DEVELOPMENT OF A TWO-WHEEL CONTINGENCY MODE FOR THE MAP SPACECRAFT

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In the event of a failure of one of MAP's three reaction wheel assemblies (RWAs), it is not possible to achieve three-axis, full-state attitude control using the remaining two wheels. Hence, two of the attitude control algorithms implemented on the MAP spacecraft will no longer be usable in their current forms: Inertial Mode, used for slewing to and holding inertial attitudes, and Observing Mode, which implements the nominal dual-spin science mode. This paper describes the effort to create a complete strategy for using software algorithms to cope with a RWA failure. The discussion of the design process will be divided into three main subtopics: performing orbit maneuvers to reach and maintain an orbit about the second Earth-Sun libration point in the event of a RWA failure, completing the mission using a momentum-bias two-wheel science mode, and developing a new thruster-based mode for adjusting the inertially fixed momentum bias. In this summary, the philosophies used in designing these changes is shown; the full paper will supplement these with algorithm descriptions and testing results.

Two-Wheel Design Philosophy

In order to be able to deliver and implement a backup two-wheel control design in a timely fashion, a design philosophy was first adopted. The elements of this philosophy are as follows:

- Wherever possible, existing control algorithms already implemented and tested would be used as is, or with as few changes as possible. ⇒ Reduces development and testing time.
- Where completely new algorithms would be needed, such as in the new science mode, they would be implemented in a manner consistent with the current flight software design, which makes extensive use of tables of the parameters needed for proper configuration. ⇒ Allows for flexibility on-orbit for configuration and tuning of the control algorithms.
- New and changed algorithms would be prioritized by when they are necessary in the mission timeline, and the development and testing schedule would reflect these priorities. ⇒ Most effectively uses available resources to maximize the chances of mission success in the event of a wheel failure.

Required Mission Functions and Implementation Plan

The following functions are required in order to be able to carry out the MAP mission. After the description of each function, the way in which this function is implemented is shown. The selected implementation was based on the philosophy discussed above.

- Safehold at Low System Momentum: The existing MAP Safehold/CSS controller uses coarse sun sensor signals for attitude and derived rate information, and it would work as is with only two wheels.

- Two-Wheel Science Mode: This mode will be fully discussed in the full paper. It is important to note here that the two-wheel science mode would work by first establishing a 20–25 Nms momentum bias about the sunline. The controller then would increase the nutation angle to the desired value to approximate the dual-spin sky coverage of the nominal science mode controller.
- Establishing and Removing Momentum Bias: The existing MAP Delta H Mode, a thruster-based mode nominally designed for dumping system momentum, can be used to establish or remove the science mode momentum bias. The only necessary changes would be to parameters in an existing flight software table.
- Thruster Operations for Orbit Maneuvers and Maintenance: In order to fulfill its mission, MAP must be at L_2, which means that it must have been able to perform a number of orbit maneuvers during phasing loops about the Earth (on the final phasing loop, MAP performed a lunar swingby which provides the final "push" to L_2). Once at L_2, orbit maintenance maneuvers must also be performed, nominally four times a year. The existing MAP Delta V Mode performs this function in both the nominal and two-wheel case.
- Thruster-Based Inertial Mode: With the loss of Inertial Mode, a wheel-based mode that allows MAP to be slewed to any inertial attitude, an alternative way would be needed to get the spacecraft in the right attitude for thruster operations. With two relatively small changes to the existing Delta V controller, it would be possible to use it for inertial slews as a Thruster-Based Inertial Mode.
- Safehold with a Momentum Bias: The two-wheel Safehold/CSS would also work with a large momentum bias (> 10 Nms) if the bias were close to its nominal orientation about the sun line. Figure 1 shows an example of the performance of this mode.
- Momentum Bias Adjustment: A big difference between the nominal and two-wheel science mode designs is that the nominal mode performs its dual spin about the sun line, whereas the two-wheel mode would perform its dual spin about a momentum bias nominally applied about the sun line. This momentum bias would be fixed in inertial space, however, and would move relative to the sun line approximately 1°/day. A new thruster control mode would be needed to perform the small daily adjustments to the momentum bias that would be necessary in flight. This algorithm will also be described in detail in the full paper.

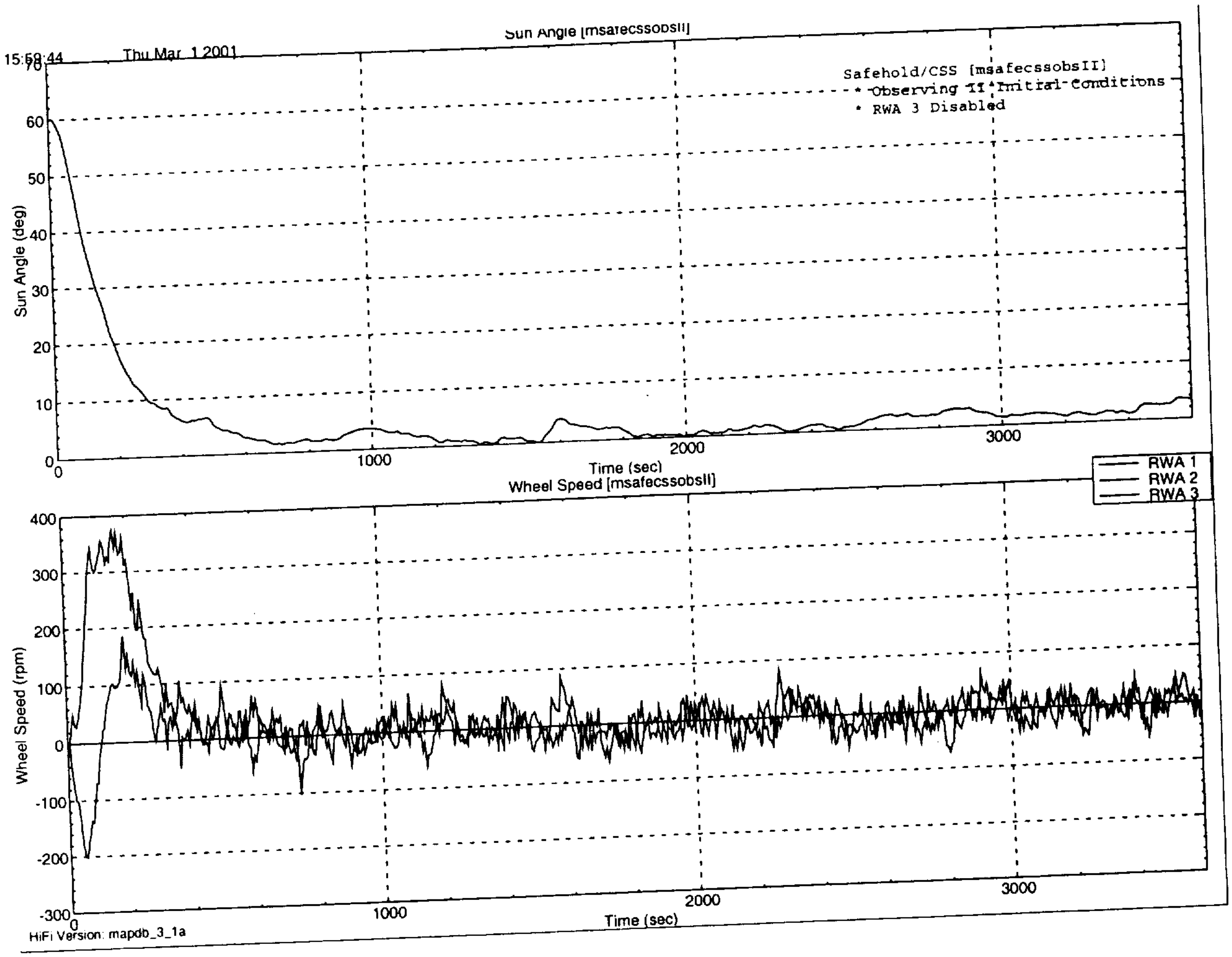

Figure 1: Safehold/CSS with Two Wheels and 20 Nms Sunline Momentum Bias

Upon reviewing the necessary functions needed for MAP to fulfill its mission, one thing became clear that both drove and simplified the development schedule. Of the functions that are not supported by existing algorithms on the spacecraft, only the Thruster-Based Inertial Mode function would have been necessary in order for MAP to be able to reach L_2. The two-wheel science mode and momentum bias adjustment functions would not be needed until MAP reached L_2, at least 90 days after launch. In order for the spacecraft to be able to get to L_2, it was necessary to get the spacecraft into the correct attitudes for its critical phasing loop thruster operations so that it could achieve the correct orbit for its lunar swingby. Because of this need, the development of the backup algorithms and software was completed in two phases. Phase 1 comprises the changes needed to get to L_2 and was completed before launch, was tested, and was available to be uploaded as a patch to the onboard software in the event of a wheel failure. The Phase I patch was tested in a full mission simulation prior to launch, and results from that test will be shown. Phase II includes the changes necessary to complete the science mission in the event of a wheel failure after reaching L_2. The patch to implement the Phase II changes was completed as quickly as personnel schedules allowed after launch.

Following are several figures showing simulation results with captions. These are representative of what will be included in the full paper.

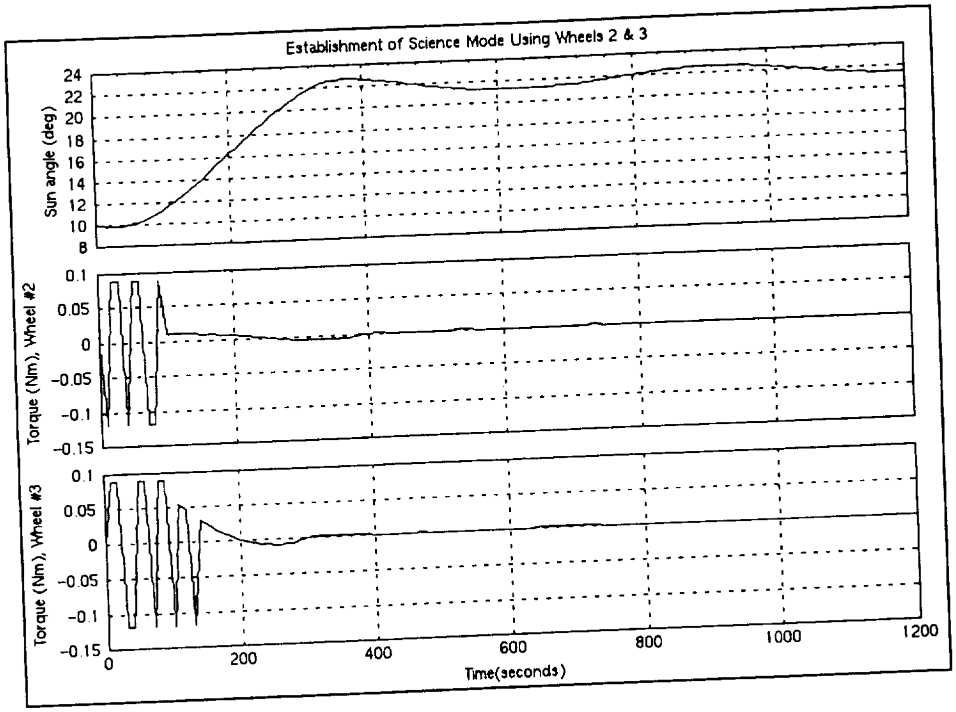

Figure 2: Case of wheel #1 failure. The jagged torque profile shows typical commands during Sun Escape, a portion of the ObservingII algorithm which is used to avoid limit cycles at low Sun angles. After error reduction, the mode is established, and torque commands become unnecessary unless the Sun angle leaves the operating range.

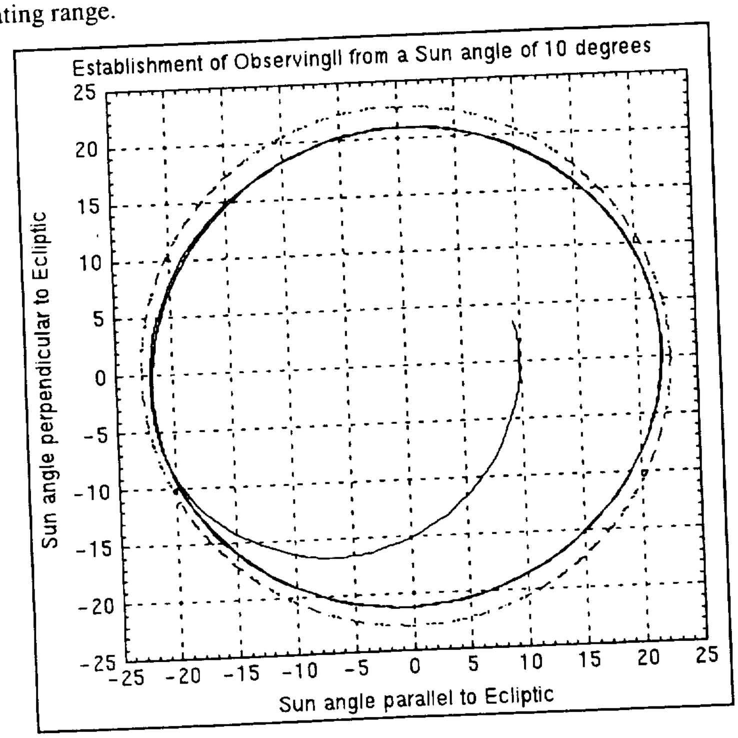

Figure 3: Case of wheel #1 failure. Establishment of mode showing the trajectory of the z-axis direction. The Sun is located at the origin; the dashed line is the 22.75° performance limit.

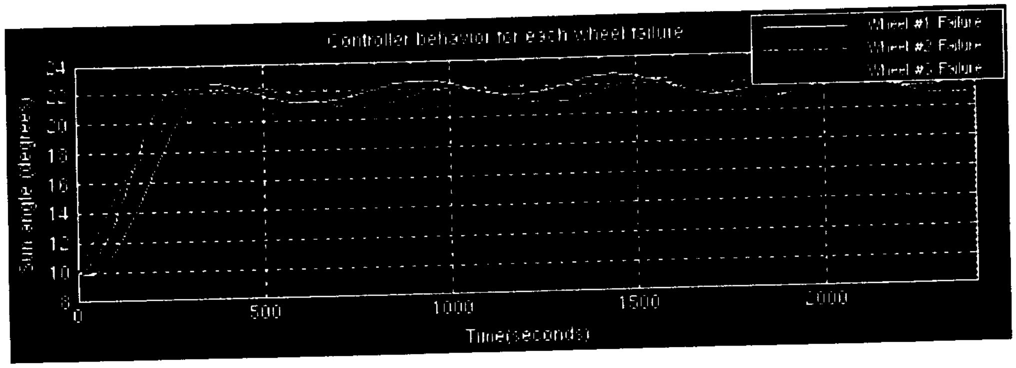

Figure 4: Establishment of ObservingII science mode in all three cases of wheel failure. Initial conditions for each case were identical.

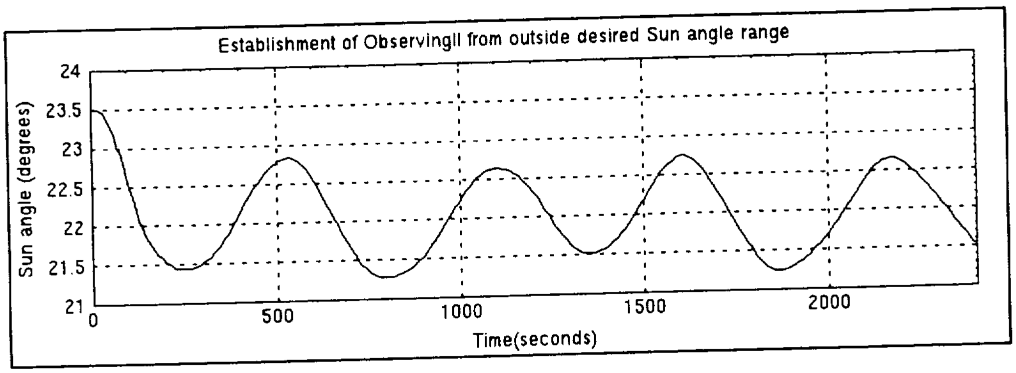

Figure 5: Because the spacecraft symmetry axis has the minimum moment of inertia, the control algorithm must be able to counteract Sun angle increases resulting from energy dissipation. From an initial Sun angle of 23.5°, science operations are restored within 10 minutes.