVE. In this way, maintenance effort is streamlined.

## 5. ISSUES

Our experience with developing and implementing a three-axis stabilized multisatellite flight dynamics support system raises several issues. These issues concern performance, testing, maintenance, and configuration management.

## 5.1 Performance Issues

The increased generality in some MTASS algorithms results in some increased execution time and memory requirements for some program steps. The necessary provision of some mission-specific modules for several satellites in MTASS could also increase code storage requirements. In practice, the actual savings are determined by competition among conflicting trends. For MTASS, the execution time of some program steps has not been as small as desired; for example, under certain conditions attitude determination has not occurred in near-real time. Moreover, the MTASS code storage requirement, measured in numbers of SLOC, has been larger than for previous systems, but is offset by the need to store only one copy of the MTASS code.

## 5.2 Testing Issues

Another issue concerning MTASS is whether, and to what extent, the benefits of a multisatellite capability that were realized in the specification and development phase extend also to the testing phase. It is well known that testing can address only a small subset of the total number of possible paths through the software system; consequently the question arises whether test cases generated for one satellite in the multisatellite system are representative of the program paths that will be used for all satellites, or whether test cases specific to every satellite must be used.

About 80 percent of MTASS consists of requirements and software common to UARS and EUVE. Thus, the pathway through the programs exercised by a UARS-specific acceptance test often exercises the pathway that would have been exercised in a comparable EUVE test, and thus separate UARS- and EUVE-specific tests were unnecessary and redundant. In this way, significant economies were realized in the combined acceptance testing of the multisatellite system.

In the 20 percent of the system where no overlap existed, separate UARS- and EUVE-specific test cases were executed. For example, in the case of antenna contact predictions, the EUVE case involved test cases in two control modes (survey mode and inertial pointing mode), whereas in the UARS case only one control mode (Earth pointing) was tested.

The common pathway approach was also utilized in the acceptance testing of the UARS and EUVE telemetry simulators, which served as test drivers for the telemetry processing programs used with MTASS. Although the telemetry processing programs are not considered part of MTASS proper, it is nonetheless instructive to consider the approach used. Although a single, multisatellite telemetry simulator might have been desirable, in fact a separate EUVE telemetry simulator was developed through a high degree of reuse of the UARS simulator. In testing the EUVE simulator, it was found possible in some cases simply to operate the simulator with UARS input and identify the expected results with the corresponding output from a previously accepted UARS simulation.

Apart from the benefits to testing that accrued from a large UARS/EUVE requirements and software commonality, a common management structure fully exploited the potential benefit of a multisatellite development environment. The acceptance testers, test coordinators, and task leaders for the testing of both satellites belonged to a single administrative unit under a single manager. This arrangement followed through on the promise and potential of the multisatellite approach and achieved significant economies and efficiency.

## 5.3 Maintenance Issues

Issues connected with the maintenance of multisatellite ground support systems are potentially more severe than issues connected with acceptance testing. The reason is that the maintenance phase of the software development life cycle is closer in time to the actual satellite launch, when the multisatellite system is more fully adapted to the idiosyncrasies of each satellite. For example, product delivery requirements and data set size requirements dictated different tailoring of associated software, such as JCL and command lists (CLISTs), for EUVE than for UARS. Thus, as the fully adapted systems approach satellite launch, the systems tend to diverge in detail and the maintenance efforts tend to lose the benefit of overlap. Moreover, because of the high concentration of effort with the approach of launch and the existence of separate project teams for the different satellites, there is pressure for separate, dedicated launch support organizations to form, and with this development some of the benefits of a common management structure may be lost. In the case of UARS and EUVE, however, we were fortunate to have the same nucleus of software maintenance personnel for both satellites in the critical prelaunch maintenance phases, thus simplifying our efforts.

## 5.4 Configuration Management Issues

MTASS is maintained under a single configuration management structure and changes originating from one satellite or another are managed as a general case. Moreover, changes are instituted simultaneously without regard for the fact that in practice one satellite will go to the launch phase before another satellite.

Configuration management issues arise from several sources. For example, the need for change may arise first in, say, a UARS launch simulation and pressures of time and budget may tempt implementation of the change in a way that is not at first sufficiently general to cover EUVE and SAMPEX. Or, a EUVE simulation may uncover the need for a change that can impact the already-launched UARS, but the routine operations organization for UARS may prefer to defer the change. For reasons such as these, the configuration management of MTASS raises issues that do not arise in conventional single-satellite systems.

# 6. TRENDS

As mentioned above, plans are in place to use MTASS to satisfy significant major functions for the flight dynamics support of TOMS, ISTP SOHO, and XTE. Other potential missions to reuse MTASS will be examined. The one major limitation of MTASS is that the spacecraft be three-axis stabilized. Since there is lately a resurgence of spin-axis stabilized spacecraft with the ISTP/Global Geospace Science (GGS) Project Interplanetary Physics Laboratory (designated WIND) and Polar Plasma Laboratory (designated POLAR) missions and the SMEX-2 Fast Auroral Snapshot Telescope (FAST) mission, the usefulness of a multimission FDSS for spinning spacecraft was recognized. Consequently, the multimission spin-axis stabilized spacecraft (MSASS) FDSS was born (see Reference 2). It is currently completing development to support both WIND and POLAR, and plans are in place to satisfy significant major functions for the SMEX-2 FAST mission.

The trend to use MTASS and MSASS for upcoming missions will continue until a more generalized, mission configurable system replaces them.

# REFERENCES

1. Goddard Space Flight Center, Flight Dynamics Division, FDD/552-90/085, *Upper Atmosphere Research Satellite (UARS)/Extreme Ultraviolet Explorer (EUVE) Flight Dynamics Support System (FDSS) Overview*, R. Coon (CSC), et al., prepared by Computer Sciences Corporation, October 1990

2. --, 552/FDD-91/027, *Multimission Spin-Axis Stabilized Spacecraft (MSASS) Flight Dynamics Support System (FDSS) System Description (Draft)*, C. Crognale (CSC), et al., prepared by Computer Sciences Corporation, August 1991

3. --, 554/FDD-92/029, *Upper Atmosphere Research Satellite (UARS) Post Launch Report*, J. Bez (CSC), et al., prepared by Computer Sciences Corporation, March 1992

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## SESSION 4