Establishment and Implementation of a Close Approach Evaluation and Avoidance Process for Earth Observing System Missions

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In the fall of 2004, the Earth Science Mission Operations (ESMO) Project tasked the Goddard Space Flight Center (GSFC) Flight Dynamics Analysis Branch (FDAB) with establishment of a process to protect the high-value Earth Observing System (EOS) missions (Terra, Aqua, and Aura) from close approaches with space debris and other orbiting objects. An agreement was put in place between GSFC and the United States Strategic Command to support this process, through which close approach data concerning GSFC assets and other space objects is computed and reported to GSFC. The ESMO project also had to establish a process to evaluate this data, assess the associated threat posed to the EOS missions, and perform any necessary mitigating action. This paper discusses both the conjunction evaluation process development and its implementation, including descriptions of new tools developed to analyze close approach data and of risk mitigation strategies employed. In October 2005, EOS Terra performed the first debris avoidance maneuver by a NASA unmanned spacecraft. This close approach example is described in detail from the initial screening identification through execution of the mitigation maneuver to illustrate the process implementation.

I. Introduction

Orbital debris poses a significant threat to spacecraft health and safety. The current estimate of the number of ‘tracked’ objects that are larger than 10 cm is greater than 11,000, with the number of objects increasing by about 200 per year.[1,2] Most of these tracked objects are classified as orbital debris. Satellites are routinely hit by small particles that cause little or no damage. However, if a large particle were to hit an operational satellite, the impact could result in the end of the mission. A large part of the orbital debris population resides in low earth orbit (LEO), where the density distribution of cataloged objects is concentrated near mean equatorial altitudes of 700 – 1100 km. Therefore, in keeping with the National Aeronautics and Space Administration’s (NASA) recent focus on limiting the generation of new space debris while minimizing the impact with existing debris[3], the Earth Science Mission Operations (ESMO) Project at NASA’s Goddard Space Flight Center (GSFC) has established an operational collision risk assessment process for the Earth Observing System (EOS) satellites: Terra, Aqua, and Aura.

To effect this process, a Memorandum of Agreement[4] (MOA) was established between NASA and the Department of Defense (DOD). In accordance with the agreement, the GSFC Flight Dynamics Analysis Branch (FDAB) works with USSTRATCOM’s 1st Space Control Squadron (SPCS) to provide the EMSO project with routine conjunction assessment services. The conjunction assessment (CA) process consists of:

1. 1st SPCS predicts close approaches between EOS missions and other objects in USSTRATCOM’s Space Object Catalog

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2. GSFC CA team assesses the collision risk posed by close approach predictions
3. GSFC CA team works with the ESMO project to plan any necessary risk-mitigating action

Since the EOS regime is densely populated with orbital debris, the close approach process is utilized several times per week as part of routine satellite operations. On average, every month each EOS spacecraft will have 1.5 close approaches that are predicted to be less than 1 km in total miss distance.[5]

Section II provides a brief description of the EOS orbital environment and operational constraints. Section III describes the ESMO CA process, and Section IV describes a particular encounter between the Terra spacecraft and debris object 14222. Section V offers the conclusion and a discussion of the future work.

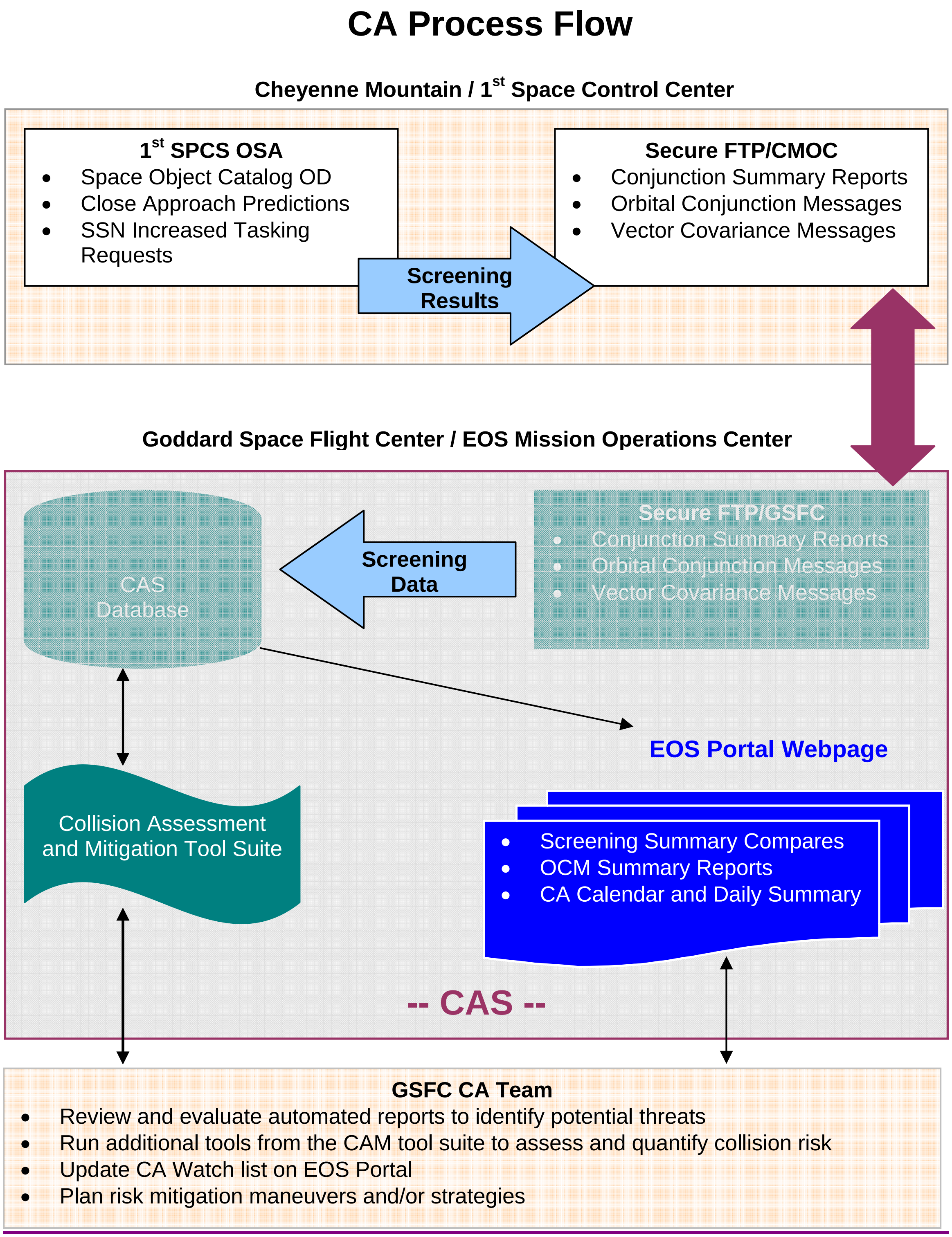
II. Earth Observing System Mission Operations

The EOS missions reside in sun-synchronous frozen orbits with a 705 km mean equatorial altitude. Their orbit ground tracks repeat in a 16-day cycle and are maintained relative to the Worldwide Reference System (WRS-2). Each performs periodic ground track maintenance maneuvers in response to drag and periodic inclination maintenance maneuvers to control the Mean Local Time of the equator crossing.

The specifics of the EOS orbit, spacecraft capabilities, and operations philosophy played a vital role in the development of the conjunction assessment operations concept. For example, none of the EOS spacecraft are able to perform retrograde maneuvers, so risk mitigating avoidance maneuvers must be sized appropriately to allow the spacecraft to remain within its ground track control box. A detailed study was performed of the acceptable maneuver sizes for Aqua to understand how the control box violations are affected by various size maneuvers under different drag conditions[6]. Also, the entire maneuver planning process nominally takes several days to ensure both access to needed Space Network assets at the appropriate times and the ability to include the maneuver in the daily command upload sent to the spacecraft. These constraints drive the timing to make the decision to begin planning a mitigation maneuver to close approach minus three days, such that the data at that point must be as accurate as possible. Therefore, a decision was made to screen seven days into the future. Seven day screenings allowed sufficient time to collect additional tracking data for the secondary object to trend and refine conjunction parameters and to plan a mitigating maneuver based on that information.

III. The Conjunction Assessment Process

This section describes the details of the CA process developed for the EOS missions. The process begins with the generation of daily predicted ephemeris files for each of the EOS missions based on the latest orbit determination solution. Next, close approach predictions are generated between each EOS spacecraft and other objects in the Space Object Catalog maintained at Cheyenne Mountain. The data are sent to GSFC and analyzed to quantify the collision risk. Finally, risk-mitigating action is taken if necessary. Further details regarding the products exchanged between 1st SPCS and GSFC are included in a draft Interagency Operating Instruction[7], while the ESMO CA evaluation process is detailed in an Operations Concept Document[8]. Figure 1 illustrates the EOS conjunction assessment process.



- Review and evaluate automated reports to identify potential threats
- Run additional tools from the CAM tool suite to assess and quantify collision risk
- Update CA Watch list on EOS Portal
- Plan risk mitigation maneuvers and/or strategies

Figure 1: ESMO CA Process Flow

A. Catalog Screening and Close Approach Predictions

The first step of the CA process is the responsibility of the 1st SPCS Orbital Safety Analysts (OSAs). They make close approach predictions between the EOS missions and other objects in the high accuracy catalog each weekday, with additional screening on weekends as warranted for high interest predicted close approaches.

1. Screening Ephemerides

Each day, EOS predictive ephemeris files are posted to the Constellation Coordination System, which is a data repository for many ESMO missions, including the EOS spacecraft. The ephemeris files are 7 days in length and include any planned maneuvers. The OSA downloads the ephemeris files, which are then used to generate close approach predictions. The Cheyenne Mountain-generated solution for each EOS mission is also evaluated in the close approach prediction process. Results from both sets of input data are provided to GSFC. The asset of interest (in this case EOS Terra, Aqua, or Aura) is typically referred to as the “primary”, while the conjuncting object is referred to as the “secondary”.

2. Safety Volumes

Two different mission safety volumes are used in the catalog screening process. The safety volumes dictate different data product deliveries as well as actions taken. The first safety volume, which is called the Monitor Volume, is defined as an ellipsoid centered on the primary object. The second safety volume, which is called the Tasking/Alert Volume, is box-shaped and is centered on the primary object. The coordinate frame for both volumes is the radial, in-track, cross-track (RIC) coordinate frame. Table 1 lists the dimensions of the safety volumes that have been defined for the EOS missions.

Table 1: Safety Volume Definitions

	Radial (km)	In-Track (km)	Cross-Track (km)	Data Product
Monitor Volume (ellipsoid)	±2	±25	±25	Conjunction Summary Report
Tasking/Alert Volume (box)	±0.5	±5	±5	Orbital Conjunction Message

The Monitor Volume is the larger of the two safety volumes and serves as the initial reporting filter. For each EOS mission, all secondary objects that are predicted to pass within the Monitor Volume during the 7-day prediction period are reported. A Conjunction Summary Report, which lists all the monitor volume violations, is provided each time the catalog screening is performed. The Conjunction Summary Report includes the catalog identification number of the secondary object and the RIC miss distance components at the time of closest approach.

The Tasking/Alert Volume is the smaller safety volume. Close approach predictions that fall within this volume require further analysis. The OSA will request additional tracking on the secondary object if necessary so that a more accurate orbit can be determined. For each Tasking/Alert Volume violation, state vector and state vector uncertainty information is provided to the GSFC CA team. This information allows for the collision probability to be calculated. Additional orbit determination details such as the fit-span, number of observations, and solve-for parameters are included as well. These details at the time of closest approach are provided in an Orbital Conjunction Message (OCM).

B. The Collision Assessment System

Once the 1st SPCS screening data set is received, the GSFC CA team performs risk assessment analysis. A Collision Assessment System (CAS) has been developed which enables the collection and evaluation of the CA data. These high-fidelity tools reside in the EOS Operations Center and are executed as part of the routine operations process for the EOS spacecraft. The CAS is comprised of the following elements[9,10]:

- Secure File Transfer Protocol (SFTP)
- Parser/Monitor Scripts

- Secure Access Database
- Collision Assessment and Mitigation (CAM) Tool Suite
    1. Conjunction Visualization Script
    2. 2-D Collision Probability Utility
    3. Monte Carlo Collision Simulation
    4. Nonlinear Collision Probability Tool
    5. Time History Trending Tool
    6. Collision Avoidance Planning Module
- Secure Webpage (EOS Portal)
- Configuration Management System

The portion of the CAS that provides the set of tools used by FDAB to analyze close approach events is known as the Collision Assessment and Mitigation (CAM) tool suite. The CAM tool suite is built using the Commercial-Off-The-Shelf (COTS) software products *FreeFlyer*® (FF) and Matlab®. The tool suite interfaces to the Secure Access Database for data input and output. The purpose of the CAM tool suite is to provide the software tools needed by the Conjunction Assessment Engineer to assess a collision threat and mitigation options.

The *Conjunction Visualization Script* allows the CA Engineer to investigate the 3-dimensional geometry of the encounter. In addition to providing time histories of the spacecrafts' orbital elements, the relative orbital geometry and 2-D and 3-D orbit visualizations are available. The *Visualization Script* is used to analyze the respective orbits of both objects. Time history orbital element information is generated and used to examine how the close approach event evolves over time; the close approach geometry is visually represented.

The Probability of Collision (P_c) is one of the primary metrics used in the risk assessment process. The CAM tool suite provides several different methods of computing the P_c. The *2-D Collision Probability Utility* is used to investigate the P_c of high relative velocity encounters as described in available literature[11, 12, 13]. Additionally, the *2-D Collision Probability Utility* performs sensitivity analysis which investigates the behavior of the P_c in response to changes in the inputs such as Hard Body Radius (the combined surface areas of the two objects) and covariance size. The *Nonlinear Collision Probability Tool* is used to investigate close approach predictions by computing an 'accumulated' collision probability. This tool is typically used for low relative velocity encounters. The development of this tool is described in Ref 14. This tool allows the CA Engineer to compute P_c in cases where the high relative velocity assumption of the 2-D tool (that the covariance is constant over the encounter time frame) may become invalid. This tool is particularly useful in investigating encounters that occur between constellation members. The *Monte Carlo Collision Simulation* is used as an independent means of verifying the results of the 2-D and 3-D tools.

Another aspect of assessing the collision risk is to look for stability in the orbit determination data. The *Time History Trending Tool* allows the engineer to plot time histories of parameters obtained from a series of OCMs. Data such as the miss distance, uncertainties, and force model parameters can be trended and examined for stability.

The *Collision Avoidance Planning Module* is used to perform avoidance maneuver trade space analysis. Two separate analyses can be performed. First, an avoidance maneuver burn is placed at a fixed time and the maneuver magnitude is varied. Second, for a fixed delta-V magnitude, the location within the orbit is varied. Both sets of analyses allow the CA Engineer to examine the effects that the maneuver has on the close approach prediction while ensuring that the maneuver doesn't induce additional close approach events post-maneuver. The output of this tool is several graphs and plots which allow the CA Engineer to assess the trade space and provide recommendations to the spacecraft maneuver planning team as to when and what size a maneuver should be to mitigate the close approach.

Due to the large number of Monitor Volume violations predicted for the EOS orbit regime, automation was added to the CAS to streamline the data storage and processing. The following paragraphs describe the automated data processing for each of the CA data files.

C. Automated Data Storage and Routine Data Processing

The CA data is received in two formats: a Conjunction Summary Report and an OCM file. The Summary Report contains the close approach date and time, as well as miss distance components expressed in the RIC frame. When the close approach screening data products are posted to the secure FTP server, the data is then automatically parsed and placed into the database. Monitor scripts watch for database updates, then automatically process new data through the CAS system.

1. Conjunction Summary Report Processing

Each time a summary report is received, two different solution comparisons are made. The first comparison is an 'overlap compare', which differences common close approach predictions between the previous screening solution and the current one. This comparison quantifies how much the event numbers have changed. Large differences are noted and discussed with the OSA if necessary. For longer prediction times, a 1-km change in the miss distance in not uncommon, but should be explainable. As the prediction times get shorter, the miss distances tend to stabilize.

A second comparison is made between each day's results produced using the Cheyenne Mountain-generated ephemeris and the GSFC-generated ephemeris. Again, large discrepancies are noted. Expected differences are on the order of 1-2 km; especially for predictions near the 7-day point. If the GSFC- generated ephemeris contains a maneuver, changes between the 'burn' and 'no-burn' solutions can vary by several kilometers depending on the size of the maneuver and the conjunction geometry. Both sets of comparisons are summarized and the results posted to an account-controlled webpage called the EOS Portal.

2. *Orbital Conjunction Message Processing*

For each Tasking/Alert Volume violation, an OCM is provided to the GSFC CA team. The OCM contains both the state vector and state vector uncertainty information at the time of closest approach. After the OCMs are ingested into the database, each OCM is automatically processed through the *2-D Collision Probability Utility* and the *Monte Carlo Collision Simulation Tool*. This processing produces a consolidated package containing a series of plots and text reports which is posted to the EOS Portal webpage for further review. The output from the *2-D Collision Probability Utility* consists of the miss distance, various collision probability calculations, conjunction geometry information, and collision probability sensitivity analysis[15]. The numerical results from the two different P_c computation utilities are placed back into the CAS database.

3. *The CA Calendar*

In order to help analysts keep track of activities involving all spacecraft, planned maneuvers and close approach predictions are listed on a 'CA Calendar'. The CA Calendar contains the following:

a. Close approach predictions that are less than 1 km
b. Close approach events that have P_c values greater than 1e-7
c. Planned EOS maneuver dates and start times

The CA Calendar is available on the EOS Portal or by subscription to an automated e-mail delivery.

D. Determining the Risk of Collision

After the data has been automatically processed through the CAS, the GSFC CA team manually reviews the reports on the EOS Portal webpage to identify which close approach events pose a potential threat and thus warrant further analysis. Each event that is flagged is placed on the CA 'watch list', indicating that further analysis must be performed. Examination of the OCM reports helps to establish the collision risk. Additional analysis is performed by running one or more of the tools from the CAM tool suite. In particular, close approach event trending is performed, which consists of 'linking' several solutions together in order to establish future trends.

An event is deemed to be a risk if a number of conditions are met. First, the trending of the orbit determination solutions must show consistent behavior. It is expected that as the time to closest approach (TCA) shortens, the covariance on well-tracked objects should decrease. Also, it is expected that successive updates to the orbit determination solutions, and hence updates to the miss-distance, should be consistent with the uncertainty represented by the covariance matrix. Trending of force model parameters such as drag coefficient and solar radiation pressure coefficient should be consistent between solutions.

Another criterion is that the P_c must be high and predicted to stay high. Several tools are used to predict the behavior of the P_c. Predicting how the collision probability value will evolve as the position uncertainty changes is called "P_c forecasting". If the P_c is high and the orbital uncertainties in the secondary object are large, chances are the P_c will drop as the time to TCA gets shorter. Sometimes the secondary object is not well tracked. In these cases, the probability metric may be mathematically "high" due to the large uncertainty, but the true risk is difficult or impossible to quantify. Within the *2-D Collision Probability Utility*, the value for P_c is plotted for various scale factors applied to the covariance. Scale factors less than 1 represent a contraction of the covariance, which is expected as time to TCA decrease. If the P_c is forecasted to go down with increased orbit determination accuracy, the event may not be a threat. If the P_c is forecasted to go up or stay static, the event may be a threat.

The angle between the primary axis of the combined covariance in the conjunction plane, which is a two dimensional surface that is perpendicular to the relative velocity vector, and the miss vector is also determined and is called the "clock angle". Investigation of this "clock angle" gives insight into how changes in the conjunction geometry will affect the P_c. For clock angles near zero, the P_c is maximized for a given miss distance and a given covariance. Changes in conjunction geometry that drive the angle away from zero can be expected to decrease the P_c. There have also been cases where the miss distance is so small that any rotation of the combined covariance in the conjunction plane will not lead to any significant reduction in the P_c. In these cases, the conjunction plane plot tells you that future changes in the orbit determination solutions will not significantly alter the P_c.

E. Collision Avoidance Planning and Risk Reduction

If the collision threat is deemed sufficiently high, risk mitigating action is initiated. Typically the action is to execute an avoidance maneuver, which changes the miss distance and collision probability to acceptable levels. For EOS, the benefit of performing a debris avoidance maneuver must be carefully weighed against the risk of not performing it. Since none of the three spacecraft are capable of retrograde maneuvers due to thermal constraints, either the location of the maneuver within the ground track control box or the size of the maneuver necessary to evade the secondary object in a permanent manner may cause the ground track requirements to be violated over a long period of time. The ability to minimize the risk of collision is a function of the placement of the maneuver within the spacecraft orbit relative to the time and location of the predicted close approach. Ideally, the maneuver should be placed on the side of the orbit that is opposite the closest approach. For a given delta-V, this placement will result in the maximum radial separation for the EOS spacecraft (near-circular orbits). Additional separation (mostly in the along-track direction) can be gained if the maneuver is executed multiple orbits prior to the close approach. Each close approach event must be examined with respect to these factors to determine the optimal placement of the maneuver. The earlier the maneuver is executed, the more efficient it is in mitigating the conjunction based on the data in hand at the time, However, the orbital uncertainties become larger as the maneuver is moved further away from the TCA and the risk posed by the close approach may not be reduced as a result.

The risk mitigation planning process begins three days prior to the time of closest approach (TCA). Three days was chosen in order to allow sufficient time to plan the collision avoidance maneuver, evaluate the ability of the maneuver to reduce the risk of the close approach, and to upload the maneuver commands to the spacecraft. At the TCA minus three day point, several close approach solutions will have been generated and trends established.

The collision avoidance maneuver options are then analyzed by using the CAM *Collision Avoidance Planning Module,* which performs a maneuver trade-space analysis on the event. Several different maneuver options are generated and compared against mission constraints. The *Collision Avoidance Planning Module* analyzes how various maneuvers will affect the close approach event. Changes to the delta-v magnitude or the maneuver time can be applied. Numerous risk mitigation candidates are generated and then compared to the satellite ground track maintenance requirements to determine if the maneuver can be performed at the current ground track control box location without violating the mission orbit and hence science requirements. Additional operational considerations such as Tracking and Data Relay Satellite System (TDRSS) contacts and time of day constraints are also considered.

Once the desirable maneuver candidates are generated, ephemeris files are generated and sent to Cheyenne Mountain for comparison screening against the Space Object Catalog. The planning process can be halted at any time based on updated screening results that indicate a reduction in the threat of the conjunction. If the maneuver is executed, a post-maneuver ephemeris is provided to USSTRATCOM for screening following the completion of the collision avoidance maneuver to ensure risk mitigation occurred as expected.

IV. Close Approach Case Study: Terra vs. 14222

This section examines a specific close approach event involving the Terra spacecraft in detail.

A. Event Summary

On Monday the 17th of October, 2005, 1st SPCS reported that a close approach between Terra and debris object 14222 (SCOUT G-1) was to occur. The TCA was reported to be at 20:53Z on the 23rd of October, 2005. The first reported miss distance on Monday was approximately 400 m with a high collision probability of 1.4e-2. Throughout the week, the close approach event was actively monitored by both 1st SPCS and the GSFC CA Team. On Thursday the 20th, the predicted miss distance had dropped below 200 m, so risk mitigation maneuver planning options were examined. Probabilistic risk assessment demonstrated that, even if the worst-case conjunction geometry were considered, the collision probability would be reduced by several orders of magnitude if any of the four maneuvers were performed.

On Friday the 21st, the predicted miss distance reached approximately 60 m and the collision probability was 5.3e-2, still the same order of magnitude as when the conjunction was initially identified. An avoidance maneuver was executed which increased the miss distance to 4.5 km and subsequently drove the collision probability to zero.

B. Close Approach Prediction Trends and Collision Risk Assessment

Figures 2 and 3 show the evolution of the miss distance and collision probability as the close approach event evolved throughout the week. The values shown in the graphs were computed at the TCA. The miss distance trend in Figure 2 shows a few hundred meter change from solution to solution for the first few days, then a steady trend downward. Near the three day prediction point, the predicted miss distance reached a minimum value of 37 m. The data points in these plots represent discrete solutions.

Figure 3 shows the P_c time history trend. The first probability calculation (made on Monday) was 1.4e-2. The graph shows that the probability remained extremely high throughout the event, staying above the 1e-2 threshold. Typically the P_c will drop as the prediction time and the position uncertainties get smaller. However, since the miss distance decreased as the event evolved, the P_c value remained high.

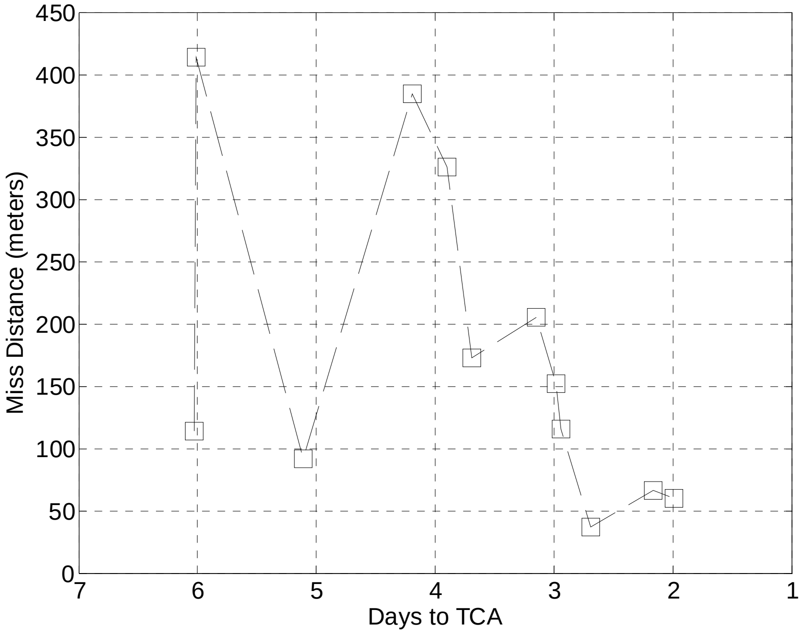


Figure 2: Terra vs. 14222 Miss Distance

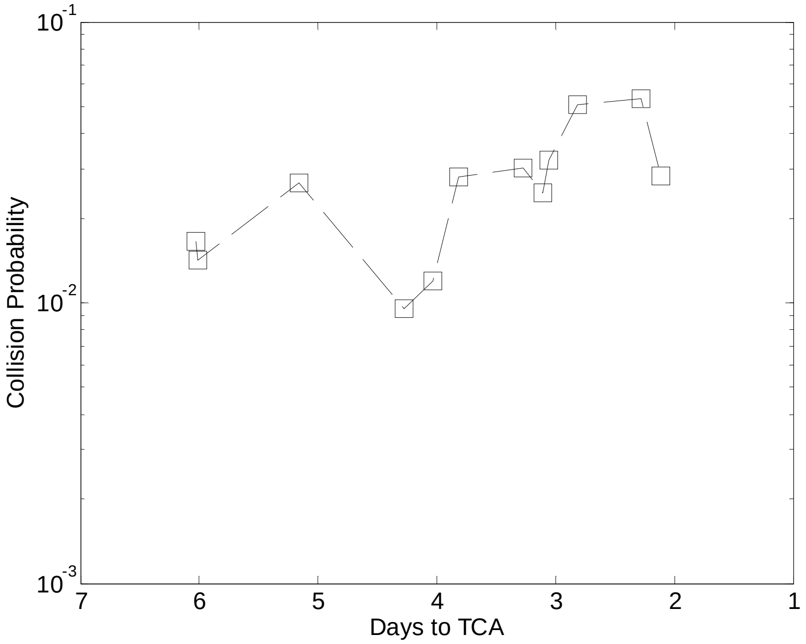


Figure 3: Terra vs. 14222 Collision Probability

One contributing factor to the high P_c value is the conjunction geometry at the TCA. The P_c calculation is made by numerically integrating the 2-D probability density function over the hard body "keep-out" region. The integration is made in the conjunction plane. Thus the orientation of the combined covariance in the conjunction plane has a direct effect on the calculated P_c. The covariance orientation is described by the conjunction plane 'clock angle', which is the angle between the principal major axis of the ellipse and the x-axis (which is in the miss distance direction). The clock angle range is -90 to +90 degrees; where the P_c will be a maximum when the clock angle is zero degrees. Trending of this angle is a way to examine the stability of the close approach event. Figure 4 below shows the clock angle trend. During the first several days, the conjunction geometry was near the maximum P_c orientation, where the clock angle remained within 10 degrees of the maximum. As the time to the close approach event was reduced, variability in the angle was observed. The last three values in Figure 4 are clearly out of family from the previous 9. This change is attributed to changes in the orbit determination solution for the secondary object. It is not clear what drove the sudden change in the close approach geometry, but it was observed that the solar radiation pressure value for the debris object was manually set to a specific value.

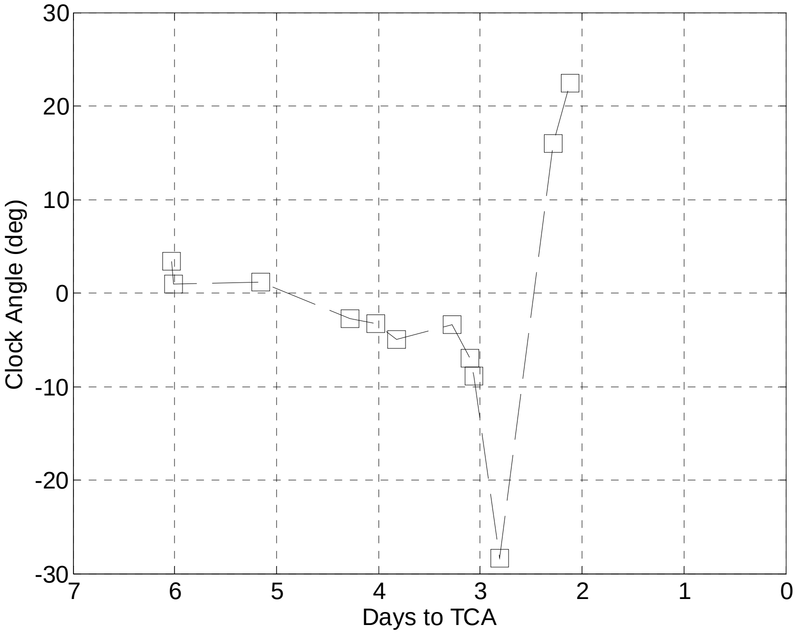


Figure 4: Terra vs. 14222 Clock Angle

C. Risk Mitigation Analysis

By Thursday the miss distance had dropped below 200 m and avoidance maneuver plans were being considered. Four different risk mitigating maneuver plans were generated and a new miss distance was computed for each. Results showed that any executed maneuver would change the miss distance to a safe value (greater than 3 km). Three maneuver options were planned with the same start time and delta-v values ranging from 0.011 – 0.017 m/s. Maneuver option 4 contained the same delta-v as option 3, but it was planned 12 hours later. For each burn case, a post-maneuver ephemeris was generated and the ground track errors examined. For a 'nominal' atmospheric drag profile, options 1 and 2 maintained the ground track requirements while options 3 and 4 'skirted' the bottom of the control box. Various drag predictions were also analyzed to examine the full trade space. Sensitivity analysis was performed to get an idea of how the event could evolve if a maneuver was not executed. In this case, the combined position uncertainty was decreased to 'near-epoch' uncertainty. If the miss distance and conjunction plane geometry remain fixed, then decreases in the position uncertainty will lead to a decrease in the collision probability calculation. This 'forecasting' behavior is clear in Figure 5, which shows that the collision probability value would not have dropped to an 'acceptable' level as the prediction time was shortened, and that a risk mitigation maneuver was needed.

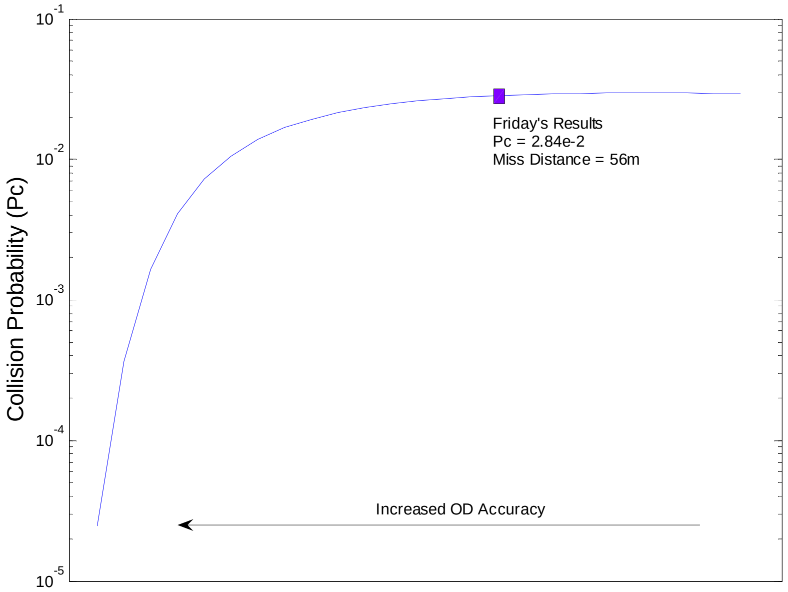


Figure 5: Terra vs. 14222 P_c Forecasting

D. Avoidance Maneuver Results

On Friday the miss distance had decreased below 100 m, so that afternoon an avoidance maneuver (burn option 2) was executed. Post-maneuver, the miss distance was increased to 4.5 km and subsequently the collision probability was zero. Figure 6 shows the total predicted miss distance throughout the week. The miss distance, which was first reported to be less than 500 m, remained low during the week.

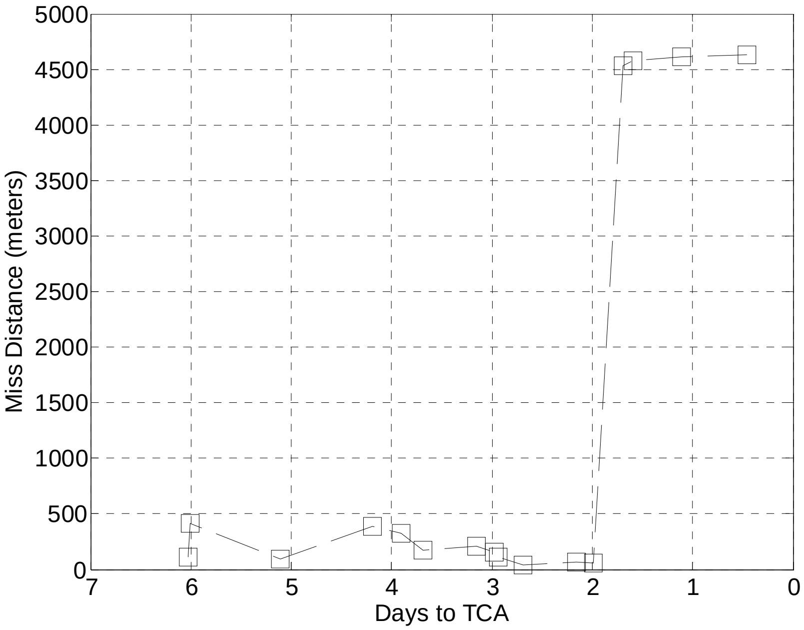


Figure 6: Terra vs. 14222 Miss Distance Including Maneuver

V. Conclusions and Future Work

Since inception of the project in the fall of 2004, the ESMO GSFC CA team has been assessing close approach predictions and mitigating the collision risk for the EOS spacecraft using advanced analytic techniques and state-of-the-art operational procedures. The conjunction assessment concept of operations has evolved as both theoretical and operational experience has been gained. Between November 2004 and March 2006, 4 mitigating actions were performed in response to the conjunction data: three planned maneuvers were waived off due to predicted close approaches following the maneuver, and one debris avoidance maneuver was executed in response to a threat to Terra. Due to the large volume of conjunction data received, much of the routine CA operations has been automated. However, it was determined that maintaining a cadre of personnel experienced in orbit determination is necessary to ensure that the appropriate risk mitigation strategy is analyzed, planned and executed. Each close approach event analyzed was found to be sufficiently unique that the approach of implementing a fixed decision-making criteria such as maneuvering any time the Pc is a certain value was not taken. Future work will include adding a probabilistic risk assessment component to the maneuver planning process.

VI. Acknowledgements

The authors would like to thank Joe Frisbee and Mike Wortham of United Space Alliance for providing both theoretical and operational support to the conjunction assessment effort at GSFC.

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