P10.4 AN OVERVIEW OF KODIAK LAUNCH COMPLEX OPERATIONAL WEATHER SUPPORT FOR THE MISSILE DEFENSE AGENCY'S INTEGRATED FLIGHT TEST 13 AND 14 LAUNCHES

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1. INTRODUCTION

The Alaska Aerospace Development Corporation (AADC) and the State of Alaska began construction on Kodiak Launch Complex (KLC), Kodiak, Alaska, (Figure 1) in early 1998 for the first non-federally owned, commercial spaceport in the United States. KLC is located at Narrow Cape on the southeastern tip of Kodiak Island, about 250 miles south of Anchorage and 45 miles south of Kodiak City (Figure 2). Kodiak Island is an ideal location for polar launch operations. With a wide launch azimuth range (Figure 3) and unobstructed downrange flight paths, spacecraft up to 8,000 lbs can be safely launched from KLC.

Meteorological phenomena are important factors in launch operation decision making. Properly integrated meteorological sensors, coupled with real-time communication with launch decision makers, are key support elements for launch commanders. Strong Aleutian weather systems develop in the Bering Sea and move through Kodiak Island and the Gulf of Alaska. These systems routinely bring strong winds, heavy rain, fog, snow, and thick cloud cover over Kodiak Launch Complex. While thunderstorms are very rare on Kodiak Island, the threat of a rocket triggering a lightning strike during launch is actually quite high because of the type and thickness of local clouds.

KLC's meteorological capability, initially developed by NASA/USAF for the Kodiak Star launch in September 2001, was greatly expanded to satisfy the increased launch weather support requirements for the Missile Defense Agency's Integrated Flight Test (IFT) - 13 and IFT-14 launch campaigns. This paper describes KLC's extensive meteorological infrastructure and capabilities required for the planning, assembly, processing, and successful launching of these rockets.

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Figure 1. Kodiak Island is located 250 miles south of Anchorage

Figure 2. Kodiak Launch Complex is located at Narrow Cape, on the southeast coast of Kodiak Island

2. WEATHER SUPPORT MISSION

The Missile Defense Agency's Integrated Flight Test (IFT)-13C (Figure 4) and IFT-14 launches occurred on December 14th, 2004 and February 13th, 2005, respectively. During the launch campaigns, the Weather Support Team's mission was to design, acquire, install, and integrate the weather infrastructure.

Figure 3. Kodiak Launch Complex Launch Azimuth

Figure 4. IFT-13C Launch Vehicle

Then, develop the procedures and processes to provide full operational weather support for planning, processing, and launch operations. This effort was divided into four tasks. The first task was to develop a combined list of launch weather constrains applicable to KLC launches and MDA IFT launch vehicles. The second task included the coordination, research, acquisition, installation, and certification of all necessary weather instrumentation to satisfy the established launch weather data requirements for these missions. The third task was to develop and implement a methodology to integrate these data into the operational support process. The fourth task was to develop and implement a data archive methodology to establish and maintain long-term meteorological data records.

3. LAUNCH WEATHER CONSTRAINTS

Launch weather constraints for space launch operations at United States spaceports normally consist of 3 sets of criteria: Launch Range and/or Vehicle Weather Constraints; Range Optics and Tracking Constraints; and Lightning Launch Commit Criteria (LLCC).

1) Launch range and/or vehicle weather constraints are specific to a range and/or vehicle. These constraints are designed to protect against meteorological phenomena that may pose a threat during either ground processing or launch operations. These constraints consist of surface and upper level wind limitations, natural and triggered lightning, precipitation, temperature and humidity. Some launch vehicles, including the IFT-13 and 14 rockets, have additional solar activity constraints. These constrains prevent 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. Specific constraints used for these two missions included: a) surface winds greater than 30 mph, 45 mph and 60 mph, depending on launch activity; b) winds aloft determined by customer-analyzed shear magnitude from a minimum of 33 upper air observations; c) rain rate greater than 1 inch/hour; d) precipitation in the flight path; and e) solar launch constraint where the 10 MeV Proton Flux must be less than 10 pfu (particles/cm2/sec/steradian), as recorded by earth orbiting satellites.

2) Range Optics and Tracking Constraints are required to allow Range Safety personnel to visually track the launch vehicle at liftoff and during the early stages of flight. The specific constraints used for these missions included: a) minimum cloud ceiling of 5,000 ft AGL and b) minimum horizontal visibility of 2 statute miles.

3) The LLCC are designed to prevent ground or launch anomalies resulting from either a natural or triggered lightning strike (Krider 1999). During vehicle ground processing, electrostatic discharges can adversely affect the electronic components and circuits in the launch vehicle or

ground station. While grounding straps are routinely used during processing, KLC takes additional precautions when the processing involves any hazardous operation, particularly explosives handling. Government agencies and the military routinely use electric field readings above 2,000 V/m as a lightning threat threshold. The specific constraints used for these missions included: a) Electric field potential of 1,500 and 2,000 V/m and b) Observations of natural lightning within 10 nm.

While natural lighting at KLC is a very rare event, weather conditions conducive to natural lightning result in elevated electric potentials and increased likelihood of electrostatic discharge or triggered lightning. A launch vehicle can trigger lightning by transiting electrically charged clouds. At Cape Canaveral, FL, Apollo 12 triggered lightning twice during its launch in November 1969 but survived because of backup systems. However, in 1987, an Atlas rocket wasn't as lucky when triggered lightning caused its destruction.

4. WEATHER INSTRUMENTATION

Weather equipment used to support these missions included: a) weather radar; b) two surface field mills; c) lightning detector; d) ceilometer; e) three upper air radiosonde systems; f) two fully instrumented weather towers; g) a fully integrated LAN and web-based weather data display system; and h) an extensive communication network.

Prior to these missions, KLC's weather instrumentation was based on the weather data requirements for the Kodiak Star mission in September 2001 (Sardonia 2004). The Integrated Flight Test missions had additional weather requirements necessitating an upgrade in KLC's weather equipment capabilities. These upgrades included the addition of five new computers, a ceilometer, two electric field mills, two tipping bucket rain gauges, an additional GPS upper air receiver, radiosondes, software upgrades, and an integrated LAN and Web data display and transfer capability.

The weather radar, an ELLASON Model E430, was used for daily weather support of pre-launch ground preparations and the evaluation of lightning and precipitation launch criteria. This weather radar has a range of 160 nautical miles. The radar transmitter and receiver were installed about 200 feet from the Range Control Center with the operator control functions and data display located at the Range Control Center.

Two Mission Instruments EFS-1000 electric field mills were used to measure atmospheric electrification in order to help evaluate indoor electrostatic discharge potential during vehicle assembly and the natural and triggered launch criteria during launch counts. The field mills are installed about two miles apart, one near the launch pad and one near the Range Control Center. The readouts are located at the Range Control Center.

KLC used a Boltek Model LD-250 lightning detector to confirm the existence or absence of cloud-to-ground lightning. A lightning detector was necessary to identify the occurrence and more important, verify the non-occurrence of natural lightning. While this phenomenon is extremely rare on Kodiak Island, it does occur several times annually. This RF sensor provides a relatively accurate azimuth and distance from the sensor to cloud-to-ground lightning strikes within 300 nautical miles of the sensor location. Because of local KLC RF interference, KLC located this sensor 25 miles away at the Kodiak NWS office.

KLC installed a Vaisalla CT-25K ceilometer to acquire cloud height and amount immediately prior to the IFT-13 launch campaign. Previously, the requirement for cloud data was met by visual observations from the ground augmented by an aircraft during the count. However, this left a gap at the critical launch time, since airspace must be cleared prior to liftoff. This instrument was positioned adjacent to the launch pad, tilted slightly from vertical to measure clouds affecting the launch trajectory. The cloud height, amount, and backscatter are displayed in the Range Control Center, about 2 miles away.

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). KLC used three Lockheed Martin Sippican GPS W-9000 upper air radiosonde systems to meet customer requirements to simultaneously track three radiosondes. These systems required significant software and hardware upgrades to enable KLC to support the 33 upper air observations required for a nominal IFT launch campaign. For the IFT-13 launch campaign, KLC upgraded the operating system from DOS to

Windows and installed GPS repeaters to allow remote radiosonde initialization. During the IFT-13 launch, the weather support team experienced a 30% radiosonde flight failure. However, backup radiosonde flights allowed the weather support team to meet 100% of the mandatory upper air observation requirements, but not necessarily within the desired timeframe. A flight failure was defined as an upper air observation not attaining minimum altitude. Prior to the IFT-14 launch, the weather team installed a new bandpass filter, low-loss RF antenna cables, data ingest and tracking software, and integrated a redesigned radiosonde. As a result of these upgrades, the weather support team met 100% of the upper air observation requirements during IFT-14 launch, with no flight failures.

Two fully instrumented weather towers were used to record and monitor basic weather parameters. A third site, located at a height of approximately 200 ft on top of Launch Pad 1, was used to monitor winds representative of what the rocket would experience immediately after ignition. This gave KLC the ability to constantly monitor wind conditions from the surface to 200 ft during the entire launch process. These data were displayed in the Range Control Center.

KLC used a high-speed LAN and internet-based data display system to provide access to web-based Alaskan weather data on PC workstations at the Range Control Center weather officer's console. Data used included satellite imagery, radar observations, synoptic weather charts, surface observations, numerical model data, earthquake activity, tsunamis, volcanic activity, and solar activity.

5. ATMOSHPERIC ELECTRIFICATION

KLC acquired and installed two Mission Instruments ELS-1000 electric field mills to measure atmospheric electrification and established a methodology of data transfer of KLC electric field readings to Professor Phil Krider, University of Arizona. Dr. Krider used these data for continuation of a study, started in 2001, to characterize the electrification of clouds in high latitude regions. The purpose of Dr. Krider's study was to evaluate the existing set of Lightning Launch Commit Criteria (Krider 1999) used in launch operations in the mid-latitude launch ranges in Florida and California and determine their application and limitations for use in high latitude launch ranges. The National Lightning Advisory Panel (LAP), chaired by Dr. Krider, is responsible for recommending the LLCC for all space launches. After review of Dr. Krider's data, the LAP recommended several LLCC modifications specific to Kodiak which both improved safety and launch availability. These KLC-tailored LLCC's were used for both IFT missions.

A field mill measures the atmospheric electric field at or near ground level. Normally, atmospheric electric field measurements are used to assess the potential for lightning to occur in and around a sensor site so hazardous operations can be discontinued or equipment/personnel can be protected prior to the occurrence of a lightning strike. When the atmosphere is clear of thunderstorm clouds, the ionosphere is the primary source of electric charge which creates an electric field on the surface of the earth. In this respect, the ionosphere can be thought of as a large electrode high above the earth which produces positive electric charges in contrast to the relatively negatively charged earth. This scenario creates what is termed a "fair weather" electric field due to the positive charge overhead. A "fair weather" electric field normally ranges from about -50 to about -200 Volts per meter (V/m). This value varies depending on the conditions in the atmosphere and local effects. Local effects include anything that can carry an electrical charge, including but not limited to, blowing dust, smoke, plastic bags, blowing snow, nearby machinery, atmospheric space charge, etc.

Highly charged convective clouds (thunderclouds) cause the formation of negative electric charges at or near the cloud base. As the electric charge builds, it creates a "foul weather" electric field which tends to cancel out the fair weather field. If this "foul weather" electric field intensifies to the point where the air can no longer insulate the powerful electric potential created between the clouds and the earth, we experience an electric discharge or lightning. It's not unusual to experience "foul weather" fields at KLC in excess of 10,000 V/m at the ground during a storm event. However, a high electric field reading does not mean a lightning strike will occur, but only that conditions are conducive to a strike occurring.

In short, the separation of positive and negative electric charges into large groups creates the lightning hazard. The groups of opposite polarity charges are naturally attracted to each other, but are held apart by the atmosphere's insulating properties. As these groups increase in strength, the force of their attraction can exceed the atmosphere's ability to keep them separated and result in a lightning discharge. Lightning is the sudden, intense electrical recombination of these groups. The local electric field varies in proportion to the strength of these groups and their distance from the measuring device, so its measurement gives an idea as to the likelihood of lightning occurring. A strong electric field indicates that the situation is conductive to the formation of lightning.

6. DATA INTEGRATION AND ARCHIVAL

KLC developed and integrated a high-speed LAN and internet-based data display system which provides access to the web-based Alaskan weather data. These data included satellite imagery, numerical model data, synoptic weather charts, radar observations, surface observations, earthquake activity, tsunamis, volcanic activity and solar activity. In addition, real time KLC observations, forecasts and upper air observations are uplinked to http://209.165.145.97, where the data are viewed and used by off-site customers. Weather data displays encompassing the entire weather network were integrated into the weather officer's console in the Range Control Center. Selected data displays were projected on large screens in the launch control room during the launch countdown.

The 10 minute and 60 minute surface weather observations are achieved on a local PC Workstation. KLC developed an Excel-based tool to ingest and display these climatological data records in order to develop a local climatological record specific to KLC. Complete observation records from 2003 and limited records since 1998 are available.

7. LAUNCH CAMPAIGNS

A summary of the launch counts for IFT-13C in December 2004 shows during 50% of the launch attempts, weather did not impact the launch count; during 40% of the launch attempts, weather caused a delay in the launch count but KLC was able to launch sometime during the window; and during 10% of the launch attempts, weather caused a launch scrub.

A summary of the launch counts for IFT-14 in February 2005 indicates weather phenomena did not impact the launch attempt during any of the four launch simulations/attempts, giving a 100% weather "green for launch".

The most violated rules were the Launch Vehicle Weather Constraint for surface winds greater than 30 mph, followed by the Range Optics cloud ceiling constraint of 5,000 ft AGL and the thick cloud rule in the LLCC (Krider 1999). However, the weather constraint for surface winds greater than 30 mph is to retract the vehicle shelter. This constraint resulted in several delays in the launch count, but not a launch scrub. At time of launch, this wind constraint increases to surface winds greater than 60 mph. This launch wind constraint was not violated at the time of launch.

7.1 Integrated Flight Test 13C Launch Campaign, November/December 2004

In October 2004, the weather team installed and integrated a ceilometer and two rain gauges, performed equipment calibration checks, pre-launch hardware and software upgrades, and operational checkout. The launch weather team returned mid-November 2004 to begin on-site weather support for the vehicle arrival and assembly for an anticipated December 8th launch.

Launch counts for a simulated launch occurred on December 4thand 6th. Winds greater than 30 mph on December 4th shorted the window but would not have impacted the launch. Weather was not a factor on December 6th. The first launch attempt occurred on December 8th, with adverse KLC weather being the primary focus. A strong Aleutian low with an associated frontal system was forecast to move into Kodiak Island during the launch window bringing low clouds, strong winds, and heavy rain. KLC counted into the window, but finally scrubbed based on ceilings less than 5,000 ft AGL and cloud thickness exceeding the LLCC thick cloud rule. On December 9th, KLC once again counted into the window, based on KLC winds greater than 30 mph at window open. The weather improved exceeding KLC minimum launch criteria, but the launch attempt was scrubbed based on violation of down range weather constraints (rain rate and clouds). While December 10th was a day off, KLC again had winds greater than 30 mph, but would have been able to launch sometime during the window. On December 11th, KLC weather was within limits during the entire window. However, the launch scrubbed due to down range weather. The December 12th launch attempt was scrubbed for a downrange hardware problem. On December

13th, KLC weather was perfect for launch with blue skies and light winds. However, the launch attempt was scrubbed due to down range weather. The December 14th KLC forecast was high winds and snow showers associated with an approaching Aleutian low, worsening during the window. KLC weather was fluctuating above and below established criteria minimums at window open and forecast to get worse. Since downrange weather and hardware were ready to launch, the KLC launch crew focused on launching early in the window. This successfully happened at 2045L, minutes before the range dropped well below the established weather criteria minimums. KLC weather at launch time was not perfect. Winds were gusting to 28 mph, near the 30 mph limit, and the cloud ceiling was 4,800 feet AGL, slightly below the 5,000 ft criteria but deemed acceptable by the launch crew.

7.2 Integrated Flight Test 14 Launch Campaign, January/February 2005

The launch weather team returned mid-January 2005 to begin on-site weather support for the IFT-14 vehicle arrival and assembly for an anticipated February 12th launch. The weather team immediately performed equipment checkout and calibration checks, pre-launch hardware and software upgrades, and an entire support system checkout. The team found everything in good shape except one of the six anemometers. The team replaced the anemometer with an on-site spare, but found the problem to be a voltage to RF converter. The equipment configuration required this component to be located outside in a "weather proof" enclosure. However, excessive adverse maintenance history indicated an equipment redesign was warranted to eliminate this component. Since this upgrade was a long-term solution, the team ordered a replacement converter and began plans for a post-launch equipment reconfiguration.

The launch team supported vehicle arrival and assembly between mid-January and the first launch count on February 10th. During this period, the team acquired a third electric field mill and began hardware and software integration. This mill was designed for permanent installation halfway between the launch pad and the Range Control Center, about 1 mile from each site. In addition, this instrument was configured to be mobile with local readouts provided through an independent control module and remote readouts via ethernet connections for viewing in the Range Control Center. This configuration allowed the customer to use the mill to monitor indoor electrostatic conditions and enable launch explosive ordnance personnel to get real-time on-site readings during vehicle assembly and arming which improved personnel and vehicle safety during the ordnance handling and arming process.

KLC experienced several strong wind and heavy rain events during this timeframe. After one of these weather events, the weather team found a significant degradation in the incoming radiosonde RF (403 MHz) signal. They replaced the RF cables with low-loss cables which improved the signal strength to a useable, but not optimum level. Then they disassembled the passive bandpass filter and found water intrusion and corrosion. They ordered and installed a replacement filter and designed plans to reconfigure the equipment to reposition the new bandpass filter indoors after the launch. The new cables and bandpass filter provided a 10dB increase in signal strength over previously acceptable levels.

The first practice count for a simulated launch occurred on February 10th. Weather was forecast to be within acceptable launch criteria for the next several days and was perfect through the entire practice count. KLC didn't count on February 11th in preparation for the launch attempt on February 12th. However, the weather remained within acceptable limits during the anticipated window. Late on February 11th, downrange launch personnel experience a hardware problem and requested a one day launch delay. On February 12th, the weather team checked out the equipment and remained ready to launch. The weather remained within acceptable limits throughout the planned launch window. KLC performed the first actual launch count on February 13th. The weather was forecast to be within limits and exceeded weather criteria minimum during the entire window. The launch successfully occurred at 2122L.

8. SUMMARY

Weather phenomena are important factors in launch operation decision-making and weather provided some challenges to these two launches. However, weather proved secondary to vehicle and down range launch support problems. KLC has built a weather support infrastructure to survive the local weather phenomena associated with a coastal location frequented by strong

Aleutian Lows. The KLC weather support infrastructure and procedures were successfully tested during these successful Integrated Flight Test launch campaigns. The current KLC weather support infrastructure proved optimal for supporting an orbital space launch from a remote launch site or a new spaceport. KLC weather support design started with local climatology customized to the weather parameters that most often affect launch operations. The weather infrastructure was then tailored to KLC, based on the conditions expected at the launch site. Minimum weather support capabilities for operational weather support at any launch site include an upper-air capability, lightning detection, and an integrated surface meteorological network. These processes and configuration proved highly successful during these launches campaigns.

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