



U.S. Department
of Transportation
**Federal Aviation
Administration**

Advisory Circular

Subject: Launch and Reentry Collision
Avoidance Analysis

Date: August 10, 2023 **AC No:** 450.169-1
Initiated By: AST-1

This Advisory Circular (AC) provides guidance to a launch or reentry operator on how to complete the launch and reentry collision avoidance analysis in accordance with Title 14 of the Code of Federal Regulations (14 CFR) § 450.169. This AC discusses: 1) the contents a launch or reentry operator should provide to the Federal Aviation Administration (FAA) to satisfy Appendix A of part 450 for the collision analysis worksheet, 2) how to submit that information to the processing entity, and 3) proper vehicle operator responses to the analysis they receive from the processing entity.

This AC describes acceptable means, but not the only means, for demonstrating compliance with the applicable regulations. The contents of this document do not have the force and effect of law and are not meant to bind the public in any way. The document is intended only to provide clarity to the public regarding existing requirements under the law or agency policies.

If you have suggestions for improving this AC, you may use the Advisory Circular Feedback form at the end of this AC.

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1 **PURPOSE.**

1.1 This AC provides guidance to launch or reentry operators on how to complete the launch and reentry collision avoidance analysis in accordance with 14 CFR § 450.169. This AC discusses: 1) the contents an operator should provide to the Federal Aviation Administration (FAA) to satisfy Appendix A of part 450 for the collision analysis worksheet, 2) how to submit that information to the processing entity, and 3) proper vehicle operator responses to the analysis they receive from the processing entity.

1.2 **Level of Imperatives.**

This AC presents one, but not the only, acceptable means of compliance with the associated regulatory requirements. Throughout this document, the word “must” characterizes statements that directly follow from regulatory text and therefore reflect regulatory mandates. The word “should” describes an option that, if used would constitute a means to comply with the regulation; variation from the provisions of this AC is possible, but must satisfy the regulation to constitute a means of compliance. The word “may” describes variations or alternatives allowed within the accepted means of compliance set forth in this AC.

2 **APPLICABILITY.**

2.1 The guidance in this AC is for launch or reentry vehicle operators required to comply with 14 CFR § 450.169, *Launch and Reentry Collision Avoidance Analysis Requirements*.

2.2 It should be noted that under § 450.169(d), launch collision avoidance analysis is not required if the maximum planned altitude for any launched object is less than 150 kilometers (km) in altitude. The guidance in this AC is therefore applicable to launch or reentry operators required to complete a collision avoidance analysis under § 450.169.

2.3 The material in this AC is advisory in nature and does not constitute a regulation. This guidance is not legally binding in its own right and will not be relied upon by the FAA as a separate basis for affirmative enforcement action or other administrative penalty. Conformity with this guidance document (as distinct from existing statutes and regulations) is voluntary only, and nonconformity will not affect rights and obligations under existing statutes and regulations.

2.4 The material in this AC does not change or create any additional regulatory requirements, nor does it authorize changes to, or deviations from, existing regulatory requirements.

3 APPLICABLE REGULATIONS AND RELATED DOCUMENTS.

3.1 Related Statutes.

- 51 United States Code (U.S.C.) Subtitle V, Chapter 509.
- 10 U.S.C. Title 10, Subtitle A, Part IV, Chapter 134, § 2274.

3.2 Related Regulations.

The following regulations from Title 14 of the CFR must be accounted for when showing compliance with 14 CFR 450.169. The full text of this regulation can be downloaded from the [U.S. Government Printing Office e-CFR](#). A paper copy can be ordered from the Government Printing Office, Superintendent of Documents, Attn: New Orders, P.O. Box 371954, Pittsburgh, PA, 15250-7954.

- Section 401.7, *Definitions*.
- Section 450.165, *Flight-commit criteria*.
- Section 450.169, *Launch and reentry collision avoidance analysis requirements*.
- Appendix A to Part 450, *Collision Analysis Worksheet*.

3.3 Related FAA Advisory Circulars.

- AC 450.117-1, *Trajectory Analysis for Normal Flight*, dated August 19, 2021.
- AC 450.119-1, *Trajectory Analysis for Malfunction Flight*, when published.

3.4 Other Related Documents.

- 18th Space Defense Squadron, *Launch Conjunction Assessment Handbook*, Version 1, dated December 2018, https://www.space-track.org/documents/LCA_Handbook.pdf.

Note: For brevity, this handbook is referred to as the ‘18th SDS LCA Handbook’ in the text of this AC.

- 18th Space Defense Squadron, *Spaceflight Safety Handbook for Satellite Operators*, version 1.5, August 2020, <https://www.space-track.org/auth/loginhttps://www.space-track.org/>.
- Alfano, Salvatore, A Numerical Implementation of Spherical Object Collision Probability. *The Journal of the Astronautical Sciences*, Vol. 53, No. 1, January-March 2005, pp. 103-109.
- Form R-15/VIM Report, <https://www.space-track.org/documentation#odr>.
- Form 22, <https://www.space-track.org/documentation#odr>.
- JSpOC Recommendations for Optimal CubeSat Operations, August 4, 2015, https://www.space-track.org/documents/Recommendations_Optimal_Cubesat_Operations_V2.pdf.

- National Aeronautics and Space Administration, NASA/SP-20205011318 NASA *Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook*, dated December 2020, https://nodis3.gsfc.nasa.gov/OCE_docs/OCE_50.pdf.

Note: The industry documents referenced in this section refer to the current revisions or regulatory authorities' accepted revisions.

4 **DEFINITIONS.**

For this AC, the terms from § 401.7 and the following definitions apply:

4.1 **Collision Avoidance (COLA)**

The process of identifying close approaches and possible collisions between the planned trajectory(s) of a launch or reentry vehicle and other artificial objects on orbit, to include active and inactive satellites, rocket bodies, debris, and objects that are not in the public catalog.

4.2 **Experienced Operator**

A launch or reentry operator that has received, processed, and executed a launch and reentry collision avoidance (COLA) analysis from the entity identified in § 450.169(e) during a prior FAA-licensed operation.

4.3 **New Operator**

A launch or reentry operator that has never received a COLA analysis from any entity identified in § 450.169(e).

4.4 **Uncertainty**

For purposes of this AC, uncertainty refers to the absence of perfectly detailed knowledge of input to the risk analysis models. Uncertainty includes incertitude (the exact value is unknown) and variability (the value is changing).

5 ACRONYMS.

18th SDS – 18th Space Defense Squadron (formerly the 18th Space Control Squadron)

19th SDS – 19th Space Defense Squadron (formerly the 19th Space Control Squadron)

AC – Advisory Circular

COLA – Collision Avoidance

CONOPS – Concept of Operations

CFR – Code of Federal Regulations

CSpOC – Combined Space Operations Center

FAA – Federal Aviation Administration

FHA – Flight Hazard Analysis

GEO – Geosynchronous or Geostationary Orbit

ISS – International Space Station

JFSCC – Joint Functional Space Component Command

JSpOC – Joint Space Operations Center

km – Kilometer

LCA – Launch Conjunction Assessment

LEO – Low Earth Orbit

NASA – National Aeronautics and Space Administration

OMB – Office of Management and Budget

RAAN – Right Ascension of the Ascending Node

SDS – Space Defense Squadron

STK – Systems Tool Kit

TBD – To Be Determined

U.S.C. – United States Code

UTC – Universal Time Coordinated

UVW – Radial unit, cross-track, and in-track coordinate system

V&V – Validation and Verification

VIM – Vehicle Information Message

6 **PROCESS, OVERVIEW, AND TIMELINE.**

The COLA analysis process identifies close approaches and prevents collisions between launched and reentering objects and cataloged space objects during launch or reentry. It also prevents close approaches to inhabitable objects, such as the International Space Station (ISS) or the Tiangong (Chinese) Space Station and vehicles transiting to and from these space stations as these objects are exceptionally susceptible to disruption and a short notice collision alarm may arrive too late for safety mitigations to be executed. Collision avoidance analysis is referred to as the 'Launch Conjunction Assessment (LCA)' by the Joint Functional Space Component Command (JFSCC) and Space Defense Squadron Combined Space Operations Center (CSpOC) of the United States Space Force. The FAA requires that operators establish window closures during launch or reentry to ensure that launch or reentry vehicles, jettisoned components, and payloads either by ensuring a sufficiently low probability of collision or by maintaining a minimum separation distance between the objects launched or reentered and cataloged space objects, as specified in § 450.169(a). Operators must ensure compliance with § 450.169(a) for all segments of flight specified in § 450.169(b). In accordance with § 450.169(f), operators must submit input data, including the information specified in Appendix A to part 450, to a Federal entity or another entity agreed to by the Administrator, who will perform the actual COLA analysis. Under § 450.169(e), operators must then implement window closures based on the COLA analysis provided by the third party as flight commit criteria.

6.1 **Missions Requiring a Launch and Reentry Collision Avoidance Analysis.**

In accordance with § 450.169(a), a vehicle operator is required to establish window closures needed to ensure that a launch or reentry vehicle, any jettisoned components, or payloads meet COLA criteria for each orbital or suborbital launch or reentry, with the regulatory exception identified in paragraph 6.5 of this AC. Because objects in orbit are constantly in motion, each separate launch or reentry attempt requires a separate analysis to account for the planned location of all objects in orbit that meet the screening time requirements in § 450.169(b).

6.2 **Launch and Reentry Collision Avoidance Criteria.**

6.2.1 Confirmation of Mission Criteria.

As discussed in paragraph 6.6 of this AC, COLA analysis is performed by a third party identified by the FAA, based on the input data submitted by an operator in accordance with § 450.169 and Appendix A to part 450. Based on the analysis provided by the COLA processing entity, an operator must establish window closures to ensure that the launch or reentry vehicle, any jettisoned components, or payloads meet the criteria set forth in § 450.169(a). It is the responsibility of the vehicle operator, and not the COLA processing entity, to ensure compliance with the appropriate mission criteria in § 450.169(a). Under § 450.169(a) for each of three categories of cataloged space objects, operators must satisfy one of several mission criteria by either ensuring a sufficiently low probability of collision or maintaining a minimum separation distance between the objects launched or reentered and cataloged space objects.

6.2.2 Mission Criteria for Inhabitable Objects.

In accordance with § 450.169(a)(1), for inhabitable objects, one of three criteria below must be met: (i) The probability of collision between the launching or reentering objects and any inhabitable object must not exceed 1×10^{-6} ; (ii) The launching or reentering objects must maintain a minimum ellipsoidal separation distance of 200 km in-track and 50 km cross-track and radially from the inhabitable object; or (iii) The launching or reentering objects must maintain a minimum spherical separation distance of 200 km from the inhabitable object.

6.2.2.1 All orbital launch and reentry trajectories vary the most in the direction of travel. This is a result of the extreme velocities required to reach or maintain a stable orbit. The three acceptable criteria apply the most conservative analysis in the in-track direction. Ellipsoidal analysis reduces the distances in the cross-track and radial components. This eliminates potential closures where orbits do not actually cross because one object is significantly higher or in a different orbital plane. An analysis of probability of collision is the highest fidelity analysis and typically provides the greatest launch window availability.

6.2.2.2 A launch or reentry operator should consider variables in the launch or reentry trajectory to determine which safety criteria best suits the space activity. For example, missions with no trajectory covariance (error) cannot be evaluated for probability of collision. Also, highly elliptical trajectories (GEO)-transfer orbits or interplanetary missions) should avoid ellipsoidal analysis as the in-track vector is significant in the radial direction. In all cases, the launch and reentry operator should select the criteria that best fit the available data and the planned activity.

Note: GEO is an acronym for geosynchronous or geostationary earth orbit.

6.2.3 Mission Criteria for Objects that are Neither Inhabitable nor Orbital Debris.

6.2.3.1 In accordance with § 450.169 (a)(2), for objects that are neither orbital debris nor inhabitable, one of the two criteria below must be met: (i) The probability of collision between the launching or reentering objects and any object must not exceed 1×10^{-5} ; or (ii) The launching or reentering objects must maintain a minimum spherical separation distance of 25 km from the object. Objects that are not classified as debris or inhabitable are sometimes referred to as “active payloads.”

6.2.3.2 Launch and reentry operators should note that the density in low Earth orbit varies greatly with altitude. For planned launch trajectories that pass through or end between 400 km and 800 km, operators are encouraged to consider probability of collision as the analysis of choice. If the operator does not have enough information to conduct a probability of collision analysis, the operator should consider obtaining a preliminary COLA analysis as soon as a practical trajectory can be determined (even

1 to 2 months prior to launch). For example, a mission that intends to burn an upper stage to extinction rather than target a specific altitude would have a covariance (error) of such a high magnitude that probability of collision analysis would not produce a result that predicts any high or even moderate risks. The covariance would effectively water down the risk analysis. A launch operator that must maintain the 25 km buffer zone during the full 3-hour post-launch trajectory may find excessive launch closures for trajectories passing through 400 km to 800 km. Therefore, an early analysis may allow the operator to alter the launch trajectory, lower the payload deployment altitude, and maintain the original launch schedule.

6.2.4 Mission Criteria for Orbital Debris.

6.2.4.1 In accordance with § 450.169 (a)(3), for all other known orbital debris, identified by the FAA or other Federal Government agency as a large object having a radar cross section greater than 1 m² and medium objects with radar cross section 0.1 m² to 1 m²; (i) The probability of collision between the launching or reentering objects and any known orbital debris must not exceed 1×10^{-5} ; or (ii) The launching or reentering objects must maintain a minimum spherical separation distance of 2.5 km.

6.2.4.2 Most cataloged debris are small objects. However, launch and reentry operators should consider significantly large debris, rocket bodies for instance, worthy of additional caution. Large objects are well tracked and, because they are not easily perturbed, the orbit predictions should be considered highly accurate until the rocket body nears atmospheric reentry. If a large debris object is identified by a COLA processing entity with a radial or cross-track distance less than 2.5 km, the operator should exercise judgment regardless of the in-track distance. As the use of probability of collision accounts for this risk, that mode of analysis is recommended. When stand-off distance is used, an operator may request analysis at distances greater than 2.5 km for debris and extract the closures that meet the regulated criteria as well as other potentially risky situations.

6.3 **Screening Times for Mission Analysis.**

Section 450.169(b) prescribes screening time, or phases of launch or reentry during which an operator must ensure compliance with § 450.169(a). Operators need not obtain COLA analysis or implement mission criteria under § 450.169(a) for phases of launch or reentry not listed in § 450.169(b).

- 6.3.1 In accordance with § 450.169(b)(1) for a suborbital launch vehicle, the screening time is the entire segment of flight above 150 km.
- 6.3.2 In accordance with § 450.169(b)(2) for an orbital launch, during ascent, the screening time is from a minimum of 150 km to initial orbital insertion and for a minimum of 3 hours from liftoff. A launch operator may provide information for a longer analysis in some instances. For example, a GEO-transfer orbit typically takes 10.5 hours to complete one orbit. Therefore, any data provided to the COLA processing entity that may account for separation or deployment maneuvers may be useful in characterizing the risks to low Earth orbit satellites and human spaceflight vehicles.
- 6.3.3 In accordance with § 450.169(b)(3), for reentry, during descent, the screening time is from initial reentry burn to 150 km altitude. Reentry should be considered an orbital maneuver. The *18th Space Defense Squadron (SDS) Spaceflight Safety Handbook for Satellite Operators* contains the processes and information that may prove helpful to commercial operators in clearing orbital maneuvers.
- 6.3.4 In accordance with § 450.169(b)(4), for disposal, during descent, the screening time is from initial disposal burn to 150 km altitude. For some disposal activities initiated from highly elliptical orbits it is possible to have portions of the trajectory dip below the 150 km point during the perigee (closest point to the Earth in an orbit). A launch or reentry operator should exercise judgement if disposal from highly elliptical orbits and provide the best available data through the orbital maneuver trajectory clearing process prior to executing the reentry attempt.
- 6.3.5 When providing mission trajectory, the timespan should include trajectories above 150 km. It is helpful to provide data points that begin below the 150 km criteria or end below 150 km for reentry, so that the entire period covered by the regulation can be analyzed. Further, most reentries will not include an ascent after the vehicle passes the 150 km point. If that is not the case, it is recommended that the operator highlight the reentry to the FAA and the COLA processing entity.

6.4 **Rendezvous.**

In accordance with § 450.169(c), planned rendezvous operations that occur within the screening time frame set forth in § 450.169(b) are not considered a violation of collision avoidance if the involved operators have pre-coordinated the rendezvous or close approach. A launch operator may choose to launch directly into the orbital plane of an orbital space object (including a space station). This direct approach does not allow the rendezvous object to perform collision avoidance maneuvers if the launched object(s) approach prematurely. In these instances, it is vitally important for the launch operator to pre-coordinate with the rendezvous object owner.

6.5 **Exceptions to Performing a COLA Analysis.**

In accordance with § 450.169(d), the COLA analysis is not required for any launched object if the maximum planned altitude by that object is less than 150 km.

6.6 **Entity to Perform COLA Analysis.**

6.6.1 As of the publication of this AC, the 19th SDS is now the most common COLA processing entity while the 18th SDS maintains the most extensive space object catalog. The DoD is also the only entity legally authorized to provide data collected by the worldwide network of government space sensors, in accordance with U.S.C., Title 10, Subtitle A, Part IV, Chapter 134, § 2274. Commercial operators interfacing with the 19th SDS to perform a COLA analysis should follow the procedures outlined in the *18th SDS Launch Conjunction Assessment Handbook*. Commercial operators are encouraged to review these procedures even if engaging with an entity other than the 19th SDS for COLA processing, as this Handbook contains helpful information and guidance.

6.6.2 Commercial operators interfacing with an entity other than the 19th SDS for COLA processing should follow the procedures identified by that entity for submitting COLA data. Per § 450.169(e), the FAA may identify another Federal entity for COLA processing, or alternative entities may be acceptable if agreed to by the Administrator.

6.7 **Launch Operations.**

In accordance with § 450.169(e)(1), the launch operator must establish flight commit criteria based on the results of the COLA. Flight commit criteria are used to ensure safety with respect to various conditions that change with the launch day conditions. Specifically, the flight commit criteria for COLA are launch holds for identified window closures, as provided by the COLA results.

6.8 **Analysis Uncertainty.**

6.8.1 In accordance with § 450.169(e)(2), the collision avoidance analysis must account for uncertainties associated with launch or reentry vehicle performance and timing. Space launch activities involve massive changes in velocity and direction as vehicles accelerate from a standstill to orbital velocities of 7 km per second. Therefore, a one (1) second delay in liftoff time would result in a launch vehicle position that differs from the intended position. A liquid-fueled rocket commonly has a variation in actual liftoff time due to engine spool-up time. Vehicle performance variations could occur due to thrust, unexpected drag, or high-altitude winds. Operators should evaluate and account for variations that could realistically alter their vehicle's position. Reentry operators should account for variations in the deorbit burn start time, as well as engine performance variations.

6.8.2 The most common approach to account for these uncertainties is to provide the covariance in the trajectory file. Covariance is developed by running a series of trajectory simulations while randomly varying the possible variations. The covariance matrix is a representation of the standard deviations in error in in-track, cross-track, and radial directions. A covariance matrix is necessary to perform a probability of collision analysis. If the covariance is not provided, then the probability of collision cannot be properly assessed, and the operator will be limited to using the separation distance to establish window closures. Even when using separation distance, operators should account for uncertainties. For example, a launch operator with significant launch liftoff time may account for the uncertainty by assuring the second before and after the planned liftoff are also clear of window closures. This is a common practice for air-dropped launch vehicles.

6.9 **Timeline for Establishing Launch Window.**

- 6.9.1 To allow sufficient time for COLA processing entities to provide the COLA analysis, § 450.169(f) requires operators submit input data, detailed in Appendix A to part 450, to the processing entity within specific timeframes. Figure 1 identifies the procedures and timelines for operators to provide COLA data to the FAA and the COLA processing entity (likely the 19th SDS, as noted above).
- 6.9.2 The deadlines to submit COLA analysis are different for New Operators and Experienced Operators under § 450.169(f).
- 6.9.3 For New Operators, the vehicle operator must file the initial COLA request with the processing entity no later than 15 days prior to the mission to satisfy the requirements found in § 450.169(f)(1)(i). This timeframe provides additional processing time for the vehicle operator to confirm the launch or reentry trajectory with the processing entity.
- 6.9.4 For an Experienced Operator, the deadline to submit the initial COLA request is 7 days prior to the mission, in accordance with § 450.169(f)(1).
- 6.9.5 For all Operators, the Administrator may agree to an alternative time frame in accordance with § 404.15.

- 6.9.6 Vehicle operators should be aware the 19th SDS specifies an earlier timeframe for submitting the COLA request.
- 6.9.6.1 According to the 19th SDS, New Operators should submit their request 30 days in advance of the launch. Experienced Operators should submit their request 15 days in advance of the launch. The timelines established in § 450.169(f)(1) account for the time necessary to evaluate and process COLA data. The 19th SDS performs many functions in addition to processing COLA data. For this reason, the FAA encourages operators to meet the 19th SDS timelines to ensure COLA products are available to meet the operator's launch dates.
- 6.9.6.2 The vehicle operator must receive the results of the COLA from the processing entity no later than 3 hours prior to launch to satisfy the requirements found in § 450.169(f)(2). The mission may proceed if the results meet the appropriate license criteria, which are discussed in the next subsection. For a launch delay, in accordance with § 450.169(e)(3), the vehicle operator can resubmit data at least 12 hours prior to the beginning of a new launch or reentry window.

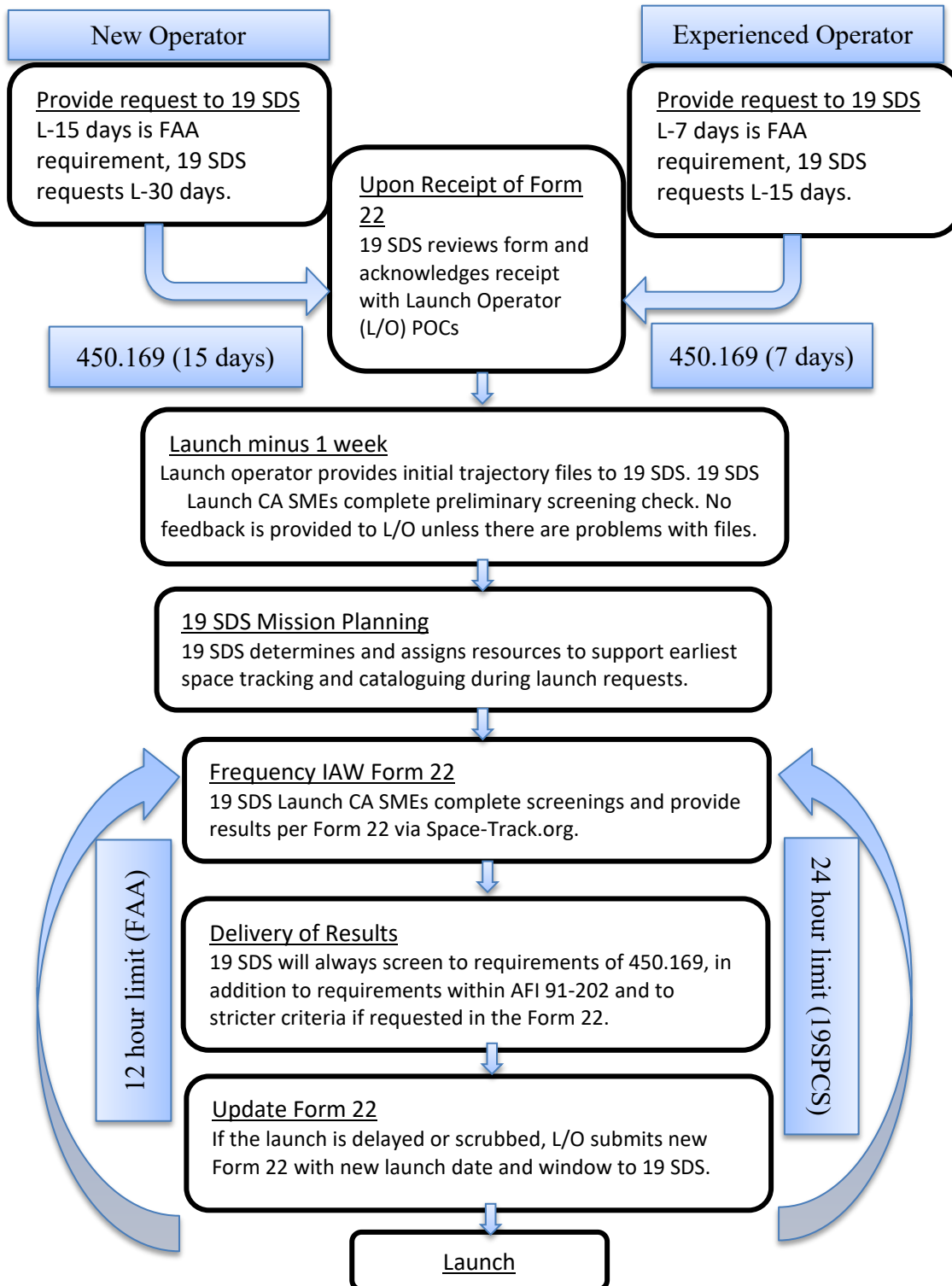


Figure 1 – Timeline for the COLA process

7 COLLISION ANALYSIS WORKSHEET.

Pursuant to § 450.169(f), operators must prepare a collision avoidance analysis worksheet for each launch or reentry using a standardized format that contains the input data required by Appendix A to part 450.

7.1 General Submittal Process.

7.1.1 If the processing entity is 19th SDS, then the FAA collision analysis worksheet information could be used to assist in filling out the two forms that 19th SDS requires.

7.1.1.1 Both can be accessed through the 19th SDS website at <https://www.space-track.org/documentation#/odr>.

7.1.1.2 The first is Form 22 to request that 19th SDS perform a COLA analysis for the launch operator. It is accessed by choosing from the web page the item “Launch Conjunction Assessment” and then “Form 22 – Launch Collision Avoidance Request.” Following the main body of the form, the document provides detailed instruction on how to fill out the specific form entries.

7.1.1.3 The second is Form R-15/VIM which specifies vehicle information. It is accessed by choosing from the web page the item “*Launch Early Orbit Determination*” and then “Form R-15/VIM Report.”

7.1.2 Much of the collision analysis worksheet in part 450 Appendix A and Launch Conjunction Assessment Form 22 consists of basic information, such as what and when is the mission, what the significant flight events are, and when and how communication between the launch operator and processing entity occur. Form R-15/VIM Report consists of details of which bodies will remain in orbit after a launch. Regardless of which processing entity is involved with the COLA, the *18th SDS LCA Handbook* contains valuable information on how to develop COLA products.

7.2 Normal Trajectory Specifications.

7.2.1 The worksheet requires a table of orbital parameters and events to satisfy part 450, Appendix A, paragraph (a)(6), Orbital Parameters. For the SDS forms, these items are entered using an R-15 form/VIM Report, Attachment A. These items include the sequence of events from liftoff to final injection into operational orbit, that may include separation of booster(s)/stage(s), motor ignition(s)/cutoff(s), jettison of pieces (fairings etc.), maneuvers and reorientation, deorbit and ejection(s) of packages/booms, and so forth. The events are defined by time, latitude, longitude, altitude, and speed in earth-rotating coordinates.

- 7.2.2 The final attained body orbits are defined in terms of Keplerian orbital parameters. The orbits follow elliptical paths and so the orbital parameters define specific elliptical path quantities. The parameters include:
- apogee altitude,
 - perigee altitude,
 - eccentricity,
 - semi-major axis radius,
 - inclination,
 - true anomaly,
 - argument of perigee, and
 - right ascension of the ascending node (RAAN), also called the Longitude of the ascending node.
- 7.2.3 The vehicle operator must provide nominal trajectory files for each mission body that reaches 150 km altitude for the collision analysis worksheet found in part 450 Appendix A, section (d), *Trajectory Files*, for the time durations discussed in Section 7.3 of this AC. The format of these files depends on requirements of the COLA processing entity. For submitting trajectory files to 19th SDS, follow the LCA Handbook that details file format and their required content.
- 7.2.4 Trajectories require position and velocity to be defined in accordance with part 450, Appendix A, section (d) for all components at sufficiently frequent time points that interpolation may be used with negligible error. Paragraph 7.3 of this AC discusses the screening criteria based on the probability of a conjunction event. If this option is selected, at each stated time of the trajectory, the applicant must provide the position covariance, in accordance with part 450, Appendix A, section (d)(3). The position covariance is based on the Gaussian distribution, and corresponds to state vector uncertainty of the position state vector computed using a set of Monte Carlo generated dispersed set of trajectories that account for uncertainty in the initial lift-off condition, Guidance and Performance, drag, etc. Dispersed trajectories are discussed in AC 450.117 *Normal Trajectory Analysis*, and AC 450.119 *Malfunction Trajectory Analysis*. In accordance with part 450, Appendix A, section (d)(2), the radial cross section of each object must be provided for each object file and is specified in the worksheet.

7.3 Screening Categories.

- 7.3.1 Part 450 license criteria contains several options for meeting the requirements specified by § 450.169(a). These options are defined in terms of screening categories, specified on the collision analysis worksheet of part 450, Appendix A, Section (e). Complete details and limitations on selecting the category can be found in the 19th SDS LCA Handbook. The vehicle operator may select probability of collision or separation distance approaches. The most effective analysis is the probability of collision approach, provided the operator can produce realistic covariance data. Operators are highly encouraged to develop a repeatable process to use probability of collision analysis.
- 7.3.2 The least conservative screening criteria, i.e., least likely to be violated, is based on the probability of collision of the conjunction event specified by part 450 Appendix A, Section (d)(3). These criterion require that the launch operator provide the position covariance at each state time. The covariance matrix should be in vehicle-centered frame, ideally the UVW coordinates. U (“radial”) is the unit vector in the radial direction, W (“cross-track”) is the unit vector normal to the launch vehicle’s inertial orbit plane, and V (“in-track”) is the unit vector which completes the right-handed coordinate system. To comply with § 450.169(a), probability of collision criteria thresholds must be either 1×10^{-6} for inhabitable objects, or 1×10^{-5} for neither inhabitable objects nor orbital debris.
- 7.3.3 If the vehicle operator does not provide the position covariance, a stand-off radius of either ellipsoidal or spherical criteria is employed. The size and shape of the exclusion volume, to avoid a conjunction event, is chosen by the vehicle operator and noted in the request for analysis (on the Form 22 for 19th SDS analysis). Alternatively, if the vehicle operator provides a positional covariance that is either too large or too small to use probability of collision analysis confidently, the FAA may inform an applicant that stand-off distance screening, either ellipsoidal or spherical, is appropriate instead of probability of collision screening. For instance, if an operator is burning an upper stage to exhaustion and not targeting a specific altitude, the positional covariance would be so large it would create unrealistically low probability of collision analysis.
- 7.3.4 The methodology used by the 19th SDS for performing the probability of collision is based on Foster’s method.¹ A more detailed description of the technique is provided in pages 38-45 of the *Spaceflight Safety Handbook for Satellite Operators*.

¹ Alfano, Salvatore, A Numerical Implementation of Spherical Object Collision Probability. The Journal of the Astronautical Sciences, Vol. 53, No. 1, January-March 2005, pp. 103-109.

7.4 Common Errors.

7.4.1 The vehicle operator should make note of the following common errors encountered with previous operators in processing their COLA analysis.

- The trajectory file contains values with the incorrect sign (plus or minus) on relevant parameters.
- The trajectory of objects before and after deployment are not continuous, i.e., pre-and post-deployment do not match.
- The trajectory files are missing some deployed objects.
- The trajectory file contains missing values or repeated values, most commonly a frozen trajectory model output is recorded.
- The trajectory file starts above 150 km, the minimum as required by the regulation. However, the trajectory should begin before 150 km, so that the analysis can start at the prescribed value.
- The covariance is an unrealistic or impossible value, specifically it is smaller than the vehicle size or extremely and unrealistically large.
- The deployed objects have a zero velocity.

7.4.2 Incorrect data files prevent the correct launch conjunctions from being identified. To check the trajectory files, one suggestion is to use a commercially available software tool designed for launch trajectory and orbit propagation. Two such tools are Systems Tool Kit (STK) offered by AGI, an ANSYS company and FreeFlyer® Astrodynamic Software by a. i. solutions. Both platforms provide visualization of the provided trajectory files. These platforms also provide the opportunity to provide a COLA analysis when loaded with the catalog of space debris. The catalogs are available from Space Track as well as through commercial providers, including STK and CelesTrak. While these tools are useful guides to troubleshoot files and provide analyses on COLA, they cannot be utilized in place of the process. For one, these catalogs do not have the covariance of space debris necessary to meet the requirements of § 450.169.

8 SPECIAL CONDITIONS: GROUPING OF OBJECTS AND CLUSTER DEPLOYMENTS.

- 8.1.1 Part 450, appendix A, paragraph (d) directs operators to prepare separate trajectory file for each jettisoned component, and payload. However, there are several instances when it simply is not practical to provide a separate file for each such object.
- 8.1.2 For example, if there are a large number of deployments (i.e. more than 20), then the number of files becomes difficult to manage and analyze. It is possible to obtain a waiver to this requirement. Several objects can be grouped together and assessed as one object by providing a single file. For the collection of the group of objects, an effective size and corresponding covariance is provided which represents the collection of individual objects in the group.
- Intra grouping requirement (distance between groups – representative and substantiated in waiver application).
 - Inter grouping requirement (distance between objects – appropriate and substantiated in waiver application).
- 8.1.3 If a vehicle operator needs to request a waiver from the requirement in Appendix A to provide individual trajectory files, the operator should demonstrate that the grouping of these objects is appropriate for the specified screen period. A petition for waiver must include the reason why granting the request for relief is in the public interest and will not jeopardize the public health and safety, safety of property, and national security and foreign policy interests of the United States as specified in § 404.5(b)(3). To demonstrate that the waiver would not jeopardize the public health and safety, the launch operator should show that the launched objects remain sufficiently close to one another, such that the trajectory file is representative for all objects in the grouping, and that the objects remain in close proximity such that the effective size accurately reflects the potential dispersion of objects, through the screening timeframe.
- 8.1.4 For the deployment of satellites, the National Aeronautics and Space Administration (NASA), and the 19th SDS provide best practices for successful deployment to ensure early orbit tracking.^{2,3} Vehicle operators should avoid deploying payloads laterally, with no change in altitude. Because the satellite and launch vehicle remain at the same altitude, there is greater potential for re-contact or collision. Variations in altitude provide for natural dispersions in object orbits. For the specification of trajectories, improperly specified deployments can result in an inadvertent re-contact.

² NASA/SP-20205011318 *Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook*, dated December 2020, available on the Space Track website.

³ JSpOC Recommendations for Optimal CubeSat Operations, dated August 4, 2015.

- 8.1.5 Early planning is also important when there are multiple deployments from a non-stabilized platform. In this scenario there is no covariance because the nominal trajectory is unavailable. It may be extremely difficult to discriminate between payloads that are randomly deployed. Screening for conjunctions is also complicated and necessitates a specific “shotgun cloud” approach tailored to the launch activity specifics. A shotgun cloud approach entails clearing a swath of space along the nominal trajectory of the payload deployer or upper stage large enough to cover the deployment and subsequent spreading out, in random directions, of multiple objects.

9 SPECIAL CONDITIONS: GROUPING OF TRAJECTORY FILES.

- 9.1 In some cases, it is not possible to provide a single trajectory file for a launch that is valid throughout the identified launch window (this is typical of a rendezvous trajectory that is targeting a specific orbital plane). A launch vehicle that performs guidance maneuvers to target a specific destination follows a different trajectory depending on the time of launch. Because launch sites rotate as the Earth revolves under fixed orbital planes, a launch differential of 1 second can change the trajectory significantly, for the purpose of a COLA analysis. For this class of launches, it is difficult and cumbersome to develop a trajectory file for every second of the launch window, and subsequently assess each file. It is possible, and advisable, to request a waiver to the requirement by providing bounding cases that are inclusive of the dispersion of the trajectory throughout the launch window.
- 9.2 For example, one recommended solution could be to provide an initial, intermediate, and final trajectory file that is representative of the possible range of trajectories. The waiver would need to include an engineering analysis justification to show that these cases are indeed representative of the range of potential trajectories. Additionally, the trajectory spacing must be such that the dispersion over time does not increase beyond intended screening standoff distances. As such, the probability of collision or separation distance from objects would be effectively analyzed.

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