

Lightning Launch Commit Criteria

1 February 1996

Prepared by

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Prepared for

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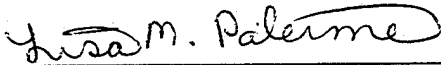
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LISA M. PALERMO, CAPT, USAF
Project Officer

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| <p>13. ABSTRACT (Maximum 200 words)</p> <p>The Airborne Field Mill Project was jointly undertaken by the USAF and NASA during the winters of 1990, 1991, and 1992, and the summer of 1991 in order to gather <i>in situ</i> airborne field mill (ABFM) data to revise the USAF and NASA lightning Launch Commit Criteria (LCC) for manned and unmanned space launches. The Marshall Space Flight Center recommended changes to the lightning LCC based on their analysis of the ABFM data obtained under the Airborne Field Mill Project.</p> <p>A committee known as the Peer Review Committee (PRC) was formed "To draft and finalize a subset of the 'Natural and Triggered Lightning Launch Commit Criteria' based on ABFM Program data."</p> <p>This report documents the LCC recommended by the PRC in March 1994 and presented to the Chief Engineers Council of the USAF Space Materiel Command for their concurrence in August 1994.</p> | | | | | |
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Section I

I. Introduction

The Airborne Field Mill Project was jointly undertaken by the USAF and NASA during the winters of 1990, '91, and '92 and the summer of 1991 in order to gather in situ airborne field mill data to revise the USAF and NASA lightning Launch Commit Criteria (LCC) for manned and unmanned space launches. The Marshall Space Flight Center recommended changes to the lightning LCC based on their analysis of the ABFM data obtained under the Airborne Field Mill Project.

A committee known as the NASA/USAF Airborne Field Mill (ABFM) Triggered Lightning Launch Commit Criteria (LCC) Peer Review Committee or Peer Review Committee (PRC) for short was formed "To draft and finalize a subset of the 'Natural and Triggered Lightning Launch Commit Criteria' based on ABFM Program data." The purpose was to provide less restrictive but equally safe LCC as compared with the then existing rules which were felt to be too conservative.

This report documents the LCC recommended by the PRC in March 1994 and presented to the Chief Engineers Council of the USAF Space Materiel Command for their concurrence in June 1994.

The members of the PRC are given in Table 1. The formal activities of the PRC leading to the March 1994 recommendations are listed in Table 2. The LCC recommended in March 1994 are contained in Section II and the charts prepared for the briefing to the Chief Engineers Council are contained in Section III.

Table 1. Members of the NASA/USAF Airborne Field Mill (ABFM) Triggered Lightning Launch Commit Criteria (LCC) Peer Review Committee.

| <u>Name</u> | <u>Title</u> | <u>Affiliation</u> |
|-----------------------------|---|--|
| Dr. James E. Dye | Senior Scientist | National Center for Atmospheric Research |
| Dr. Harry C. Koons | Senior Scientist | Space and Environment Technology Center The Aerospace Corporation |
| Dr. E. Philip Krider | Professor and Director | Institute of Atmospheric Physics University of Arizona |
| Dr. W. David Rust | Chief, Storm Electricity & Cloud Physics Research | NOAA/National Severe Storms Laboratory |
| Dr. Richard L. Walterscheid | Senior Scientist | Space and Environment Technology Center The Aerospace Corporation |
| Dr. John C. Willett | Physicist | Geophysics Directorate Phillips Laboratory |

Table 2. Formal Activities of the Peer Review Committee

| <u>Activity</u> | <u>Location</u> | <u>Date</u> |
|-------------------|------------------------------|----------------|
| Committee Meeting | Marshall Space Flight Center | 3-5 Aug 1992 |
| Teleconference | | 15 Apr 1993 |
| Teleconference | | 18 Jun 1993 |
| Teleconference | | 22 Nov 1993 |
| Committee Meeting | Kennedy Space Flight Center | 14-17 Feb 1994 |

Section II

4.5 Natural and Triggered Lightning Constraints

NOTICE: ANY CHANGE TO THIS SECTION REQUIRES COORDINATION WITH THE 45th SPACE WING RANGE SAFETY OFFICE

Even when these constraints are not violated, if any other hazardous condition exists, the Launch Weather Officer will report the threat to the Launch Director. The Launch Director may HOLD at any time based on the instability of the weather.

The Launch Weather Officer must have clear and convincing evidence that the following constraints are not violated:

- A. Do not launch if any type of lightning is detected within 10 NM of the flight path within 30 min prior to launch time,

unless:

- 1. the meteorological condition that produced the lightning has moved more than 10 NM away from the flight path.

- B. Do not launch if, at launch time, the flight path will carry the vehicle:
1. Through a cumulus cloud with its top between the +5.0 deg C and -5.0 deg C levels,
unless:
 - a. The cloud is not producing precipitation.and
 - b. The horizontal distance from the cloud top to at least one working field mill is less than the altitude of the 0.0 deg C level or 3 NM, whichever is smaller.and
 - c. All field mill readings within 5 NM of the flight path are between -100 V/m and +1000 V/m for the preceding 15 min.
 2. Through cumulus clouds with tops higher than the -5.0 deg C level.
 3. Through or within 5 NM of the nearest edge of cumulus clouds with tops higher than the -10.0 deg C level.
 4. Through or within 10 NM of the nearest edge of any cumulonimbus or thunderstorm cloud including nontransparent parts of its anvil.
 5. Through or within 10 NM of the nearest edge of a nontransparent detached anvil for the first hour after detachment from the parent cloud.

C. Do not launch if, for ranges equipped with a working surface electric field mill network, at any time during the 15 min prior to launch time the absolute value of any electric field intensity measurement at the ground is greater than 1000 V/m within 5 NM of the flight path,

unless:

1. There are no clouds within 10 NM of the flight path,

except:

a. transparent clouds

or

b. clouds with tops below the +5.0 deg C level that have not been associated with convective clouds with tops above the -10.0 deg C level within the last 3 hr.

and

2. A known source of electric field (such as ground fog) that is occurring near the sensor and that has been determined to be benign is clearly causing the elevated readings.

D. Do not launch if the flight path is through a vertically continuous layer of clouds with an overall depth of 4,500 ft or greater where any part of the clouds is located between the 0.0 deg C and the -20.0 deg C levels.

E. Do not launch if the flight path is through any clouds that extend to altitudes at or above the 0.0 deg C level and moderate or greater precipitation is occurring within 5 NM of the flight path.

- F. Do not launch if, at launch time, the flight path will carry the vehicle:
1. Through any nontransparent debris cloud during the first 3 hr after the debris cloud formed from a parent cloud.
 2. Within 5 NM of the nearest edge of a nontransparent debris cloud during the first 3 hr after the debris cloud formed from a parent cumulonimbus or thunderstorm cloud,
unless
 - a. There is at least one working field mill within 5 NM of the debris cloudand
 - b. All electric field intensity measurements at the ground are between +1000 V/m and -1000 V/m within 5 NM of the flight path during the 15 min preceding the launch time.and
 - c. The maximum radar return from the entire debris cloud is less than 10 dBz during the 15 min preceding launch time.
 3. The start of the 3-hr period is reckoned as follows:
 - a. If it is known that the cloud is detached, the 3-hr period begins at the earliest time shown by observation that the cloud is detached, or the time of the last detected lightning discharge (if any) from the detached debris cloud, whichever is later.
 - b. If it is not known whether the cloud is detached, or the debris cloud forms from the decay of the parent cloud, the 3-hr period begins at the time of the last detected lightning discharge (if any) from the parent cloud or debris cloud, or the time when the parent cloud decays to below the -10.0 deg C level, whichever is later.
- G. For cloud types described in Rules D, E, and F, those rules need not be applied if, during the 15 min prior to launch time, the absolute value of the instantaneous vector electric field sampled within the cloud volume expected to be along the flight path is less than E_c where E_c is shown as a function of altitude in Figure G-1.

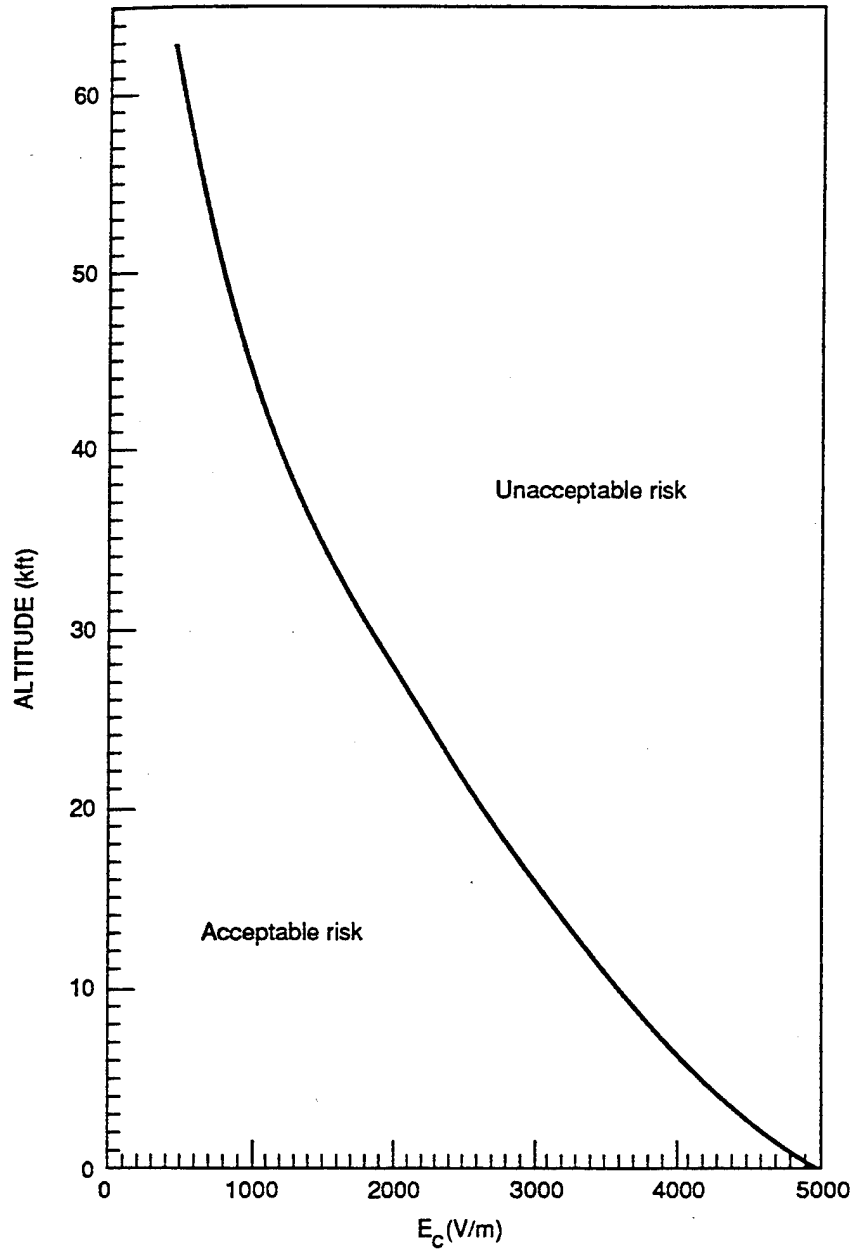


Figure G-1. Instantaneous critical electric field intensity vs. altitude.

H. Definitions:

1. **Anvil:** Stratiform or fibrous cloud produced by the upper level outflow or blow-off from thunderstorms or convective clouds.
2. **Cloud Edge:** The visible cloud edge is preferred. If this is not possible, then the 10 dBz radar cloud edge is acceptable.
3. **Cloud Layer:** An array of clouds, not necessarily all of the same type, whose bases are approximately at the same level. Also, multiple arrays of clouds at different altitudes that are connected vertically by cloud elements, e.g., turrets from one cloud array to another. Convective clouds (e.g., clouds falling under Rule B) are excluded from this definition unless they are imbedded with other cloud types.
4. **Cloud Tops:** The visible cloud top is preferred. If this is not possible, then the 13 dBz radar cloud top is acceptable.
5. **Cumulonimbus Cloud:** Any convective cloud with any part above the -20 deg C temperature level.
6. **Debris Cloud:** Any nontransparent cloud, that has become detached from a parent cumulonimbus cloud or thunderstorm or results from the decay of a parent cumulonimbus cloud or thunderstorm.
7. **Electric Field:** Here, electric field means the one-minute arithmetic average of the field mill readings and the polarity of the electric field is the same as that of the potential gradient; that is, the field polarity is the same as that of the charge overhead for fields measured at the ground.
8. **Flight Path:** The planned flight path including its uncertainties ("error bounds").
9. **Thunderstorm:** Any cloud that produces lightning.
10. **Transparent:** Synonymous with visually transparent. Sky cover through which higher clouds, blue sky, stars etc. may be clearly observed from below. Also, sky cover through which terrain, buildings etc. may be clearly observed from above. Sky cover through which blurred, indistinct forms are visible is not transparent.

CONCURRENCE:

We want the record to show that we believe the best way to ensure safety from atmospheric electricity hazards, and also to improve launch availability, is to use an instrumented aircraft in conjunction with the ground-based field mill network to measure the electric field environment and its time development along and near the flight path. This recommendation has previously been made in the H. A. Heritage Report titled "Launch Vehicle Lightning/Atmospheric Electrical Constraints Post-Atlas/Centaur '67 Incident," in the National Academy of Science Panel Report titled "Meteorological Support for Space Operations," and in our August 1992 recommendations made at the Marshall Space Flight Center.

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Section III

Revisions to the Lightning Launch Commit Criteria

by

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Concept Development Subdivision

Objective

- **Present the revisions to the lightning launch constraint criteria**
 - **Recommended by the Lightning Peer Review Committee**
 - **Joint AF/NASA Committee**
 - **Met at KSC in February 1994**
- **General belief that the current Lightning LCCs are too conservative**
- **Increase launch opportunities while maintaining safety**

Overview

- **Launch failures related to hazardous meteorological conditions**
- **Description of triggered lightning and triboelectric charging**
- **Historical “rules” approach to launch commit criteria**
- **New revisions to the lightning LCC**
- **Concerns**
- **Recommendations**

USA Launch Vehicle Failures

USA DOD

| vehicle | flight | fail date | fail subsys |
|---------------|--------|-----------|-------------|
| Titan IV | K-11 | 08/02/93 | propulsion |
| Titan 34D | D-3 | 09/02/88 | propulsion |
| Atlas-Centaur | AC-67 | 03/26/87 | other |
| Titan 34D | D-9 | 04/18/86 | propulsion |
| Titan 34D | D-7 | 08/28/85 | propulsion |

USA non-DOD

| vehicle | flight | fail date | fail subsys |
|----------------|--------|-----------|-------------|
| Atlas-Centaur | AC-74 | 03/25/93 | propulsion |
| Atlas-Centaur | AC-71 | 08/22/92 | propulsion |
| Pegasus | F-2 | 07/17/91 | separation |
| Atlas-Centaur | AC-70 | 04/18/91 | propulsion |
| Titan III | CT-2 | 03/14/90 | separation |
| Delta | 178 | 05/03/86 | electrical |
| STS-Challenger | 51-L | 01/28/86 | propulsion |
| Atlas-Centaur | AC-62 | 06/09/84 | propulsion |



Launches Seriously Affected by Lightning and Triboelectrification

- **Triggered lightning**
 - **Apollo 12 on 14 Nov 1969**
 - **Struck by lightning twice**
 - **Massive electrical outages**
 - **Mission continued**
 - **Atlas/Centaur-67 on 26 March 1987 (FltSatCom F-6)**
 - **Struck by lightning**
 - **Mission lost**
- **Triboelectric charging**
 - **Europa II F-11 on 5 Nov 1971**
 - **Electrostatic charging of an ungrounded screen**
 - **Mission lost**

Lightning LCC Impact on Launch Scrubs

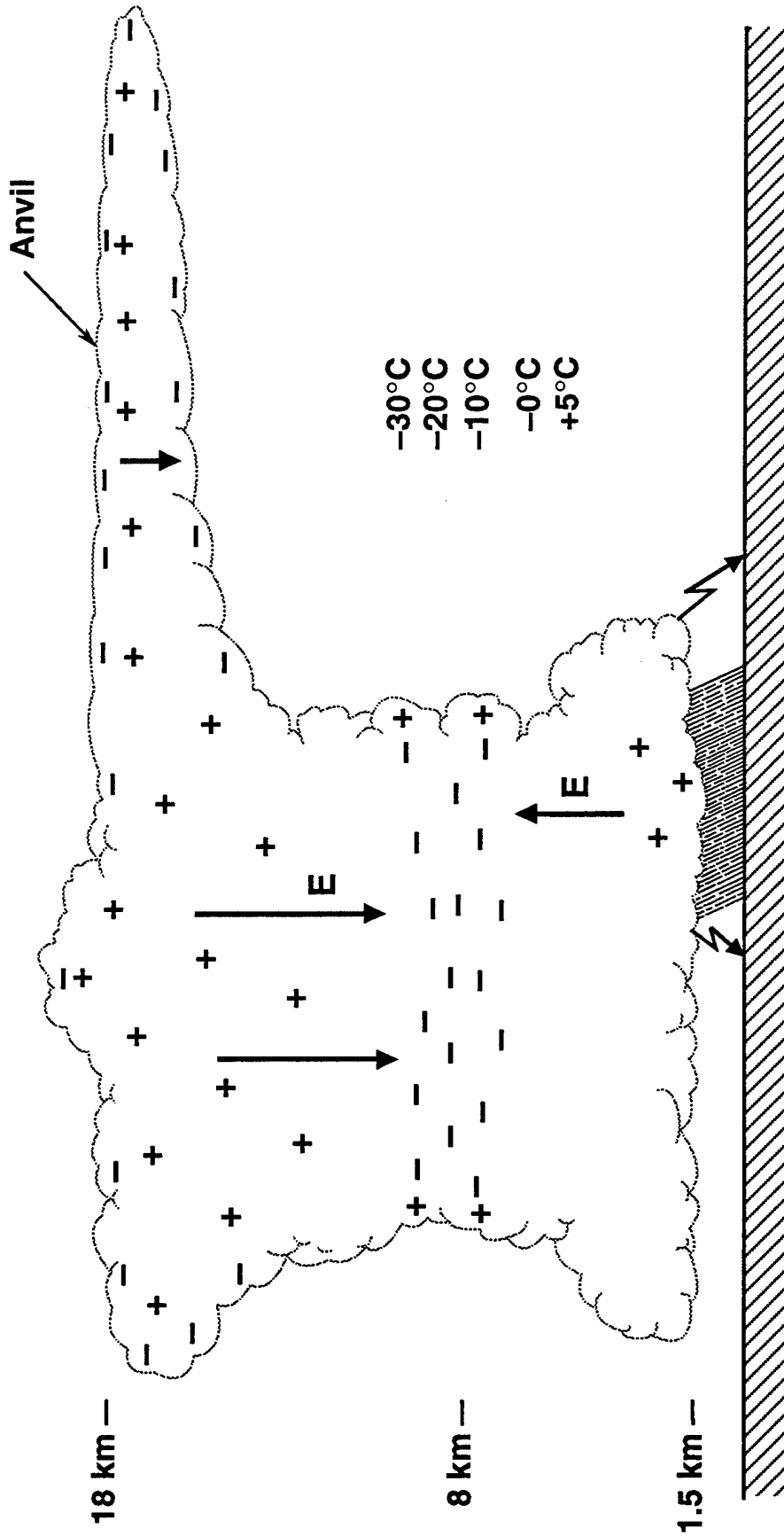
| | Total Scrubs | Weather Scrubs | Lightning Scrubs |
|------|--------------|----------------|------------------|
| All | 101 | 46 | 16 |
| ELVs | 56 | 30 | 14* |
| STS | 45 | 16 | 2 |

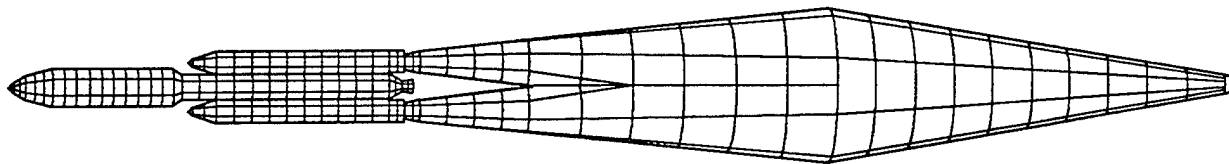
* Next largest category of weather scrubs is loads with 11

ELVs 1987-94

STS 1981-86 and 1988-94

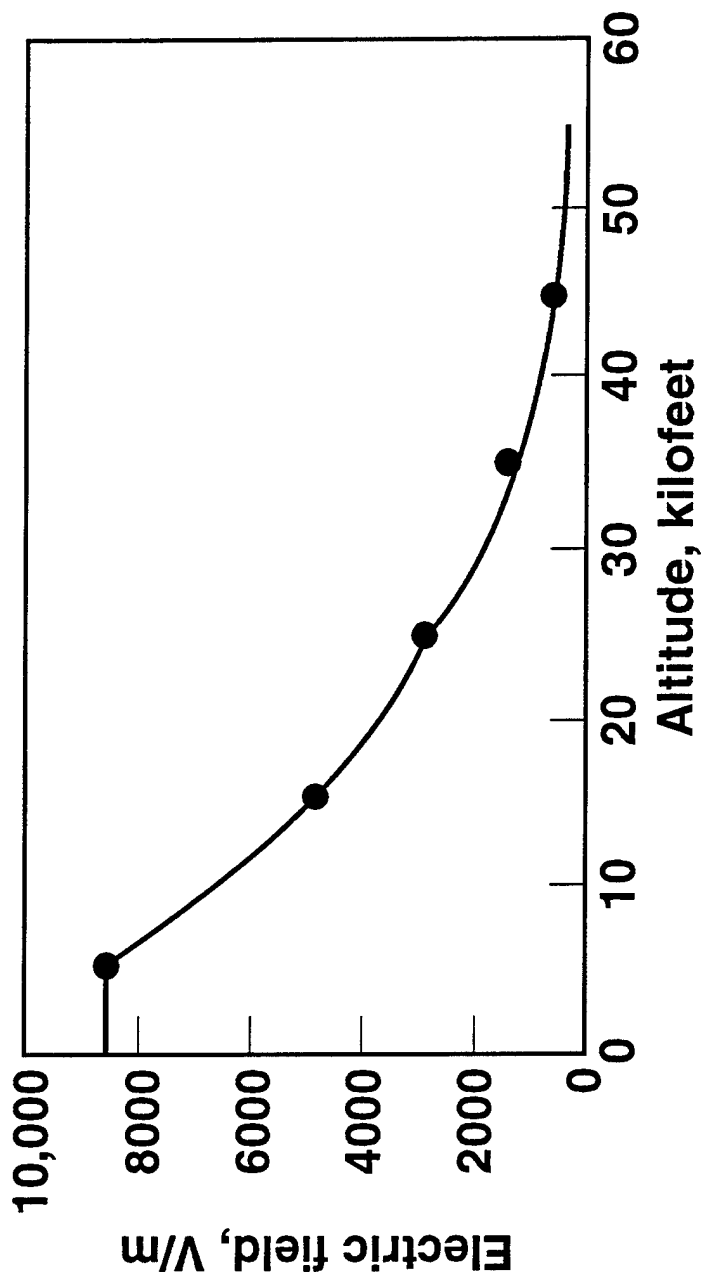
Electric Fields



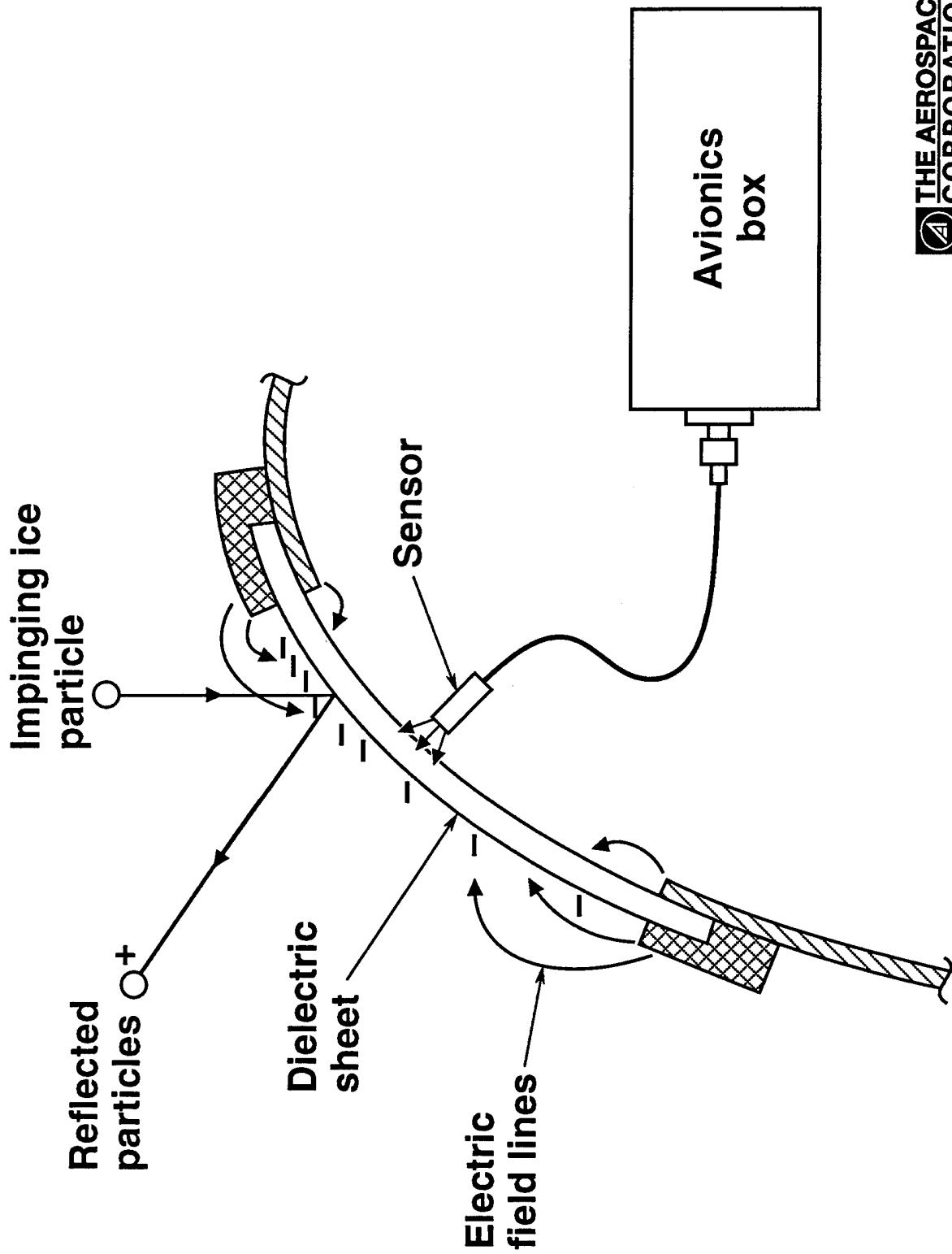


Triggered Lightning

- Breakdown electric field
 - Proportional to the ambient electric field
 - 2.6×10^6 V/m at sea level
 - Proportional to the dynamic air density
 - Depends on the plume length as $1/L^{0.8}$



Triboelectric Charging



Evolution of Lightning LCCs

- **Post-Apollo 12 Launch Rules**
 - Exclusively meteorological
- **Apollo-Soyuz Launch Rules, 1975**
 - Short window required for linkup
 - Added ground-based and airborne field mill measurements
- **Post Atlas/Centaur AC-67 Launch Rules**
 - Heritage Committee convened by Aerospace at the request of Space Division Commander
 - Airborne field mill recommended but not included in rules
- **Current Launch Rules**
 - Coordination of AF (Heritage Committee) and NASA rules

Overview of Recommended Rules

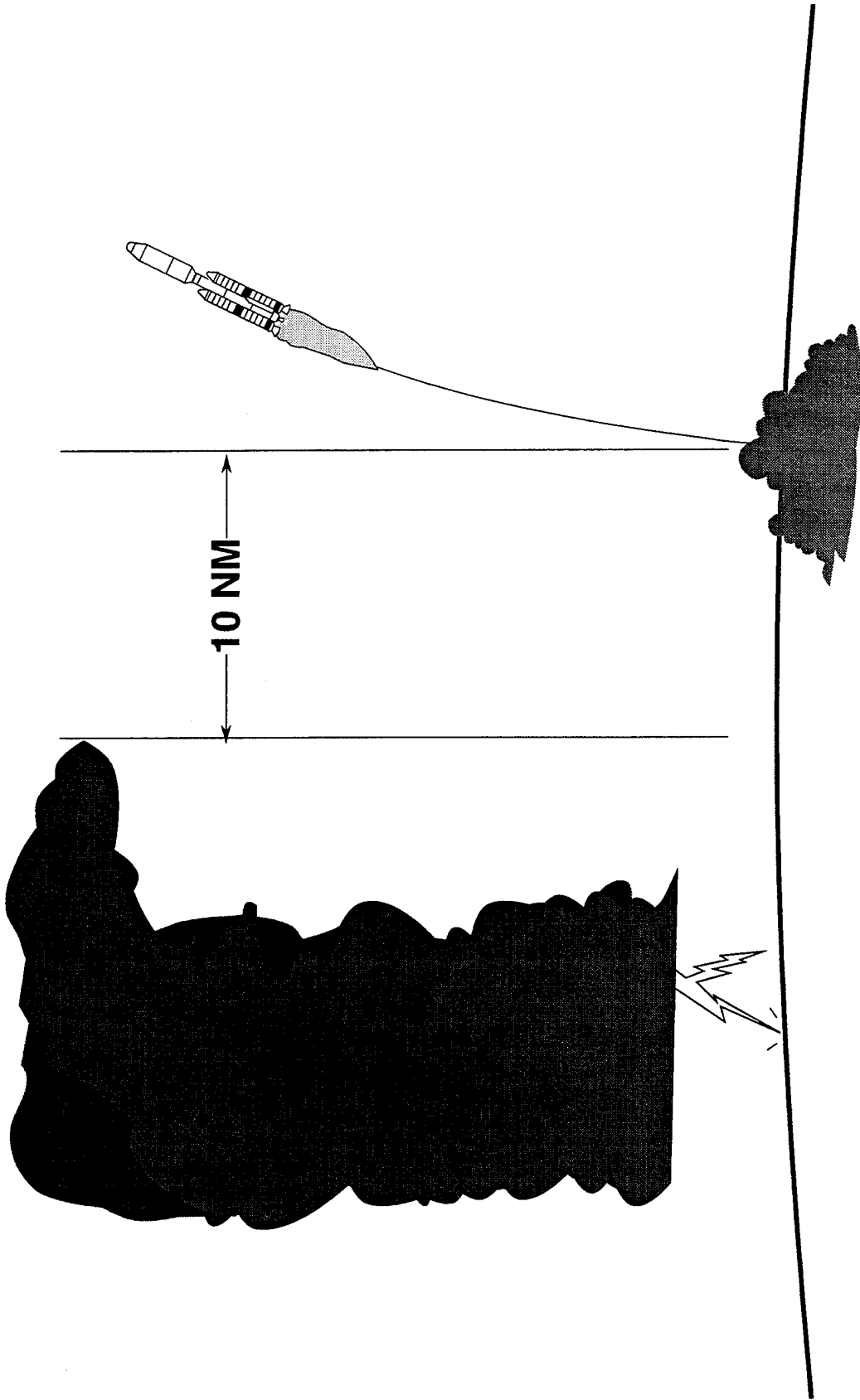
- **A. Active thunderstorms**
- **B. Developing cumulus clouds**
- **C. Ground-based field mills**
- **D. Layered clouds**
- **E. Disturbed weather**
- **F. Debris clouds**
- **G. Airborne field mill**

Lightning Scrub Statistics

Scrubs

- Current rules
 - A. Active thunderstorms... 3
 - B. Developing cumulus clouds... 15
 - C. Ground-based field mills... 6
 - D. Layered clouds... 5
 - E. Disturbed weather... 2
 - F. Debris clouds... 5
- Cases are not independent

Rule A Thunderstorms



Recommended Launch Commit Criteria

Rule A

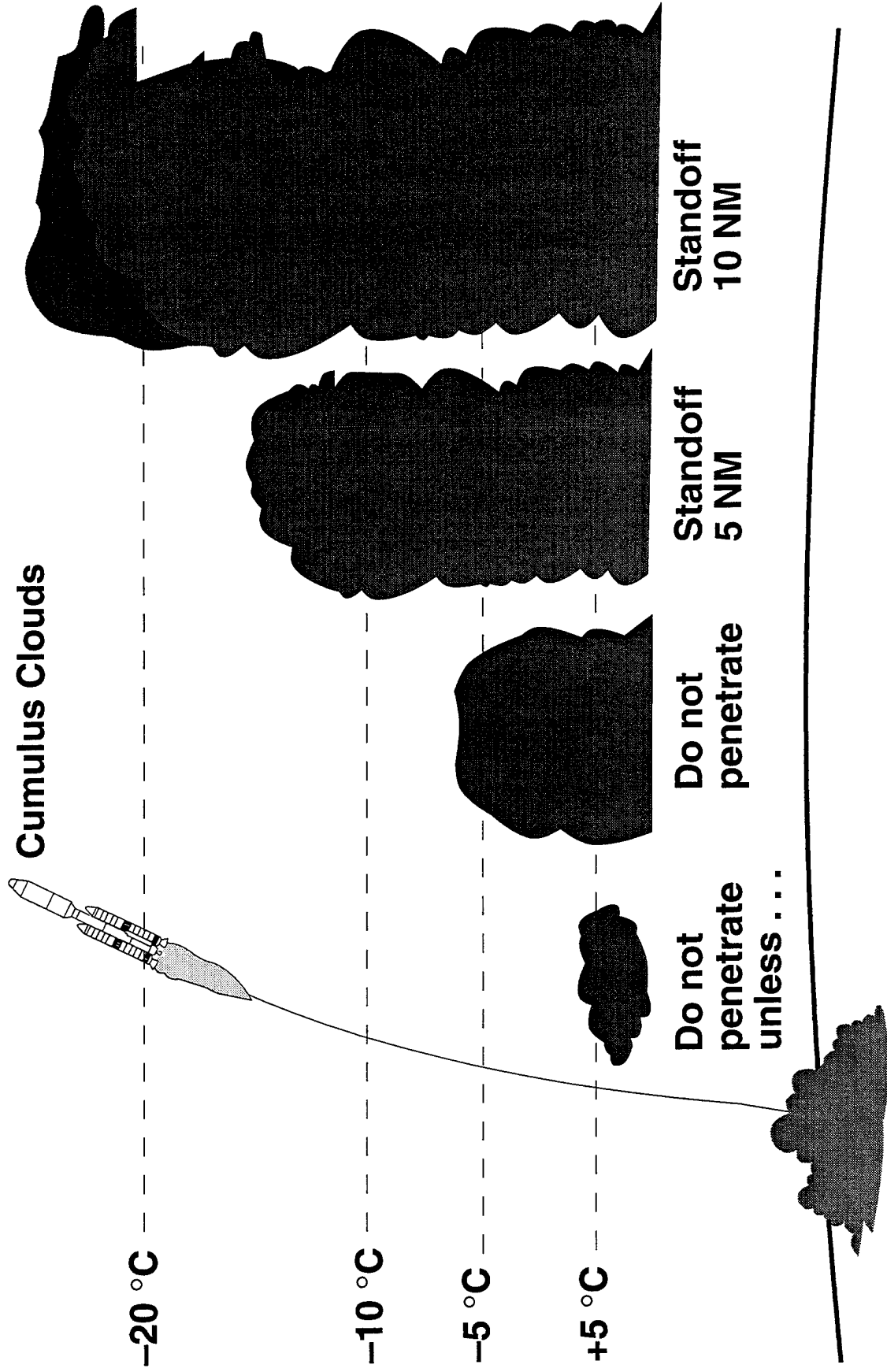
- A. Do not launch if any type of lightning is detected within 10 NM of the flight path within 30 min prior to launch time, unless:
 - 1. the meteorological condition that produced the lightning has moved more than 10 NM away from the flight path.

Changes in Rule A

- Substantially unchanged

Rule B

Cumulus Clouds



Recommended Launch Commit Criteria Rules B.1. and B.2.

- **B. Do not launch if, at launch time, the flight path will carry the vehicle:**
 - **1. Through a cumulus cloud with its top between the +5.0 deg C and -5.0 deg C levels,**
unless:
 - **a. The cloud is not producing precipitation.**
 - and**
 - **b. The horizontal distance from the cloud top to at least one working field mill is less than the altitude of the 0.0 deg C level or 3 NM, whichever is smaller.**
 - and**
 - **c. All field mill readings within 5 NM of the flight path are between 100 V/m and +1000 V/m for the preceding 15 min.**
 - **2. Through cumulus clouds with tops higher than the -5.0 deg C level**

Changes in Rule B

- **B.1. and B. 2.**
 - Provide additional launch opportunities when cumulus clouds are in the altitude range from the +5.0 deg C level to the -5 deg C level. Replaces B(1)
 - Increases launch availability

Recommended Launch Commit Criteria

Rule B.3.

- **B. Do not launch if, at launch time, the flight path will carry the vehicle:**
 - **3. Through or within 5 NM of the nearest edge of cumulus clouds with tops higher than the -10.0 deg C level.**

Changes in Rule B cont.

- **B.3.**
 - **Unchanged**

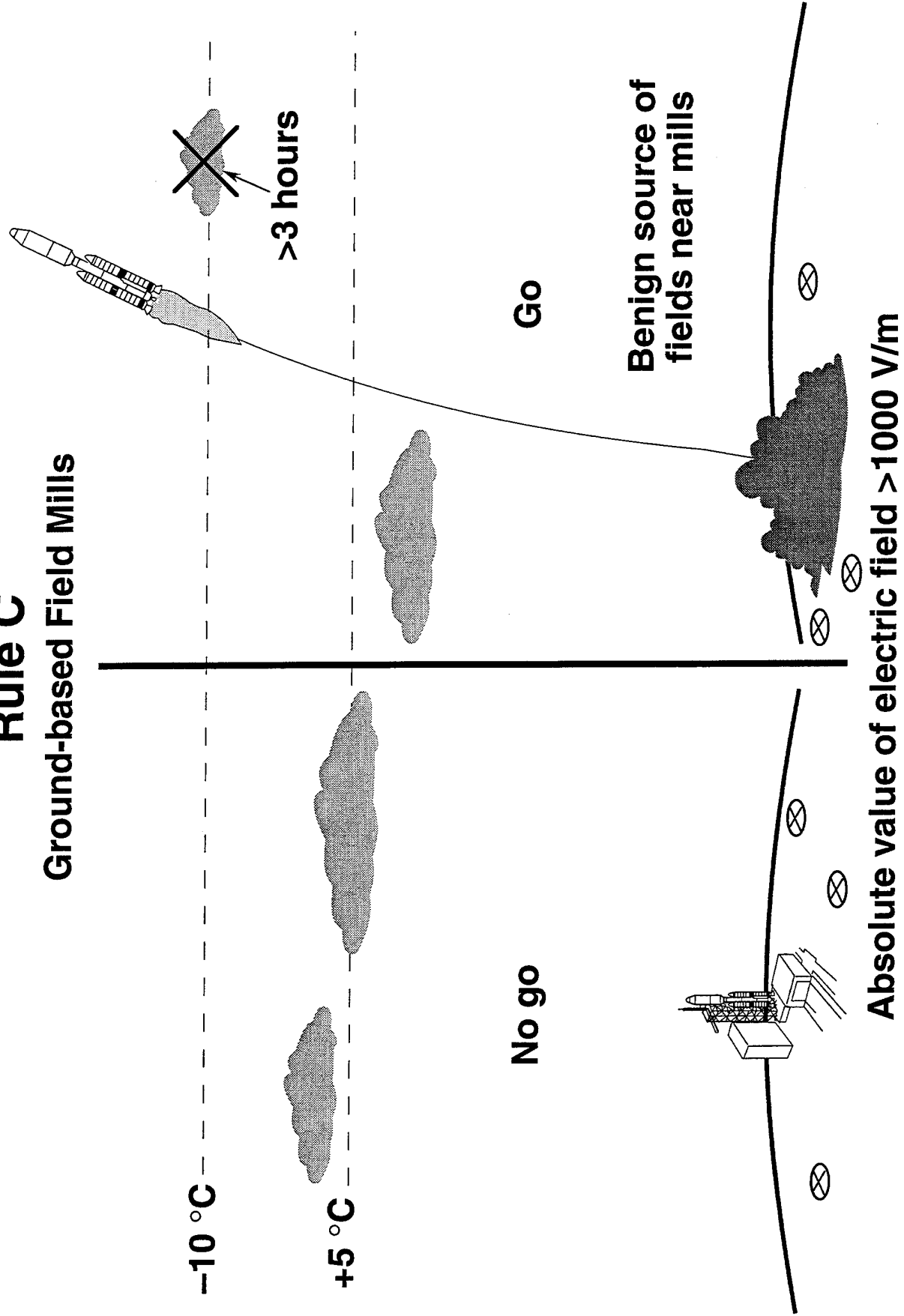
Recommended Launch Commit Criteria

Rules B.4. and B.5.

- **B. Do not launch if, at launch time, the flight path will carry the vehicle:**
 - **4. Through or within 10 NM of the nearest edge of any cumulonimbus or thunderstorm cloud including nontransparent parts of its anvil.**
 - **5. Through or within 10 NM of the nearest edge of a nontransparent detached anvil for the first hour after detachment from the parent cloud.**

Rule C

Ground-based Field Mills



Changes in Rule B cont.

- **B.4.**
 - **Changed to simplify wording**
 - **Combines the current rules B(3) and B(4)**
 - **The phrase “associated anvil” has been changed to “nontransparent parts of its anvil” to clarify the intent of the rule. This increases launch opportunities**
 - **The “-20 degrees Celsius” phrase has been incorporated into the definition of a cumulonimbus cloud**
- **B.5.**
 - **Addresses detached anvils as a separate case**
 - **Increases launch opportunities by limiting 10 NM standoff period to 1 hour**

Recommended Launch Commit Criteria

Rule C.1.

- C. Do not launch if, for ranges equipped with a working surface electric field mill network, at any time during the 15 min prior to launch time the absolute value of any electric field intensity measurement at the ground is greater than 1000 V/m within 5 NM of the flight path,
unless:
 - 1. There are no clouds within 10 NM of the flight path,
except:
 - a. transparent clouds
 - or
 - b. clouds with tops below the +5.0 deg C level that have not been associated with convective clouds with tops above the -10.0 deg C level within the last 3 hr.

Changes in Rule C

- C.1.
 - Increases launch opportunities by deleting the cloud cover clauses
 - committee believes that the percent of cloud cover plays no role in triggering lightning
 - Retained only clouds that have been associated with disturbed weather within a 3-hour period before launch

Recommended Launch Commit Criteria

Rule C.2.

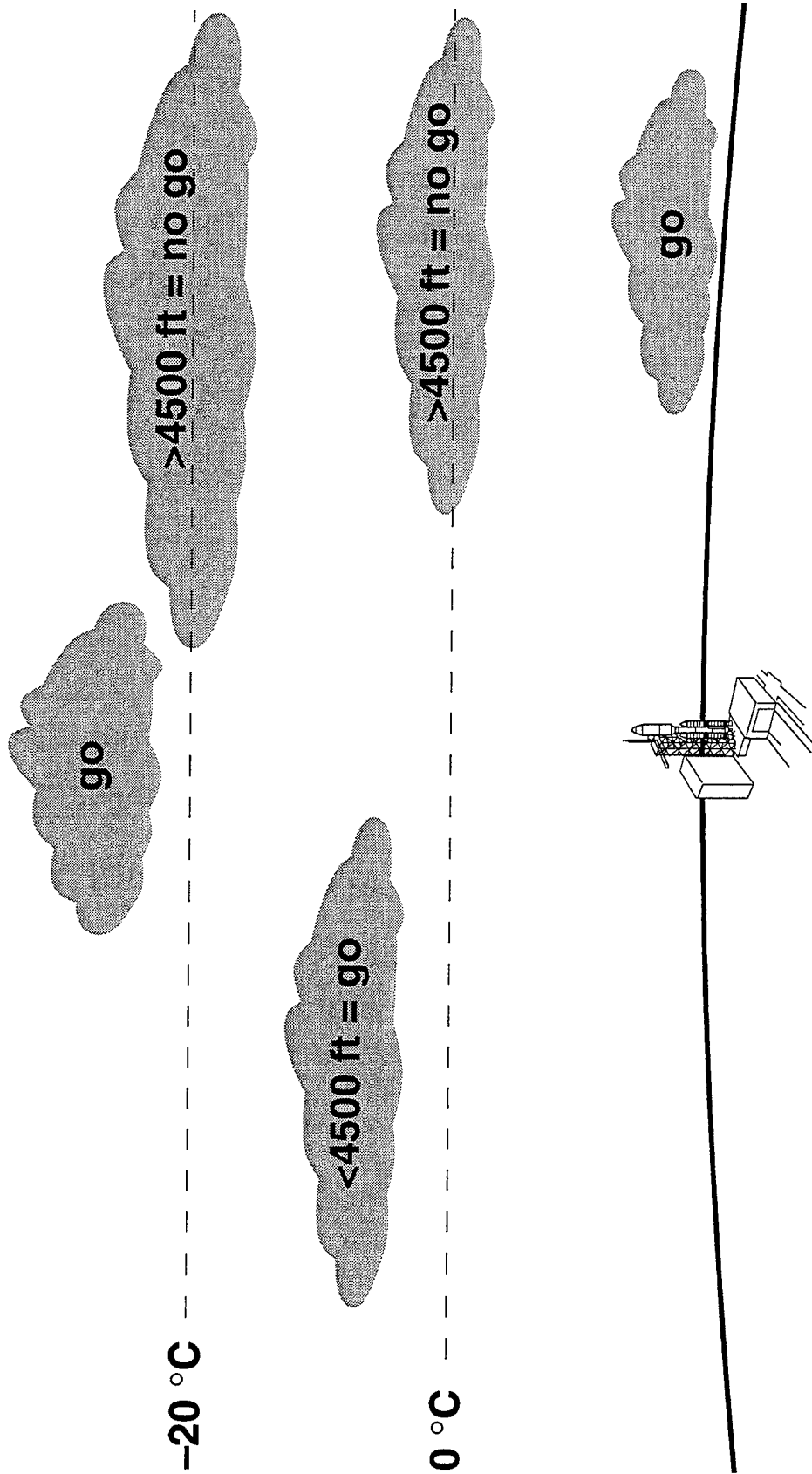
- C. Do not launch if, for ranges equipped with a working surface electric field mill network, at any time during the 15 min prior to launch time the absolute value of any electric field intensity measurement at the ground is greater than 1000 V/m within 5 NM of the flight path, unless:
 - 2. a known source of electric field (such as ground fog) that is occurring near the sensor and that has been determined to be benign is clearly causing the elevated readings.

Changes in Rule C cont.

- **C.2.**
 - **Increases safety but decreases launch availability**
 - **The maritime inversion clause has been deleted**
 - **Committee believes that there is insufficient evidence to retain this rule (which had been provisional)**
 - **Will be reevaluated if more data on the phenomena are collected**

Rule D

Layered Clouds



Recommended Launch Commit Criteria

Rule D

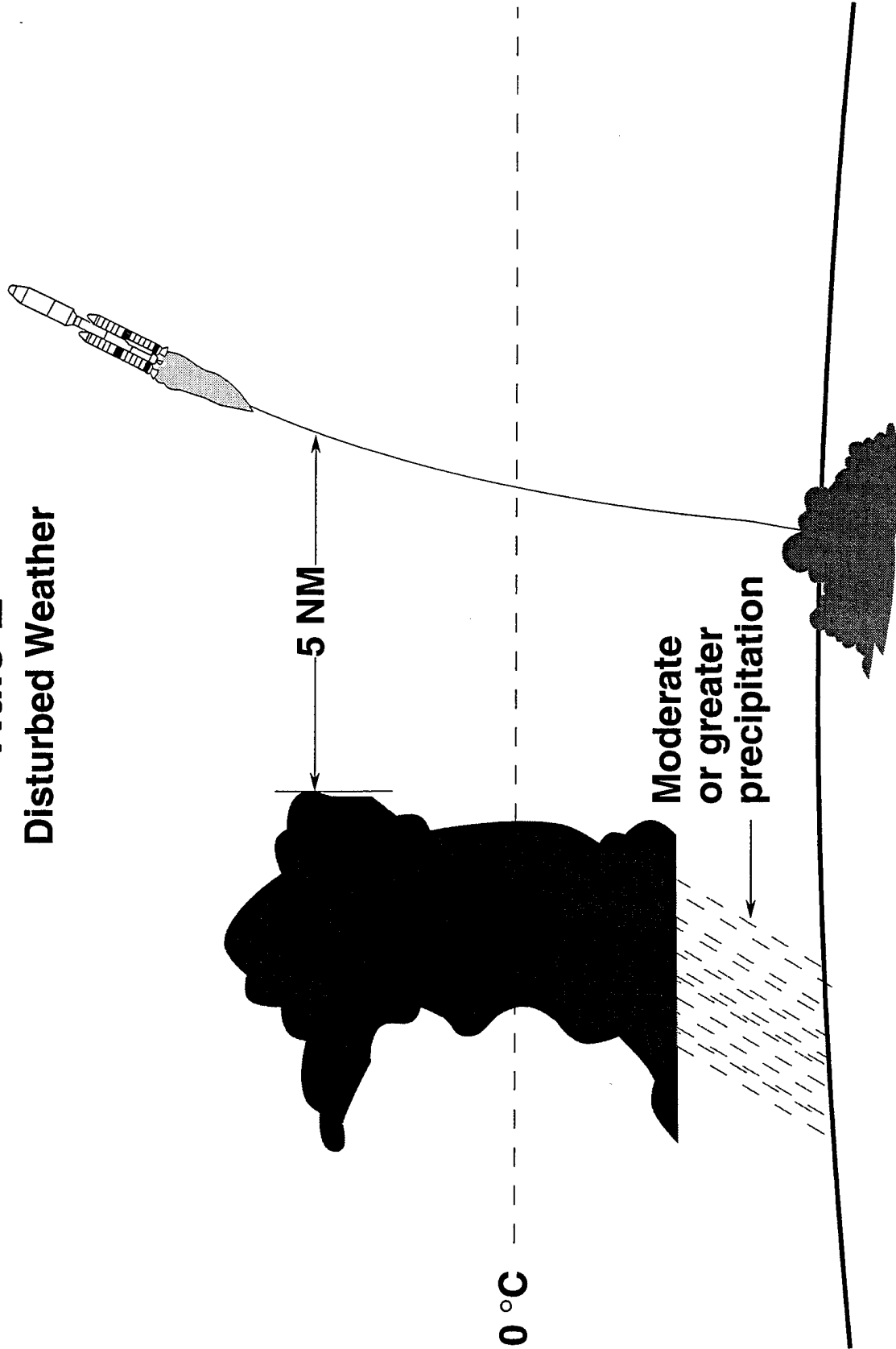
- D. Do not launch if the flight path is through a vertically continuous layer of clouds with an overall depth of 4,500 ft or greater where any part of the clouds is located between the 0.0 deg C and the -20.0 deg C levels.

Changes in Rule D

- **Unchanged**

Rule E

Disturbed Weather



Recommended Launch Commit Criteria

Rule E

- E. Do not launch if the flight path is through any clouds that extend to altitudes at or above the 0.0 deg C level and moderate or greater precipitation is occurring within 5 NM of the flight path.

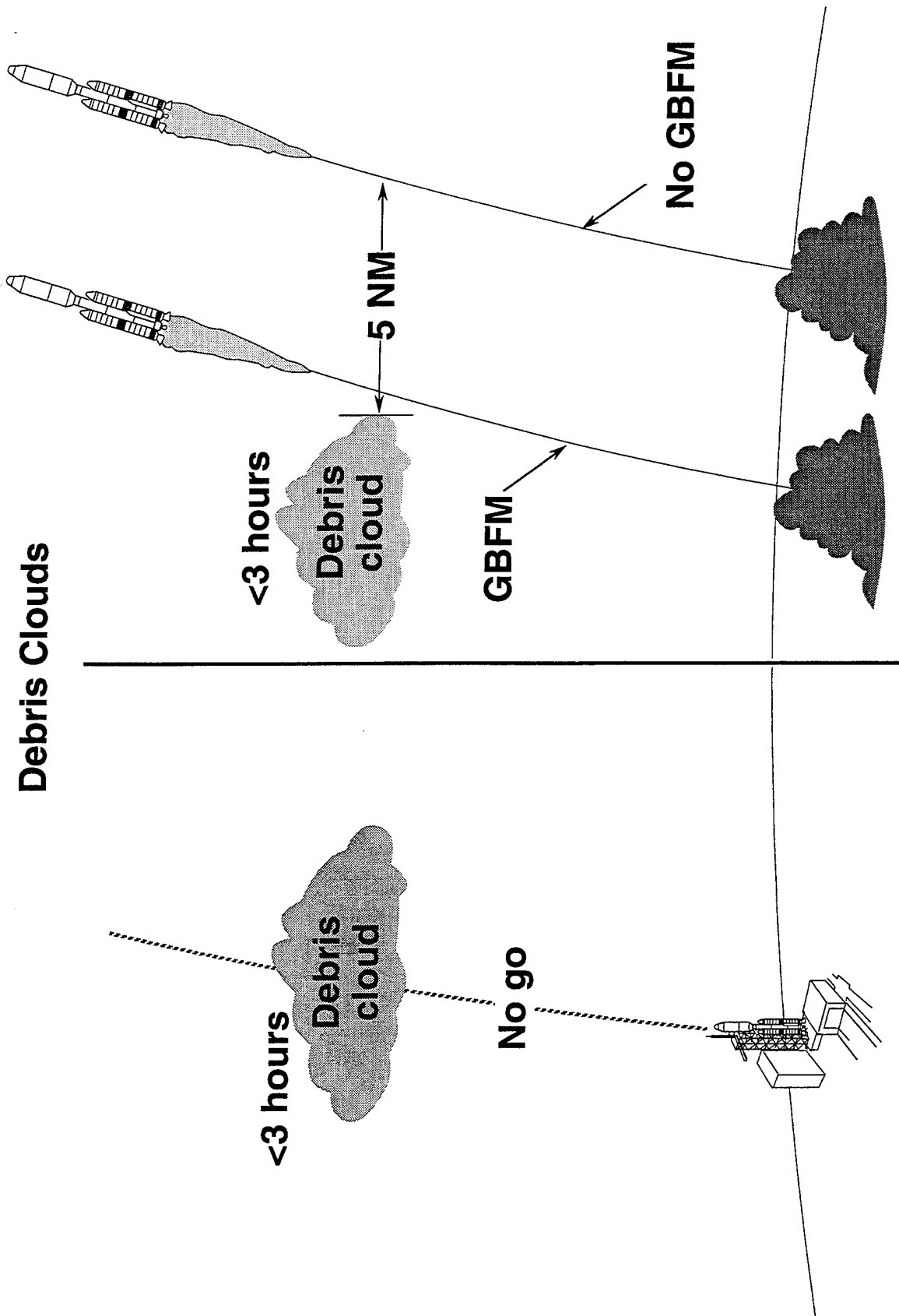
Changes in Rule E

- Unchanged



Rule F

Debris Clouds



Recommended Launch Commit Criteria Rule F.1.

- **F. Do not launch if, at launch time, the flight path will carry the vehicle:**
 - **1. Through any nontransparent debris cloud during the first 3 hr after the debris cloud formed from a parent cloud.**

Recommended Launch Commit Criteria

Rule F.2.

- F. Do not launch if, at launch time, the flight path will carry the vehicle:
 - 2. within 5 NM of the nearest edge of a nontransparent debris cloud during the first 3 hr after the debris cloud formed from a parent cumulonimbus or thunderstorm cloud, unless
 - a. there is at least one working field mill within 5 NM of the debris cloud

and

 - b. all electric field intensity measurements at the ground are between +1000 V/m and -1000 V/m within 5 NM of the flight path during the 15 min preceding the launch time

and

 - c. the maximum radar return from the entire debris cloud is less than 10 dBz during the 15 min preceding launch time

Recommended Launch Commit Criteria

Rule F.3.

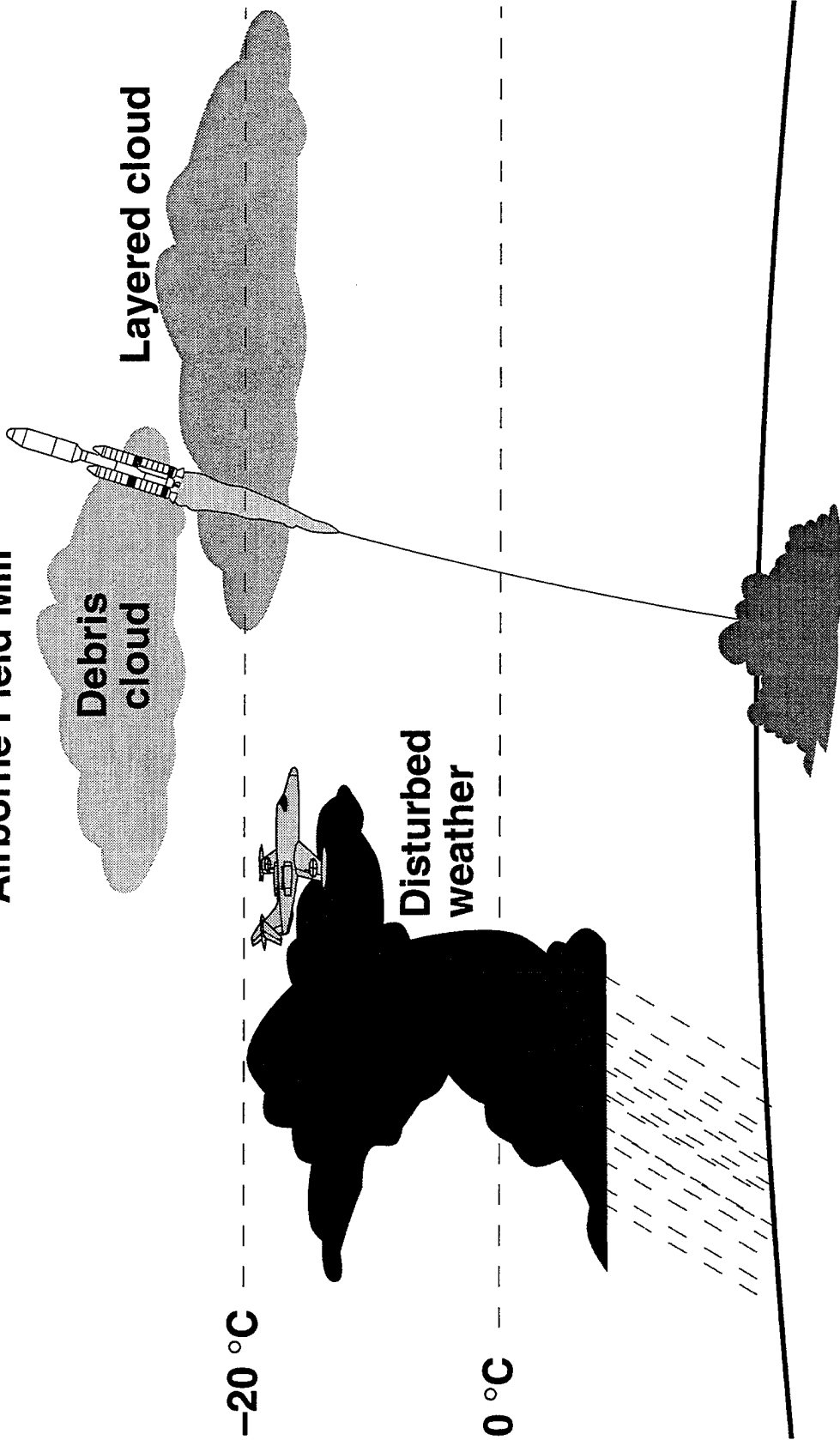
- F. Do not launch if, at launch time, the flight path will carry the vehicle:
 - 3. The start of the 3-hr period is reckoned as follows:
 - a. If it is known that the cloud is detached, the 3-hr period begins at the earliest time shown by observation that the cloud is detached, or the time of the last detected lightning discharge (if any) from the detached debris cloud, whichever is later.
 - b. If it is not known whether the cloud is detached, or the debris cloud forms from the decay of the parent cloud, the 3-hr period begins at the time of the last detected lightning discharge (if any) from the parent cloud or debris cloud, or the time when the parent cloud decays to below the -10.0 deg C level, whichever is later.

Changes in Rule F

- Extensively revised to increase launch opportunities through debris clouds
 - 3-hour time limit after detachment
 - 5-NM standoff not required if field mill and radar indicate that the conditions are safe

Rule G

Airborne Field Mill



-20 °C

0 °C

Supersedes rules D, E, and F for layered clouds, disturbed weather and debris clouds

Recommended Launch Commit Criteria

New Rule G

- G. For cloud types described in Rules D, E, and F, those rules need not be applied if, during the 15 min prior to launch time, the absolute value of the instantaneous vector electric field sampled within the cloud volume expected to be along the flight path is less than E_c where E_c is shown as a function of altitude in Figure G-1.

Changes in Rule G

- **Offers the opportunity for significantly increasing launch opportunities and increasing safety**
 - **Requires the use of an airborne field mill**
 - **Measure fields within cloud types that are difficult to monitor by ground-based field mills**
 - **Cloud layers**
 - **Disturbed weather**
 - **Debris Clouds**

Committee Recommendation

- **We want the record to show that we believe the best way to ensure safety from atmospheric electricity hazards, and also to improve launch availability, is to use an instrumented aircraft in conjunction with the ground-based field mill network to measure the electric field environment and its time development along and near the flight path. This recommendation has previously been made in the H. A. Heritage Report titled "Launch Vehicle lightning/Atmospheric Electrical Constraints Post-Atlas/Centaur '67 Incident," in the National Academy of Science Panel Report titled "Meteorological Support for Space Operations," and in our August 1992 recommendations made at the Marshall Space Flight Center.**

Dr. John C. Willett

Dr. Richard L. Walterscheid

Dr. E. Philip Krider

Dr. Harry C. Koons

Dr. W. David Rust

Recommended Launch Commit Criteria

Definitions

- **1. Anvil:** Stratiform or fibrous cloud produced by the upper level outflow or blow-off from thunderstorms or convective clouds.
- **2. Cloud Edge:** The visible cloud edge is preferred. If this is not possible, then the 10 dBz radar cloud edge is acceptable.
- **3. Cloud Layer:** An array of clouds, not necessarily all of the same type, whose bases are approximately at the same level. Also, multiple arrays of clouds at different altitudes that are connected vertically by cloud elements, e.g., turrets from one cloud array to another. Convective clouds (e.g., clouds falling under Rule B) are excluded from this definition unless they are imbedded with other cloud types.
- **4. Cloud Tops:** The visible cloud top is preferred. If this is not possible, then the 13 dBz radar cloud top is acceptable.
- **5. Cumulonimbus Cloud:** Any convective cloud with any part above the -20 deg C temperature level.

Recommended Launch Commit Criteria Definitions cont.

- **6. Debris Cloud:** Any nontransparent cloud, that has become detached from a parent cumulonimbus cloud or thunderstorm or results from the decay of a parent cumulonimbus cloud or thunderstorm.
- **7. Electric Field:** Here, electric field means the one-minute arithmetic average of the field mill readings and the polarity of the electric field is the same as that of the potential gradient; that is, the field polarity is the same as that of the charge overhead for fields measured at the ground.
- **8. Flight Path:** The planned flight path including its uncertainties ("error bounds").
- **9. Thunderstorm:** Any cloud that produces lightning.
- **10. Transparent:** Synonymous with visually transparent. Sky cover through which higher clouds, blue sky, stars etc. may be clearly observed from below. Also, sky cover through which terrain, buildings etc. may be clearly observed from above. Sky cover through which blurred, indistinct forms are visible is not transparent.

Current Launch Commit Criteria

Rule A

- A. Do not launch if any type of lightning is detected within 10 nautical miles of the launch site or planned flight path within 30 minutes prior to launch, unless the meteorological condition that produced the lightning has moved more than 10 nautical miles away from the launch site or planned flight path.

Current Launch Commit Criteria

Rule B

- B. Do not launch if the planned flight path will carry the vehicle:
 - (1) Through cumulus clouds with tops higher than the 5 degrees Celsius level
 - (2) Through or within 5 nautical miles of cumulus clouds with tops higher than the -10 degrees Celsius level; or
 - (3) Through or within 10 nautical miles of cumulus clouds with tops higher than -20 degrees Celsius level; or
 - (4) Through or within 10 nautical miles of the nearest edge of any cumulonimbus or thunderstorm cloud including its associated anvil.

Current Launch Commit Criteria

Rules C(1)

- C. Do not launch it, for Ranges equipped with a surface electric field mill network, at any time during the 15 minutes prior to launch time the one minute average of absolute electric field intensity at the ground exceeds 1 kilovolt per meter (1 kV/m) within 5 nautical miles of the launch site unless:
 - (1) There are no clouds within 10 nautical miles of the launch site

Current Launch Commit Criteria Rules C(1) cont.

- **Relative to (1):**
 - **The following clouds are acceptable if they have not been previously associated with a thunderstorm nor with convective clouds with tops greater than the -10 degree Celsius temperature level within the last 3 hours:**
 - **(a) Thin fibrous (optically transparent) clouds,**
 - **(b) Less than or equal to 2/8 cumulus, stratocumulus, or stratus (CU/SC/ST) with tops below or equal to the +5 degree Celsius temperature level.**
- For example 3/8 CU/SC/ST is not acceptable regardless of cloud top level, nor is any CU/SC/ST above the +5 degree Celsius temperature level.**

Current Launch Commit Criteria

Rules C(2)

- C. Do not launch it, for Ranges equipped with a surface electric field mill network, at any time during the 15 minutes prior to launch time the one minute average of absolute electric field intensity at the ground exceeds 1 kilovolt per meter (1 kV/m) within 5 nautical miles of the launch site unless:
 - (2) Smoke or ground fog is clearly causing abnormal readings.
- Relative to (2): This also includes a maritime inversion with an onshore/along-shore wind present over the electric field mills, causing those mills located near the ocean to be elevated with a positive polarity between 1 kV/m and 1.5 kV/m inclusive.

Current Launch Commit Criteria

Rule D

- D. Do not launch if the planned flight path is through a vertically continuous layer of clouds with an overall depth of 4,500 feet or greater where any part of the clouds are located between the zero (0) degree and the minus 20 (-20) degree Celsius temperature level.

Current Launch Commit Criteria

Rule E

- E. Do not launch if the planned flight path is through any cloud type that extend to altitudes at or above the zero degree Celsius temperature level and that are associated with disturbed weather within 5 nautical miles of the flight path.

Current Launch Commit Criteria Rule F

- **F. Do not launch through thunderstorm debris clouds, or within 5 nautical miles of thunderstorm debris clouds not monitored by a field mill network or producing radar returns greater than or equal to 10 dBz.**

Current Launch Commit Criteria

Definitions

- (1) **Debris Cloud:** Any cloud layer other than a thin fibrous layer, that has become detached from the parent cumulonimbus within 3 hours before launch.
- (2) **Disturbed Weather:** Any meteorological phenomenon that is producing moderate or greater precipitation.
- (3) **Cumulonimbus Cloud:** Any convective cloud which exceeds the -20 degree Celsius temperature level.
- (4) **Cloud Layer:** Any cloud broken or overcast layer or layers connected by cloud elements, e.g., turrets from one cloud layer to another.

Current Launch Commit Criteria Definitions cont.

- **(5) Planned Flight Path:** The trajectory of the flight vehicle from the launch pad through its flight profile until it reaches the altitude of 100,000 feet. The flight path may vary plus or minus 0.5 nautical miles horizontally up to an altitude of 25,000 feet.
- **(6) Anvil:** Stratiform or fibrous cloud produced by the upper level outflow from thunderstorms or convective clouds. Anvil debris does not meet the definition if it is optically transparent

Concerns

- **ABFM data show cloud thickness is poorly correlated with layered cloud electric fields**
 - **No “failure to detect” but one case with no margin vis-a-vis electric field hazard criterion (3 kV/m) at minimum cloud thickness**
- **ABFM data show significant electric fields near standoff distance for cumulonimbus**
 - **Measurements not adequate to define level of hazard**
- **Lack of Ground Based Field Mills at VAFB increase risk to vehicles launched from WTR**
 - **Monitor fields when hazard may be obscured**

Concerns (cont.)

- Recent observations of “lightning” high above severe storms
 - Extends from cloud tops to ionosphere (~10 to 60 km)
 - Present standoff criterion 10 nm (20 km) in all directions
 - Current density in discharges not known
- Value of electric field required for triggered lightning is poorly known
 - Discharge
 - Vehicle dependent
 - Velocity dependent
 - Altitude dependent
 - Conditions for leader propagation poorly understood
- Volcanic dust may cause triboelectric charging hazard

Recommendations

- **Approve the revised launch constraints**
- **Use ABFM to support launches**
- **Install GBFM network at VAFB**
- **Support measurement and analysis of ABFM data to assess**
 - **Layered cloud criterion and standoff distances**
 - **Use of radar as indicator of electric fields in clouds**
- **Support activities in support of Interagency Lightning LCC Action Team**

Airborne Field Mill Project

- **Concern that the current Lightning LCCs are too restrictive**
- **AF/NASA MSFC ABFM measurements performed at Cape to obtain electric field data in cloud types contained in restrictive rules**
 - **Campaigns in summer and winter 1991 and winter 1992**
- **MSFC developed rules based on radar data in place of cloud thickness and debris cloud rules**
- **Peer Review Committee**
 - **Recommended that further work be done before accepting radar based rules**
 - **Examined current lightning LCCs in light of ABFM measurements and other data and recommended changes that we are presenting today**

Post-Apollo 12 Launch Rules

- The space vehicle will not be launched if the nominal flight path will carry the vehicle:
 - A. Within 5 statute miles of a cumulonimbus (thunderstorm) cloud or within 3 statute miles of an associated anvil.
 - B. Through cold-front or squall-line clouds which extend above 10,000 ft
 - C. Through middle cloud layers 6,000 ft or greater in depth where the freeze level is in the clouds
 - D. Through cumulus clouds with tops at 10,000 ft or higher

Apollo-Soyuz Launch Rules, 1975

Part 1

- The space vehicle will not be launched if the nominal flight path will carry the vehicle:
 - A. Through a cumulonimbus (thunderstorm) cloud.
 - B. Within 5 statute miles of a cumulonimbus (thunderstorm) cloud or within 3 statute miles of an associated anvil. This rule may be relaxed at the discretion of the launch director if the electric field at the launch pad is less than 1 kV/m.
 - C. Through cold-front or squall-line clouds which extend above 10,000 ft
 - D. Through middle cloud layers 6,000 ft or greater in depth where the freeze level is in the clouds
 - E. Through cumulus clouds with the freeze level in the clouds

Apollo-Soyuz Launch Rules, 1975

Part 2

- F. Rules C, D, and E may be relaxed at the discretion of the launch director when electric field measurements in the launch pad area are stable and measure less than 1 kV/m.
- G. Rules C, D, and E above may be further relaxed provided that airborne and ground electric field measurements meet the criteria defined in Figure 4-1.

Post Atlas/Centaur AC-67 Launch Rules

- **Lightning Review Committee chaired by Hugh Heritage**
 - **Study weather conditions surrounding the incident**
 - **Study the then existing launch vehicle constraints**
 - **Provide recommendations**
- **Recommendations published 31 August 1988**
 - **Aerospace Report No. TOR-0088(3441-45)-2**
- **Coordinated recommendations with NASA**
- **Current Lightning Launch Constraint Criteria resulted from this coordination**

fail date: 03/26/87

launch site: Eastern Range

fail subsys: other

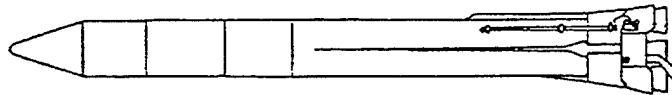
fail time: 70.7 s

Cause of failure:

The Atlas G vehicle was struck by lightning, which resulted in an erroneous full-scale positive yaw command induced by an electrical transient at 48.4 s. The erroneous yaw maneuver resulted in the loss of vehicle control. The destruct signal was sent at 70.7 s into flight.

Corrective action:

- Improve training of managers on critical launch support functions.
- Specify duties and responsibilities of launch weather team.
- Revise launch vehicle weather criteria and update to current knowledge.
- Improve voice communication circuits.



SETUP AND VALIDATION OF ABFM SYSTEM

- **Nonrecurring Costs \$492,000**
 - **Configure**
 - **Integrate**
 - **Test**
 - **Calibrate**
 - **Etc.**
- **KSC Deployments \$491,000**
 - **Lease of Lear 25 aircraft**
 - **Four 4-week seasonal deployments**
- **Data Analysis for Go/Nogo Criteria \$120,000**
 - **Best day-of-launch flight plans**
 - **Final report**

DAY-OF-LAUNCH ABFM SUPPORT COSTS

- **Setup and Validation**
 - Integration, test, and calibration
 - KSC deployments
- **Dedicated ABFM**
 - To support ELV and Shuttle launches
 - Further enhance LCC
- **On Call ABFM Option**
 - Support for specified missions
- **Sources of Cost Information**
 - Aeronet (Tulsa, Ok.)
 - SRI (Menlo Park, Ca.)

DEDICATED ABFM

- **Nonrecurring Costs**
 - Absorbed in Setup and Validation Costs
- **Per Year Costs \$311,000**
 - Lease of Lear 25 aircraft
 - Two pilots and ground support
- **Per Mission Costs \$20,000**
 - Mission support of equipment
- **Flight Costs**
 - \$1,376/hr (fuel not GFE)
 - \$847/hr (fuel GFE)

ON CALL ABFM Option

- **Nonrecurring Costs**
 - Absorbed in Setup and Validation Costs

- **Per Mission Costs \$64,000**
 - Support KSC four-day deployment

- **Flight Costs**
 - \$1,376/hr (fuel not GFE)
 - \$847/hr (fuel GFE)

TECHNOLOGY OPERATIONS

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Mechanics and Materials Technology Center: Evaluation and characterization of new materials: metals, alloys, ceramics, polymers and composites; development and analysis of advanced materials processing and deposition techniques; nondestructive evaluation, component failure analysis and reliability; fracture mechanics and stress corrosion; analysis and evaluation of materials at cryogenic and elevated temperatures; launch vehicle fluid mechanics, heat transfer and flight dynamics; aerothermodynamics; chemical and electric propulsion; environmental chemistry; combustion processes; spacecraft structural mechanics, space environment effects on materials, hardening and vulnerability assessment; contamination, thermal and structural control; lubrication and surface phenomena; microengineering technology and microinstrument development.

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