SWALES AEROSPACE

Getting Your Ideas Off The Ground

THEMIS

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Swales Aerospace / University of California, Berkeley (UCB)
Ground Operations Coordination

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SIGNATURE PAGE

This is a controlled document. Any changes require the approval of the Configuration Control Board.

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Document Change Record

Revision	Description	Date	Approval
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1.0 SCOPE

This document defines the interfaces, roles and responsibilities for developing the tools and performing the post launch Attitude Control System (ACS) functions. Mission Operations Command and Telemetry is covered in the Ground System Interface Control Document (ICD).

2.0 ORBIT DETERMINATION

1. Orbit determination algorithms and code are the responsibility of University of California, Berkeley (UCB).
2. Orbit determination requirements are levied on UCB.
3. UCB will receive Goddard Trajectory Determination System (GTDS) for orbit determination from NASA GSFC.
4. Swales will verify GTDS runs using STK.

3.0 MANEUVER PLANNING

1. Orbit maneuver planning algorithms and code are the responsibility of UCB.
2. UCB will receive General MANeuver Program (GMAN) for maneuver planning from NASA GSFC.
3. Swales / Hammers will use representative GMAN output (thruster commands) for ACS design and software testing.

4.0 ATTITUDE DETERMINATION

1. There are several attitude determination needs:
   (a) Ground-based science observation (long-term attitude determination)
   (b) Ground-based slew monitoring (e.g., attitude determination immediately before and after thruster firing)
   (c) On-orbit slew monitoring (for fault protection)
2. There are two attitude determination paradigms:
   - **Bus perspective (magnetometer is an ACS sensor):** The bus side (Swales) combines instrument magnetometer data with its bus sun sensor data for attitude determination.
   - **Science / instrument perspective (sun sensor is an instrument):** The instrument side (UCB) combines bus sun sensor data with its instrument magnetometer and Electric Field Instrument (EFI) data for attitude determination.
3. We should choose the appropriate perspective for each attitude determination need. The cleanest and most sensible arrangement is as follows (Table 4-1):
   (a) Ground-based science observation attitude determination algorithms are the responsibility of UCB.

(b) Ground-based slew monitoring algorithms are the responsibility of Swales.

(c) On-orbit attitude determination for fault protection is the responsibility of Swales.

Krishan Khurana’s 8/13/2003 email (Attachment A) explains how the instrument team can perform the necessary ground-based attitude determination to achieve science objectives.

This would have several benefits for the program:

(a) It clearly delineates responsibilities for attitude determination algorithm development.

(b) It removes Swales from the science-based attitude determination requirements development and responsibility.

(c) It diminishes the level of Swales insight needed into the heavily instrument dependent ground-based attitude determination algorithms.

(d) It provides a cleaner interface for bus testing. Representative command files are needed from UCB for testing and representative telemetry will be produced for running through ground software.

4. Multimission Spin Axis Stabilized Spacecraft Attitude Determination System (MSASS) will be used for attitude determination to support ground operations. UCB will receive MSASS from NASA GSFC.

5. Ground-based ACS algorithms for slew monitoring may exist in MSASS. However, due to lack of availability of MSASS, Swales will need to produce algorithms and simulation software that show we can meet requirements (Table 4-1).

6. UCB is responsible for MSASS modifications if necessary (Table 4-1).

Table 4-1 Attitude Determination Responsibility Matrix

Attitude Determination Purpose	Ground-Based Science	Ground-Based Maneuver Support	On-Board Maneuver Support and Fault Protection
Algorithms	UCB	Swales	Swales
Implementation	UCB	UCB	tHC
Testing	UCB	UCB Swales	Swales tHC

5.0 TESTING

1. The Swales / Hammers test effort will require a representative command profile for all operation scenarios for each probe to perform an end-to-end test. The Berkeley planning system will not be needed at Swales.
2. Post-test analysis of VirtualSat achieved files along with captured telemetry will be used to validate the ACS flight software for thruster maneuvers, on-orbit attitude determination, and fault protection.
3. Captured telemetry from VirtualSat will be used to validate attitude determination ground software.

APPENDIX A – DEFINITIONS

ABBREVIATION	DEFINITION
ACS	Attitude Control System
EFI	Electric Field Instrument
FGM	Flux Gate Magnetometer
GSFC	Goddard Space Flight Center
GMAN	General MANeuver Program
GTDS	Goddard Trajectory Determination System
ICD	Interface Control Document
MSASS	Multimission Spin Axis Stabilized Spacecraft Attitude Determination System
NASA	National Aeronautics and Space Administration
STK	Satellite Tool Kit
UCB	University of California, Berkeley

ATTACHMENT A – KRISHAN KHURANA'S 8/13/2003 E-MAIL

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Richard,
              See my answers/comments below in CAPS.  Regards.  Krishan

-----Original Message-----
From: Richard LeBoeuf [mailto:rleboeuf@swales.com]
Sent: Wednesday, August 13, 2003 3:59 PM
To: Kkhurana@Igpp. Ucla. Edu
Cc: Ertaylor@Ssl. Berkeley. Edu; Tajluni@Swales. Com;
vassilis@ssl.berkeley.edu
Subject: Algorithms/Codes and modeling data


Krishan,

Vassilis and I just went over his email and he suggested I ask you for the
algorithms and codes for post-processing referred to therein.  However, to
be sure I understand the information, here are my assumptions about the
first three items in the email:

TO MAKE SURE WE BOTH ARE TALKING ABOUT THE SAME THINGS,
LET ME FIRST DEFINE SOME COORDINATE SYSTEMS THAT WE USE.

FGM COORDINATE SYSTEM: A NON-ORTHOGONAL ROTATING
COORDINATE SYSTEM BASED ON THE THREE FGM SENSOR
DIRECTIONS.

ORTHOGONALIZED FGM COORDINATE SYSTEM: AN ORTHOGONAL
ROTATING COORDINATE SYSTEM IN WHICH THE Z AXIS OF THE
SENSOR POINTS TO THE TRUE SPIN AXIS AND X AND Y LIE IN THE
TRUE SPIN PLANE OF THE SPACECRAFT.

ROTATING SPACECRAFT COORDINATE SYSTEM: AN ORTHOGONAL
ROTATING COORDINATE SYSTEM WHICH HAS Z-AXIS ALONG THE NOMINAL
SPIN AXIS AND X AND Y AXIS IN THE SPIN PLANE. (THE NOMINAL SPIN AXIS
DIRECTION IS WHAT THE ENGINEERS BELIEVE THE SPIN AXIS
DIRECTION IS.THE DIFFERENCE BETWEEN NOMINAL AND TRUE SPIN AXES
MAY BE  A FRACTION OF A DEGREE.)

INERTIAL SPACECRAFT COORDINATE SYSTEM: AN ORTHOGONAL
DEPUN COORDINATE SYSTEM IN WHICH THE Z-AXIS IS ALONG THE
NOMINAL SPIN AXIS AND X AND Y POINT IN SOME FIXED DIRECTION IN
SPACE.

GEOPHYSICAL COORDINATE SYSTEM LIKE GSE OR GSM

SO THE PROCESS OF GETTING DATA IN A GEOPHYSICAL
COORDINATE SYSTEM GOES SOMETHING LIKE THIS.

STEP 1. FGM TO ORTHOGONALIZED FGM SYSTEM
             NEEDS A MATRIX AND ZERO LEVELS OF SENSORS THAT
            CAN BE OBTAINED FROM POST PROCESSING OF SPINNING
            RAW DATA.
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STEP 2. ORTHOGONALIZED FGM SYSTEM TO INERTIAL SPACECRAFT SYSTEM.
NEEDS SPIN PHASE INFORMATION.
FIRST IT IS ASSUMED THAT THE ORTHOGONALIZED FGM SYSTEM IS THE SAME AS THE ROTATING SPACECRAFT SYSTEM. THUS ANY ERRORS IN PHASE OR ELEVATION ANGLES SUPPLIED BY THE SUN SENSOR ARE IGNORED AT FIRST. THEY ARE RECOVERED LATER BY THE FOLLOWING PROCEDURE.

ROTATE THE SENSOR DATA IN THE EARTH'S INNER MAGNETOSPHERE TO THE INERTIAL SPACECRAFT SYSTEM. THEN OBTAIN PREDICTIONS FOR THE FIELD FROM MODELS (LIKE TSYGANENKO, 1987) IN THE SAME COORDINATE SYSTEM. CALCULATE THE CORRECTION MATRIX THAT WILL MINIMIZE THE DIFFERENCE BETWEEN THE DATA AND THE MODEL. THE CORRECTION MATRIX FROM THIS STEP IS COMBINED WITH THE ROTATION MATRIX NEEDED IN STEP 3.

STEP 3. INERTIAL SPACECRAFT SYSTEM TO GEOPHYSICAL SYSTEM.
NEEDS A MATRIX THAT RELATES THE TWO COORDINATE SYSTEMS.

NOW I AM READY TO REPLY TO YOUR COMMENTS.

1) Assuming the probe is spinning about its principle axis, "FGM orientation relative to the spin-axis" means the spin axis vector expressed in FGM coordinates. Therefore, I assume you have an algorithm/code that will estimate the orientation of the probe spin-axis vector in the FGM frame to within 0.1 deg, 3 sigma of its true orientation relative to the FGM frame for an entire revolution of the probe.
THIS IS CORRECT. WE GET A MATRIX THAT TELLS US THE RELATIONSHIP BETWEEN THE FGM COORDINATES AND THE ORTHOGONALIZED FGM COORDINATES.

2A) "FGM absolute orientation" means the transformation from an inertial frame (e.g., ECI) to the FGM frame. Having this transform along with #1 above, would enable us to transform the spin vector expressed in FGM coordinates to inertial coordinates, thereby producing spin axis inertial knowledge, an ACS requirement. Therefore, I assume you have an algorithm/code that will estimate the transformation from an inertial frame (e.g., ECI) to the FGM frame to within 0.5 deg, 3 sigma. That is, if I transform from ECI to FGM frame using the estimate, the estimated FGM axes will be within 0.5 degrees, 3 sigma of their true locations for an entire revolution of the probe.

I DESCRIBED THE PROCEDURE OF GOING INTO A GEOPHYSICAL COORDINATE SYSTEM ABOVE. ONE NEEDS TO PERFORM 2 SETS OF CALIBRATIONS. I TALKED WITH PROF. CHRIS RUSSELL ABOUT THESE CALIBRATIONS AND HE CONCURS THAT GETTING ACCURACY OF 0.5 DEGREES SHOULD NOT BE DIFFICULT.

2B) "Spin-axis to s/c Z-axis" means the spin axis vector expressed in spacecraft (probe) coordinates.

It sounds like you have an algorithm/code that estimates the transformation

from an inertial frame to the FGM frame as well as the spin axis vector expressed in probe coordinates.
ACTUALLY WE OBTAIN A MATRIX THAT ROTATES THE OBSERVED
DATA INTO THE SPINNING ORTHOGONAL FGM FRAME. THEN WE
DESPIN THE DATA INTO THE INERTIAL SPACECRAFT SYSTEM. NEXT
WE APPLY A MATRIX THAT TAKES US INTO A GEOPHYSICAL
COORDINATE SYSTEM.

3) "EFI offset from FGM (or spin axis)" means the transformation from the EFI frame to the FGM frame. "EFI offset from (spin axis)" means spin axis vector expressed in EFI frame coordinates. "EFI frame" means the non-orthogonal frame defined by the axial boom (nominally the probe Z-axis) as one axis, and the other two axes in the plane of the wire booms. The wire booms will not be orthogonal to the axial boom due to principle axis misalignment or orthogoanl to each other due to canting of the EFI wire booms to accomodate a larger tank.

It wasn't clear to me if you had this algorithm/code or if this was just conceptual.

I HAVE NEVER USED THE TECHNIQUE I DESCRIBED ABOVE FOR
ELECTRIC FIELD DATA. BUT I DO NOT SEE WHY WE COULD NOT
USE THE SAME TECHNIQUE TO GET THE RELEVANT MATRICES FOR
THE ELECTRIC FIELD DATA.

We will be looking at the problem of determining the spin axis inertial orientation and the inertial spin phase (related to #1 and #2 above) using a combination of sun sensor data and FGM data. Do you have the following modeling information:

A) What is the accuracy (3 sigma) of the FGM data relative to the FGM frame (i.e., measured B-field orientation relative to actual B-field orientation?

AFTER THE CALIBRATIONS HAVE BEEN PERFORMED, THE TWO SHOULD
BE WITHIN 0.5 DEGREES.

B) What is the accuracy (3 sigma) of the B-field model data, particularly during a perigee pass (i.e., modeled B-field orientation relative to the actual B-field orientation)?

IF HIGH RESOLUTION DATA ARE AVAILABLE (EIGHT OR MORE SAMPLES
PER SPIN), AGAIN 0.5 DEGREES.

Any help would be appreciated since we are using the instrument magnetometer as an ACS sensor.

WE CAN PROVIDE PROGRAMS BUT THERE IS A STEEP LEARNING CURVE.
SOME ONE SHOULD VISIT US FOR A FEW DAYS TO LEARN THE PROGRAMS.
IT WOULD BE PREFERABLE IF UCLA OR BRAUNSCHWEIG DID THESE
CALIBRATIONS FOR SWALES.

Thanks,

Richard LeBoeuf

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-----Original Message-----
From: Vassilis Angelopoulos [mailto:vassilis@ssl.berkeley.edu]
Sent: Monday, August 11, 2003 8:23 PM
To: Richard Leboeuf
Cc: Ertaylor@Ssl. Berkeley. Edu; Tajluni@Swales. Com; Kkhurana@Igpp. Ucla. Edu
Subject:

I had an action item with regards to ACS. I spoke with Krishan Khurana and Forrest Mozer regarding FGM-to-EFI post-processing knowledge.

1) Krishan confirmed that FGM-post processing can provide the FGM orientation relative to spin axis at better than 0.1deg (in strong enough field regions can do fraction of above).

2) FGM can provide its absolute orientation to within 0.5 degrees, by taking spin-pulse data from spacecraft and doing post-processing to determine spin-axis to s/c Z-axis accurately.

First (reasonable, within a few degrees) guesses of the s/cZ axis offset from spin axis, and elevation angle from sun-sensor help converge faster.

The process uses magnetic field models at perigee. Krishan mentioned more sophisticated models from IGRF, such as Tsyganenko, which take into account solar wind pressure and geomagnetic activity. However, this method does not differ from Triad in principle.

3) EFI-to-FGM: I discussed with Forrest Mozer:

The EFI instrument data post-processed will provide the offset from the FGM (or spin axis) to within the required accuracy to perform the science. Accuracy of 0.1 degrees is questionable but a worthy goal with THEMIS booms - we just have to try and see. Stability of 0.1degrees is possible even at moderate tip angles.

The bottom-line is that post-processing knowledge of spin-axis to spacecraft Z-axis (PB.ACS-18) should not be 0.1degrees.

As stated in the mission requirements we want absolute knowledge of 1 degree. Since the FGM-to-spin axis can be known to 0.1deg (above) at most times in the orbit (not only through perigee) the main other contributor is the spinaxis to Z-axis.
Can TRIAD achieve an ACS solution to within that accuracy using MAG data?. UCLA can then improve on

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that as necessary. Alternatively, UCLA can be involved in
routine processing of the perigee data and report to all, or provide
the ACS Team with code...

4) Spin-phase. I noticed, and then others noticed too, that
spin phase is given to 0.25deg. We need the spin-phase to 0.1degrees
with some averaging (say, over few spins) to beat down noise.
Elevation is less critical than spin phase; there 0.25deg
seems reasonable to me.

   We either need to do this processing on the IDPU or on the BAU,
but definately we need a pulse that does not jump by more than 0.1deg.
Folded into that are sensor age and threshold drifts etc.

   Based on discussions with Pankow/Carlson the 0.25 deg is pretty
standard for sun sensor, and the processing required to beat down the noise
is
also pretty standard. You can check with Pankow,
Dave Curtis, regarding how it was done on FAST, HESSI etc. It should
not drive the design or electronics.

 5) Krishan is availabe Thursday Aug 21 for discussion if we can
schedule our next ACS telecon then.

 6) Question: What does 3sigma mean: 0.1deg-3sigma means 0.033deg-1sigma?

 Regards

 Vassilis
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