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SPACEFLIGHT SAFETY HANDBOOK FOR SATELLITE OPERATORS

VERSION 1.7 ◆APRIL 2023

18 & 19 SDS Processes for On-Orbit Conjunction Assessment & Collision Avoidance

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1.1	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	1. Definitions of ellipsoid and covariance screenings, pg. 5-6	27 Aug 16
1.3	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	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
1.5	1. Replaced all references to USSTRATCOM and JFSCC with USSPACECOM and CFSCC as needed 2. Replaced references to Orbital Safety Crew with Conjunction Assessment Team as needed 3. Changed reference to launch support and early orbit determination to Launch Early Orbit Protection pg. 2 4. Provided various edits for cleaner communication as needed 5. Replaced UVW references to include the interchangeable value of RTN/UVW 6. Replaced references to "Day of Year" to Julian Day 7. Changed ephemeris time formats to reflect "JJJ" 8. Replaced "OEM" ephemeris format examples lost in previous version 9. Added additional guidance for "OEM" format regarding reference frame annotations 10. Added clarification for submitting ephemeris via email pg. 24 11. Added clarification for Space-track username pg. 24 12. Re-formatted tables pg. 28-31	Aug 20

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1.6	1. Replaced 18 SPCS Patch on Front Page 2. Removed instances of SSA Sharing phone number 3. Removed instances of HAC 1-v-1 on demand as a supported service pg. 7 4. Removed 18 SPCS co-location with CSpOC pg. 3 5. Replaced all references to Vandenberg Air Force Base to Vandenberg Space Force Space 6. Corrected Table 6: Advanced Reporting Criteria for a CDM generated for Near Earth (LEO 1-4) O/O Ephemeris screening to 2km x 25km x 25km pg. 10 7. Removed Phone Call criteria from Tables 5 and 6 pg. 10 8. Added paragraph describing propagation time constraints for ephemeris-based screenings pg. 15 9. Removed mention of using UCN/UCD as acceptable options for ephemeris file naming pg. 23 10. Clarified that e-mailing ephemeris should be utilized for urgent situations and not for nominal operations pg. 25 11. Adjusted maximum total size for Space-Track uploads to 200 MB pg. 26/35 12. Changed instance of operators who have access to the Operator panel 'will automatically be given permissions' to 'may be given permissions' pg. 34 13. Clarified that e-mailing a maneuver notification should be utilized for urgent situations and not for nominal operations pg. 36 14. Added Annex C: 18 SPCS CDM Fields Explained pg. 47	Apr 22
1.7	1. Updated 18 SDS patch & added 19 SDS patch on front page 2. Updated 18 SDS and 19 SDS unit responsibilities throughout handbook 3. Updated email addresses and phone numbers throughout handbook 4. Updated "SSA Sharing Team" to "SDA Partnership and Coalition Engagement (SPACE) Office" 5. Included O/O Ephemeris vs HAC details 6. Updated tasking criteria 7. Updated Conjunction Assessment screening workflow and timeline 8. Updated 19 SDS Conjunction Assessment contact information 9. Adjusted maximum total size for Space-Track uploads to 512 MB. Included note to check "Help" tab for regular updates to maximum upload size	Apr 23

USSPACECOM SSA Sharing Program

PROGRAM DESCRIPTION

The Unites 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 SDA 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, the 18th Space Defense Squadron (18 SDS) 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 SDS 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, or CSpOC as of July 2018) until July 2016, at which time 18 SDS was activated and assumed all space surveillance functions. In 2022, 19 SDS was activated and assumed the mission of performing Conjunction Assessment to include on-orbit CA and collision avoidance (COLA) functions, as well as launch conjunction assessment and collision avoidance (LCA or LCOLA). 18 SDS still provides the support needed through the lifetime of a satellite from pre-launch preparation to end-of-life disposal, including pre-launch support and early orbit determination, anomaly support, end-of-life and disposal support, deorbit support, and reentry assessment. 18 SDS is still responsible for all functions related to Human Spaceflight Safety and NASA CARA, including Human Spaceflight Safety launch conjunction assessment (HSF LCA). 19 SDS is currently located at Dahlgren Naval Base, Virginia. 18 SDS is currently located at Vandenberg Space Force Base. Both units support the mission of performing space surveillance, maintaining the space catalog, and providing foundational SDA and 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. It is managed and populated by 18 SDS and 19 SDS. 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 to access the full scope of SSA data and services available through the SSA Sharing Program.

Conjunction Assessment Process

ON-ORBIT CONJUNCTION ASSESSMENT (CA)

The 19 SDS Conjunction Assessment (CA) process identifies close approaches between all resident space objects (RSOs) in the 18 SDS 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 SDS 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 SDS High Accuracy Catalog (HAC). The 19 SDS 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.).

19 SDS 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

19 SDS 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.

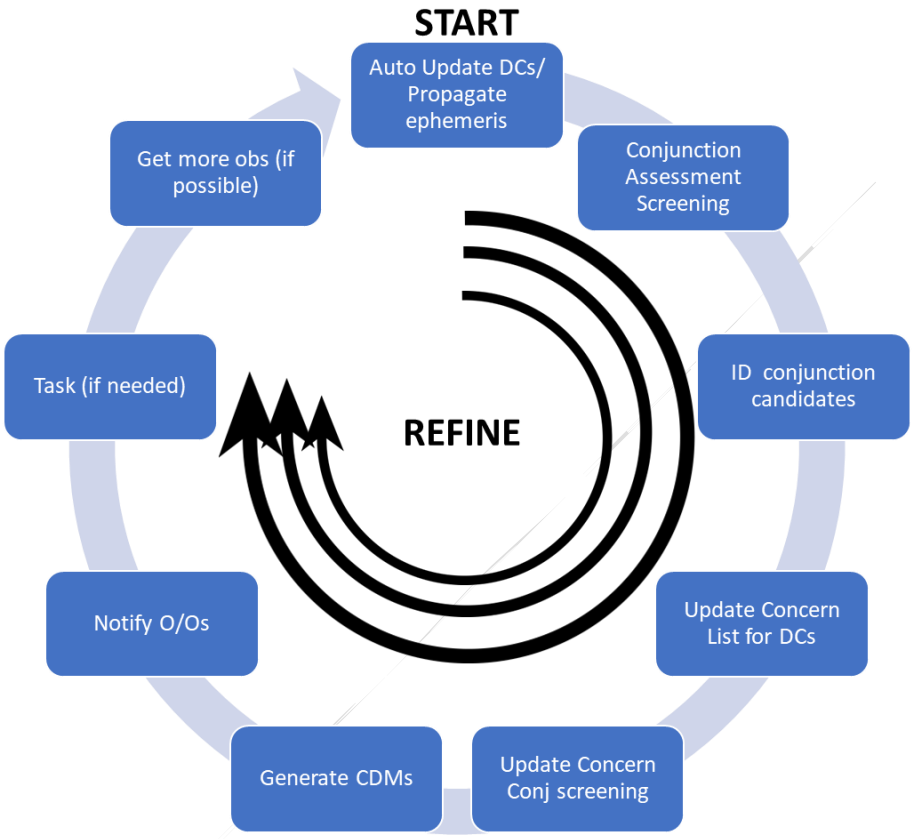


Figure 1: Conjunction Assessment Screening Process

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, 19 SDS performs a conjunction assessment screening of RSOs against the rest of the catalog to identify conjunctions within screening criteria. These objects are evaluated by the Conjunction Assessment Team to ensure that the most current observations are incorporated into the OD, if not they are placed on a "Concern List" for manual Differential Correction updates. If the parameters of the conjunction fall within criteria that identify a close approach and the close approach involves an active satellite, the 19 SDS will notify the O/O of the active satellite(s) in accordance the methods listed in Reporting Criteria. Based on these results, 19 SDS also generates Concern Lists to use in follow-on

screenings. Concern Lists include all candidates that produce conjunctions with probability of collision (Pc) ≥ e^-7 in NE and miss distance ≤ 5km in DS. Throughout this cycle, 18 SDS is always performing DCs and refining orbital states. Depending on the quality of the OD, 19 SDS works with 18 SDS to increase sensor tasking on the primary or secondary objects. A tasking list is sent back to 18 SDS for integration into their tasking process. HAC vs HAC screenings include:

1. NE All HAC: All NE objects vs all NE objects, based on 18 SDS SP data (NE is defined as Period ≤ 225 minutes)
2. DS All HAC: All DS objects vs all DS objects, based on 18 SDS SP data (DS is defined as period ≥ 225 minutes)
3. NE Concern List HAC: Screening of all conjunction pairs identified in NE All HAC screening with Pc ≥ e^-7 and the time of closest approach (TCA) ≤ 5 days
4. DS Concern List HAC: Screening of all conjunction pairs identified in DS All HAC screening with overall miss distance ≤ 5km, and the time of closest approach (TCA) ≤ 5 days

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

All O/O's may submit predictive ephemeris to the 19 SDS 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, 19 SDS assumes these will occur; otherwise, the files should be submitted as Special. Operational files will be screened according to the schedule in Tables 1 and 2. Please note for O/O EPH vs HAC screenings, O/O ephemeris is screened only once within 8 hours of the time the O/O uploaded that ephemeris to Space-Track. A **Special** file represents where the satellite is planning 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 19 SDS 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. Please note, this is only applicable to O/O EPH vs. O/O EPH screenings—

CONJUNCTION ASSESSMENT PROCESS

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 to perform collision avoidance by maneuvering their satellite. If the O/O decides to consider COLA actions, they may send 19 SDS their predictive ephemeris data (in approved formats and coordinate systems) which 19 SDS will then screen against the HAC and provide results within reporting criteria so that the O/O may decide how to proceed. This exchange of data may continue until the time of closest approach (TCA), after which 19 SDS will resume routine screening of the active satellite in accordance with the screening schedule. If they do not perform COLA, 19 SDS will continue to monitor the conjunction and provide updates based on data from the SSN until the TCA has passed.

BASIC EMERGENCY CA AND COLA SERVICES

19 SDS performs CA and provides COLA support for all satellite operators of active spacecraft as an 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

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:

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. Access to propagated SP ephemeris (without covariance) for all RSOs in the unclassified space catalog
6. Access to SP state vectors (without covariance) for all objects in the unclassified catalog

7. Access to propagated SP ephemeris (without covariance) for all objects in the unclassified catalog

SCREENING SCHEDULE

19 SDS 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 followed by two Concern List screenings, 8 hours apart, every 24 hours.) For O/O Ephemeris screenings, the ephemeris file name dictates how 19 SDS will process files. If the O/O designates it as **Special,** the 19 SDS will process it as high-interest and screen it as soon as possible. If it is designated as **Operational,** the 19 SDS 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 19 SDS screening schedule shifts one hour when the state of Virginia (United States) transitions between Eastern Standard Time (EST) and Eastern Daylight Time (EDT), which generally occurs in March and November each year. Both schedules are provided below:

TABLE 1: EST SCREENING SCHEDULE (24-HOUR CYCLE)

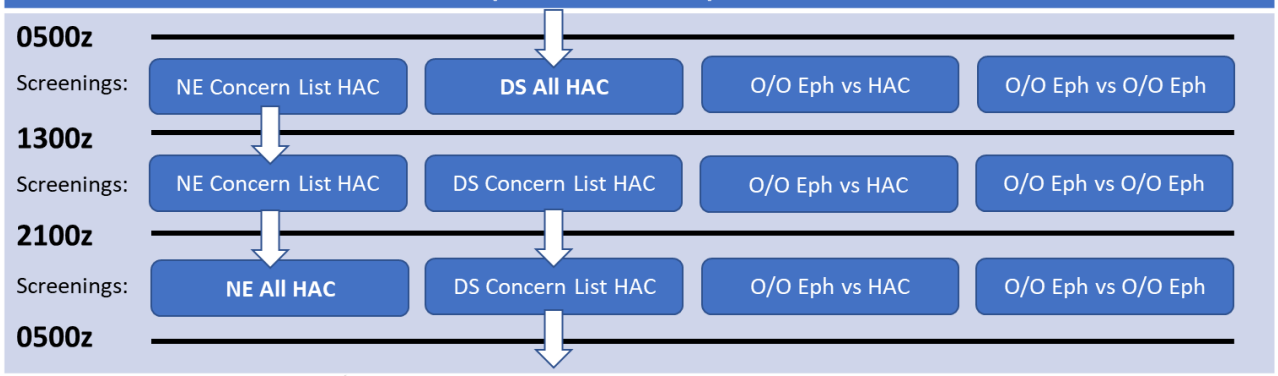
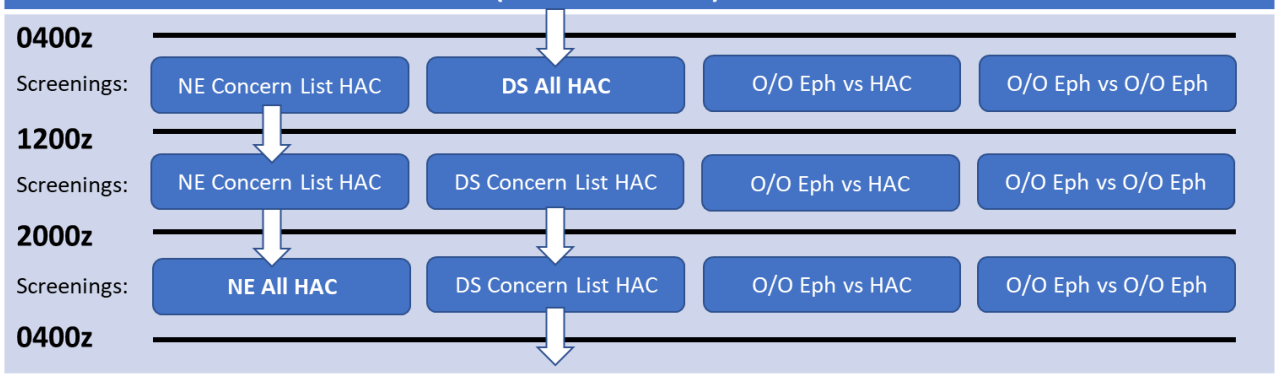


TABLE 2: EDT SCREENING SCHEDULE (24-HOUR CYCLE)



SCREENING VOLUMES

The following tables define the screening volumes and durations 19 SDS uses for basic CA, advanced CA, and ephemeris screenings. 19 SDS 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 (Pc) 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 19 SDS 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 < 35º	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

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
Notification Method	**Conjunction Data Message (CDM)**	**Conjunction Data Message (CDM) & Close Approach Notification (CAN) email**
Deep Space HAC	TCA ≤ 10 days and Overall miss ≤ 5km	TCA ≤ 3 days and Overall miss ≤ 5km
Deep Space O/O Ephemeris	TCA ≤ 10 days and Overall miss ≤ 5km	TCA ≤ 3 days and Overall miss ≤ 5km
Near Earth: HAC	TCA ≤ 3 days and Overall miss ≤ 1km and Probability of Collision ≥ e^-7	TCA ≤ 3 days, Overall miss ≤ 1km and Probability of Collision ≥ e^-4
Near Earth O/O Ephemeris	TCA ≤ 3 days and Overall miss ≤ 1km and Probability of Collision ≥ e^-7	TCA ≤ 3 days and Overall miss ≤ 1km and Probability of Collision ≥ e^-4

TABLE 6: ADVANCED REPORTING CRITERIA

	Space-Track Criteria	Emergency Criteria
Notification Method	**Conjunction Data Message (CDM)**	**Conjunction Data Message (CDM) & Close Approach Notification (CAN) email**
Deep Space, HAC	TCA ≤ 10 days and all results w/in 10km x 10km x 10km	TCA ≤ 3 days and Overall miss ≤ 5km
Deep Space O/O Ephemeris	TCA ≤ 10 days and all results w/in 20km x 20km x 20km	TCA ≤ 3 days and Overall miss ≤ 5km
Near Earth (LEO 1-4) **HAC**	TCA ≤ 5 days and Probability of Collision ≥ e^-7	TCA ≤ 3 days, Overall miss ≤ 1km and Probability of Collision ≥ e^-4
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

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 website based on files that the 19 SDS Conjunction Assessment Crew has 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). These notifications are only sent to email addresses that the O/O has designated to receive CANs on their Space-Track account. (Contact 18 SDS SPACE Office – 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 SDS 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.
- 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.

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.

BASIC EMERGENCY CA NOTIFICATIONS

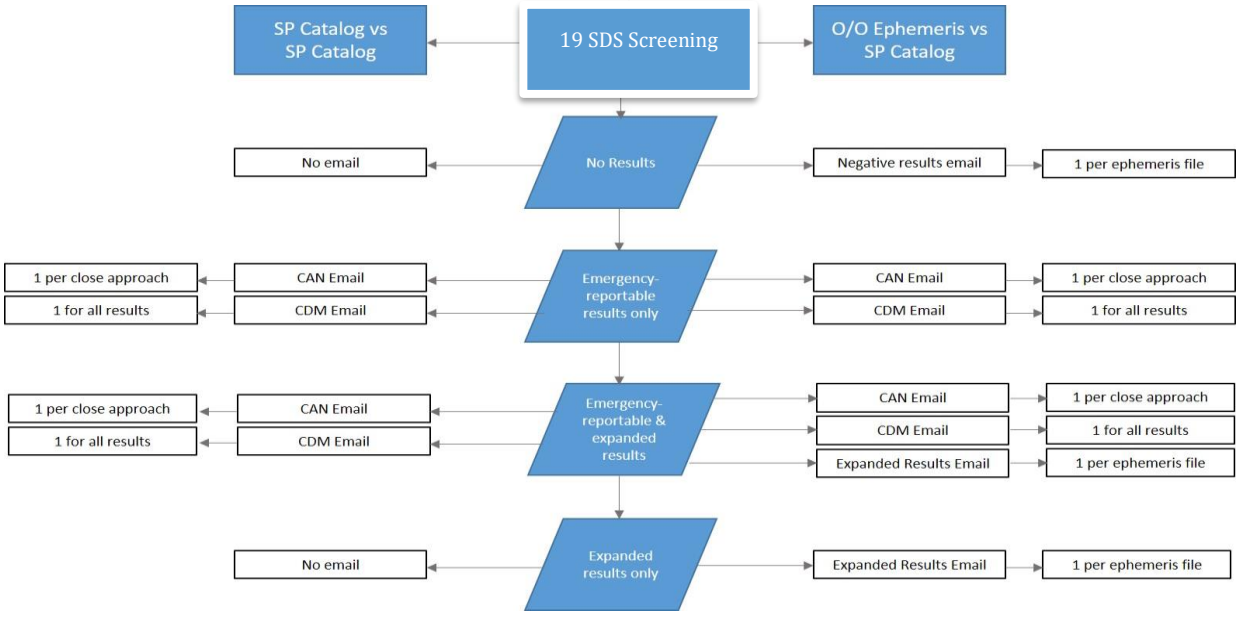


Figure 2: Basic Emergency CA Notifications

CONJUNCTION ASSESSMENT PROCESS

ADVANCED CA NOTIFICATIONS

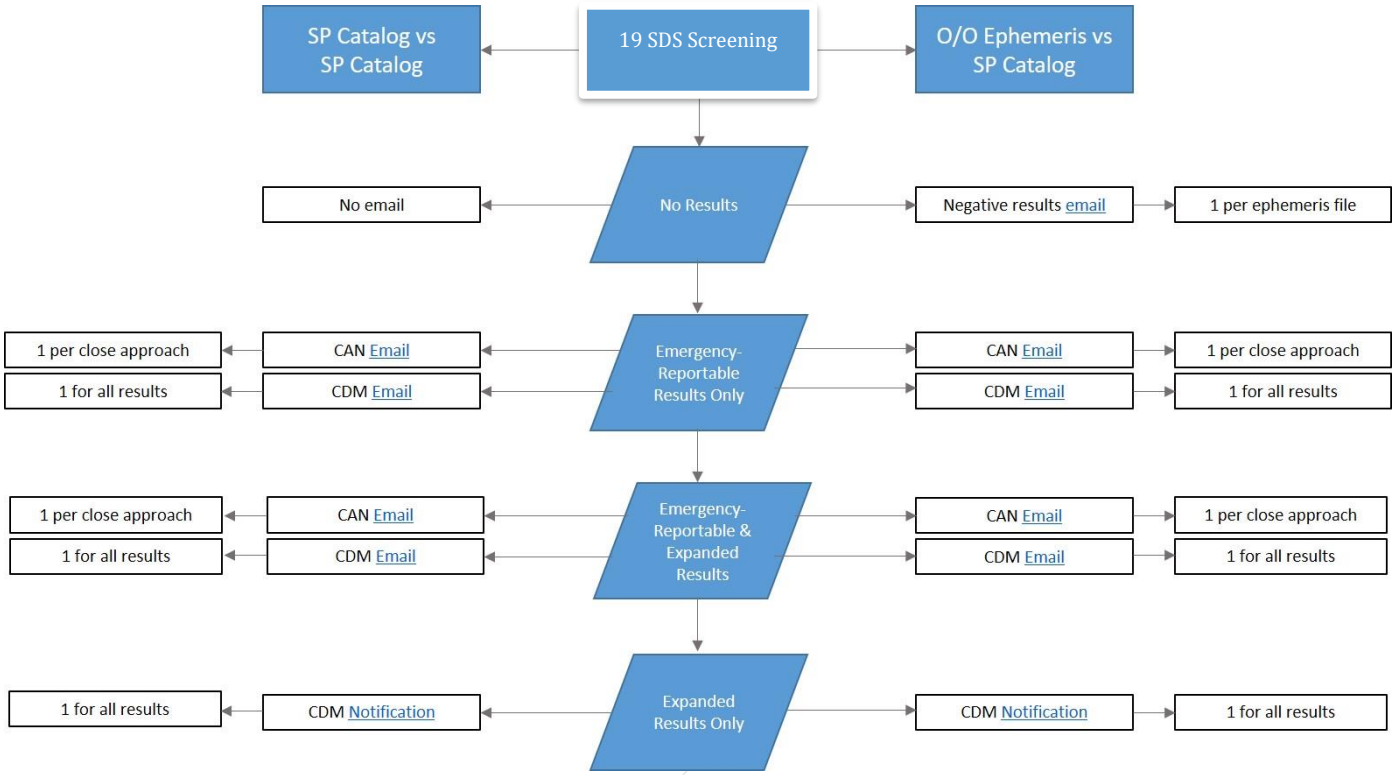


Figure 3: Advanced CA Notifications

LAUNCH CONJUNCTION ASSESSMENT

19 SDS 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, 19 SDS 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. 19 SDS 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**. 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

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 SDS 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, 19 SDS can provide CA screenings, and 18 SDS can 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 SDS 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

CONJUNCTION ASSESSMENT PROCESS

TASKING

In certain situations, more observations on an object will improve the quality of the conjunction prediction. If an object meets any of the following criteria, 18 SDS will automatically increase the tasking priority and revisit frequency assigned to sensors. 19 SDS has embedded this in the routine screening cycle, as seen in Figure 1. We are not able to increase tasking upon demand:

- Less than 20 observations in current Differential Correction (DC), or
- Most recent observation is over three days old, or
- At least one component of covariance over 100,000 m^2

Ephemeris Formats

OVERVIEW

Satellite operators may provide ephemeris in various formats, which will be converted into formats that can be processed by 19 SDS' ASW (Astrodynamics Support Workstation). Using the Super Computation of Miss Between Orbits *(*COMBO) software, 19 SDS 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.

19 SDS' 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 19 SDS mission system corrects for leap seconds.

For any screening utilizing ephemeris, 19 SDS will only propagate out 7 days in advance for Near Earth ephemeris and 10 days in advance for Deep Space. This propagation is from the moment the screening commences from 19 SDS. Any ephemeris that is delivered with a starting time and date outside of the propagation will not be screened.

The NASA and UTC formats include position and velocity only. 19 SDS 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, https://public.ccsds.org/default.aspx) website for more information on the OEM.

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, dy) values.

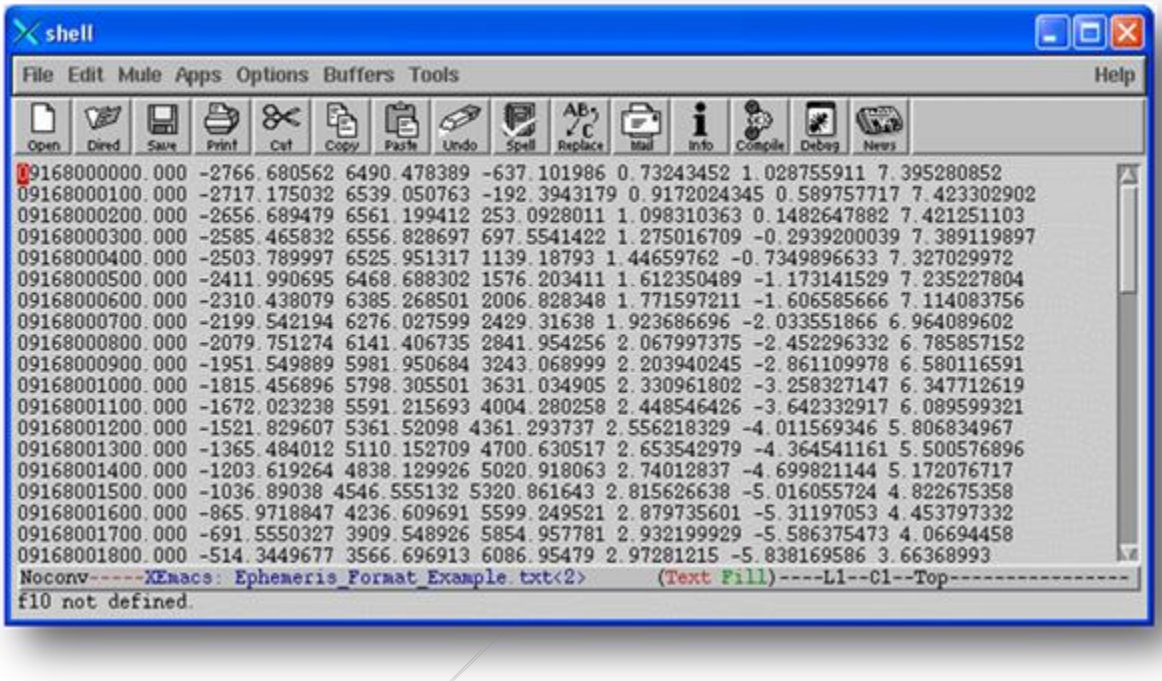


Figure 4: NASA Ephemeris Format Example

19 SDS' 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.

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, dy) values.

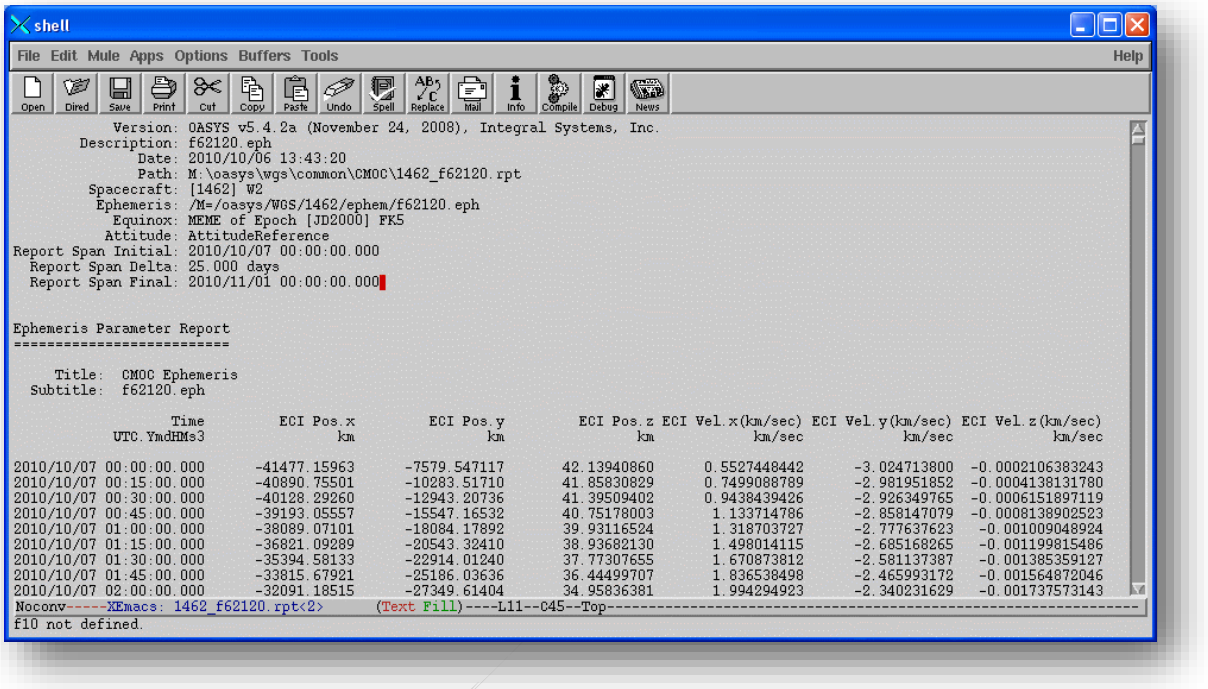


Figure 5: UTC Ephemeris Format Example

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, considering any adjustment needed for a leap year.

This ephemeris format does not include covariance values.

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.

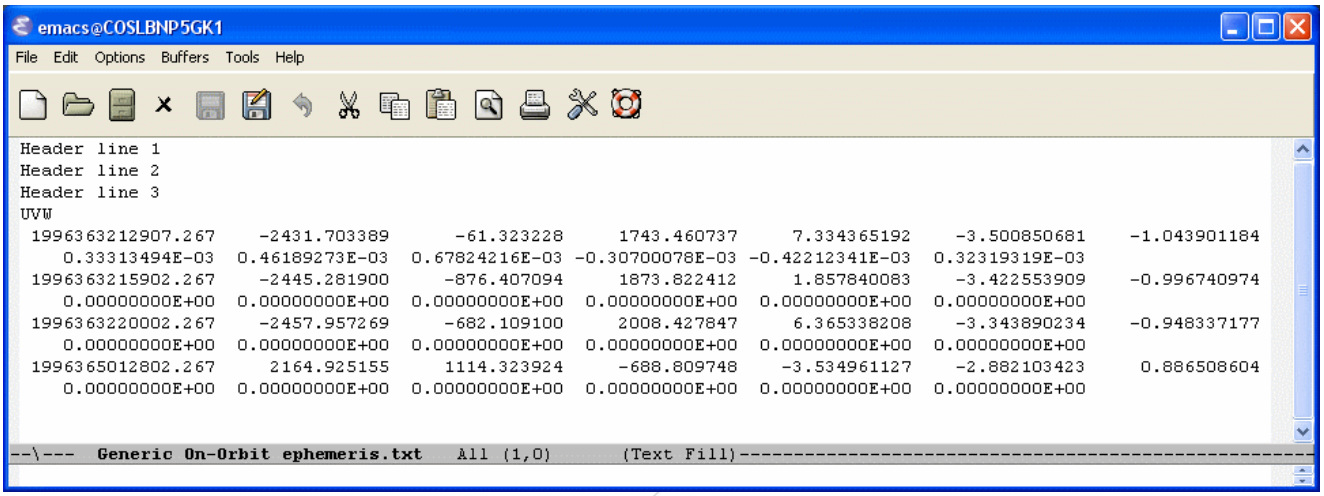


Figure 6: Generic On-Orbit Data Example

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.

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 6x6 lower triangular position and velocity covariance matrix.

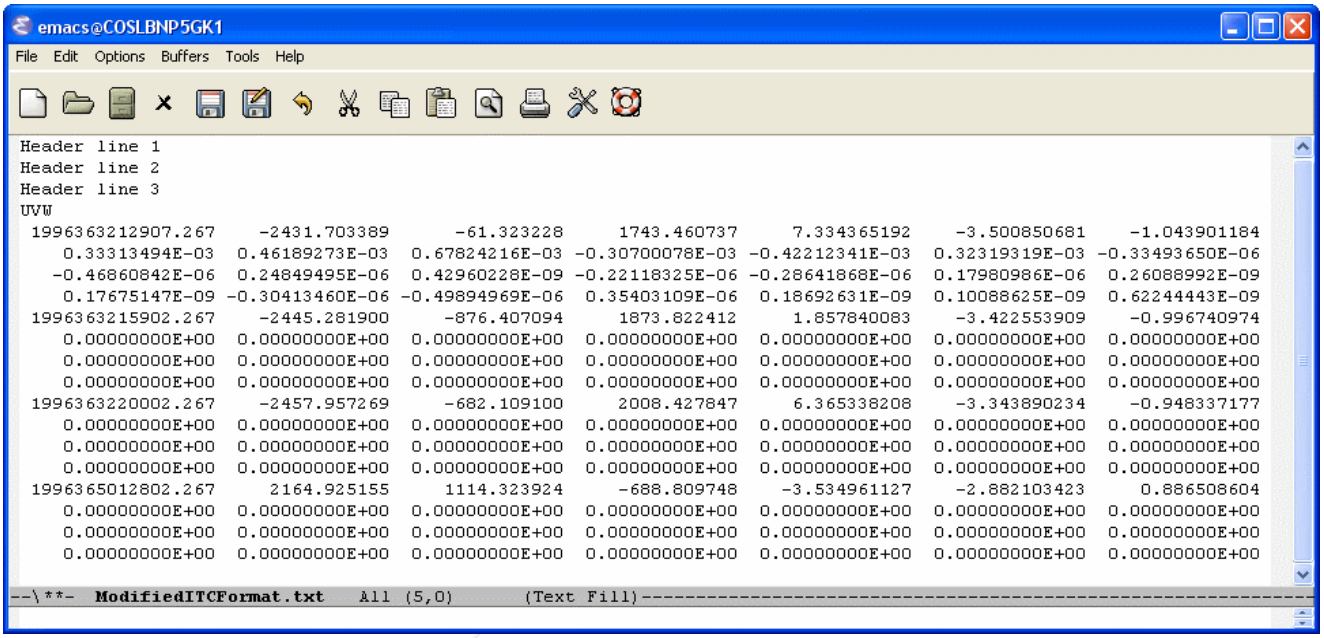


Figure 7: Modified ITC Data Example

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.

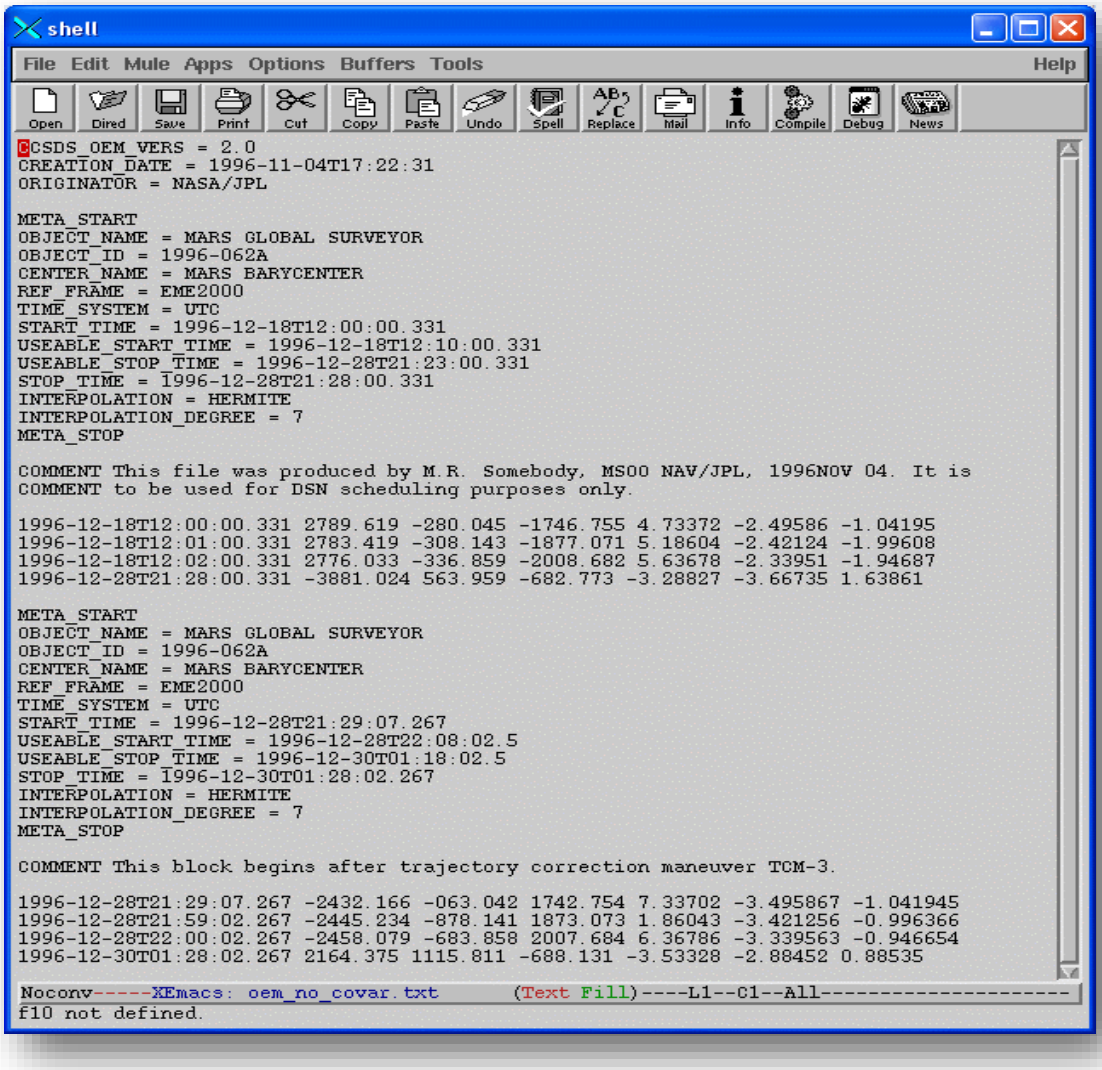
The combined date/time field is separated into year, Day of Year, hour, minute, and second values.

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.

Figure 8: OEM (without covariance) Example



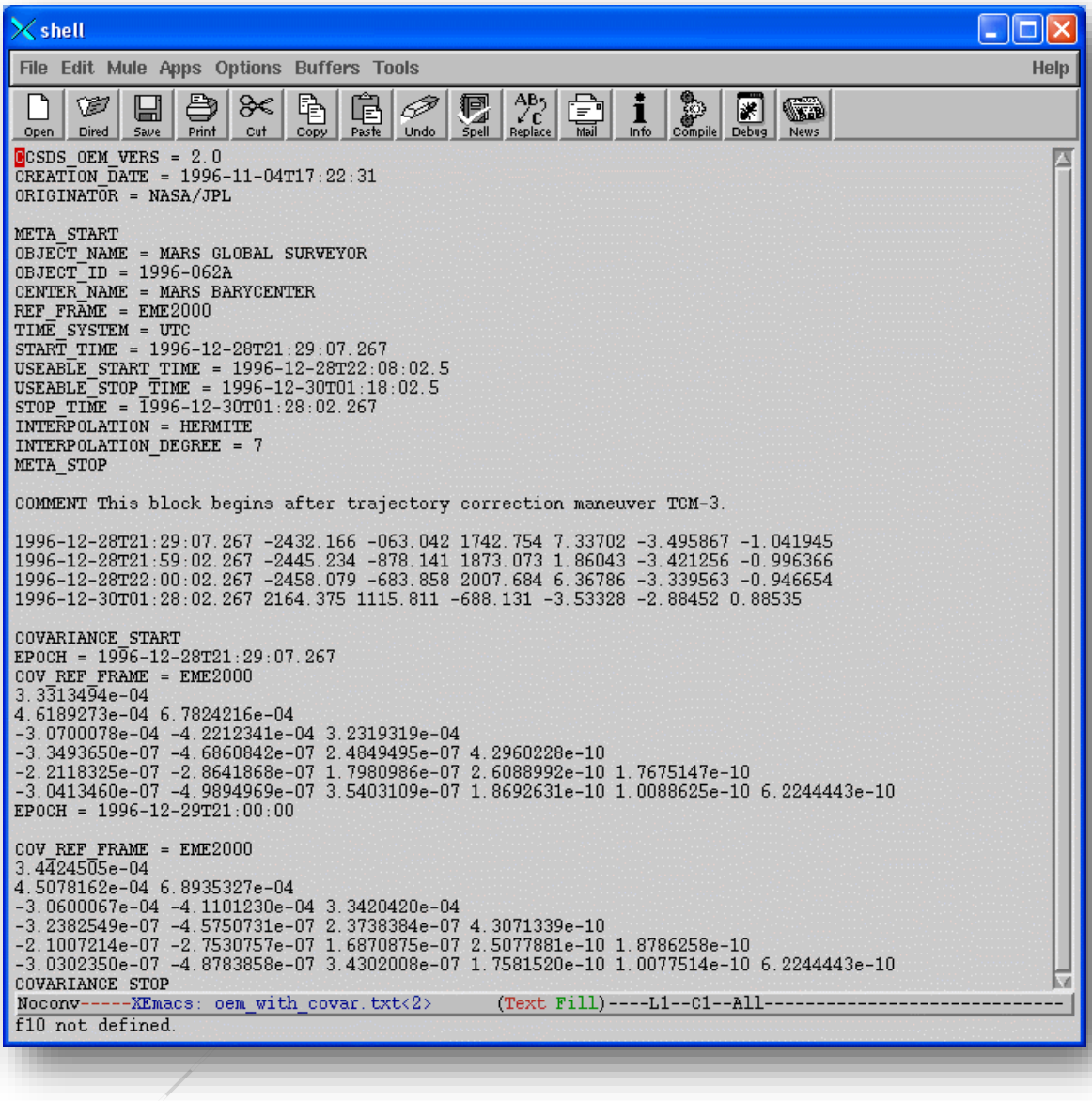


Figure 9: OEM (with covariance) Example

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

data block throughout the OEM file (COV_REF_FRAME, Figure 9). If no annotation is provided, the 19 SDS 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, considering 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.

EPHEMERIS REFERENCE FRAMES

Our system can support the following reference frames in ephemeris:

Table 8: Ephemeris Reference Frames

Vector Reference Frame	*Covariance Frame*
EME2000	EME2000
EME2000	J2000
EME2000	RTN
EME2000	RSW
EME2000	UVW
J2000	EME2000
J2000	J2000
J2000	RTN

J2000	RSW
J2000	UVW
ITRF	ITRF
TEME	RTN
TEME	RSW
TEME	UVW

How to Name Ephemeris Files

OVERVIEW

19 SDS 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>_<Catalog#>_<CommonName>_<DayTimeGroup>_<Operational/Special>_<MetaData>_<Classification>.<FileExtension>

Table 9: Ephemeris File Name Convention

Data Field	*Description*	*Normative Value (N) or Example€)*	*Obligatory*
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 the 9-digit number assigned to you by 18 SDS (Contact the 18 SDS SPACE Office at 18SPCS.DOO.CustomerService@us.af.mil for detail€	(E) 25544 (E) 00900 €(E) 795000000 (E) 795999999	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)€S (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. Please note, any portion of the ephemeris file that takes place prior to the time of screening will not receive results. The system cannot produce results for events in the past. Further, the system cannot produce results for ephemeris projected too far in the future (generally, o€ 7-10 days).	(E) 3001224 = Oct 26, 2020 at 12:24pm UTC	Yes

Continued on next page

Table 9: Ephemeris File Name Convention, cont.

Data Field	*Description*	*Normative Value (N) or Example (E)*	*Obligatory*
Operational/ 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 SDS assumes these will occur. Otherwise, the files should be submitted as **Special**. A **Special** file represents where the satellite is planned to go if a special maneuver is executed 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. *Multiple Special files may be submitted for the same satellite, but only one Operational file at a time can be submitted per satellite*	(N) Oper (N) Special	Yes
MetaData	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**	(E) nomnvr (E) sationkeepingmnvr (E) burn02 (E) __	Yes
Classification	The security classification of the data. Only unclassified files will be accepted through www.space-track.org	(E) unclassified (E) UNCLASSIFIED (E) Unclassified	Yes
File Extension	Indicates the type of file	(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_799500234_Sat1_1651200_special_separation_unclassified.txt

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 19 SDS Orbital Safety Crew at 19SDS.orbital.safety@spaceforce.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 SDS SPACE Office at 18SPCS.doo.customerservice@us.af.mil. The SPACE Office 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 e-mail addresses (as registered on Space-Track) of the personnel who will upload ephemeris for your satellite constellation

The SPACE Office will create a permissions-based ephemeris folder for your organization that will only be accessed by 18 SDS, 19 SDS, and the personnel you authorize. (Note: e-mail addresses that are not registered on Space-Track cannot be included.) You will have upload, download, and delete permissions to

the folder, which you will access through the Files Panel:

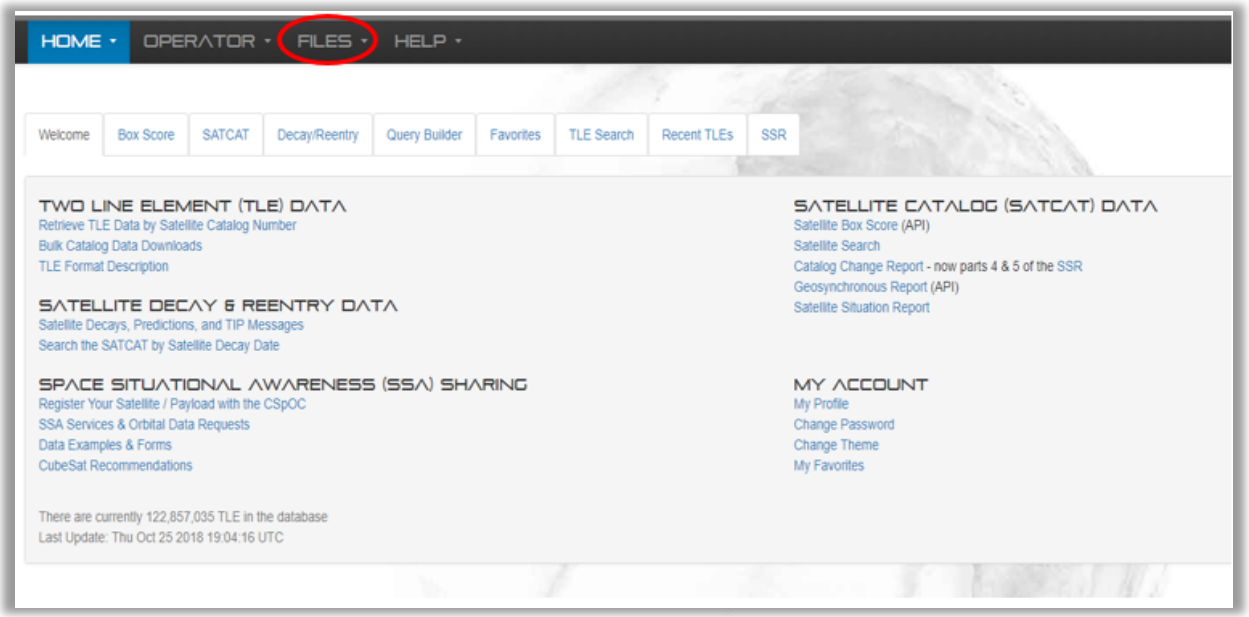


Figure 10: Files Panel on Space-Track.org

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 folders will display in the 'Destination' dropdown menu:

HOW TO SUBMIT EPHEMERIS FILES

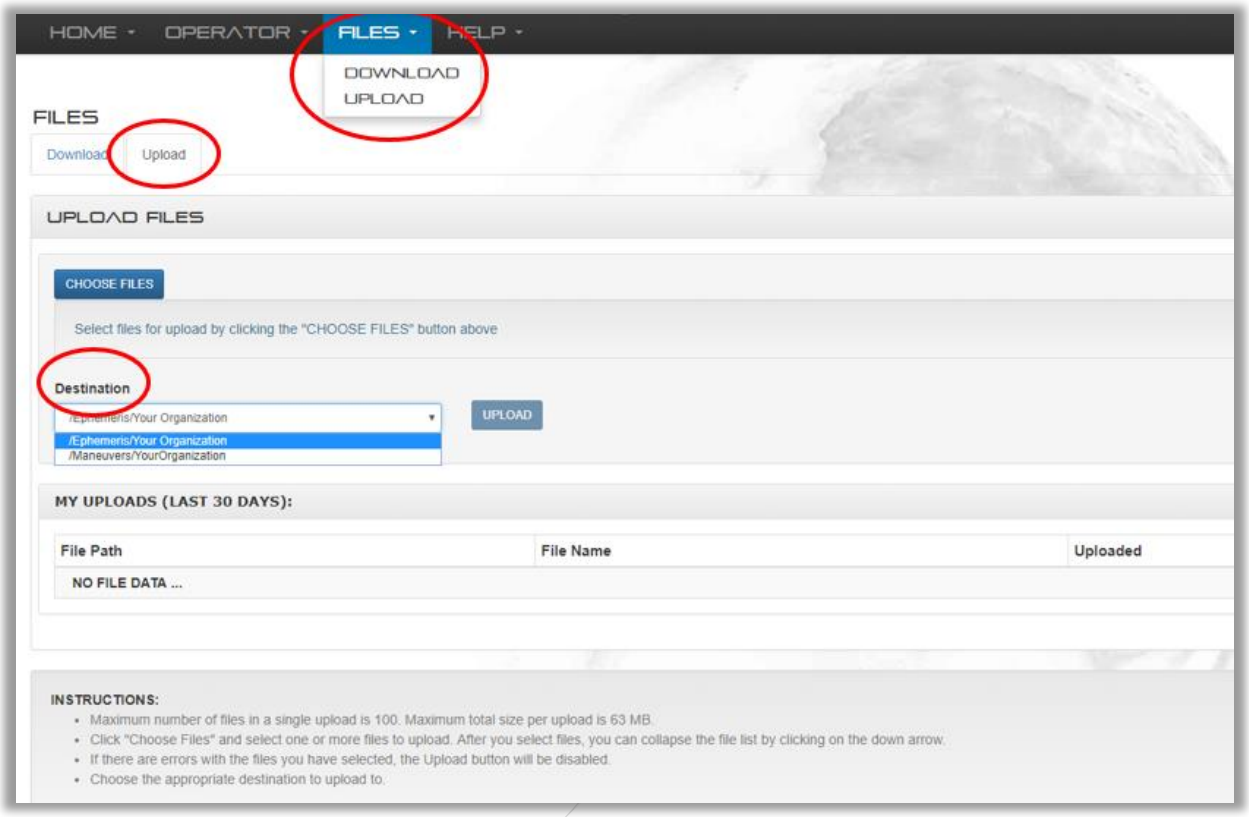


Figure 11: Files Panel Upload Tab - Ephemeris

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 512 MB (This is subject to change, reference the "Help" tab on Space-Track.org for updates)

   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
6. The 19 SDS Conjunction Assessment 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 Crew to notify them that you need an immediate response: +1-540-284-3999 or 19SDS.orbital.safety@spaceforce.mil.

HOW TO SUBMIT EPHEMERIS FILES

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 19 SDS Conjunction Assessment 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 Crew to notify them that you need an immediate response: +1-540-284-3999 or 19SDS.orbital.safety@spaceforce.mil.

EMAIL

In a non-nominal and urgent situation, if your organization does not have an ephemeris folder on the Files Panel, you may send your ephemeris by email to the 19 SDS Conjunction Assessment Crew at 19SDS.orbital.safety@spaceforce.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 19 SDS Conjunction Assessment Crew (19SDS.orbital.safety@spaceforce.mil or +1-540-284-3999) 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

OVERVIEW

19 SDS respectfully requests that satellite operators notify 19 SDS of planned, confirmed, and cancelled maneuvers. This allows 19 SDS to maintain a more accurate catalog, anticipate spaceflight safety risks, and provide more relevant conjunction notifications. 19 SDS has chosen the Orbital Parameter Message (OPM) as the most appropriate method of exchanging maneuver information. However, to make it applicable to 19 SDS operations and reporting procedures, 19 SDS 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 10: 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

	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 11: 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	• 5-digit satellite catalog number assigned by USSPACECOM, or • 9-digit satellite number assigned by 18 SDS	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

TABLE 12: 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 13: 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 14: 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 15: 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

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 16: 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	1st component of the velocity increment	km/s	Yes
MAN_DV_2	2nd component of the velocity increment	km/s	Yes
MAN_DV_3	3rd 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

	OTHER (Other) PER_RED (Period reduction) RELOCATION (Relocation) SCI_OBJ (Science objective) SPIN_RATE_ADJUST (Spin rate adjust) SK (Station-keeping) TRAJ_CORR (Trajectory correction)		
USER_DEFINED_TCA	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.	UTC	**Yes** for COLA maneuver, **No** for all others
USER_DEFINED_MAN_ STATUS	Acceptable values: PREDICTED, DETERMINED, CANCELLED. PREDICTED = planned maneuver DETERMINED = confirmed maneuver CANCELLED = cancelled maneuver	n/a	Yes

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

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 19 SDS Conjunction Assessment Crew at 19SDS.orbital.safety@spaceforce.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 may 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 SDS SPACE Office at 18spcs.doo.customerservice@us.af.mil.

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

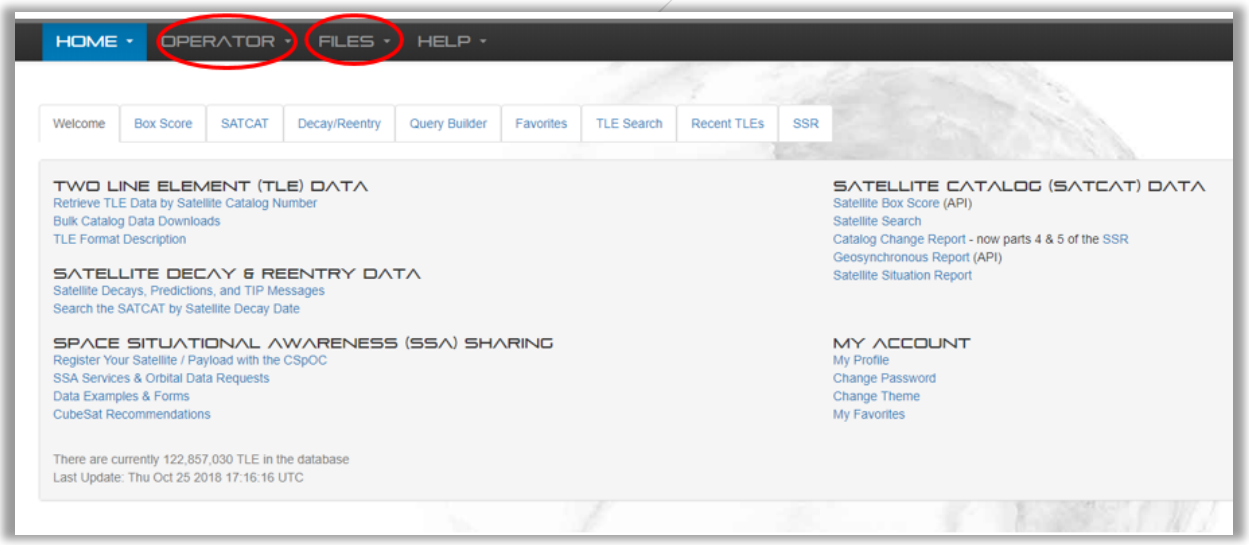


Figure 12: Files Panel on Space-Track.org

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:

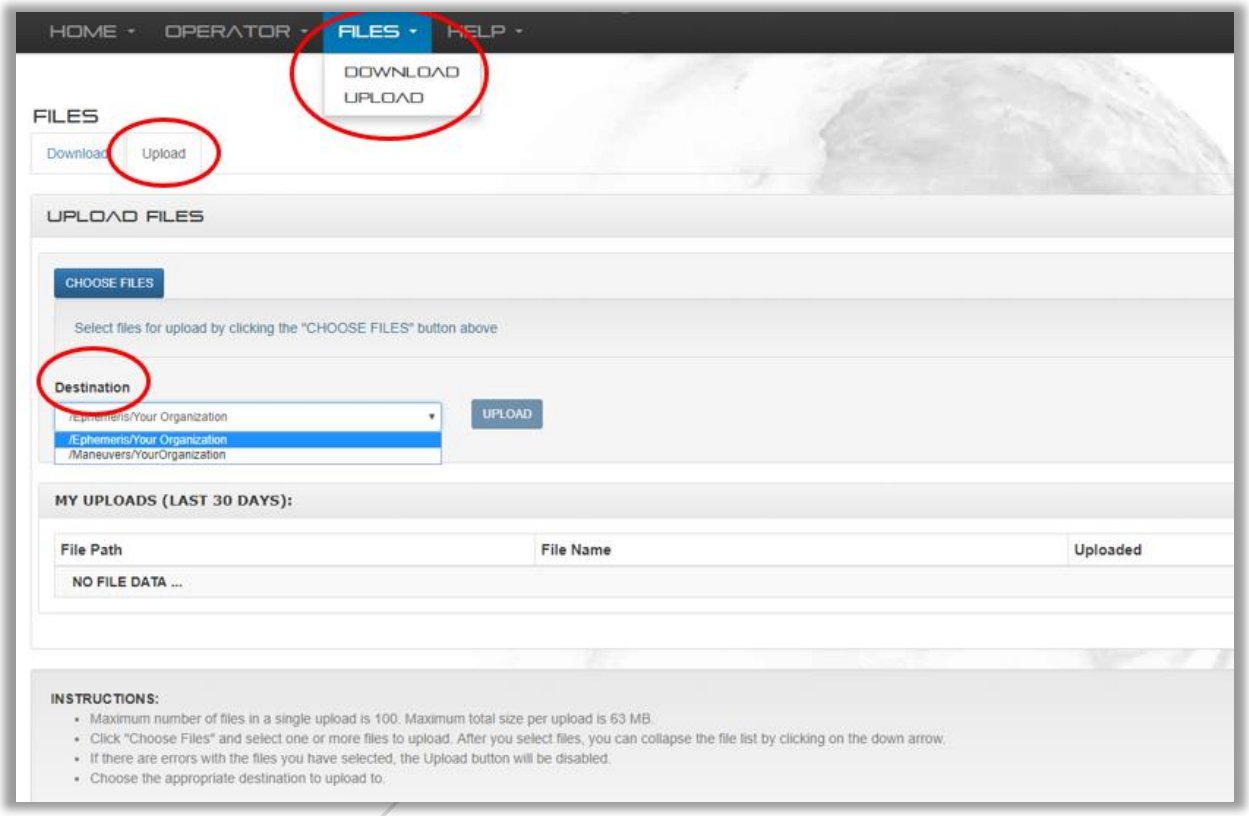


Figure 13: Files Panel Upload Tab - Maneuvers

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 512 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 SDS SPACE Office at 18SPCS.doo.customerservice@us.af.mil.)
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 19 SDS 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 19 SDS 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: +1-540-284-3999 or 19SDS.orbital.safety@spaceforce.mil.

EMAIL

In an urgent situation, if your organization doesn't have access to the Operator and Files Panels, you may send your maneuver notifications by email to the 19 SDS Conjunction Assessment Team at 19SDS.orbital.safety@spaceforce.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

19 SDS CONJUNCTION ASSESSMENT TEAM

For questions on conjunction assessment and collision avoidance support, please contact the 19 SDS Orbital Safety Crew by email at 19SDS.orbital.safety@spaceforce.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 SDS SPACE OFFICE

For questions about specialized SSA support or data products, please contact the 18 SDS SPACE Office by email at 18SPCS.doo.customerservice@us.af.mil. 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

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: 19 SDS Probability of Collision

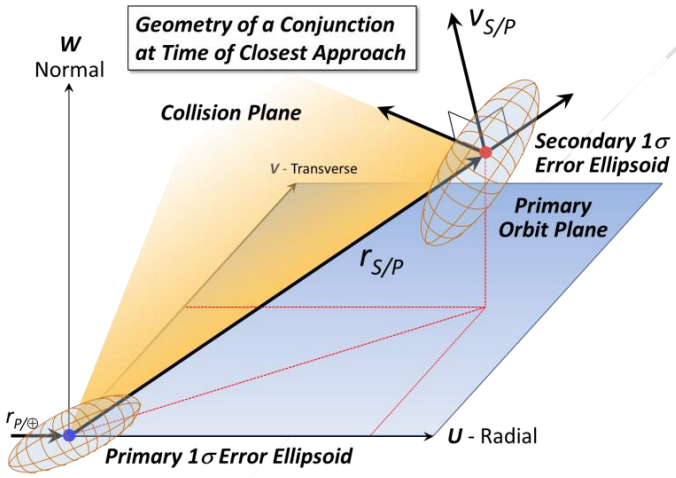


Figure 14: Geometry of a Conjunction

HOW 19 SDS CALCULATES PROBABILITY OF COLLISION

For a conjunction[1] between two objects in earth orbit, the 19th Space Defense Squadron (19 SDS) can compute and report a value commonly referred to as probability of collision (Pc[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 part[3]. If an O/O chooses to provide the Hard Body Radius (HBR) of their satellite on Space-Track, this can be used in the calculation of Pc^2.

[1] Also referred to as a "close approach"

[2] Also PoC, POC

[3] When an assumption is made in the calculation of Pc, it's made on the side of overestimating the Pc, in other words, being conservative. In this way O/Os 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, 19 SDS not knowing the exact size, shape and orientation of both objects at TCA being one of the major ones. 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 Pc 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. The Pc value calculated always has this factor of conservatism built in.

ANNEX A: 19 SDS PROBABILITY OF COLLISION

The data at the time of closest approach (TCA) required to compute Pc 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 Pc 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 objects[4] is called AREA_PC in the CDM and given in square meters. The CDM Blue Book[5] 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.*

SuperCOMBO[6] is used to identify conjunctions in 19 SDS. It has three modes: standoff radius, ellipsoid, and covariance. Pc 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 above, it represents \

[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.

ANNEX A: 19 SDS PROBABILITY OF COLLISION

POSITION AND VELOCITY VECTORS

The position and velocity vectors[9] 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 19 SDS the position and velocity of the objects at TCA are normally computed by interpolating between ephemeris points[10]. The ephemeris points are obtained by propagating forward in time the object's special perturbations (SP) state vector at epoch[11]. 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 19 SDS by the satellite owner/operator[12]. 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) coordinates of the primary object[13]. Also provided are overall MISS_DISTANCE and RELATIVE_SPEED. Relative position and velocity offer a more intuitive view of the conjunction[14] 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

[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

[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."

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 19 SDS[15].

An owner/operator may also send 19 SDS an ephemeris that includes covariance[16]. In these cases, the covariance values in the CDM are interpolated from the ephemeris (with covariance) provided by the owner/operator.

The one-standard-deviation[17] three-dimensional (3D) error ellipsoid may be used to visualize the "size" of the position uncertainty at TCA. Diagonalization of the 3X3 covariance matrix yields the size, shape, and orientation of the error ellipsoid[18]. Often, because of drag, the largest uncertainty will be in the direction of the satellite's motion relative to the atmosphere[19].

ASSUMPTIONS

When computing Pc at 19 SDS 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.

[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)

[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.

- 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 small[20]."

Technical papers have been written to address the computation and/or validity of Pc 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 Pc 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 Pc 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.

COMPUTATION

Computation of Pc takes place in the collision plane[21]. 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 Pc is:

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

In this double integral equation:

- π = 3.141592653589793.
- C is the 2X2 projection of the combined 3X3 covariance at TCA onto the collision plane[22].
- $Det(C)$ is the determinant of C.
- d is the sum of the two object sizes[23].
- "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 $x^2 + y^2 \le d^2$.
- $\mathbf{r}_{S/P} = (r_{S/P}, 0)^T$ 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.

[20] This test is needed to trap zero covariance.

[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

This equation integrates the 2D Gaussian probability density function (centered on the secondary object) over the circle of radius d (centered on the primary object[24]).

Methodologies, coordinate transformations, assumptions, combining Gaussian distributions, limitations, and techniques used to facilitate computation of Pc are discussed at length in technical papers listed in the bibliography[25].

NOTES

19 SDS uses error functions (ERF) for computing the double integration in the Pc equation. In addition, 19 SDS 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 Pc but gives a very slightly larger – but safe – value.

For these and other reasons agencies may compute slightly different values for Pc for the same conjunction. If the difference is large however further investigation is warranted[26].

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

[25] The computation of Pc 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 Pc 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 Pc.

[26] In 2000 AFSPC/A9 numerically validated the computation of Pc in SuperCOMBO.

ANNEX A: 19 SDS PROBABILITY OF COLLISION

BIBLIOGRAPHY

Several excellent references for understanding the computation of Pc 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 Pc for Space Shuttle and International Space Station (ISS) safety of flight analysis. A version of the NASA algorithm for computing Pc was integrated into the ASW program SuperCOMBO in 2000. Certain theoretical issues were modified and expanded 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

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 SDS and 19 SDS spaceflight safety services?

At this time, 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 SDS and 19 SDS highly encourage all O/Os to share their contact information with other O/Os. If it's not available there, you can contact 18 SDS, 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 19 SDS has not predicted any conjunction events that meet reportable criteria. (Reference Tables 5 and 6.) You may contact the 18 SDS SPACE Office at 18SPCS.doo.customerservice@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 SDS SPACE Office at 18SPCS.doo.customerservice@us.af.mil.

ANNEX B: FREQUENTLY ASKED QUESTIONS

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.

ANNEX C: 19 SDS CDM FIELDS EXPLAINED

Annex C: 19 SDS CDM Fields Explained

OVERVIEW

The Conjunction Data Message (CDM) is the primary product that 19 SDS will deliver for on-orbit Conjunction Assessment. The format 19 SDS utilizes closely resembles the format recommended by CCSDS Conjunction Data Message Recommended Standard (CDM) 508.0-P-1.0.1. The table below is a comprehensive reference on the fields included in a 19 SDS CDM.

Table 17: 19 SDS CDM Fields

Keyword	Description	Example
CCSDS_CDM_VERS	CDM format version in the form of X.Y.	1.0
COMMENT	A comment can be placed here for reader's information. Currently 18 SPCS places the CDM ID in the comment section	CDM_ID:XXXXXXXXX
CREATION_DATE	File creation date/time in UTC	2015-07-04T12:00:00.000000
ORIGINATOR	Creating agency or operator	JSPOC
MESSAGE_FOR	Spacecraft name for which the CDM is provided	STARLINK-61
MESSAGE_ID	ID that uniquely identifies the CDM message.	000012345_conj_000054321_202 2067143221_06514372256137
TCA	The Date and Time of the conjunction in UTC	2015-07-04T12:00:00.000000
MISS_DISTANCE	The overall separation distance of both objects at TCA in meters	437
RELATIVE_SPEED	The magnitude of the relative velocity vector in meters/sec. The speed at which both objects are moving relative to each other at TCA in meters/second	15031
RELATIVE_POSITION_R	The R component of Object 2's position relative to Object 1 in an RTN coordinate frame in meters	43.2, -574
RELATIVE_POSITION_T	The T component of Object 2's position relative to Object 1 in an RTN coordinate frame in meters	43.2, -574

ANNEX C: 19 SDS CDM FIELDS EXPLAINED

RELATIVE_POSITION_N	The N component of Object 2's position relative to Object 1 in an RTN coordinate frame in meters	43.2, -574
RELATIVE_VELOCITY_R	The R component of Object 2's velocity relative to Object 1's velocity in an RTN coordinate frame in meters/second	-36.3, 41.7, 12971.8
RELATIVE_VELOCITY_T	The T component of Object 2's velocity relative to Object 1's velocity in an RTN coordinate frame in meters/second	-36.3, 41.7, 12971.8
RELATIVE_VELOCITY_N	The N component of Object 2's velocity relative to Object 1's velocity in an RTN coordinate frame in meter/second	-36.3, 41.7, 12971.8
COLLISION_PROBABILITY	If applicable, the probability of collision (PoC) calculated by 18 SPCS from values of 0.0 to 1.0	0.000003656957
COLLISION_PROBABILITY_METHOD	The method utilized to calculate probability of collision	FOSTER-1992
COMMENT Screening Option	The screening mode used by the 18 SPCS to predict the conjunction contained in the CDM. Options include stand-off radius, ellipsoid and covariance	Stand-Off, Ellipsoid, Covariance
COMMENT Screened with	The data used by 18 SPCS to generate the CDM	inertial state vector unknown state vector type
OBJECT	The object for which the metadata applies for	OBJECT 1 OBJECT 2
OBJECT_DESIGNATOR	The SCC or NORAD CAT ID for the object	25544
CATALOG_NAME	The satellite catalog used for the object	SATCAT
OBJECT_NAME	The common name for the object	STARLINK-61, COSMOS 1408 DEB
INTERNATIONAL_DESIGNATOR	The International Designator for the object in a YYYY-DDDXXX format notating the year and day of launch followed by at least one capital letter to	1998-067A

ANNEX C: 19 SDS CDM FIELDS EXPLAINED

	discern between objects of the same launch	
OBJECT_TYPE	Category of type of object	PAYLOAD, ROCKET BODY, DEBRIS, UNKNOWN, OTHER
OPERATOR_CONTACT_POSITION	The contact position of the owner/operator of the object. Space-Track will place a URL for a query that will lead to this information	
OPERATOR_ORGANIZATION	The organization of the owner/operator of the object	SpaceX, Iridium, CNES
OPERATOR_PHONE	The phone number of the owner/operator of the object. Space-Track will place a URL for a query that will lead to this information	
OPERATOR_EMAIL	The e-mail of the owner/operator of the object. Space-Track will place a URL for a query that will lead to this information	
EPHEMERIS_NAME	The name of the ephemeris utilized if the data source is ephemeris	NONE MEME_25544_ISS_1651200_oper_ _unclassified.txt
COVARIANCE_METHOD	The method of which covariance is calculated. When covariance cannot be calculated, default values may be used. Caution should be used when using default values when calculating PoC	CALCULATED DEFAULT
MANEUVERABLE	The maneuver capability of the object	YES, NO, N/A
REF_FRAME	Name of the reference frame for the provided state vectors	ITRF
GRAVITY_MODEL	The name of the gravity model used for propagation	EGM-96: 36D 360
ATMOSPHERIC_MODEL	The name of the atmospheric model used for propagation	JBH09
N_BODY_PERTURBATIONS	The gravitational perturbation models used in a comma separated format	MOON,SUN

ANNEX C: 19 SDS CDM FIELDS EXPLAINED

SOLAR_RAD_PRESSURE	Indicates whether solar radiation pressure was used during the Orbit Determination (OD) of the object	YES NO
EARTH_TIDES	Indicates whether solid Earth and ocean tides were used in the OD of object	YES NO
INTRACK_THRUST	Indicates whether in-track thrust modeling was used for the OD and propagation of the object	YES NO
COMMENT Covariance Scale Factor	The scale that covariance is multiplied by	1.000000
COMMENT Exclusion Volume Radius	The radius of a sphere in meters to create a spherical volume representative of the object and used in the PoC calculation	5.000000
TIME_LASTOB_START	The time in UTC of the start of the timespan that contains observations used in the OD. This time will start at the latest accepted observation	2015-07-04T12:00:00.000000
TIME_LASTOB_END	The time in UTC of the end of the timespan that contains observations used in the OD. This time will end at the most recent accepted observation	2015-07-04T12:00:00.000000
RECOMMENDED_OD_SPAN	The recommended time span for the OD of the object in days	2.76
ACTUAL_OD_SPAN	The actual time span used in the OD of the object in days	2.76
OBS_AVAILALBE	Total amount of observations available for the OD of the object	57
OBS_USED	Actual number of observations used in the OD of the object	57
RESIDUALS_ACCEPTED	The percentage of residuals accepted in the OD of the object	99.3
WEIGHTED_RMS	The weighted Root Mean Square (RMS) of the residuals from a batch least squares	1.446

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COMMENT Apogee Altitude	The apogee of the object in km	460
COMMENT Perigee Altitude	The perigee of the object in km	437
COMMENT Inclination	The inclination of the object in deg	60.7
COMMENT Operator Hard Body Radius	If input by an owner/operator, the Hard Body Radius of the object in meters	0.00
AREA_PC	The area of the object used in the PoC calculation in m^2	2.2642
CD_AREA_OVER_MASS	The object's C_D•A/m used in the propagation of the vector and covariance to TCA in m^2/kg	0.161615504658
CR_AREA_OVER_MASS	The object's C_R•A/m used in the propagation of the vector and covariance to TCA in m^2/kg	0
THRUST_ACCELERATION	The object's acceleration in the In-track or R direction (RTN) used for propagating the state vector and covariance until TCA in m/s^2	0 0.634
SEDR	The average amount of energy being removed from an object's orbit due to atmospheric drag in W/kg	0.020492
X	Object position vector X component in km	1670.352554
Y	Object position vector Y component in km	-6834.579872
Z	Object position vector Z component in km	-1430.950837
X_DOT	Object velocity vector X component in km/s	2.780391335
Y_DOT	Object velocity vector Y component in km/s	2.808606433
Z_DOT	Object velocity vector Z component in km/s	-5.751722603
COMMENT DCP Density Forecast Uncertainty	The dynamic considers parameter (DCP) 1-sigma uncertainty of the relative atmospheric density for the specified object (given as a simple ratio). This is the uncertainty of the average	2.143370310000000E-01

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	atmospheric density exerting drag on the object, relative to the nominal (measured) atmospheric density	
COMMENT DCP Sensitivity Vector RTN Pos	The DCP position sensitivity vector expressed in the object's radial-transverse-normal (RTN) reference frame in meters. This sensitivity vector relates changes in the object's TCA position vector to variations in relative atmospheric density	-7.345809012167026E+02 3.865957136169006E+05 -1.456925086066596E+02
DCP Sensitivity Vector RTN Vel	The DCP velocity sensitivity vector relates changes in the object's TCA inertial velocity vector to variations in relative atmospheric density and is in meters/sec	-2.195009966872100E+02 2.630946954519584E-01 3.265607422364180E-01
CR_R	Object covariance matrix [1,1] in m^2	
CT_R	Object covariance matrix [2,1] in m^2	
CT_T	Object covariance matrix [2,2] in m^2	
CN_R	Object covariance matrix [3,1] in m^2	
CN_T	Object covariance matrix [3,2] in m^2	
CN_N	Object covariance matrix [3,3] in m^2	
CRDOT_R	Object covariance matrix [4,1] in m^2/s	
CRDOT_T	Object covariance matrix [4,2] in m^2/s	
CRDOT_N	Object covariance matrix [4,3] in m^2/s	
CRDOT_RDOT	Object covariance matrix [4,4] in m^2/s^2	
CTDOT_R	Object covariance matrix [5,1] in m^2/s	
CTDOT_T	Object covariance matrix [5,2] in m^2/s	
CTDOT_N	Object covariance matrix [5,3] in m^2/s	

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CTDOT_RDOT	Object covariance matrix [5,4] in m^2/s^2	
CTDOT_TDOT	Object covariance matrix [5,5] in m^2/s^2	
CNDOT_R	Object covariance matrix [6,1] in m^2/s	
CNDOT_T	Object covariance matrix [6,2] in m^2/s	
CNDOT_N	Object covariance matrix [6,3] in m^2/s	
CNDOT_RDOT	Object covariance matrix [6,4] in m^2/s^2	
CNDOT_TDOT	Object covariance matrix [6,5] in m^2/s^2	
CNDOT_NDOT	Object covariance matrix [6,6] in m^2/s^2	
CDRG_R	Object covariance matrix [7,1] in m^3/kg	
CDRG_T	Object covariance matrix [7,2] in m^3/kg	
CDRG_N	Object covariance matrix [7,3] in m^3/kg	
CDRG_RDOT	Object covariance matrix [7,4] in $m^3/(kg*s)$	
CDRG_TDOT	Object covariance matrix [7,5] in $m^3/(kg*s)$	
CDRG_NDOT	Object covariance matrix [7,6] in $m^3/(kg*s)$	
CDRG_DRG	Object covariance matrix [7,7] in m^4/kg^2	
CSRP_R	Object covariance matrix [8,1] in m^3/kg	
CSRP_T	Object covariance matrix [8,2] in m^3/kg	
CSRP_N	Object covariance matrix [8,3] in m^3/kg	
CSRP_RDOT	Object covariance matrix [8,4] in $m^3/(kg*s)$	
CSRP_TDOT	Object covariance matrix [8,5] in $m^3/(kg*s)$	
CSRP_NDOT	Object covariance matrix [8,6] in $m^3/(kg*s)$	
CSRP_DRG	Object covariance matrix [8,7] in m^4/kg^2	
CSRP_SRP	Object covariance matrix [8,8] in m^4/kg^2	