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THE COLLISION RISK ASSESSMENT & RISK MITIGATION PROCESS FOR THE NPP & NPOESS MISSIONS

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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 estimated at approximately 20,000. Most of these tracked objects are characterized 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. Because of the ever increasing threat posed by orbiting objects, the National Polar-Orbiting Operational Environmental Satellite System (NPOESS) Program Office has established a risk assessment and risk mitigation process for the NPOESS satellite constellation. This process consists of daily analysis of close approach data produced by the United States Strategic Command's (USSTRATCOM) Joint Functional Component Command for Space (JFCC-Space) through its 24/7 operations center, the Joint Space Operations Center (JSpOC).

This document describes the collision risk assessment operations concept that will be employed for the NPOESS project. The NPOESS program is managed by a tri-agency Integrated Program Office (IPO), involving personnel from the Department of Commerce (DoC), Department of Defense (DoD) and the National Aeronautics and Space Administration (NASA).

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I. INTRODUCTION

Orbital debris poses a significant threat to spacecraft health and safety. During the past few years, debris generating events such as the Iridium – Cosmos collision and China's anti-satellite (ASAT) test have led to an even greater awareness and concern in the satellite community. Both of these events have caused a significant increase in the orbital debris population in LEO and have measurable operational impacts to the National Polar-orbiting Operational Environment Satellite System (NPOESS) project[1].

Because of the threat posed by orbiting objects, the NPOESS IPO has established an operational risk assessment and risk mitigation process to protect the NPOESS constellation, including the NPOESS Preparatory Project (NPP). The following sections describe in detail the NPP/NPOESS collision risk for the NPOESS constellation and risk mitigation process. Section II characterizes the debris environment of the NPP/NPOESS operational orbital regime. Section III provides an overview of the risk assessment and risk mitigation process. Section IV describes the tools and products used to quantify the risk of collision. Section V describes the steps involved in planning and executing a collision avoidance maneuver. Conclusions and a discussion of future work are presented in Section VI.

II. CHARACTERIZATION OF THE NPOESS ORBITAL REGIME

The NPOESS orbital regime is densely populated. Figure 1 shows the density of objects in low earth orbit. The distribution of debris from both the Fengyun 1-C ASAT test and the Iridium – Cosmos collision are also shown. Note that the peak density for these two events falls between 760 – 840 km, where they make up 49% of the population. The NPOESS satellites will operate at a mean altitude of 828 km with NPP operating slightly lower at 824 km.

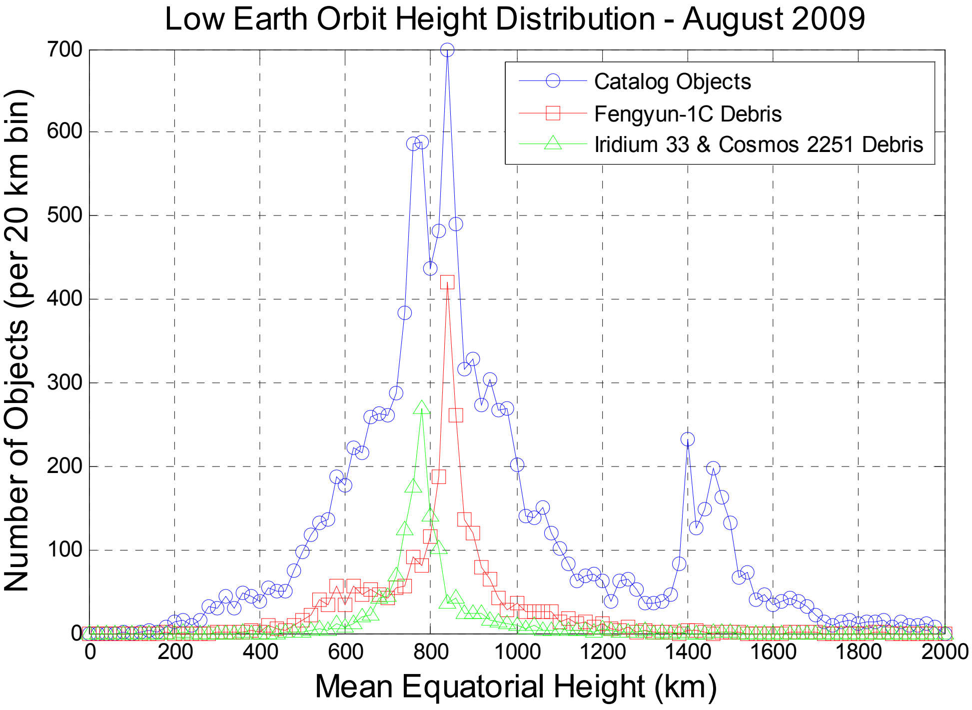

Figure 1. Low Earth height distribution.

In order to quantify the risk of collision in this orbital regime, event statistics have been collected for the 13 operational Defense Meteorological Satellites Program (DMSP) & National Oceanic and Atmospheric Administration (NOAA) Polar Operational Environmental Satellites (POES) satellites since early 2007. Since the NPP/NPOESS satellites will fly in the same orbital regime as the DMSP & POES satellites, the conjunction event data that has been collected for these satellites provides a useful tool in characterizing the density of objects in that regime. From January – August of 2009 these 13 satellites have had 395 conjunction events that violate a 1 km miss threshold, with six of these having miss distances less than 100 m. Five conjunction events had probability of collision (Pc) values greater than 1e-3; three of these events were distinct from those below 100 m. This represents nine unique 'high-interest events.' These events are listed in Table 1 below. 'Primary' satellite refers to the satellite of concern in the conjunction event, and objects that have conjunction events with these satellites are referred to as 'secondary' objects.

Table 1. Conjunction events from 2009 with miss distance less than 100m or Pc greater than 1e-3.

Primary Satellite	Secondary Object	Time of Close Approach (TCA)	Miss Distance (m)	Collision Probability
DMSP 5D-2 F14	COSMOS 1275 DEB	12-May-2009 15:28:33	55.2	2.62E-03
DMSP 5D-2 F14	FENGYUN 1C DEB	05-Jun-2009 04:54:50	68.2	6.47E-03
NOAA 18	FENGYUN 1C DEB	12-Apr-2009 04:48:03	69.9	3.73E-15
DMSP 5D-3 F16	DMSP 5D-3 F17 DEB	26-Feb-2009 06:48:05	83.4	6.94E-08
DMSP 5D-2 F14	METEOR 1-20	18-Feb-2009 23:15:31	89.8	1.31E-14
DMSP 5D-2 F13	COSMOS 1275 DEB	09-Jun-2009 15:27:34	97.4	3.63E-23
NOAA 16	FENGYUN 1C DEB	28-Apr-2009 15:43:38	156.6	1.30E-02
DMSP 5D-3 F17	FENGYUN 1C DEB	05-May-2009 01:39:36	218.4	1.27E-03
DMSP 5D-3 F16	UNKNOWN	23-Apr-2009 15:16:05	977.4	1.02E-03

Conjunction Events with Active Payload Satellites

Conjunction events with other active payloads[*] make up a small percentage of the total that have been identified for DMSP & POES. Figure 2 shows how the number of conjunction events with active payload satellites compares to several other categories of objects that have been encountered. The category 'Other Debris' consists of debris objects not attributed to the Fengyun 1-C or Iridium – Cosmos debris fields and 'Analyst Satellites' are objects whose origin cannot be determined. These statistics are gathered for unique events spanning Feb 2007 – Feb 2008 and Nov 2008 – Aug 2009. Of the 109 conjunction events with active payload satellites, 26 unique satellites have been seen representing 10 different countries of origin. A listing of these satellites appears in Table 5 of the Appendix.

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[*] Union of Concerned Scientists Satellite Database, UCS_Satellite_Database_4-10-09.xls, www.ucsusa.org/satellite_database

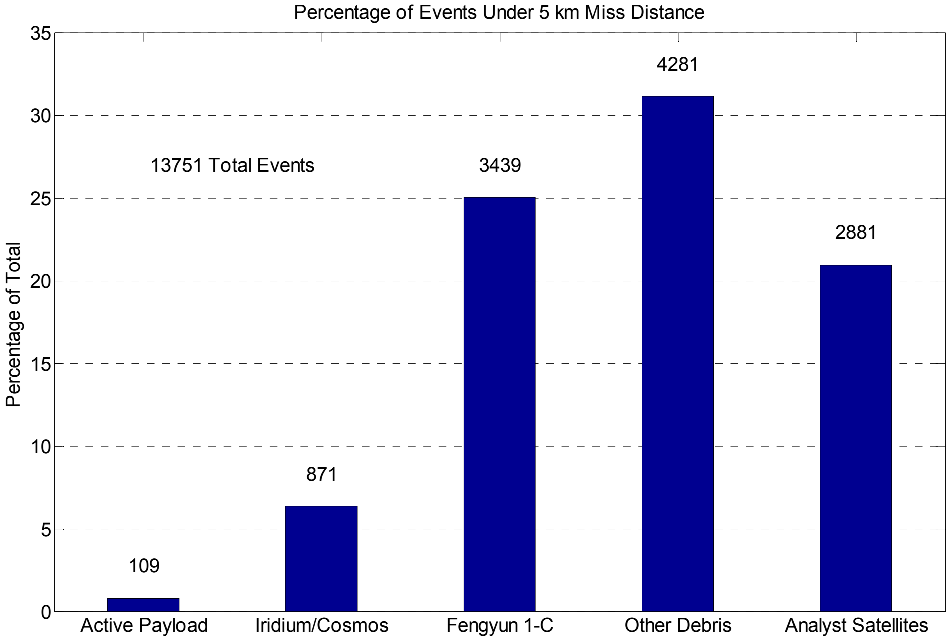

Figure 2. Percentage of secondary objects attributed to active payloads and debris.

The miss distance distribution for these events is nearly uniform within the 5 km screening volume used for DMSP & POES. Three conjunction events had miss distances below 1 km, with a minimum of 552 m. Table 2 lists statistics characterizing the orbits of the active payload satellites seen in conjunction events. The same statistics for DMSP & POES are shown in Table 3 for comparison.

The positions of active payload satellites are generally known with more accuracy than that for debris objects, allowing better resolution of the risk of collision. Still, the threat of collision exists since an active payload satellite might perform an unexpected maneuver that could have an adverse effect on the conjunction geometry. The NPOESS program is working to establish contacts with stakeholders of other active payloads to facilitate communication should a possible conjunction event with the satellite of a friendly nation be predicted.

Table 2. Orbital statistics for active payload satellites having conjunction events with DMSP & POES.

	Median	Minimum	Maximum
Height (km)	804.2	405.0	850.8
Eccentricity	0.0028	0.0001	0.0314
Inclination (deg)	98.2	13.0	108.0

Table 3. Orbital statistics for DMSP & POES.

	Median	Minimum	Maximum
Height (km)	847.1	801.7	866.1
Eccentricity	0.0010	0.0001	0.0014
Inclination (deg)	98.7	98.5	99.2

III. OPERATIONAL COLLISION RISK ASSESSMENT PROCESSING

This section describes the Collision Risk Assessment operation concept for the NPOESS constellation. Operational collision risk assessment consists of receiving conjunction data from the United States Strategic Command's (USSTRATCOM) Joint Functional Component Command for Space (JFCC-Space) through its 24/7 operations center, the Joint Space Operations Center (JSpOC), quantifying the collision risk, and developing risk mitigation strategies as necessary. The major participants/stakeholders that form the collision risk team include: Joint Space Operations Center (JSpOC) Orbit Analysts, the a.i. solutions Collision Risk Assessment Team (CRAT), the NPP/NPOESS Mission Operations Team (MOT), and the NPP/NPOESS Mission Management. Figure 3 summarizes the responsibilities of each of the major participants/stakeholders and illustrates the operational flow of data and communications.

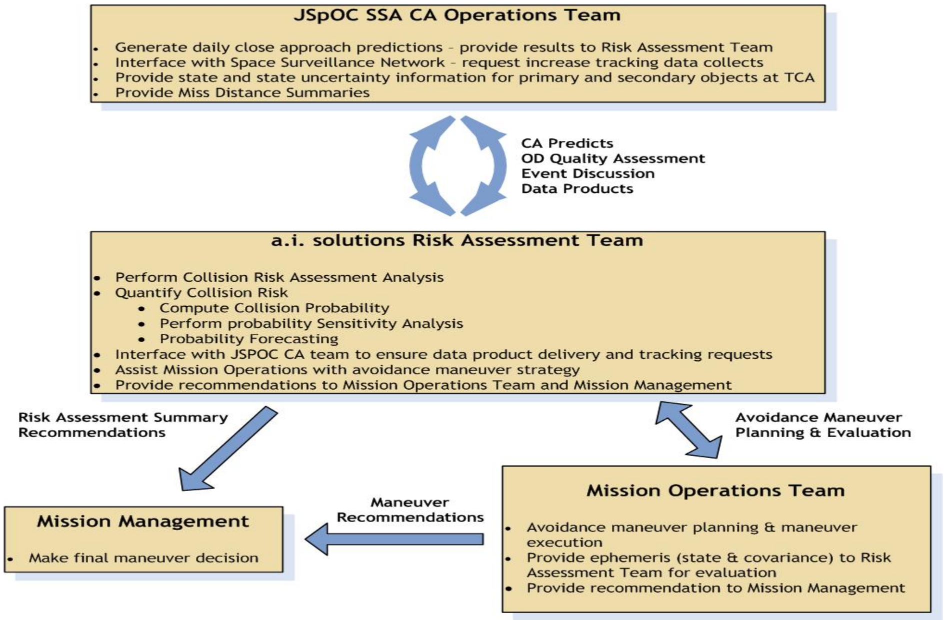

Figure 3. NPOESS operational flow between major participants and stakeholders.

JSpOC Conjunction Assessment (CA) Operations Team: The JSpOC CA Operations Team is responsible for generating daily close approach predictions and other conjunction data. Conjunction event notifications, state vectors and state uncertainty information are provided to the NPOESS Collision Risk Assessment Team. The JSpOC is the primary interface to the Space Surveillance Network and ensures that sufficient tasking data is being collected for secondary objects.

NPOESS Collision Risk Assessment Team: The Collision Risk Assessment Team is responsible for analyzing the conjunction data provided by the JSpOC and for performing collision risk assessment analysis. The CRAT processes the CA data and reports analysis results to all mission stakeholders. The CRAT works with the Mission Operations Team during collision avoidance maneuver planning. The CRAT will work with the JSpOC to ensure all necessary data has been provided.

NPP/ Mission Operations Team: The NPOESS Mission Operations Team (MOT) is responsible for planning and executing collision avoidance maneuvers. The MOT will work with the CRAT during maneuver planning activities.

Mission Management/Integrated Program Office: Mission Management and representatives from the Integrated Program Office (IPO) will ultimately be responsible for making the decision to perform a collision avoidance maneuver. The decision makers will take recommendations from both the MOT and the CRAT.

IV. SPACE SITUATIONAL AWARENESS (SSA) COLLISION RISK ASSESSMENT TOOLS DESCRIPTION

The CRAT has been tasked by the IPO to provide risk assessment analysis for the NPP and NPOESS missions. Tools developed to support those missions are currently being utilized in support of the DMSP & POES missions. Analysis performed by the CRAT allows the MOT to ensure the safety of their satellites and satisfy NASA's requirement for the limitation of orbital debris[2].

Collision risk assessment is a three step process involving the JSpOC and the CRAT. The JSpOC uses the Space Surveillance Network (SSN) catalog of tracked space objects to generate close approach predictions (Step 1). This data is sent to the CRAT, who performs quality assessment (Q/A) checks on the data and evaluates the tracking and orbit determination data used in the close approach predictions (Step 2). The CRAT then performs collision probability calculations and performs collision probability sensitivity analysis (Step 3). Finally, the CRAT produces daily reports with miss and Pc trends for upcoming conjunctions events. High interest events warrant a more detailed report which includes much of the analysis shown in this section. These products and recommendations resulting from the steps above are provided to the MOT. A flowchart illustrating these steps is shown in Figure 4.

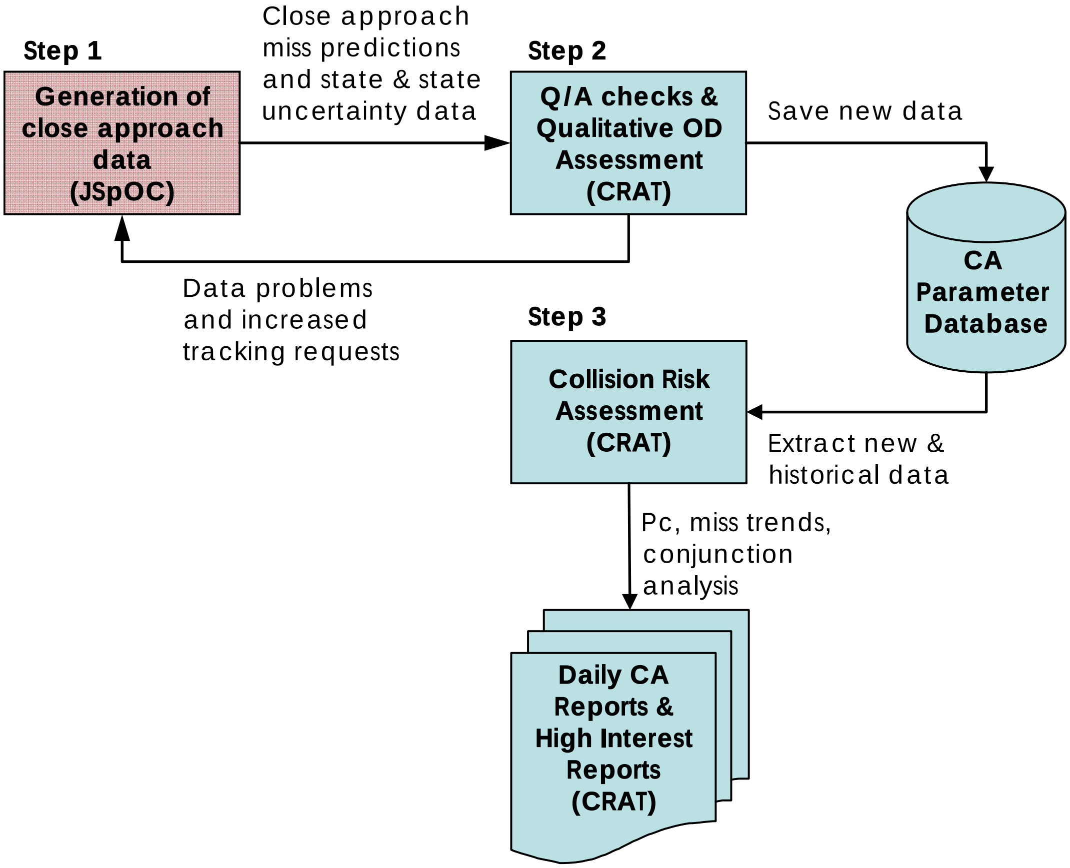

Figure 4. Flow of risk assessment process.

Details of the risk assessment process follow:

Step 1. Generation of Close Approach Predictions. Daily close approach predictions are first generated by the JSpOC. This data is generated by screening the state vectors of the asset satellites, e.g. NPOESS, against the SSN catalog of space objects. A summary list of close approaches, or conjunction events, is produced and sent to the CRAT. The criteria for this list is based on miss distance. Time of close approach (TCA), miss distance, and radial, intrack, & crosstrack (RIC) miss components are reported, along with the corresponding two object numbers.

For conjunction events with a smaller miss distance the JSpOC also generates an Orbital Conjunction Message (OCM). The OCM contains input and output parameters from the orbit determination that was used to generate state and state uncertainty data for the primary (asset) and secondary objects. The state data is propagated to the TCA.

Step 2. Q/A Checks and Qualitative OD Assessment. The CRAT checks the data that is produced by the JSpOC for data validity and to ensure that data is consistent for each conjunction event. These checks are grouped into three categories: Q/A checks on all data, Qualitative OD Assessment, and Event Trending.

Q/A Checks. The CRAT performs Q/A checks to ensure the integrity of the data received from the JSpOC. Any issues, such as incomplete data, are communicated to the JSpOC. A list of the Q/A checks follows:

Data validity checks are performed on all data products to make certain that all fields are populated, and uniqueness checks ensure that the data is new. Checks of force model solve-for flags determines if there are deviations from the normal set of parameters updated during the OD. Conjunctions that are not reported for the full 5-day screening span are also flagged.

Consistency checks look for large changes in the data from one update to the next. Large changes in the conjunction geometry should be explainable by some change in the OD. Data that is checked include miss distance, number of tracks, length of OD fit span, etc.

The CRAT classifies the secondary objects seen in the daily close approach predictions according to a few categories. Lists of sparsely tracked objects and high covariance objects are maintained. These lists are an aid to indicate whether an object may be difficult to track or may experience high drag. Additional lists are maintained for active payload satellites and debris from the Fengyun 1-C ASAT test and the Iridium – Cosmos collision. Secondary objects for new conjunction events are compared against these lists to aid in the collision risk assessment process and to characterize the secondary object population.

Qualitative OD Assessment. To effectively assess the risk of collision an evaluation of the orbit determination is made. The quality of the tracking data is of importance since it plays the largest role in the quality of the state solution. Realistic force model parameters play a role in the OD solution as well as the propagation of the state vector.

Data used to generate the OD state solution is evaluated through several parameters provided in the OCM. Tracking frequency should be adequate to accurately determine the object's orbit. Also, the time span from which tracking data is taken should fit the orbit type of the observed object. LEO objects with long OD fit spans will average out the short term dynamics of the atmosphere, which may impede the quality of the solution. The number of tracking sites is another important factor. Using multiple tracking sites in an OD generally improves the solution. A greater portion of the orbit is observed so there is more opportunity to view the dynamic portions of the object's orbit. The CRAT will work with the JSpOC to attempt to schedule additional tracking if tracking is insufficient.

Force model parameters located on the OCM provide the drag and solar radiation pressure forces calculated during the OD process. These values are checked to determine if they are in family with previous values for the object being tracked, as well as with objects of similar size belonging to the same orbital regime.

Event Trending. The evolution of the conjunction event solution-to-solution plays a role in predicting the risk at TCA. Each OCM is evaluated for large changes in previously reported values; discrepancies that cannot be reconciled are discussed with the JSpOC. This analysis is important to develop confidence in the data that is used in the risk assessment of each conjunction event. Two of the more informative trends will be illustrated below: *event uncertainty trending* and *miss sigma level*.

An evaluation of the consistency of the state and the state uncertainty is performed through *event uncertainty trending.* This trend compares the miss distance and combined position uncertainty of the two objects for each OCM received. This data is displayed in the RIC frame centered on the primary satellite. This provides another way to keep track of how the conjunction event is evolving with subsequent OCMs. Each objects' state uncertainty is provided on the OCM in the form of a covariance matrix. See Figure 5 for an example of these plots, where all values are normalized by the total miss distance that was initially reported.

The error bars in Figure 5 represent one standard deviation in position error. Given an accurate representation of the uncertainty, the next state update should keep the miss component within three standard deviations of the previous value. These plots also provide the geometrical relationship between the two objects and the position uncertainty distribution amongst the different components. Reduction in propagation time contributes to the reduction in uncertainty.

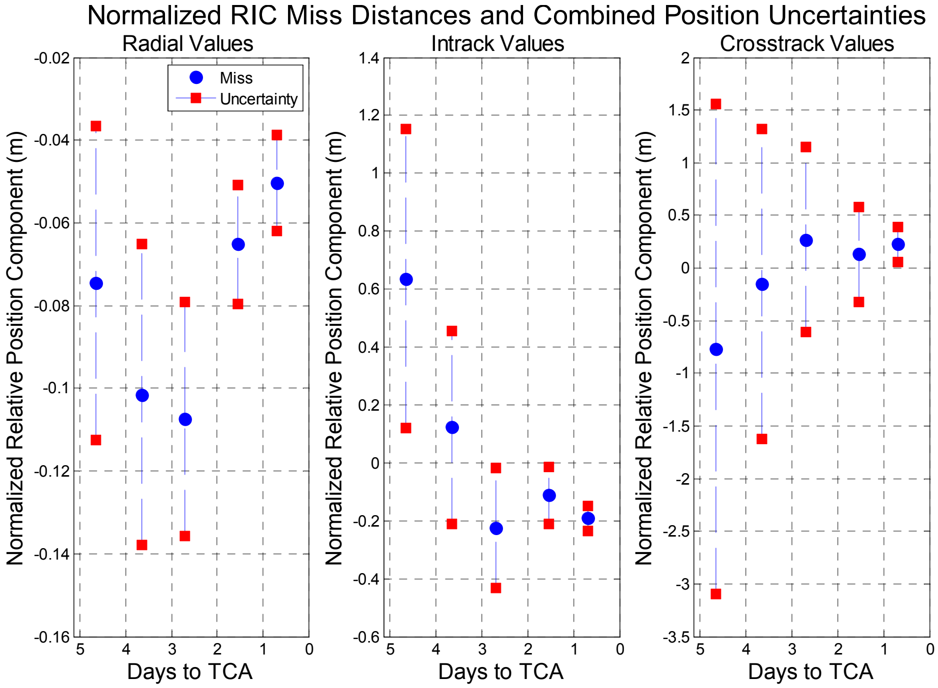

Figure 5. RIC miss distances & combined position uncertainties normalized by initial miss distance.

The *miss sigma level* (MSL) computation provides additional insight into the consistency of the OD solution received in the OCMs. This is a derived parameter that provides a measure of how well the covariance matrix represents the position uncertainty; i.e., is the reported state error accurately bounding the problem. It compares the position uncertainty of an OD solution to the change in miss distance resulting from the subsequent solution. The MSL is defined as,

$$MSL = \frac{\rho_i(n+1) - \rho_i(n)}{\sigma_i(n)} \tag{1}$$

where ρ represents miss distance, σ represents position uncertainty, $i \in$ (R,I,C), and *n* designates the OD solution. Figure 6 shows an example of a MSL plot; note that the data are plotted at the *n+1* OD solution time. Ideally, the change in miss distance should remain within the reported 3σ uncertainty, i.e., MSL should be bounded by ±3. MSL levels outside of this bounded region point to problems with the OD solution—the CRAT will interface with the JSpOC to determine the issue.

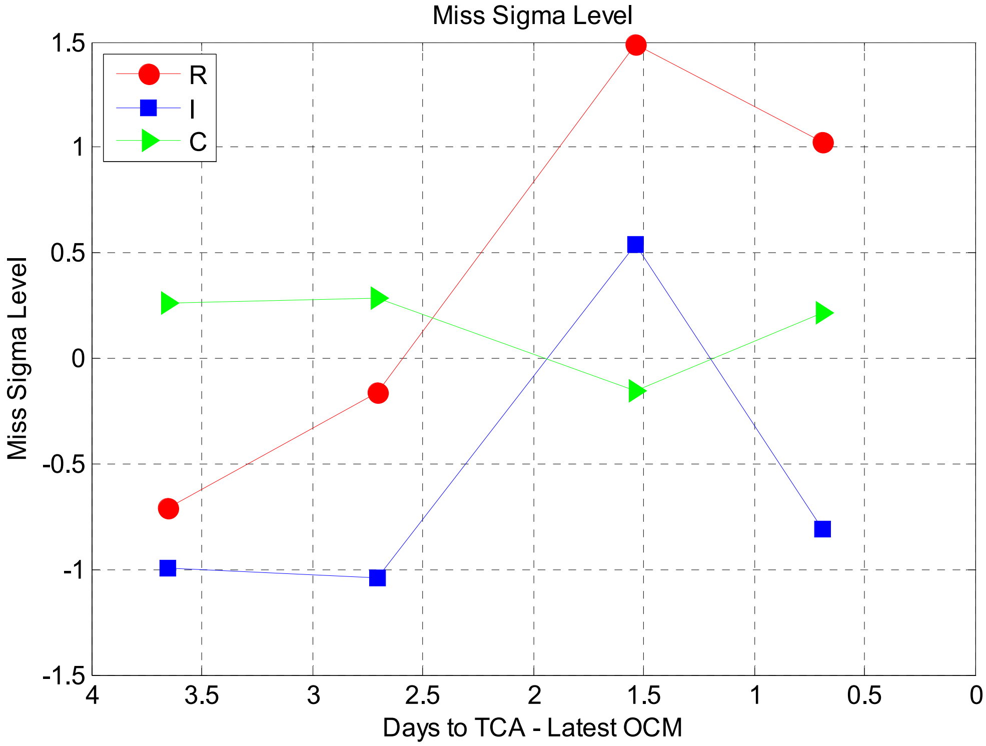

Figure 6. Miss Sigma Level is a measure of the consistency of subsequent OD solutions.

Step 3. Collision Risk Assessment Analysis. This set of tools use the state and state uncertainty data provided in OCMs to assess the risk of a conjunction event. The primary calculation is that of the probability of collision, Pc. The Pc and the miss distance are the two metrics most frequently referenced when assessing the risk of a conjunction event. Using this data and the assessment of the OD performed in Step 2, the CRAT is able to quantify the risk of collision and provide this information to the MOT.

Additional analysis is performed to ascertain the level of risk that will be seen at the TCA. Conjunction assessment is a prediction problem; therefore, the CRAT performs probabilistic sensitivity analysis to determine how the risk will change given changes to the input data. The primary tool utilized in this analysis is ‘Pc Forecasting.’

Collision Probability Sensitivity Analysis. Pc sensitivity analysis is performed to ascertain how the risk will evolve with time. This can be done through scaling of the covariance data, both in size and shape. Pc Forecasting is the process of predicting how the collision probability will behave as the covariance is scaled down to a typical definitive size. Figure 7 shows an example of a Pc Forecasting plot. This plot is read from right to left, as the first representation of position uncertainty is that of the latest OD solution; it is then reduced in size, forecasting how the Pc will evolve with time.

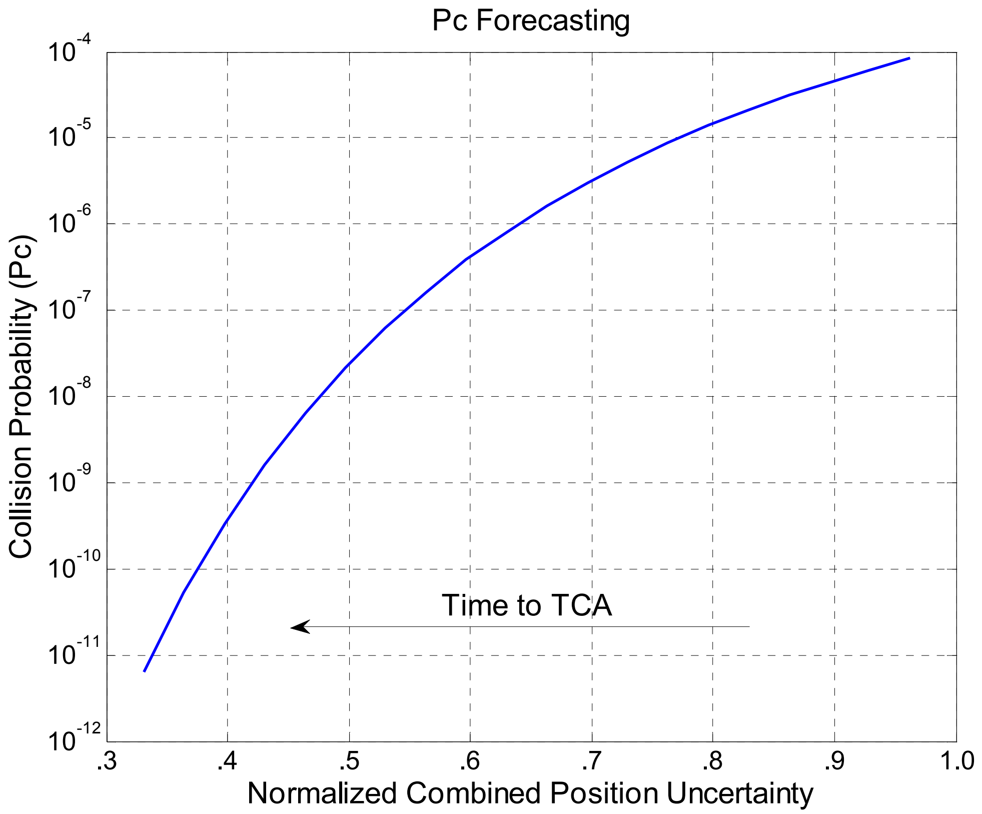

Figure 7. Pc Forecasting plot used to predict how Pc will evolve with time.

Changing the size of the covariance is an attempt to remove the growth in covariance that takes place during propagation. Since the covariance of the two objects is propagated from the OD solution epoch, which is typically tied to the time of last observation, to the TCA, the propagation time can be from zero to several days. High interest conjunction events that show a small reduction in risk in the Pc Forecasting analysis may be candidates for avoidance maneuver planning. This topic is discussed next.

V. AVOIDANCE MANEUVER PLANNING AND EVALUATION

The Maneuver Trade Space and Maneuver Evaluation Utilities compute post maneuver collision probability and miss distance values. They will be used to aid in the planning of risk mitigation maneuvers. They will allow the MOT to decide on a maneuver that will be optimal in mitigating the threat of collision while maintaining any mission constraints. A strategy that targets a defined miss distance does not take into account the conjunction geometry and position uncertainty of both objects, thereby excluding some maneuver options. More detail on these two utilities is included in the following section, that expands the maneuver planning and evaluation steps.

If the CRAT determines that the collision risk is sufficiently high, then the avoidance maneuver planning process will begin. The risk mitigation maneuver planning process will be executed in 4 steps requiring iterations between the CRAT, the MOT, and the JSpOC. The CRAT initiates the initial maneuver planning (Step 1). Maneuver refinement is then performed by the MOT

(Step 2). The CRAT and MOT then work to obtain a final acceptable avoidance maneuver strategy (Step 3). Finally, a maneuver ephemeris is sent to the JSpOC (Step 4). The JSpOC will then generate close approach predictions against the rest of the space object catalog. Figure 8 provides a flowchart capturing the 4 steps in the planning process.

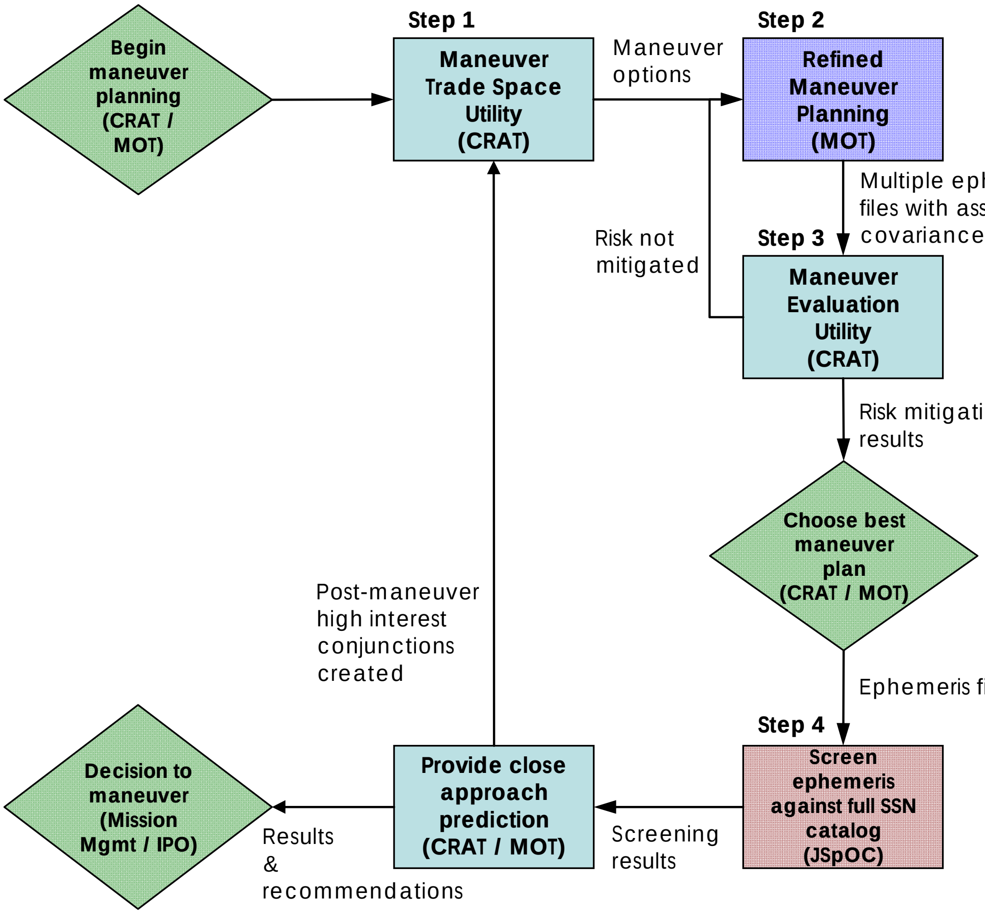

Figure 8. Avoidance maneuver planning process flow.

The details of the four avoidance maneuver planning steps are given below:

Step 1: Maneuver Planning Trade Space Utility. The CRAT will initiate the collision avoidance maneuver planning process if the collision risk is sufficiently high. Avoidance maneuver options are generated with the Maneuver Planning Trade Space Utility. This utility examines how the miss distance and collision probability values change for a given maneuver. Thus the trade space is generated by varying both the size and time of the maneuver. Sample output is show below in Figure 9.

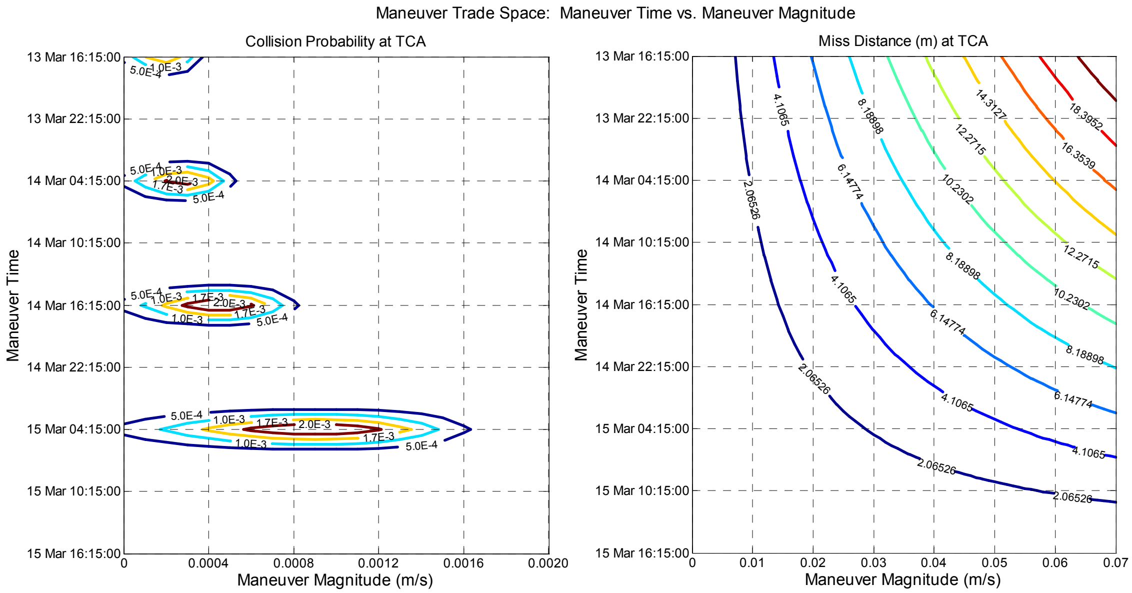

Figure 9. Trade space output of Maneuver Planning Trade Space Utility.

These plots display contours of constant miss distance (m) and collision probability as a function of maneuver time and maneuver magnitude. The maneuver magnitude is on the *x*-axis and maneuver time is on the *y*-axis. Notice that the range of maneuver magnitudes is reduced for the Pc contour plot to show the non-zero Pc values.

Additionally, the Maneuver Planning Trade Space Utility collects and reports all of the post-maneuver conjunction events that violate a user specified criteria. This output is provided in tabular form and provides a complete evaluation of how the avoidance maneuver will affect the interaction with the secondary object. The output of this planning utility is passed to the MOT so that refined maneuver planning can occur.

Step 2: MOT Maneuver Planning. The CRAT will deliver the output from the Maneuver Trade Space Utility to the MOT to aid in their maneuver planning. This will allow the MOT to overlay their mission constraints on top of the maneuver trade space and choose one or more candidate maneuvers to mitigate the risk, while maintaining mission constraints. Using the candidate maneuver(s) as a starting point, the MOT will use their high fidelity mission analysis software to plan the maneuver. They will generate an ephemeris file and covariance file for each candidate maneuver and pass this data on to the CRAT.

Step 3: Maneuver Evaluation Utility. In the next step of the process the CRAT will use the ephemeris and covariance files provided by the MOT for each candidate maneuver in the Maneuver Evaluation Utility. This utility is designed to compare two ephemeris files and report the miss distance at a designated TCA, and find any conjunctions below a defined miss distance. Collision probability and miss components in the RIC frame are also reported. An example of the output of this tool is shown in Table 4. The first table below lists the miss components and Pc for the conjunction that prompted the maneuver. The ‘Delta-T’ value is the amount of time the TCA has shifted due to the maneuver. The second table shows that an additional close approach was created by the maneuver. In this case, the post-maneuver conjunction would not warrant a re-plan of the maneuver.

Table 4. Sample of Maneuver Evaluation Utility output.

Results for TCAs of Interest:

TCAs	Delta-T (sec)	Miss Distance (m)	R (m)	I (m)	C (m)	Pc
21-Jan-2009 10:46:11.371	0.651	645.4	70.6	-625.0	144.5	0.000e+000

Results for Miss Distances within the 5 km threshold:

TCAs	Miss Distance (m)	R (m)	I (m)	C (m)	Pc
22-Jan-2009 00:44:34.502	2512.8	-1075.7	2073.0	927.3	0.000e+000

Step 4: Final Maneuver Evaluation – Trajectory Compare Against Entire Catalog. The output shown in Table 4 will be sent to the MOT for review. Once the MOT and the CRAT agree on a maneuver plan that satisfies mission requirements and effectively mitigates risk, an ephemeris file reflecting the maneuver will be sent to the JSpOC for a full catalog screening.

If at any time a maneuver plan is found ineffective at mitigating risk or creates another high risk conjunction, the process can return to step 2 for the MOT to generate a new maneuver plan. As further orbit determinations are performed prior to the planned maneuver, an ephemeris file will be generated and sent to the JSpOC to ensure that the problem has not changed significantly.

VI. CONCLUSIONS

The NPP/NPOESS collision risk assessment process continues to be developed. Useful insight has been gained by routine processing of the DMSP & POES conjunction event data. In the last six months these missions have seen nine high interest conjunction events. This demonstrates the need for a sophisticated collision assessment process. By adding a probabilistic approach to the collision risk assessment process, the Collision Risk Assessment Team will allow the government Mission Management to effectively manage a problem that faces all satellites in LEO. The experience gained through the support of the DMSP & POES missions continues to contribute to the understanding of the JSpOC orbit determination and data generation process, which is a necessary component to analyzing and quantifying the collision risk.

Future work will include adding mission unique constraints to the avoidance maneuver planning utilities. Other work will include the development of a process to share orbit data with active payload satellites in situations when a conjunction event is predicted to occur with a friendly nation.

REFERENCES

[1]Duncan, M., and Wysack, J., "DMSP Close Approach Summary Part III Analysis Performed for the NPOESS Project," March 2008.

[2]NASA Office of Safety and Mission Assurance, "NASA Procedural Requirements for Limiting Orbital Debris," NPR 8715.6, August 2007.

[3]Frigm, R. C., "CA Operations Risk Assessment: Figures of Merit," FDF-209-152, November 2008.

APPENDIX: CONJUNCTION EVENTS WITH ACTIVE PAYLOAD SATELLITES

The DMSP and POES satellites have experienced a total of 109 conjunction events with active payloads. Table 5 lists the unique satellites seen in these conjunction events, along with the country of origin, number of unique events, and minimum miss distance.

Table 5. List of active payload satellites that have had close approaches with DMSP & POES under 5 km miss distance during the time spans: Feb 2007 – Feb 2008 and Nov 2008 – Aug 2009.

Object ID	Satellite Name	Country of Origin	Unique Event Count	Minimum Miss Distance (m)
28366	LatinSat-D	Argentina	3	2018
27843	MOST (Microvariability & Oscillations of STars)	Canada	2	754
33434	Chuangxin 2 (Innovation 2)	China	1	3138
31491	Zheda Pixing (ZP-1 Zhejiang University-1)	China	1	2170
27431	Fengyun 1D (FY-1D)	China	4	3127
25635	Ørsted (Sunsat)	Denmark	5	2758
25260	Spot 4	France/Belgium/Sweden	2	4614
24971	IRS-1D (Indian Remote Sensing Satellite 1D)	India	2	4277
28051	IRS-P6 (Resourcesat-1)	India	6	957
27848	Cubesat XI-IV (Oscar 57 CO-57)	Japan	2	2912
31792	Tselina-2 (Cosmos 2428)	Russia	25	1068
29052	COSMIC-F	Taiwan/USA	2	1300
29048	COSMIC-B	Taiwan/USA	2	1817
29047	COSMIC-A	Taiwan/USA	4	2414
29049	COSMIC-C	Taiwan/USA	7	2131
29051	COSMIC-E	Taiwan/USA	9	552
28375	Amsat-Echo (Oscar 51 AO-51)	USA	1	1909
24285	FAST (Fast Auroral SnapshoT)	USA	1	2109
22827	WavSat-1 (ITAMSat Healthsat II)	USA	1	4266
24920	FORTÉ (Fast On-orbit Recording of Transient Events)	USA	2	1662
25420	ORBCOMM FM-13 (ORBCOMM B1)	USA	2	4043
32765	C/NOFS (Communication/Navigation Outage Forecasting System)	USA	2	4403
25159	ORBCOMM FM-4 (ORBCOMM G2)	USA	5	3584
27640	Coriolis (Windsat)	USA	6	1197
25789	QuikScat (QUIcKSCATterometer)	USA	6	1965
25158	ORBCOMM FM-3	USA	6	2266