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NASA STANDARD FOR LIGHTNING LAUNCH COMMIT CRITERIA FOR SPACE FLIGHT

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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 that have been endorsed as standard for NASA programs and projects, including requirements for selection, application, and design criteria of an item.

This NASA Technical Standard is approved for use by NASA Headquarters and NASA Centers and Facilities and may be cited in contract, program, and other Agency documents as a technical requirement. It may also apply to the Jet Propulsion Laboratory and other contractors only to the extent specified or referenced in applicable contracts.

This NASA Technical 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.

This NASA Technical Standard is the definitive document for the most up-to-date LLCC in support of launches and will be updated periodically as the rules are revised. This NASA Technical Standard provides mission assurance requirements for NASA Programs, in addition to public safety requirements, so that intercepting natural or triggered lightning does not result in the loss of another payload or launch vehicle. Additional information regarding the LLCC, including their definitions and detailed scientific rationale, are located in the NASA Technical Paper, NASA/TP-2016-219439. 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 NASA Technical Standard.

The LLCC are developed in cooperation with the United States Air Force (USAF) 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/USAF 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.

Requests for information should be submitted via “Feedback” at https://standards.nasa.gov. Requests for changes to this NASA Technical Standard should be submitted via MSFC Form 4657, Change Request for a NASA Engineering Standard.

Concurrence:

Original signed by — 06/27/2017

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1. SCOPE

1.1 Purpose

The purpose of this NASA Technical Standard is to establish common Lightning Launch Commit Criteria (LLCC) for avoidance of natural and triggered lightning to launch vehicles during ascent that are developed by the Lightning Advisory Panel (LAP) for United States space launch.

1.2 Applicability

This NASA Technical Standard is applicable to all Federal Government ranges involved with spaceflight operations, including all NASA Centers and the Department of Defense (DoD). Federal Aviation Administration (FAA) Commercially licensed Expendable Launch Vehicles launched from commercially licensed launch sites (spaceports) are required to follow similar requirements Under Title 14 Code of Federal Regulations, Chapter III Appendix G to Part 417, Natural and Triggered Lightning Flight Commit Criteria (LFCC); also referred to as LFCC.

This NASA Technical Standard is approved for use by NASA Headquarters and NASA Centers and Facilities and may be cited in contract, program, and other Agency documents as a technical requirement. It may also apply to the Jet Propulsion Laboratory and other contractors only to the extent specified or referenced in applicable contracts.

Verifiable requirement statements are numbered and indicated by the word “shall”; this NASA Technical Standard contains 38 requirements. Explanatory or guidance text is indicated in italics beginning in section 4. To facilitate requirements selection and verification by NASA programs and projects, a Requirements Compliance Matrix is provided in Appendix A.

1.3 Tailoring

[LLCCR 1] Tailoring of this NASA Technical Standard for application to a specific program or project shall be formally documented as part of program or project requirements and approved by the responsible Technical Authority in accordance with NPR 7120.5, NASA Space Flight Program and Project Management Requirements.

2. APPLICABLE DOCUMENTS

2.1 General

The documents listed in this section contain provisions that constitute requirements of this NASA Technical Standard as cited in the text.

2.1.1 [LLCCR 2] The latest issuances of cited documents shall apply unless specific versions are designated.

2.1.2 [LLCCR 3] Non-use of specifically designated versions shall be approved by the responsible Technical Authority.

The applicable documents are accessible at https://standards.nasa.gov, may be obtained directly from the Standards Developing Body or other document distributors, or information for obtaining the document is provided.

2.2 Government Documents

National Aeronautics and Space Administration (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 NASA Technical Standard do not supersede or waive existing requirements and standard practices found in other Agency documentation.

2.4.2 [LLCCR 4] Conflicts between this NASA Technical Standard and other requirements documents shall be resolved by the responsible Technical Authority.

3. ACRONYMS AND DEFINITIONS

3.1 Acronyms and Abbreviations

°C	degrees Celsius
Cm	centimeter
dBZ	decibel relative to Z
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	International System of Units
STD	Standard
USAF	United States Air 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 or are physically connected.

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 vertically continuous array of clouds, not necessarily of the same type, 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 on a scale larger than the individual clouds or cells. Examples of disturbed weather include fronts, troughs, and squall lines.

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.

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 ambient electrostatic field.

Flight Path: The volume defined by the vertical and horizontal uncertainties resulting from all three-sigma guidance and performance deviations about a launch vehicle's planned flight trajectory.

Horizontal Distance: A distance that is measured horizontally between a field mill (or electric field measurement point) 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 of its channels and branches.

Maximum Radar Reflectivity (MRR): The largest radar reflectivity within a specified volume that is associated with an evaluation point. (Section 4.2.2 provides full details on how to calculate MRR.)

Moderate Precipitation: A precipitation rate of 0.1 inch per hour or a radar reflectivity of 30 dBZ.

Non-transparent: One or more of the following conditions apply:

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.

Precipitation: Detectable rain, snow, hail, graupel, or sleet at the ground; virga; or a radar reflectivity greater than 18 dBZ. Note this definition of precipitation is more inclusive than the Glossary of Meteorology definition. For a better understanding, see NASA/TP-2016-219439.

Radar Reflectivity: The radar reflectivity factor due to hydrometeors, in dBZ.

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.

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 1.4 km (4500 feet). Cloud layers are combined with neighboring layers for determining total thickness only when they are physically connected by vertically continuous clouds.

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 in order to launch. These include criteria for trained weather personnel to monitor the meteorological conditions and implement each launch constraint developed using the following Natural and Triggered Lightning Launch Commit Criteria. The launch operator is required to have clear and convincing evidence that none of the criteria is violated at the time of launch.

[LLCCR 5] Whenever there is ambiguity about which of several LLCC applies to a particular situation, all potentially applicable LLCC shall be applied.

If any other potential natural or triggered lighting hazards exist, other than those identified below, 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 the LLCC are not exact but are within accuracy of reading the instrumentation. A launch operator may not launch unless the weather conditions satisfy these Natural and Triggered Lightning Launch Commit Criteria.

a. [LLCCR 6] In order to meet the LLCC, a launch operator shall employ:

(1) Weather monitoring and measuring equipment needed,

AND

(2) Procedures needed to verify compliance.

b. [LLCCR 7] When equipment or procedures such as a field mill or calculation of the maximum radar reflectivity (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.

c. [LLCCR 8] A launch operator shall not turn off available instrumentation to create the appearance of meeting a requirement.

d. [LLCCR 9] A launch operator shall use all radar reflectivity measurements within a specified volume for an MRR calculation.

e. [LLCCR 10] If a launch operator proposes any alternative LLCC, the launch operator shall demonstrate clearly and convincingly that the alternative provides an equivalent level of safety to that required in this NASA Technical Standard.

4.1 Evaluation Criteria

4.1.1 Lightning

4.1.1.1 [LLCCR 11] 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 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 NASA Technical Standard, have been less than 1000 V m^{-1} for at least 15 minutes.

4.1.1.2 [LLCCR 12] 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.

4.1.2 Surface Electric Fields

4.1.2.1 [LLCCR 13] A launch operator shall wait 15 minutes to launch after the absolute value of any 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}.

4.1.2.2 [LLCCR 14] A launch operator shall wait 15 minutes to launch after the absolute value of any 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}, 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) Have not been part of convective clouds with cloud tops at altitudes where the temperature was colder than or equal to –10 °C for 3 hours.

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 15] 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 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 NASA Technical 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 16] Flight path between 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 17] Flight path between 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 18] Flight path through or within 3 nmi of cloud: If a flight path will carry a launch vehicle 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 slant distance of less than or equal to 1 nmi from the flight path.

4.1.4.2 [LLCCR 19] Flight path between 3 nmi and 5 nmi from 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 20] Flight path between 5 nmi and 10 nmi from 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 21] Flight path through 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) Any 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 22] Flight path between 0 nmi and 3 nmi from 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 accomplish the following:

a. 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, unless:

(1) The portion of the detached anvil cloud 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 slant distance of less than or equal to 1 nmi from the flight path;

AND

b. If a launch operator is unable to launch in the first 30 minutes under section 4.1.5.2a in this NASA Technical Standard, wait to launch for 3 hours 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:

(1) 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 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(1)A in this NASA Technical 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;

OR

(2) Both of the following are true:

A. 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

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

4.1.5.3 [LLCCR 23] Flight path between 3 nmi and 10 nmi from 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 24] 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 25] Flight path through 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 NASA Technical 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 26] Flight path between 0 nmi and 3 nmi from cloud: If the flight path will carry the launch vehicle at a slant distance of greater than or equal to 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 NASA Technical Standard, unless 4.1.6.3a or 4.1.6.3b applies:

a. Launch if:

(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 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 NASA Technical 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. Launch if:

(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 slant distance of less than or equal to 1 nmi from the flight path.

4.1.7 Disturbed Weather

[LLCCR 27] 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. Two or more cloud layers must be combined if they are physically connected by towering cumuliform clouds, but a cumulus cloud is never combined with cloud layers to increase the total thickness beyond the combined thickness of the layered clouds.

4.1.8.1 [LLCCR 28] A launch operator shall not launch if the flight path will carry the launch vehicle through a non-transparent cloud layer that is:

a. Greater than or equal to 1.4 km (4500 ft) thick and any part of the cloud layer within the flight path is located at an altitude where the temperature is between 0 °C and -20 °C, inclusive;

OR

b. 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 and has any part located at any altitude where the temperature is between 0 °C and -20 °C, inclusive.

4.1.8.2 [LLCCR 29] A launch operator shall be permitted to launch despite section 4.1.8.1 in this NASA Technical Standard if the thick cloud layer:

a. Is a cirriform cloud layer that has never been associated with 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 30] A launch operator shall not be required to apply the LLCC in section 4.1.8.1 in this NASA Technical Standard if the 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.

4.1.9 Smoke Plumes

[LLCCR 31] A launch operator shall not launch if the flight path will carry the launch vehicle through any non-transparent cumulus cloud that has developed from a smoke plume 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.

4.1.10 Triboelectrification

4.1.10.1 [LLCCR 32] 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 33] Section 4.1.10.1 in this NASA Technical 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 34] 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 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.

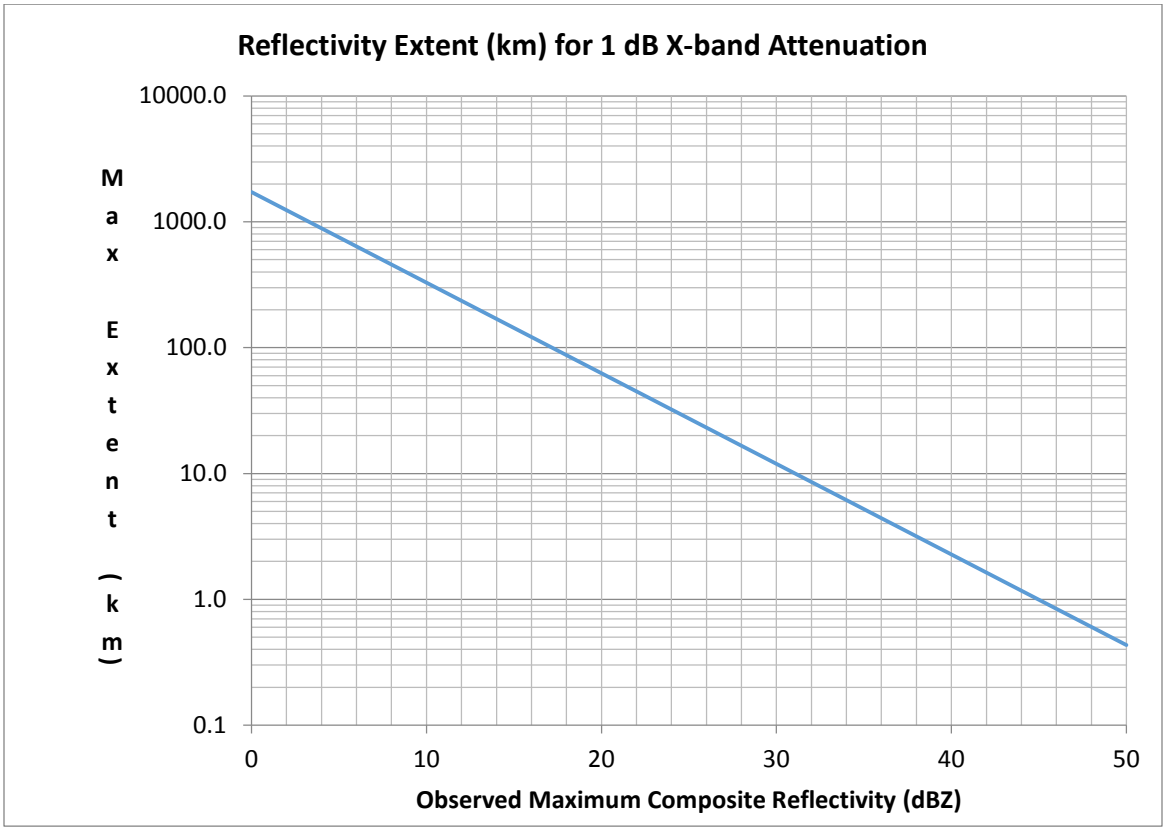


Figure 1—Relationship between Maximum Observed Composite Reflectivity and Maximum Permissible Extent of >10 dBZ along a Line of Sight for 3 cm Radars

4.2.2 Computation of MRR

[LLCCR 35] 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 measurement within the specified volume;

AND

c. If the MRR defined in section 4.2.2b in this NASA Technical 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 altitudes of 4 km or greater above mean sea 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 section 4.2.2d in this NASA Technical Standard to additional MRR evaluation points outside the flight path that are required in certain rule exceptions.

4.2.3 Measurement of Electric Field

[LLCCR 36] A launch operator who measures an electric field to comply with these LLCC shall:

a. Employ a ground-based field mill;

AND

b. Ensure that all field mills are calibrated such that the polarity of the 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;

AND

d. Ensure that the altitude of the flight path of the launch vehicle is less than or equal to 20 km (66,000 ft) everywhere above a horizontal circle of 5 nmi centered on the field mill being used;

AND

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

4.2.4 Determination of Non-Transparent Cloud or Precipitation Boundaries

[LLCCR 37] 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.

4.2.5 Determination of Slant Distance from Lightning

[LLCCR 38] 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 provides no 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 NASA Technical Standard to any portion of the flight path at an altitude greater than 37 km (20 nmi).

APPENDIX A

REQUIREMENTS COMPLIANCE MATRIX

A.1 Purpose

This Appendix provides a listing of requirements contained in this NASA Technical Standard for selection, tailoring, and verification of requirements by programs and projects. *(Note: Enter "Yes" to describe the requirement's applicability to the program or project; or enter "No" if the intent is to tailor, and enter how tailoring is to be applied in the "Rationale" column.)*

NASA-STD-4010				
Section	Description	Requirement in this Standard	Applicable (Yes or No)	If No, Enter Rationale
1.3	Tailoring	[LLCCR 1] Tailoring of this NASA Technical Standard for application to a specific program or project shall be formally documented as part of program or project requirements and approved by the responsible Technical Authority in accordance with NPR 7120.5, NASA Space Flight Program and Project Management Requirements.		
2.1.1	Applicable Documents, General	[LLCCR 2] The latest issuances of cited documents shall apply unless specific versions are designated.		
2.1.2	Applicable Documents, General	[LLCCR 3] Non-use of specifically designated versions shall be approved by the responsible Technical Authority.		
2.4.2	Applicable Documents, Order of Precedence	[LLCCR 4] Conflicts between this NASA Technical Standard and other requirements documents shall be resolved by the responsible Technical Authority.		
4	Lightning Launch Commit Criteria (LLCC)	[LLCCR 5] Whenever there is ambiguity about which of several LLCC applies to a particular situation, all potentially applicable LLCC shall be applied.		
4a	Lightning Launch Commit Criteria (LLCC)	[LLCCR 6] In order to meet the LLCC, a launch operator shall employ: (1) Weather monitoring and measuring equipment needed, AND		

NASA-STD-4010				
Section	Description	Requirement in this Standard	Applicable (Yes or No)	If No, Enter Rationale
		(2) Procedures needed to verify compliance.		
4b	Lightning Launch Commit Criteria (LLCC)	[LLCCR 7] When equipment or procedures such as a field mill or calculation of the maximum radar reflectivity (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.		
4c	Lightning Launch Commit Criteria (LLCC)	[LLCCR 8] A launch operator shall not turn off available instrumentation to create the appearance of meeting a requirement.		
4d		[LLCCR 9] A launch operator shall use all radar reflectivity measurements within a specified volume for an MRR calculation.		
4e	Lightning Launch Commit Criteria (LLCC)	[LLCCR 10] If a launch operator proposes any alternative LLCC, the launch operator shall demonstrate clearly and convincingly that the alternative provides an equivalent level of safety to that required in this NASA Technical Standard.		
4.1.1.1	Lightning	[LLCCR 11] 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 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 NASA Technical Standard, have been less than 1000 V m^{-1} for at least 15 minutes.		
4.1.1.2	Lightning	[LLCCR 12] 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.		

NASA-STD-4010				
Section	Description	Requirement in this Standard	Applicable (Yes or No)	If No, Enter Rationale
4.1.2.1	Surface Electric Fields	[LLCCR 13] A launch operator shall wait 15 minutes to launch after the absolute value of any 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}.		
4.1.2.2	Surface Electric Fields	[LLCCR 14] A launch operator shall wait 15 minutes to launch after the absolute value of any 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}, 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) Have not been part of convective clouds with cloud tops at altitudes where the temperature was colder than or equal to –10 °C for 3 hours.		
4.1.3.1	Cumulus Clouds	[LLCCR 15] 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		

NASA-STD-4010				
Section	Description	Requirement in this Standard	Applicable (Yes or No)	If No, Enter Rationale
		(3) All 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 NASA Technical 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 16] Flight path between 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 17] Flight path between 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 18] Flight path through or within 3 nmi of cloud: If a flight path will carry a launch vehicle 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 slant distance of less than or equal to 1 nmi from the flight path.		
4.1.4.2	Attached Anvil Clouds	[LLCCR 19] Flight path between 3 nmi and 5 nmi from 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	Attached Anvil Clouds	[LLCCR 20] Flight path between 5 nmi and 10 nmi from 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		

NASA-STD-4010				
Section	Description	Requirement in this Standard	Applicable (Yes or No)	If No, Enter Rationale
		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 21] Flight path through 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) Any 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 22] Flight path between 0 nmi and 3 nmi from 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 accomplish the following: a. 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, unless: (1) The portion of the detached anvil cloud 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 slant distance of less than or equal to 1 nmi from the flight path;		

NASA-STD-4010				
Section	Description	Requirement in this Standard	Applicable (Yes or No)	If No, Enter Rationale
		AND b. If a launch operator is unable to launch in the first 30 minutes under section 4.1.5.2a in this NASA Technical Standard, wait to launch for 3 hours 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: (1) 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 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(1)A in this NASA Technical 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; OR (2) Both of the following are true: A. 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		

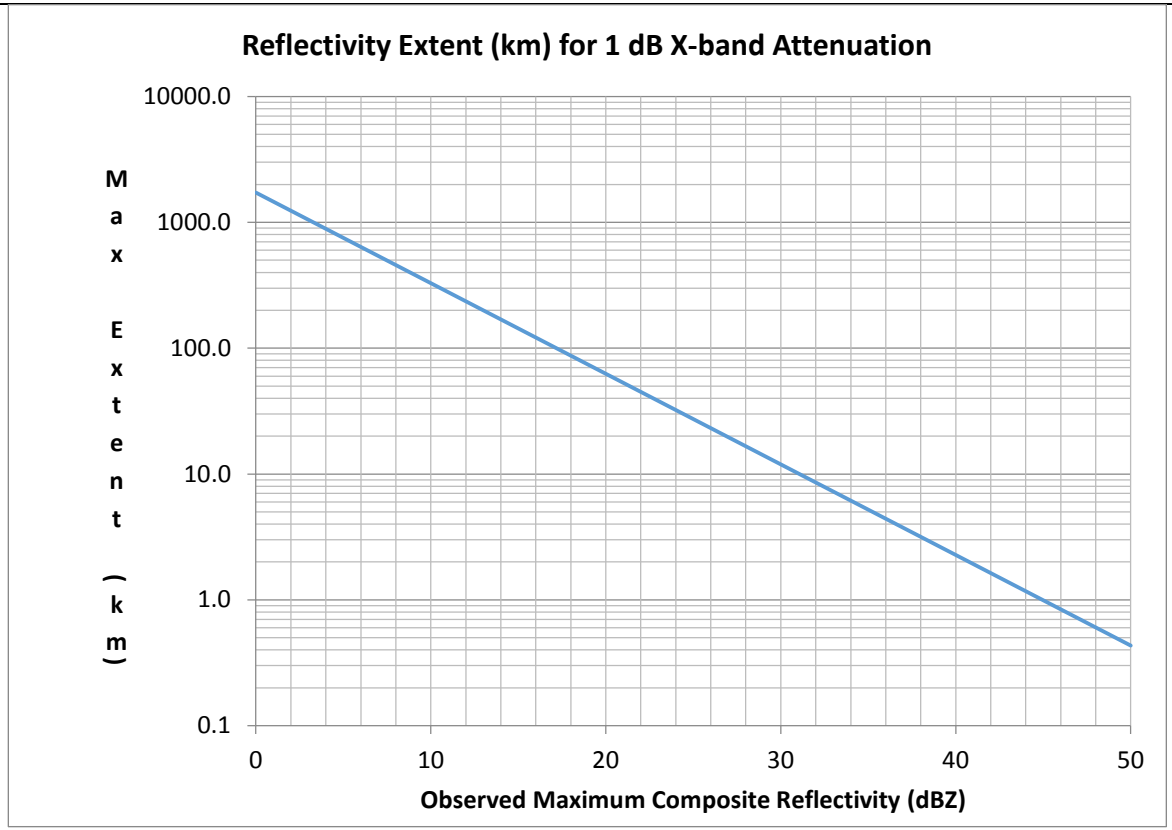
NASA-STD-4010				
Section	Description	Requirement in this Standard	Applicable (Yes or No)	If No, Enter Rationale
		B. The MRR is less than +7.5 dBZ at every point at a slant distance of less than or equal to 1 nmi from the flight path.		
4.1.5.3	Detached Anvil Clouds	[LLCCR 23] Flight path between 3 nmi and 10 nmi from 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 24] 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 25] Flight path through 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 NASA Technical 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.		

NASA-STD-4010				
Section	Description	Requirement in this Standard	Applicable (Yes or No)	If No, Enter Rationale
4.1.6.3	Debris Clouds	[LLCCR 26] Flight path between 0 nmi and 3 nmi from cloud: If the flight path will carry the launch vehicle at a slant distance of greater than or equal to 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 NASA Technical Standard, unless 4.1.6.3a or 4.1.6.3b applies: a. Launch if: (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 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 NASA Technical Standard, have been less than 1000 Vm^{-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. Launch if: (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 slant distance of less than or equal to 1 nmi from the flight path.		
4.1.7	Disturbed Weather	[LLCCR 27] 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		

NASA-STD-4010				
Section	Description	Requirement in this Standard	Applicable (Yes or No)	If No, Enter Rationale
		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.		
4.1.8.1	Thick Cloud Layers	[LLCCR 28] A launch operator shall not launch if the flight path will carry the launch vehicle through a non-transparent cloud layer that is: a. Greater than or equal to 1.4 km (4500 ft) thick and any part of the cloud layer within the flight path is located at an altitude where the temperature is between 0 °C and -20 °C, inclusive; OR b. 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 and has any part located at any altitude where the temperature is between 0 °C and -20 °C, inclusive.		
4.1.8.2	Thick Cloud Layers	[LLCCR 29] A launch operator shall be permitted to launch despite section 4.1.8.1 in this NASA Technical Standard if the thick cloud layer: a. Is a cirriform cloud layer that has never been associated with 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.		

NASA-STD-4010				
Section	Description	Requirement in this Standard	Applicable (Yes or No)	If No, Enter Rationale
4.1.8.3	Thick Cloud Layers	[LLCCR 30] A launch operator shall not be required to apply the LLCC in section 4.1.8.1 in this NASA Technical Standard if the 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.		
4.1.9	Smoke Plumes	[LLCCR 31] A launch operator shall not launch if the flight path will carry the launch vehicle through any non-transparent cumulus cloud that has developed from a smoke plume 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.		
4.1.10.1	Triboelectrification	[LLCCR 32] 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 33] Section 4.1.10.1 in this NASA Technical 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.		

NASA-STD-4010				
Section	Description	Requirement in this Standard	Applicable (Yes or No)	If No, Enter Rationale
4.2.1	Measurement of Cloud Radar Reflectivity	[LLCCR 34] 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 AND d. A 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-4010				
Section	Description	Requirement in this Standard	Applicable (Yes or No)	If No, Enter Rationale
		 **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	Computation of MRR	[LLCCR 35] A launch operator who measures MRR to comply with these LLCC shall ensure that:		

NASA-STD-4010				
Section	Description	Requirement in this Standard	Applicable (Yes or No)	If No, Enter Rationale
		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 measurement within the specified volume; AND c. If the MRR defined in section 4.2.2b in this NASA Technical 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 altitudes of 4 km or greater above mean sea 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 section 4.2.2d in this NASA Technical Standard to additional MRR evaluation points outside the flight path that are required in certain rule exceptions.		
4.2.3	Measurement of Electric Field	[LLCCR 36] A launch operator who measures an electric field to comply with these LLCC shall: a. Employ a ground-based field mill;		

NASA-STD-4010				
Section	Description	Requirement in this Standard	Applicable (Yes or No)	If No, Enter Rationale
		AND b. Ensure that all field mills are calibrated such that the polarity of the 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; AND d. Ensure that the altitude of the flight path of the launch vehicle is less than or equal to 20 km (66,000 ft) everywhere above a horizontal circle of 5 nmi centered on the field mill being used; AND e. Use only direct measurements from a field mill and never interpolate between mills.		
4.2.4	Determination of Non-Transparent Cloud or Precipitation Boundaries	[LLCCR 37] 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		

NASA-STD-4010				
Section	Description	Requirement in this Standard	Applicable (Yes or No)	If No, Enter Rationale
		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.		
4.2.5	Determination of Slant Distance from Lightning	[LLCCR 38] 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 provides no 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 NASA Technical Standard to any portion of the flight path at an altitude greater than 37 km (20 nmi).		

APPENDIX B

REFERENCES

B.1 Purpose and/or Scope

This Appendix provides reference material related to this NASA Technical Standard.

B.2 Reference Documents

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

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, 2017). Note the rationale reference document is not updated as often as this NASA Technical 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. (2017): *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.