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SPACEFLIGHT SAFETY HANDBOOK FOR SATELLITE OPERATORS

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18 SPCS Processes for On-Orbit Conjunction Assessment & Collision Avoidance

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SIGNIFICANT REVISION HISTORY

Significant Revision History

Version	Description of Changes	Date
1.1	<ol style="list-style-type: none"> 1. Corrected NORAD_CAT_ID in Maneuver Notification format, pg. 25 2. Addition of contact information for Space-Track.org, pg. 32 	12 Aug 16
1.2	<ol style="list-style-type: none"> 1. Definitions of ellipsoid and covariance screenings, pg. 5-6 	27 Aug 16
1.3	<ol style="list-style-type: none"> 1. Screening schedule, pg. 4 2. Correction to Basic Reporting Criteria for LEO CDMs, pg. 4 3. Added decimal notation requirement to OEM, pg. 18 4. Added "USER_DEFINED_MAN_ID" to maneuver notification, pg. 27 5. Added additional values to "USER_DEFINED_MAN_PURPOSE," pg. 28 6. Changed "SOLVED" to "DETERMINED" for "USER_DEFINED_MAN_STATUS," pg. 28 7. Under "How to Name Maneuver Notifications" update "File Names" and added "File Verification," pg. 29 8. Updated "Submitting Maneuver Notifications" to explain that each organization has their own maneuver folder, pg. 31 9. Added "Updating Maneuver Notifications," pg. 31 	3 Jan 17
1.4	<ol style="list-style-type: none"> 1. Replaced JSpOC and JFCC SPACE references with 18 SPCS, CSpOC or JFSCC, throughout the document as needed 2. Added SSA Sharing Program description, pg. 2 3. Added HAC vs HAC, O/O Ephemeris vs HAC, and O/O Ephemeris vs O/O Ephemeris descriptions, pg. 4-5 4. Added PDT/PST times to Screening Schedule, pg. 7 5. OEM state and covariance components must be in decimal notation, pg. 21 6. USER_DEFINED_MAN_ID added to maneuver notification, pg. 30 7. Added additional options to USER_DEFINED_MAN_PURPOSE, pg. 30 8. Added Annex A: How 18 SPCS Calculates Probability of Collision 	Feb 19
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SIGNIFICANT REVISION HISTORY

	<ol style="list-style-type: none">9. Updated HAC screening volumes in Table 3, pg. 910. Updated basic reporting criteria in Table 5, pg. 1011. Updated advanced reporting criteria in Table 6, pg. 1012. Added information on 799500000 satellite number range, pg. 1313. Removed 'fewer than two sensors' tasking criteria, pg. 1414. Clarified requirements for covariance reference frames, pg. 1515. Clarified requirements for covariance reference frames in OEM, pg. 2116. Changed 'CatalogNumber' to 'SatelliteNumber' in ephemeris file-naming guidance, pg. 2317. Added 9-digit temporary satellite numbers to Ephemeris File Name Convention in Table 8, pg. 2318. Clarified that deviations from CCSDS OPM standard are indicated by 'User Defined' fields, pg. 2819. Changed OBJECT_ID in Maneuver Notification OPM to not obligatory, pg. 2920. Changed USER_DEFINED_NORAD_CAT_ID in Maneuver Notification OPM to obligatory, pg. 2921. Added 9-digit option to USER_DEFINED_NORAD_CAT_ID in Maneuver Notification OPM, pg. 2922. Added Frequently Asked Questions, Annex B	
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USSPACECOM SSA SHARING PROGRAM

USSPACECOM SSA Sharing Program

PROGRAM DESCRIPTION

The United States Space Command (USSPACECOM), as the U.S. government entity responsible for space domain awareness (SDA) and space situational awareness (SSA), is committed to promoting a safe, stable, sustainable and secure space environment through the sharing of SSA information. In 2009, the United States Strategic Command (USSTRATCOM) initiated the SSA Sharing Program to provide no-cost basic, emergency, and advanced SSA data and services that cover the full scope of support needed through the lifetime of a satellite from pre-launch preparation to end-of-life disposal. In 2019, the program was handed over to USSPACECOM.

Services include Launch Conjunction Assessment (LCA), Launch and Early Orbit Phase (LEOP) support, On-Orbit Conjunction Assessment (CA), Collision Avoidance (COLA), anomaly support, end-of-life/disposal support, de-orbit support, and re-entry assessment. These services are available to all operators of active spacecraft at the basic emergency level, and at the advanced level for entities who have signed SSA Sharing Agreements with USSPACECOM. Basic SSA data is disseminated to the world through the website www.space-track.org, which is accessible to anyone with a registered user account. USSPACECOM has delegated management of the SSA Sharing Program to the Combined Force Space Component Command (CFSCC). While CFSCC oversees the SSA Sharing program as a whole, the 18th Space Control Squadron (18 SPCS) has been directed to execute day-to-day SSA data sharing and support, and act as the direct interface between satellite operators and the U.S. Department of Defense. The 18 SPCS performs the space surveillance mission for the U.S. Space Force, and provides foundational SSA for the U.S. government and global space partners through the SSA Sharing Program. This role was performed by the Joint Space Operations Center (JSpOC) until July 2016, at which time 18 SPCS was activated and assumed all space surveillance functions. In July 2018, the JSpOC became the Combined Space Operations Center (CSpOC). The 18 SPCS is currently co-located with the CSpOC at Vandenberg Air Force Base, but now has the separate and distinct mission of providing frontline space defense, maintaining the space catalog, and providing foundational SSA to U.S. and global partners.

SPACE-TRACK.ORG

Space-Track.org (www.space-track.org) is a public website owned by USSPACECOM and CFSCC, and managed and populated by 18 SPCS. It is the primary method of sharing SSA information with the global space community at the basic, emergency, and advanced levels. All satellite operators should register for a user account in order to access the full scope of SSA data and services available through the SSA Sharing Program.

CONJUNCTION ASSESSMENT PROCESS

Conjunction Assessment Process

ON-ORBIT CONJUNCTION ASSESSMENT (CA)

The 18 SPCS Conjunction Assessment (CA) process identifies close approaches between all resident space objects (RSOs) in the 18 SPCS catalog. It begins with satellite observations from the U.S. Space Surveillance Network (SSN), which includes a variety of sensors throughout the world that detect, track, catalog, and identify man-made objects orbiting Earth. SSN observations are input into the 18 SPCS mission system, which implements “Special Perturbations” (SP) orbit propagation theory. Orbit determination (OD) is performed automatically multiple times per day to determine the position and velocity of each object, which is then updated in the 18 SPCS High Accuracy Catalog (HAC). The 18 SPCS Conjunction Assessment Team uses the HAC to screen the orbital trajectories of all RSOs against all other RSOs, to include active satellites and non-active objects (debris, rocket bodies, dead payloads, etc).

18 SPCS performs three types of screenings:

1. HAC vs. HAC: SP catalog data for all RSOs screened against SP catalog data for all other RSOs
2. O/O Ephemeris vs. HAC: Ephemeris provided by the satellite owner/operator (O/O) screened against the SP catalog data for all RSOs
3. O/O Ephemeris vs. O/O Ephemeris: Ephemeris provided by the satellite O/O screened against ephemeris provided by all other O/O's

CONJUNCTION ASSESSMENT PROCESS

18 SPCS performs screenings for every RSO and owner/operator (O/O) ephemeris a minimum of once every 24 hours in accordance with the process in the following diagram. The initial screening may begin with all near earth objects, all deep space objects, near earth concern lists, deep space concern lists, or O/O-provided ephemeris.

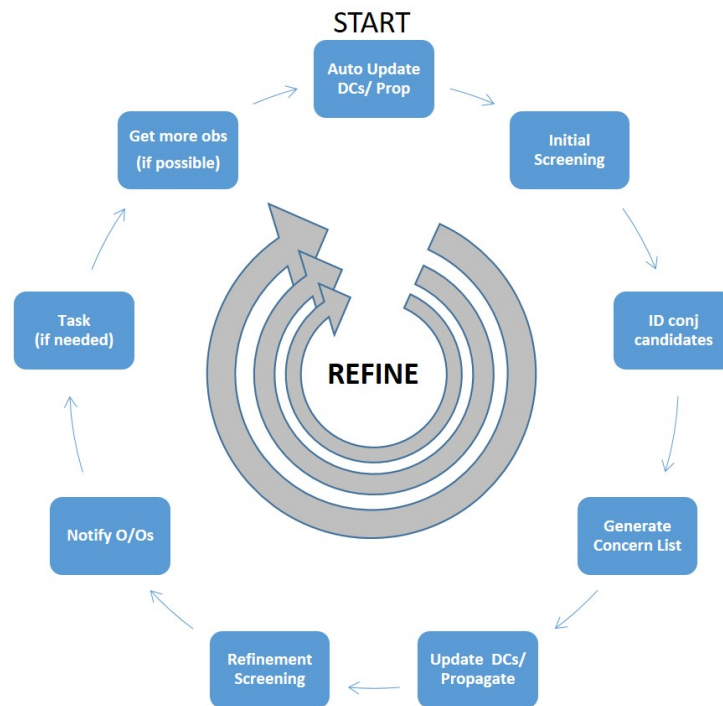


Figure 1: Conjunction Assessment Screening Process

HAC vs HAC

The screening process starts with the update of orbital information for the entire catalog based on data from the SSN sensors and updated Dynamic Calibration Atmosphere (DCA) coefficients, which is then propagated 7 days for near-earth (NE) objects and 10 days for deep-space (DS) objects. These updates take place every 8 hours. Using this data, 18 SPCS performs an initial screening of RSOs against the rest of the catalog to identify conjunction candidates within screening criteria. Based on these results, 18 SPCS also generates Concern Lists to use in follow-on screenings. Concern Lists include all candidates that produce conjunctions with probability of collision (P_c) $\geq e^{-7}$ in NE, and miss distance ≤ 5 km in DS. These candidates are reevaluated by the Conjunction Assessment Team to ensure that all of the most current observations are incorporated into the OD. The 18 SPCS then conducts a refinement screening to update the conjunction estimates of all of the candidates identified in the initial screening. If the parameters of the conjunction fall within criteria that identify a close approach and the close approach involves an active satellite, the 18 SPCS will notify the O/O of the active satellite(s) in accordance with the methods listed in Reporting Criteria. Depending on the quality of the OD, 18 SPCS may increase sensor tasking on the primary or secondary objects. HAC vs HAC screenings include:

CONJUNCTION ASSESSMENT PROCESS

1. NE All HAC: All NE objects vs all NE objects, based on 18 SPCS SP data (NE is defined as Period \leq 225 minutes)
2. DS All HAC: All DS objects vs all DS objects, based on 18 SPCS SP data (DS is defined as period \geq 225 minutes)
3. NE Concern List HAC: Screening of all conjunction pairs identified in NE All HAC screening with $P_c \geq e^{-7}$ and the time of closest approach (TCA) \leq 5 days. Concern List objects will be screened through TCA.
4. DS Concern List HAC: Screening of all conjunction pairs identified in DS All HAC screening with overall miss distance \leq 5km, and the time of closest approach (TCA) \leq 10 days. Concern List objects will be screened through TCA.

O/O Ephemeris vs HAC (O/O EPH vs HAC)

All O/O's may submit predictive ephemeris to the 18 SPCS for screening against the HAC. O/Os must submit ephemeris as Operational or Special. An **Operational** file represents where the satellite is planned to go and may or may not include maneuvers. These files typically incorporate normal station-keeps or represent a freefall orbit. If maneuvers are included, 18 SPCS assumes these will definitely occur; otherwise, the files should be submitted as Special. Operational files will be screened according to the schedule in Tables 1 and 2. A Special file represents where the satellite is planned to go if a maneuver is being considered for a non-routine event, such as orbit raising, relocations, or COLA. A **Special** file is used for planning purposes only, unless the maneuver becomes operational, in which case it must be resubmitted as Operational. All Special files will be treated as high-interest and screened as soon as possible after receipt by the 18 SPCS Conjunction Assessment Team. Multiple special files may be submitted for the same satellite, but only one operational file at a time can be submitted per satellite. Results will be provided in accordance with reporting criteria.

O/O Ephemeris vs O/O Ephemeris (O/O EPH vs O/O EPH)

All **Operational** O/O ephemeris will be screened against all other **Operational** O/O ephemeris on a scheduled basis. O/O ephemeris labeled as **Special** will not be screened against O/O ephemeris. Results will be provided in accordance with reporting criteria. **Operational O/O-provided ephemeris is screened through its duration, meaning that 18 SPCS will retain it in the system and continually screen it every 8 hours until there is less than 8 hours of propagated ephemeris for NE objects or less than 12 hours for DS objects remaining in the file.** This is only applicable to O/O EPH vs. O/O EPH screenings.

ON-ORBIT COLLISION AVOIDANCE (COLA)

In response to a close approach, an O/O may consider performing collision avoidance (COLA), which is the process of planning and possibly executing a maneuver to mitigate the risk of collision. Based on information received in the CA notifications, or from other data sources, the O/O decides whether or not to perform collision avoidance by maneuvering their satellite. If the O/O decides to consider COLA actions, they may send 18 SPCS their predictive ephemeris data (in approved formats and coordinate systems) which 18 SPCS will then screen against the HAC and provide results within reporting criteria so that the

CONJUNCTION ASSESSMENT PROCESS

O/O may decide how to proceed. This exchange of data may continue until the time of closest approach (TCA), after which 18 SPCS will resume routine screening of the active satellite in accordance with the screening schedule. If they do not perform COLA, 18 SPCS will continue to monitor the conjunction and provide updates based on data from the SSN until the TCA has passed. 18 SPCS cannot provide maneuver recommendations.

BASIC EMERGENCY CA AND COLA SERVICES

18 SPCS performs CA and provides COLA support for all satellite operators of active spacecraft as a basic emergency service to ensure spaceflight safety. All operators are eligible for this basic emergency service, which includes the following using basic screening volumes and reporting criteria:

1. HAC vs HAC screenings
2. Operational O/O Ephemeris vs HAC screenings
3. Operational O/O Ephemeris vs Operational O/O Ephemeris screenings
4. Special O/O Ephemeris vs HAC screenings
 - 4.1 O/O Ephemeris versus secondary object, or
 - 4.2 O/O Ephemeris versus full catalog
5. HAC '1-versus-1' requests: screening one primary object against one secondary using HAC data

ADVANCED CA AND COLA SERVICES

O/Os who have signed an SSA Sharing Agreement with USSPACECOM may request Advanced CA and COLA through the Orbital Data Request (ODR) process. (Visit <https://www.space-track.org/documentation#/odr> for more information.) Advanced CA and COLA support includes the following using advanced screening volumes and reporting criteria. Advanced screening volumes will be assigned based on the orbital regime of the satellite, in accordance with Table 3.

1. HAC vs HAC screenings
2. Operational O/O Ephemeris vs HAC screenings
3. Operational O/O Ephemeris vs Operational O/O Ephemeris screenings
4. Special O/O Ephemeris vs HAC screenings
 - 4.1 Ephemeris versus secondary object, or
 - 4.2 Ephemeris versus full catalog
5. HAC '1-versus-1' requests: screening one primary object against one secondary using HAC data
6. Access to propagated SP ephemeris (without covariance) for all RSOs in the unclassified space catalog
7. Access to SP state vectors (without covariance) for all RSOs in the unclassified catalog

CONJUNCTION ASSESSMENT PROCESS

SCREENING SCHEDULE

18 SPCS performs HAC vs. HAC screenings for all NE and DS objects once every 24 hours, followed by Concern List screenings for each regime every 8 hours. (i.e., one full HAC vs HAC screening which includes a Concern List screening, followed by two Concern List screenings, 8 hours apart, every 24 hours.) For O/O Ephemeris screenings, the ephemeris file name dictates how 18 SPCS will process files. If the O/O designates it as **Special**, the 18 SPCS will process it as high-interest and screen it as soon as possible. If it is designated as **Operational**, the 18 SPCS will screen it according to the schedule in Table 1. Results for **Special** ephemeris are provided within 4 hours of receiving the ephemeris, and **Operational** results are provided within 8 to 12 hours of the scheduled screening times, depending on when it is submitted by the O/O.

The 18 SPCS screening schedule shifts one hour when the state of California (United States) transitions between Pacific Standard Time (PST) and Pacific Daylight (PDT) time, which generally occurs in March and November each year. Both schedules are provided below:

Table 1: PST Screening Schedule (24-hour cycle)

0630z	_____			
Screenings:	NE All HAC*	DS Concern List HAC	O/O Eph vs HAC	O/O Eph vs O/O Eph
1430z	_____			
Screenings:	NE Concern List HAC	DS All HAC*	O/O Eph vs HAC	O/O Eph vs O/O Eph
2230z	_____			
Screenings:	NE Concern List HAC	DS Concern List HAC	O/O Eph vs HAC	O/O Eph vs O/O Eph
0630z	_____			
	*Includes Concern List HAC screening			

Table 2: PDT Screening Schedule (24-hour cycle)

0530z	_____			
Screenings:	NE All HAC*	DS Concern List HAC	O/O Eph vs HAC	O/O Eph vs O/O Eph
1330z	_____			
Screenings:	NE Concern List HAC	DS All HAC*	O/O Eph vs HAC	O/O Eph vs O/O Eph
2130z	_____			
Screenings:	NE Concern List HAC	DS Concern List HAC	O/O Eph vs HAC	O/O Eph vs O/O Eph
0530z	_____			
	*Includes Concern List HAC screening			

CONJUNCTION ASSESSMENT PROCESS

SCREENING VOLUMES

The following tables define the screening volumes and durations 18 SPCS uses for basic CA, advanced CA, and ephemeris screenings. 18 SPCS conducts two types of screenings: **ellipsoid** and **covariance**. Both screenings use covariance-based “uncertainty volumes” around the satellites and the physical size of the satellites themselves (referred to as “exclusion volumes”). The same basic mathematical approach is used for both ellipsoid and covariance options, although probability of collision (P_c) is only computed for the covariance option. For the ellipsoid screening option, the uncertainty volume is static throughout the screening process, whereas covariance screenings employ a joint uncertainty volume that is based on time-varying covariance values for the primary and secondary objects at the time of closest approach. Please reference Annex A for more information on how 18 SPCS calculates probability of collision.

Table 3: HAC Screening Volumes

Screening	Orbit Regime Definition	Propagation	Radial	In-Track	Cross-Track
Deep Space (GEO/HEO/MEO) Ellipsoid	1300 min < Period < 1800 min Eccentricity < 0.25 & Inclination < 35°	10 days	10 km	10 km	10 km
LEO 4 Covariance	1200 km < Perigee ≤ 2000 km Eccentricity < 0.25	5 days	0.4 km	2 km	2 km
LEO 3 Covariance	750 km < Perigee ≤ 1200 km Eccentricity < 0.25	5 days	0.4 km	12 km	12 km
LEO 2 Covariance	500 km < Perigee ≤ 750 km Eccentricity < 0.25	5 days	0.4 km	25 km	25 km
LEO 1 Covariance	Perigee ≤ 500 km Eccentricity < 0.25	5 days	0.4 km	44 km	51 km

Table 4: O/O Ephemeris Screening Volumes

Screening	Orbit Regime Definition	Propagation	Radial	In-Track	Cross-Track
Deep Space Ellipsoid	Period > 225min	10 days	20 km	20 km	20 km
Near Earth Covariance	Period < 225min	7 days	2 km	25 km	25 km

CONJUNCTION ASSESSMENT PROCESS

REPORTING CRITERIA

The following tables define the reporting criteria used for basic and advanced CA and COLA. The advanced service provides more data further in advance of TCA and may be requested through the Orbital Data Request (ODR) process. These tables apply to both High Accuracy Catalog (HAC) and ephemeris screenings. “Deep space” includes Geosynchronous Earth Orbit (GEO), Highly Elliptical Orbit (HEO) and Medium Earth Orbit (MEO). “Near earth” includes all Low Earth Orbit (LEO) regimes.

Table 5: Basic Reporting Criteria

	Space-Track Criteria	Emergency Criteria	Emergency Phone Call Criteria
Notification Method	Conjunction Data Message (CDM)	Conjunction Data Message (CDM) & Close Approach Notification (CAN) email	CDM, CAN email & phone call
Deep Space HAC	TCA ≤ 10 days and Overall miss ≤ 5km	TCA ≤ 3 days and Overall miss ≤ 5km	TCA ≤ 3 days and Overall miss ≤ 500m
Deep Space O/O Ephemeris	TCA ≤ 10 days and Overall miss ≤ 5km	TCA ≤ 3 days and Overall miss ≤ 5km	N/A
Near Earth HAC	TCA ≤ 3 days and Overall miss ≤ 1km	TCA ≤ 3 days & Overall miss ≤ 1km & Probability of Collision ≥ e ⁻⁴	TCA ≤ 3 days and Overall miss ≤ 1km and Probability of Collision ≥ e ⁻²
Near Earth O/O Ephemeris	TCA ≤ 3 days and Overall miss ≤ 1km	TCA ≤ 3 days & Overall miss ≤ 1km & Probability of Collision ≥ e ⁻⁴	N/A

Table 6: Advanced Reporting Criteria

	Space-Track Criteria	Emergency Criteria	Emergency Phone Call Criteria
Notification Method	Conjunction Data Message (CDM)	Conjunction Data Message (CDM) & Close Approach Notification (CAN) email	CDM, CAN email & phone call
Deep Space HAC	TCA ≤ 10 days & all results w/in 5km x 5km x 5km	TCA ≤ 3 days & Overall miss ≤ 5km	TCA ≤ 3 days & Overall miss ≤ 500 m
Deep Space O/O Ephemeris	TCA ≤ 10 days & all results w/in 20km x 20km x 20km	TCA ≤ 3 days & Overall miss ≤ 5km	N/A
Near Earth (LEO 1-4) HAC	TCA ≤ 5 days & Probability of Collision ≥ e ⁻⁷ w/in HAC screening volumes	TCA ≤ 3 days & Overall miss ≤ 1km & Probability of Collision ≥ e ⁻⁴	TCA ≤ 3 days & Overall miss ≤ 1km & Probability of Collision ≥ e ⁻²
Near Earth (LEO 1-4) O/O Ephemeris	TCA ≤ 7 days & all results w/in 2km x 25km x 25km	TCA ≤ 3 days and Overall miss ≤ 1km & Probability of Collision ≥ e ⁻⁴	N/A

CONJUNCTION ASSESSMENT PROCESS

NOTIFICATIONS

O/Os will receive a variety of email notifications depending on the screening performed and results produced. All of these emails are generated and transmitted by the Space-Track.org website based on files that the 18 SPCS Conjunction Assessment Team uploaded to the website. The messages are:

- Close Approach Notification (CAN) email: sent for every prediction that meets emergency reportable criteria. Includes primary object, secondary object, miss distances, TCA, and for near earth events, probability of collision (Pc). Only sent to email addresses that the O/O has designated to receive CANs. (Controlled by each organization's Primary Representative or 18 SPCS through the Operator Panel on Space-Track.org. Contact 18SPCS.doo.customerservice@us.af.mil for assistance.)
- CDM email: notifies O/Os that new CDMs are available on Space-Track for their organization. All users with 'CDM Notification' permissions receive this email. (Controlled by each organization's Primary Representative or 18 SPCS through the Operator Panel on Space-Track.org.)
- Negative results email: Confirms that a specific ephemeris file has been screened and states that there are no results within the ephemeris screening volume. All users with 'CDM Notification' permissions receive this email.
- Expanded results email: Confirms that a specific ephemeris file has been screened, and that there are results that are within the ephemeris screening volumes, but not within emergency reportable criteria. O/Os who do not have the advanced CA service may receive this notification. All users with 'CDM Notification' permissions receive this email.

There are slight differences between the notifications sent for basic and advanced services. The following figures show which messages should be expected for different scenarios within the CA and COLA process.

CONJUNCTION ASSESSMENT PROCESS

BASIC EMERGENCY CA NOTIFICATIONS

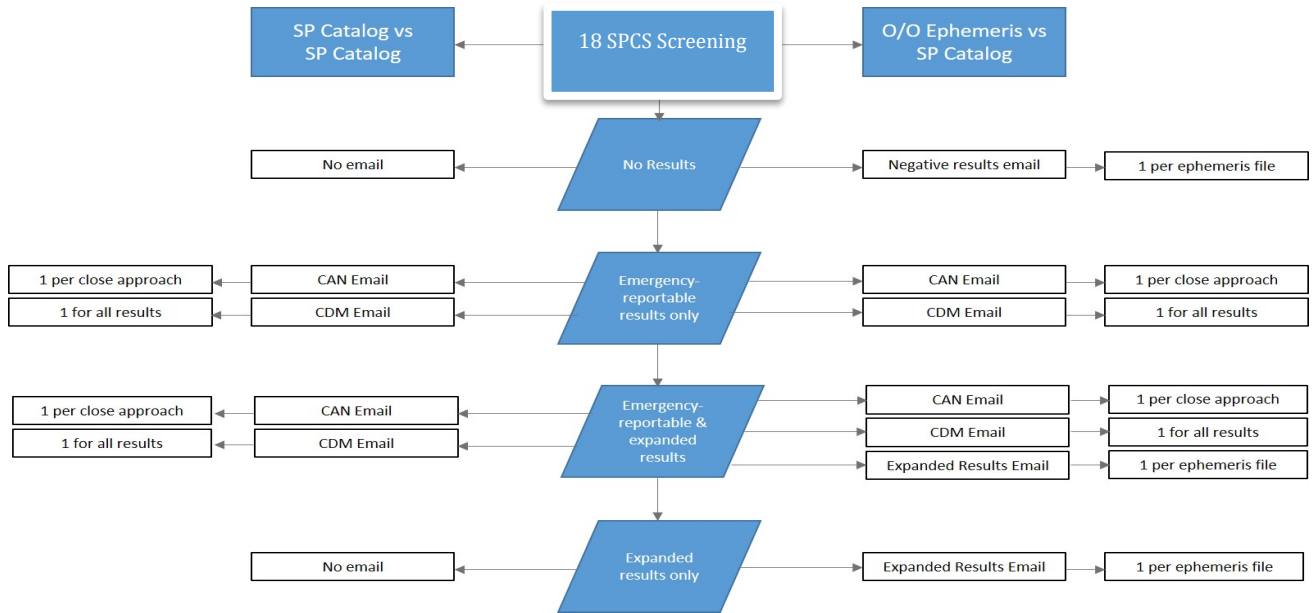


Figure 2: Basic Emergency CA Notifications

ADVANCED CA NOTIFICATIONS

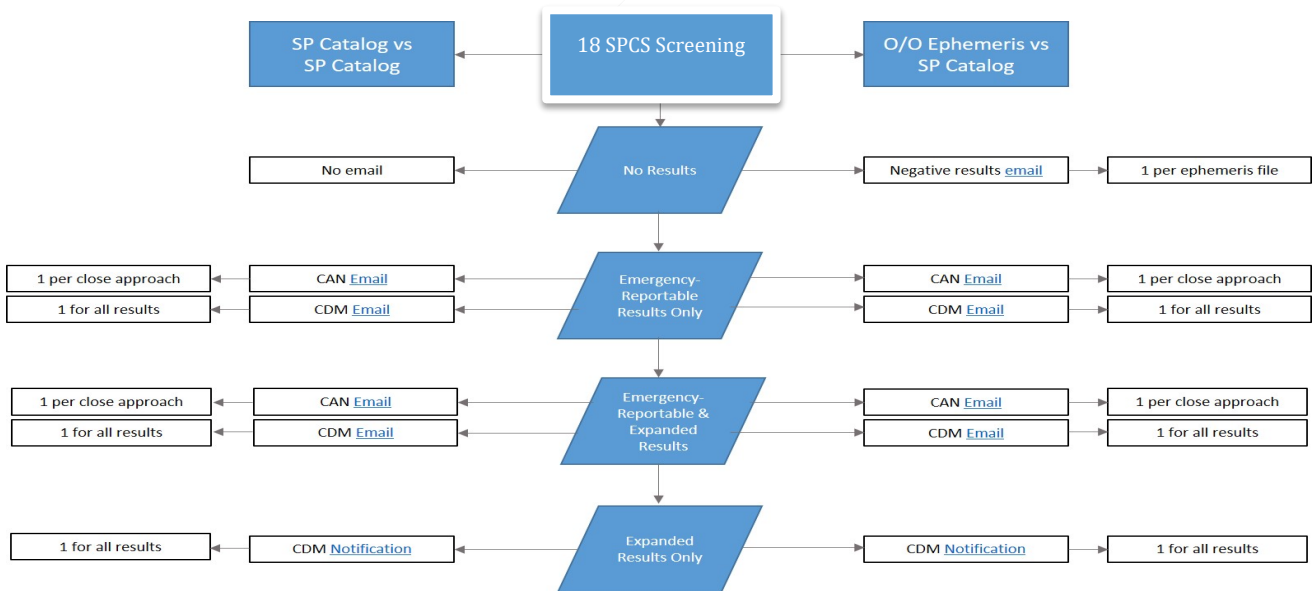


Figure 3: Advanced CA Notifications

CONJUNCTION ASSESSMENT PROCESS

LAUNCH CONJUNCTION ASSESSMENT

18 SPCS also provides launch conjunction assessment (CA), which identifies potential conjunctions that may result in a collision between launching objects and on-orbit objects. Using O/O-provided information, 18 SPCS screens the launch vehicle against the space catalog and identifies periods during the launch window which may put the rocket and payload at increased risk for collision. For more information on this service, reference the Launch Conjunction Assessment Handbook, which is available on Space-Track's Help Page.

EARLY ORBIT CONJUNCTION ASSESSMENT

Early orbit CA includes the screening of O/O-provided ephemeris against the catalog to facilitate the safe maneuvering of a newly launched object into its final orbit. 18 SPCS will screen the ephemeris using early orbit screening volumes and report all results in accordance with advanced reporting criteria. The O/O may provide more than one ephemeris file for each maneuver to allow analysis of multiple scenarios, but they must be labeled **Special**. 18 SPCS may pre-assign temporary satellite numbers in the 799500000 range to be used in the ephemeris file name. This will allow the O/O to receive screening results through the Space-Track CDM database. Once the newly launched satellites are cataloged in the 5-digit range, the O/O can seamlessly transition to the new catalog number. To receive early orbit CA support the O/O needs to:

- Pre-launch:
 - Submit an [ODR](#) requesting early orbit CA, specifying the preferred screening volume
 - Register for a user account on Space-Track.org
 - Provide the early orbit maneuver plan
 - Send in pre-launch ephemeris for testing, if desired
- Post-launch:
 - Provide ephemeris in an approved format and using the correct file name format for each screening
 - Provide an updated maneuver plan, as needed

Table 7: Early Orbit Screening Volumes					
Screening	Orbit Regime Definition	Propagation	Radial	In-Track	Cross-Track
Deep Space Ellipsoid	Perigee > 2000 km & Eccentricity > 0.25	10 days	40 km	77 km	107 km
Near Earth Covariance	Perigee ≤ 2000 km & Eccentricity < 0.25	7 days	2 km	44 km	51 km

CONJUNCTION ASSESSMENT PROCESS

END-OF-LIFE/DISPOSAL SUPPORT

If an O/O decides to move a satellite to a less-populated orbit at the end of its lifetime, 18 SPCS will assist the O/O by screening maneuver ephemeris and providing results. All O/O-provided ephemeris will be screened using standard ephemeris screening volumes, and results will be provided in accordance with basic or advanced reporting criteria. To receive end-of-life/disposal CA the O/O needs to:

- Submit an Orbital Data Request (ODR) if all results within advanced reporting criteria are desired (no ODR is required for basic reporting criteria)
- Provide the maneuver plan
- Provide ephemeris in an approved format and using the correct file name format for each screening

DEORBIT SUPPORT

A deorbit is the controlled reentry of a satellite into the Earth's atmosphere. If an O/O decides to deorbit a satellite or rocket stage through a series of maneuvers, 18 SPCS can provide CA screenings, as well as coordinate with NASA to ensure the deorbiting spacecraft safely descends through the International Space Station's (ISS) orbit. After the spacecraft completes its maneuvers, 18 SPCS can confirm final reentry. To receive this service, the O/O needs to:

- Submit an ODR if all results within advanced reporting criteria are desired (no ODR is required for basic reporting criteria)
- Provide the maneuver plan
- Provide ephemeris in an approved format and using the correct file name format for each screening

TASKING

In certain situations, more observations on an object will improve the quality of the conjunction prediction. To collect more observations, 18 SPCS can increase the tasking priority and revisit frequency assigned to sensors. 18 SPCS has embedded this in the routine screening cycle, as seen in Figure 1. If an object meets any of the following criteria, its tasking will be automatically increased:

- Not tracked within 72 hours, or
- Less than 20 observations in current Differential Correction (DC), or
- At least one component of covariance over 100,000 m²

For emergency reportable events, the O/O may contact 18 SPCS to confirm that both objects in the conjunction are tasked appropriately by emailing 18SPCS.doo.orbitalsafety@us.af.mil.

Ephemeris Formats

OVERVIEW

Satellite operators may provide ephemeris in various formats, which will be converted into formats that can be processed by 18 SPCS' ASW (Astrodynamics Support Workstation). Using the Super Computation of Miss Between Orbits (COMBO) software, 18 SPCS screens O/O ephemeris against the HAC or other O/O ephemeris to identify potential conjunctions and generate conjunction data messages. Operators may elect to include covariance data in order to accommodate probability of collision calculations.

All ephemeris formats must be in the mean equator/mean equinox (MEME) J2000.0 frame with positional values (x, y, z) given in kilometer units and velocity values (dX, dY, dZ) given in units of kilometers/second. If covariance values are provided, they must be in decimal notation and in the same reference frame as the positional values unless otherwise specified in the ephemeris file (see OEM format CCSDS Orbit Data Message (ODM) Blue Book).

All ephemeris formats may include informational header lines prior to the data lines which provide date, time, and state vector (position and velocity) values. Each format differs in the number and content of header lines, format of the date and time values, and different precision (number of decimal places) for the state vector components.

18 SPCS' conversion utility software converts all ephemeris formats to true equator/mean equinox (TEME) of Date for epoch J2000. The most recent time constants data file within the 18 SPCS mission system corrects for leap seconds.

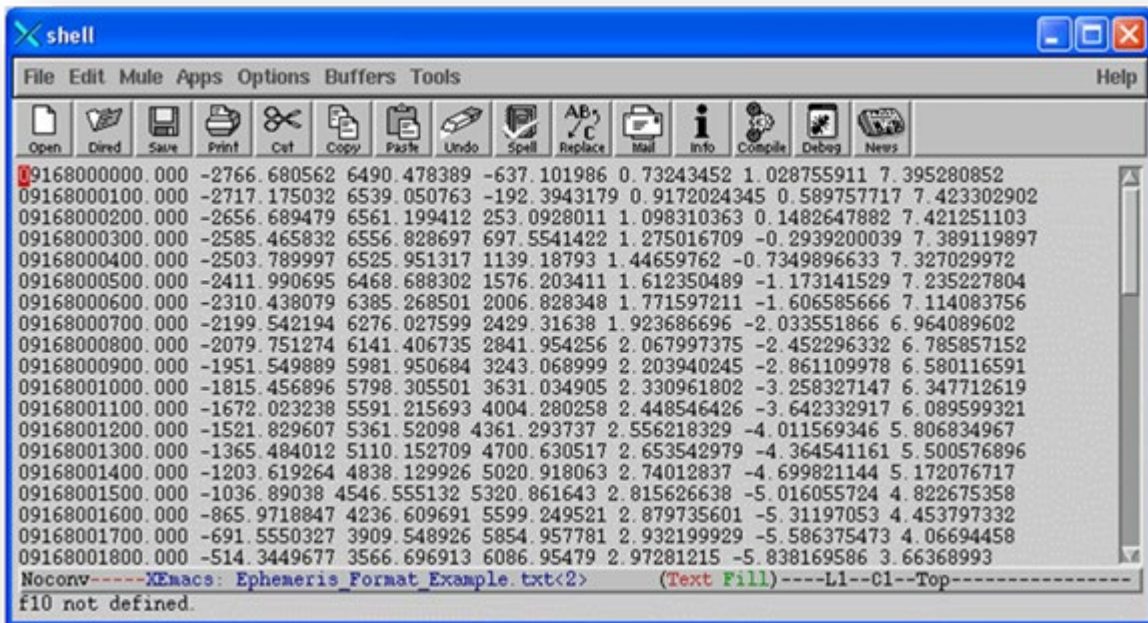
The NASA and UTC formats include position and velocity only. 18 SPCS accepts three formats with covariance:

- General On-Orbit (GOO) may include 3 x 3 (6 lower triangular matrix) position covariance data values,
- Modified ITC may include 6 x 6 (21 lower triangular matrix) position and velocity covariance data values
- Orbital Ephemeris Message (OEM) format, both with and without covariance data, which includes a capability for processing 6 x 6 (21 lower triangular matrix) position and velocity covariance data values. Visit the Consultative Committee for Space Data Systems (CCSDS) website for more information on the OEM.

EPHEMERIS FORMATS

NASA EPHEMERIS FORMAT

The NASA ephemeris data file format contains no descriptive header lines preceding the ephemeris data. Each data line contains a date formatted as YYDOY (last two digits of year and Day of Year (DOY) in place of month and day), a time stamp formatted as HHMMSS.SSS, and the state vector position (x, y, z) and velocity (dx, dy, dz) values.



```
09168000000.000 -2766.680562 6490.478389 -637.101986 0.73243452 1.028755911 7.395280852
09168000100.000 -2717.175032 6539.050763 -192.3943179 0.9172024345 0.589757717 7.423302902
09168000200.000 -2656.689479 6561.199412 253.0928011 1.098310363 0.1482647882 7.421251103
09168000300.000 -2585.465832 6556.828697 697.5541422 1.275016709 -0.2939200039 7.389119897
09168000400.000 -2503.789997 6525.951317 1139.18793 1.44659762 -0.7349896633 7.327029972
09168000500.000 -2411.990695 6468.688302 1576.203411 1.612350489 -1.173141529 7.235227804
09168000600.000 -2310.438079 6385.268501 2006.828348 1.771597211 -1.606585666 7.114083756
09168000700.000 -2199.542194 6276.027599 2429.31638 1.923686696 -2.033551866 6.964089602
09168000800.000 -2079.751274 6141.406735 2841.954256 2.067997375 -2.452296332 6.785857152
09168000900.000 -1951.549889 5981.950684 3243.068999 2.203940245 -2.861109978 6.580116591
09168001000.000 -1815.456896 5798.305501 3631.034905 2.330961802 -3.258327147 6.347712619
09168001100.000 -1672.023238 5591.215693 4004.280258 2.448546426 -3.642332917 6.089599321
09168001200.000 -1521.829607 5361.52098 4361.293737 2.556218329 -4.011569346 5.806834967
09168001300.000 -1365.484012 5110.152709 4700.630517 2.653542979 -4.364541161 5.500576896
09168001400.000 -1203.619264 4838.129926 5020.918063 2.74012837 -4.699821144 5.172076717
09168001500.000 -1036.89038 4546.555132 5320.861643 2.815626638 -5.016055724 4.822675358
09168001600.000 -865.9718847 4236.609691 5599.249521 2.879735601 -5.31197053 4.453797332
09168001700.000 -691.5550327 3909.548926 5854.957781 2.932199929 -5.586375473 4.06694458
09168001800.000 -514.3449677 3566.696913 6086.95479 2.97281215 -5.838169586 3.66368993
Noconv-----XEmacs: Ephemeris Format Example.txt<2> (Text Fill)-----L1--C1--Top-----
f10 not defined.
```

Figure 4: NASA Ephemeris Format Example

18 SPCS' conversion utility separates the entries on each ephemeris data line wherever one or more space (i.e. " ") characters are found. For each data line this processing results in a combined date/time field (i.e. "yyDOYhhmmss.sss") and each state vector component (i.e. position (x, y, z) and velocity (i.e. dx, dy, dz)) value. This ephemeris format does not include covariance values.

EPHEMERIS FORMATS

UTC EPHEMERIS FORMAT

The UTC ephemeris data file format contains 21 descriptive and header lines preceding the ephemeris data. Each data line contains a date formatted as YYYY/MM/DD, a time stamp formatted as HH:MM:SS.SSS, and the state vector position (x, y, z) and velocity (dx, dy, dz) values.

```
Version: OASYS v5.4.2a (November 24, 2008), Integral Systems, Inc.
Description: f62120.eph
Date: 2010/10/06 13:43:20
Path: M:\oasys\wgs\common\CMOC\1462_f62120.rpt
Spacecraft: [1462] W2
Ephemeris: /M=/oasys/WGS/1462/ephem/f62120.eph
Equinox: MEME of Epoch [JD2000] FK5
Attitude: AttitudeReference
Report Span Initial: 2010/10/07 00:00:00.000
Report Span Delta: 25.000 days
Report Span Final: 2010/11/01 00:00:00.000

Ephemeris Parameter Report
=====
Title: CMOC Ephemeris
Subtitle: f62120.eph

Time          ECI Pos. x   ECI Pos. y   ECI Pos. z   ECI Vel. x   ECI Vel. y   ECI Vel. z
UTC.YmdHMs3   km           km           km           km/sec       km/sec       km/sec
2010/10/07 00:00:00.000 -41477.15963 -7579.547117  42.13940860  0.5527448442 -3.024713800 -0.0002106383243
2010/10/07 00:15:00.000 -40890.75501 -10283.51710  41.85830829  0.7499088789 -2.981951852 -0.0004138131780
2010/10/07 00:30:00.000 -40128.29260 -12943.20736  41.39509402  0.9438439426 -2.926349765 -0.0006151897119
2010/10/07 00:45:00.000 -39193.05557 -15547.16532  40.75178003  1.133714786  -2.858147079 -0.0008138902523
2010/10/07 01:00:00.000 -38089.07101 -18084.17892  39.93116524  1.318703727  -2.777637623 -0.001009048924
2010/10/07 01:15:00.000 -36821.09289 -20543.32410  38.93682130  1.498014115  -2.685168265 -0.001199815486
2010/10/07 01:30:00.000 -35394.58133 -22914.01240  37.77307655  1.670873812  -2.581137387 -0.001385359127
2010/10/07 01:45:00.000 -33815.67921 -25186.03636  36.44499707  1.836538498  -2.465993172 -0.001564872046
2010/10/07 02:00:00.000 -32091.18515 -27349.61404  34.95836381  1.994294923  -2.340231629 -0.001737573143

Mocov: XEmacs: 1462_f62120.rpt<2> (Text Fill) ---L11--C45--Top
f10 not defined
```

Figure 5: UTC Ephemeris Format Example

The conversion utility ignores the 21 header and descriptive lines and separates the entries on each ephemeris data line wherever one or more space (i.e. “ ”) characters are found. For each data line this processing results in a date field (i.e. “yyyy/mm/dd”), a time field (i.e. “hh:mm:ss.sss”) and each state vector component (i.e. position (x, y, z) and velocity (i.e. dx, dy, dz)) value.

The date field is separated into month, day, and year values wherever a forward slash (i.e. “/”) character is found; and the time field is separated into hour, minute, and second values wherever a colon (i.e. “:”) character is found. The Day of Year (DOY) value is calculated from the month and day, taking into account any adjustment needed for a leap year.

This ephemeris format does not include covariance values.

EPHEMERIS FORMATS

GENERIC ON-ORBIT EPHEMERIS FORMAT

The Generic On-Orbit ephemeris data file format is the only format that is required to contain position covariance data in addition to ephemeris data. It contains four descriptive and header lines, where the fourth indicates the orbital reference frame of the covariance data. For each ephemeris data point, the data section includes one line which contains the epoch date/time and state vector, followed by one line holding the six values of the 3x3 lower triangular position covariance matrix.

```
Header line 1
Header line 2
Header line 3
UVW
1996363212907.267 -2431.703389 -61.323228 1743.460737 7.334365192 -3.500850681 -1.043901184
0.33313494E-03 0.46189273E-03 0.67824216E-03 -0.30700078E-03 -0.42212341E-03 0.32319319E-03
1996363215902.267 -2445.281900 -876.407094 1873.822412 1.857840083 -3.422553909 -0.996740974
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
1996363220002.267 -2457.957269 -682.109100 2008.427847 6.365338208 -3.343890234 -0.948337177
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
1996365012802.267 2164.925155 1114.323924 -688.809748 -3.534961127 -2.882103423 0.886508604
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
--\--- Generic On-Orbit ephemeris.txt All (1,0) (Text Fill)-----
```

Figure 6: Generic On-Orbit Data Example

The conversion utility makes a rudimentary check that the correct number of data lines are present. The number of header lines is subtracted from the number of lines in the ephemeris data file; if the result is not divisible by 2 (a state vector line plus a covariance data line) a warning message is output, but the conversion continues.

The conversion utility ignores the header and descriptive lines except for the covariance orbit frame reference value. (Figure 6 depicts 'UVW' which is the same as 'RTN.'). It then reads the data lines in groups of two and separates the entries on each data line wherever one or more space (i.e. " ") characters are found. For each group of two data lines this processing results in a date/time field (i.e. "yyyDOYhhmmss.sss"), each state vector component (i.e. position (x, y, z) and velocity (i.e. dx, dy, dz)) value and 6 covariance values.

The combined date/time field is separated into year, Day of Year, hour, minute, and second values.

EPHEMERIS FORMATS

MODIFIED ITC EPHEMERIS FORMAT

The Modified ITC ephemeris data file format is the only format that is required to contain both positional and velocity covariance data in addition to ephemeris data. It contains four descriptive and header lines, where the fourth indicates the orbital reference frame of the covariance data. For each ephemeris point, the data section includes one line which contains the epoch date and time and state vector, followed by three lines holding the twenty-one values of the 6 x 6 lower triangular position and velocity covariance matrix.

```
emacs@COSLBNP5GK1
File Edit Options Buffers Tools Help
[Icons]
Header line 1
Header line 2
Header line 3
UVM
1996363212907.267 -2431.703389 -61.323228 1743.460737 7.334365192 -3.500850681 -1.043901184
0.33313494E-03 0.46189273E-03 0.67824216E-03 -0.30700078E-03 -0.42212341E-03 0.32319319E-03 -0.33493650E-06
-0.46860842E-06 0.24849495E-06 0.42960228E-09 -0.22118325E-06 -0.28641868E-06 0.17980986E-06 0.26088992E-09
0.17675147E-09 -0.30413460E-06 -0.49894969E-06 0.35403109E-06 0.18692631E-09 0.10088625E-09 0.62244443E-09
1996363215902.267 -2445.281900 -876.407094 1873.822412 1.857840083 -3.422553909 -0.996740974
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
1996363220002.267 -2457.957269 -682.109100 2008.427847 6.365338208 -3.343890234 -0.948337177
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
1996365012802.267 2164.925155 1114.323924 -688.809748 -3.534961127 -2.882103423 0.886508604
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
--\ **- ModifiedITCFormat.txt All (5,0) (Text Fill)-----
```

Figure 7: Modified ITC Data Example

The conversion utility makes a rudimentary check that the correct number of data lines are present. The number of header lines is subtracted from the number of lines in the ephemeris data file; if the result is not divisible by 2 (a state vector line plus a covariance data line) a warning message is output, but the conversion continues.

The preprocessing script ignores the header and descriptive lines except for the covariance orbit frame reference value. It then reads the data lines in groups of four and separates the entries on each data line wherever one or more space (i.e. “ ”) characters are found. For each group of four data lines this results in a date/time field (i.e. “yyyDOYhhmmss.sss”), each state vector component (i.e. position (x, y, z) and velocity (i.e. dx, dy, dz)) value and 21 covariance values.

The combined date/time field is separated into year, Day of Year, hour, minute, and second values.

EPHEMERIS FORMATS

ORBITAL EPHEMERIS MESSAGE (OEM) FORMAT

The OEM ephemeris data file format contains a variable number of optional descriptive lines interspersed with blocks of ephemeris and optionally covariance data. Note that blocks of covariance data may contain more than one set of covariance data separated by EPOCH keywords.

For a complete discussion of this ephemeris data format refer to please visit the Consultative Committee for Space Data Systems (CCSDS) website and reference the 'Orbit Data Messages' Blue Book.

```
shell
File Edit Mule Apps Options Buffers Tools Help
Open Dired Save Print Cut Copy Paste Undo Spell Replace Mail Info Compile Debug News
CCSDS OEM VERS = 2.0
CREATION_DATE = 1996-11-04T17:22:31
ORIGINATOR = NASA/JPL

META_START
OBJECT_NAME = MARS GLOBAL SURVEYOR
OBJECT_ID = 1996-062A
CENTER_NAME = MARS BARYCENTER
REF_FRAME = EME2000
TIME_SYSTEM = UTC
START_TIME = 1996-12-18T12:00:00.331
USEABLE_START_TIME = 1996-12-18T12:10:00.331
USEABLE_STOP_TIME = 1996-12-28T21:23:00.331
STOP_TIME = 1996-12-28T21:28:00.331
INTERPOLATION = HERMITE
INTERPOLATION_DEGREE = 7
META_STOP

COMMENT This file was produced by M.R. Somebody, MS00 NAV/JPL, 1996NOV 04. It is
COMMENT to be used for DSN scheduling purposes only.

1996-12-18T12:00:00.331 2789.619 -280.045 -1746.755 4.73372 -2.49586 -1.04195
1996-12-18T12:01:00.331 2783.419 -308.143 -1877.071 5.18604 -2.42124 -1.99608
1996-12-18T12:02:00.331 2776.033 -336.859 -2008.682 5.63678 -2.33951 -1.94687
1996-12-28T21:28:00.331 -3881.024 563.959 -682.773 -3.28827 -3.66735 1.63861

META_START
OBJECT_NAME = MARS GLOBAL SURVEYOR
OBJECT_ID = 1996-062A
CENTER_NAME = MARS BARYCENTER
REF_FRAME = EME2000
TIME_SYSTEM = UTC
START_TIME = 1996-12-28T21:29:07.267
USEABLE_START_TIME = 1996-12-28T22:08:02.5
USEABLE_STOP_TIME = 1996-12-30T01:18:02.5
STOP_TIME = 1996-12-30T01:28:02.267
INTERPOLATION = HERMITE
INTERPOLATION_DEGREE = 7
META_STOP

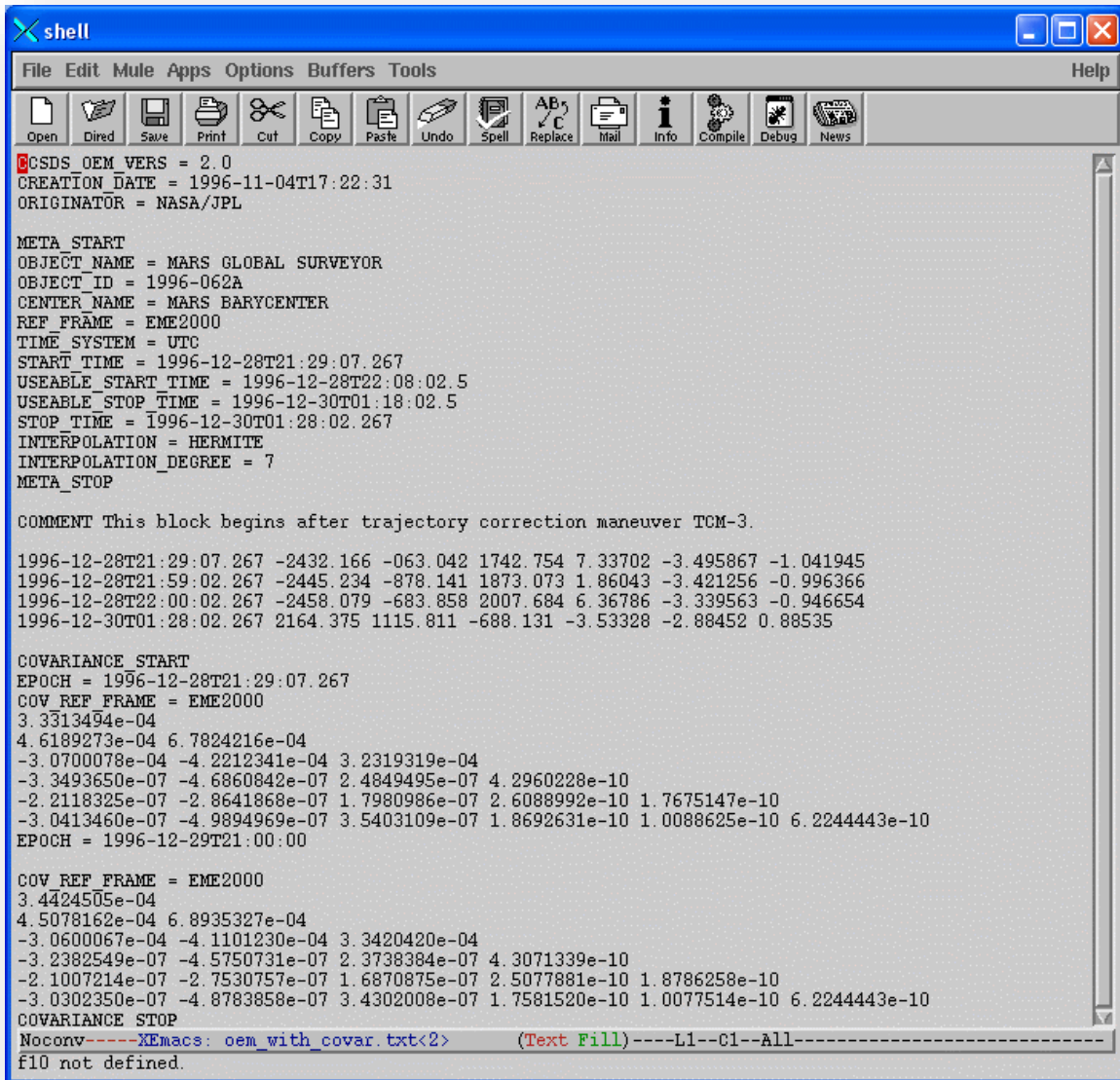
COMMENT This block begins after trajectory correction maneuver TCM-3.

1996-12-28T21:29:07.267 -2432.166 -063.042 1742.754 7.33702 -3.495867 -1.041945
1996-12-28T21:59:02.267 -2445.234 -878.141 1873.073 1.86043 -3.421256 -0.996366
1996-12-28T22:00:02.267 -2458.079 -683.858 2007.684 6.36786 -3.339563 -0.946654
1996-12-30T01:28:02.267 2164.375 1115.811 -688.131 -3.53328 -2.88452 0.88535

Noconv-----XEmacs: oem_no_covar.txt (Text Fill)-----L1--C1--All-----
f10 not defined.
```

Figure 8: OEM (without covariance) Example

EPHEMERIS FORMATS



```
shell
File Edit Mule Apps Options Buffers Tools Help
Open Dired Save Print Cut Copy Paste Undo Spell Replace Mail Info Compile Debug News
CCSDS_OEM_VERS = 2.0
CREATION_DATE = 1996-11-04T17:22:31
ORIGINATOR = NASA/JPL

META_START
OBJECT_NAME = MARS GLOBAL SURVEYOR
OBJECT_ID = 1996-062A
CENTER_NAME = MARS BARYCENTER
REF_FRAME = EME2000
TIME_SYSTEM = UTC
START_TIME = 1996-12-28T21:29:07.267
USEABLE_START_TIME = 1996-12-28T22:08:02.5
USEABLE_STOP_TIME = 1996-12-30T01:18:02.5
STOP_TIME = 1996-12-30T01:28:02.267
INTERPOLATION = HERMITE
INTERPOLATION_DEGREE = 7
META_STOP

COMMENT This block begins after trajectory correction maneuver TCM-3.

1996-12-28T21:29:07.267 -2432.166 -063.042 1742.754 7.33702 -3.495867 -1.041945
1996-12-28T21:59:02.267 -2445.234 -878.141 1873.073 1.86043 -3.421256 -0.996366
1996-12-28T22:00:02.267 -2458.079 -683.858 2007.684 6.36786 -3.339563 -0.946654
1996-12-30T01:28:02.267 2164.375 1115.811 -688.131 -3.53328 -2.88452 0.88535

COVARIANCE_START
EPOCH = 1996-12-28T21:29:07.267
COV_REF_FRAME = EME2000
3.3313494e-04
4.6189273e-04 6.7824216e-04
-3.0700078e-04 -4.2212341e-04 3.2319319e-04
-3.3493650e-07 -4.6860842e-07 2.4849495e-07 4.2960228e-10
-2.2118325e-07 -2.8641868e-07 1.7980986e-07 2.6088992e-10 1.7675147e-10
-3.0413460e-07 -4.9894969e-07 3.5403109e-07 1.8692631e-10 1.0088625e-10 6.2244443e-10
EPOCH = 1996-12-29T21:00:00
COV_REF_FRAME = EME2000
3.4424505e-04
4.5078162e-04 6.8935327e-04
-3.0600067e-04 -4.1101230e-04 3.3420420e-04
-3.2382549e-07 -4.5750731e-07 2.3738384e-07 4.3071339e-10
-2.1007214e-07 -2.7530757e-07 1.6870875e-07 2.5077881e-10 1.8786258e-10
-3.0302350e-07 -4.8783858e-07 3.4302008e-07 1.7581520e-10 1.0077514e-10 6.2244443e-10
COVARIANCE_STOP
Noconv-----XEmacs: oem_with_covar.txt<2> (Text Fill)----L1--C1--All-----
f10 not defined.
```

Figure 9: OEM (with covariance) Example

The conversion utility removes all lines that are blank or contain the keywords (defined in the format document) CCSDS_OEM_VERS, CENTER_NAME, COMMENT, COV_REF_FRAME, CREATION_DATE, INTERPOLATION, INTERPOLATION_DEGREE, META_START, META_STOP, OBJECT_ID, OBJECT_NAME, ORIGINATOR, REF_FRAME, START_TIME, STOP_TIME, TIME_SYSTEM, USEABLE_START_TIME, or USEABLE_STOP_TIME. This reduces the data file to lines containing blocks of ephemeris data and optional blocks of covariance data. The covariance data blocks are delimited by lines containing the keywords COVARIANCE_START and COVARIANCE_STOP. The reference frame must be annotated for each covariance

EPHEMERIS FORMATS

data block throughout the OEM file (COV_REF_FRAME, Figure 9). If no annotation is provided, the 18 SPCS system defaults to the reference frame annotated in the header of the file (REF_FRAME, Figure 9). There can be more than one section of covariance data within a block, each delimited by an EPOCH line. The date/time values of the optional covariance data on the EPOCH lines are not guaranteed by the format standard to match any ephemeris data date/time values.

The values on each ephemeris data line are separated out wherever one or more space (i.e. “ ”) characters are found.

For each ephemeris data line, further processing results in date/time fields (i.e. “yyyy-mm-dd” and “hh:mm:ss.sss”) and each state vector component (i.e. position (x, y, z) and velocity (i.e. dx, dy, dz)) value. For each optional block of covariance data, processing results in date/time fields (i.e. “yyyy-mm-dd” and “hh:mm:ss.sss”) and the 21 covariance values. **Note that state vector and covariance components must be in decimal notation as seen in Figure 9.**

The date field is separated into month, day, and year; values wherever a dash (i.e. “-”) character is found; and the time field is separated into hour, minute, and second values wherever a colon (i.e. “:”) character is found. The Day of Year (DOY) value is calculated from the month and day, taking into account any adjustment needed for a leap year.

The conversion utility then matches the covariance data, if it exists, by date/time to a line of ephemeris data. If the date/time exactly matches, the covariance data is appended to the ephemeris state vector for that date/time. The covariance data is discarded if the date/time does not match for a section of ephemeris data. Ephemeris data lines that do not have date and time matches of covariance data will have twenty-one zero (i.e. “0.0”) values following the state vector.

HOW TO NAME EPHEMERIS FILES

How to Name Ephemeris Files

OVERVIEW

18 SPCS requires that satellite operators name their files following a specific format, which dictates how the ephemeris file will be processed. When the O/O submits their files through the website Space-Track.org, Space-Track will verify the file is named correctly and return error messages if it is not. The file name format is:

<DataType>_<SatelliteNumber#>_<CommonName>_<DayTimeGroup>_<Operational/Special>_<MetaData>_<Classification>.<FileExtension>

Table 8: Ephemeris File Name Convention

<i>Data Field</i>	<i>Description</i>	<i>Normative Value (N) or Example (E)</i>	<i>Obligatory</i>
DataType	The type of data being provided.	(N) MEME (unless otherwise directed by 18 SPCS) This entry must be in uppercase letters	Yes
Catalog#	The 5-digit designator for the object as defined in USSPACECOM's satellite catalog https://www.space-track.org/#/catalog If the object is not cataloged, use: <ul style="list-style-type: none"> • UCN## for near-earth objects or UCD## for deep-space objects (Substitute ## with 01, 02, 03 etc. up to the total number of files submitted), or • The 9-digit number assigned to you by 18 SPCS (Contact 18 SPCS SSA Sharing for details.) 	(E) 25544 (E) 00900 (E) UCN01 (E) UCD02 (E) 799500000 (E) 799599999	Yes
CommonName	The spacecraft name for the object. Recommend using the common name listed in USSPACECOM's satellite catalog https://www.space-track.org/#/catalog If the object is not cataloged, use the common name designated by the satellite operator	(E) ISS (ZARYA) (E) CALSHERE 1	Yes
DayTimeGroup	Start time of the ephemeris, using three-digit day of year and HH:MM in UTC, where HH is the hour in the 24-hour system	(E) 3001224 = Oct 26, 2020 at 12:24pm UTC	Yes

Continued on next page

HOW TO NAME EPHEMERIS FILES

Table 8: Ephemeris File Name Convention, cont.

<i>Data Field</i>	<i>Description</i>	<i>Normative Value (N) or Example (E)</i>	<i>Obligatory</i>
Operational/ Special	<p>An Operational file represents where the satellite is planned to go and may or may not include maneuvers. These files typically incorporate normal station-keeps, or represent a freefall orbit.</p> <p>If maneuvers are included, 18 SPCS assumes these will definitely occur. Otherwise, the files should be submitted as Special.</p> <p>A Special file represents where the satellite is planned to go if a special maneuver is executed.</p> <p>A Special file is used for planning purposes only, unless the maneuver becomes operational, in which case it must be resubmitted as Operational.</p> <p>All Special files will be treated as high-interest.</p> <p>*Multiple Special files may be submitted for the same satellite, but only one Operational file at a time can be submitted per satellite*</p>	(N) Operational (N) Special	Yes
MetaData	<p>Additional information provided at the discretion of the satellite operator. Often used to indicate maneuver status, or maneuver option plan. If there is no additional information to provide there must be a double underscore between Operational/Special and Classification</p>	(E) nomnvr (E) stationkeepingmnvr (E) burn02 (E) _	Yes
Classification	<p>The security classification of the data. Only unclassified files will be accepted through www.space-track.org</p>	(E) unclassified (E) UNCLASSIFIED (E) Unclassified	Yes
File Extension	<p>Indicates the type of file</p>	(N) .txt (unless otherwise directed by 18 SPCS)	Yes

FILE NAME EXAMPLES

- MEME_25544_ISS_1651200_oper_unclassified.txt
- MEME_25544_ISS(ZARYA)_1651200_operational_nomnvr_UNCLASSIFIED.txt
- MEME_25544_ISS_1651200_special_mnvr01_Unclassified.txt
- MEME_UCN01_SPACESAT1_1651200_special_burn01_Unclassified.txt
- MEME_799500234_Sat1_1651200_special_separation_unclassified.txt

HOW TO SUBMIT EPHEMERIS FILES

How to Submit Ephemeris Files

OVERVIEW

Ephemeris files may be submitted in three ways:

1. Through the website Space-Track.org (preferred):
 - 1.1 Manually, or
 - 1.2 Using Application Programming Interface (API)
2. By email to the 18 SPCS Orbital Safety Crew at 18SPCS.doo.orbitalsafety@us.af.mil. **This method should only be used if the satellite operator cannot access Space-Track.**

Space-Track.org is the most efficient and secure method of submitting ephemeris files on a recurring basis. To set up access, contact the 18 SPCS SSA Sharing Team at 18SPCS.doo.customerservice@us.af.mil or +1-805-605-5219. The SSA Sharing Team will request the following information:

1. The title of your CDM organization (the organization name under which you access CDMs on the Operator Panel)
2. The Space-Track user names of the personnel who will upload ephemeris for your satellite constellation

The SSA Sharing Team will create a permissions-based ephemeris folder for your organization that will only be accessed by 18 SPCS and the personnel you authorize. You will have upload, download, and delete permissions to the folder, which you will access through the Files Panel:

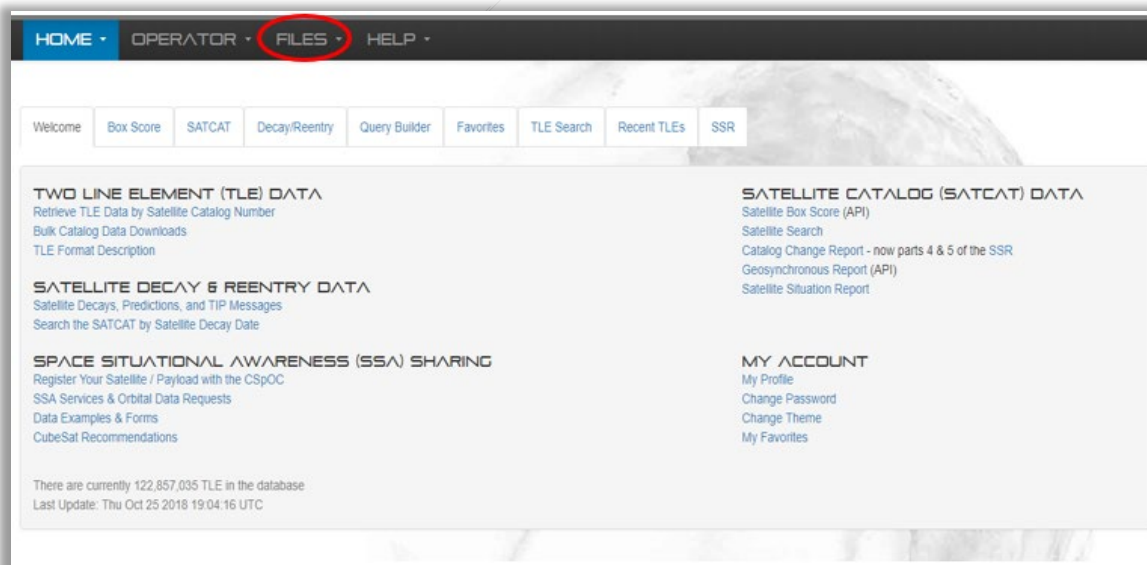


Figure 10: Files Panel on Space-Track.org

HOW TO SUBMIT EPHEMERIS FILES

SUBMITTING EPHEMERIS THROUGH SPACE-TRACK.ORG

Once you have an ephemeris folder on the Files Panel, you will also have access to the 'Download' and 'Upload' tabs. On the 'Upload' tab you can upload a variety of files to the folders you have permissions to. All of these folders will display in the 'Destination' dropdown menu:

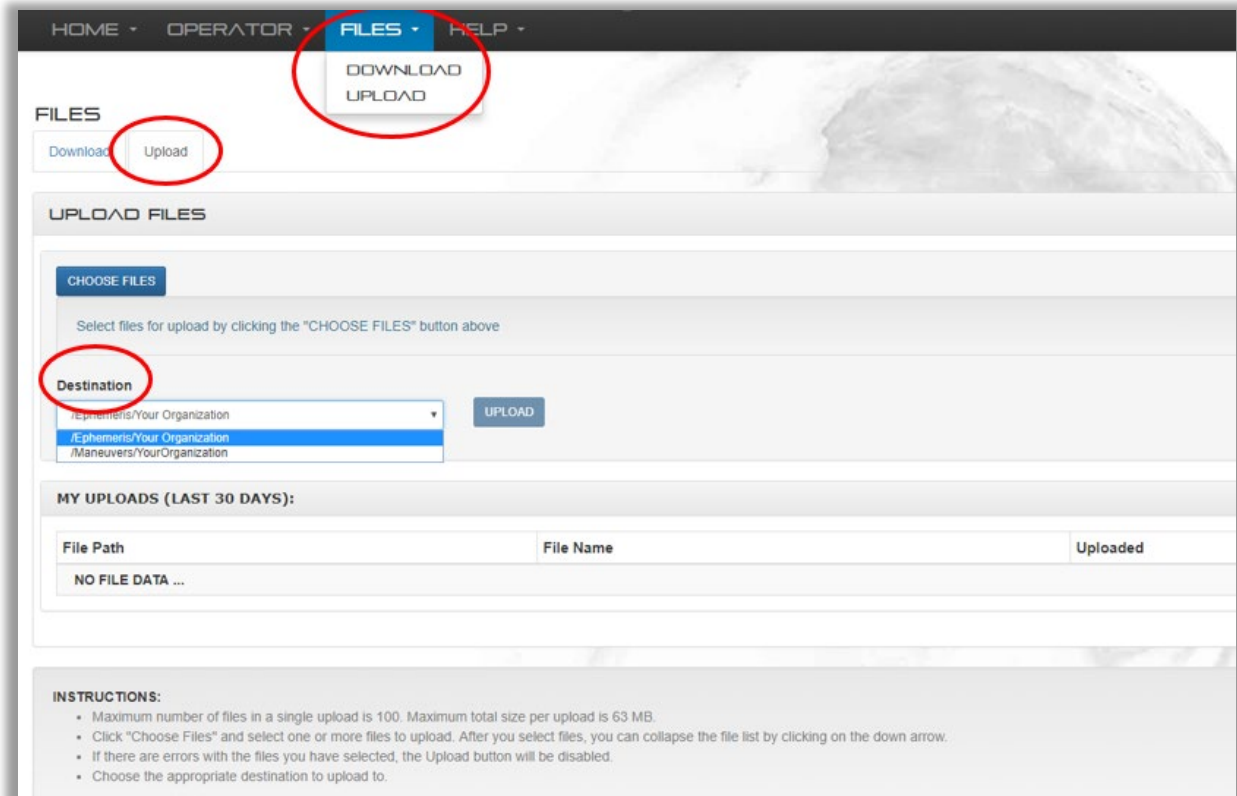


Figure 11: Files Panel Upload Tab - Ephemeris

MANUAL UPLOAD OF EPHEMERIS FILES

1. Log in to Space-Track.org, click on 'Files' at the top of the page, and then click on the 'Upload' tab
2. Click 'Choose Files' and select your ephemeris files
 - 2.1 Maximum number of files in a single upload is 100
 - 2.2 Maximum total size per upload is 60 MB
 - 2.3 Files must be named in accordance with guidelines in 'How to Name Ephemeris Files'
3. Using the 'Destination' dropdown menu, select the '/Ephemeris/' folder for your organization
4. Click 'Upload' to upload the files
5. After a successful upload, the files will display in 'My Uploads (Last 30 Days)' Table

HOW TO SUBMIT EPHEMERIS FILES

6. The 18 SPCS Orbital Safety Crew will receive a notification that you have uploaded new ephemeris files for screening. However, if the ephemeris is **Special** or in response to a **high-interest event**, please phone or email the Conjunction Assessment Team to notify them that you need an immediate response: +1-805-605-3533 or 18SPCS.doo.orbitalsafety@us.af.mil.

API UPLOAD OF EPHEMERIS FILES

Please visit Space-Track.org's 'API' and 'How To' pages for the most up-to-date guidance (including usage limitations) on API capabilities: <https://www.space-track.org/documentation#/api> and <https://www.space-track.org/documentation#/howto>. Similar to manual uploads:

1. Files must be named in accordance with guidelines in 'How to Name Ephemeris Files'
2. After a successful upload, the files will display in 'My Uploads (Last 30 Days)' Table
3. The 18 SPCS Orbital Safety Crew will receive a notification that you have uploaded new ephemeris files for screening. However, if the ephemeris is **Special** or in response to a **high-interest event**, please phone or email the Conjunction Assessment Team to notify them that you need an immediate response: +1-805-605-3533 or 18SPCS.doo.orbitalsafety@us.af.mil.

EMAIL

If your organization does not have an ephemeris folder on the Files Panel, you may send your ephemeris by email to the 18 SPCS Conjunction Assessment Team at 18SPCS.doo.orbitalsafety@us.af.mil. Please:

1. Name files in accordance with guidelines in 'How to Name Ephemeris Files'
2. Send only .txt files - **.zip files cannot be accepted**

GUIDANCE FOR HIGH-INTEREST EVENTS

After you submit your ephemeris, please send an email or phone the 18 SPCS Conjunction Assessment Team (18SPCS.doo.orbitalsafety@us.af.mil or +1-805-605-3533) to provide the following information regarding the high-interest request:

1. The conjunction event that you are concerned about (provide secondary object, CDM ID number, and/or time of closest approach)
2. The object(s) you need your ephemeris screened against (for example, one object, a short list of objects, or the whole catalog)
3. Reference your approved Orbital Data Request, if applicable
4. Confirmation that you do or do not have an SSA Sharing Agreement with USSPACECOM (For more information on SSA Sharing Agreements, please visit <https://www.space-track.org/documentation#/odr>)

MANEUVER NOTIFICATION FORMAT

Maneuver Notification Format

OVERVIEW

18 SPCS respectfully requests that satellite operators notify 18 SPCS of planned, confirmed, and cancelled maneuvers. This allows 18 SPCS to maintain a more accurate catalog, anticipate spaceflight safety risks, and provide more relevant conjunction notifications. 18 SPCS has chosen the Orbital Parameter Message (OPM) as the most appropriate method of exchanging maneuver information. However, to make it applicable to 18 SPCS operations and reporting procedures, 18 SPCS has made modifications to the message, which are detailed in the following Maneuver Notification Format. Guidelines that add to or deviate from the direction provided in the CCSDS Orbit Data Message Blue Book are indicated by "USER_DEFINED" in the keyword. To access the Blue Book visit the CCSDS website.

FORMAT

The OPM shall be represented as a combination of the following: (1) a header, (2) metadata (data about data), (3) data, and (4) optional comments. Space-Track only accepts KVN (Key/Value Notation).

The following tables specify for each section of the OPM: (1) the keyword to be used, (2) a short description of the item, (3) examples of allowed values or the units of the time, when applicable, and (4) whether the item is obligatory or optional.

Table 9: OPM Header			
Keyword	Description	Example	Obligatory
CCSDS_OPM_VERS	Format version in the form of 'x.y', where 'y' is incremented for corrections and minor changes, and 'x' is incremented for major changes.	2.0	Yes
COMMENT	Reference ODM Blue Book 6.7	This is a comment	No
CREATION_DATE	File creation date/time in UTC	2015-07-04T12:00:00	Yes
ORIGINATOR	Creating agency or operator. Must be the same title as the CDM account on Space-Track.org	CNES, JAXA, ESA, IRIDIUM	Yes
USER_DEFINED_RELEASABILITY	Acceptable values: PUBLIC, PRIVATE PUBLIC: Operator agrees to share file with all other satellite operators who have access to Space-Track's Operator Panel	PUBLIC	No. If not provided, will default to PRIVATE

MANEUVER NOTIFICATION FORMAT

	PRIVATE: Operators agrees to share file with 18 SPCS only		
USER_DEFINED_CLASSIFICATION	Acceptable value: UNCLASSIFIED 18 SPCS will only accept unclassified files.	UNCLASSIFIED	Yes

TABLE 10: OPM METADATA

Keyword	Description	Example	Obligatory
COMMENT	Reference Orbital Data Message Blue Book 6.7	This is a comment	No
OBJECT_NAME	Spacecraft name for which the orbit state or maneuver information is provided. Recommend using common names in the Satellite Catalog on www.space-track.org	ISS (ZARYA)	Yes
OBJECT_ID	Object identifier of the object for which the orbit state is provided. Use international designator as published on Space-Track.org using format YYYY-NNNP{PP}, where: YYYY = Year of launch. NNN = Three digit serial number of launch in year YYYY (with leading zeros). P{PP} = At least one capital letter for the identification of the part brought into space by the launch.	1998-067A	No
USER_DEFINED_NORAD_CAT_ID	<ul style="list-style-type: none"> • 5-digit satellite catalog number assigned by USSTRATCOM, or • 9-digit satellite number assigned by 18 SPCS 	25544 799500234	Yes
CENTER_NAME	Origin of reference frame	Earth	Yes
REF_FRAME	Name of reference frame in which the state vector and optional Keplerian element data are given	MEME2000 International Terrestrial Reference Frame (ITRF) ICRF TOD TDR	Yes, if state vector included
REF_FRAME_EPOCH	Epoch of reference frame, if not intrinsic to the definition of the reference frame.	2001-11-06T11:17:33	No
TIME_SYSTEM	Time system used for state vector, maneuver, and covariance data. Must be UTC.	UTC	Yes

MANEUVER NOTIFICATION FORMAT

TABLE 11: OPM DATA – STATE VECTOR COMPONENTS IN SPECIFIED COORDINATE SYSTEM

Keyword	Description	Units	Obligatory
COMMENT	Reference Orbital Data Message Blue Book 6.7	N/A	No
EPOCH	Epoch of state vector in UTC	N/A	No
X	Position vector X-component	km	No
Y	Position vector Y-component	km	No
Z	Position vector Z-component	km	No
X_DOT	Velocity vector X-component	km/s	No
Y_DOT	Velocity vector Y-component	km/s	No
Z_DOT	Velocity vector Z-component	km/s	No

TABLE 12: OPM DATA – Osculating Keplerian Elements in Specified Reference Frame

Keyword	Description	Units	Obligatory
COMMENT	Reference Orbital Data Message Blue Book 6.7	n/a	No
SEMI_MAJOR_AXIS	Semi-major axis	km	No
ECCENTRICITY	Eccentricity	n/a	No
INCLINATION	Inclination	deg	No
RA_OF_ASC_NODE	Right ascension of the ascending node	deg	No
ARG_OF_PERICENTER	Argument of pericenter	deg	No
MEAN_ANOMALY	Mean anomaly	deg	No
GM	Gravitational coefficient (Gravitational Constant x Central Mass)	km**3/s**2	No

TABLE 13: OPM DATA – SPACECRAFT PARAMETERS

Keyword	Description	Units	Obligatory
COMMENT	Reference Orbital Data Message Blue Book 6.7	n/a	No
MASS	Spacecraft mass	kg	No
SOLAR_RAD_AREA	Solar Radiation Pressure Area (A_R)	m**2	No
SOLAR_RAD_COEFF	Solar Radiation Pressure Coefficient (C_R)	n/a	No
DRAG_AREA	Drag Area (A_D)	m**2	No
DRAG_COEFF	Drag Coefficient (C_D)	n/a	No

TABLE 14: OPM DATA – POSITION/VELOCITY COVARIANCE MATRIX

Keyword	Description	Units	Obligatory
COMMENT	Reference Orbital Data Message Blue Book 6.7	n/a	No
COV_REF_FRAME	Coordinate system for covariance matrix	n/a	No
CX_X	Covariance matrix [1,1]	km**2	No
CY_X	Covariance matrix [2,1]	km**2	No
CY_Y	Covariance matrix [2,2]	km**2	No
CZ_X	Covariance matrix [3,1]	km**2	No
CZ_Y	Covariance matrix [3,2]	km**2	No
CZ_Z	Covariance matrix [3,3]	km**2	No

MANEUVER NOTIFICATION FORMAT

CX_DOT_X	Covariance matrix [4,1]	km**2/s	No
CX_DOT_Y	Covariance matrix [4,2]	km**2/s	No
CX_DOT_Z	Covariance matrix [4,3]	km**2/s	No
CX_DOT_X_DOT	Covariance matrix [4,4]	km**2/s**2	No
CY_DOT_X	Covariance matrix [5,1]	km**2/s	No
CY_DOT_Y	Covariance matrix [5,2]	km**2/s	No
CY_DOT_Z	Covariance matrix [5,3]	km**2/s	No
CY_DOT_X_DOT	Covariance matrix [5,4]	km**2/s**2	No
CY_DOT_Y_DOT	Covariance matrix [5,5]	km**2/s**2	No
CZ_DOT_X	Covariance matrix [6,1]	km**2/s	No
CZ_DOT_Y	Covariance matrix [6,2]	km**2/s	No
CZ_DOT_Z	Covariance matrix [6,3]	km**2/s	No
CZ_DOT_X_DOT	Covariance matrix [6,4]	km**2/s**2	No
CZ_DOT_Y_DOT	Covariance matrix [6,5]	km**2/s**2	No
CZ_DOT_Z_DOT	Covariance matrix [6,6]	km**2/s**2	No

TABLE 15: OPM DATA – MANEUVER PARAMETERS

Keyword	Description	Units	Obligatory
COMMENT	Reference ODM Blue Book 6.7	n/a	No
MAN_EPOCH_IGNITION	Epoch of ignition. Reference ODM Blue Book 6.5.9	UTC	Yes
MAN_DURATION	Maneuver duration (If = 0, impulsive maneuver)	s	Yes
MAN_DELTA_MASS	Mass change during maneuver (value is < 0)	kg	No
MAN_REF_FRAME	Coordinate system for velocity increment vector (value must be selected from OPM Blue Book annex A)	n/a	Yes
MAN_DV_1	1 st component of the velocity increment	km/s	Yes
MAN_DV_2	2 nd component of the velocity increment	km/s	Yes
MAN_DV_3	3 rd component of the velocity increment	km/s	Yes
USER_DEFINED_MAN_ID	A unique ID applied to the specific maneuver by the operator. Unique IDs may be 1-30 alphanumeric characters, dashes, or underscores	n/a	No
USER_DEFINED_DV_OVERALL	If this field is not populated, Space-Track will calculate it based on component DVs	km/s	No
USER_DEFINED_EPHEM	Name of the corresponding ephemeris file, if the operator has submitted ephemeris to 18 SPCS for screening	n/a	No
USER_DEFINED_MAN_PURPOSE	Specifies the purpose of the maneuver. Acceptable values: AEROBRAKE (Aerobraking) ATT_ADJUST (Attitude adjust) COLA (Collision avoidance) DEORBIT (Deorbit) DISPOSAL (Disposal) FLYBY_TARG (Flyby targeting) LEOP (Launch & Early Orbit) MNVR_CLEANUP (Maneuver cleanup) MASS_ADJUST (Mass adjust) TRIM (Orbit trim)	n/a	Yes

MANEUVER NOTIFICATION FORMAT

	<p>OTHER (Other)</p> <p>PER_RED (Period reduction)</p> <p>RELOCATION (Relocation)</p> <p>SCI_OBJ (Science objective)</p> <p>SPIN_RATE_ADJUST (Spin rate adjust)</p> <p>SK (Station-keeping)</p> <p>TRAJ_CORR (Trajectory correction)</p>		
USER_DEFINED_TCA	<p>For COLA maneuvers, provide the Time of Closest Approach (TCA) in UTC of the corresponding conjunction event. Recommend using the TCA in the Conjunction Data Message.</p>	UTC	Yes for COLA maneuver, No for all others
USER_DEFINED_MAN_STATUS	<p>Acceptable values: PREDICTED, DETERMINED, CANCELLED.</p> <p>PREDICTED = planned maneuver</p> <p>DETERMINED = confirmed maneuver</p> <p>CANCELLED = cancelled maneuver</p>	n/a	Yes

HOW TO NAME MANEUVER NOTIFICATIONS

How to Name Maneuver Notifications

OVERVIEW

To simplify the process for O/Os, Space-Track will generate the file name for each maneuver notification using information provided within the OPM, specifically the RELEASABILITY, USER_DEFINED_NORAD_CAT_ID, ORIGINATOR, and CLASSIFICATION fields. In the file name, the O/O only needs to include their organization name (must be the same as their CDM account on Space-Track) and a unique identifier, such as a sequence number or timestamp, followed by the .opm extension:

<CDM Organization>_<unique identifier>_<metadata>.opm

EXAMPLES

As long as the obligatory fields are correctly included within the OPM, the operator may name their file anything they want as long as the first two fields are the CDM Organization and a unique identifier:

- NASA_1234_ISS.opm
- NASA_1235_25544.opm
- NASA_165120000.opm
- NASA_165120001_25544COLA.opm

HOW TO SUBMIT MANEUVER NOTIFICATIONS

How to Submit Maneuver Notifications

OVERVIEW

Maneuver notifications may be submitted in three ways:

1. Through the website Space-Track.org (preferred)
 - 1.1 Manually, or
 - 1.2 Using Application Programming Interface (API)
2. By email to the 18 SPCS Conjunction Assessment Team at 18SPCS.doo.orbitalsafety@us.af.mil. **(This method should only be used in the event the satellite operator cannot access Space-Track.)**

Space-Track.org is the most efficient and secure method of submitting maneuver notifications on a recurring basis. All operators who have access to the Operator Panel will automatically be given permissions to upload maneuver notifications for the satellites assigned to their CDM account. To set up a CDM account or a Maneuver folder, contact the 18 SPCS SSA Sharing Team at 18spcs.doo.customerservice@us.af.mil or +1-805-605-5219.

Once an active CDM account is established, the operator(s) assigned to the account will have access to the Operator and Files Panels:

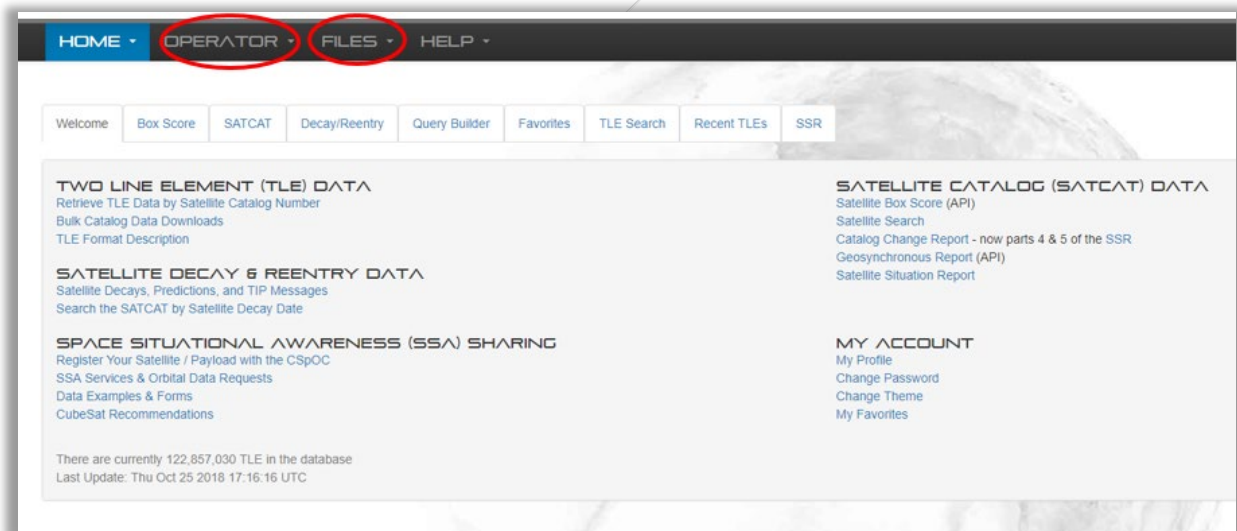


Figure 12: Files Panel on Space-Track.org

HOW TO SUBMIT MANEUVER NOTIFICATIONS

SUBMITTING MANEUVERS NOTIFICATIONS THROUGH SPACE-TRACK.ORG

On the Files Panel, you will have access to the 'Download' and 'Upload' tabs. On the 'Upload' tab you can upload a variety of files to the folders you have permissions to. All of these folders will display in the 'Destination' dropdown menu:

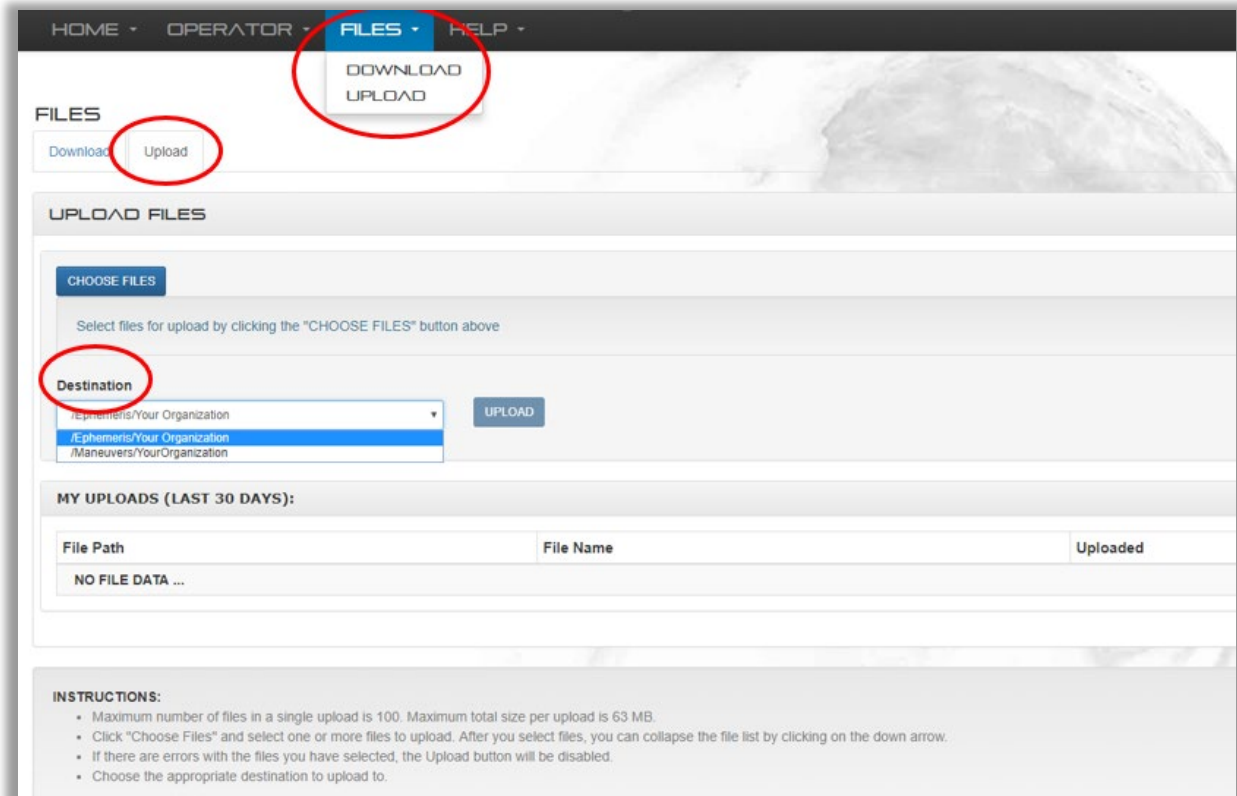


Figure 13: Files Panel Upload Tab - Maneuvers

MANUAL UPLOAD OF MANEUVER NOTIFICATIONS

1. Log in to Space-Track.org, click on 'Files' at the top of the page, and then click on the 'Upload' tab
2. Click 'Choose Files' and select your OPM maneuver notification files
 - 2.1 Maximum number of files in a single upload is 100
 - 2.2 Maximum total size per upload is 60 MB
 - 2.3 Files must be formatted in accordance with 'Maneuver Notification Format'
3. Using the 'Destination' dropdown menu, select the '/Maneuvers/YourOrganization' folder. (Note: To set up a maneuver folder, contact the 18 SPCS SSA Sharing Team at 18SPCS.doo.customerservice@us.af.mil or +1-805-605-5219.)

HOW TO SUBMIT MANEUVER NOTIFICATIONS

4. Click 'Upload' to upload the files.
5. After a successful upload, the files will display in 'My Uploads (Last 30 Days)' Table
6. The 18 SPCS Orbital Safety Crew will receive a notification that you have uploaded new maneuver information.

API UPLOAD OF MANEUVER NOTIFICATIONS

Please visit Space-Track.org's 'API' and 'How To' pages for the most up-to-date guidance (including usage limitations) on API capabilities: <https://www.space-track.org/documentation#/api> and <https://www.spacetrack.org/documentation#/howto>. Similar to manual uploads:

1. Files must be formatted in accordance with 'Maneuver Notification Format'
2. After a successful upload, the files will display in 'My Uploads (Last 30 Days)' Table
3. The 18 SPCS Conjunction Assessment Team will receive a notification that you have provided new maneuver information. However, if the maneuver requires attention as a high-interest event, please phone or email the Conjunction Assessment Team at: +1-805-605-3533 or 18SPCS.doo.orbitalsafety@us.af.mil.

EMAIL

If your organization doesn't have access to the Operator and Files Panels, you may send your maneuver notifications by email to the 18 SPCS Conjunction Assessment Team at 18SPCS.doo.orbitalsafety@us.af.mil. Please:

1. Format the files in accordance with 'Maneuver Notification Format'
2. Send only .opm files - .zip files cannot be accepted. Or,
3. If it's not possible to use the OPM format, maneuver notification may be provided in the body of an email.

Contact Us

18 SPCS CONJUNCTION ASSESSMENT TEAM

For questions on conjunction assessment and collision avoidance support, please contact the 18 SPCS Orbital Safety Crew by email at 18SPCS.doo.orbitalsafety@us.af.mil or by phone at +1-805-605-3533.

Examples of support include:

- Questions about screening results
- Screenings for high-interest events
- Missing CDMs

18 SPCS SSA SHARING TEAM

For questions about specialized SSA support or data products, please contact the 18 SPCS SSA Sharing Team by email at 18SPCS.doo.customerservice@us.af.mil or by phone at +1-805-605-5219. Examples include:

- Submitting an Orbital Data Request for advanced services or support
- Questions about data formats
- Space-Track access and permissions
- Registering your satellite to receive spaceflight safety support
- Access to Space-Track.org's for-testing-only website

SPACE-TRACK.ORG ADMINISTRATION TEAM

For questions about the Space-Track.org website, please contact admin@space-track.org. Examples include:

- API queries
- Automation
- Website performance

ANNEX A: 18 SPCS PROBABILITY OF COLLISION

Annex A: 18 SPCS Probability of Collision

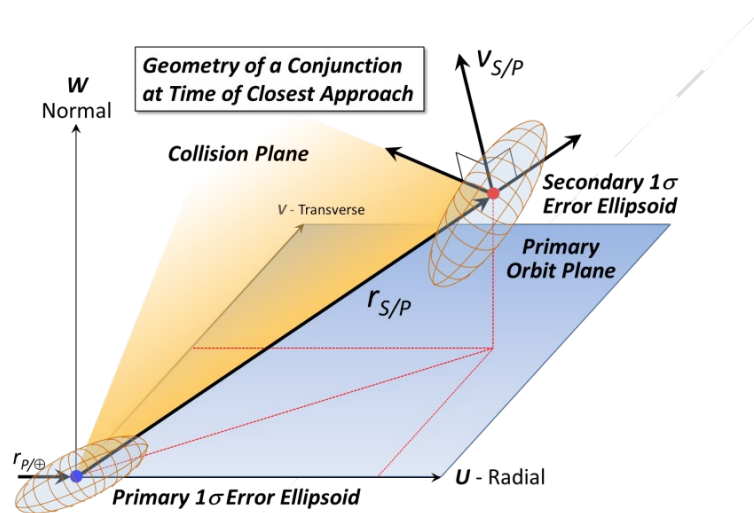


Figure X: Geometry of a Conjunction

HOW 18 SPCS CALCULATES PROBABILITY OF COLLISION

For a conjunction¹ between two objects in earth orbit, the 18th Space Control Squadron (18 SPCS) can compute and report a value commonly referred to as probability of collision (P_c^2). This value can be used by a satellite owner/operator (O/O) as a warning and may motivate further study of the encounter on their part³.

¹ Also referred to as a "close approach"

² Also PoC, POC

³ When an assumption is made in the calculation of P_c , it's made on the side of overestimating the P_c , in other words, being conservative. In this way O/O's are made aware of all potential encounters. The first place where this conservatism appears is in what is actually calculated. What is computed is not probability of collision but rather the probability that two objects are less than a specified distance apart at their time of closest approach (TCA). This is due to several factors, 18 SPCS not knowing the exact size, shape and orientation of both objects at TCA being one of the major ones. So the approach is to determine the longest distance the two satellite's centers of mass can be apart and still have the two satellites touch. This defines the "specified distance apart" that is used in the P_c calculation. Note that if the two satellites are not spheres, then a simple change in orientation means that they may not touch and no collision would occur. So the P_c value calculated always has this factor of conservatism built in.

ANNEX A: 18 SPCS PROBABILITY OF COLLISION

The data at the time of closest approach (TCA) required to compute P_c includes:

- The size of the primary object
- The size of the secondary object
- The inertial position and velocity vectors of the primary object
- The inertial position and velocity vectors of the secondary object
- The 3-dimensional position covariance of the primary object
- The 3-dimensional position covariance of the secondary object

If available and reliable these data items are provided in the Conjunction Data Message (CDM).

OBJECT SIZE

The P_c calculation requires an estimate of the sizes of the primary and secondary objects. Because of a dimensionality reduction of the problem (to be described subsequently), the combined sizes of the two objects ultimately will be represented as an area in a projected plane—the “conjunction plane.” The typical procedure is to circumscribe the primary and secondary objects each by a sphere, add the two sphere radii to generate a supervening sphere that can contain both circumscribing spheres, and project this supervening sphere into the conjunction plane as a circle.

The size of the objects⁴ is called AREA_PC in the CDM and given in square meters. The CDM Blue Book⁵ states:

AREA PC: The actual area of the object (m^2). The area could be known by the owner/operator of the satellite or defined by using a Radar Cross Section (RCS) as in the case of debris. If the value of the area is unknown or not available, “0.0” may be displayed. This parameter can be useful for calculation collision probability.

SuperCOMBO⁶ is used to identify conjunctions in 18 SPCS. It has three modes: standoff radius, ellipsoid, and covariance. P_c is computed in covariance mode. It requires that the sizes of both objects be input by the operator. Size is specified (in meters) by the Radius of Exclusion Volume; as stated

⁴ The primary and secondary objects are referred to as OBJECT1 and OBJECT2 in the CDM.

⁵ Conjunction Data Message Recommended Standard CCSDS 508.0-B-1 BLUE BOOK, June 2013

⁶ Super Computation of Miss Between Orbits. SuperCOMBO is an application program in the Astrodynamics Support Workstation (ASW). It is based on the Air Force Space Command (AFSPC) [Astrodynamics Standards](#) program COMBO.

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above, it represents the minimum radius of a sphere that can contain the object⁷ ⁸. SuperCOMBO can also assign specific values or use an RCS catalog to establish size.

Caution is advised if RCS is used to establish size. For many reasons RCS may not represent the physical size of an object, and certainly not its shape or orientation at TCA.

POSITION AND VELOCITY VECTORS

The position and velocity vectors⁹ of the primary and secondary objects at TCA are given in the CDM in the fields X, Y, Z, X_DOT, Y_DOT, and Z_DOT. Position units are km and velocity units are km/sec. They are normally referenced to the International Terrestrial Reference Frame (ITRF), but other coordinate frames may be specified in accordance with the CDM Blue Book. The velocity vectors are not explicitly used in the computation of Pc. However, they are required in order to establish the point and time of closest approach, to perform needed coordinate transformations/rotations to prepare the data properly for the Pc calculation, and to determine encounter geometry at TCA.

In 18 SPCS the position and velocity of the objects at TCA are normally computed by interpolating between ephemeris points¹⁰. The ephemeris points are obtained by propagating forward in time the object's special perturbations (SP) state vector at epoch¹¹. The state vector at epoch is computed using an orbit determination method based on minimum variance differential correction (DC).

In some cases ephemeris points of an object are provided to 18 SPCS by the satellite owner/operator¹². If so, these are used in lieu of, or in addition to, internal ephemeris.

While not explicitly input to compute Pc, the position and velocity of the secondary relative to the primary at TCA are included in the CDM. They are given in Radial, Transverse, and Normal (RTN)

⁷ If an O/O reports object size to 18 SPCS in m^2 then that should be the area of a circle that completely "covers" the object when viewed from any angle. 18 SPCS would then compute the Radius of Exclusion Volume from this area as (O/O-reported-size divided by π)*0.5.

⁸ Pre-assigned default values for payloads and platforms (5 meters), rocket bodies and unknown objects (3 meters) and debris (1 meter) were determined through a study of sizes of objects in the space object catalog and are normally used. Plans are being developed to allow O/O's to provide a more accurate value of this parameter for use in CA screening in the future.

⁹ Together, often referred to as the state vector

¹⁰ An ephemeris is a time ordered listing of an object's position and velocity vectors (that may include covariance).

¹¹ Or general perturbations (GP) element set (ELSET) in the absence of an SP state vector

¹² In J2000 mean equator mean equinox coordinates

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coordinates of the primary object¹³. Also provided are overall MISS_DISTANCE and RELATIVE_SPEED. Relative position and velocity offer a more intuitive view of the conjunction¹⁴ and tell the user if the secondary is moving fast or slow relative to the primary at TCA.

COVARIANCE AND ERROR ELLIPSOIDS

The covariance matrix, provided separately for the primary and secondary object (as described in Annex C of CCSDS 508.0-B-1), is routinely furnished in 6 x 6 form, even though only the position portion is needed for the Pc calculation as described in this memorandum. A covariance matrix characterizes the uncertainty in a satellite state vector, similar to the way that variance, the square of the standard deviation, is a metric for assessing the spread of student test scores about the mean. An example of a position covariance, using the notation of the CCSDS standard, is given as the symmetric matrix below. The diagonal elements represent the variance in each of the components (R, T, and N), and the off-diagonal terms give the covariance between the two named components (the product of the two components' standard deviations and their correlation coefficient):

$$Cov = \begin{pmatrix} CR_R & CT_R & CN_R \\ CT_R & CT_T & CN_T \\ CN_R & CN_T & CN_N \end{pmatrix}$$

The covariance matrix for each object is referenced to its own RTN coordinate frame. For each object matrix components are computed using 5-point Lagrange interpolation of the covariance in the ephemeris file produced by the 18 SPCS¹⁵.

An owner/operator may also send 18 SPCS an ephemeris that includes covariance¹⁶. In these cases the covariance values in the CDM are interpolated from the ephemeris (with covariance) provided by the owner/operator.

¹³ Also called the Radial-Intrack-Crosstrack (RIC) coordinate frame or the UVW system

¹⁴ For example, at TCA the secondary relative to the primary is at "eleven o'clock high."

¹⁵ Covariance at TCA quantifies uncertainty in the state vector at TCA. Covariance at epoch quantifies uncertainty at epoch. Covariance at epoch in essence maps the observed-minus-computed residuals in the observations used in the DC to the uncertainty in the state vector produced by the DC.

¹⁶ Owner/operators provide ephemeris with covariance in three formats: (1) the Generic On-Orbit (GOO) (2) Modified ITC, or Orbital Ephemeris Message (OEM)

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The one-standard-deviation¹⁷ three dimensional (3D) error ellipsoid may be used to visualize the “size” of the position uncertainty at TCA. Diagonalization of the 3 x 3 covariance matrix yields the size, shape, and orientation of the error ellipsoid¹⁸. Often, because of drag, the largest uncertainty will be in the direction of the satellite’s motion relative to the atmosphere¹⁹.

ASSUMPTIONS

When computing P_c at 18 SPCS several assumptions are made. These include:

- Object sizes are known or can otherwise be assigned an upper bound.
- The conjunction is “hyperkinetic, meaning that the conjunction duration is very short; this allows the additional simplifying assumption that the relative motion between objects is rectilinear throughout the encounter.
- Gaussian theory and statistics apply.
- Covariance for both objects is known and constant throughout the encounter.
- Primary and secondary errors are independent allowing “combined” covariance to be the simple sum of the individual covariances (in a common frame), resulting in the “joint” covariance.
- The covariance is not “too large.”
- The covariance is not “too small²⁰.”

Technical papers have been written to address the computation and/or validity of P_c when one or more of these assumptions come into question. If at TCA (1) covariance is too small, (2) covariance is too large, or (3) the relative speed of the secondary relative to the primary is too small, then P_c is not computed in SuperCOMBO. The values for covariance “too large” and relative speed “too small” are user-settable.

Another concern is covariance realism: does the covariance used in the computation of P_c truly reflect the uncertainty in the state vectors at TCA? Because quantitative studies have shown that covariance is often underestimated, empirical techniques have been devised to scale or otherwise inflate the covariance – make it larger – to compensate for the underestimation.

¹⁷ 1 sigma or 1σ

¹⁸ The square root of each of the eigenvalues of the covariance matrix gives the sizes of the ellipsoid axes. The eigenvectors provide the orientation of the ellipsoid axes relative to the object’s RTN coordinate frame.

¹⁹ A very rough estimate of the sizes of the three axes of the error ellipsoid can be obtained by taking the square root of each of the diagonal elements CR_R, CT_T, and CN_N.

²⁰ This test is needed to trap zero covariance.

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COMPUTATION

Computation of P_c takes place in the collision plane²¹. This is the plane perpendicular to the relative velocity vector at TCA. This reduces the mathematics from 3D to 2D, and the kinematics from dynamic to static. In 2D the equation used to compute P_c is:

$$PoC = \frac{1}{2\pi |Det(C)|^{1/2}} \iint_{x^2+y^2 \leq d^2} \exp\left(-\frac{1}{2}(\mathbf{r} - \mathbf{r}_{S/P})^T C^{-1}(\mathbf{r} - \mathbf{r}_{S/P})\right) dx dy$$

In this double integral equation:

- $\pi = 3.141592653589793$.
- C is the 2X2 projection of the combined 3X3 covariance at TCA onto the collision plane²².
- $Det(C)$ is the determinant of C .
- d is the sum of the two object sizes²³.
- “exp” is the exponential function, i.e., e to the power in parentheses with $e = 2.718281828459045$.
- $\mathbf{r} = (x, y)^T$ is any point in the collision plane such that $x^2 + y^2 \leq d^2$.
- $\mathbf{r}_{S/P} = (r_{S/P}, 0)^T$ is the position of the secondary relative to the primary along the x-axis in the collision plane.
- C^{-1} is the inverse of C .

This equation integrates the 2D Gaussian probability density function (centered on the secondary object) over the circle of radius d (centered on the primary object²⁴).

²¹ Also called the encounter plane

²² The combined covariance is the sum of the covariance matrices corresponding to each object (both referenced to the same coordinate frame). The applicability of Gaussian statistics allows for combining two covariance matrices into one using term-by-term summation.

²³ The sum of the radii of exclusion volumes for the two objects

²⁴ With the primary object located at the origin of a 2D coordinate frame in the collision plane

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Methodologies, coordinate transformations, assumptions, combining Gaussian distributions, limitations, and techniques used to facilitate computation of P_c are discussed at length in technical papers listed in the bibliography²⁵.

NOTES

18 SPCS uses error functions (ERF) for computing the double integration in the P_c equation. In addition 18 SPCS performs integration over a square circumscribing the circle of radius d . This square is aligned with the axes of the combined 2D probability density function in the collision plane. This simplifies the computation of P_c but gives a very slightly larger – but safe – value.

For these and other reasons agencies may compute slightly different values for P_c for the same conjunction. If the difference is large however further investigation is warranted²⁶.

BIBLIOGRAPHY

Several excellent references for understanding the computation of P_c are listed at the Space Assigned Number Authority (SANA) registry at http://sanaregistry.org/r/cdm_cpm/cdm_cpm.html.

In addition the following references are valuable because in the 1990s Doctor Foster matured much of the theory and methodology used by NASA to compute P_c for Space Shuttle and International Space Station (ISS) safety of flight analysis. A version of the NASA algorithm for computing P_c was integrated into the ASW program SuperCOMBO in 2000. Certain theoretical issues were modified and expanded

²⁵ The computation of P_c is a dynamic 3D problem: the two objects are moving in 3-dimensions. However, it can be simplified by reducing the dynamic 3D problem to a static 2D problem. This is accomplished by performing calculations in the 2D collision plane. Consider the two error ellipsoids of the primary and the secondary objects at the instant of TCA as they “punch holes” in the collision plane that’s perpendicular to the relative velocity vector. The problem of computing P_c immediately collapses to a static 2D problem in the collision plane. The ellipsoids become ellipses in the collision plane representing the 1σ “contour lines” of the two-dimensional Gaussian probability density functions (pdf) of the objects. One can think of the 2D Gaussian (“bell-shaped”) probability density functions for the primary and the secondary as being “little hills” sitting over their respective satellite positions at TCA in the collision plane. In effect, the ellipse for one object is but one of many nested “Russian Doll” contour lines going out to infinity in the 2D collision plane for the Gaussian pdf, just as in 3D the error ellipsoid is but one of an infinite number of nested Russian dolls. These two “little hills” combine into one hill – one pdf – centered over the secondary for the actual computation of the P_c .

²⁶ In 2000 AFSPC/A9 numerically validated the computation of P_c in SuperCOMBO.

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by F.C. Chan in his important monograph *Spacecraft Collision Probability* (El Segundo, CA: Aerospace Press, 2008).

Foster, J.L., and Frisbee, J.H., *Comparison of the Exclusion Volume and Probability Threshold Methods for Debris Avoidance for the STS Orbiter and International Space Station*. NASA /TP-2007-214751. Houston, Texas: NASA Johnson Space Flight Center, May 2007 (written in October 1999).

Foster, J.L., and Wortham, M.B., *ISS Debris Avoidance Maneuver Threshold Analysis*. NASA /TP-2007-214752. Houston, Texas: NASA Johnson Space Flight Center, May 2007 (written in October 1999).

Foster, J.L., *The Analytic Basis for Debris Avoidance Operations for the International Space Station*. Proceedings of the Third European Conference on Space Debris, p. 441-445, Darmstadt, Germany, 19 - 21 March 2001.

ANNEX B: FREQUENTLY ASKED QUESTIONS

Annex B: Frequently Asked Questions

1. HOW AND WHEN DO I SIGN UP FOR CONJUNCTION ASSESSMENT (CA) ALERTS?

First, register for a user account on Space-Track.org. Then fill out a satellite registration form and send it to 18SPCS.DOO.CustomerService@us.af.mil. We will set up a CDM account for your organization that helps us route alerts to the right people. You can do this at any time, whether you have a satellite on orbit, or are waiting for the satellite to be launched. We recommend contacting us a few weeks prior to launch.

2. DO I NEED TO SUBMIT AN ORBITAL DATA REQUEST FOR CA SERVICES?

You do not need to submit an ODR for basic CA services. ODRs are only required for advanced services.

3. IS THERE A CHARGE FOR 18 SPCS SPACEFLIGHT SAFETY SERVICES?

All of our services are provided at no cost to the owners and operators (O/Os) of active spacecraft.

4. MY SATELLITE HAS A PREDICTED CONJUNCTION WITH ANOTHER ACTIVE SATELLITE, HOW CAN I CONTACT THE OTHER OPERATOR?

If the other O/O has chosen to share their contact information with other O/Os on Space-Track.org, you can find it on the Directory Tab of the Operator Panel. 18 SPCS highly encourages all O/Os to share their contact information with other O/Os. If it's not available there, you can contact 18 SPCS, but it will likely take extra time as we will ask to receive their permission before we give you their contact information.

5. I HAVEN'T RECEIVED ANY CONJUNCTION DATA IN A WHILE, IS SOMETHING WRONG?

This likely indicates that 18 SPCS has not predicted any conjunction events that meet reportable criteria. (Reference Tables 5 and 6.) You may contact the Conjunction Assessment Team at 18SPCS.doo.orbitalsafety@us.af.mil to confirm.

6. WHY IS ANOTHER GROUP RECEIVING CONJUNCTION DATA FOR OUR CO-OWNED SATELLITE WHEN MY GROUP HAS NOT RECEIVED ANY?

The other group likely has advanced CA services while yours are at the basic level, so they will have access to more data. To confirm, contact the 18 SPCS SSA Sharing Team at 18SPCS.doo.customerservice@us.af.mil.

7. HOW CAN I SUBMIT PREDICTED EPHEMERIS FOR SCREENING? WHAT ABOUT PREDICTED MANEUVER INFORMATION?

Contact 18SPCS.DOO.CustomerService@us.af.mil, and we'll set up folders on Space-Track.org where you can upload your predicted ephemeris and maneuver files. You can specify who should have access to the folder.

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8. I NEED TO HAVE LARGER THAN NORMAL SCREENINGS FOR MY SATELLITE. WHAT CAN 18 SPCS DO?

If you have a valid SSA Sharing Agreement with USSPACECOM, you may submit an Orbital Data Request (ODR) form to request advanced CA services. For more information, on pursuing an SSA Sharing Agreement contact stratcom.offutt.j51.mbx.j513@mail.mil. For more information on how to submit an ODR contact 18SPCS.doo.ssasharing@us.af.mil.

9. CAN I CHANGE THE CONTACTS IN MY SPACE-TRACK.ORG ORGANIZATION/CDM ACCOUNT?

Primary Representatives (PR) for the account can make the changes. If you don't have a PR or need to add/change one, contact us at 18SPCS.DOO.CustomerService@us.af.mil for assistance.

10. WHAT DOES IT MEAN WHEN AN OBJECT IN THE CDM HAS A NUMBER IN THE 80000'S?

A satellite number from 80,000-89,999 indicates that it is an "analyst object." These are on-orbit objects that are tracked by the U.S. Space Surveillance Network (SSN) but with insufficient fidelity for publication in the public satellite catalog (SATCAT).

11. WHAT DOES IT MEAN WHEN AN OBJECT IN THE CDM HAS A NUMBER IN THE 799500000'S?

A satellite number from 799500000-799999999 is a temporary number that 18 SPCS has assigned to a newly launched satellite. This allows the O/O of the satellite to submit ephemeris and receive CDM results prior to the satellite being entered into the public catalog and assigned a 5-digit number.

12. Can the 18 SPCS analyze my data, make recommendations, or help me choose a plan of action?

We are legally prohibited from performing analysis or making recommendations, but we will provide you with the best possible data to assist in your decision making.

13. IF I SUBMIT AN ORBITAL DATA REQUEST FOR ADVANCED CA SERVICES, CAN I PICK WHICH SCREENING VOLUME I WOULD LIKE?

No, you will receive the screening volume for the orbital regime that your satellite is operating in, in accordance with Table 3. If this changes due to orbit raising or deorbiting, 18 SPCS may adjust the screening volume.

14. I HAVE QUESTIONS, IS THERE SOMEONE I CAN TALK TO?

Contact the 18 SPCS SSA Sharing Team at 18SPCS.doo.customerservice@us.af.mil or +1-805-605-5219.