Conjunction Assessment Verification Data and Process

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Purpose

This test set is designed to aid in improving Space Situational Awareness (SSA) by providing a robust input dataset and trusted answer key to SSA providers, enabling them to self-evaluate and potentially remediate their conjunction screening algorithms. This test set was devised primarily to evaluate conjunction geometry at the time of closest approach (TCA), with an emphasis on 1) finding all the same events and 2) for those events, accurately computing the TCA and primary/secondary state and covariance. Suggested thresholds for differences in TCA between two conjunction screening tools, along with other pertinent conjunction assessment (CA) validation information, are provided in the 2025 AMOS paper, *Validation Methodology for TraCSS Conjunction Assessment* [1]. While probability of collision (Pc) metrics do exist in the answer key, direct comparison of Pc values requires the same method of Pc computation and is therefore not a key metric of this dataset.

Disclaimer

While the ephemeris dataset was crafted to include stressing edge cases in addition to an operational catalog, it is not completely comprehensive, as there are nearly infinite combinations of orbits and conjunction geometries possible. Additionally, the answer key was generated using

Aerospace's internal tool called Conjunction Sieve (CSieve), a validated conjunction assessment tool [2], that is expected to find nearly all the events within the dataset, but we cannot guarantee exhaustive results. This test set should not be used as a validation benchmark for operational use of a conjunction screening algorithm; it should only be used as a diagnostic tool for self-evaluation. Additional information regarding the CSieve algorithm can be found here [3].

Input Test Set

As summarized in Table 1, this test set is comprised of five (5) total files: the input ephemeris dataset; two conjunction data message (CDM) results files, one for a constant spherical screening volume and one for the Space Flight Safety Handbook (SFSH) [4] rectangular screening volumes; a key for mapping the SFSH screening volumes to specific objects, and this user's guide for how to effectively utilize this test set.

Table 1. Files for Comparative Analysis

Input	Filename	Size
Ephemeris dataset	AerospaceIVVDataset_20251009a.tar.gz	21.74 GB
Spherical Screening Volume Results	IVV_Releasable_Dataset_Spherical_DefaultHBR.csv.gz	204 MB
SFSH Screening Volume Results	IVV_Releasable_Dataset_SFSH_DiscreteHBR.csv.gz	144 MB
SFSH Screening Volume Mappings	AerospaceIVVDataset_20251009a_Size_ScreeningVolumes.csv.gz	145 KB
User's Guide	Conjunction_Screening_Testset_Users_Guide.pdf	

All files, with the exception of the User's Guide, are either tar.gz or gz and will need to be properly decompressed prior to processing.

Ephemeris Dataset

The ephemeris dataset is comprised of Orbit Comprehensive Message (OCM)-formatted ephemerides [5] spanning roughly the first week of January 2025. The screening window implemented in The Aerospace Corporation's CSieve run configuration is 2025-01-01T12:00:00 to 2025-01-08T12:00:00. SSA providers should configure the screening window for the same time span. All ephemerides in the dataset provided should be run in an all-vs-all configuration. By design, some ephemerides in the dataset start and/or end within the screening window. An SSA provider's tools should be expected to properly handle all ephemerides, including accounting for the "useable" start and stop times listed withing the individual OCM-formatted ephemerides.

The input ephemeris is comprised of multiple different object types, which are listed in Table 2 with the accompanying range of object IDs for those object types. The term “victim” is used to describe ephemeris specifically generated to pair with another ephemeris to produce a conjunction event.

Table 2. Object ID Numbers for the Various Object Types in the Dataset

Catalog ID Numbers	Object Type	Notes
00005-62461	TLEs	From the public Space-Track TLE Catalog on/around 1 Jan 2025
90006-90190	Maneuvering ephemerides & victims	Synthetic ephemerides containing maneuvers and the fictitious objects generated to conjunct with a maneuver ephemeris (victims)
95000-95407	Historical CDMs	State and covariance at TCA forward and back propagated to generate ephemeris
99000-99008	Fictitious objects & victims	Objects generated to fulfill remaining dataset requirements not satisfied by the other objects [1]
99996-99999	Osiris-Rex Sample Return Capsule & victims	Reconstructed ephemeris of reentering, heliocentric object. Osiris Rex is Object 99999.

The covariance for the TLE-derived portion of the dataset and the fictitious objects is constructed using COVGEN [6]. For the fictitious objects, the COVGEN covariance corresponding to a TLE in a similar regime is assigned.

SFSH Screening Volume Mappings

This file contains per-object hard-body radius (HBR) values and per-object UVW screening volume values, along with the corresponding screening volume categories that are specified in Table 3 in the **Screening Volume** Section. Note: The volumes in this file are half-volumes. For example, 10 km in the radial (U) direction is the maximum absolute value of radial separation from the primary object to the secondary object (in the frame of the primary object).

Algorithm Configuration

General

For both screening volume configurations, all objects should be screened against all other objects, commonly referred to as an ALL vs. ALL screening. While the ephemerides may be grouped into different directories based on object type, they should all be screened against one another in the same run. There are some ephemerides with the same object designator, as would be the case when conducting a conjunction mitigation analysis, where ephemerides with different mitigation maneuvers are screened alongside the nominal ephemeris for the same object to demonstrate the impact of intervention. These types of ephemerides are referred to as candidate OCMs and should not be screened against one another or against the nominal ephemeris of the same object designator, i.e. conjunctions should not be generated for interactions between different ephemeris of the same object. Alternatively, each individual candidate OCM, in addition to the nominal OCM for that object designator, should be screened against all other objects.

Configuration

1. Only CDMs with a TCA between 2025-01-01 12:00:00Z and 2025-01-08 12:00:00Z should be provided. Algorithms should be configured to only return events where TCA is within the analysis timespan. Algorithms should not return events where the event is within the screening volume at the beginning or end of the screening window, but the TCA is outside the screening window.
2. Usable start/stop times in the input OCMs should be accounted for.
3. No Pc pre-filter should be applied.
4. Using the OD_EPOCH field in the ephemeris, analysis should only be performed on element sets with an orbit determination (OD) epoch < 14 days from the beginning of the screening window.
5. Assign screening volumes as specified below.
6. Assign HBR values as specified below (if computing Pc).

Screening Volume

There exists one input dataset and two distinct output "answer keys." The two different answer keys correspond to two different screening volume configurations: 1) a single spherical screening volume of 10 km and 2) the orbit-regime-dependent screening volumes defined in the Space Flight Safety Handbook with some additional definitions for those objects which are not accounted for in the SFSH.

A single spherical screening volume represents the most simplistic form, and the output dataset resulting from this configuration should be used in the initial round of evaluation as it reduces the sources of possible discrepancy between tools. Evaluation using the SFSH screening volumes is advised in the second round of testing.

1) **Single Spherical Screening Volume of 10 km:** An initial test using a single spherical screening volume may be beneficial to eliminate the possible variability in the configuration between algorithms and ensure proper functionality of the core part of the

algorithm. For this reason, a CSieve run was conducted using a spherical screening volume of 10 km[1] and a default HBR of 0.5m.

a. Only provide CDMs with a miss distance of up to 10 km (constant spherical screening volume for all objects)
b. Use a constant HBR of 0.5 m for probability of collision calculation
c. Because screening volumes are spherical and the same for all objects, if a conjunction exists between Object A and Object B, then there should also exist a conjunction between Object B and Object A at the same TCA. **Both of these CDMs should be reported.**

2) **SFSH Variable-Sized Rectangular Screening Volumes**: The rectangular screening volumes from the Space Flight Safety Handbook for each regime are defined in Table 3. The dimensions of the screening volumes are provided in the UVW (aka Radial, In-track, Cross-track or RIC) local reference frame. This run uses discrete HBR values and screening volumes which are provided in the SFSH Screening Volume Mappings file.
   a. Use screening volumes (per-object) as provided in the input mappings file
      i. All screening volumes are rectangular.
      ii. For purposes of comparison testing, do not screen any ephemeris as a primary if the object does not have a provided screening volume; Objects that do not have provided screening volumes should still be included in the all versus all screening as secondaries.
   b. Use HBR values (per-object) as provided in the input mappings file, if computing Pc.
   c. Because screening volumes are not the same for all objects, and due to the nature of rectangular screening volumes oriented to local coordinate frames, a conjunction may exist between Object A and Object B but might not necessarily exist between Object B and Object A (at the same TCA). In other words, if Object B is within Object A's screening volume, but Object A is not within Object B's screening volume, only the conjunction with Object A as the primary should be generated. Alternatively, if Object B is within Object A's screening volume, and Object A is within Object B's screening volume, both conjunctions should be

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[1] The choice of screening volume and size affects the conjunctions output. The input dataset was designed to capture as many edge cases as possible; some edge cases will present as conjunctions in the output and others will not, depending on screening volume choice. Whatever edge cases are not captured using the SFSH screening volumes should ideally be captured by the spherical screening volume and vice versa. Note that not all historical CDM objects will produce a conjunction due to the screening volume size and shape selected. CSieve was run with the 68 km spherical radius to capture the largest dimension of the SFSH screening volumes, but only those with a miss distance of 10 km or smaller are included here to maintain manageable output conjunction counts. Therefore, if some of the input ephemeris objects do not appear as expected in the CSieve results, this is why and should not be reason for concern.

reported, one with Object A as the primary and Object B as the secondary, and one with Object B as the primary and Object A as the secondary.[2]

Table 3. Space Flight Safety Handbook Screening Volumes.

ID	U (km)	V (km)	W (km)	Description	Orbit Regime Definition
1	10	10	10	SFS Handbook Table 3 Deep Space	1300 min < Period < 1800 min Eccentricity < 0.25 & Inclination < 35º
2	0.4	2	2	SFS Handbook Table 3 LEO4	1200 km < Perigee ≤ 2000 km Eccentricity < 0.25
3	0.4	12	12	SFS Handbook Table 3 LEO3	750 km < Perigee ≤ 1200 km Eccentricity < 0.25
4	0.4	25	25	SFS Handbook Table 3 LEO2	500 km < Perigee ≤ 750 km Eccentricity < 0.25
5	0.4	44	51	SFS Handbook Table 3 LEO1	Perigee ≤ 500 km Eccentricity < 0.25
6	20	20	20	SFS Handbook Table 4 Deep Space	Period > 225min
7	2	25	25	SFS Handbook Table 4 LEO/ SFS Handbook Table 4 Near Earth	Period < 225min
8	20	50	20	Hyperbolic Screening Criteria[3]	Eccentricity >= 1

CSieve Output: Conjunction Data

By definition, and in the context of this comparison analysis, a conjunction should only be reported if the local minimum of miss distance is within the screening volume. If the local component minimum of miss distance occurs outside any component of the screening volume, or if a time close to TCA is within all components of the screening volume but not at the local minimum of miss distance, a conjunction should NOT be reported. As an example, if a screening volume is 2 x 10 x 10 km in the RIC frame, and the analysis timespan is 2025-01-01 12:00:00 to 2025-01-08 12:00:0, Table 4 showcases what would and would not constitute a conjunction based on the component miss distance and TCA.

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[2] The rectangular screening volumes are meant to circumscribe the regions of highest risk, thus reducing the number of events reported or processed with Pc. Because the rectangular screening volumes are oriented to the local RIC frame of each object, it is possible for Object A to be within Object B's volume but Object B to not be within A's volume, even if the screening volumes are exactly the same size. It is recognized that this is a limitation of rectangular screening volumes in the operational context and is an accepted/known discrepancy that is not expected to influence the calculations in a meaningful way in the context of this dataset.

[3] The Hyperbolic Screening Criteria is not part of the SFSH screening volumes definitions; it is included here for the purpose of testing screening capabilities on hyperbolic objects.

Table 4. Component Miss Distances Constituting a Conjunction given the Component Screening Volume and Screening Time Window.

Conjunction	TCA	Radial	In-Track	Cross-Track	Report Conjunction
A	2025-01-01 13:00:00.0	3.0	0.0	0.0	No
B	2025-01-08 11:00:00.0	2.0	5.0	5.0	Yes
C	2025-01-01 11:59:59.0	2.0	5.0	5.0	No

The output from CSieve is presented as a CSV file containing all the pertinent information that would be contained in a CDM. The columns are defined in Table 5.

Note: the Sat ID is used to identify unique objects. It is equivalent to the NORAD ID when the object exists in the Space-Track catalog and is an arbitrary 5-digit number for fictitious or regenerated objects.

Table 55. CSieve Conjunction Results Output File Specifications.

Entry in CSieve Output File	Definition
run_id	Integer ID for the CA tool run, should be same for entire dataset
conj_id	Unique ID for Conjunction
obj1	Sat ID of first object
met_criteria1	Flag (0 or 1) to indicate if event triggered via Object 1's screening criteria
obj2	Sat ID of second object, obj2 > obj1
met_criteria2	Flag (0 or 1) to indicate if event triggered via Object 2's screening criteria
min_range	Miss distance in km
Vrel	Relative velocity in km/s
prob	Pc via Alfano 2004 method.
dilution	Value of 1 indicated diluted covariance (right side of max Pc on Pc versus scale factor curve) and a value of 0 indicates robust covariance (left side of max Pc on Pc versus scale factor curve)
mdistance	Mahalanobis Distance
epoch	TCA in UTC time system
jdate	TCA as a Julian Date
x1, y1, z1, vx1, vy1, vz1	Position and velocity of object 1 at TCA in J2000 coordinate frame, km & km/s
local_x1, local_y1, local_z1	Relative position of object 2 with respect to object 1 at TCA, in Object 1's UVW coordinate frame, km

C1_xx	UVW Covariance for Object 1(Upper Triangular Matrix)
x2, y2, z2, vx2, vy2, vz2	Position and velocity of Object 2 at TCA in J2000 coordinate frame, km & km/s
local_x2, local_y2, local_z2	Relative position of Object 1 with respect to object 2 at TCA, in Object 2's UVW coordinate frame, km
C2_xx	UVW Covariance for Object 2 (Upper Triangular Matrix)
obj1_file, obj2_file	Names of Files 1 and 2 used to generate conjunction

If the values for Pc, Mahalanobis distance, or dilution are set to NULL, this means that these covariance-based metrics couldn't be computed for some reason, most likely that the covariance at that time point is non-positive definitive. Alternatively, it could mean that covariance wasn't available for one or both objects, or that the Pc calculation failed for some reason, Although the latter is very unlikely for otherwise good covariances.

Table of Acronyms

CA	Conjunction Assessment
CDM	Conjunction Data Message
CSieve	Conjunction Sieve
HBR	Hard Body Radius
OCM	Orbit Comprehensive Message
OD	Orbit Determination
Pc	Probability of Collision
RIC	Radial, In-track, Cross-Track
SFSH	Space Flight Safety Handbook
SSA	Space Situational Awareness
TCA	Time of Closest Approach
TLE	Two-Line Element
UTC	Coordinated Universal Time
UVW	Radial, In-track, Cross-Track

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