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NASA STANDARD FOR LIGHTNING LAUNCH COMMIT CRITERIA FOR SPACE FLIGHT

DOCUMENT HISTORY LOG

Status	Document Revision	Change Number	Approval Date	Description
Baseline			2017-06-27	Initial Release
Revision	A		2023-09-12	Significant changes were made to this NASA Technical Standard. It is recommended that it be reviewed in its entirety before implementation. Key changes were: Updated definitions in section 3.2. Reorganized the introduction of section 4. Modified/updated/clarified the criteria in section 4.1.2, Surface Electric Fields; section 4.1.5.2, Detached Anvil Clouds; section 4.1.6.3, Debris Clouds; 4.1.8, Thick Cloud Layers; and section 4.1.9, Smoke Plumes. Added new sections 4.2.2, Quantification of Precipitation, and 4.3, Special Exceptions for Specific Physically Connected Cloud Scenarios.

FOREWORD

This NASA Technical Standard is published by the National Aeronautics and Space Administration (NASA) to provide uniform engineering and technical requirements for processes, procedures, practices, and methods endorsed as standard for NASA programs and projects, including requirements for selection, application, and design criteria of an item.

This Standard establishes common Lightning Launch Commit Criteria (LLCC) for avoidance of natural and triggered lightning to launch vehicles during ascent. Both Apollo XII and Atlas/Centaur-67 triggered lightning upon launch. Apollo XII recovered and completed the mission successfully; however, Atlas/Centaur-67 was destroyed. Since Atlas/Centaur-67 and the rigorous implementation of the LLCC, no other launch vehicles have intercepted or triggered lightning on launch in the United States.

This Standard provides mission assurance requirements for NASA Programs, in addition to public safety requirements, so that during ascent the launch vehicle does not intercept natural or triggered lightning which could result in the loss of another vehicle or payload. Additional information regarding the LLCC, including their definitions and detailed scientific rationale, is in the NASA Technical Paper, NASA/TP-2016-219439, Rationales for the Lightning Launch Commit Criteria. Since the process to document and edit the rationale is lengthy and may require greater time to update, the NASA Technical Paper may not reflect the latest modifications as documented in this Standard.

The LLCC are developed in cooperation with the United States Space Force (USSF) and the Federal Aviation Administration (FAA) for United States launches. The LLCC are based upon publicly available research, as well as analysis led by the joint NASA/USSF Lightning Advisory Panel (LAP), consisting of world-wide recognized experts in atmospheric electricity and associated disciplines. The criteria in whole or part are used across the globe due to the rigor of the documented criteria and associated rationale.

Submit requests for information via “Email Feedback” at https://standards.nasa.gov. Submit requests for changes to this Standard via Marshall Space Flight Center (MSFC) Form 4657,

Change Request for a NASA Engineering Standard, or the "Suggest a Change to this Standard" link on the Standard's Summary Page at https://standards.nasa.gov.

Concurrence:

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NASA STANDARD FOR LIGHTNING LAUNCH COMMIT CRITERIA FOR SPACE FLIGHT

1. SCOPE

1.1 Purpose

This NASA Technical Standard establishes common LLCC for avoidance of natural and triggered lightning to launch vehicles during ascent that are developed by the LAP for United States space launch.

1.2 Applicability

1.2.1 This Standard is approved for use by NASA Headquarters and NASA Centers and Facilities, and applicable technical requirements may be cited in contract, program, and other Agency documents. This language applies to the Jet Propulsion Laboratory (a Federally Funded Research and Development Center), other contractors, recipients of grants, cooperative agreements, or other agreements only to the extent specified or referenced in the applicable contracts, grants, or agreements.

1.2.2 As the definitive document for the most up-to-date LLCC in support of launches, this Standard has been adopted for use by other Federal Government agencies involved with spaceflight operations, including the Department of Defense (DoD) and the FAA. USSF and FAA regulations refer to this publication as a common standard for criteria intended to protect against the hazards associated with natural and triggered lightning.

1.2.3 Requirements for USSF launches may be found in SSCMAN 91-710, Volume 6, Attachment 4, section A4.2.5, Natural and Triggered Lightning. Requirements for FAA commercially licensed launches fall under Title 14 Code of Federal Regulations, Chapter III, Part 450.163(a)(1), Lightning Hazard Mitigation, and in Appendix G to Part 417, Natural and Triggered Lightning Flight Commit Criteria (LFCC).

1.2.4 References to “this Standard” refer to NASA-STD-4010A; references to other documents state the specific document information.

1.2.5 Verifiable requirement statements are designated by the acronym “LLCCR” (Lightning Launch Commit Criteria Requirement), numbered, and indicated by the word “shall.” This Standard contains 35 requirements. To facilitate requirements selection by NASA programs and projects, a Requirements Identification Matrix is provided in Appendix A.

1.2.6 Explanatory or guidance text is indicated in italics beginning in section 4. The terms “may” or “can” denote discretionary privilege or permission, “should” denotes a good practice and is recommended but not required, “will” denotes expected outcome, and “is/are” denotes descriptive material or a statement of fact.

1.3 Tailoring

Tailoring of the requirements in this Standard for application to a specific program or project is acceptable when formally approved by the delegated NASA Technical Authority in accordance with NPR 7120.5, NASA Space Flight Program and Project Management Requirements, and documented in program or project requirements.

2. APPLICABLE DOCUMENTS

2.1 General

2.1.1 Documents listed in this section contain provisions constituting requirements of this Standard as cited in the text. Latest issuances of cited documents apply unless specific versions are designated. Obtain approval from the delegated NASA Technical Authority to use a version other than as designated.

2.1.2 Access the applicable document at https://standards.nasa.gov.

Note: References are available in Appendix B.

2.2 Government Documents

NASA

NPR 7120.5 NASA Space Flight Program and Project Management Requirements

2.3 Non-Government Documents

None.

2.4 Order of Precedence

2.4.1 The requirements and standard practices established in this Standard do not supersede or waive existing requirements and standard practices found in other Agency documentation.

2.4.2 Conflicts between this Standard and other requirements documents will be resolved by the delegated NASA Technical Authority.

3. ACRONYMS, ABBREVIATIONS, AND DEFINITIONS

3.1 Acronyms and Abbreviations

°C	degrees Celsius
CFR	Code of Federal Regulations

cm	centimeter
dBZ	decibel relative to radar reflectivity factor (Z) in $mm^6 m^{-3}$
DoD	Department of Defense
FAA	Federal Aviation Administration
ft	feet
ft s^{-1}	feet per second
km	kilometer
LAP	Lightning Advisory Panel
LFCC	Lightning Flight Commit Criteria
LLCC	Lightning Launch Commit Criteria
LLCCR	Lightning Launch Commit Criteria Requirement
m s^{-1}	meters per second
mm hr^{-1}	millimeters per hour
MRR	Maximum Radar Reflectivity
NASA	National Aeronautics and Space Administration
nmi	nautical mile
SI	Système Internationale or metric system of measurement
SP	Special Publication
SSCMAN	Space Systems Command Manual
STD	Standard
TP	Technical Paper
USSF	United States Space Force
V m^{-1}	volts per meter

3.2 Definitions

Definitions are provided only for technical terms (e.g., “triboelectrification”) and for terms that are used in non-standard ways (e.g., “associated”). For all undefined terms, the Glossary of Meteorology (American Meteorological Society, Boston, MA, 2nd ed., 850 pp., 2000) applies. For the purpose of these LLCC:

Anvil Cloud: A stratiform or fibrous cloud formed by the upper-level outflow or blow-off from a thunderstorm or convective cloud.

Associated: Two or more clouds are caused by the same disturbed weather.

Bright Band: An enhancement of radar reflectivity caused by frozen hydrometeors falling and beginning to melt at any altitude where the temperature is 0 °C or warmer.

Cloud: A visible collection of suspended water droplets or ice particles, or a combination of water droplets and ice particles. The cloud is the entire volume containing such particles.

Cloud Layer: A spatially continuous array of clouds, not necessarily of the same type or height, whose bases are approximately at the same altitude.

Cone of Silence: The volume within which a radar cannot detect any object and is an inverted circular cone centered on the radar antenna. A cone of silence consists of all elevation angles greater than the maximum elevation angle reached by the radar.

Debris Cloud: Any cloud, except an anvil cloud, that has become detached from a parent cumulonimbus cloud or thunderstorm, or that results from the decay of a parent cumulonimbus cloud or thunderstorm.

Disturbed Weather: A weather system where a dynamical process destabilizes air to form clouds on a scale larger than that of an individual cloud or cell. Examples of disturbed weather include fronts, troughs, squall lines, and tropical (easterly) waves. Weather systems that are not considered to be disturbed weather are those in which the initial lifting of air results from topography or local surface heating; therefore, a sea-breeze or land-breeze convergence, frictional convergence lines, and convective outflow boundaries are not examples of disturbed weather.

Field Mill: An electric-field sensor that uses a moving, grounded conductor to induce a time-varying electric charge on one or more sensing elements in proportion to the electric field, including the electrostatic (DC) component.

Flight Path: The volume defined by the union of the normal flight envelope, as defined by 14 CFR 401.7, and the malfunction flight envelope within which a flight safety system potentially vulnerable to lightning could be active.

Horizontal Distance: A distance that is measured horizontally between a field mill or maximum radar reflectivity (MRR) evaluation and the nearest part of the vertical projection of an object or flight path onto the surface of the Earth, or the shortest distance between the vertical projections of any two extended objects onto a common horizontal reference plane.

Lightning: The entire lightning discharge, including all its channels and branches.

Maximum Radar Reflectivity (MRR): The largest radar reflectivity within a specified volume that corresponds to an evaluation point. *(Note: Section 4.2.3 in this Standard provides full detail on calculating MRR.)*

Moderate Precipitation: A precipitation intensity at or above the ground identifiable as greater than "light (trace) precipitation," either visually, by precipitation sensors at or above the ground, or by radar. For a more detailed understanding and recommended measurement values, see section 4.2.2 in this Standard.

Non-transparent: One or more of the following conditions apply *(Note: Section 4.2.5 in this Standard provides full detail on determining non-transparency)*:

a. Objects above, including higher clouds, blue sky, and stars, are blurred, indistinct, or obscured when viewed from below when looking through a cloud at visible wavelengths; or

objects below, including terrain, buildings, and lights on the ground, are blurred, indistinct, or obscured when viewed from above when looking through a cloud at visible wavelengths;

OR

b. Objects above or below an observer are seen distinctly only through breaks in a cloud layer;

OR

c. The cloud has a radar reflectivity of 0 dBZ or greater.

Physically Connected: Non-transparent parts of two or more clouds are touching. *(Note: Section 4.3 in this Standard provides full detail on evaluating physically connected clouds of the same or different types.)*

Precipitation: All hydrometeors formed in the atmosphere, including liquid, solid, or a combination of the two, that are large enough to fall as a result of gravity. Hydrometeors include detectable rain, drizzle, snow, ice pellets, hail, or graupel identified either visually or by precipitation sensors at or above the ground or by a radar reflectivity consistent with light (starting at trace) or greater precipitation. *(Note: For a more detailed understanding, see section 4.2.2 in this Standard.)*

Radar Reflectivity: The radar reflectivity factor due to hydrometeors, in dBZ. *(Note: Section 4.2.1 in this Standard provides full detail on measuring radar reflectivity.)*

Slant Distance: The shortest distance between measurement points and/or objects in three-dimensional space. Note that slant distance to a volume, such as a cloud or the flight path, refers to the nearest part of that volume.

Smoke Cumulus Cloud: Any cumulus cloud that has developed from a smoke plume.

Surface Electric Field: The rate that the electrostatic potential increases with altitude near the surface of the Earth. It is measured in volts per meter ($V\ m^{-1}$) using the polarity convention that a positive electric field is produced by a positive charge overhead. *(Note: Section 4.2.4 in this Standard provides full detail on measuring surface electric field.)*

Thick Cloud Layer: One or more cloud layers whose combined vertical extent from the base of the bottom cloud layer to the top of the uppermost cloud layer exceeds the threshold specified in section 4.1.8 Thick Cloud Layers in this Standard. Cloud layers are combined with neighboring layers for determining total thickness only when they are physically connected by vertically continuous clouds or by precipitation.

Thunderstorm: Any convective cloud that produces lightning.

Triboelectrification: The transfer of electrical charge between ice particles and a launch vehicle when the ice particles collide with the vehicle during flight.

4. LIGHTNING LAUNCH COMMIT CRITERIA (LLCC)

The LLCC identify each condition that is required to be met to launch. A launch operator may not launch unless the weather conditions satisfy all these natural and triggered LLCC. These include criteria for trained weather personnel to monitor the meteorological conditions and implement each launch constraint developed using the following natural and triggered LLCC in this Standard. The launch operator is required to have clear and convincing evidence that none of the criteria is violated at the time of launch.

a. [LLCCR 1] Whenever there is ambiguity about which of several LLCC applies to a particular situation, all potentially applicable LLCC **shall** be applied, including the procedures for evaluating physically connected clouds provided in section 4.3 of this Standard.

b. [LLCCR 2] To meet the LLCC, a launch operator **shall** employ:

(1) All weather monitoring and measuring equipment needed,

AND

(2) All procedures needed to verify compliance.

c. [LLCCR 3] When equipment or procedures, such as a field mill or calculation of the MRR of clouds, are used with the LLCC to increase launch opportunities, a launch operator **shall** evaluate all applicable measurements to determine whether the measurements satisfy the criteria when applying these natural and triggered LLCC.

For example, a launch operator may not turn off available instrumentation to create the appearance of meeting a requirement and may not ignore any radar reflectivity measurements within a specified volume for an MRR calculation.

d. [LLCCR 4] If a launch operator proposes any alternative LLCC, the launch operator **shall** demonstrate clearly and convincingly that the alternative provides an equivalent (or higher) level of safety to that required in this Standard when applying these natural and triggered LLCC.

If any other natural or triggered lightning hazards exist, other than those identified in this Standard, the launch weather team will report the hazardous condition to the final approval authority for launch, who will determine whether launching would expose the launch vehicle to a lightning hazard and not launch in the presence of the hazard.

Section 4.1 contains the launch commit criteria for avoiding natural lightning strikes and lightning triggered by the flight of a launch vehicle through or near an electrified environment. The measurements required to evaluate the criteria are provided in section 4.2. Unit conversions

for an evaluation threshold found within the LLCC are not exact, but are within accuracy of reading the instrumentation.

4.1 Evaluation Criteria

4.1.1 Lightning

4.1.1.1 [LLCCR 5] A launch operator **shall** wait 30 minutes to launch after any type of lightning occurs at a slant distance of less than or equal to 10 nmi from the flight path, unless:

a. The non-transparent part of the cloud that produced the lightning is at a slant distance of greater than 10 nmi from the flight path;

AND

b. At least one working field mill is at a horizontal distance of less than or equal to 5 nmi from each such lightning discharge;

AND

c. The absolute values of all surface electric field measurements at a horizontal distance of less than or equal to 5 nmi from the flight path, and at each field mill specified in section 4.1.1.1b in this Standard, have been less than 1000 V m^{-1} for at least 15 minutes.

4.1.1.2 [LLCCR 6] A launch operator **shall** wait 30 minutes to launch after any type of lightning occurs within or from a thunderstorm if the flight path will carry the launch vehicle at a slant distance of less than or equal to 10 nmi from any non-transparent part of that thunderstorm.

Section 4.1.1.2 does not apply to an anvil cloud that is attached to a parent thunderstorm. Anvil clouds are handled separately in section 4.1.4 and section 4.1.5 of this Standard.

4.1.2 Surface Electric Fields

4.1.2.1 [LLCCR 7] A launch operator **shall** wait 15 minutes to launch after the absolute value of any surface electric field measurement at a horizontal distance of less than or equal to 5 nmi from the flight path has been greater than or equal to 1000 V m^{-1}, but less than 1500 V m^{-1}, unless:

a. No clouds at a slant distance of less than or equal to 10 nmi from the flight path are non-transparent;

OR

b. All non-transparent clouds at a slant distance less than or equal to 10 nmi from the flight path:

(1) Have tops at altitudes where the temperature is warmer than or equal to +5 °C;

AND

(2) For 3 hours have not been part of convective clouds with tops at altitudes where the temperature was colder than or equal to -10 °C.

4.1.2.2 [LLCCR 8] A launch operator **shall** wait 15 minutes to launch after the absolute value of any surface electric field measurement at a horizontal distance of less than or equal to 5 nmi from the flight path has been greater than or equal to 1500 V m^{-1}, unless all of the following have been true for at least 15 minutes:

a. No clouds at a slant distance of less than or equal to 10 nmi from the flight path have been non-transparent;

AND

b. Only one field mill has reported a surface electric field measurement greater than or equal to 1500 V m^{-1} at a horizontal distance of less than or equal to 5 nmi from the flight path;

AND

c. There are at least two working field mills that are located at a horizontal distance of less than or equal to 3 nmi from the field mill specified in section 4.1.2.2b of this Standard;

AND

d. All surface electric field measurements at a horizontal distance of less than or equal to 3 nmi from the field mill specified in section 4.1.2.2b, including the mills specified in section 4.1.2.2c of this Standard, have been less than 1000 V m^{-1}.

4.1.3 Cumulus Clouds

This section applies to non-transparent cumulus clouds, except for cirrocumulus, altocumulus, or stratocumulus clouds. This section does not apply to an anvil cloud that is attached to a parent cumulus cloud.

4.1.3.1 [LLCCR 9] Flight path through the cloud: A launch operator **shall not** launch if the flight path will carry the launch vehicle through any cumulus cloud if either of the following conditions applies:

a. The cloud has a top at an altitude where the temperature is colder than or equal to +5 °C and warmer than -5 °C unless:

(1) The cloud is not producing precipitation;

AND

(2) The horizontal distance from the center of the cloud top to at least one working field mill is less than 2 nmi;

AND

(3) All surface electric field measurements at a horizontal distance of less than or equal to 5 nmi from the flight path, and at each field mill specified in section 4.1.3.1a(2) in this Standard, have been between -100 V m^{-1} and +500 V m^{-1} for at least 15 minutes;

OR

b. The cloud has a top at an altitude where the temperature is colder than or equal to -5 °C.

4.1.3.2 [LLCCR 10] Flight path > 0 nmi and ≤ 5 nmi from the cloud: A launch operator **shall not** launch if the slant distance to the flight path is greater than 0 nmi and less than or equal to 5 nmi from any cumulus cloud that has a top at an altitude where the temperature is colder than or equal to -10 °C.

4.1.3.3 [LLCCR 11] Flight path > 5 nmi and ≤ 10 nmi from the cloud: A launch operator **shall not** launch if the slant distance to the flight path is greater than 5 nmi and less than or equal to 10 nmi from any cumulus cloud that has a top at an altitude where the temperature is colder than or equal to -20 °C.

4.1.4 Attached Anvil Clouds

This section applies to any non-transparent anvil cloud formed from a parent cloud that has, or had at any time, a top at an altitude where the temperature is colder than or equal to -10 °C.

4.1.4.1 [LLCCR 12] Flight path through or ≤ 3 nmi from the cloud: If a flight path will carry a launch vehicle at a slant distance of less than or equal to 3 nmi from any attached anvil cloud, the launch operator **shall not** launch unless:

a. The portion of the attached anvil cloud at a slant distance of less than or equal to 5 nmi from the flight path is located entirely at altitudes where the temperature is colder than 0 °C;

AND

b. The MRR is less than +7.5 dBZ at every point at a horizontal distance of less than or equal to 1 nmi from the flight path.

4.1.4.2 [LLCCR 13] Flight path > 3 nmi and ≤ 5 nmi from the cloud: If a flight path will carry a launch vehicle at a slant distance of greater than 3 nmi and less than or equal to 5 nmi from any attached anvil cloud, a launch operator **shall** wait 3 hours to launch after every lightning discharge within or from the parent cloud or anvil cloud, unless the portion of the attached anvil cloud at a slant distance of less than or equal to 5 nmi from the flight path is located entirely at altitudes where the temperature is colder than 0 °C.

4.1.4.3 [LLCCR 14] Flight path > 5 nmi and ≤ 10 nmi from the cloud: If the flight path will carry the launch vehicle at a slant distance of greater than 5 nmi and less than or equal to 10 nmi from any attached anvil cloud, the launch operator **shall** wait to launch for 30 minutes after every lightning discharge within or from the parent cloud or anvil cloud, unless the portion of the attached anvil cloud that is at a slant distance of less than or equal to 10 nmi from the flight path is located entirely at altitudes where the temperature is colder than 0 °C.

4.1.5 Detached Anvil Clouds

This section applies to any non-transparent anvil cloud formed from a parent cloud that had, at or before detachment, a top at an altitude where the temperature was colder than or equal to -10 °C.

4.1.5.1 [LLCCR 15] Flight path through the cloud: If the flight path will carry the launch vehicle through a detached anvil cloud, the launch operator **shall not** launch unless:

a. The launch operator waits 4 hours after every lightning discharge within or from the detached anvil cloud, and observation shows that 3 hours have passed since the anvil cloud detached from the parent cloud;

OR

b. Each of the following conditions exists:

(1) The portion of the detached anvil cloud at a slant distance of less than or equal to 5 nmi from the flight path is located entirely at altitudes where the temperature is colder than 0 °C;

AND

(2) The MRR is less than +7.5 dBZ everywhere within the flight path.

4.1.5.2 [LLCCR 16] Flight path > 0 nmi and ≤ 3 nmi from the cloud: If a flight path will carry a launch vehicle at a slant distance of greater than 0 nmi and less than or equal to 3 nmi from a detached anvil cloud, the launch operator **shall** either:

a. Demonstrate both of the following:

(1) The portion of the detached anvil cloud at a slant distance of less than or equal to 5 nmi from the flight path is located entirely at altitudes where the temperature is colder than 0 °C;

AND

(2) The MRR is less than +7.5 dBZ at every point at a horizontal distance of less than or equal to 1 nmi from the flight path;

OR

b. Accomplish both of the following:

(1) Wait 30 minutes to launch after every lightning discharge within or from the parent cloud or anvil cloud before detachment of the anvil cloud, and after every lightning discharge within or from the detached anvil cloud after detachment;

AND

(2) Wait an additional 2.5 hours to launch after every lightning discharge within or from the parent cloud or anvil cloud before detachment of the anvil cloud, and after every lightning discharge within or from the detached anvil cloud after detachment, unless all of the following are true:

A. There is at least one working field mill at a horizontal distance of less than or equal to 5 nmi from the detached anvil cloud;

AND

B. The absolute values of all surface electric field measurements at a horizontal distance of less than or equal to 5 nmi from the flight path, and at each field mill specified in section 4.1.5.2b(2)A in this Standard, have been less than 1000 V m^{-1} for at least 15 minutes;

AND

C. The largest radar reflectivity from any part of the detached anvil cloud at a slant distance of less than or equal to 5 nmi from the flight path has been less than +10 dBZ for at least 15 minutes.

4.1.5.3 [LLCCR 17] Flight path > 3 nmi and ≤ 10 nmi from the cloud: If a flight path will carry a launch vehicle at a slant distance of greater than 3 nmi and less than or equal to 10 nmi

from a detached anvil cloud, the launch operator **shall** wait 30 minutes to launch after every lightning discharge within or from the parent cloud or anvil cloud before detachment, and after every lightning discharge within or from the detached anvil cloud after detachment, unless the portion of the detached anvil cloud at a slant distance of less than or equal to 10 nmi from the flight path is located entirely at altitudes where the temperature is colder than 0 °C.

4.1.6 Debris Clouds

This section applies to any non-transparent debris cloud whose parent cumuliform cloud had any part at an altitude where the temperature was colder than -20 °C *or to any debris cloud formed by a thunderstorm. This section does not apply to either an attached or a detached anvil cloud.*

4.1.6.1 [LLCCR 18] A launch operator **shall** calculate a "3-hour period" as starting at the latest of the following times:

a. The debris cloud is observed to be detached from the parent cloud;

OR

b. The debris cloud is observed to have formed by the collapse of the parent cloud top to an altitude where the temperature is warmer than -10 °C;

OR

c. Any lightning discharge occurs within or from the debris cloud.

4.1.6.2 [LLCCR 19] Flight path through the cloud: If a flight path will carry a launch vehicle through a debris cloud, the launch operator **shall not** launch during the "3-hour period" in section 4.1.6.1 of this Standard, unless:

a. The portion of the debris cloud at a slant distance of less than or equal to 5 nmi from the flight path is located entirely at altitudes where the temperature is colder than 0 °C;

AND

b. The MRR is less than +7.5 dBZ everywhere within the flight path.

4.1.6.3 [LLCCR 20] Flight path > 0 nmi and ≤ 3 nmi from the cloud: If the flight path will carry the launch vehicle at a slant distance of greater than 0 nmi and less than or equal to 3 nmi from the debris cloud, the launch operator **shall not** launch during the "3-hour period" in section 4.1.6.1 of this Standard, unless:

a. All the following are true:

(1) There is at least one working field mill at a horizontal distance of less than or equal to 5 nmi from the debris cloud;

AND

(2) The absolute values of all surface electric field measurements at a horizontal distance of less than or equal to 5 nmi from the flight path, and at each field mill specified in section 4.1.6.3a(1) in this Standard, have been less than 1000 V m^{-1} for at least 15 minutes;

AND

(3) The largest radar reflectivity from any part of the debris cloud less than or equal to a slant distance of 5 nmi from the flight path has been less than +10 dBZ for at least 15 minutes;

OR

b. Both of the following are true:

(1) The portion of the debris cloud at a slant distance of less than or equal to 5 nmi from the flight path is located entirely at altitudes where the temperature is colder than 0 °C;

AND

(2) The MRR is less than +7.5 dBZ at every point at a horizontal distance of less than or equal to 1 nmi from the flight path.

4.1.7 Disturbed Weather

[LLCCR 21] A launch operator **shall not** launch if the flight path will carry the launch vehicle through a non-transparent cloud associated with disturbed weather that includes clouds with tops at altitudes where the temperature is colder than 0 °C and that contains, at a slant distance of less than or equal to 5 nmi from the flight path, either:

a. Moderate or greater precipitation;

OR

b. Evidence of melting precipitation such as a radar bright band.

4.1.8 Thick Cloud Layers

This section does not apply to either attached or detached anvil clouds. The thickness of two or more cloud layers must be combined if they are physically connected by vertically continuous clouds or by precipitation, but a cumulus cloud is not combined with cloud layers to increase the total thickness beyond the combined thickness of the layered clouds unless it is a smoke cumulus cloud that:

a. *Is still attached to its smoke plume;*

OR

b. *Has been detached from that plume for less than or equal to 60 minutes.*

4.1.8.1 [LLCCR 22] A launch operator **shall not** launch if the flight path will carry the launch vehicle through a non-transparent cloud layer that:

a. Is, at a slant distance of less than or equal to 5 nmi from the flight path, greater than or equal to 1.4 km (4500 ft) thick with any part at an altitude where the temperature is between 0 °C and -20 °C, inclusive;

OR

b. Is connected to a thick cloud layer that, at a slant distance of less than or equal to 5 nmi from the flight path, is greater than or equal to 1.4 km (4500 ft) thick with any part at an altitude where the temperature is between 0 °C and -20 °C, inclusive.

4.1.8.2 [LLCCR 23] A launch operator **shall not** be required to apply the LLCC in section 4.1.8.1 in this Standard if the cloud layer and any connected thick cloud layer:

a. Is a cirriform cloud layer that has never been connected to convective clouds;

AND

b. Is located entirely at altitudes where the temperature is colder than or equal to -15 °C;

AND

c. Shows no evidence of containing liquid water.

4.1.8.3 [LLCCR 24] A launch operator **shall not** be required to apply the LLCC in section 4.1.8.1 in this Standard if either of the following is satisfied:

a. The cloud layer and any connected thick cloud layer does not contain a radar reflectivity of 0 dBZ or greater at any location that is less than or equal to 5 nmi from the flight path;

OR

b. Within the last hour, the cloud layer and any connected thick cloud layer has not contained an MRR of +7.5 dBZ or greater at any point at a horizontal distance of less than or equal to 2 nmi from the flight path.

MRR is to be calculated according to its normal definition (i.e., upward from the altitude of the 0 °C level). However, the bottom of the cloud can extend to altitudes below the 0 °C isotherm and must be used to determine cloud thickness.

4.1.9 Smoke Plumes

4.1.9.1 [LLCCR 25] A launch operator **shall not** launch if the flight path will carry the launch vehicle through any non-transparent smoke cumulus cloud while the cloud is attached to the smoke plume, or for the first 60 minutes after the cumulus cloud is observed to be detached from the smoke plume.

4.1.9.2 [LLCCR 26] A launch operator **shall** also evaluate any cumulus cloud described in section 4.1.9.1 simultaneously under section 4.1.3, Cumulus Clouds, in this Standard.

4.1.10 Triboelectrification

4.1.10.1 [LLCCR 27] A launch operator **shall not** launch if the flight path will carry the launch vehicle through any part of a cloud at any altitude where:

a. The temperature is colder than or equal to -10 °C;

AND

b. The launch vehicle's velocity is less than or equal to 910 m s^{-1} (3000 ft s^{-1}).

4.1.10.2 [LLCCR 28] Section 4.1.10.1 in this Standard **shall not** apply if either:

a. The launch vehicle is treated for surface electrification so that:

(1) All surfaces of the launch vehicle susceptible to ice particle impact are such that the surface resistivity is less than 10^9 ohms per square;

AND

(2) All conductors on surfaces, including dielectric surfaces that have been coated with conductive materials, are bonded to the launch vehicle by a resistance that is less than 10^5 ohms;

OR

b. A launch operator demonstrates by test or analysis that electrostatic discharges on the surface of the launch vehicle caused by triboelectrification will not be hazardous to the launch vehicle or the spacecraft.

4.2 Measurements Used in Criteria Evaluation

4.2.1 Measurement of Cloud Radar Reflectivity

[LLCCR 29] A launch operator who measures radar reflectivity to comply with these LLCC **shall** employ a weather radar and ensure that:

a. The radar wavelength is greater than or equal to 3 cm, and the following additional criteria are met if the wavelength is less than 5 cm:

(1) The surface of the radome of the radar is hydrophobic and the precipitation rate at the radar site is less than 15 mm hr^{-1} rainfall equivalent,

AND

(2) For each point at which a measurement is made, the horizontal extent of composite radar reflectivity greater than 10 dBZ along the line of sight between the radar and the point in question may not exceed the value shown in Figure 1, Relationship between Maximum Observed Composite Reflectivity and Maximum Permissible Extent of > 10 dBZ along a Line of Sight for 3 cm Radars, for the observed largest value of the composite reflectivity along that line of sight;

AND

b. A radar reflectivity measurement is due to a meteorological target;

AND

c. A radar reflectivity measurement is not affected by significant attenuation by intervening precipitation or by water or ice on the radome;

AND

d. A desired radar reflectivity measurement is not located within the cone of silence, nor within any blocked sector, unless that location is determined by other means (e.g., visual or

another radar) to contain no non-transparent cloud, in which case the radar reflectivity there may be taken as less than 0 dBZ.

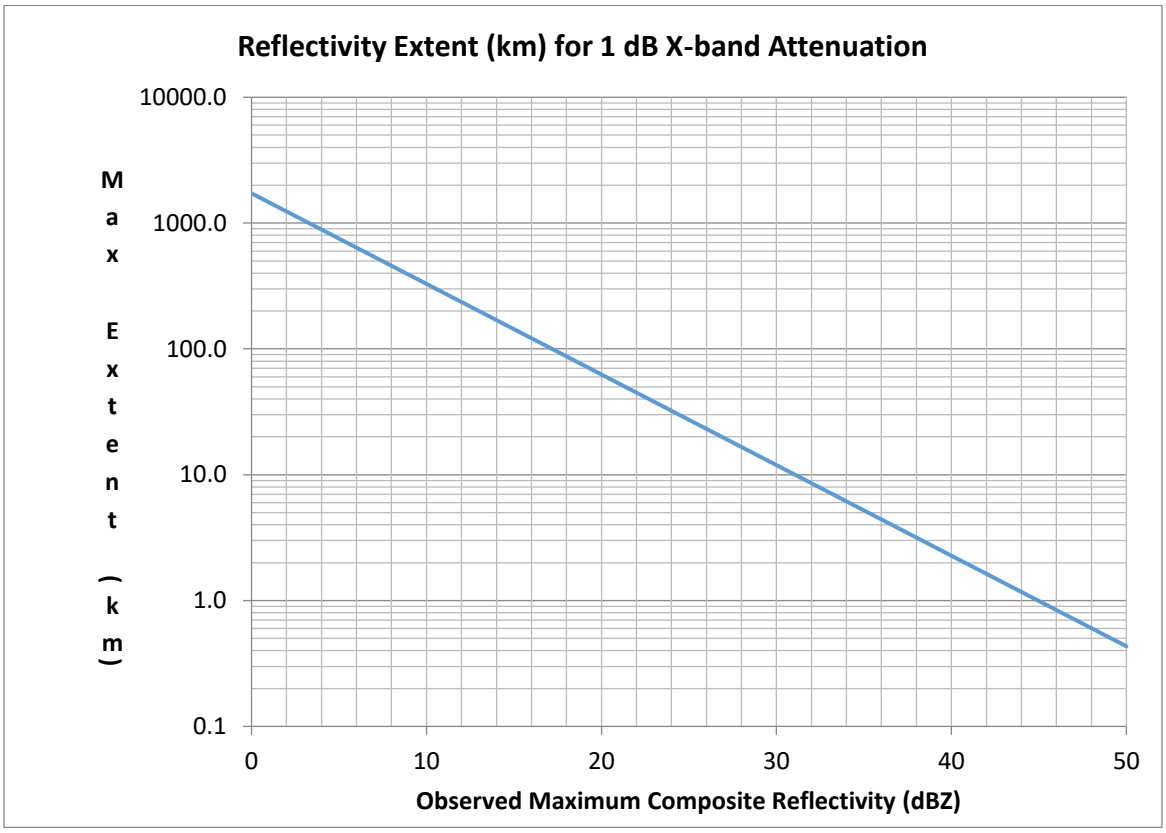


Figure 1—Relationship between Maximum Observed Composite Reflectivity and Maximum Permissible Extent of > 10 dBZ along a Line of Sight for 3 cm Radars

4.2.2 Quantification of Precipitation

[LLCCR 30] A launch operator who measures precipitation to comply with these LLCC **shall** ensure that one or more of three basic methods be employed to detect and measure precipitation and moderate precipitation.

Precipitation is detected when any of the following three detection methods indicate precipitation. The detection of precipitation as determined by one method cannot be invalidated through another method. Acceptable methods to detect precipitation are direct visual airborne or ground observations evaluated by trained weather personnel, precipitation measurements by ground-based sensors or airborne probes, and radar measurements.

a. The detection of precipitation is defined as:

(1) Visual Observations: Between the ground and cloud base, or between cloud layers, a visual observation of any amount of rain, drizzle, snow, ice pellets, hail, or graupel, including virga, constitutes "precipitation";

OR

(2) Ground-Based Measurements: A precipitation rate greater than trace (0.01 inch per hour);

OR

(3) Radar Measurements: Within clouds or at any altitude above the ground, a radar reflectivity measurement of 18 dBZ or greater.

b. The detection of moderate or greater precipitation is defined as:

(1) Visual Observations: Between the ground and cloud base, or between cloud layers, a visual observation of moderate or greater rain, snow, ice pellets, graupel, or any amount of hail, including virga, constitutes "moderate or greater precipitation";

OR

(2) Ground-Based Measurements: A precipitation rate at or above the ground greater than 0.1 inch per hour;

OR

(3) Radar Measurements: Within clouds or at any altitude above the ground, a radar reflectivity measurement of 30 dBZ or greater.

4.2.3 Computation of MRR

[LLCCR 31] A launch operator who measures MRR to comply with these LLCC **shall** ensure that:

a. The specified volume is the volume bounded in the horizontal by vertical, plane, perpendicular sides located 5.5 km (3 nmi) north, east, south, and west of the point where MRR is to be evaluated; on the bottom by the 0 °C level; and on the top by an altitude of 20 km above mean sea level;

AND

b. MRR is the largest radar reflectivity within the specified volume;

AND

c. If the MRR defined in section 4.2.3b in this Standard cannot be accurately determined, then the MRR is the largest composite reflectivity at a horizontal distance of less than or equal to 7.5 km (4 nmi) from the point where MRR is to be evaluated;

AND

d. All MRR evaluation points within the flight path are:

(1) Greater than a slant distance of 10 nmi from any radar reflectivity of 35 dBZ or greater at or above the 0 °C level;

AND

(2) Greater than a slant distance of 10 nmi from any type of lightning that has occurred in the previous 5 minutes;

AND

(3) A launch operator need not apply sections 4.2.3d(1) and 4.2.3d(2) in this Standard to additional MRR evaluation points outside the flight path that are required in certain LLCC exceptions.

4.2.4 Measurement of Surface Electric Field

[LLCCR 32] A launch operator who measures a surface electric field to comply with these LLCC **shall**:

a. Employ a ground-based field mill capability;

AND

b. Ensure that all field mills are calibrated such that the polarity of the surface electric field measurement is the same as the polarity of the voltage placed on a test plate above the sensor;

AND

c. Use only the one-minute arithmetic average of the instantaneous readings from that field mill for the surface electric field measurement;

AND

d. Disregard any surface electric field measurement from a field mill for which the altitude of the flight path is greater than 20 km (66,000 ft) everywhere above a horizontal circle of 5 nmi radius centered on that field mill;

AND

e. Use only direct measurements from a field mill and never interpolate between mills.

4.2.5 Determination of Non-Transparent Cloud or Precipitation Boundaries

[LLCCR 33] A launch operator who locates non-transparent cloud boundaries or precipitation regions to comply with these LLCC **shall** ensure that:

a. If more than one of the three conditions specified in the definition of non-transparent apply, then the condition that most restricts launch availability is used;

AND

b. The Sun or the Moon is not used to evaluate non-transparency;

AND

c. If radar is used, then allowance is made for the vertical and horizontal spatial resolution of the radar in computing any cloud or precipitation boundary;

AND

d. If radar is used, the radar-display threshold is set sufficiently lower than the boundary threshold (0 dBZ for cloud, 18 dBZ for precipitation, etc.), at least intermittently, so that the next lower radar reflectivity display bin would be shown if that lower radar reflectivity were present in the atmosphere at similar range;

AND

e. The thickness of a cloud that is not observed visually but that contains a radar reflectivity of 0 dBZ or greater is evaluated according to its radar-observed dimensions;

AND

f. If a cloud layer has a visible base but no visual observation of its top is available and it does not contain a radar reflectivity of 0 dBZ or greater, then the thickness of that cloud is taken as zero.

4.2.6 Determination of Slant Distance from Lightning

[LLCCR 34] A launch operator who locates lightning to comply with these LLCC **shall** ensure that:

a. The three-dimensional nature of lightning is taken into account;

AND

b. If a two-dimensional lightning-locating system locates channels and branches but does not explicitly provide altitude information, then the slant distance between the lightning and the flight path is taken as the horizontal distance between the vertical projections of both the flight path and the lightning onto a common, two-dimensional reference surface such as the surface of the Earth;

AND

c. A launch operator need not apply the standoff requirement in section 4.1.1.1 in this Standard to any portion of the flight path at an altitude greater than 37 km (20 nmi).

4.3 Special Exceptions for Specific Physically Connected Cloud Scenarios

[LLCCR 35] A launch operator **shall** ensure that, from the time that two or more clouds to which these LLCC apply become physically connected until the time that the individual clouds are no longer distinguishable, the most conservative evaluation of any applicable sections in this Standard applies to their combined non-transparent cloud volume; and, if individual clouds are no longer distinguishable, review all LLCC in this Standard.

This general requirement is modified in the following special cases:

a. If one or more attached anvil clouds and one or more additional cumulus and/or smoke cumulus clouds become physically connected, a launch operator must ensure that each cloud is assessed independently. In other words, any applicable sections in this Standard apply individually to each cloud.

b. If one or more detached anvil clouds and one or more cumulus and/or smoke cumulus clouds become physically connected, a launch operator must ensure that each cloud is assessed independently. Note that any detached anvil cloud that becomes physically connected to a cumulus or smoke cumulus cloud that has, or had at any time, a top at an altitude where the temperature is colder than or equal to -10 °C is assessed independently as an attached anvil cloud under section 4.1.4 in this Standard.

c. If one or more thick cloud layers and one or more cumulus clouds become physically connected, a launch operator must ensure that each cloud is assessed independently. Note that

the thickness of each thick cloud layer must be evaluated according to the definition, as modified by the note at the beginning of section 4.1.8 in this Standard.

d. If one or more cloud layers and one or more smoke cumulus clouds become physically connected, the smoke cumulus clouds are considered part of the cloud layers for evaluation of thickness if and only if these smoke cumulus clouds have not been observed to be detached from their smoke plumes for more than 60 minutes. If the combined cloud volume so obtained meets the thickness criteria in section 4.1.8.1 in this Standard, a launch operator must ensure that the combined non-transparent cloud volume is assessed as a thick cloud layer. Note that such a smoke cumulus cloud is still assessed simultaneously as a cumulus cloud under section 4.1.3 in this Standard.

e. Sections 4.3a through 4.3d in this Standard provide exceptions for certain situations where only two types of clouds to which these sections apply are physically connected (even though they might comprise more than two individual clouds). If three or more cloud types to which these LLCC apply become physically connected, then a launch operator must ensure that the most conservative evaluation of any applicable sections in this Standard, accounting for the special cases in sections 4.3a through 4.3d, applies to their combined non-transparent cloud volume.

APPENDIX A: REQUIREMENTS IDENTIFICATION MATRIX

A.1 PURPOSE

Due to the complexity and uniqueness of space flight, it is unlikely that all the requirements in a Standard will apply. The Requirements Identification Matrix below contains this Standard's technical authority requirements and may be used by programs and projects to indicate requirements that are applicable or not applicable. Enter "Yes" in the "Applicable" column if the requirement is applicable to the program or project or "No" if the requirement is not applicable to the program or project. The "Comments" column may be used to provide specific instructions on how to apply the requirement, specify proposed tailoring, or provide an explanation/justification when not applicable.

Table 1—Requirements Identification Matrix

NASA-STD-4010A				
Section	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
4a	Lightning Launch Commit Criteria (LLCC)	[LLCCR 1] Whenever there is ambiguity about which of several LLCC applies to a particular situation, all potentially applicable LLCC **shall** be applied, including the procedures for evaluating physically connected clouds provided in section 4.3 of this Standard.		
4b	Lightning Launch Commit Criteria (LLCC)	[LLCCR 2] To meet the LLCC, a launch operator **shall** employ: (1) All weather monitoring and measuring equipment needed, AND (2) All procedures needed to verify compliance.		
4c	Lightning Launch Commit Criteria (LLCC)	[LLCCR 3] When equipment or procedures, such as a field mill or calculation of the MRR of clouds, are used with the LLCC to increase launch opportunities, a launch operator **shall** evaluate all applicable measurements to determine whether the measurements satisfy the criteria when applying these natural and triggered LLCC.		
4d		[LLCCR 4] If a launch operator proposes any alternative LLCC, the launch operator **shall** demonstrate clearly and convincingly that the alternative provides an equivalent (or higher) level of safety to that required in this Standard when applying these natural and triggered LLCC.		

NASA-STD-4010A				
Section	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
4.1 Evaluation Criteria				
4.1.1.1	Lightning	[LLCCR 5] A launch operator **shall** wait 30 minutes to launch after any type of lightning occurs at a slant distance of less than or equal to 10 nmi from the flight path, unless: a. The non-transparent part of the cloud that produced the lightning is at a slant distance of greater than 10 nmi from the flight path; AND b. At least one working field mill is at a horizontal distance of less than or equal to 5 nmi from each such lightning discharge; AND c. The absolute values of all surface electric field measurements at a horizontal distance of less than or equal to 5 nmi from the flight path, and at each field mill specified in section 4.1.1.1b in this Standard, have been less than 1000 V m^{-1} for at least 15 minutes.		
4.1.1.2	Lightning	[LLCCR 6] A launch operator **shall** wait 30 minutes to launch after any type of lightning occurs within or from a thunderstorm if the flight path will carry the launch vehicle at a slant distance of less than or equal to 10 nmi from any non-transparent part of that thunderstorm.		
4.1.2.1	Surface Electric Fields	[LLCCR 7] A launch operator **shall** wait 15 minutes to launch after the absolute value of any surface electric field measurement at a horizontal distance of less than or equal to 5 nmi from the flight path has been greater than or equal to 1000 V m^{-1}, but less than 1500 V m^{-1}, unless: a. No clouds at a slant distance of less than or equal to 10 nmi from the flight path are non-transparent; OR b. All non-transparent clouds at a slant distance less than or equal to 10 nmi from the flight path: (1) Have tops at altitudes where the temperature is warmer than or equal to +5 °C; AND		

NASA-STD-4010A				
Section	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
		(2) For 3 hours have not been part of convective clouds with tops at altitudes where the temperature was colder than or equal to –10 °C.		
4.1.2.2	Surface Electric Fields	[LLCCR 8] A launch operator **shall** wait 15 minutes to launch after the absolute value of any surface electric field measurement at a horizontal distance of less than or equal to 5 nmi from the flight path has been greater than or equal to 1500 V m^{-1}, unless all of the following have been true for at least 15 minutes: a. No clouds at a slant distance of less than or equal to 10 nmi from the flight path have been non-transparent; AND b. Only one field mill has reported a surface electric field measurement greater than or equal to 1500 V m^{-1} at a horizontal distance of less than or equal to 5 nmi from the flight path; AND c. There are at least two working field mills that are located at a horizontal distance of less than or equal to 3 nmi from the field mill specified in section 4.1.2.2b of this Standard; AND d. All surface electric field measurements at a horizontal distance of less than or equal to 3 nmi from the field mill specified in section 4.1.2.2b, including the mills specified in section 4.1.2.2c of this Standard, have been less than 1000 V m^{-1}.		
4.1.3.1	Cumulus Clouds	[LLCCR 9] Flight path through the cloud: A launch operator **shall not** launch if the flight path will carry the launch vehicle through any cumulus cloud if either of the following conditions applies: a. The cloud has a top at an altitude where the temperature is colder than or equal to +5 °C, and warmer than -5 °C unless: (1) The cloud is not producing precipitation; AND		

NASA-STD-4010A				
Section	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
		(2) The horizontal distance from the center of the cloud top to at least one working field mill is less than 2 nmi; AND (3) All surface electric field measurements at a horizontal distance of less than or equal to 5 nmi from the flight path, and at each field mill specified in section 4.1.3.1a(2) in this Standard, have been between -100 V m^{-1} and +500 V m^{-1} for at least 15 minutes; OR b. The cloud has a top at an altitude where the temperature is colder than or equal to -5 °C.		
4.1.3.2	Cumulus Clouds	[LLCCR 10] Flight path > 0 nmi and ≤ 5 nmi from the cloud: A launch operator **shall not** launch if the slant distance to the flight path is greater than 0 nmi and less than or equal to 5 nmi from any cumulus cloud that has a top at an altitude where the temperature is colder than or equal to -10 °C.		
4.1.3.3	Cumulus Clouds	[LLCCR 11] Flight path > 5 nmi and ≤ 10 nmi from the cloud: A launch operator **shall not** launch if the slant distance to the flight path is greater than 5 nmi and less than or equal to 10 nmi from any cumulus cloud that has a top at an altitude where the temperature is colder than or equal to -20 °C.		
4.1.4.1	Attached Anvil Clouds	[LLCCR 12] Flight path through or ≤ 3 nmi from the cloud: If a flight path will carry a launch vehicle at a slant distance of less than or equal to 3 nmi from any attached anvil cloud, the launch operator **shall not** launch unless: a. The portion of the attached anvil cloud at a slant distance of less than or equal to 5 nmi from the flight path is located entirely at altitudes where the temperature is colder than 0 °C; AND b. The MRR is less than +7.5 dBZ at every point at a horizontal distance of less than or equal to 1 nmi from the flight path.		
4.1.4.2	Attached Anvil Clouds	[LLCCR 13] Flight path > 3 nmi and ≤ 5 nmi from the cloud: If a flight path will carry a launch vehicle at a slant distance of greater than 3 nmi and less than or equal to 5 nmi from any attached anvil cloud, a launch operator **shall** wait 3 hours to launch after every lightning discharge within or from the parent cloud or anvil cloud, unless the portion of the attached anvil cloud at a slant distance of less than or equal to 5 nmi from the flight path is located entirely at altitudes where the temperature is colder than 0 °C.		

NASA-STD-4010A				
Section	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
4.1.4.3	Attached Anvil Clouds	[LLCCR 14] Flight path > 5 nmi and ≤ 10 nmi from the cloud: If the flight path will carry the launch vehicle at a slant distance of greater than 5 nmi and less than or equal to 10 nmi from any attached anvil cloud, the launch operator **shall** wait to launch for 30 minutes after every lightning discharge within or from the parent cloud or anvil cloud, unless the portion of the attached anvil cloud that is at a slant distance of less than or equal to 10 nmi from the flight path is located entirely at altitudes where the temperature is colder than 0 °C.		
4.1.5.1	Detached Anvil Clouds	[LLCCR 15] Flight path through the cloud: If the flight path will carry the launch vehicle through a detached anvil cloud, the launch operator **shall not** launch unless: a. The launch operator waits 4 hours after every lightning discharge within or from the detached anvil cloud, and observation shows that 3 hours have passed since the anvil cloud detached from the parent cloud; OR b. Each of the following conditions exists: (1) The portion of the detached anvil cloud at a slant distance of less than or equal to 5 nmi from the flight path is located entirely at altitudes where the temperature is colder than 0 °C; AND (2) The MRR is less than +7.5 dBZ everywhere within the flight path.		
4.1.5.2	Detached Anvil Clouds	[LLCCR 16] Flight path > 0 nmi and ≤ 3 nmi from the cloud: If a flight path will carry a launch vehicle at a slant distance of greater than 0 nmi and less than or equal to 3 nmi from a detached anvil cloud, the launch operator **shall** either: a. Demonstrate both of the following: (1) The portion of the detached anvil cloud at a slant distance of less than or equal to 5 nmi from the flight path is located entirely at altitudes where the temperature is colder than 0 °C; AND		

NASA-STD-4010A				
Section	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
		(2) The MRR is less than +7.5 dBZ at every point at a horizontal distance of less than or equal to 1 nmi from the flight path; OR b. Accomplish both of the following: (1) Wait 30 minutes to launch after every lightning discharge within or from the parent cloud or anvil cloud before detachment of the anvil cloud, and after every lightning discharge within or from the detached anvil cloud after detachment; AND (2) Wait an additional 2.5 hours to launch after every lightning discharge within or from the parent cloud or anvil cloud before detachment of the anvil cloud, and after every lightning discharge within or from the detached anvil cloud after detachment, unless all of the following are true: (A) There is at least one working field mill at a horizontal distance of less than or equal to 5 nmi from the detached anvil cloud; AND (B) The absolute values of all surface electric field measurements at a horizontal distance of less than or equal to 5 nmi from the flight path, and at each field mill specified in section 4.1.5.2b(2)A in this Standard, have been less than 1000 V m^{-1} for at least 15 minutes; AND (C) The largest radar reflectivity from any part of the detached anvil cloud at a slant distance of less than or equal to 5 nmi from the flight path has been less than +10 dBZ for at least 15 minutes.		

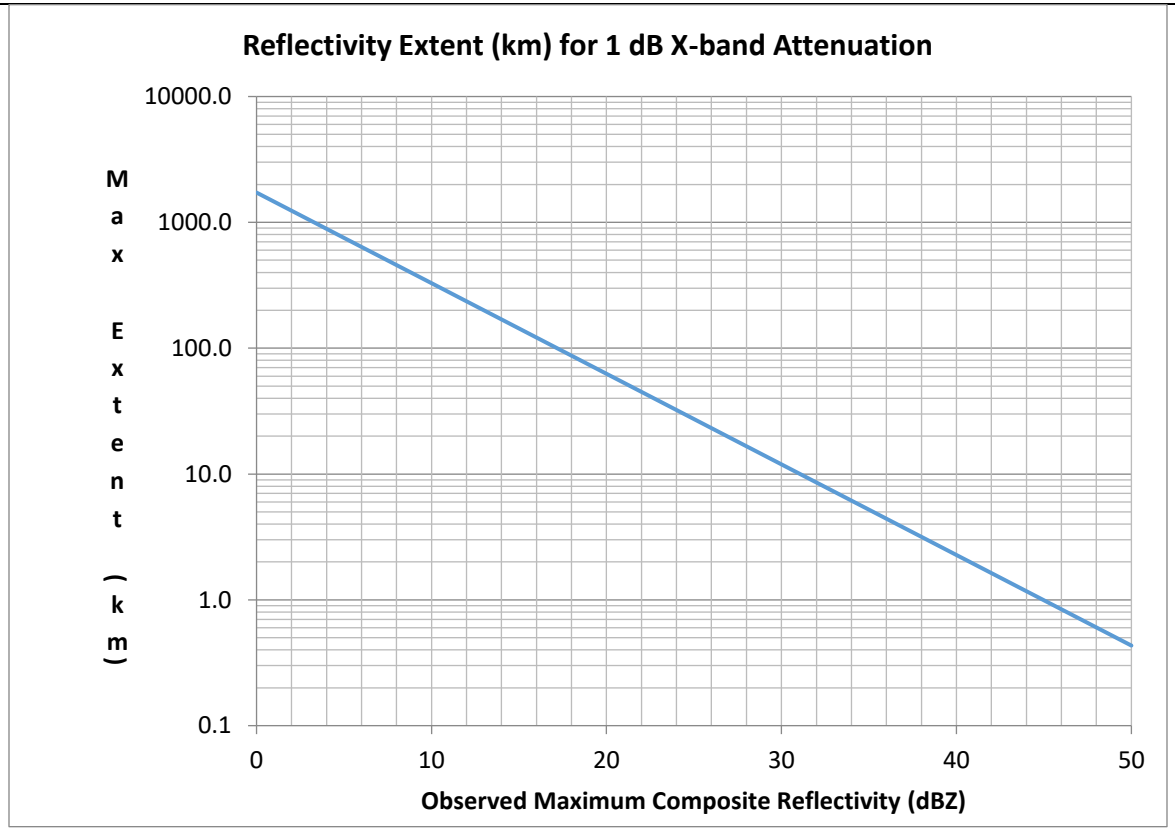
NASA-STD-4010A				
Section	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
4.1.5.3	Detached Anvil Clouds	[LLCCR 17] Flight path > 3 nmi and ≤ 10 nmi from the cloud: If a flight path will carry a launch vehicle at a slant distance of greater than 3 nmi and less than or equal to 10 nmi from a detached anvil cloud, the launch operator **shall** wait 30 minutes to launch after every lightning discharge within or from the parent cloud or anvil cloud before detachment, and after every lightning discharge within or from the detached anvil cloud after detachment, unless the portion of the detached anvil cloud at a slant distance of less than or equal to 10 nmi from the flight path is located entirely at altitudes where the temperature is colder than 0 °C.		
4.1.6.1	Debris Clouds	[LLCCR 18] A launch operator **shall** calculate a "3-hour period" as starting at the latest of the following times: a. The debris cloud is observed to be detached from the parent cloud; OR b. The debris cloud is observed to have formed by the collapse of the parent cloud top to an altitude where the temperature is warmer than -10 °C; OR c. Any lightning discharge occurs within or from the debris cloud.		
4.1.6.2	Debris Clouds	[LLCCR 19] Flight path through the cloud: If a flight path will carry a launch vehicle through a debris cloud, the launch operator **shall not** launch during the "3-hour period" in section 4.1.6.1 of this Standard, unless: a. The portion of the debris cloud at a slant distance of less than or equal to 5 nmi from the flight path is located entirely at altitudes where the temperature is colder than 0 °C; AND b. The MRR is less than +7.5 dBZ everywhere within the flight path.		
4.1.6.3	Debris Clouds	[LLCCR 20] Flight path > 0 nmi and ≤ 3 nmi from the cloud: If the flight path will carry the launch vehicle at a slant distance of greater than 0 nmi and less than or equal to 3 nmi from the debris cloud, the launch operator **shall not** launch during the "3-hour period" in section 4.1.6.1 of this Standard, unless: a. All of the following are true:		

NASA-STD-4010A				
Section	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
		(1) There is at least one working field mill at a horizontal distance of less than or equal to 5 nmi from the debris cloud; AND (2) The absolute values of all surface electric field measurements at a horizontal distance of less than or equal to 5 nmi from the flight path, and at each field mill specified in section 4.1.6.3a(1) in this Standard, have been less than 1000 V m^{-1} for at least 15 minutes; AND (3) The largest radar reflectivity from any part of the debris cloud less than or equal to a slant distance of 5 nmi from the flight path has been less than +10 dBZ for at least 15 minutes; OR b. Both of the following are true: (1) The portion of the debris cloud at a slant distance of less than or equal to 5 nmi from the flight path is located entirely at altitudes where the temperature is colder than 0 °C; AND (2) The MRR is less than +7.5 dBZ at every point at a horizontal distance of less than or equal to 1 nmi from the flight path.		
4.1.7	Disturbed Weather	[LLCCR 21] A launch operator **shall not** launch if the flight path will carry the launch vehicle through a non-transparent cloud associated with disturbed weather that includes clouds with tops at altitudes where the temperature is colder than 0 °C and that contains, at a slant distance of less than or equal to 5 nmi from the flight path, either: a. Moderate or greater precipitation; OR		

NASA-STD-4010A				
Section	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
		b. Evidence of melting precipitation such as a radar bright band.		
4.1.8.1	Thick Cloud Layers	[LLCCR 22] A launch operator **shall not** launch if the flight path will carry the launch vehicle through a non-transparent cloud layer that: a. Is, at a slant distance of less than or equal to 5 nmi from the flight path, greater than or equal to 1.4 km (4500 ft) thick with any part at an altitude where the temperature is between 0 °C and -20 °C, inclusive; OR b. Is connected to a thick cloud layer that, at a slant distance of less than or equal to 5 nmi from the flight path, is greater than or equal to 1.4 km (4500 ft) thick with any part at an altitude where the temperature is between 0 °C and -20 °C, inclusive.		
4.1.8.2	Thick Cloud Layers	[LLCCR 23] A launch operator **shall not** be required to apply the LLCC in section 4.1.8.1 in this Standard if the cloud layer and any connected thick cloud layer: a. Is a cirriform cloud layer that has never been connected to convective clouds; AND b. Is located entirely at altitudes where the temperature is colder than or equal to -15 °C; AND c. Shows no evidence of containing liquid water.		
4.1.8.3	Thick Cloud Layers	[LLCCR 24] A launch operator **shall not** be required to apply the LLCC in section 4.1.8.1 in this Standard if either of the following is satisfied: a. The cloud layer and any connected thick cloud layer does not contain a radar reflectivity of 0 dBZ or greater at any location that is less than or equal to 5 nmi from the flight path; OR		

NASA-STD-4010A				
Section	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
		b. Within the last hour, the cloud layer and any connected thick cloud layer has not contained an MRR of +7.5 dBZ or greater at any point at a horizontal distance of less than or equal to 2 nmi from the flight path.		
4.1.9.1	Smoke Plumes	[LLCCR 25] A launch operator **shall not** launch if the flight path will carry the launch vehicle through any non-transparent smoke cumulus cloud while the cloud is attached to the smoke plume, or for the first 60 minutes after the cumulus cloud is observed to be detached from the smoke plume.		
4.1.9.2	Smoke Plumes	[LLCCR 26] A launch operator **shall** also evaluate any cumulus cloud described in section 4.1.9.1 simultaneously under section 4.1.3, Cumulus Clouds,, in this Standard.		
4.1.10.1	Triboelectrification	[LLCCR 27] A launch operator **shall not** launch if the flight path will carry the launch vehicle through any part of a cloud at any altitude where: a. The temperature is colder than or equal to -10 °C; AND b. The launch vehicle's velocity is less than or equal to 910 m s^{-1} (3000 ft s^{-1}),		
4.1.10.2	Triboelectrification	[LLCCR 28] Section 4.1.10.1 in this Standard **shall not** apply if either: a. The launch vehicle is treated for surface electrification so that: (1) All surfaces of the launch vehicle susceptible to ice particle impact are such that the surface resistivity is less than 10^9 ohms per square; AND (2) All conductors on surfaces, including dielectric surfaces that have been coated with conductive materials, are bonded to the launch vehicle by a resistance that is less than 10^5 ohms; OR b. A launch operator demonstrates by test or analysis that electrostatic discharges on the surface of the launch vehicle caused by triboelectrification will not be hazardous to the launch vehicle or the spacecraft.		
4.2.1	Measurement of Cloud Radar Reflectivity	[LLCCR 29] A launch operator who measures radar reflectivity to comply with these LLCC **shall** employ a weather radar and ensure that:		

NASA-STD-4010A				
Section	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
		a. The radar wavelength is greater than or equal to 3 cm, and the following additional criteria are met if the wavelength is less than 5 cm: (1) The surface of the radome of the radar is hydrophobic and the precipitation rate at the radar site is less than 15 mm hr^{-1} rainfall equivalent; AND (2) For each point at which a measurement is made, the horizontal extent of composite radar reflectivity greater than 10 dBZ along the line of sight between the radar and the point in question may not exceed the value shown in figure 1, Relationship between Maximum Observed Composite Reflectivity and Maximum Permissible Extent of > 10 dBZ along a Line of Sight for 3 cm Radars, for the observed largest value of the composite reflectivity along that line of sight; AND b. A radar reflectivity measurement is due to a meteorological target; AND c. A radar reflectivity measurement is not affected by significant attenuation by intervening precipitation or by water or ice on the radome; AND d. A desired radar reflectivity measurement is not located within the cone of silence, nor within any blocked sector, unless that location is determined by other means (e.g., visual or another radar) to contain no non-transparent cloud, in which case the radar reflectivity there may be taken as less than 0 dBZ.		

NASA-STD-4010A				
Section	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
		 **Figure 1—Relationship between Maximum Observed Composite Reflectivity and Maximum Permissible Extent of > 10 dBZ along a Line of Site for 3 cm Radars**		
4.2.2	Quantification of Precipitation	[LLCCR 30] A launch operator who measures precipitation to comply with these LLCC **shall** ensure that one or more of three basic methods be employed to detect and measure precipitation and moderate precipitation.		
4.2.3	Computation of MRR	[LLCCR 31] A launch operator who measures MRR to comply with these LLCC **shall** ensure that:		

NASA-STD-4010A				
Section	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
		a. The specified volume is the volume bounded in the horizontal by vertical, plane, perpendicular sides located 5.5 km (3 nmi) north, east, south, and west of the point where MRR is to be evaluated; on the bottom by the 0 °C level; and on the top by an altitude of 20 km above mean sea level; AND b. MRR is the largest radar reflectivity within the specified volume; AND c. If the MRR defined in section 4.2.3b in this Standard cannot be accurately determined, then the MRR is the largest composite reflectivity at a horizontal distance of less than or equal to 7.5 km (4 nmi) from the point where MRR is to be evaluated; AND d. All MRR evaluation points within the flight path are: (1) Greater than a slant distance of 10 nmi from any radar reflectivity of 35 dBZ or greater at or above the 0 ºC level; AND (2) Greater than a slant distance of 10 nmi from any type of lightning that has occurred in the previous 5 minutes; AND (3) A launch operator need not apply sections 4.2.3d(1) and 4.2.3.d(2) in this Standard to additional MRR evaluation points outside the flight path that are required in certain LLCC exceptions.		
4.2.4	Measurement of Surface Electric Field	[LLCCR 32] A launch operator who measures a surface electric field to comply with these LLCC **shall**: a. Employ a ground-based field mill capability;		

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Section	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
		AND b. Ensure that all field mills are calibrated such that the polarity of the surface electric field measurement is the same as the polarity of the voltage placed on a test plate above the sensor; AND c. Use only the one-minute arithmetic average of the instantaneous readings from that field mill for the surface electric field measurement; AND d. Disregard any surface electric field measurement from a field mill for which the altitude of the flight path is greater than 20 km (66,000 ft) everywhere above a horizontal circle of 5 nmi radius centered on that field mill; AND e. Use only direct measurements from a field mill and never interpolate between mills.		
4.2.5	Determination of Non-Transparent Cloud or Precipitation Boundaries	[LLCCR 33] A launch operator who locates non-transparent cloud boundaries or precipitation regions to comply with these LLCC **shall** ensure that: a. If more than one of the three conditions specified in the definition of non-transparent apply, then the condition that most restricts launch availability is used; AND b. The Sun or the Moon is not used to evaluate non-transparency; AND c. If radar is used, then allowance is made for the vertical and horizontal spatial resolution of the radar in computing any cloud or precipitation boundary;		

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Section	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
		AND d. If radar is used, the radar-display threshold is set sufficiently lower than the boundary threshold (0 dBZ for cloud, 18 dBZ for precipitation, etc.), at least intermittently, so that the next lower radar reflectivity display bin would be shown if that lower radar reflectivity were present in the atmosphere at similar range; AND e. The thickness of a cloud that is not observed visually but that contains a radar reflectivity of 0 dBZ or greater is evaluated according to its radar-observed dimensions; AND f. If a cloud layer has a visible base but no visual observation of its top is available and it does not contain a radar reflectivity of 0 dBZ or greater, then the thickness of that cloud is taken as zero.		
4.2.6	Determination of Slant Distance from Lightning	[LLCCR 34] A launch operator who locates lightning to comply with these LLCC **shall** ensure that: a. The three-dimensional nature of lightning is taken into account; AND b. If a two-dimensional lightning-locating system locates channels and branches but does not explicitly provide altitude information, then the slant distance between the lightning and the flight path is taken as the horizontal distance between the vertical projections of both the flight path and the lightning onto a common, two-dimensional reference surface such as the surface of the Earth; AND c. A launch operator need not apply the standoff requirement in section 4.1.1.1 in this Standard to any portion of the flight path at an altitude greater than 37 km (20 nmi).		
4.3	Special Exceptions for Specific Physically	[LLCCR 35] A launch operator **shall** ensure that, from the time that two or more clouds to which these LLCC apply become physically connected until the time that the individual clouds are no longer distinguishable, the most conservative evaluation of any applicable sections in this Standard applies to their		

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Section	Description	Requirement in this Standard	Applicable (Enter Yes or No)	Comments
	Connected Cloud Scenarios	combined non-transparent cloud volume; and, if individual clouds are no longer distinguishable, review all LLCC in this Standard.		

APPENDIX B: REFERENCES

B.1 PURPOSE

This Appendix provides information of a general or explanatory nature but does not contain requirements. The latest issuances of reference documents apply unless specific versions are designated. Access reference documents at https://standards.nasa.gov or obtain documents directly from the Standards Developing Body, other document distributors, information provided or linked, or by contacting the office of primary responsibility designee for this Standard.

B.2 REFERENCE DOCUMENTS

Glossary of Meteorology, Boston, MA: American Meteorological Society (2nd ed., 2000), 850 pp.

Space Systems Command Manual (SSCMAN) 91-710, *Range Safety User Requirements Manual Volume 6, Ground and Launch Personnel, Equipment, Systems, and Material Operations Safety Requirements*, Attachment 4, Section A4.2.5, Natural and Triggered Lightning.

Title 14 Code of Federal Regulations, Chapter III, Part 450.163(a)(1), Lightning Hazard Mitigation.

Title 14 Code of Federal Regulations, Appendix G to Part 417, Natural and Triggered Lightning Flight Commit Criteria (LFCC).

The background, reasoning, and supporting literature used in development of the LLCC was first officially documented by Willett and Merceret (2010) and has undergone a revision with a new document number and title (Willett and Merceret, 2016). Note the rationale reference document is not updated as often as this Standard and may not contain the most current LLCC.

Willet, J. C., and Merceret, F. J. (Eds.), Krider, E. P., Dye, J. E., O'Brien, T. P., Rust, W. D., Walterscheid, R. L., Madura, J. T., and Christian, H. J. (2010): *Rationales for the Lightning Flight-Commit Criteria*, NASA/TP-2010-216291, 236 pp.

Willet, J. C., and Merceret, F. J. (Eds.), Krider, E. P., Dye, J. E., O'Brien, T. P., Rust, W. D., Walterscheid, R. L., Madura, J. T., and Christian, H. J. (2016): *Rationales for the Lightning Launch Commit Criteria*, NASA/TP-2016-219439, 265 pp.

History of the development of the LLCC and the LAP is available in the reference below. The history includes the previous launch vehicle incidents involving triggered lightning, the advances in research and measurement technology, and the implementation of systems and technology to evaluate LLCC.

Merceret, F. J., and Willett, J. C. (Eds.), Christian, H. J., Dye, J. E., Krider, E. P., Madura, J. T., O'Brien, T. P., Rust, W. D., and Walterscheid, R. L. (2010): *A History of the Lightning Launch Commit Criteria and the Lightning Advisory Panel for America's Space Program*, NASA/SP-2010-216283, 234 pp.