6.2 **Kodiak Star: An Overview of Operational Weather Support at the Kodiak Launch Complex for Alaska's first Orbital Space Launch**

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1. INTRODUCTION

In early 1998, the State of Alaska and the Alaska Aerospace Development Corporation (AADC) began construction on Kodiak Island, Alaska for the first fully commercial spaceport in the United States. The Kodiak Launch Complex (KLC) is located on the southeastern tip of Kodiak Island, about 250 miles south of Anchorage in the Gulf of Alaska and 25 miles south of Kodiak City (Figure 1). Kodiak Island was chosen because it provides an ideal location for polar launch operations. With a wide launch azimuth range and unobstructed downrange flight paths, spacecraft up to 8000 lbs can be safely launched from KLC and placed into nearly any low-earth polar orbit.

This launch capability, however, does not come without challenges. Some of North America's most intense weather systems develop and move through Kodiak Island and the Gulf of Alaska. Strong winds, heavy rain, snow, and thick cloud cover are a way of life on Kodiak Island. While thunderstorms are very rare on Kodiak Island, the threat of a rocket triggering a lightning strike during launch is actually quite high at KLC because of the types and thickness of clouds that frequently exist there.

In preparation for Alaska's first orbital space launch (Kodiak Star), experts from NASA, Lockheed Martin and AADC teamed to address all areas of concerns of an inaugural space launch from a new launch site. The meteorological aspects of launching in a high-latitude location such as Kodiak Island were determined to be one of the biggest challenges for the mission. In order to meet these challenges, a Weather Working Group was established at Kennedy Space Center, FL in 1998.

NASA's Kodiak Star mission, originally planned for launch in early summer 2001, consisted of a collection of 4 small experimental payloads riding atop a Lockheed Martin Athena 1 launch vehicle. Problems with the Launch vehicle and spacecraft would delay the launch until late September 2001.

This paper describes the weather support provided for the planning, processing and launch of Kodiak Star.

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Figure 1. Kodiak Launch Complex is located on the southeastern tip of Kodiak Island in the Gulf of Alaska.

2. WEATHER WORKING GROUP

The Kodiak Star Weather Working Group consisted of members from NASA, Lockheed Martin, AADC, the University of Alaska, and the USAF's 45th Weather Squadron located at Patrick Air Force Base, FL. The Working Group's primary task was to create the weather infrastructure and processes to provide full operational weather support to the daily ground processing and launch of the Lockheed Martin Athena 1 launch vehicle carrying the Kodiak Star Mission. This effort included the coordination, acquisition, installation, and certification of all weather instrumentation. Also, an unprecedented study to characterize the electrification of clouds in high latitude regions was successfully completed. The purpose of this study was to determine any limitations and make modifications to the existing set of Lightning Launch Commit Criteria (Krider 1999) used in launch operations in the mid-latitude launch ranges in Florida and California.

2.1 Kodiak Launch Weather Constraints

Weather constraints for all space launch operations in the United States consist of 3 sets of criteria; Launch

Vehicle specific weather constraints, Range Optics and Tracking constraints and Lightning Launch Commit Criteria (LLCC).

Launch Vehicle weather constraints are designed to protect against meteorological conditions that may pose a threat to a specific rocket on the ground and during launch. These rules usually consist of wind limitations at the surface and aloft, temperature, humidity and precipitation constraints. Some launch vehicles including the Athena rocket have a solar activity constraint. This prevents a launch when the sun is producing elevated levels of high-energy particles that could affect the avionics and electronics of spacecraft flying in low-earth orbits.

Range Optics and Tracking constraints are required to allow Range Safety personnel to visually track the launch vehicle in the early stages of flight when telemetry data can be noisy. The constraints for this mission included a minimum cloud ceiling of 5000 ft AGL and a minimum horizontal visibility of 2 statute miles.

The LLCC are designed to prevent launch failures from both natural and triggered lightning (Krider 1999). A launch vehicle can trigger lightning by penetrating clouds that are electrically charged. Apollo 12 triggered lightning twice during its launch in November 1969, but survived only because of backup systems. However, triggered lightning caused the destruction of an Atlas rocket in 1987 at Cape Canaveral, FL. The existing set of LLCC used in Florida and California are designed for mid-latitude weather regimes. In order to determine the safety of the current LLCC in high-latitude regions such as Kodiak Island, the Weather Working Group determined that a study to characterize the electrification of clouds in Alaska was needed.

2.2 Cloud Electrification Study

During the spring and summer of 2001, Dr. Phil Krider of the University of Arizona led an unprecedented effort to characterize the electrification of clouds in Alaska and make recommended changes to the LLCC to be used for the Kodiak Star launch. Surface electric field mills were installed at both KLC and the Kodiak City NWS office. These sensors collected data continuously on the atmospheric electric potential as weather systems and cloud formations moved through the region. Other data collected included surface and upper-air observations from Kodiak City (PADQ), satellite imagery and continuously updated video images from a 360-degree panorama camera in Kodiak City in order to monitor local cloud formations in near real-time. Using the data collected, Dr. Krider consulted with the National Lightning Advisory Panel (LAP) which he chairs. The LAP is responsible for recommending the LLCC for all space launches. The LAP recommended several LLCC modifications which both improved safety and launch availability. As a result of this successful study, a set of LLCC that ensured launch safety for the Kodiak Star mission was approved for use at KLC.

2.3 KLC Weather Instrumentation

In order to properly evaluate all launch weather constraints for this mission, the Weather Working Group determined an extensive array of weather instrumentation would be required at KLC. Systems recommended and implemented included: surface field mills (described above), Kodiak Island's first-ever fixed weather radar, a cloud-to-ground lightning detector, three fully instrumented weather towers, a weather reconnaissance aircraft capability, an extensive communication network, and a fully integrated meteorological display system located in the KLC Launch Control Center for the Launch Weather Officer on the day of launch. An upper-air rawinsonde capability mandatory for all launches already existed at KLC. This entire network of weather instrumentation provides a basic blueprint for a weather monitoring capability at any remote launch site.

The Weather Working Group recommended the installation of a basic non-Doppler weather radar at KLC. A weather radar is necessary for the evaluation of several LLCC on launch day and is extremely useful for daily weather support of pre-launch ground preparations. The radar installed at KLC was an ELLASON© model E430 weather radar with a range of 160 nautical miles. The radar transmitter and receiver were installed at KLC with the display located at the Launch Weather Officer's console in the Launch Control Center.

Although natural lightning is very rare near Kodiak Island, some method was required to confirm the existence or absence of lightning from nearby clouds, which might later drift over or near the Athena's flight path containing high electric charge. To meet this requirement, a BOLTEK© model LD-250 lightning detector was acquired and installed at the launch site. This sensor provides a relatively accurate azimuth and distance to all cloud-to-ground lightning strikes within 300 nautical miles of the sensor location.

In order to monitor basic meteorological parameters at the surface, three fully instrumented weather towers were installed. Meteorological data from the surface to the top of the launch tower is required at any launch site in order to allow for a safe launch at ignition. The three weather towers at KLC allow for the constant monitoring of wind speeds, ambient temperatures and humidities from the surface to 200 ft AGL. A locally produced visual display of this data is located at the weather officer's console.

The KLC upper-air system consists of a SIPPICAN© W-9000 workstation and GPS based rawinsondes. Upper-air profiles are critical for: launch vehicle steering and load analyses prior to every launch, evaluation of Lightning Launch Commit Criteria, and general weather forecasting for resource protection and ground processing (Boyd 1997).

A high-speed LAN with microwave-based connectivity at KLC provides access to web-based Alaskan weather data on PC workstations at the weather officer's console. Satellite imagery, synoptic weather charts, surface observations, numerical model data, and solar activity updates can be obtained from publicly available websites.

Critical for the evaluation of LLCC on the day of launch, a weather aircraft capability was recommended and obtained. A pressurized twin-engine turbo-prop capable of altitudes of 30,000 ft and speeds of at least 200 MPH was under contract to obtain cloud thickness and distance data during the launch countdown. Communication between the weather officer and the weather aircraft was accomplished through the use of Marine Band radios integrated into the KLC communication network. The weather officer was able to communicate and provide instructions to the pilot using the same headset and communication panel used to brief Launch Management during the launch countdown.

All displays for the entire weather network were integrated into the weather officer's console in the Launch Control Center. This allowed easy access to all required weather data during the launch countdown. Also, all weather displays were integrated into a local Closed Circuit TV network that could be viewed from any launch team position or projected on large screens in the launch control room.

3. LAUNCH CAMPAIGN

Data from a daily evaluation of the LLCC for the Kodiak Star launch in the months prior to September 2001 indicated a 55-60% chance weather would cause a launch scrub on any given day during August and September. The most violated rules were the Range Optics cloud ceiling constraint of 5000 ft AGL, and the Thick Cloud Rule in the LLCC (Krider 1999). This matched closely with the standard surface climatology for Kodiak City for cloud ceilings. It was also observed that a cycle of unfavorable weather for launch was occurring in August and September 2001. Strong weather systems moved rapidly though Kodiak Island providing 2-3 days a week of unfavorable weather followed by 1-2 days of favorable launch weather in the High pressure between frontal systems.

With all range and weather instrumentation in place, the launch team assembled on Kodiak Island in August in preparation for an early-September launch. The tragic events of September 11, 2001 caused an extended delay and the launch was rescheduled for Sep 21. However, in the days prior to Sep 21 a strong Aleutian low with an associated frontal system was expected to move into Kodiak Island providing strong winds and heavy rain. As expected, surface winds gusting to 45 knots on the morning of Sep 21 prevented launch tower removal operations. The launch was rescheduled for Sep 22 as favorable weather was expected. Unfortunately, a mandatory telemetry radar system would not operate forcing another scrub. On Sep 23, thick cloud cover and low cloud ceilings over the launch site forced another delay. On Sep 24, as the weather was beginning to look promising, one of the largest earth-pointing solar flares ever recorded erupted and sent a wave of extremely high-energy protons towards earth. The Athena launch vehicle has a Solar launch constraint where the 10 MeV Proton Flux must be less than 10 pfu (particles/cm^2/sec/steradian) to protect sensitive avionics. The 10 MeV Proton Flux recorded at earth orbiting satellites such as GOES 8 was over 1000 pfu (Figure 2) on Sep 24. The elevated Proton Flux due to this solar flare caused a 5-day launch delay. On September 29, 2001, a demanding launch campaign concluded with the successful launch and placement of all 4 satellites in their proper orbits.

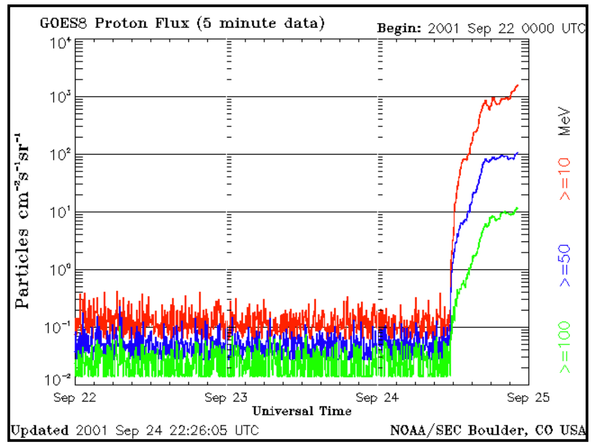

Figure 2. High Energy Proton Flux on Sep 24, 01 as measured by GOES 8. This intense Proton event was caused by an earth-pointing X-Class solar flare and resulted in a 5-day launch delay of the Kodiak Star mission. Courtesy of NOAA Space Environment Center.

4. SUMMARY

A model has been developed for designing the basic meteorological infrastructure needed to support an orbital space launch from a remote launch site or a newly built spaceport. Weather support for a new launch site begins with a climatology customized to the weather parameters that most affect launch operations. Weather infrastructure is then determined based on the conditions expected at the launch site. Capabilities necessary for proper operational weather support at any site include an upper-air capability, lightning detection, surface meteorological network and a weather aircraft capability. This method proved to be highly successful during the launch campaign of Kodiak Star, Alaska's first Orbital Space launch.

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