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S-NPP Risk Mitigation Maneuver Response Time Optimization via Pre-verified Maneuver Sequences

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The Suomi National Polar-orbiting Partnership (S-NPP) satellite operates in a dense debris environment; therefore, monitoring and responding to close approaches between debris objects and the spacecraft is vital to mission success. The current method for responding to close approaches is both resource- and time-intensive and requires the Mission Operations Team (MOT) to start the process before a threat to the spacecraft is

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fully analyzed. A new method for preparing and executing a Risk Mitigation Maneuver (RMM) could reduce the time and resources required for responding to a close approach. By reducing response time, the MOT is able to allow more time for the close approach to be analyzed and characterized as actionable, preventing unnecessary reaction to non-actionable threats. This new method, called the On-Board Stored Maneuver Sequence (OSMS) system, uses pre-verified command sequences and ground commands to execute a RMM.

Nomenclature

CARA	=	Conjunction Assessment Risk Analysis
CBM	=	Command Block Memory
CERES	=	Clouds and the Earths Radiant Energy Systems
DAS	=	Detailed (Daily) Activity Schedule
DMU	=	Drag Makeup Maneuver
MOT	=	Mission Operations Team
NOAA	=	National Oceanic and Atmospheric Administration
NASA	=	National Aeronautics and Space Administration
OMPS	=	Ozone Mapping Profiler Suite
OSMS	=	Onboard Stored Maneuver Sequence
RMM	=	Risk Mitigation Maneuver
S-NPP	=	Suomi National Polar-orbiting Partnership
TCA	=	Time of Closest Approach

I. Introduction

IN January 2014, S-NPP MOT responded to several close approaches. The MOT started RMM planning for four threats during this period. Three of these events did not lead to an executed RMM due to dissipated threat levels from new tracking data. At the moment when these events were cancelled, the MOT had completed most of the steps needed to make an RMM ready for execution. Preparation for an RMM demands a significant resource and time allocation from the S-NPP MOT, which requires significant lead times and limits the MOTs ability respond to several close approaches simultaneously. S-NPP operates at an altitude of approximately 824 km, which Ref. 1 identified to be a dense and potentially hazardous debris environment. Due to this dense environment, the MOT experiences frequent close approach events. It was soon realized that the MOT needed improved tools and processes to optimize RMM planning and reduce response times to close approach events. Reducing response times is necessary as better detection capabilities in the near future are expected to increase the number of predicted close approaches[2].

Two different approaches were selected to improve the RMM process. One approach was to provide the MOT additional tools for optimizing RMM planning, such that the aggregate risk of conjunction with multiple objects is reduced, taking into account the spacecraft requirements and constraints. The other was developing a flexible and less resource-intensive method for configuring the spacecraft for maneuvers and executing an RMM. The latter will be discussed in this paper.

The MOT typically executes an RMM twelve to twenty four hours before the Time of Closest Approach (TCA) to minimize the size of the avoidance maneuver. The current method takes approximately twenty hours or two business days of preparation prior to executing the maneuver, requiring the RMM process to be started approximately seventy-two hours before TCA. Additional tracking is required to reduce uncertainties in the position of the approaching object, which is taking place during the period that the MOT is preparing the maneuver. The largest step in the process is the creation, validation, and testing of the Detailed Activity Schedule (DAS) command load containing the commands to execute an RMM. This step requires roughly ten to twelve hours of time to accomplish and required each burn time and duration to be tested using an aging simulator. Creating a method of executing an RMM using pre-verified maneuver sequences stored on the spacecraft will remove this ten- to twelve-hour step from the process, allowing more time for uncertainties to reduce prior to responding, and will remove the dependency on a single point of failure simulator and mission planning system resources.

The OSMS system uses a set of on-board Command Block Memory (CBM) sequences, a sequence of relative time commands, and a set of ground system scripts to command an RMM without the need for a DAS. This system was put through a period of ground testing and on-orbit testing and integration. Once declared operational, this system will significantly improve how much time is needed to execute an RMM.

II. Designing the OSMS System

Before the OSMS system could be used on-orbit and before it could be tested, it had to be designed and built. The MOT reviewed several proposed concepts for the OSMS system. After selecting a concept, the components for the system were created.

A. Conception & Design of the OSMS System

The MOT held internal discussions on how to design the pre-verified maneuver sequence system. From these meetings an overall design was created to execute maneuvers without the DAS command loads.

Before designing the OSMS system, the MOT investigated different alternatives to executing an RMM. The first approach called for software that would look for certain conditions before executing a maneuver. The first condition required the spacecraft to be in eclipse and the second was a flag set by ground command. This approach lacked flexibility in maneuver placement and was vulnerable to mis-commanding causing an unplanned maneuver execution. Another approach called for commands to be inserted into the DAS from the ground. These commands would either be the entire command sequence or a call to a segment of CBM that contained the maneuver commands. This method couldn’t be used due to the inability to insert commands into the DAS. An alternate method that wasn’t discussed, but was available, called for the entire maneuver sequence to be executed via ground commands. While all the components for this system have been built previously, it required a ground or TDRSS contact for the maneuver. Due to the short-notice nature and timing of an RMM, ground or TDRSS contacts may not always be available to allow for ground commanding.

The process decided upon by the MOT called for the placement of CBM sequences containing the maneuver commands for executing an RMM on the spacecraft and for the development ground system scripts that would configure and execute the CBM sequences. This method:

1) Affords the MOT the flexibility to schedule an RMM
2) Provides the necessary automation to execute the burn if a contact is not available
3) Eliminates the generation, validation, and testing of a DAS

B. System Components

The OSMS system consists of components for the spacecraft and ground system. The spacecraft portions of the system are a series of CBM sequences containing all instructions for executing an RMM. The ground components of the system are comprised of ground scripts that will configure and execute the on-orbit CBM sequences.

The on-orbit CBM is made up of four sequences. Two sequences consist of maneuver commands for the spacecraft, each covering one of the two delta-V modes. The two other sequences contain the commands to prepare the CERES and OMPS instruments for a maneuver and return both instruments to science mode following the RMM. Each maneuver sequence has two sections. The first section is a series of configurable slots that the ground scripts will populate with time delays appropriate for placing the delta-v burn of the RMM at the desired time. The second section contains the maneuver sequence. In the maneuver sequence, there are three empty slots that are populated by the ground scripts. The first two slots are reserved for CBM execution commands for the CERES and OMPS sequences. The third slot is reserved for the delta-v burn command and is populated with the appropriate command and desired magnitude for the burn.

The ground portion of the system consists of two scripts. The first script will ask the user when the delta-v burn of the RMM should be scheduled, the duration of the burn in milliseconds, and whether CERES and OMPS should be configured for the maneuver. After taking into account the user inputs, it will:

1) Select the delta-v burn mode based on requested duration
2) Calculate the delay needed to place the burn as requested by the user
3) Insert the needed delays in the delay section of the maneuver CBM
4) Insert the CBM calls for the CERES and OMPS sequences,
5) Insert the burn command with the appropriate magnitude based on selected burn duration
6) Execute the maneuver CBM sequence

The second script, the back out script, will clean up the maneuver CBM sequences and conduct a check to confirm the on-orbit CBM is in its pre-maneuver configuration.

III. Testing

Before the OSMS system could be declared operational, a series of tests had to be performed. The MOT developed a set of ground and on-orbit tests to validate OSMS.

A. Ground Testing Methodology

Prior to loading the CBM sequences to S-NPP and placing the ground scripts onto the operational ground system, all components had to be thoroughly tested on the spacecraft simulator. Over the course of four months, five sets of tests were performed to validate:

1) All four OSMS CBM sequences
2) All twenty-four pre-selected burn durations
3) Setup and back out ground scripts

After each test set, tests results were reviewed. Any identified deficiencies in either testing or in the OSMS system were repaired and tested in the next test set.

Tests were created to validate the four OSMS CBM sequences. During each test, the test engineer kept track of which sequence was executed. After execution, command logs were dumped from the simulator and archived for post-test analysis. After each test set, the tester reviewed the command logs to confirm that all desired commands in the sequence were executed in the proper order and at the requested times.

The OSMS system contains twenty-four different burn duration options. For each selection, the OSMS ground system will configure both the spacecraft and the appropriate maneuver CBM to execute the desired burn. To confirm each selection, a tester commanded all of the options on the simulator and recorded the burn results. After testing, the burn results were compared to the list of expected results to validate all OSMS burn options.

As mentioned previously, the OSMS system needs ground scripts for proper execution of a non-DAS-based RMM. Several tests had to be performed to properly evaluate these scripts. After the setup and back out scripts were tested with inputs appropriate for realistic RMM scenarios, ground system logs were gathered and CBM sequences were dumped for post-test analysis. After each test, the tester reviewed the logs to confirm that the scripts performed all setup and back out steps in an accurate and timely manner. The CBM sequences that were dumped confirmed:

1) The setup script properly configured the sequence for an RMM and
2) After the RMM, the back out script properly deconfigured the sequence.

B. On-Orbit Testing Methodology

While ground testing of OSMS was completed, on-orbit testing needed to be completed before the system could be declared operational. After several discussions, it was decided that testing would be in the form of three main tests:

1) No-Burn Test
2) Open-Loop Burn Mode, the delta-v burn mode for short-duration burns, Drag Make Up (DMU) Test
3) Closed-Loop Burn Mode, the delta-v mode for long-duration burns, DMU Test

Before testing the OSMS system by executing an actual maneuver, all operationally deployed ground scripts were tested. During the ground tests, it was identified that differences between the simulator environment and the operational environment could not be fully accounted for. The MOT wanted to test the setup and back out ground scripts to confirm that they will perform properly on the operational ground system. To test these scripts, a RMM for both open- and closed-loop burns was executed via the setup script. Upon conclusion of the setup script and before the first scheduled command for the RMM, the maneuver was aborted. After each test, all ground logs and spacecraft command logs were gathered for post-test analysis.

To evaluate the full performance of the OSMS system on-orbit, it was decided to have the OSMS system perform an open- and a closed-loop DMU. DMUs are identical to RMMs but without the compressed planning sequence. Each maneuver will be planned like a nominal DMU except for submitting a DAS request to the mission planners. On the day of the DMU, the OSMS system will be executed to set up and perform the maneuver. After each DMU, command logs, CBM sequences, and telemetry files will be gathered for post-test analysis.

IV. Results

A. Ground Test Results

All post-test artifacts from the ground test sets were reviewed by the MOT. Analysis of the simulator command logs confirmed that all OSMS CBM sequences executed in their proper order and at the requested times. All burn options were proven valid after comparing test results with predicted results. Command logs and ground system logs confirmed that the setup and back out scripts performed as desired. After reviewing results, it was concluded that all OSMS components were ready to be deployed to the operational ground system and uplinked to the spacecraft.

B. On-Orbit Test Results

At the time of the writing of this paper, the no-burn and open-loop mode tests have been successfully performed. The no-burn test was performed on November 18, 2015. The no-burn test confirmed that the OSMS ground scripts would perform properly on the operational ground system and placed all commands within two seconds of their desired times. The open-loop test was performed on February 24, 2016, but due to ground track restrictions, the closed-loop test will not be performed for several months. During the open-loop test, OSMS performed DMU 22 and placed all commands within one second of their desired execution times. Despite the lack of closed-loop maneuver testing, the no-burn and open-loop test confirmed that the OSMS system can command an RMM without the need for the creation, validation, and testing of a DAS.

V. Conclusion

While all on-orbit tests have not been completed, results gathered so far show promise for the OSMS system. All time delays and burn options were validated, removing the need to simulate future maneuvers. The OSMS system can perform open-loop burn RMMs without the need for a DAS. Once the closed-loop test can be completed, the need for a DAS for RMM execution can be safely removed. Removing the need for creating, validating, and testing the DAS will eliminate ten to twelve hours of RMM preparation time and lower the total time to respond to an RMM from two days to less than one day. With a less than one-day response time, the MOT can delay the start of RMM preparations. The delay will allow time for additional tracking information to be received, reducing positional uncertainty in the approaching object and reducing the calculated risk of conjunction. Reduced risk of conjunction/collision often eliminates the need for executing the maneuver, saving the team the time and effort of a planning exercise for an event that is not executed.

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References

[1] Englert, C. R., Bays, T. B., Marr, K. D., Brown, C. M., Nicholas, A. C., Finne, T. T., “Optical orbital debris spotter,” *Acta Astronautica*, Vol. 104, No 1, Nov. 2014, pp. 99-105.

[2] Frigm, R. C., Hejduk, M. D., Johnson, L. C., Plakalovic, D., "Total Probability of Collision as a Metric for Finite Conjunction Assessment and Collision Risk Management,” *Advanced Maui Optical and Space Surveillance Technologies (AMOS) Conference*, Maui Economic Development Board, Inc., Hawaii, 2015.