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Meteorological Support To Assure Safe Access To Space

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Introduction

On March 26, 1987 an Atlas Centaur rocket (AC-67) carrying a Navy communications satellite was given a green light for launch by Cape Canaveral Range Weather. There were rain-showers in the area. By the time liftoff occurred, one had moved over the launch complex. AC-67 ascended into a heavy shower where the plume of ionized exhaust gasses assisted in triggering a lightning strike...a deadly conduit to an electrically-charged atmosphere. The booster's guidance system was fried and the rocket veered off course. To protect the public, the rocket was destroyed by the range safety officer (RSO). The accident cost taxpayers \$250 million. A cloud quite literally formed over Air Force weather support to the space program.

The good news is in the subsequent 10 years, the Department of Defense, in concert with universities and national laboratories, learned a great deal about how to prevent this kind of incident from happening again. As a result, the record since AC-67 has been flawless.

The United States Air Force's (USAF) 45th Weather Squadron (45 WS) provides all operational spacelift weather services to both the USAF Eastern Range (ER) and the National Aeronautics and Space Administration's (NASA) Kennedy Space Center (KSC). Although other weather organizations are involved in supporting the nation's space program, it is the 45 WS which is responsible for ensuring safe launch into a dynamic atmosphere using time-tested weather support procedures and a superb suite of instrumentation at the ER and KSC.

Two primary factors contribute to the weather support challenge in Florida: (1) the geographical location of the ER/KSC complex, and (2) the operational mission. The "thunderstorm capitol of the United States" is just west of Cape Canaveral Air Station (CCAS) and KSC. Consequently, the greatest threats to operations are frequent thunderstorms, associated lightning, and potentially damaging winds.

In addition to the usual threat to ER/KSC personnel and resources, weather presents a significant hazard to all phases of spacelift operations including the around-the-clock, continuous cycle of prelaunch ground processing operations at each launch complex leading up to the day-of-launch (DOL). On liftoff, the rocket and payload are even at more risk, primarily due to: (1) the possibility of the vehicle triggering and being hit by a lightning strike, or (2) wind shear exceeding structural design limits.

This paper describes the operational weather support provided by the 45th Weather Squadron and the instrumentation suite and data processing/display systems used to provide these services.

Operational Weather Support

Resource protection, prelaunch ground processing, day-of-launch weather, and specialized safety support are provided by the 45th Weather Squadron's Range Weather Operations (RWO) located in the Range Operations Control Center (ROCC) on Cape Canaveral Air Station. As the 45th Weather Squadron's nerve center, the RWO provides comprehensive operational weather service to all aspects of NASA's manned Space Shuttle program; Air Force and commercial expendable space launch vehicles, including the Titan IV, Atlas II, Delta II, and Athena programs; and the Navy's Trident II submarine launched ballistic missile program. It is here where weather data from the world's densest operational network of weather sensors and equipment are assembled into a massive database and then analyzed daily by forecasters to provide the launch customer with a complete picture of the operational environment at CCAS, KSC, and the remainder of the Eastern Range.

Resource Protection

Range Weather Operations provides resource protection to some 25,000 personnel and over \$8 billion in assets. Manned 24 hours per day, the RWO issues 24-hour forecasts for the KSC Shuttle Landing Facility (SLF) and provides a KSC/CCAS 7-Day Outlook daily. RWO forecasters are also responsible for issuing numerous weather watches, warnings, and advisories when hazardous weather conditions are either expected or occurring.

In the summer, lightning at KSC/CCAS is an almost daily occurrence requiring forecasters to issue area-specific lightning advisories to ensure personnel safety while maximizing ER productivity. Figure 1 shows specific areas on KSC and CCAS for which lightning advisories are issued. In 1997, the RWO issued over 320 weather warnings and over 1500 weather advisories. About 1400 of those advisories were issued for lightning alone.

Prelaunch Ground Processing Support

In addition to normal day-to-day resource protection, forecasters also support a myriad of prelaunch operations. Preparing launch vehicles and their payloads involves hundreds of ground processing tasks including loading propellants, installing ordnance, and calibrating sensitive electronic systems. Every operation is potentially at risk from nearby or direct lightning strikes, winds, and precipitation. Table 1 shows a typical example of a RWO daily operations status report used to keep on top of what's happening on the ER and KSC. This table illustrates that individual launch programs are busy with various ground processing operations, each having explicit weather constraints. Due to the criticality of most prelaunch operations, tailored, real-time support is provided by Launch Weather Officers (LWO) assigned to each particular launch vehicle program.

Day-of-Launch Support

Weather support plays a very decisive role during actual launch countdowns. For this reason, on the day-of-launch, 45 WS assembles a team of highly trained and experienced military and civilian operational meteorologists. Led by the primary LWO for the given launch vehicle program, the Launch Weather Team (LWT) continually monitors and forecasts weather conditions leading up to the actual launch. The team focuses primarily on the evaluation of a complex set of vehicle-specific, weather launch commit criteria (LCC). When any LCC is violated or forecast to become

violated, the LWT, through the primary LWO, notifies the range and the launch customer of a *red* condition.

Later, if conditions improve and LCCs are no longer violated, the LWT can revert back to *green* allowing the launch countdown to continue, provided there is still time in the launch window. Figure 2 shows the numbers and percentage of launch delays and scrubs over a 9-year period (Maier, 1998). Weather was a major factor, causing more launch delays and scrubs than due to any other reason. Most weather scrubs and delays are caused by upper-level winds exceeding the launch vehicle structural design limits, with the potential for triggered lightning running a close second. Maier (1998) describes weather related scrubs and delays in extended detail.

Specialized Safety Support

The 45 WS also provides data and support to Range Safety. The ER safety office has multiple weather support requirements, including observation of the vehicle during ascent, toxic hazard forecasts, potential blast effects of an explosion at the launch pad, and debris fallout in case of a disaster after launch. Meteorological support to Range Safety is thoroughly described by Parks et. al. (1996).

Current Weather Systems

To support these four meteorological requirements: resource protection, prelaunch ground processing, day-of-launch, and specialized safety support, an extensive suite of instrumentation is deployed throughout the ER and KSC. The Air Force and NASA work together to continuously improve this instrumentation suite. ER instrumentation includes: four independent lightning detection systems, an extensive upper-air system, hundreds of boundary layer sensors, two weather radars, direct satellite read-out, and a Meteorological Interactive Data Display System (MIDDS).

Lightning Detection Systems

There are four primary ER lightning detection systems (Maier, et. al., 1995). First is the Launch Pad Lightning Warning System (LPLWS)—a network of 31 field mills distributed in and around the launch and operations areas as shown in Figure 3. The network measures the electric field at the surface and also detects electric discharges. The NASA Marshall Space Flight Center developed the LPLWS field mill instruments and base station computer. The USAF 45th Space Wing (45 SW) developed the LPLWS host computer and real-time display and also integrated and tested the overall system.

The second ER lightning detection system is the Cloud-to-Ground Lightning Surveillance System (CGLSS) consisting of a network of five gated, wide-band magnetic direction finders (MDFs) deployed in and around the launch and operations area as shown in Figure 3. They are deployed on relatively short baselines and operate at low gain to meet the requirement for high location accuracy and detection efficiency of cloud-to-ground strikes. This arrangement limits CGLSS effective range to about 100 km.

Data from the National Lightning Detection Network (NLDN) are used to satisfy cloud-to-ground lightning detection requirements beyond 100 km. The NLDN is a long baseline mix of high gain

MDFs and time-of-arrival (TOA) sensors operated as a commercial service by Global Atmospherics, Inc. Sensor data are collected and processed in real-time at a network control center in Tucson, Arizona. Processed data are broadcast to subscriber locations over a dedicated satellite link.

Finally, the Lightning Detection and Ranging (LDAR) system, consisting of a network of seven receiver sites (also shown in Figure 3), detects: inter-cloud, intra-cloud, and cloud-to-ground lightning. Each LDAR site receives VHF radiation at 66 MHz, logarithmically amplifies received signals, and then transmits the signals to a central site using dedicated microwave links. LDAR was developed, and is operated and maintained, by the NASA KSC Instrumentation and Measurements Branch.

Upper-Air Systems

The ER upper-air system, described in detail by Wilfong et. al. (1996), is operated and maintained at CCAS and Ascension Auxiliary Field by the ER Technical Services Contractor. The frequency of upper-air observations varies from two or three rawinsondes per day (for routine forecasting needs) to as many as 18 (rawinsondes and jimspheres), to support a single Shuttle launch. The added observations are required for direct support to Range Safety and launch customers.

Over the past 25 years, the radar-tracked jimsphere combined with the ROSE (Rising Observational SpherE) program has evolved as the primary system for making high resolution wind profile measurements in support of the Space Shuttle and other launches for vehicle structural design limitations. During this period, wind profile climatologies have been developed which today are used for vehicle performance analyses as well as new design evaluations.

The jimsphere balloon was designed to reduce errors in detailed wind profiles introduced by spurious horizontal balloon motions caused by vortex shedding in ascent. By adding roughness elements in the shape of cones, the amplitude of the self-induced motions is reduced. The resulting design is a 2 m diameter sphere with 398 roughness elements (cones), each approximately 0.08 m high. A superpressure of 6-8 hPa is maintained by two opposing valves which vent helium as the balloon rises. A ballast of 0.1 kg positioned near one of the vents lowers the center of gravity and helps reduce spurious rotation.

While the jimsphere is actively tracked by radar, the rawinsondes used on the ER are transceiver sondes, which are tracked by the Meteorological Sounding Systems (MSS). MSSs were developed in the 1970s and installed at the ER in 1982 in a joint procurement by the Army, Navy, and Air Force. The MSS processes data from the transceiver sondes to provide upper-level temperature, humidity, pressure, and winds. The MSS uses a 2.4 m solid aluminum parabolic tracking antenna to communicate with and track the airborne sonde. At the ER, standard 600 or 800 gram latex balloons are used to loft an MSS sonde.

Atmospheric measurements are taken from an altitude of 20 km up to 90 km using the Super Loki meteorological rocket system. A 10.2 cm diameter solid propellant rocket is launched, with separation of the rocket motor and payload dart occurring at about 1.5 km, after which the dart coasts to apogee. The system provides information on winds, temperature, pressure, density, speed-of-sound, and wind shear after data analysis and reduction.

While the rawinsonde and jimsphere continue to be primary, evaluation of radar wind profilers to directly improve structural stress analysis began at the ER in 1987, when NASA awarded a contract to design and build a demonstration super-profiler system to be installed next to the Shuttle Landing Facility at KSC (Smith, 1989). A wide range of parameter settings provides flexibility in the radar operating characteristics. The NASA/KSC Doppler Radar Wind Profiler operates at 49.25 MHz (commonly referred to as the 50 MHz DRWP) and measures winds from 2 to 16 km once every five minutes. The locations of the 50 MHz DRWP and the rawinsonde/jimsphere release point are shown in Figure 4.

Boundary Layer Sensors

Boundary layer sensing is accomplished by two major systems: a network of five 915 MHz radar wind profilers (RWPs) with Radio Acoustic Sounding Systems (RASS), and a network of 44 towers with wind, temperature, and dew point sensors, referred to as the Weather Information Network Display System (WINDS).

To fill the data gap from the top of the wind towers to the lowest gate of the 50 MHz DRWP, the ER is in the final stage of testing and certifying five 915 MHz boundary layer profilers with RASSs (Heckman et. al., 1995). This network will sample low level winds from 120 m to 3 km every 10 minutes and produce a virtual temperature profile every 15 minutes, greatly enhancing forecasters' ability to track sea breeze convergence zones. It will also produce near real-time winds for use in emergency toxic dispersion calculations. The network is arranged in a diamond-like pattern over the area with an average spacing of 10-15 km, as shown in Figure 4.

The locations of the WINDS platforms are shown in Figure 5. The network covers approximately 1200 km² for an average spacing of 27 km². Sensors are located at heights from 2 to 165 m, and report wind, temperature and dew point either each minute or every five minutes. Instrumentation and response time varies with primary purpose. The towers are organized into three different groups based on their primary operational application. This application in turn determines the sensor complement on the tower, how the tower is interrogated by the base station, and how the data are processed and displayed at the base station. The three tower groups are: (1) launch critical, (2) safety critical, and (3) forecast critical. While each tower is assigned to one of these three groups, all data are processed and displayed as an integrated network. Any tower can contribute to any application.

Weather Surveillance Radar

The ER has a modified WSR-74C radar (5 cm wavelength) equipped with the Interactive Radar Information System (IRIS). The IRIS analysis workstations are located at CCAS. The antenna, transmitter/receiver, signal and control processors, and IRIS radar workstation are located at Patrick Air Force Base (AFB).

The IRIS allows forecasters to construct and display Constant Altitude Plan Position Indicator (CAPPI), vertical cross-section, echo tops, vertically integrated liquid between user selected altitude levels, and maximum reflectivity animated displays from 2.5 minute radar volume scans. These rapid volumetric updates along with the capability to perform Range Height Indicator (RHI) scans provide for improved early detection of rapidly developing precipitation echoes.

The ER also has direct access to the WSR-88D Doppler radar (owned and operated by the Melbourne National Weather Service office) via three Principal User Processors (PUPs), located at CCAS and the Patrick AFB weather station.

Satellite and Display Systems

The ER currently receives Geostationary Operational Environmental Satellite (GOES) imagery. The current satellite receive and integrated display system, the Meteorological Interactive Data Display System (MIDDS) was installed in 1984/85 and first described by Erickson et. al. (1985). Over the years it has undergone many modifications, but today is still a derivative of the University of Wisconsin Space Science and Engineering Center's (SSEC) IBM MVS operating system variant of the Man-computer Interactive Data Access System (McIDAS). The original goal of MIDDS was to consolidate all meteorological data (from over 900 pieces of meteorological equipment and two-dozen systems) required for Range Weather Operations (RWO) into a single data management and display system. That goal remains valid today, but has not yet been totally achieved.

The MIDDS consists of two dedicated IBM Model 4381 mainframe-class computer systems located at the Range Operations Control Center (ROCC). Both mainframes continuously receive meteorological data from the huge variety of sources.

While many ER systems input data to MIDDS, the most critical interfaces are the two external 2.11 Mb/s connections to the two antenna (4.5 m diameter), receiver, and preprocessor strings used for the direct local reception of GOES meteorological spacecraft data. The two independent antenna and receive systems permit simultaneous reception from the nominal complement of the GOES east and the GOES west spacecraft.

Summary

History confirms that one of the leading dangers in assuring America's access to space is the very atmosphere to be transited in the journey there. From a meteorological perspective, few locations in the United States are less conducive to space launch than Florida's central eastern coast.

Vigilant observation of current conditions and accurate forecasts for ground operations and spacelift are paramount to sustain the national treasures we call Cape Canaveral Air Station and Kennedy Space Center.

Forecasting, detecting, and measuring natural lightning, triggered lightning, precipitation, cloud ceilings, visibility, and both surface and upper-level winds are the business and expertise of the Air Force's 45th Weather Squadron. Superbly performing this mission protects the lives and equipment associated with the space program and ensures safe launch into a dynamic atmosphere.

Weather operational and systems support for the ER and KSC have been presented. Through the combined efforts of the USAF, NASA, National Oceanic and Atmospheric Administration, and other organizations, weather support to our Nation's space program is continuously being improved.

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