FUTURE IN GROUND BASED ATTITUDE SUPPORT ACTIVITIES

R. D. Werking

NASA/Goddard Space Flight Center
Greenbelt, MD

L. J. Happel

Old Dominion Systems, Inc.
Gaithersburg, MD

ABSTRACT

A significant change in the objectives of ground based attitude support of NASA/GSFC spacecraft will occur with advent of autonomous onboard attitude systems. The new philosophy and objectives of ground based attitude support will focus on the support of an onboard computer. The new tasks of the support activity will be to determine those parameters required by the onboard computer to determine attitude, provide closed loop control, anticipate configuration changes dictated by mission objectives, support spacecraft system anomaly investigation, and provide emergency control in case of spacecraft subsystem failure. With this evolution come advantages which will streamline the ground processings functions and clear some of the logistical log jams of spacecraft data processing, merging and distribution.

Keywords: Attitude, Autonomy, Ground Support, Future

1. INTRODUCTION

At the Goddard Space Flight Center (GSFC), an organization has developed over the years which provides ground attitude support functions for a variety of spacecraft. These activities have been provided to support weather observation satellites in near Earth and geosynchronous orbits, various astronomy missions in near Earth as well as lunar orbits, solar observation missions in near Earth orbits, plasma study missions in a variety of orbits, communications satellites in geosynchronous orbits and atmospheric and magnetic field studies in near Earth orbit. The support provided by this group has included the development and operation of ground based attitude software for determining attitude and for the generation of attitude commands which were necessary to meet mission objectives.

One of the factors behind the creation of such an organization was the centralization of these computational activities so that the experience gained on one mission could be applied to future missions. To this end, this effort has succeeded as is evidenced by the recent publication of the handbook in Reference 1. However, this centralization has brought to the forefront the obvious need to provide more autonomous spacecraft. Figure 1 represents the data flow which was used for a large number of missions supported at the GSFC. To accomplish the objectives depicted in Figure 1, extensive use is made of general purpose computational facilities available at the GSFC in the form of IBM 360/95 and 75 computers where the actual attitude computations are performed. These computational activities are broken down into basically two functions. The interface with payload operations control centers (POCC's) is used to satisfy the health and safety aspects of a mission. The interface with the sensor data processing facility (SDPF) is used to satisfy the need for the production of definitive attitude or an attitude history of the mission. To accomplish these objectives, the yearly budget to provide this support, excluding the cost of computer hardware, has been about two million dollars.

It is now estimated that the ground attitude support for a mission with a 2-year life without autonomy can cost in excess of two million dollars including the preparation (approximately 3 years) and the operational support for the mission life-time. This again includes only the cost to define software, to develop the software and to operate the software (almost all software makes use of interactive graphics).

Because of the significant cost and because of the problems associated with large amounts of data which were being transferred from one place to another, the need to make the spacecraft more autonomous became a major objective at the GSFC.

The major drivers for autonomy in the attitude control area are:

- more responsive control systems
- increased attitude pointing accuracy requirements
- increased hardware component standardization

The major drivers for autonomy in the attitude determination area are:

- elimination of the need for large amounts of data transfer
- rapid delivery of ancillary data products to the user

The end result of these objectives was expected to be the reduction and possible elimination of the traditional ground based attitude support functions.

The Solar Maximum Mission (SMM) was the first mission flown by the GSFC with the expressed purpose of meeting these objectives. Based on the experience to date, the objectives of the major drivers appear to have been met, however, there still exists a very real need for a ground based attitude support function. The emphasis has shifted, as expected, toward the validation and verification aspect of the mission. However, if anything, the sophistication associated with the ground based support has increased. It has likewise been observed that this transition will also affect the day to day support which is provided and will present challenges in staffing for support of autonomous missions. The sensor calibration activity has taken on a significant new dimension since the results of this activity are now critical to the successful performance of the spacecraft orbital operations.

This paper will attempt to project the near term future of ground based attitude support functions and the relationship to other flight dynamics elements. This will be done by a brief examination of the past, a comparison of the support provided for a conventional mission and the SMM and an evaluation of what this experience has indicated.

Proc. Int. Symp. Spacecraft Flight Dynamics, Darmstadt, FRG, 18-22 May 1981 (ESA SP-160, Aug. 1981)

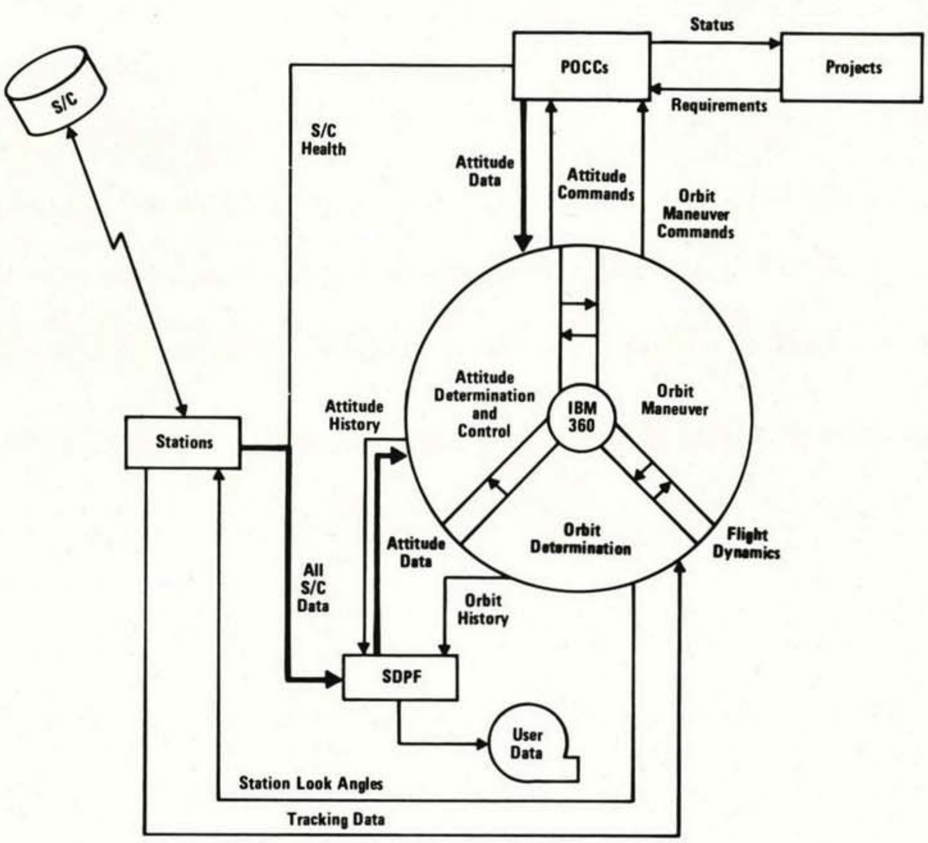

Figure 1. Conventional attitude data flow at GSFC

2. BACKGROUND

Until recently, spacecraft attitude determination has been a primary ground support function for most NASA/GSFC spacecraft. Telemetry data from on-board sensors was received on the ground and processed for a real-time solution or stored for near real-time and/or offline processing. Typically, large "batch mode" computers were used for this effort (e.g., IBM 360/95 or 360/75). Attitude was determined and notification of the results delivered to the project office and the POCC. If necessary, reorientation commands or attitude correction commands were prepared offline and relayed to the POCC. In order to prepare such commands, complex prediction systems were run in a "batch mode" environment based on attitude determined during ground processing. This process is depicted in Figure 2.

In addition to typical operations support, some projects required "definitive" attitude determination, i.e., best estimates of attitudes history were computed offline and stored on magnetic tapes which were then merged with other spacecraft and experiment data and distributed to various spacecraft data recipients.

With the advent of semi-autonomous attitude systems, capable of determining attitude on board, the requirements for attitude system operational support will change. Though support requirements will still exist, the objective of the support operation will primarily be one of supporting the on-board computer (OBC) or more aptly the "care and feeding" of the OBC.

Attitude determination will be carried out by the OBC in real-time rather than as a ground function. However, many ground support functions will still be retained since the OBC will require the input of a variety of parameters necessary for the attitude computation exercise. Additionally, with the use of Tracking and Data Relay Satellite System (TDRSS), pointing of the spacecraft high gain antenna (HGA) will be a function of attitude and may be controlled by the OBC. Figure 3 depicts a generalized concept of a ground support system for a semi-autonomous attitude determination/control system. It should be noted that although the capability to compute and verify attitude is retained, it is not performed with the same frequency as before. Rather, the function is retained primarily for validation and calibration purposes.

The main activity of the ground support system will be to provide the OBC with the data base information it requires. Such information would typically include calibration constants, scale factors, alignment data, and biases for a variety of attitude sensors. The parameters initially would be determined from ground tests performed on the spacecraft. However, once in orbit these parameters will be updated as necessary to account for real or observed system performance. In addition, it may be necessary to provide other support data to assist the OBC in carrying out the needed tasks. This could include such parameters as sensor occultations, guide stars or other aids of similar nature. It is envisioned that with attitude systems similar to those developed for the SMM and Landsat-D spacecraft, updates for the OBC parameters would be required only on an infrequent basis. The total software/analysis requirements, however, may not change significantly for two reasons: most of the present attitude determination functions must be retained to support spacecraft system validation and calibration activities, and almost all missions have unique attitude control requirements which will present drivers for unique supporting data for OBC usage.

The final, and possibly most significant change in the attitude ground support scenario would be that attitude history tapes would no longer be required since the attitude computed by the OBC would be placed directly in the telemetry stream with all other spacecraft engineering and scientific data logistically, the result should be much more efficient than the conventional process.

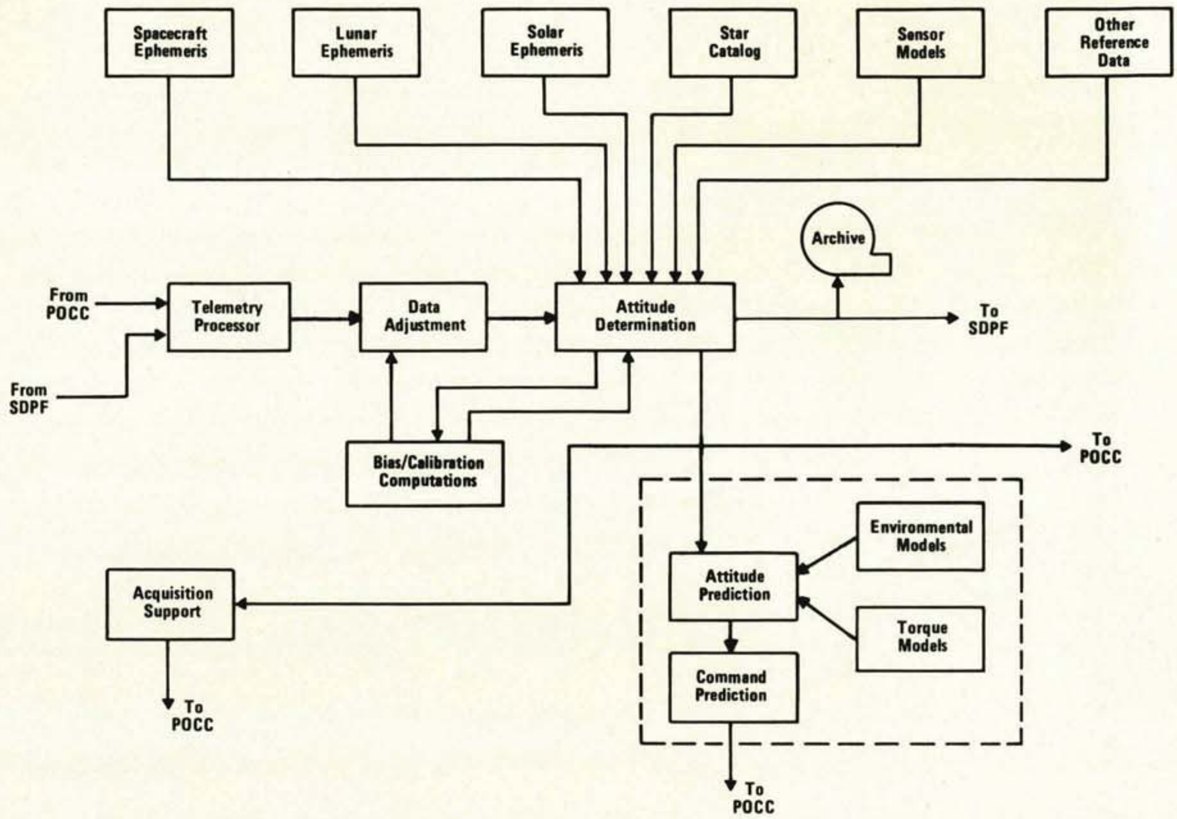

Figure 2. Generalized attitude support ground system without on-board processing

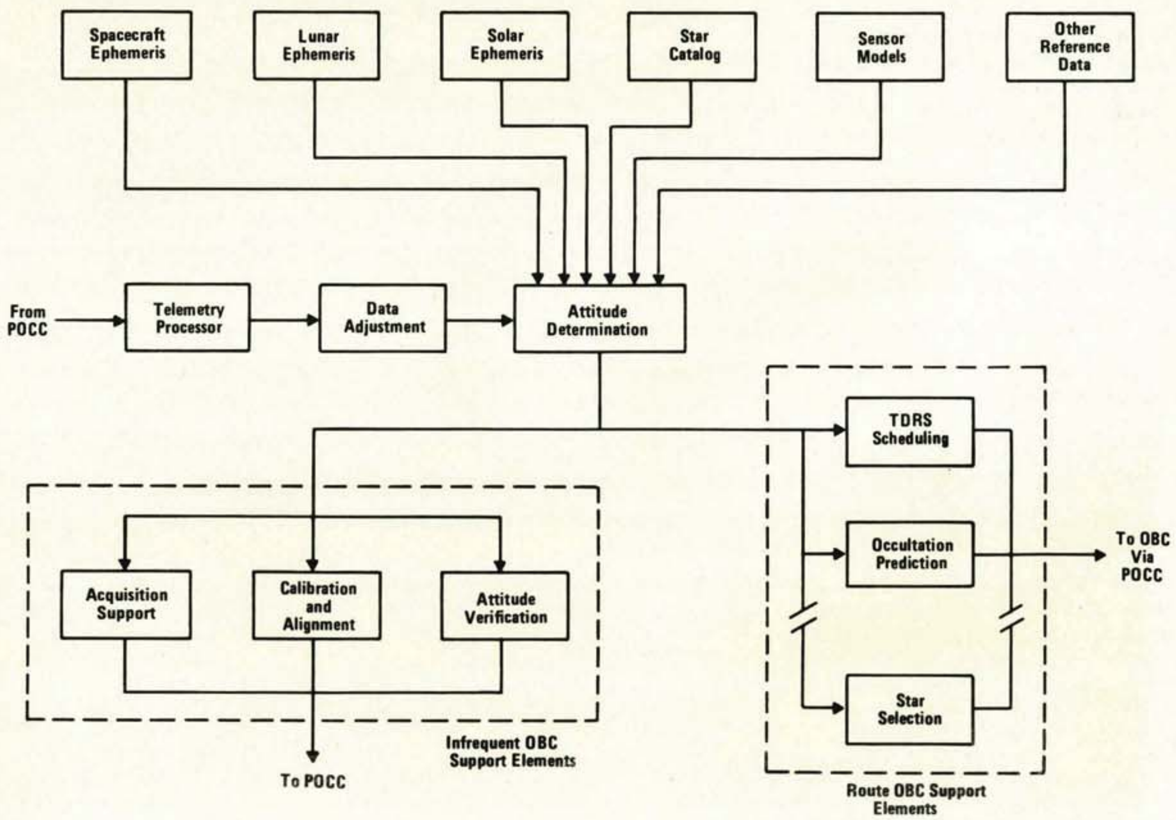

Figure 3. Generalized attitude support ground system with on-board processing

However, this type of support places two demanding requirements on the ground: (1) to make certain that OBC supporting data is always current and correct to avoid attitude control problems, and (2) to rapidly and correctly compute the sensor calibration data which is used by the OBC for both attitude control and determination computations.

3. MISSION TYPES AND REQUIREMENTS

As in the past, it is expected that spacecraft will continue to be built with a variety of configurations. With respect to attitude support objectives, there are two broad categories of spacecraft which have and most likely will continue to be utilized: scanning spacecraft and pointed spacecraft. The present discussion concerning autonomy has been directed toward those missions falling into the pointed spacecraft configuration category and as such will be addressed in this paper. However, some of the examples used are in fact derived from scanning missions and furthermore it is recognized that scanning spacecraft can in fact be made autonomous.

In order to develop the details of the ground support tasks for an on-board attitude determination system, one must investigate the types of missions to be flown and their specific requirements. In general, some limited standardization of the ground support elements can be achieved when similar attitude references are required. Much of this mission type information can be found in Reference 2, section 3.1.

3.1 Earth Pointing Mission

This mission class requires that the spacecraft experiment sensors be oriented toward Earth, typically nadir pointing. Some offset targeting may also be required. Basically, the local vertical becomes the primary attitude reference and attitude is defined in terms of roll, pitch, and yaw angles.

Previously, IR horizon scanners have been used to provide roll and pitch angular errors for Earth viewing spacecraft, however, future Multimission Modular Spacecraft (MSS) type vehicles may rely on Fixed Head Star Trackers (FHST) for attitude updates while using rate gyro assemblies (RGAs) for the primary control reference (see also Reference 3). This change will, most likely, result in more accurate attitude systems than in the past, however, it will possibly result in a more complex ground system to support the routine support activities. Much of this will depend on the complexity of the OBC software.

Ground support processing will most probably include at least sensor calibration and guide star catalog selection to meet the basic mission objectives.

3.2 Solar Pointing Mission

Solar missions utilize the sun line to the spacecraft as a primary attitude reference. Though direct pointing at the sun is usually most desirable, some offset pointing and/or scanning may be required. Attitude can be defined in terms of Euler angles in body coordinates with solar aspect angles also defined. Primary sensors for such a mission using an MMS type system would probably be similar to that used on the SMM spacecraft, i.e., high resolution sun sensors combined with RGA's.

Ground support processing may include not only the computation of sensor calibration, misalignment, scale factors, etc., but also solar occultation periods and guide star occultation periods. Additionally, the same attitude validation and TDRS scheduling capabilities must be available.

3.3 Stellar Pointing Mission

For the stellar observing mission, the primary reference for attitude control would be a line to a point on the celestial sphere. Though scanning would not be required and offset pointing not applicable, the ground support process for these missions are generally more demanding since the attitude reference is infinitely variable and large slew maneuvers must be supported. Attitude is defined in an inertial reference system in terms of Euler angles, i.e., right ascension, declination and phase angle. Primary sensors for MMS type systems would be RGA's with FHST's used for updates.

The ground system must be capable of providing a variable selection of guide stars for FHST targeting based on the line of sight requirements of the experimenters if the function is not performed within the OBC. Thus, the entire star catalog must be available along with control models capable of simulating large slewing maneuvers. The frequency of attitude verification with such missions may increase due to the increased frequency of gross repositioning of the spacecraft, a situation not regularly encountered in Earth or solar missions.

Sensor calibration, misalignment, scale factor and bias parameters would still be required along with TDRS schedules and look angles.

3.4 Ground System Functional Requirements

The detailed design of a ground support system for a spacecraft attitude system is also a function of the stabilization technique to be used. Based on mission requirements, a specific attitude stabilization configuration is usually developed for the spacecraft. The attitude system can be active or passive. See also References 1, 4, 5, and 6.

Much has been said concerning the excessive cost of ground support for attitude and attitude related activities. The cost impacts are in fact dependent upon two major considerations: (1) control system complexity, and (2) attitude knowledge accuracy requirements. Unfortunately, it is not possible to make a universal claim that passive control systems are less costly to support than active control systems or that high accuracy missions are more costly than medium accuracy missions. Regardless of the autonomy questions, two trends are in fact occurring which have presented change over the past years: (1) more emphasis on pointed missions, and (2) a desire for more accurate attitude knowledge. These present opposing effects on the ground support functions. On one hand, the use of pointing missions tends to reduce the day to day data processing requirement to check the attitude state (although constraints checking on commands for stellar missions can increase), however there is a tendency to make the attitude accuracy less stringent than the knowledge accuracy and there is a tendency for the knowledge requirement to push the state of the art for the attitude sensors being flown, hence the cost of definitive support becomes more expensive.

With the advent of on-board digital computers, attitude control systems took on a new appearance. The spacecraft became much more adaptive to a greater variety of mission scenarios. Control and attitude error (knowledge) could be handled by the on-board system in a closed system more adaptively and with more flexibility. However, attitude determination is still a ground support function.

With the maturation of computers technology spacecraft will be capable of determining attitude as well as maintaining closed loop control. This will only be achieved, however if the knowledge requirements are constrained in such a manner as to not approach the ultimate accuracy of the attitude sensors being used.

3.5 Evolution of Attitude Systems

The evolutionary development of the ground support requirements for spacecraft attitude systems is exemplified in Figures 4 and 5. Figure 4 depicts the functional flow of the ground support system for the Orbiting Solar Observatory -8 (OSO-8) which used spin stabilization for attitude control. Maneuvering was accomplished using an electromagnet commanded from the ground.

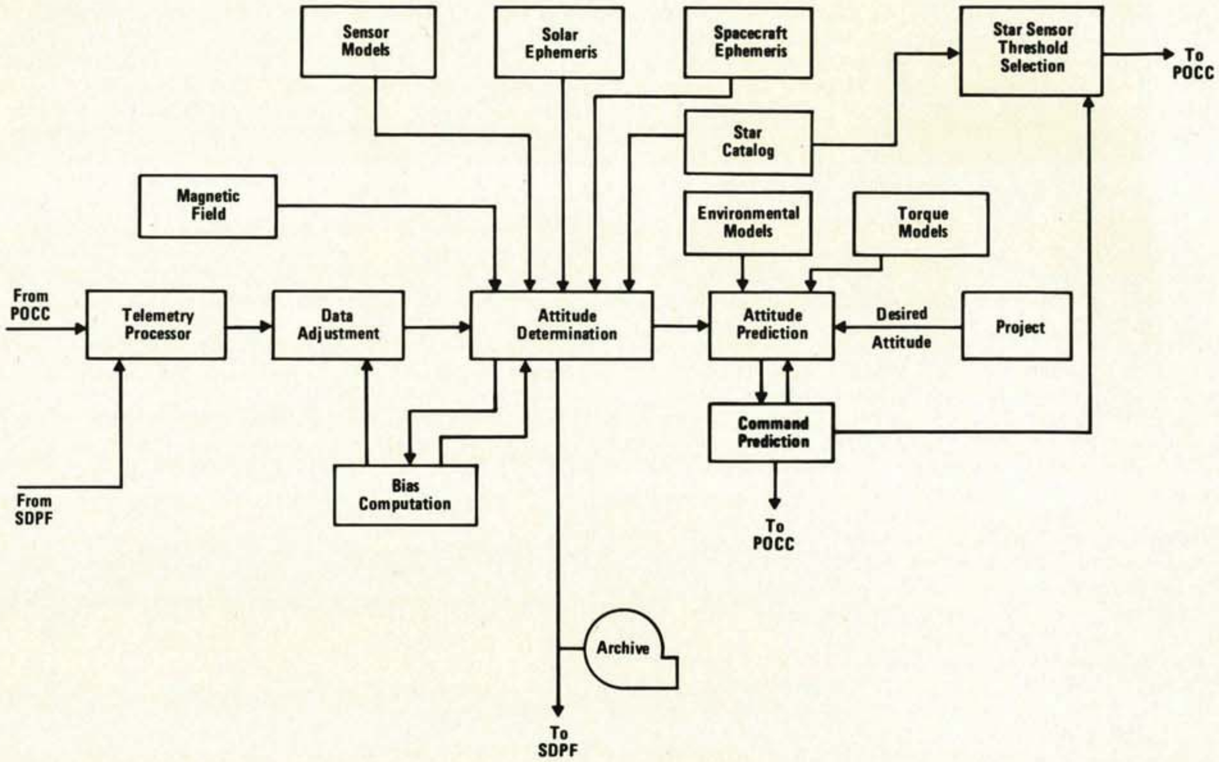

Figure 4. OSO-8 attitude support ground system

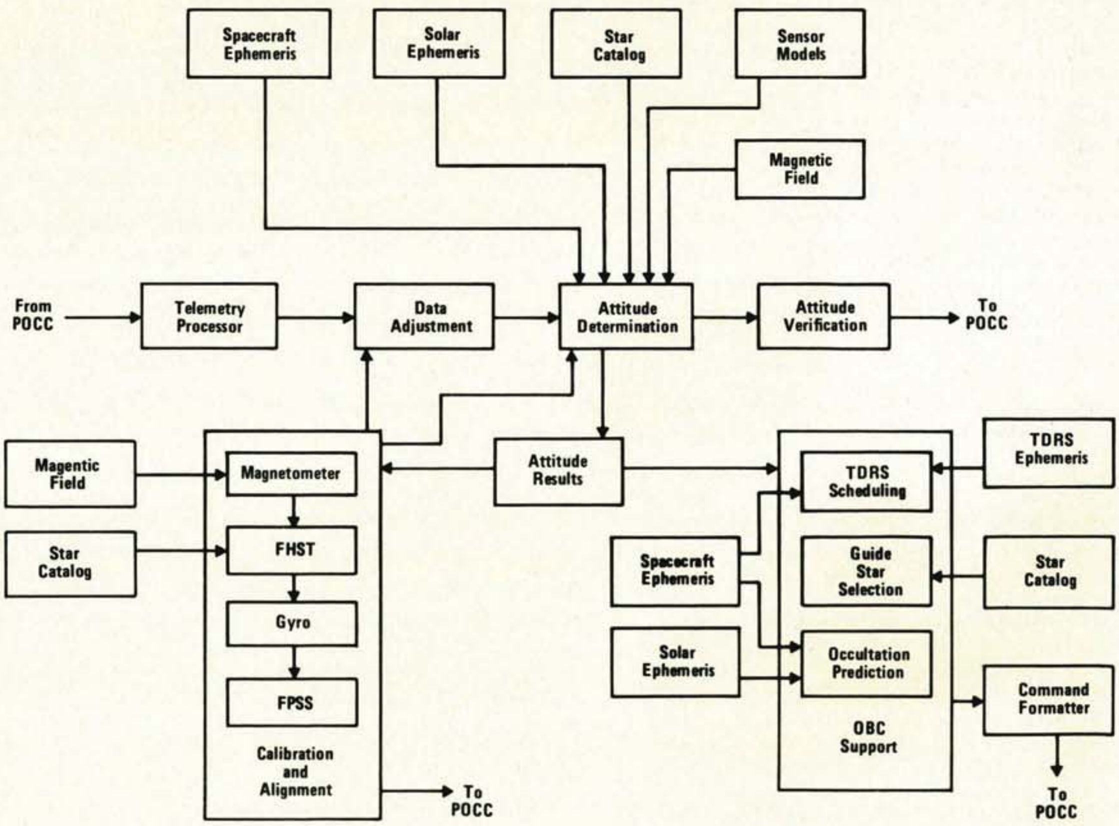

Figure 5. SMM attitude support ground system

The objective of the OSO-8 mission was to point a despun instrument package toward the Sun for solar observations and to scan the celestial sphere and record the location of stellar X-ray sources detected. The scanning was accomplished by spinning spacecraft a 6 rpm.

The typical operational scenario included near real time attitude determination using sun sensor and magnetometer data for coarse attitude. More precise attitude was then determined using data from a V-slit spinning star scanner. Real-time data and playback data were used to determine attitude. Since the spacecraft required daily reorientation (dictated by mission requirements), control commands in the form of spin axis magnetic coil operation times were prepared. Spin axis control of the spacecraft was strictly open loop.

The seuqence of events from data retrieval to command generation required the execution of a telemetry processor, coarse attitude determination program, star scanner attitude program and an attitude predictor/control program.

The offline operation included regular attitude determination for spacecraft health and safety and experiment data correlation. The correlation of attitude data with experiment observations was critical to this mission since the objective was to map the location of the X-ray sources on the celestial sphere.

With the development of MMS type spacecraft and specifically with the launch of SMM the attitude control systems took another evolutionary step toward what might be called autonomy. The attitude was not only capable of on-board programmable control as had been demonstrated on the Applications Technology Satellite -6 (ATS-6), but was also able to provide complete attitude knowledge in the telemetry stream. Using the NSSC-1 computer, the attitude was able to care for itself requiring regular inputs from the ground (every 2 days) containing guide stars and occultation times and infrequent updates to sensor calibration, bias and alignment parameters. Figure 5 depicts a functional block diagram of the attitude system ground support developed for SMM. The SMM spacecraft was designed as a solar observatory, hence the objective unlike OSO-8 was to point the entire platform toward the Sun. To achieve the goal, the spacecraft was equipped with fine pointed Sun sensors, rate gyro assemblies, momentum wheels, magnetometers, coarse Sun sensors, electromagnetic coils, and fixed head star trackers.

Ground support processing included the determination of the initial spacecraft roll angle (orientation about the Sun line), the calibration and alignment of the various sensors, the generation of predicted sensor occultation times and the selection of guide stars to be used. Additionally, the capability was developed to support the use of the Tracking and Data Relay Satellite (TDRS) for command and data acquisition, however, it is unlikely that this capability will be exercised.

As was indicated in Reference 8, it was necessary to determine attitude to maintain confidence in the flight system, however, the frequency was greater than had been expected.

4. IMPLEMENTATION OF GROUND SUPPORT SYSTEM

With the advent of autonomous spacecraft attitude systems, the frequency of ground support computations may decrease and the philosophy of ground support objectives will change somewhat. Thus, one might seek to know: What ground support problems are created by self-sufficient flight systems? For which spacecraft is attitude autonomy practical? What are the specific advantages and disadvantages of autonomous systems? What impact will such attitude systems have on future ground processing and support systems?

To provide some assistance in answering these questions and to evaluate the reasons for attitude autonomy, the SMM support activities are compared with the OSO which were flown in the late 60's and early 70's and in particular OSO-8 which was the last in the long and distinguished series. The OSO-8 spacecraft is a classical configuration and requires computation of various attitude parameters to maintain health and safety of the spacecraft, control the spin axis of the spacecraft, and compute post facto attitude products for the experimenter's use. The SMM spacecraft, as was previously mentioned, has semiautonomous capabilities. As a result, only the health and safety function had to be supported.

The primary objective of the ground system for both OSO-8 and SMM was to determine and in some way control the roll angle for each mission. The roll angle is the angle of rotation about a spacecraft axis co-linear with the sunline and measured from the solar north pole. The objectives of the ground system for OSO-8 were as follows:

- Provide roll attitude which is known and which can be used by various experimenters to correlate data.
- Support a control plan laid out by the scientific team using as little gas as possible.
- Select the proper star sensor threshold to insure that sufficient stars exist for an accurate roll attitude determination.
- Maintain the pitch angle and spin rate within defined limits to conserve gas and to permit successful experiment operation.

In order to satisfy mission objectives, it was necessary to perform the following functions:

- Coarse attitude determination using magnetometer and Sun sensor data.
- Fine aspect attitude determination using star sensor data.
- Prediction of the effects of disturbance torques and the necessary control torques to satisfy experiment requirements.
- Selection of star sensor threshold.
- Determination of alignment data for the star sensor and bias determination for the magnetometers.
- Production of attitude history data for experimenter use.

Operationally, the OSO-8 attitude ground system was required to provide support for the (1) health, safety and attitude control, and (2) attitude history generation.

To meet the health, safety and attitude control objectives, an operational team was established to provide 24 hr/day, 7 days/wk coverage to process data received from the control center. The spin axis orientation was determined twice per day. This processing, likewise, satisfied the spacecraft health requirement. With these results, a prediction of the expected attitude was computed to determine the control torques which should be implemented to cause the desired spin axis precession and spin rate control. On a weekly basis, star sensor threshold settings were computed based on stars available and their magnitudes. In addition, monthly planning activities were performed to insure that the general control and star sensor threshold objectives could be met.

To meet the attitude history objective, a production team was established to process all of the data taken by the OSO-8 spacecraft. This objective required that all the star sensor and fine sun sensor data be processed in such a manner that a continuous history of the attitude could be provided to the experimenters. After some initial difficulties, which required a few months to resolve, the results could be made available about 8 weeks after the data was taken.

Thus, to satisfy the major attitude objectives for OSO-8, a large amount of software was developed and tested to perform the various tasks. Likewise, two teams of people were required to perform the operational day-to-day data processing and finally considerable amounts of computer time were required to perform the processing activities.

Consider now the Solar Maximum Mission (SMM). Mission requirements to be met by the SMM ground system were as follows:

- Provide accurate solar disk pointing requiring roll knowledge to 0.1 degree.
- Provide sufficient data on-board such that computed attitudes will meet post event processing accuracies (5 arc seconds pitch and yaw and 0.1 degree roll).
- Calibrate attitude sensors relative to experiments to provide needed co-alignment control accuracies.
- Provide data required to support on-board computer operations.

To satisfy these objectives the following software systems and operational capabilities were developed:

- Initial attitude determination using the coarse attitude system (magnetometer and Sun sensor data).
- Fine attitude determination for roll reference using star data.
- Alignment and calibration of the magnetometers, star cameras, gyro, and fine pointed Sun sensor.
- Guide star selection software.
- Prediction of solar and guide star occultations.

The operational activities required to satisfy the SMM attitude function required the around-the-clock processing of data for the first 5 weeks of the mission in order to:

- Determine the initial roll angle.
- Compute the alignment and calibration parameters for the magnetometers, star cameras, fine pointed Sun sensor, and the gyros.
- Uplink sensor alignment and calibration data to the spacecraft.
- Confirm that the updated information was correct.

After the first 5 weeks of processing, it was planned that daily monitoring of the attitude sensors and on-board computer performance would be performed on a weekly basis. In addition, and most importantly, command loads would be generated every other day which contain the selected guide stars and the occultation times to support the on-board computer.

However, the mission in fact never became routine (went into safe mode in November after three wheel failures). Initially there were a number of occasions upon which roll reference was lost due to a variety of difficulties including overly optimistic tolerances, OBC software errors, and ground operations failures. This presented an unanticipated challenge in the ground support area. Unlike the case of OSO-8, the data received and processed in evaluating the health and safety of SMM was different in content than the data used to compute roll reference during the early stages of the mission. Since the data was different, it made the task of training junior people very difficult. The significance of this problem was subsequently reduced when it was decided for other reasons to modify the OBC software in a manner which permitted the acquisition of data to perform the determination activities at any time.

The calibration and alignment activities were more demanding for the SMM than for the OSO-8 mission and more demanding than had been anticipated prior to launch. As was mentioned on OSO-8, problems were encountered in the production of the attitude history data. Although the delivery of data was delayed, it was recoverable. In the case of SMM, the calibration and alignment of the attitude sensors were critical to (1) the operation of the spacecraft, and (2) the inclusion of attitude knowledge in the telemetry stream. At present it appears that the calibration and alignment work which was done during the mission was sufficient to meet the control needs, however, it is questionable as to whether the knowledge requirements were satisfied until after about 5 months of operations. We are still involved in the post flight sensor calibration activities and it is entirely conceivable that, to obtain the most benefit from the data, it may be necessary to compute definitive attitude data using the refined calibration and alignment data to be used in the science data reduction activities.

5. PRACTICALITY OF ON-BOARD PROCESSING

Obviously, on-board processing for attitude determination will not be practical for all types of stabilization techniques. Only those missions whose requirements demand it and whose budgets can support it will develop autonomous attitude systems. Typically, such spacecraft will use only fully active attitude control systems. Those spacecraft which utilize semi-passive or passive stabilization techniques would probably not incorporate autonomous attitude determination capability due to the increase in spacecraft cost. Estimates developed by Martin-Marietta, in Reference 2, indicate that the costs of such systems would be prohibitive to low budget missions.

It is reasonable to assume then that missions which require passive or semi-passive stabilization systeme (e.g., SAS-1, ISEE-3, Magsat) will always require full ground support capability and attitude determination computations for health and safety support and experimenter information. It is, however, beyond the scope of this study to resolve the exact implementation of such services for low budget missions in an era of attitude system autonomy.

6. IMPACT ON GROUND PROCESSING

The major effect of autonomous attitude systems on the ground support effort will be the change in emphasis; i.e., the shift to the "care and feed" of the OBC in lieu of complete attitude determination and control computations. Figure 3 shows a generalized functional block diagram of such a support system. In comparing Figure 3 to Figure 2 (Figure 2 defines the present support system for spacecraft without on-board attitude determination capability), there is very little difference. It might be expected that the functional entities of the attitude ground support system would be reduced with on-board attitude determination, however, this is not the case. The requirements for attitude determination on the ground are required for validation purposes and periodic checking of the on-board computations. The frequency of ground attitude computations and the preparation of attitude history for experimenters will be eliminated. The latter task is removed due to the placement of attitude data directly in the telemetry stream on board the spacecraft. TDRS interfaces with the spacecraft will be new to the ground system and will require prediction of satellite and high gain antenna (HGA) look angles. On earlier MMS type spacecraft like SMM, once the schedule is uplinked to the OBC, the initial commanded look angles must be computed on the ground and uplinked to the antenna command systems. Future on-board systems may even eliminate this requirement.

Smaller ground computers may be feasible for ground support of on-board attitude systems since large amounts of data will no longer be archived and experimenter attitude tapes will no longer be written. The reduced computational loading on the computer hardware may also enhance the possibility of using smaller machines.

Initial attitude acquisition support will in all probability remain unchanged. Even with reliable on-board systems, initial operations will, most likely, require close monitoring and backup computations to assure proper initial stabilization.

Flexible appendage modeling may present a significant problem to on-board systems. Typical analytical models are lengthy and complex and perhaps too taxing for current and near future on-board systems. Certainly, additional studies would be necessary to identify simplified parametric, space conservative algorithms for use with an OBC. Required parameters could be computed on the ground using more extensive models and uplinked as with calibration data. Perhaps the use of on-board systems such as the Attitude Transfer System developed for the Magsat spacecraft could be used to reduce or eliminate computational loading (see Reference 7). Since the Magsat system provides appendage deflections directly, extensive on-board models may not be required.

One might also anticipate a greater degree of standardization of the attitude ground support systems in the future with on-board processing. However, since most missions have unique requirements for attitude control/determination and sensor complements vary from mission to mission, complete standardization may not be fully realized. Certainly, the use of standard NASA sensors, as discussed in Reference 2, will lead to greater possibilities of standardization of the ground system than will the use of on-board processing.

Environmental models would still be required as they are now (e.g., gravity, magnetic, solar pressure, aerodynamic). To a large extent, these models are standardized at present. Future studies into the simplification of the models and making them space conservative for use in the OBC could be very important to the development of fully autonomous on-board attitude processing.

The experience which was gained on SMM and Magsat would tend to indicate that the calibration and alignment activities are extremely difficult tasks to undertake and that the reality of the situation may dictate a reconsideration of the philosophy to be used to satisfy all of the objectives. This change must be an appreciation of the fact that, regardless of the method used to provide attitude knowledge (on-board computation or ground computation), the computation of the ultimate accuracy will require a considerable amount of time and that the results will vary with time. This will always be true when the attitude accuracies are equivalent to the capabilities of the attitude sensors and/or the model of the reference (i.e., Earth) being sensed. This could result in the realization that selected post processing and generation of attitude history data may be the most effective and efficient procedure to be followed to meet all needs.

7. CONCLUSIONS

As previously stated, the anticipated effects of autonomous attitude systems on ground support would be to:

- eliminate the need for large amounts of data transfer
- provide for more rapid delivery of ancillary data products to the user
- reduce the need for ground support

Based on the experience with the SMM spacecraft, the first two objectives have been met successfully. The data transfer required to satisfy the attitude requirements may be reduced to a weekly evaluation in the near future. The inclusion of SMM attitude in the telemetry stream has satisfied the requirement for rapid delivery of ancillary data since it is available when the user data is available.

However, SMM experience has not demonstrated that the need for actual ground support has been significantly reduced. The software required to support SMM was at least equivalent to the OSO-8 software and it also is obvious that due to occasional problems, it is necessary to provide re-acquisition support which requires an experienced team of people to perform the needed operations. And finally, the calibration activity has taken on a new dimension since the results of this activity are now critical to the health of the spacecraft as well as to the proper interpretation of the telemetered attitude results, i.e., there is no second chance to get things right. Though the latter time is not new to NASA activities, it does result in a more sophisticated and timely solution to problems which cost more to implement in the initial software outlay. And, has been mentioned earlier, it is now believed that this activity was not entirely successful on SMM. The end result of this exercise may be a more practical approach to meeting all of the mission objectives such as selected processing to obtain high accuracy requirements.

For semi-autonomous attitude determination systems, the main objective of the ground support attitude system will be the "care and feeding" of the OBC. However, many ground support functions would still be retained since in the semi-autonomous mode, the OBC will require the input of a variety of parameters necessary for the attitude computation exercise. In addition, validation of the OBC computations must be performed periodically.

8. REFERENCES

1. Wertz, James R., Editor, *Spacecraft Attitude Determination and Control*, D. Reidel Publishing Company, 1978, Chapter 18.

2. Martin-Marietta Aerospace, *On-Board Attitude Determination System (OADS) Final Study Report*, April 1978.

3. *Specifications for the Multi-Mission Modular (MMS) Attitude Control Subsystem*, GSFC-5-700-17, April 1978, revised.

4. Fischell, R. E., *Spacecraft Attitude Control*, Johns Hopkins University Applied Physics Laboratory, August 1966, Chapters 3 and 4.

5. McClinchey, L. F. and R. E. Rose, "Pointing and Control of Planetary Spacecraft–The Next 20 Years," Parts 1 and 2, *Astronautics and Aeronautics*, AIAA, Oct./Nov. 1979.

6. Kaplan, M. H., *Modern Spacecraft Dynamics and Control*, John Wiley & Sons, 1979, Chapter 5.

7. Johns Hopkins University, *Magsat Spacecraft Description*, Applied Physics Laboratory, SDO 5146 (Preliminary), September 1978, Pages 80–82.

8. Happel, L. J. and R. D. Werking, *Ground Support Processing for Spacecraft with Autonomous Attitude System*, AIAA/AAS Astrodynamics Conference, August 11–13, 1980.