U.S. Department
of Transportation
Federal Aviation
Administration

Advisory Circular

Subject: Tracking for Launch and Reentry Safety Analysis

Date: 09/29/2022

Initiated By: AST-1

AC No: 450.167-1

This advisory circular (AC) provides guidance for an operator to measure and record in real time the position and velocity of a launch or reentry vehicle during flight, in accordance with Title 14 of the Code of Federal Regulations (14 CFR) § 450.167, *Tracking*. Under § 450.167(a), the system used to track the vehicle must provide data to predict the expected impact locations of all stages and components, and obtain vehicle performance data in real time for comparison to pre-flight performance predictions. In accordance with § 450.167(b), an applicant must identify and describe each method or system used to meet these tracking requirements in their license application.

The Federal Aviation Administration (FAA) considers this AC an accepted means of compliance for complying with the regulatory requirements of § 450.167. It presents one, but not the only, acceptable means of compliance with the associated regulatory requirements. 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 the guidance is voluntary only and nonconformity will not affect rights and obligations under existing statues and regulations.

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

KELVIN B COLEMAN

Digitally signed by KELVIN B COLEMAN
Date: 2022.09.29 11:15:20 -04'00'

Kelvin Coleman
Associate Administrator
FAA, Office of Commercial Space Transportation

Contents

Contents (continued)

1 PURPOSE.

1.1 This AC provides guidance and an acceptable means of complying with the requirement to track the flight of a launch or reentry vehicle under 14 CFR § 450.167 using onboard hardware, launch site services, or other means. In addition, this AC provides an understanding of the current technologies and parameters used for implementing tracking services, which operators may use to meet the requirements of § 450.167. The real-time tracking guidance in this AC can also be used to meet tracking requirements when using a flight safety system for any phase of flight where an operator must implement flight abort in accordance with § 450.108.

1.2 **Level of Imperatives**.

This AC presents one, but not the only, acceptable means of compliance with the associated regulatory requirements. The FAA will consider other means of compliance that an applicant may elect to present. In addition, an operator may tailor the provisions of this AC to meet its unique needs, provided the changes are accepted as a means of compliance by the FAA. Throughout this document, the word "must" characterizes statements that directly follow from regulatory text and therefore reflect regulatory mandates. The word "should" describes a requirement if electing to use this means of compliance; variation from these requirements is possible but must satisfy the regulation to constitute an alternative 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 and reentry vehicle applicants and operators required to comply with 14 CFR part 450. The guidance in this AC is for those seeking a launch or reentry vehicle operator license, and licensed operators seeking to renew or modify existing vehicle operator licenses.

2.2 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 the FAA will not rely upon this guidance 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.

2.3 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 United States Code (U.S.C.) Statute.

- 51 U.S.C. Subtitle V, Chapter 509.

3.2 Related FAA Commercial Space Transportation Regulations.

The following 14 CFR regulations must be accounted for when showing compliance with § 450.167. The full text of these regulations 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 450.35, *Means of compliance*.
- Section 450.108, *Flight abort.*
- Section 450.145, *Highly reliable flight safety system*.
- Section 450.167, *Tracking.*

3.3 Related FAA Advisory Circulars.

FAA Advisory Circulars are available through the FAA website, http://www.faa.gov.

- AC 450.35-1, *Means of Compliance*, when published.

3.4 Related Industry and Government Documents.

- Air Force Space Command Instruction (AFSPCI) 91-701, *Launch and Range Safety Program Policy and Requirements*, dated February 1, 2019. https://static.e-publishing.af.mil/production/1/afspc/publication/afspci91-701/afspci91-701.pdf.
- Air Force Space Command Manual (AFSPCMAN) 91-710, Volume 2, *Range User Launch Safety Requirements Manual,* Volume 2, *Flight Safety Requirements*, dated July 13, 2017. https://static.e--publishing.af.mil/production/1/afspc/publication/afspcman91-710v2/afspcman91-710v2.pdf.
- Alaska Aerospace Corporation, *Pacific Spaceport Complex Alaska Commercial Launch Site Safety Manual*, dated May 2018. http://www.akaerospace.com/sites/default/files/download/Commercial%20Launch%20Site%20Safety%20Manual.pdf.
- Goddard Space Flight Center, *Space Network User's Guide* (SNUG), Revision 10, dated August 3, 2012. http://everyspec.com/NASA/NASA-GSFC/GSFC-Code-Series/450-SNUG_REV-10_50333/.
- National Aeronautics and Space Administration (NASA) Technical Standard, *Goddard Flight Facility Range Safety Manual*, GSFC-STD-8009, dated June 05, 2019. https://standards.nasa.gov/standard/gsfc/gsfc-std-8009.

- Powell, O., Dickens, Devin, and Lyle, Jack. 2017. *Space Launch Automation and Integration: A Common Architecture for Mission Assurance, Safety, and Launch Operations. 33rd Space Symposium*, Technical Track, Colorado Springs, CO, dated April 3, 2017. http://2019.spacesymposium.org/wp-content/uploads/2017/10/Powell_Rusty_Space_Launch_Automation_and_Integration.pdf
- Range Commanders Council (RCC), *Inter-Range Instrumentation Group (IRIG) Standard 106-19, Telemetry Standards*, dated July 2019. http://www.irig106.org/docs/106-19/106-19_Telemetry_Standards.pdf
- RCC Standard 262-14, C (G) – *Band and X (I) Non-coherent Radar Transponder Performance Specification Standard*, dated June 2014.http://www.irig106.org/docs/rcc/262-14_Radar_Transponder_Specification.pdf
- RCC Standard 319-14, *Flight Termination Systems Commonality Standard*, dated September, 2014. ADA620923.pdf (dtic.mil)
- RCC Standard 321-10, *Common Risk Criteria Standards for National Test Ranges*, dated December 2010. https://apps.dtic.mil/dtic/tr/fulltext/u2/a639830.pdf
- RCC Standard 324-11, *Global Positioning and Inertial Measurements Safety Tracking Systems Commonality Standard*, dated February 2011. https://www.wsmr.army.mil/RCCsite/Documents/324-11_GPS_Inertial_Msmts_Safety_Tracking_Sys/324-11_GPS_Inertial_Msmts_Safety_Tracking_Sys.pdf
- U.S. Air Force, *Eastern Range User Handbook*, 45th Space Wing, dated January 2019. https://www.patrick.af.mil/About-Us/New-Customer-Information/
- U.S. Air Force, *Western Range User Handbook*, 30th Space Wing Instruction 13-203, dated August 26, 2009. https://static.e-publishing.af.mil/production/1/30sw/publication/30swi13-203/30swi13-203.pdf

4 DEFINITIONS.

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

4.1 State Vector

A set, at a minimum, is comprised of three-component positions and three-component velocities with a point in time along a vehicle's trajectory. A state vector may also include vehicle mass, thrust, orientation, angular velocity, and other parameters.

4.2 Verified Tracking Source

A tracking source is considered to be verified when it produces the same solution as another independent tracking source. A verified tracking source must be re-verified after a shock event such as stage separation.

5 ACRONYMS.

AC – Advisory Circular

AFSPCI – Air Force Space Command Instruction

AFSPCMAN – Air Force Space Command Manual

AFSS – Autonomous Flight Safety System

AST – Office of Commercial Space

CFR – Code of Federal Regulations

DOP – Dilution of Precision

ELV – Expendable Launch Vehicle

FAA – Federal Aviation Administration

FSS – Flight Safety System

GPS – Global Positioning System

GRGT – Guam Remote Ground Terminal

GSFC – Goddard Space Flight Center

IIP – Instantaneous Impact Point

IMU – Inertial Measurement Unit

IRIG – Inter-Range Instrumentation Group

MOCC – Mission Operation Control Center

NAS – National Airspace System

NASA – National Aeronautics and Space Administration

NIMO – Network Integration Management Office

RCC – Range Commander’s Council

RLV – Reusable Launch Vehicle

RSS – Root of the sum of the squares

RTS – Range Tracking System

RV – Reentry Vehicle

TDRSS – Tracking and Data Relay Satellite System

TMIG – Telemetered Inertial Guidance

U.S.C. – United States Code

WSC –White Sands Complex

6 OVERVIEW.

In accordance with § 450.167(a), during the flight of a launch or reentry vehicle, an operator must measure and record in real-time (i.e. track) the position and velocity of the vehicle. The system used to track the vehicle must provide data to predict the expected impact locations of all stages and components and to obtain vehicle performance data for comparison with the pre-flight performance predictions.

6.1 Importance of Tracking Data.

Tracking data enables operators to compare post-flight data under § 450.103(d), respond to mishaps in accordance with § 450.173, and satisfy the flight abort requirements of § 450.108(f)(1) when flight abort is used as the hazard control strategy under § 450.107.

6.1.1 Tracking Data used for Post-flight Reporting.

An operator must employ a process for evaluating post-flight data in accordance with § 450.103(d). Recorded tracking data is used to compare predicted performance to actual performance. The tracking data is also used to ensure the flight was conducted in accordance with mission analyses and enables operators to identify and resolve any issues affecting public safety before the next flight occurs. Under § 450.215(b)(4), the operator must provide the actual trajectory flown if requested by the FAA.

6.1.2 Tracking Data during a Mishap.

Mishaps present a risk to public safety. Tracking data sufficient to predict the location of any vehicle or component impacts following an off-nominal situation can enable an appropriate response, such as knowing where to apply fire suppression resources, or where to evacuate the public to protect against predicted toxic plumes. Tracking data obtained pursuant to § 450.167(a) would enable operators to effectively implement their mishap response plan in accordance with § 450.173. Should a mishap occur midflight, tracking data should be recorded at least as long as necessary to establish expected impact locations of all stages and components, or until vehicle break-up occurs.

6.1.3 Tracking Data for Flight Abort.

The FAA requires that all part 450 licensees perform vehicle tracking in accordance with § 450.167, irrespective of the hazard control strategy selected under § 450.107. The FAA notes, however, that for phases of flight that use flight abort as a hazard control strategy, real-time position and velocity of the vehicle are used to evaluate flight abort rules under § 450.108. In accordance with § 450.108(f)(2)(i), the flight safety system must abort flight when valid real-time data indicates that the vehicle has violated any flight safety limit. As discussed in paragraph 8 below, the FAA requires tracking data to be as close to real time as practicable, and pursuant to § 450.108(d)(4), operators must account for any time delay in their flight safety limits, including uncertainties between the violation of a flight abort rule and the time when the flight safety system is expected to activate. Therefore, real-time data is necessary to meet the flight safety limit objectives of § 450.108(c). For guidance on flight abort rules see AC 450.108 Flight Abort Rule Development.

6.1.3.1 The flight abort rules established in accordance with § 450.108(f)(2)(iii) govern the conduct of the launch or reentry if tracking data is invalid and further flight has the potential to violate a flight safety limit. In the event valid data is lost, an operator must use flight safety limits to calculate when flight abort rules should activate the flight safety system, which could include destruction of the vehicle amongst other actions, in accordance with § 450.108(d)(3). If at any point during the mission flight abort is required, the lack of valid tracking data will trigger the data loss abort rule.

6.1.3.2 Data loss flight time, also known as green numbers on the Eastern Range, is the time during which the launch vehicle moves from normal flight to activation of the flight abort system to ensure the safety of a protected area. See AC 450.108-1, *Flight Abort Rule Development* for more information on loss of data used to evaluate flight abort rules, including acceptable durations of data loss.

6.1.3.3 **Scenario**: An operator is flying with two tracking sources. Both of the tracking sources are providing the same solution therefore both sources are validated. If one tracking source is lost, the remaining tracking source is still considered to have valid data. A stage separation event causes a shock. At that point, the single tracking source becomes invalid and must be re-validated by a new source. If it is not validated, the operator would need to implement an approach (e.g. data loss flight times) to account for the loss of valid data in order to evaluate the flight abort rules in accordance with § 450.108(d)(3).

7 TRACKING MEASUREMENT.

7.1 General Guidance.

7.1.1 Applicability and Availability of each Tracking Method.

Each method of tracking has inherent advantages and disadvantages and cannot be universally applied at every phase of flight for every vehicle. Additionally, with the exception of local suborbital flights, geographical limitations of launch site support services, such as radar, necessitate the use of multiple services throughout a complete launch or reentry mission. This situation is due to inherent coverage limitations from telemetry and radar line of site. The intent of this paragraph of this AC is to provide an overview for the applicability and availability of each tracking method, as well as define the publicly available guidance documents that state common standards for each.

7.1.2 Tracking Methodologies.

Historically, a combination of methods such as skin- or beacon-track radar, optical tracking, Global Positioning System (GPS), transponders, or Inertial Measurement Units (IMU) validated with another IMU source, have been utilized to provide tracking throughout a mission. Other metric tracking systems methods proposed by an applicant would be evaluated for reliability, accuracy, and timeliness to provide an equivalent level of safety. These metrics are discussed in paragraph 8 of this AC for recommended fidelity and acceptability.

7.1.3 Launch Sites.

Each launch site has unique capabilities and systems that users need to be familiar with before deciding on which methodology will be utilized for tracking to meet the requirements of § 450.167. For launch from a Federal launch site, it is advisable to contact the associated safety office for a Range User Handbook when determining which system will be utilized for each mission. Services available at federal launch sites may not be available at commercial launch facilities. Design changes may be required if commercial tracking capabilities/systems are not available. Although each launch site maintains their own requirements for tracking systems, the requirements imposed at Federal launch sites are similar to the tracking requirements of part 417, and would meet the requirements of § 450.167. The following are requirements imposed by AFSPCMAN 91-710 at Federal launch sites, which may serve as guidelines for operators in developing a means to comply with § 450.167 when operating at non-Federal launch sites:

- Each tracking source and plan is designed so that no single order vehicle failure or ground based instrumentation failure mode could cause the loss of all tracking sources.
- Data from one tracking source will not influence another tracking source.
- At least two tracking sources should be operationally verified prior to launch.

- No less than two adequate and independent tracking sources from lift-off to orbital insertion (or past the final gate specified by flight analysis, analogous to end of flight abort conditions under § 450.108(e)) for an orbital flight, or to the end of powered flight for a suborbital launch.
- Any gap in coverage should not occur at the same time as any planned switching of command transmitters.[1]

7.2 **Applicability of Various Tracking Methods**.

7.2.1 Launch Vehicle Flights.

Each method of tracking listed in paragraph 7.3 of this AC may be utilized for any phase of launch so long as it can measure and record in real-time the position and velocity of the vehicle. At least one verified tracking source should be operational for all phases of launch for which tracking is required under § 450.167.

7.2.2 Reentry Vehicle Flights.

Each method of tracking listed in paragraph 7.3 of this AC can be used during and after the de-orbit burn up to and following the plasma phase of reentry, at which point the only tracking methods known to currently work are radar and/or optical tracking. Note that during reentry, radar and optical signatures of RVs are dependent upon several complex phenomena, which can complicate both pre-flight modeling tracking and post-flight analysis. As explained in paragraph 8 below, in order to satisfy § 450.167(b), an applicant should include the outcomes of any such modeling and analysis in their description of each tracking method or system used. Examples of these phenomena include vehicle shape and material construction, hard body surface temperature, trajectory conditions (altitude, velocity, and orientation), and details of the flow field surrounding and behind the vehicle. These flow field details include local distribution of temperature and chemical composition including plasma for part of the trajectory, and flow field turbulence. Position and velocity data recorded on board the Reentry Vehicle (RV) during plasma phase of reentry using IMU(s) must be provided to FAA post-flight to compare the actual and predicted nominal performance of the vehicle upon request, in accordance with § 450.215(b)(4).

7.2.3 Stage or Component Impact Locations.

In accordance with § 450.167(a), the system used to track the vehicle must provide data to predict the expected impact locations of all stages and components. Section 450.167 does not require operators to track individual components all the way down to the earth's surface or body of water; the FAA requires only that operators track the vehicle in real time for the entirety of the flight such that they could identify expected impact locations of all stages and components. The FAA requires that operators employ a method of tracking sufficient to predict expected impact landings so that operators could properly respond in the event of an unplanned event or emergency. The use of

[1] Air Force Space Command Manual (AFSPCMAN) 91-710, Volume 2, *Range User Launch Safety Requirements Manual,* Volume 2, *Flight Safety Requirements*, July 13, 2017.

state vector data provided by telemetry and tracking services should be sufficient to predict impact locations of staging and components at a 3-sigma level in order to account for systematic dispersions such as velocity errors and environmental dispersions such as wind.

7.3 Availability of Tracking Methods.

The following is a discussion of current tracking methods. An operator may propose new methods or a combination of new and current methods to meet § 450.167.

7.3.1 Telemetered Inertial Guidance.

The telemetered inertial guidance (TMIG) method of tracking is widely used as a primary independent source of real-time and/or post-operation tracking data. These systems receive, record, and relay signals from launch vehicles, satellites, and other aeronautical vehicles to determine position and performance. Signal data is collected and processed by a central telemetry hub and then forwarded to operators. This method relies upon a transmitter from the launch vehicle and a telemetry ground receiver geographically dispersed around the launch site. Coverage, number of antennas, track limits, and other restrictions are entirely dependent upon which launch site is being utilized. However, timing, modulation, formats, and rates are all Inter-Range Instrumentation Group (IRIG) compatible at each federal range. The IRIG is the standards body of the Range Commanders Council (RCC). It is generally recommended at federal ranges to validate inertial guidance against another accepted source, unless the inertial guidance solution has already been qualified under RCC 324. Federal ranges have published locations and antenna characteristics in user or instrumentation guides. Mobile solutions are generally available for use at commercial spaceports but should be funded and have schedules de-conflicted prior to committing to their use for a commercial mission.

7.3.2 Radar Beacon Tracking.

Ranges typically support beacon tracking of coherent or non-coherent C-band transponders. These transponders provide metric data in real time and post-flight in the form of time, range, azimuth, elevation, and coordinates. Transponders are tracking aids for radars and extend the range and accuracy of in-place radars by replying to coded pulse interrogations from ground radars with a single return pulse in the same band. These transponders operate in the C (G)-band and X (I)-band as non-coherent, pulse-type transponder equipment. The transponder return pulses allow differentiation of stages of the vehicle or payload when in close proximity, overcoming the natural inaccuracy of skin track radars downrange. Guidance for radar transponder usage and standards at federal ranges can be found within RCC 262-14. RCC 324 is an acceptable means of compliance for the airborne tracking sources such as C-Band transponders used with ground based command systems and for GPS receivers and inertial measurement units used as airborne tracking data sources.[2]

[2] RCC Standard 324-11, *Global Positioning and Inertial Measurements Safety Tracking Systems Commonality Standard*, dated February 2011.

7.3.3 Radar Skin Tracking.

Radar Skin Tracking is a method that is generally available at Federal launch facilities, though radar availability is unique to each range. Generally, these are very long-range radars operating in the C-band spectrum that can provide line of sight coverage to hundreds or thousands of miles. Characteristics such as antenna size, gain, beam width, polarization, and other technical classifiers should be discussed with the individual ranges. On both Eastern and Western ranges, the radars are geographically distributed throughout the coast, but the data are processed centrally at the range. Mobile solutions such as radars are available but have a high cost with movement and setup. Each range radar has advantages and disadvantages associated with it and users are encouraged to become familiar with the peculiarities, locations, and design of range instrumentation through user handbooks and instrumentation guides before designing a mission-tracking plan to comply with § 450.167. A downfall of utilizing radar skin tracking as the only tracking source is that when the vehicle being tracked is at a great distance from the radar, it is difficult to differentiate the deployed objects in close proximity such as payload, first stage, fairings, etc. due to weak signal strength. This difficulty is overcome by utilizing beacons as stated in paragraph 7.3.2 of this AC, but it is still recommended not to utilize radar skin tracking as the sole source of flight tracking as it is more likely to lose tracking data needed to ensure compliance with § 450.167(a).

7.3.3.1 Sensitivity Guidelines.

Users should be cautioned that natural dispersions in radio waves as well as beam length characteristics can cause unavoidable uncertainty built into position and velocity data received at a range ground processing station. The particular uncertainties with a radar at a range should be built into the assumed flight safety rules of the vehicle and mission. A tracking margin of 6 dB above noise is recommended for quality data.

7.3.3.2 Ceiling Guidelines.

Users of skin-tracking radars should ensure that an alternate source is available until the radar can provide quality data. Coverage limitations and minimum beam travel distance often prevent tracking in initial stages of flight or in certain geographic locations due to blockage zones.

7.3.4 Tracking and Data Relay Satellite System.

The Tracking and Data Relay Satellite System (TDRSS) is a network of geosynchronous satellites managed by National Aeronautics and Space Administration’s (NASA) Goddard Space Flight Center (GSFC). Of the total number of satellites, only several are active at any time. Each active satellite provides coverage over either the Atlantic Ocean, Pacific Ocean, or Indian Ocean region. Each satellite has one S-band single access antenna available for tracking purposes and needs to be de-conflicted well in advance with national tracking priorities in order to be utilized for commercial launches. This network system has multiple uses for data, voice, and navigational system relay, but can also provide nearly 100 percent coverage of telemetry data receipt from space vehicles during launch. Data are relayed either to White Sands Complex (WSC) or Guam Remote Ground Terminal (GRGT) and are then forwarded to the end user. End user Mission Operation Control Centers (MOCCs) are already established at Eastern and Western Ranges. To use this system at a commercial spaceport or remote location, an end user would need to establish a data and crypto logical agreement with GSFC's Network Integration Management Office (NIMO). Users seeking to utilize this system to augment tracking data receipt must obtain a NASA Space Network compatible transmitter and coordinate with NIMO. Specifications for transmitter characteristics, usage and network interfaces can be found in the Space Network User's Guide published by GSFC.

7.3.5 GPS Metric Tracking via S-band Telemetry Downlink.

The GPS metric tracking method via S-band telemetry downlink utilizes existing GPS satellite base navigation system capability to significantly reduce the test range's operations and maintenance costs. The exception to the S-band telemetry downlink is if an Autonomous Flight Safety System (AFSS) is utilized because the termination decision is made aboard the vehicle. For many vehicle systems, the tracking capabilities are currently operational from pre-launch activities until when flight abort is no longer necessary. The system onboard the vehicle consists of GPS L-band receiver antennas, a GPS tracking unit, and S-band transmitters and antennas. A benefit of this system is the availability of a precise GPS time base onboard the vehicle to provide tighter time correlation with external instrumentation and video, along with the opportunity to better time-synchronize vehicle dynamic and thermal analog data. Overall, the system provides position, velocity, and timing information to the end user. Federal range standards for configuration of the GPS metric tracking standards for testing, and guidance as tailored for Expendable Launch Vehicles (ELV) are found in RCC 324.[3] For vehicles whose GPS metric tracking systems do not meet the Federal range standards, system qualification tests should be performed to ensure compatibility with the GPS network.

7.3.6 Optical Tracking.

Optical systems provide two-dimensional position-versus-time data. Optical systems include both fixed and mobile trackers. Optical systems are useful for rapid evaluation of launch vehicle attitude and integrity during early times of flight while other systems have tracking blockage zones. Optical systems are also useful for post mission analysis of data integrity from onboard tracking systems. Inherent limitations with line of sight and focal limits prevent these solutions from being utilized for the entire length of a mission, but for suborbital flights or open ocean captive carry type missions, optical tracking may be a suitable solution to demonstrate compliance with § 450.167.

[3] RCC Standard 324-11, *Global Positioning and Inertial Measurements Safety Tracking Systems Commonality Standard*, dated February 2011.

8 TRACKING AND RECORDING DATA.

During the flight of a launch or reentry vehicle, an operator must measure and record in real time the position and velocity of the vehicle, in accordance with § 450.167. A real-time system is one that adheres to functional (behavior) and temporal (timing constraints, deadlines) requirements. Real-time systems involve and affect hardware, software, communication, and human-in-the-loop contributions from tracking systems, GPS, data processing systems, display systems, command control systems, and flight safety systems. A real-time system requires results to be produced within a specified time period. Real-time does not mean zero lag time. Tracking must be sufficient to meet the requirements in § 450.167(a) to predict the expected impact locations and obtain vehicle performance data for comparison with pre-flight predictions.

8.1 Data to be Tracked in Real Time.

The primary types of data that an operator should provide for real-time tracking by the Flight Safety System (FSS) to aid in monitoring for off-nominal behavior are listed below. When monitoring behavior of the vehicle, the data should be defined in a coordinate system for position and velocity. Many types of coordinate systems are utilized and recognized by Federal ranges. These may include geodetic, polar, or Cartesian coordinate systems, among others. For example, to show a location about Earth using an earth-centered inertial system, Cartesian coordinates are used when tracking a vehicle.

8.1.1 If an operator intends to launch from a Federal range, these coordinate systems should be defined and discussed with local flight safety organizations to ensure compatibility with local tracking and recording systems. Coordinate systems should be defined for position and velocity, and implemented in a fashion in which the operator can communicate impact predictions to the FAA and range provider if necessary. The FAA does not prescribe the use of any particular coordinate system; however, as described in paragraph 9 below, pursuant to § 450.167(b), operators must identify and describe in their application any coordinate system used to satisfy § 450.167(a). In order to determine vehicle position and velocity as a function of time in accordance with § 450.167(a), operators should record the following parameters as a function of time:

- Instantaneous Impact Point
- Orientation
- Orientation change rates
- Occurrence of discrete events such as staging, fairing jettison, engine cut off, etc.

8.2 Methods of Recording.

To compare vehicle pre-flight performance predictions and actual performance, an operator should propose methods of recording the tracking data that will allow the operator to identify any discrepancy or non-nominal activity occurring during the launch countdown and flight, as well as any deviation from any term of the license, or any other event posing a material risk to public safety. Recording tracking data also allows operators and the FAA to identify corrective actions for future flights.

8.2.1.1 Operators should be able to identify any flight environment that is not consistent with maximum predictions, identify any measured wind profiles not consistent with predictions used for launch, and should enable the prediction of impact location of any staging and components.

8.2.1.2 For any data that cannot be collected in real time due to line of sight limitations (e.g. while achieving orbit), operators may propose the use of alternative methods for recording and storing such data as an equivalent level of safety to § 450.167(a).

8.3 **Data Fidelity**.

In accordance with § 450.167(a), during the flight of a launch or reentry vehicle, an operator must measure and record in real time the position and velocity of the vehicle. The following tracking fidelity guidelines are derived from AFSPCI 91-701 and RCC 324-11, which operators may find helpful in meeting the requirements of § 450.167(a). The FAA has adapted their descriptions for performance-based utilization. Further guidance specific to Federal ranges can be found in these manuals, and the metrics are as follows:

8.3.1 Sample Rate (S) [4]

The specified sample rate(s) of the Range Tracking System (RTS), including Telemetry/Any Band downlink and ground processing, should ensure that the data delivered to ground processing systems is sufficient to allow evaluation of the flight abort rules and the prediction of expected impact locations of all stages and components. An operator may propose a lower data rate—at various points or all of the trajectory—based on vehicle performance, reliability and a limited impact to public safety. The specified sample rate(s) should be maintained throughout the flight period.[5] Each sample should be a unique measurement and not a repeat or extrapolation of the previous value. Typically, a 10 Hz sample rate is recommended for FSS action. An operator may propose a lower data rate at various times in the trajectory such as coast after powered flight, or other times based on vehicle performance, reliability, and a limited impact to public safety such as remoteness to populated areas, ships, and aircraft. The use of an AFSS will ease this requirement.

8.3.2 System Delay Time (L) [6]

State vector timeliness should enable an operator to terminate the vehicle's motion or flight in accordance with mission parameters or, if an AFSS is utilized, in time to meet safety and analysis requirements. The total system delay time, including delays in RTS, Flight Termination System, and Range Safety Officer reaction time (where applicable),

---

[4] *See* RCC Standard 324-11, *Global Positioning and Inertial Measurements Safety Tracking Systems Commonality Standard*, dated February 2011. See paragraph 2.1.3.

[5] See paragraph A.2.1.3 of RCC Standard 324-11, *Global Positioning and Inertial Measurements Safety Tracking Systems Commonality Standard*, dated February 2011.

[6] *See* Air Force Space Command Instruction AFSPCI 91-701, Launch and Range Safety Program Policy and Requirements, February 1, 2019. See definition of "adequate," and paragraphs 6.1.2, 6.1.3, 6.4, and 6.9.6.

should allow evaluation of flight abort rules and prediction of the expected impact locations of all stages and components. The delay (data latency) introduced by each component or subsystem of the RTS should support the total system delay requirement. This system delay time calculation should be measured from airborne sensor or radio frequency reception through the Range Safety display including any data buffering, transfer, processing, or smoothing. In general, a latency of less than 250 ms will meet most vehicle applications. The combination of all sources of delay from transmission of data to evaluation of parameters for off-nominal indications and operator corrective termination action should not exceed 5 seconds, although each Federal range will have different requirements. These latencies must be accounted for in generation of flight safety limits in accordance with § 450.108(d)(4).

8.3.3 Accuracy.

The accuracy of the state vector[7] delivered to the ground safety display systems should be sufficient to allow for the evaluation of the flight abort rules and the prediction of expected impact locations of all stages and components of a flight vehicle when using flight abort in accordance with § 450.145(d)(4). The accuracy of the airborne and applicable ground RTS should be specified to support development of flight safety limits.[8] The range users' RTS accuracy should be factored into any range supplied ground systems to ensure the overall accuracy meets Range Safety requirements. The required accuracy should be maintained throughout nominal vehicle flight. The RTS should not produce out-of-specification state vector accuracy during non-nominal flight. The specified accuracy should include noise and systematic errors. In accordance with RCC Standard 324-11, *Global Positioning and Inertial Measurements Safety Tracking Systems Commonality Standard*, for various flight trajectories, the following 3-sigma parameters may be necessary to ensure accurate tracking:[9]

- Launch area Instantaneous Impact Point (IIP) (IIP Range < 66,000 feet) uncertainties should not exceed 330 feet for cross-range or down-range. Present position uncertainties, expressed as the square root of the sum of the squares (RSS) of the errors in the 3 orthogonal axes, should not exceed 250 feet.[10]
- Midcourse IIP (IIP Range > 66,000 feet) cross-range uncertainties should not exceed 0.5 percent of the vacuum IIP range, and down-range uncertainties are recommended not to exceed 1.0 percent of the vacuum IIP range.

[7] See paragraph *2.1.10,* RCC Standard 324-11 *Global Positioning and Inertial Measurements Safety Tracking Systems Commonality Standard*, dated February 2011.
[8] *See* AFSPCI 91-701, February 1, 2019, para. 6.10.2.3.
[9] *See Id.*, para. 6.4.2.1.2.
[10] See paragraph A2.1.10 of RCC Standard 324-11, *Global Positioning and Inertial Measurements Safety Tracking Systems Commonality Standard*, dated February 2011.

8.3.4 Reliability (R) [11]

In accordance with paragraph 2.1.4 of RCC 324-11[12], the RTS reliability for a nominal mission should ensure that the minimum number of required tracking sources (two in most cases) are available at least 97 percent of the time period when flight abort is required as a hazard control strategy. Each source should have no single point failure mode showing a non-nominal vehicle is nominal—these failure modes include but are not limited to forward prediction, Kalman filters, or indications of data loss.

8.3.5 Quality/Confidence Indicators (R)(Q) [13]

The RTS should provide indications of system performance status. This data should allow real time evaluation of the critical performance parameters. Quality indicators (flags) should be made available for detectable events that result in out-of-specification state vector performance data.[14] In general, GPS should include dilution of precision (DOP) and number of satellites tracked.

8.3.6 Independence (I) [15]

All required tracking sources should be independent of each other to the extent necessary to ensure that a failure of one tracking source does not adversely affect any required performance parameter of the other. A source is considered independent if it is electrically, mechanically, and structurally separate from any other tracking source, so that one does not influence another tracking source.

---

[11] *See* AFSPCI 91-701, para. 6.9.6.3.1.

[12] See paragraph A2.1.4, RCC Standard 324-11, *Global Positioning and Inertial Measurements Safety Tracking Systems Commonality Standard*, dated February 2011.

[13] *See* RCC Standard 324-11, para. 2.1.11.

[14] See paragraph 2.1.11 of RCC Standard 324-11, *Global Positioning and Inertial Measurements Safety Tracking Systems Commonality Standard*, dated February 2011.

[15] See paragraph. 2.1.9. of RCC Standard 324-11, *Global Positioning and Inertial Measurements Safety Tracking Systems Commonality Standard*, dated February 2011.

9 APPLICATION REQUIREMENTS.

Under § 450.167(b), an applicant must identify and describe each method or system used to meet the tracking requirements of § 450.167(a).

9.1 Methods.

An applicant must identify and describe in their application each tracking method used to meet § 450.167(a). An applicant may elect to use any of the methods listed in in Paragraph 7.3 of this AC it proposes to use, either alone or in combination, or any other tracking method. If the operator plans to use different tracking methods for different phases of flight, then the operator should identify which method will be used for each phase of flight. The FAA reviews the use of the proper method or combination of methods used during the application process for protection of the public.

9.2 Systems.

An applicant must describe each tracking system used to meet § 450.167(a). An applicant may use C-Band telemetry to download tracking data to the ground. An applicant should describe how vehicle data will be used to predict impact locations.

9.3 Range Commander's Council (RCC) 324.

An applicant may use RCC 324, *Global Positioning and Inertial Measurements Safety Tracking Systems Commonality Standard* to demonstrate compliance with the requirements of § 450.167(b). Since RCC 324 is generally tailored to the particular operation, an applicant utilizing this standard to show compliance with § 450.167 should similarly provide a tailored RCC 324 at the time of application.

OMB Control Number: 2120-0746
(Expiration Date: 08/31/2023)

Advisory Circular Feedback Form

If you find an error in this AC, have recommendations for improving it, or have suggestions for new items/subjects to be added, you may let us know by (1) emailing this form to ASTApplications@faa.gov, or (2) faxing it to (202) 267-5450.

Subject: (insert AC title/number here) Date: Click here to enter text.

Please check all appropriate line items:

☐ An error (procedural or typographical) has been noted in paragraph Click here to enter text. on page Click here to enter text..

☐ Recommend paragraph Click here to enter text. on page Click here to enter text. be changed as follows:

Click here to enter text.

☐ In a future change to this AC, please cover the following subject:
(Briefly describe what you want added.)

Click here to enter text.

☐ Other comments:

Click here to enter text.

☐ I would like to discuss the above. Please contact me.

Submitted by: ________________________________ Date: __________________________