

Monitoring Direct Effects of Delta, Atlas, and Titan Launches from Cape Canaveral Air Station

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Abstract

Launches of Delta, Atlas, and Titan rockets from Cape Canaveral Air Station (CCAS) have potential environmental effects that could arise from direct impacts of the launch exhaust (e.g., blast, heat), deposition of exhaust products of the solid rocket motors (hydrogen chloride, aluminum oxide), or other effects such as noise. Here we: 1) review previous reports, environmental assessments, and environmental impact statements for Delta, Atlas, and Titan vehicles and pad areas to clarify the magnitude of potential impacts; 2) summarize observed effects of 15 Delta, 22 Atlas, and 8 Titan launches; and 3) develop a spatial database of the distribution of effects from individual launches and cumulative effects of launches.

The review of previous studies indicated that impacts from these launches can occur from the launch exhaust heat, deposition of exhaust products from the solid rocket motors, and noise. The principal effluents from solid rocket motors are hydrogen chloride (HCl), aluminum oxide (Al_2O_3), water (H_2O), hydrogen (H_2), carbon monoxide (CO), and carbon dioxide (CO_2). The exhaust plume interacts with the launch complex structure and water deluge system to generate a launch cloud. Fall out or rain out of material from this cloud can produce localized effects from acid or particulate deposition. Delta, Atlas, and Titan launch vehicles differ in the number and size of solid rocket boosters and in the amount of deluge water used. All are smaller and use less water than the Space Shuttle. Acid deposition can cause damage to plants and animals exposed to it, acidify surface water and soil, and cause long-term changes to community composition and structure from repeated exposure. The magnitude of these effects depends on the intensity and frequency of acid deposition. Plants differ in resistance to acid damage. Soils of the coastal barrier island are alkaline with high buffering capacity. Noise could affect wildlife species independent of exposure to rocket exhaust products.

We monitored the effects of 15 Delta, 22 Atlas, and 8 Titan launches between May 1995 and December 1997. Delta launches produced acid and particulate deposition. All Atlas launches caused heat scorching, and Atlas IAS launches also caused particulate deposition. Titan launches caused heat scorching, acid deposition, and particulate deposition. Acid deposition was similar to the far-field deposition from the Space Shuttle. However, acid formation is sensitive to the amount of deluge water and the interaction of the launch plume, pad structure, and deluge water. The first launch of a Delta II rocket in January 1998 from the modified Launch Complex 17B produced an impact area similar though smaller than the Shuttle near-field impact area.

The Delta II rocket launched January 17, 1997 exploded at an altitude of about 484 m. Although there was significant damage to facilities and structures,

impacts to the natural environment were limited. Burned vegetation is recovering.

No animal mortality has been observed that could be attributed to launches. Behavior of Scrub-Jays observed after launches has been normal, indicating no noise-related effects.

We mapped effects for 14 Delta, 20 Atlas, and 8 Titan launches and developed a Geographic Information System (GIS) database for these effects. Vegetation scorching has been limited to small areas (<1 ha) close to (<150 m) the launch complexes for Atlas and Titan launches. Acid and particulate deposition for Delta launches has extended less than 1 km from the launch complex and affected relatively small areas, 7.1 and 45.8 ha, respectively. For Titan launches, continuous acid deposition has not exceeded 1 km from the launch complex. However, isolated acid deposition has occurred up to 9.3 km from the launch site under certain meteorological conditions, apparently due to interaction of the launch cloud and rainfall or other clouds. Particulate deposition from Titan launches has occurred over larger areas (2,366 ha) and up to 14.6 km from the launch site. No discernable vegetation or other environmental damage appears to be caused by this particulate deposition. The spatial scale of effects from Delta, Atlas, and Titan launches is substantially less than that from the Space Shuttle.

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Introduction

Launches of Delta, Atlas, and Titan rockets from Cape Canaveral Air Station (CCAS) have potential environmental effects. These could arise from direct impacts of the launch exhaust (e.g., blast, heat), deposition of exhaust products of the solid rocket motors (hydrogen chloride, aluminum oxide), or other effects such as noise. Monitoring has been conducted for some Titan launches (Larson et al. 1993), but less is known about both acute and long-term effects of these unmanned vehicles than is known about the Space Shuttle. Monitoring of Space Shuttle launches has been conducted since 1981 (Schmalzer et al. 1993).

This project was initiated in 1995 with funding from the 45th Space Wing, Civil Engineering, Environmental Office, Patrick Air Force Base to develop a more comprehensive assessment of effects from Delta, Atlas, and Titan launch vehicles on the environment of Cape Canaveral Air Station. This required two coordinated approaches. One was to characterize the environment surrounding the launch complexes, with particular attention to natural resources, such as populations of threatened and endangered species, that might be sensitive to effects of launches. The second approach was characterizing the effects of launches, including the acute effects of individual launches and the cumulative effects of repeated launches particularly the spatial distribution of launch effects.

In this report we:

1. Review previous reports, environmental assessments (EAs), and environmental impact statements (EISs) for Delta, Atlas, and Titan vehicles and pad areas to clarify the magnitude of potential impacts;
2. Summarize observed effects of 15 Delta, 22 Atlas, and 8 Titan launches; and
3. Develop a spatial database of the distribution of effects from individual launches and cumulative effects of launches.

A second report will characterize the environment surrounding the launch complexes including threatened and endangered species and species of special concern.

Review of Literature on Launch Impacts

Introduction

This review summarizes information on environmental impacts from launching the Delta, Atlas, and Titan Expendable Launch Vehicles (ELVs). Impacts can occur from the launch exhaust heat, deposition of exhaust products from the solid rocket motors (SRMs), and noise. Descriptions and development histories of the vehicles and the launch complexes at Cape Canaveral Air Station from which they are launched are included in this review. Exhaust constituents and environmental effects of the ELVs have been compared with the exhaust effluent and impacts of the Space Shuttle. Space Shuttle exhaust products, ground cloud formation, and launch impacts are similar to those of the ELVs but occur on a larger scale. Much of the information contained in this report comes from environmental impact statements and assessments, reports, and publications written in support of the Space Shuttle program, as well as environmental assessments and reports developed in support of ELV programs.

Vehicle Descriptions

Delta

The Delta vehicle consists of two liquid fueled stages with SRM augmentation, an interstage adapter, optional solid propellant third stage, and a nose fairing. The Delta II launch vehicle (see Figure 1) utilizes two solid rocket motor configurations: Delta 6925 and Delta 7926 (Dames and Moore 1989). The 6925 uses nine Castor IVA SRMs and is used to launch lightweight satellites. The 7925 is for heavier satellites and has nine graphite epoxy motors (GEMs) which are 6 feet (1.8 m) longer than the Castor IVA SRMs and contain more propellant. The Delta is launched from Launch Complexes (LC) 17A and LC17B. Six SRMs are ignited on liftoff (t+0). The remaining three SRMs are ignited 59 seconds into flight. The first stage main engine burns RP-1, a highly refined kerosene, and liquid oxygen, and is ignited during liftoff. The second stage contains Aerozine 50 fuel (50% 1,1-unsymmetrical dimethyl hydrazine and 50% hydrazine) and nitrogen tetroxide oxidizer. The TR-201 main engine can burn for over 300 seconds. A spin-stabilized solid propellant motor serves as the Delta third stage when required (NASA 1979, Dames and Moore 1989).

Atlas

The Atlas-Centaur vehicle consists of an Atlas booster, interstage adapter, Centaur Upper Stage, split barrel, and a nose fairing. It is launched from Launch Complex 36, LC36A or LC36B. The engine system burns RP-1 and liquid oxygen. The system utilizes two main engines and two smaller vernier engines, also burning at lift-off, which help control the vehicle in flight. The main

Figure 1

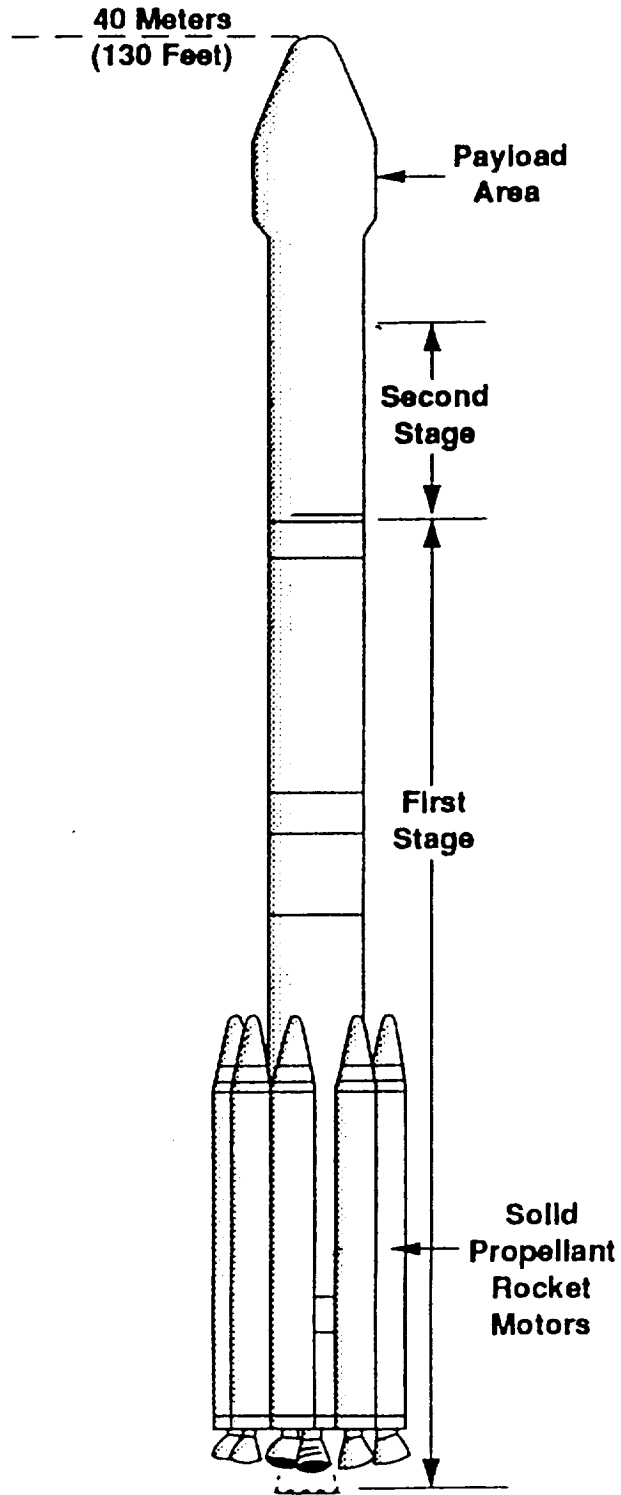


Figure 1. Delta II launch vehicle (USAF 1991a).

propulsion system of the Centaur stage consists of two engines burning liquid oxygen and liquid hydrogen, used to achieve final trajectory after Atlas burn out (NASA 1979).

The Atlas IIA booster rocket was reconfigured to the Atlas IIAS with the addition of four Castor IVA SRMs (see Figure 2). The additional SRMs enable the Atlas IIAS to accommodate a wider class of payloads than the capacity of the Atlas IIA, thus increasing available launch capacity and strengthening the United States' competitive position in international launch markets (USAF 1991b).

For Atlas IIAS launches, two of the four Castor IVA SRMs ignite just after ignition of the main engine while the vehicle is still on the launch pad. Burnout of the ground-fired SRMs occurs approximately 56 seconds after launch at an altitude of approximately 6,553 m (21,500 ft). The other two SRMs ignite approximately 65 seconds after liftoff and burn from an altitude of approximately 9,754 m (32,000 ft) to 35,052 m (115,000 ft). The two air-fired SRMs do not produce ground-level effects (USAF 1991b).

Titan

The Titan III launch vehicle consisted of a three-stage core using a liquid propellant propulsion system and two solid rocket motors (Stage 0) attached on opposite sides of the core. Each solid fuel motor was approximately 3 m (9.8 ft.) in diameter and 26 m (85.3 ft.) tall. The two solid fuel rocket motors developed more than 7 meganewtons (2.4×10^6 pound-force) of thrust at lift-off. Stages I, II, and III were ignited above the troposphere and surface mixing layer. Only Stage 0 with two SRMs contributed effluents to the ground cloud (Bendura and Crumbly 1977). Titan III solid boosters were about one-half the size of Shuttle boosters (Stephens and Stewart 1977). Depending upon the second and third stage vehicles used, the Air Force had different designations for the overall Titan launch vehicle: Titan III-C and Titan III-E. Regardless of this designation, the exhaust effluents that Stage 0 contributed to the stabilized ground cloud were identical (Gregory et al. 1976).

The Air Forces' Complementary Expendable Launch Vehicle (CELV) program utilized modified Titan 34D space boosters originally called the Titan 34D7. It was later renamed Titan IV - Type 1 when the CELV program was expanded (USAF 1990). The CELV was not a new design but expanded versions of the existing 34D and Centaur upper-stage vehicles. The 5 1/2 segments of solid propellant on the 34D were extended to 7 segments for CELV missions. The core vehicle was a standard Titan 34D core with Stages I and II lengthened 2.8 meters (9.2 ft) to provide for additional liquid propellant. The upper stage consisted of either a Centaur or inertial upper stage (IUS), depending on the mission. The payload fairing (a protective shield) had the same 4.6 m (15 ft) x 18.3 m (60 ft) capacity as the Space Shuttle Orbiter's payload bay. The Titan IV - Type 1 used only Stage 0, its SRMs, for liftoff and in the first 114 seconds of

Figure 2

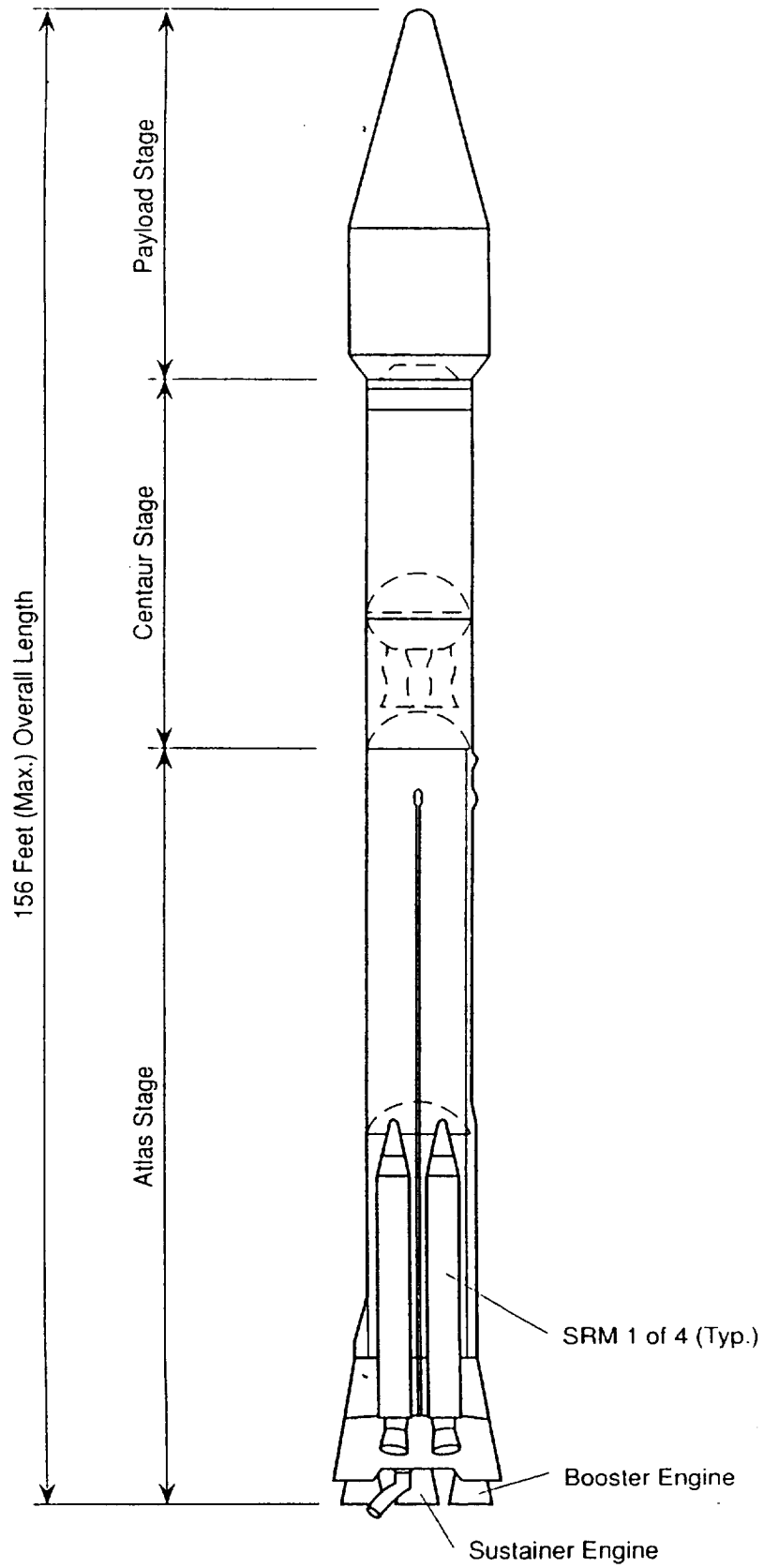


Figure 2. Atlas IIAS launch vehicle (USAF 1991b).

flight (ESE 1986). It was capable of launching payloads in the 4,545 kg (10,000 lb) class to geosynchronous orbit and 14,545 kg (32,000 lb) to low earth orbit (USAF 1990).

In 1987 the USAF began development of the Solid Rocket Motor Upgrade (SRMU), a larger, modified solid rocket motor (SRM) intended to increase the payload capacity of the Titan IV by 25-35% (see Figure 3). The SRMU consists of three segments with a 5% larger diameter than the SRM. The performance specification for the Titan IV/SRMU - Type 2 is 5,773 kg (12,700 lb) to geosynchronous orbit and 18,182 kg (40,000 lb) to low earth orbit (USAF 1990).

Launch Complex Area Descriptions and History

Launch Complex 17 (Delta)

Launch Complex 17 is located on CCAS, approximately 0.8 km (0.5 miles) west of the Atlantic Ocean and 2.4 km (1.5 miles) east of the Banana River (Figure 4). LC17 was built for the Thor intermediate range ballistic missile (IRBM) research and development program, and included two launch pads and a blockhouse. On January 25, 1957, LC17B supported its first Thor launch. The first Thor launch from LC17A was on August 30, 1957. LC17 supported 35 Delta missions between 1960 and 1965. The Air Force sponsored six ASSET (Aerothermodynamic/Elastic Structural Systems Environmental Test) launches from LC17 between September 1963 and February 1965. In the spring of 1965, the Air Force transferred LC17 to the National Aeronautics and Space Administration (NASA) after having determined there was no further military use for Thor facilities at the Cape. Many research, communications and weather satellites were launched from LC17 before and after its transfer to NASA. Launch operations on LC17 were expected to wind down with more payloads being launched on the Space Shuttle in the 1980's. However, after the Challenger disaster in January 1986, a new generation of Deltas became involved in military and commercial space activities at the Cape. Eventually the Air Force transferred all of its new NAVSTAR II Global Positioning System (GPS) payloads from the Space Shuttle to the new Delta II launch vehicle. Civilian customers also began using the Delta II. In 1988, responsibility for LC17 was transferred from NASA back to the Air Force. Modifications to LC17A to accommodate the Delta II launch vehicles were completed in 1988. On February 14, 1989, the first Delta II was launched from LC17A. After reconstruction was completed at LC17B, a Delta II was launched on August 27, 1989. Between 1989 and 1993, LC17 supported 22 successful NAVSTAR II missions (Fiorillo pers. comm.). LC17B has been modified recently to support Delta III launches.

Launch Complex 36 (Atlas)

Launch Complex 36 (Figure 4) was built for the Atlas/Centaur program and was operated under NASA's sponsorship from the inception of that program until the

Figure 3

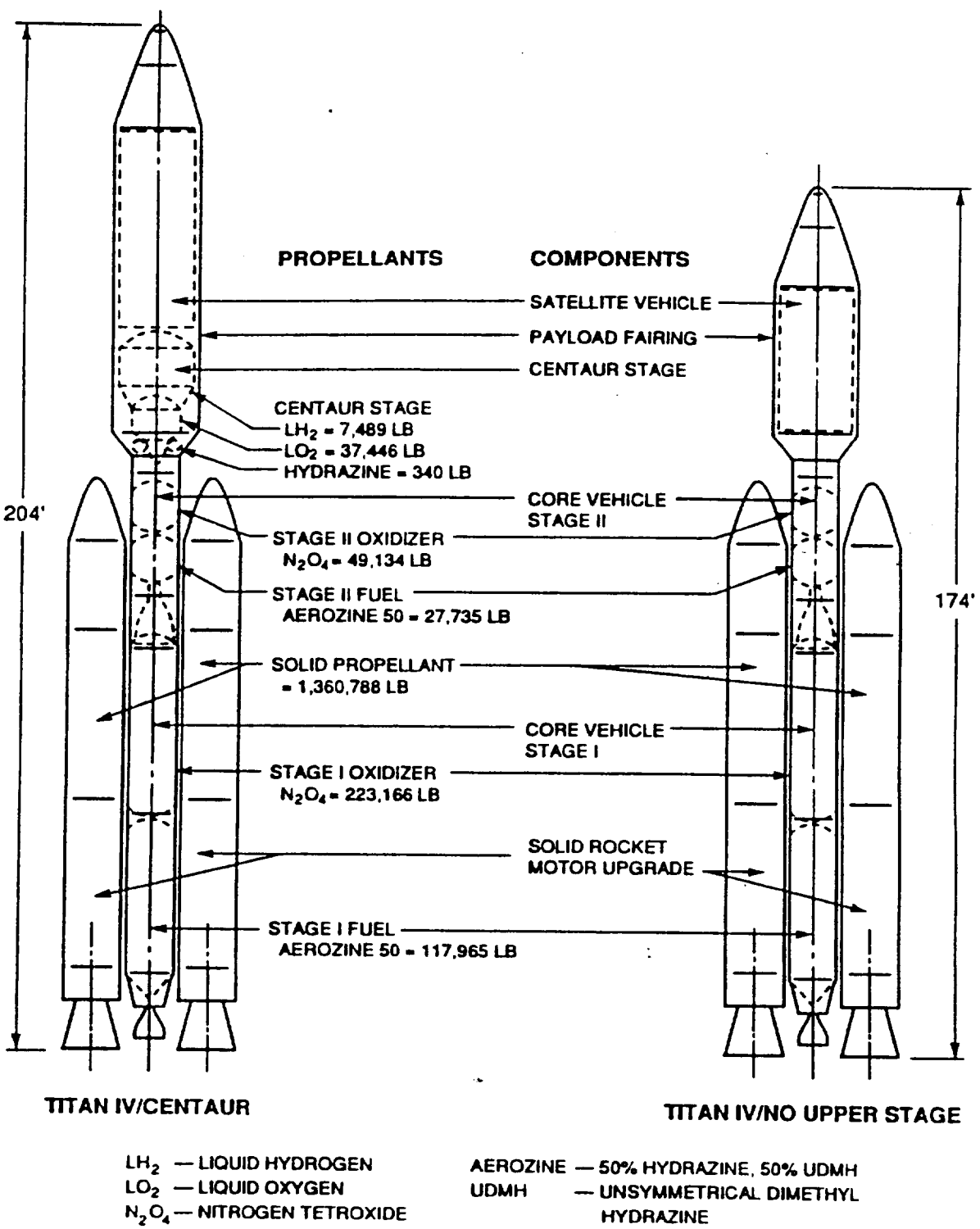


Figure 3. Titan IV/Rocket Motor Upgrade (SRMU) launch vehicle (USAF 1990).

Figure 4.

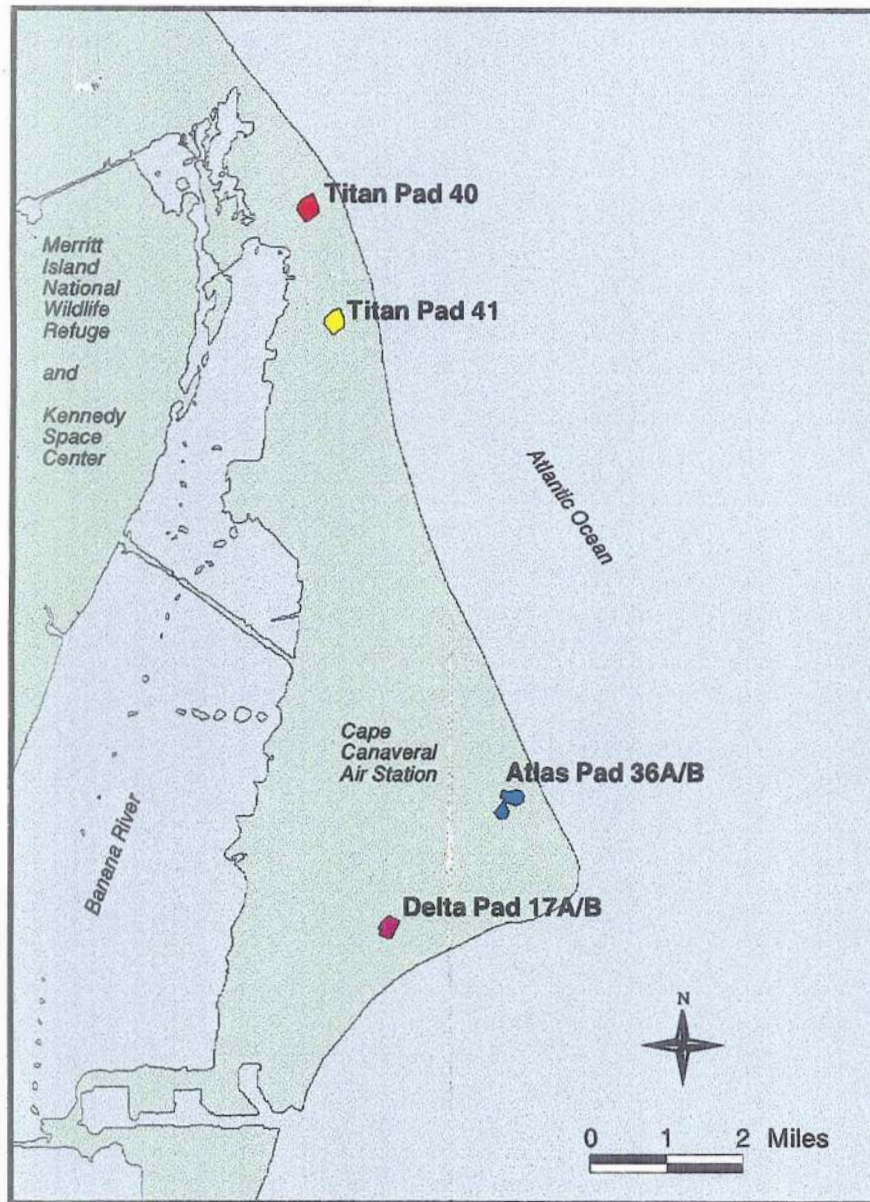
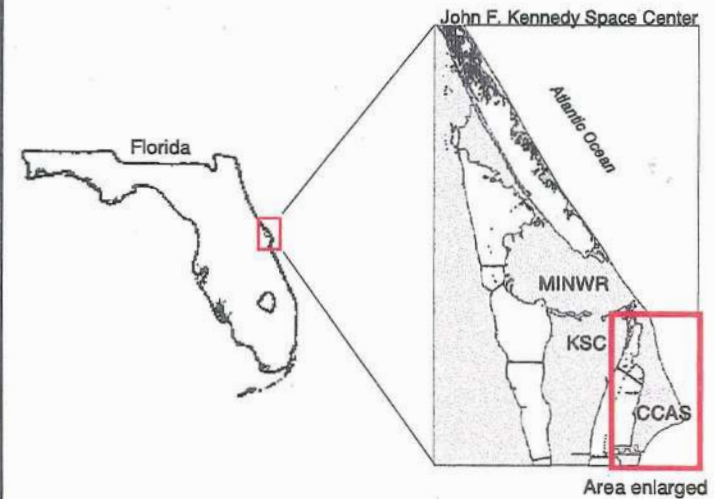


Figure 4: Location of launch complexes on Cape Canaveral Air Station (CCAS). Launch complexes include Titan 40, Titan 41, Atlas 36 A/B, and Delta 17 A/B. Cape Canaveral Air Station is located on the east coast of Florida, and is situated adjacent to Merritt Island National Wildlife Refuge (MINWR) and John F. Kennedy Space Center (KSC).



late 1980's. The blockhouse and LC36A were completed and occupied in 1961 with LC36B construction completed in 1964. Between May 1962 and October 1966, LC36 supported the first eight development flights for the Atlas/Centaur vehicle. Many interplanetary and communications satellite missions, under NASA sponsorship, were also launched from LC36. These included SURVEYOR, MARINER, PIONEER, and INTELSAT IV and V. The first launch of a NASA sponsored Fleet Satellite Communications (FLTSATCOM) satellite at Complex 36 occurred on February 9, 1978. During the next decade, six more FLTSATCOM missions were launched from LC36 until NASA transferred Complex 36 to the Air Force in January 1990. The old Atlas/Centaur complex was refurbished for the new Atlas II, Atlas IIA, and Atlas IAS vehicles. On December 7, 1991, the first commercial Atlas II/Centaur vehicle was launched from LC36B. The first Atlas IIA/Centaur was launched from LC36B on June 10, 1992. The Air Force launched the first two military Atlas II/Centaur missions from LC36A in 1992. These missions featured the new Defense Satellite Communications System (DSCS) III spacecraft. On December 16, 1993, the first commercial Atlas IAS/Centaur was launched from LC36B (Fiorillo pers. comm.).

Launch Complexes 40 and 41 (Titan)

Launch Complexes 40 (LC40) and 41 (LC41) are located in the Integrate Transfer and Launch (ITL) area at the north end of CCAS (Figure 4). They were constructed to support the U. S. Air Force Titan IIIC program. LC40 was constructed in 1965, and was in use until 1990, when refurbishment was initiated. The first Titan IIIC launch from LC40 was on June 18, 1965. A renovation project at LC40 was completed in June 1993, in time for its first Titan IV/Centaur launch on February 7, 1994 (Fiorillo pers. comm.).

Launch Complex 41 is essentially a duplicate of LC40 and is surrounded by KSC property except for the tracks that lead to the ITL area. From 1965 to 1977, LC41 was used to launch Titan space boosters. On December 21, 1965, the first Titan IIIC launch occurred on LC41. Since the end of 1965, both complexes have supported a wide variety of military space missions involving Titan IIIC, Titan 34D, and Titan IV vehicles. In 1972, LC41 was modified by NASA to provide a Titan IIIE/Centaur launch vehicle capability. LC41 was the Titan IIIE launch site for NASA's Viking missions to Mars in 1975 and NASA's Voyager missions to the outer planets in 1977. At the end of 1977, LC41 was deactivated, but was renovated during 1986 to 1988 for the Titan IV program. LC41 supported its first Titan IV launch on June 14, 1989 (Fiorillo pers. comm.).

Propellants

Liquid

Common liquid propellants include liquid oxygen and kerosene used in the core vehicles of the Atlas and Delta rockets. These produce carbon dioxide (CO₂) and carbon monoxide (CO) as well as water vapor as products of ignition. Nitrogen tetroxide and hydrazine, both highly toxic, are used in the Titan rocket (Aftergood 1991).

No liquid fueled engines burn at liftoff during launches of the Titan. In contrast, the liquid fueled Shuttle main engines are ignited 7 seconds prior to liftoff. The liquid oxygen and liquid hydrogen fueled Space Shuttle main engines produce water vapor as a major exhaust constituent and may affect the formation of aqueous hydrogen chloride and cause synergistic effects with aluminum oxide (Stephens and Stewart 1977). Ground level impacts from nitrogen oxides (NO_x) produced from the liquid fuel propellants on the Titan IV are expected to be negligible since the liquid fuel stage (Stage I) is ignited 115 seconds into the launch cycle (ESE 1986).

Solid

The largest solid propellant fueled rocket motors are those employed on NASA's Space Shuttle and the Air Force Titan IV. Smaller solid propellant rockets are used for thrust augmentation at launch on the Delta and Delta II, the Atlas IIAS, and several Ariane-4 configurations, as well as on Chinese Long March (CZ-2) and Japan's H-2. The Ariane-5 will employ large boosters somewhat smaller than Titan IV's. Several smaller space launchers employ all-solid propulsion systems; e.g., the U. S. Scout, Pegasus, Taurus, and Conestoga, Japan's Mu-series, India's SLV and PLSV, and Israel's Shavit (AIAA 1991).

The main ingredients of most widely used solid propellants for current and projected solid rocket boosters are ammonium perchlorate oxidizer and a polymer based fuel consisting of the propellant binder, loaded with powdered aluminum. The most common formulation is comprised of 15% aluminum and 70% ammonium perchlorate, with the hydrocarbon polymer, to bind the fuel and oxidizer together, making up the rest. An iron oxide catalyst is also added to the mixture (Aftergood 1991, AIAA 1991).

The principal effluents from solid rocket motors are hydrogen chloride (HCl), aluminum oxide (Al₂O₃), water (H₂O), hydrogen (H₂), CO, and CO₂. The mean flow and associated turbulence in the atmospheric boundary layer transport and disperse rocket plume effluents, and hence determine the concentration of effluents downstream of the launch or test site (AIAA 1991).

Exhaust Cloud Constituents and Formation

General

During the launch of solid-fuel rockets, the SRMs release a visible exhaust cloud that is a dynamic mixture of H₂O, CO, CO₂, HCl, Al₂O₃, and aluminum chloride (AlCl₃) at potentially toxic levels (McRae et al. 1987). Table 1 presents estimated amounts of the predominate exhaust products in a typical Space Shuttle ground cloud. The exhaust plume impinges on the launch complex structure, a flame deflector, and a water filled trench. Due to the low launch velocities of large rockets, much of the exhaust material is concentrated in the lower troposphere. Initially, exhaust materials and other products of launch are concentrated in a launch pad cloud, a flame trench cloud, and a column cloud. Portions of these quickly combine to form a ground cloud that can contain 10-25% of the total effluent from the rocket, as well as steam from injected cooling water and launch platform sand and debris (Radke et al. 1982). A hazardous environment is created on the ground by the tremendous exhaust expelled by the departing vehicle. The cloud rises to its maximum or stabilization altitude, typically 1 km (0.62 miles) to 2 km (1.24 miles) above the Earth's surface depending on the heat content of the cloud and the height of the local atmospheric mixing layer, in a period of 5 to 10 minutes after launch (Bendura and Crumbly 1977, Stephens and Stewart 1977). The ground cloud is a mixture of particles and trace gases that evolves with time due to both internal physical and chemical processes and to interaction with the ambient air. The transport phase then begins with the cloud drifting around for long periods of time with the potential for affecting air quality as well as the earth's surface through dry and wet deposition. At stabilization, the clouds typically contain 99.9 percent of their mass as ambient air entrained during the rise portion of their trajectory (Stephens and Stewart 1977). After stabilization, the cloud continues to grow while some exhaust effluents, including HCl, are dispersed to the ground in its downwind path. The launch pad area undergoes a dynamic process of HCl rain-out, followed by periods of revolatilization of the hazardous vapors (Bendura and Crumbly 1977, McRae et al. 1987).

Table 1. Estimated amount of principal exhaust products in a typical Space Shuttle ground cloud at stabilization (NASA 1979).

<i>Exhaust Product</i>	<i>Kilograms</i>	<i>Pounds</i>
Carbon dioxide	76,800	169,300
Water	65,300	144,000
Aluminum oxide	56,100	123,700
Hydrogen chloride	35,200	77,600
Chlorine	4,000	8,800
Oxides of nitrogen	2,300	5,100
Carbon monoxide	240	530

Of the emissions produced during launch, Al_2O_3 , NO_x , and HCl are of the most concern from an air pollutant impact standpoint. Potential HCl and Al_2O_3 emissions from the Atlas IIAS, Delta II, Titan IV, and Space Shuttle programs are presented in Table 2. Carbon monoxide will be emitted during vehicle launches for all launch programs. The tendency for CO to continue to burn in the hot plume and rapidly oxidize to CO_2 due to initial high temperatures and abundance of oxygen mitigates the air quality impact of CO (Dames and Moore 1989, USAF 1991a,b).

Table 2. Comparison of potential HCl and Al_2O_3 emissions from the Atlas IIAS, Delta II, Titan IV, and Space Shuttle programs (USAF 1991b).

<i>Launch Program</i>	<i>HCl Emissions per Launch (tons)</i>	<i>HCl Emissions per Launch (kg)</i>	<i>Al_2O_3 Emissions per Launch (tons)</i>	<i>Al_2O_3 Emissions per Launch (kg)</i>
Atlas IIAS	10	9090	18	16364
Delta II (Delta 6925)	21	19090	22	20000
Titan IV	117	106364	167	151818
Space Shuttle	158	143636	252	229091

Deposition formed by atomization of the deluge water at the launch pad is composed of H_2O , Al_2O_3 particles, HCl, and trace materials. In a sample collected at the pad following a Shuttle launch, deposition was 70% liquid and 30% solids (Anderson and Keller 1983a, b). Copper plates and pH papers deployed along the pad perimeter fence during a Shuttle launch indicated the pH of the deposition was less than 1 (Anderson and Keller 1983b). Acidic species have the greatest potential impact on the near-field and adjacent-surface environments. The halogen, chlorine, particularly in the form of hydrogen chloride gas, an acid more commonly referred to as hydrochloric acid, is of primary concern. Wet acid deposition results mainly from the use of halogens in launch vehicle propellants, although there is also some deposition of nitric acid

(HNO₃) from NO_x (AIAA 1991). Nitrogen oxides are always present downstream of the exit plane of the exhaust nozzle, because atmospheric nitrogen is entrained into the rocket plume and after-burned. Nitrogen is also present as a propellant constituent in some systems. The resulting NO_x will eventually interact with the environment through a series of chemical reactions that lead to the formation of HNO₃ and ozone (O₃) (AIAA 1991).

Under certain atmospheric conditions, the ELV ground cloud could entrain enough water to generate a light rain or mist, encounter rain from a higher stratum cloud, or be convected into a rain-generating cloud. The rain or mist precipitated through the exhaust cloud could absorb HCl and produce acidic rain (ESE 1986). Modeling of acidic rain potential from the Titan III ground cloud has resulted in conclusions that rain acidities of pH less than 1.0 are possible at distances of up to 20 km (12 miles) from the launch site under certain meteorological conditions. This is a worst case condition where volumetric average maximum acidity levels for initial rainfall are centered through the ground cloud. The final acidity is a function of progressive washout of the ground cloud, the diluting effect of subsequent rainfall, and for rainwater contacting the ground, the buffering capacity of the soil (ESE 1986).

The potential exists at each launch and test facility for disposal and/or deposition of trace metals and organics in the boundary layer, depending on propellant and facility characteristics. Heavy metals and toxic organics may be produced or dispersed by the launch or test process. These metals and organics may be derived from minor constituents in propellants or rocket components eroded in the firing process, or from paints and construction materials eroded and dispersed from the facility. Soil samples analyzed from the Launch Complex (LC) 39 area at KSC indicate trace heavy metal deposition (AIAA 1991).

Titan

Titan III launches produced a plume of hot exhaust effluents that mixed with moist ambient air and rose due to buoyancy forces. Only the SRM boosters contributed effluents to the ground cloud since the liquid propellant was ignited at a higher altitude. The exhaust cloud usually rose for 4 to 8 minutes after launch, stabilized at an altitude of 1 to 2 km depending on the meteorological conditions, and then drifted with the prevailing winds (Sebacher et al. 1980).

Each Titan IV SRM contains 309,406 kg (680,694 lb) of propellant (USAF 1988). Total solid propellant weights (both SRMs) for Titan IV-Type 1 and Type 2 are 536,364 kg (1,180,000 lb) and 618,182 kg (1,360,000 lb), respectively. Type 2 SRMU solid propellant weight is about 15% greater than that of Type 1. Total solid propellant weight for a pair of Space Shuttle SRMs is 1,007,589 kg (2,216,696 lb), 63% greater than for the SRMU (USAF 1990).

Chemical reactions within the exhaust plume of a Titan IV rocket slightly alter nozzle exhaust products within a short time after emissions. Chlorine reacts with H_2 to produce HCl, the remaining H_2 oxidizes to form water, some CO oxidizes to form CO_2 , and some N_2 within the exhaust plume produces a small amount of NO_x . The exhaust plume contacts deluge water forming a sludge. Constituents of the sludge are primarily Al_2O_3 , $AlCl_3$, HCl, and ablative material from the flame bucket (USAF 1988).

Combustion products are distributed along the vehicle trajectory to an altitude of roughly 50 km. Due to the rate of acceleration of the vehicle and the staging processes, the quantities of exhaust gases emitted per unit length of the trajectory are greatest at ground level and decrease continuously. The portion of the exhaust plume that persists for more than a few minutes is emitted during the first few seconds after ignition. These emissions are concentrated in the pad area within the ground cloud (USAF 1990). Measurements made during a Titan III rocket launch from Cape Canaveral showed the Titan cloud was initially wet, then dry, and finally wet again and dispersed primarily in the horizontal plane (Radke et al. 1982).

During early stages of formation and transport, ground clouds contain large amounts of SRM effluent in both gaseous and aerosol form. Aerosols are mostly water droplets containing dissolved HCl and particulate Al_2O_3 from SRM exhaust. Larger aerosols settle out of the cloud near the pad. Therefore, the greatest deposition is near the pad and amounts rapidly decrease downwind. The mass of aerosol deposited is influenced by the quantity of deluge water used, amount of water produced by combustion, and water content and temperature of ambient air that mixes with the ground cloud. Shuttle ground clouds contain substantially greater amounts of water than Titan ground clouds, because of the Shuttle's larger SRMs, main engine exhaust, and greater deluge water requirements. Titan exhaust clouds are drier than Shuttle clouds and produce less acidic aerosol deposition covering a smaller area (USAF 1990). Most of the deposition occurs within the near-field area, close to the launch site. Exhaust ducts force exhaust plumes eastward. If winds are from the west or southwest, which they usually are in the morning when launches frequently occur, deposition from the ground cloud would be diluted in the Atlantic Ocean. If winds are from the east or southeast, which is infrequent, deposition would occur in wetland areas adjacent to the launch sites and to a lesser extent into the Banana River (USAF 1990). Hydrogen chloride emissions from Titan vehicles present a modest environmental hazard, estimated to be confined to controlled areas even under unfavorable meteorological conditions (USAF 1986).

During a static firing test of a Titan 34D 5 1/2 segment SRM, a viscous green rainout occurred. The valley in front of the thrust stand was inundated with acidic rainout and deluge water. Deposition caught in collection pans increased further away from the test article and became less acidic due to large amounts of

buffered deluge water which were blasted away from the test stand and rained out in the area without much contact with the HCl plume. Acid vapors were present two days after the firing and persisted for a week due to revolatilization of available unreacted HCl (Rinehart and Berlinrut 1988).

The exhaust cloud from a Titan III is 40% as large as the Shuttle's exhaust cloud (Pellet et al. 1983a,b). The twin boosters on a Space Shuttle exhaust about 2.4 times as much HCl within the first 1,500 m in altitude (~48 tons) as Titan III launches (Pellett et al. 1983a,b). The solid propellant rocket motor of the Titan III produces approximately half the exhaust HCl of a Shuttle launch. However, similar proportions of HCl to other exhaust products are released in both Titan III and Space Shuttle exhaust clouds (Sebacher et al. 1984). During a Titan IV launch an acidic mist of pH 3.0 or lower is formed by contact of the deluge water with the rocket exhaust during ignition (USAF 1988). Cooling water tested after Shuttle launches shows pH ranging from 1.6 to 2.0 due to HCl absorption. The pH of the mist ranges from 0.5 to 1.0 for Titan vehicles (USAF 1986).

Delta

The ground cloud produced by Delta II vehicles is similar in composition to that produced by the Titan. It is considerably smaller in size since Delta II vehicles and SRMs contain less propellant, produce less vapor, and accelerate off the launch pad more quickly. The Delta II also uses less than 10% of the deluge water required by the Titan (Dames and Moore 1989).

Delta II engines and SRMs activated at liftoff contain less than 40% of the propellant by volume of Titan propulsion systems used at liftoff. Since it accelerates off the pad and leaves the lower atmosphere more quickly than the Titan and Space Shuttle vehicles, the Delta generates a smaller cloud containing fewer contaminants with less potential for environmental effects. A Delta launch vehicle uses less than 5% of the quantity of solid propellant used by the Shuttle and produces a much smaller exhaust cloud containing approximately 5% of the HCl contained in the Shuttle exhaust cloud. The volume of water vapor produced during a Delta launch that is available for mixing with the other exhaust products in the ground cloud is also significantly smaller than the water vapor produced by the Shuttle. Large quantities of water are produced by the Shuttle through vaporization of deluge water and formation of water vapor by the reaction of liquid oxygen and liquid hydrogen in the main engines. The first stages of both the Shuttle and the Delta produce water vapor, but the volume of water vapor produced by the Space Shuttle main engines results in more water vapor in the Shuttle ground cloud than in the Delta ground cloud. The Delta vehicle uses less than 10% of the volume of deluge water used by the Shuttle. Since the Shuttle has a slower ascent from the launch pad, the proportion of deluge water vaporized by exhaust heat is greater. Both water and water vapor scrub out of the exhaust cloud in the form of liquid HCl. Since the exhaust cloud produced by the Delta vehicle contains less water vapor than the Shuttle and is

therefore drier, more of the HCl will stay in a gaseous form and will not be deposited directly on land or in adjacent surface waters (Dames and Moore 1989). A scaling factor of 0.4 was used to convert predicted Titan launch impacts into an estimate of Delta II impacts (Dames and Moore 1989).

Atlas

Primary air effluents from the Atlas main engine are H₂O (25%), CO₂ (24%), and CO (44%). The high exhaust temperatures cause the CO to oxidize forming CO₂ within a few seconds after emission. Primary air pollutants emitted by the SRMs are HCl, Al₂O₃, and CO (USAF 1991b).

Airborne measurements were made over periods of several hours in the effluents of the ground cloud when an Atlas/Centaur was launched at night from Cape Canaveral (Radke et al. 1982). The Atlas ground cloud was dry and dispersed primarily in the horizontal plane. The ground cloud initially contained elevated concentrations of NO_x, hydrocarbons, and particulate mass. Dispersion of the cloud quickly reduced the concentrations of these materials and the lightscattering coefficient of the cloud (Radke et al. 1982).

During the first few seconds after ignition of the Atlas IAS SRMs and main engines, the exhaust is directed downward onto the ground forming a ground cloud in the vicinity of the launch complex. Based on experience at other sites at which similar SRMs are used, most of the ground cloud components, particularly Al₂O₃ and much of the HCl, would be expected to fall from the cloud to land surface within several hundred feet of the launch complex. The remaining ground cloud typically disperses within several minutes as a result of the mechanically and thermally induced turbulence of the rocket exhaust (USAF 1991b).

Rocket Exhaust Effluent Diffusion Model

The Rocket Exhaust Effluent Diffusion (REED) model was developed to predict launch cloud effects on a near real-time basis (Stephens and Stewart 1977). The model was developed over a period of years (Stephens and Stewart 1977, Environmental Applications Branch Staff 1983, Bowman et al. 1984) and incorporated data from studies of Titan III launches in the early 1970's; Titan III rockets used solid rocket motors about 40% the size of those of the Space Shuttle. Predictions are made based on inputs of meteorological data from rawinsonde readings of vertical profiles of wind direction, wind speed, air temperature, atmospheric pressure, and relative humidity from the surface to 3,048 m (10,000 ft). Submodels within the program predict: 1) plume rise, modeling the launch vehicle as an instantaneous source under normal launch conditions, 2) chemistry of HCl within the cloud, 3) turbulent cloud growth, 4) dispersion using a Gaussian approach, and 5) concentration or deposition of exhaust products (Stephens and Stewart 1977, Environmental Applications Branch Staff 1983, Bowman et al. 1984). Early versions of this model (Bjorklund

et al. 1982) predicted gaseous HCl concentrations and Al₂O₃ deposition. Observations from early Space Shuttle launches (Bowie 1981, Knott 1982, The Bionetics Corporation 1982a,b) showed that the model correctly predicted direction of launch effects but placed these effects much farther from the launch site than they actually occurred. In addition, gaseous HCl was seldom detected outside the immediate launch pad area, but acidic deposition occurred up to 22 km from the launch site (Knott et al. 1983). In 1984, the model was modified to predict gravitational HCl (hydrochloric acid) deposition (Bowman et al. 1984). The revised model predicted higher deposition near the launch pad declining with distance in qualitative agreement with observations (Schmalzer et al. 1986). Duncan and Schmalzer (1994) compared model predictions with ground patterns using a spatial database of deposition patterns from 49 Space Shuttle launches; they found that the model correctly predicted direction of launch cloud movement but over-predicted maximum distance from the launch pad that deposition occurred and total area receiving deposition.

The REED model has the capability to predict acid deposition from Titan and Delta launches. These predictions have not been tested against ground patterns of deposition.

Noise

Sound levels at CCAS range from quiet (40 - 55 dB) in isolated areas to high (75 dB and above) due to launch activities, aircraft movements, and other support related activities. Sound levels associated with rocket launches and related activities include energy over a wide range of frequencies from below 1 Hz to over 100,000 Hz (Dames and Moore 1989).

Delta

Measurements of sound levels during a Delta II launch taken 1,524 m (5,000 feet) from the launch pad were characterized by: maximum A-weighted sound level (slow) - 104 dB, maximum sound pressure level (slow) - 118 dB, time above 65 dB - 75 seconds, and Single Event Level (SEL) - 113 dB (Dames and Moore 1989).

Atlas

Measurements at Atlas launches showed peak sound pressure levels of about 120 dB at frequencies below 37 Hz at a distance of about 1,524 m. Structural damage would not be expected outside of a 0.9 to 1.8 km radius from launch. Only resistant structures are located within these distances from the pads (ESE 1986).

Titan

Noise level peak amplitudes at frequencies of 0 to 20 kHz at selected instances (1.2 km (0.75 miles), 2.0 km (1.25 miles), 3.2 km (2 miles), and 6.4 km (4 miles)) from the Titan IV SRM firing test site at Edwards Air Force Base were measured to be less than 80 dB in all cases. Noise levels as close as 1.2 km (0.75 miles) should be less than 80 dB at frequencies between 0 to 20 kHz. Sound pressure levels were 85 dBA or less for distances of 5.5 km (3.4 miles) or greater (USAF 1988). Around the launch pad, maximum sound pressure reaches a level of about 170 dB. At a distance of 3.2 km (2 miles), a maximum sound pressure of 125 dB might occur for about 30 seconds after launch. At distances of 8.1 km (5 miles) and 16.1 km (10 miles) from the pad, sound pressure levels of 110 and 100 dBA respectively, would be anticipated for 2 minutes after liftoff (USAF 1990).

Launch Impacts

Surface Water

Space Shuttle

Acidification of lagoonal waters in the vicinity of LC39A monitored for ten launches corresponded spatially with areas directly impacted by deposition from the Shuttle ground cloud and runoff of the deluge water from the north side of the launch pad (Schmalzer et al. 1993). Levels of impact vary spatially and temporally with meteorological conditions at time of launch. Maximum pH reductions of 6 to 7 units were found at the surface and in the area adjacent to the stormwater drainage ditch in line with the flame trench at each pad. In these areas, pH depression may be acute and lethal to organisms utilizing gills for respiration. Minimal effects were observed around the edges of the ground cloud footprint and at depths where buffering and dilution minimized chemical impacts. Metal concentrations in the water column increased dramatically during the period of reduced pH and returned to pre-launch levels as normal pH levels returned. No long-term elevations in metal concentrations have been observed (Schmalzer et al. 1993).

Delta

Surface runoff from LC17 flows west toward the Banana River. Sources of surface water contamination associated with the Delta launches include deluge water generated during launches, and contamination of surface waters from exhaust cloud deposition of HCl and Al₂O₃. Direct discharge of deluge water is not expected to occur since it is retained in holding ponds and released to a swale system for control of runoff. Exhaust cloud impact on surface water quality is a function of the composition of the cloud, duration of contact with water, windspeed and wind direction, and other atmospheric conditions (Dames and Moore 1989).

The formation of HCl produced by SRM combustion is the primary concern associated with exhaust cloud impacts on water quality. The Delta exhaust cloud is drier than the Shuttle exhaust cloud and contains only the exhaust from the first few seconds of the SRM burn due to the rapid ascent off the launch pad. Depending on wind direction, a significant portion of the exhaust may drift toward the Banana River or the Atlantic Ocean. Short-term acidification of surface water may result from contact with the exhaust cloud and through HCl deposition in the form of dryfall. Under rainfall conditions, wet deposition of HCl may occur. Impacts to surface waters should be restricted to the area immediately adjacent to LC17. No significant impacts to surface waters of the Atlantic Ocean and the Banana River should occur due to the bicarbonate buffering capacity of these waters. A short-term decrease in pH could occur in drainage canals adjacent to LC17. The buffering capacity of the Banana River should prevent any impact from the pH of these canal waters discharging into the lagoon (Dames and Moore 1989).

Atlas

Surface water impacts of the Atlas IAS Castor IVA SRM exhaust have not been studied directly previously. Potential impacts were evaluated based on results of modeling exhaust cloud composition and dynamics. Rainfall immediately after launch would have the greatest potential for surface water impacts from the washout of HCl and Al_2O_3 from the Atlas IAS exhaust cloud. Without rain, the exhaust cloud would be carried farther from the launch pad, allowing for greater dispersion and therefore, reduced loading rates of HCl and Al_2O_3 to surface water. Significant pH decreases in the marine waters near CCAS are unlikely because of dilution and the natural buffering capacity of the water. As mentioned earlier, Al_2O_3 is relatively insoluble at the ambient pH of surface water on and adjacent to CCAS. It is unlikely that Al_2O_3 deposition would result in significant increases in aluminum concentrations. Since there would only be a temporary decrease in pH from HCl in the exhaust cloud, Al_2O_3 deposition should not contribute to increased aluminum solubility in area surface water (USAF 1991b).

Titan

Approximately 1.5×10^6 L (400,000 gallons) of deluge and washdown water is required per Titan IV launch at LC40 and LC41. Some of the 1.2×10^6 L (300,000 gallons) of deluge water is evaporated by the exhaust, while 80% of the deluge and washdown water is collected in the launch duct sump and drained to percolation ponds. The remaining 3.1×10^5 L (80,000 gallons) is discharged onto uncontrolled areas of the launch facility where most either percolates into highly permeable soils or vaporizes and disperses into the atmosphere. Some deluge water is expected to fall directly into the Atlantic Ocean or Banana River. Wastewater from the overpressure suppression system (1.7×10^5 L (44,400 gallons) of coolant water) also drains to percolation ponds. Good management

of percolation ponds should prevent surface runoff from reaching wetlands on the west side of LC41 (USAF 1990).

Surface water quality should not be significantly impacted by the deposition of HCl or Al₂O₃ from the ground cloud produced during liftoff of the Titan vehicle. Any HCl deposited in surrounding surface waters should be rapidly neutralized by the extensive buffering capacity of the Banana River and adjacent marshes. In addition, any Al₂O₃ deposited in surface waters should remain insoluble and not be toxic to aquatic life (USAF 1990).

Groundwater

Delta

Discharge of deluge water from the catchment basin to grade within the launch complex perimeter is a potential source of groundwater contamination associated with a Delta launch. Starting approximately 5 seconds before liftoff, approximately 1.1×10^5 L (27,500 gallons) of deluge water is released within 5 minutes to suppress acoustic levels and dissipate excess heat from the launch platform area. In addition, 7,692 L (2,000 gallons) of water is released for fire suppressant and launch complex washdown. Most of the deluge and washdown water is collected in a flume directly beneath the launch vehicle and flows into a sealed concrete catchment basin. Based on reported observations of previous Delta launches, minimal amounts of the deluge water and fire suppressant water will run off the launch pad directly to grade (Dames and Moore 1989). Deluge water collected in the catchment basin is treated with a 50% sodium hydroxide (NaOH) solution within 72 hours after completion of washdown to raise the pH to a uniform 8.0 ± 0.5 , analyzed and discharged to grade if state and federal discharge criteria are met. If catchment basin waters fail to meet applicable regulatory criteria, they are disposed of off-base by a certified contractor. Groundwater recharge occurs from the overall disposal to grade and subsequent percolation of deluge, washdown, and fire suppressant water at LC17 following each launch. Water percolates into the groundwater table and flows west toward the Banana River (Dames and Moore 1989).

Atlas

At LC36, spent deluge water percolates to shallow groundwater through surficial soils within the perimeter of the complex. During the 3 seconds or less that the Atlas IAS vehicle is on the pad after ignition, the deluge water will contact exhaust from the SRMs. Based on known exhaust characteristics of the Castor IVA SRM and past analyses of deluge water from other facilities using the Castor IVA, the quality of the deluge water could be affected (USAF 1991b).

Titan

There is a potential for contamination of groundwater in the surficial aquifer by deluge and washdown water at LC40 and LC41 as it infiltrates into permeable soils underlying the percolation ponds (USAF 1990). Much of CCAS and its launch complexes are underlain by the Canaveral complex and the Canaveral-Urban land complex consisting of soils that are mixtures of sand and shell fragments (Huckle et al. 1974). These soils should be well buffered, as are the soils in the LC39 area. After 24 launches, soil pH at LC39A was still alkaline. Therefore, the aluminum deposited by the exhaust cloud was not in an exchangeable form (Schmalzer et al. 1993).

One effect of disposal of wastewater (deluge and washdown water) following a Titan launch would be slight groundwater mounding beneath the launch complex. If the 1.4×10^6 L (364,000 gallons) of wastewater were to infiltrate into 4.8 ha (10 acres) of ground surrounding the percolation ponds on the east side of LC41, the average water level rise per launch would be 0.09 m (0.3 ft) (USAF 1990). A minimum of 11 years would be required for groundwater to reach wetlands, 365.8 m (1,200 ft) west of the percolation ponds, according to a groundwater mounding analysis based on groundwater impacts from wastewater discharges following launch. Most deluge water is captured and treated before release. Mixing with groundwater should dilute contaminants to acceptable levels. Contaminated groundwater from repeated Titan IV launches as well as other launches at CCAS could have a long-term impact on nearby wetlands (USAF 1990).

Vegetation

Much of the information available on launch impacts to terrestrial vegetation has been gathered from studies conducted for NASA's Space Shuttle program and observations of Shuttle postlaunch effects. The phytotoxicity of products released from the ground cloud was studied by the Statewide Air Pollution Research Center at the University of California, Riverside (Granett 1984). The non-toxic nature of Al_2O_3 was confirmed in laboratory tests. Also, the response of plants exposed to Al_2O_3 and HCl gas at ambient or elevated humidity levels was not influenced by the particles. A mist of HCl droplets falls from the Shuttle ground cloud and causes foliar spotting on plants at KSC. Similar necrotic lesions were produced on most species tested with HCl mist applied in glasshouse studies. Less injury occurred following evening exposure than morning or mid-day exposures. Acidity of the mist was more important than the length of exposure in determining the extent of the injuries. Leaves were the most likely part of the plant to be injured, with lower surfaces more sensitive to damage than upper surfaces. Differences in sensitivity to acidic mist were revealed when different plant species were tested (Granett 1984).

In tests conducted at North Carolina State University, plants were found to be more sensitive to HCl during fall and spring than during winter. Increased

humidity or water on leaf surfaces during exposure made plants more sensitive to HCl but not to Al₂O₃. Exposure of selected plants to large doses of Al₂O₃ did not cause injury or affect growth. Plants responded to mixtures of Al₂O₃ and HCl the same way they did to HCl alone (Heck et al. 1980).

Selected plants were exposed to Cl₂ or NO₂ to determine relative sensitivity in relation to sensitivity to HCl. Plants were four to 20 times more sensitive to Cl₂ than to HCl but were two to four times less sensitive to NO₂ (Heck et al. 1980).

Sensitive plant species are injured by HCl gas at concentrations above 5 ppm in 60 minute or longer exposures. Response to shorter exposure times or to multiple exposures is not known. No biological effects are known for Al₂O₃, but chemically active particulates can injure plants and cause growth reductions. Alumina may act as a carrier for HCl and indirectly cause injury to plants (Heck et al. 1980).

Large necrotic areas, bifacial and interveinal, were typical symptoms of foliar injury from HCl. Dose response exposures showed concentration was more important in causing foliar injury than exposure duration. Exposure of plants to SRF exhaust in field chambers, using a controlled burn facility, showed HCl was the principal phytotoxicant. Alumina did not cause foliar injury nor alter growth in any of the plants tested. If Al₂O₃ particulate acts as an HCl carrier, it was not apparent in these exposures. Aluminum oxide could cause plant damage if aluminum concentration increased in acid soils, since free Al³⁺ is toxic to plants (Heck et al. 1980).

Injury effects of two or more short exposures to HCl were additive for the plants tested. The expected Cl₂ component of SRM exhaust could be as injurious to sensitive vegetation as the HCl component. Hydrogen chloride concentrations that caused injury to the most sensitive species were generally higher than the maximum (4 to 6 ppm for 10 min) expected at ground level from the SRM exhaust from launches of the Shuttle at KSC. Species on Merritt Island are less sensitive than the most sensitive species tested, thus it was not expected that the SRM exhaust cloud would have significant adverse effects on the natural vegetation and citrus in and around KSC (Heck et al. 1980).

Sensitive plants were injured by gaseous HCl from less than 10 to 20 ppm when the length of exposure was 20 minutes or less and from less than 5 to 10 ppm when the exposure duration was 40 to 80 minutes. Plants were not injured by Al₂O₃ alone or in combination with HCl. Plants were injured by SRF exhaust at dosages similar to those causing injury by HCl alone (Heck et al. 1980).

Vegetation changes from the first nine Shuttle launches have been summarized by Schmalzer et al. (1985) and include loss of sensitive species, loss of plant community structure, reduction in total cover, and replacement of some species

by weedy invaders. Vegetation damage is more extensive following a launch where thunderstorms occurred a few hours prior to launch, perhaps due to high humidity and wet condition of the vegetation. Near-field impacts are caused by the intense acid deposition from the ground cloud moving across the ground, vegetation, and lagoonal waters. Launch effects are not uniform across the near-field study area in terms of frequency of being hit or intensity of deposition if hit. Changes in species and cover occur over the entire impact zone.

Considerable turnover, replacement, and loss of herbaceous species have occurred. Loss of cover has resulted from complete or partial killing of shrubs and small trees, removing the shrub layer and changing the community structure. Grasses and sedges seem fairly resistant to effects of the launch cloud with an increase in dominance of some species as more sensitive species were eliminated (Schmalzer et al. 1985).

Repeated exposure to the Shuttle exhaust cloud caused community level changes which included: 1) reduction in species richness as a result of the elimination of sensitive species, 2) grasses, sedges, and weedy herbs replaced shrubs and small trees which could not survive repeated defoliation, 3) a decrease in total vegetative cover as strata and individual species were lost. The area of bare ground increased with the loss of cover, which in turn increased the potential for erosion (Schmalzer et al. 1985).

Just one exposure to the severe near-field effects of the exhaust cloud can result in considerable damage, particularly to sensitive dune and strand vegetation. Substantial recovery will occur within about six months without a repeat exposure. No structural changes were observed in dune and strand communities with only one exposure to the launch cloud (Schmalzer et al. 1985).

Far-field deposition occurs after the exhaust cloud rises and moves with the prevailing wind. Vegetation damage from far-field deposition consists of acid spotting and dry deposition of aluminum oxide on leaves. Deposition on the leaf surface may be mixed so that a spot of aluminum oxide will include a ring of acid burn around it. The amount of leaf surface involved is usually about 1-5%, occasionally ranging up to 10%. Although deposition persists on leaf surfaces for long periods of time, no mortality has been associated with this minor loss of photosynthetic tissue. Far-field environmental impacts are much less serious than near-field impacts since a smaller amount of deposition occurs over a relatively large area. No changes in community composition or structure have resulted from far-field launch effects (Schmalzer et al. 1985).

Occasionally, small brush fires are associated with Titan launches. Heat from the launch may singe vegetation within 20 m (66 ft) of the pad perimeter. Brush fires are contained and limited to ruderal vegetation within the launch complexes.

Past singeing has not permanently affected vegetation near the pads (USAF 1990).

Gaseous HCl and particulate Al_2O_3 from the Titan ground cloud should be sufficiently dilute so as not to have a direct impact on vegetation at LC40 and LC41. Wet deposition could damage or kill vegetation in high deposition zones (USAF 1990). In a worst case scenario, 22 ha (46 acres) of scrub vegetation adjacent to each pad might experience a partial loss of tree and shrub species and increase in grass and sedge species as observed near LC39 (USAF 1989, Schmalzer et al. 1985). Vegetation should recover during long intervals between deposition episodes since far-field deposition is not likely to occur over the same area for each launch (USAF 1990).

Structural damage is possible with high-intensity noise composed predominantly, of low frequencies. Damage to plants might occur at noise levels similar to those causing structural damage, although no such damage from rocket launches is known to have been observed (ESE 1986).

Wildlife

There is a potential for acute impacts to fish and wildlife from noise, blast debris, heat, and toxic chemicals (primarily HCl) in the vicinity of the launch pads. Chronic impacts may result from subtle alterations in habitat and the potential for bioaccumulation of pollutants that may be released into the environment. After ten years of Space Shuttle launches, the localized wildlife impacts appear minimal and manageable when considered at the landscape scale (Schmalzer et al. 1993).

Deposition from ground clouds could occur in wetlands and the Banana River. Aquatic resources including fish and insects could be adversely affected. The concentration of HCl in the ground cloud associated with the Titan IV/SRMU should be less than 0.25 ppm and should have significantly less effect than that associated with the Space Shuttle. The potential does exist for temporarily increased acidity to affect biota in adjacent wetlands and the Banana River (USAF 1990).

A fish kill occurs after most Shuttle launches as a direct result of surface water acidification, often exceeding 5 pH units. The fish kill occurs in direct relation to the spatial pattern of the near-field deposition footprint (Schmalzer et al. 1993). Several species of fish common to the lagoonal waters at KSC were placed in buckets near the launch pad and exposed to the Shuttle exhaust plume during launch (Hawkins et al. 1984). All experimental fish exposed to the exhaust plume had severely damaged gills. The damage consisted mainly of necrosis and sloughing of pavement cells of secondary lamellae. Other histological changes included swelling and clubbing of secondary lamellae, loss of microridges from the filament pavement cells, and mucus secretion. Changes

were probably caused by sudden exposure to acid conditions as recorded in buckets exposed to the exhaust plume. Recovery of fish from effects of the exhaust plume indicate that the fish kills caused by the exhaust occur abruptly, and fish do not continue to die afterwards. Examination of fishes from the lagoon area that had been the site of previous kills revealed no latent pathologic changes that might have been related to previous exposures to the exhaust plume. Lagoon fish might be more susceptible to subsequent exhaust plume exposure since a much higher percentage of them died in full exposures than did fish from a control site (Hawkins et al. 1984).

During a test of the Titan rocket motors, it was assumed that ground animals might come in contact with mist for short period of time. This was not expected to be significant since the pH would be near 3.0 and the exhaust cloud would remain over any single point a relatively short time (USAF 1986). Airborne species may suffer eye and respiratory tract membrane irritation. This is unlikely to occur since birds will be frightened away by the noise of the launch. Birds have been observed flying through downwind exhaust clouds formed from solid rocket propellant burning operations (Titan and other propellants) but avoid direct contact with the most concentrated portions of the plumes especially if large temperature differences exist between the plume and ambient air (USAF 1986).

The majority of birds flee the pad area in a fright response to the firing of Shuttle main engines which occurs 7 seconds prior to ignition of the SRBs. Occasionally some animals are caught in the exhaust blast and are killed or injured; examples include armadillos, marsh rabbits, Snowy Egret, Killdeer, and frogs in the impact zone. Alligators have also been found unharmed in the impact area. Injured animals tend to hide in burrows or dense vegetation. Therefore, the actual number of animals killed or injured is probably greater than observed (Schmalzer et al. 1993).

Effects of noise on wildlife might be expected to be similar to those on man; these would include hearing damage at sufficiently high noise levels, and various psychological effects. Dufour (1980) characterized effects of aircraft noise, which should be similar to those from rocket launches, into four general areas: hearing impairment, communication masking, nonauditory physiological effects, and behavioral modifications (Kull and Fischer 1986).

A literature survey by Kull and Fischer (1986) cited the following studies and observations of high noise level effects on various birds, domestic and wild. Broody Broad Breasted Bronze turkeys were subjected to high intensity jet noise (110-135 dB) to determine if it affected nesting. Another group was treated with progesterone. The birds treated with sound had significantly shorter nesting periods than birds treated with progesterone or the control group (Jeannoutot and Adams 1961). No measurable effects on hatchability or quality of chicks were observed when chicken eggs were exposed to 96 dB noise inside

incubators (Stadelman 1958). Eleven out of twelve broody hens exposed to 115 dB noise lost their broodiness. The hen that remained broody hatched only one of the twelve fertile eggs laid (Stadelman 1958). Great Egret, Snowy Egret, Tricolored Heron, Little Blue Heron, and Cattle Egret colonies and a control area were monitored in areas flown over by F-16 aircraft. Reproductive behavior of approximately 220 individual birds was not observed to be altered during 57 overflights of F-16's at 420 knots (216 m/s) and up to 100 dBA (Black et al. 1984). Researchers in Dade County, Florida studied effects of jet overflight in an area which held 12 active Florida Everglade Kite nests (Snyder et al. 1978). There were 30 to 40 kites using the area. A range of behaviors were observed including mating, feeding, nest-building, incubation, care of young, and general flight behavior. Researchers concluded there was no clear evidence that kites were adversely affected by jet overflights. The same species of kite, as well as several incidental bird species, were observed at the Barranquilla Airport, Columbia. Black-collared Hawks, Yellow-headed Caracaras, Greater Black Hawks, Limpkins, Common Egrets, Black-crowned Night Herons, and kites did not appear to be adversely affected by the presence of the airport, although aircraft did seem to frighten Common Egrets and Night Herons (Snyder et al. 1978). There was no distinction found between Herring Gull behavior underneath the flightpath of jets near Kennedy International Airport and behavior of a colony exposed to subsonic planes (Burger 1981). However, more gulls flew up from their nest and engaged in more fights during jet flyovers. Mean clutch size for the exposed colony decreased, but pairs nesting outside the colony, but still exposed to subsonic jet noise, did not exhibit clutch size decline. Lower clutch size was attributed to the frequent fights as a result of supersonic aircraft disturbances, rather than from noise of other aircraft.

"Realistic" industrial-type sound did not interfere with the health of rats (Borg 1979). Hearing loss for rats exposed to 85 dB noise was about 10-15 dB. At 105 dB, hearing loss was disproportionately greater, possibly indicating that the noise threshold for rats is approximately 80-85 dB (Kull and Fischer 1986). In one study, caged wild rats and mice were subjected to sounds of varying frequencies (100-25,000 Hz) and sound pressure levels (60-140 dB) (Sprock et al. 1967). Effects of the noise included decreased nesting near the sound source and death at very high intensities (USEPA 1971).

Increased personnel activity and elevated noise levels associated with launches will temporarily disturb wildlife in the immediate vicinity of the launch complex (USAF 1988). Noise exceeding 95 dBA from Titan IV launches could cause temporary hearing loss in sensitive wildlife near the pads (USAF 1990). The 95 dBA radius of impact for a Titan IV launch is estimated to be about 24 km (15 mi). Wildlife heavily dependent on sound information could be more susceptible to predation with short-term hearing loss. Scrub-Jays were observed not responding to alarm calls after the Titan IV launch in June 1989 (USAF 1990).

Cumulative effects of noise from ELV launches at CCAS might impact the survival of sensitive species, depending on the duration of hearing loss. If each launch impaired the hearing of sensitive animals residing within a given noise impact zone (e.g., launch noise exceeding 95 dBA), and noise impact zones of various launches overlapped in areas where sensitive wildlife resides, these animals could be affected the number of times per year there are launches (USAF 1990).

Summary

The Titan, Delta, and some Atlas vehicles utilize SRMs during launch. Combustion of these SRMs produces a ground cloud containing Al_2O_3 , HCl, CO, CO_2 , AlCl_3 , and H_2O . Exhaust constituents of primary concern environmentally are Al_2O_3 and HCl. The other combustion products are nontoxic, react to form nontoxic compounds, or are present in insignificant quantities.

Deluge and fire suppressant water is collected in percolation ponds and/or released to grade where it infiltrates through surficial soils to shallow groundwater. There is a potential for contamination of groundwater from deluge and washdown water; however, this potential is reduced by treatment before release. Deluge water does not drain directly to surface waters. Any HCl deposited in surface waters by the exhaust cloud will be neutralized by the buffering capacity of the water. Without significant decreases in pH, any Al_2O_3 deposited in surface waters will remain insoluble and nontoxic to the biota.

Some vegetation damage may occur from occasional brush fires and/or heat from the launch, and wet deposition of HCl and Al_2O_3 in the near-field areas. Some loss of tree and shrub species and an increase of grass and sedge species may occur. Far-field vegetation should recover between launches since far-field deposition will not occur in the same area after each launch.

There is potential for temporarily increased acidity to affect aquatic biota in surface waters and wetlands adjacent to the launch complexes. Most birds are frightened away from the pad area by launch noise and would likely avoid concentrated portions of the exhaust plumes. There should be no significant impact on terrestrial wildlife from the exhaust cloud since it remains in any one area for a very short time. Elevated noise levels during launch will disturb animals in the immediate vicinity of the launch complexes. Temporary hearing loss may occur in wildlife near the pads. Degree of impact will vary based on launch vehicle, pad configuration, distance, and sensitivity of animals.

Overall, environmental impacts from the launch of ELVs, as indicated by previous work, appear to be similar to those occurring after a Shuttle launch, but on a much smaller scale.

Methods

We observed effects of launches of Delta, Atlas, and Titan rockets beginning in May 1995. After launches, we mapped areas of impacts on mylar overlaid on 1995 aerial color infrared photographic prints of the areas near the launch complexes. For some Titan launches, effects extended beyond the area covered by the photograph, and a topographic quadrangle map (U.S. Geological Survey, 1:24,000) was used for mapping in these instances.

For Delta and Titan launches, we ran the REED Model to predict expected deposition. For Atlas launches, we examined rawinsonde data to determine wind direction and speed that might influence launch impacts. Here, we summarize observed effects of launches through December 1997.

Effects were classified as heat scorched or burned vegetation, acid deposition, or particulate deposition. For Space Shuttle launches, impacts fall into one of two categories: near-field deposition or far-field deposition. Near-field deposition is that occurring from the ground cloud sweeping turbulently across the ground, vegetation, and lagoon waters (Schmalzer et al. 1993). Far-field deposition occurs after the exhaust cloud rises and moves with the prevailing wind. Near-field and far-field deposition impacts were mapped based on visible effects on surrounding vegetation. Spots of acid or dry deposition on plant leaves indicated that the area received deposition. Variations in impact areas can occur with differing meteorological conditions at launch (Schmalzer et al. 1993). However, observations of Delta, Atlas, and Titan launches have not found impacts similar to near-field deposition of Shuttle launches, with the exception of one Delta launch discussed later. Instead impacts have fallen into three classes: heat scorching, acid deposition, and particulate deposition.

The Delta, Atlas, and Titan launch complexes are located within 1 km of coastal dune and strand vegetation. Plant species sensitive to acid deposition occurring in these areas include: beggar's ticks (*Bidens pilosa*), beach sunflower (*Heterotheca subaxillaris*), camphorweed (*Helianthus debilis*), marsh elder (*Iva imbricata*), horse mint (*Monarda punctata*), sea ox-eye (*Borrchia frutescens*), and groundsel tree (*Baccharis halimifolia*). These plants have all shown foliar injury when exposed to HCl, primarily in areas closest to the Shuttle launch complexes (Schmalzer et al. 1985, 1993). During post-launch surveys for Delta, Atlas, and Titan launches, these species were examined for acid damage.

Field crews mapped individual launch impacts on mylar sheets, overlaying 1995 color infrared aerial photographs. A set of master ground control points (GCPs), located on the aerial photographs were transferred onto each mylar overlay. The coordinates for each GCP were collected in the field previously by using a submeter Differential Global Positioning System (DGPS) (Trimble Navigation Limited 1994). Geographic Information System (GIS) coverages were created

by digitizing the mylar sheets using ARC/INFO 7.1.1 (ESRI 1991). The GCPs were used to register the coverages. Labels were added according to impact type: 1-scorch, 2-acid, or 3-particulate. Coverages were edited for errors, and quality checked.

In order to assess the cumulative launch effects from several launches, the individual coverages were combined using an overlay process. In ARC, the coverages were "unioned". In order to automate the overlay process, a computer program, ccasunion.aml, was written using AML (Advanced Macro Language). The AML, ccasunion.aml, was modeled after a similar AML, bdunion.aml, written by Brean Duncan, and used to assess cumulative launch effects of the Space Shuttle. The final coverage contained polygons labeled according to type of launch effect, scorch, acid, or particulate, and the number of times the area was impacted. Arcview 3.0 (ESRI 1994) was used to present the results from the overlay process.

Florida Scrub-Jays were color-banded for identification within several months after the beginning of the study (Woolfenden and Fitzpatrick 1984). Pre-launch surveys of the study areas for Scrub-Jays were conducted before each launch (usually twenty-four hours) when permitted. Post-launch surveys were conducted during the nearest daylight hours after launches. Field investigations included a census of families and observations regarding individual's behavior.

Results

Delta

Fifteen Delta II launches occurred between August 1995 and December 1997 from LC17, eight from LC17A and seven from LC17B (Table 3). Fourteen of these launches were normal, but one (January 17, 1997) ended in an explosion. We present observed effects of the normal launches first. None of the normal Delta launches caused vegetation scorching outside the pad perimeter fence. Most Delta launches (13 of 14) produced some acid deposition, and all produced particulate deposition (Table 3). All Delta II launches employ solid rocket boosters that produce HCl as an exhaust product. Acid deposition observed after these launches consisted of acid spots on leaves of sensitive species (e.g., beach sunflower, beggar's ticks); this deposition was similar to the acid, far-field deposition of Space Shuttle launches (Schmalzer et al. 1986). Particulate deposition consisted of brown to gray powdery material similar to the particulate, far-field deposition of Space Shuttle launches (Schmalzer et al. 1986). For some launches, sand grains were mixed with the powdery deposition. Neither acid or particulate deposition was of such intensity as to cause long-term vegetation damage.

We mapped effects for 14 of 15 launches; restricted access after the Delta explosion of January 17, 1997 prevented mapping. Particulate deposition occurred at least once in an area of 458,079 m² (45.8 ha) around LC17 and extended up to 902 m from the pad perimeter fence (Figure 5, 6). Acid deposition occurred at least once in an area of 70,807 m² (7.08 ha) around LC17 and extended up to 648 m from the pad perimeter fence (Figure 5, 6). Only small areas near the launch complex received repeated deposition impacts (Figure 5, 6).

We observed one case of animal mortality after the Delta launch of January 14, 1996; this was a Chuck-will's-widow (*Caprimulgus carolinensis*). Whether this bird was killed by the launch or other factors could not be determined. Ten to fifteen Florida Scrub-Jay territories have been present within a 1 km radius of LC17 during this study. Scrub-Jays have been observed after all 14 normal launches. Behavior of Scrub-Jays after launches has been normal. Scrub-Jays were colorbanded during this project. Particulate deposition from some Delta launches has affected Scrub-Jay territories but caused no discernable vegetation damage.

The Delta II rocket launched January 17, 1997 exploded 13 seconds after liftoff at an altitude of about 484 m. Burning debris damaged structures at LC17 and ignited fires in the vegetation of the surrounding area. Access to the area was

Table 3. Environmental conditions and effects of observed Delta launches.

Date	Launch Vehicle	Launch Pad	Launch Time	Wind Direction	Wind Speed (m/s)	Relative Humidity (%)	Vegetation Scorching	Acid Deposition	Particulate Deposition
August 5, 1995	Delta II	LC17B	711	SSE	0.1	N/A ¹	No	Yes	Yes
December 30, 1995	Delta II	LC17A	847	NNE	1.5	N/A ¹	No	Yes	Yes
January 14, 1996	Delta II	LC17B	610	WNW	2.1	92	No	Yes	Yes
February 17, 1996	Delta II	LC17B	1502	WNW	3.1	26	No	Yes	Yes
March 27, 1996	Delta II	LC17B	1921	SE	2.6	88	No	No	Yes
May 23, 1996	Delta II	LC17B	2110	E	2.6	88	No	Yes	Yes
July 15, 1996	Delta II	LC17B	2050	SE	1.5	89	No	Yes	Yes
September 12, 1996	Delta II	LC17A	434	W	1.5-5.5	95	No	Yes	Yes
November 7, 1996	Delta II	LC17A	1201	SE	5.1	75	No	Yes	Yes
December 4, 1996	Delta II	LC17B	158	N-NNW	2.1-4.9	93	No	Yes	Yes
January 17, 1997	Delta II	LC17A	1128	N	6.7-11.1	86	Yes	N/A ²	N/A ²
May 20, 1997	Delta II	LC17A	1839	SE	3.6	71	No	Yes	Yes
July 22, 1997	Delta II	LC17A	2343	SE	3.1	85	No	Yes	Yes
August 25, 1997	Delta II	LC17A	1039	NE	2.1	66	No	Yes	Yes
November 5, 1997	Delta II	LC17A	1853	NE	3.1	75	No	Minor	Yes

¹ N/A: Data not available

² N/A: Data not available, explosion prevented access

Figure 5.
Delta Launch Effects

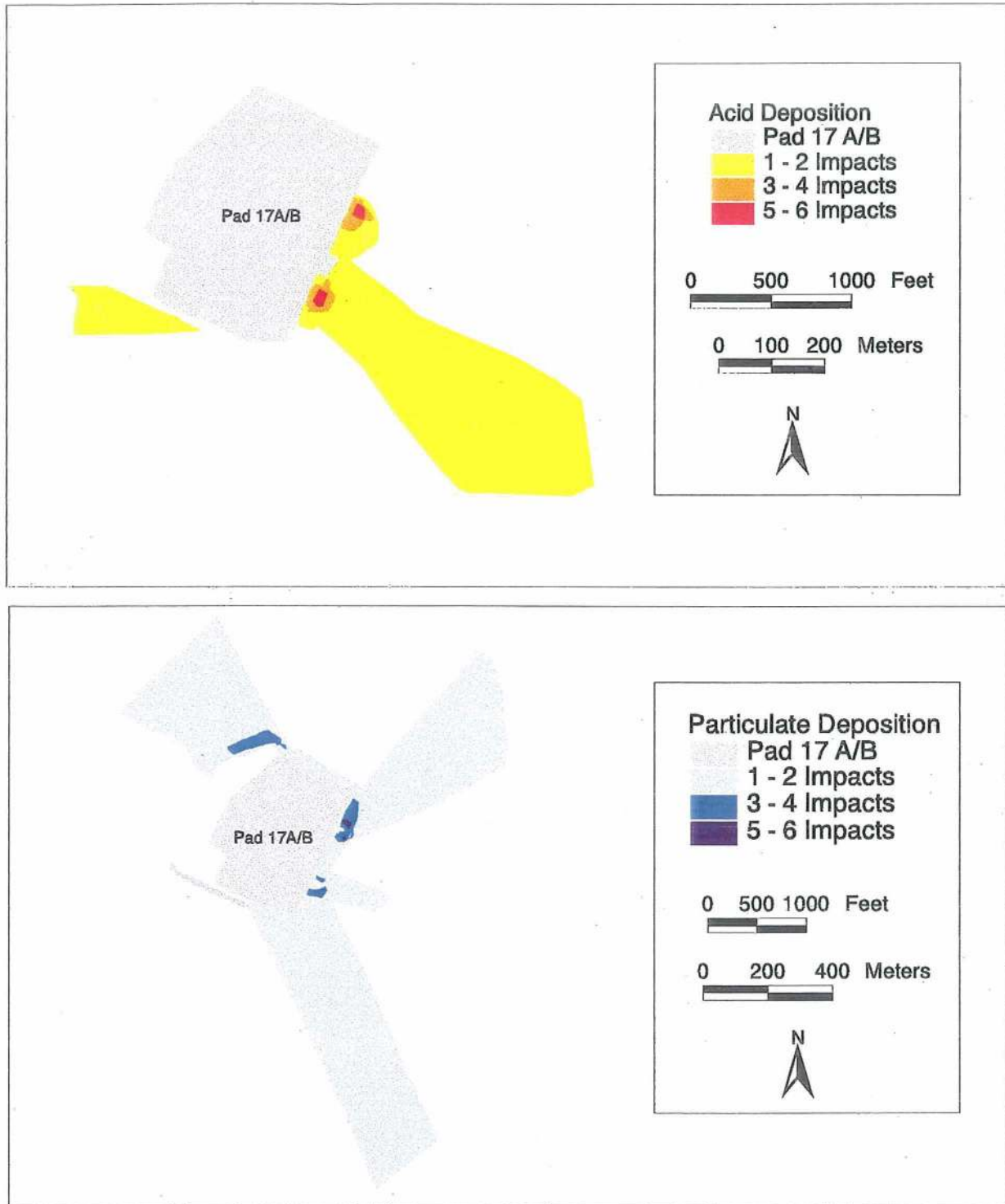
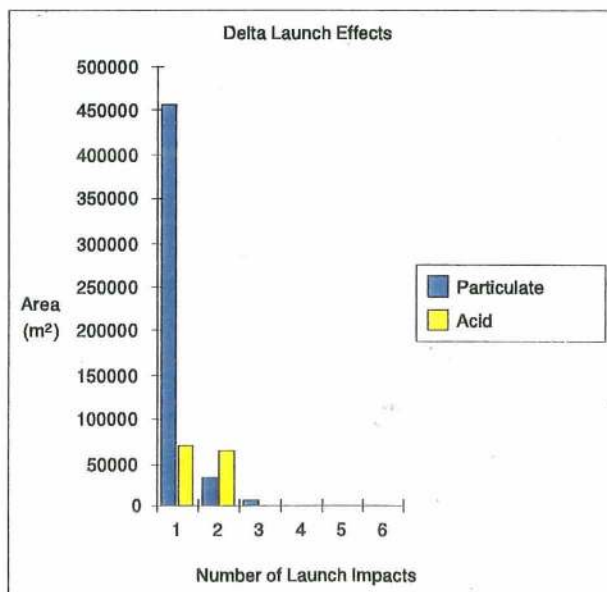
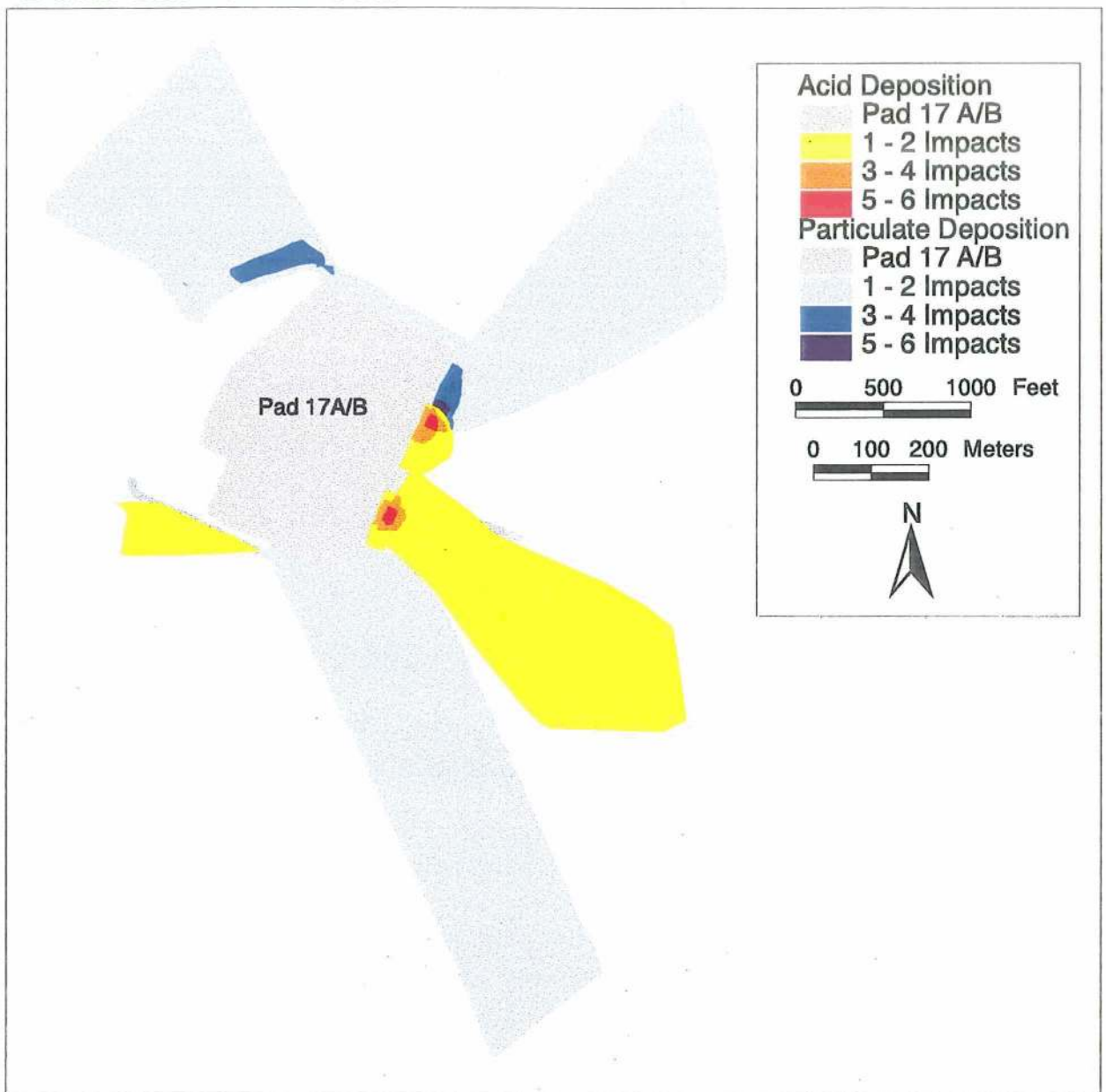


Figure 5. Delta rocket launch deposition for fourteen launches from August 7, 1995 through November 5, 1997. This figure shows separately the cumulative distribution for acid and particulate deposition. Deposition types are defined as the following: acid refers to the area impacted by acid deposition; particulate refers to the area impacted by small particulate deposition. Patterns were determined by overlaying maps of individual launches using a geographical information system.

Figure 6.
Delta Launch Effects



Impacts	Acid (m²)	Particulate (m²)
1	70807	458082
2	63302	33858
3	1994	9464
4	1335	2596
5	948	487
6	101	101

Figure 6. Delta rocket launch deposition for fourteen launches from August 7, 1995 through November 5, 1997. This figure shows the cumulative distribution for acid and particulate deposition together. The total area impacted is shown spatially in the figure above, and quantitatively in the table above. Patterns were determined by overlaying maps of individual launches using a geographical information system.

restricted after the explosion for safety reasons. The first survey for Scrub-Jays after the explosion was conducted February 13-14, 1997 but only from Pier Road. At the time of the Delta explosion, 13 Scrub-Jay families were resident within a 1 km radius of LC17. Some members of all 13 groups were observed in the first post-launch survey, and their behavior was normal. Two breeders, a male and a female from separate groups, were observed prior to the launch (January 10-11, 1997) but not after. These disappearances were probably not a result of the launch and explosion, but due to the time that elapsed between the surveys no definite conclusion is possible. At least a portion of the territory of each group was affected by the explosion. These effects included burned vegetation, littered debris, and depressions formed by debris impacts.

The coastal scrub and coastal strand vegetation surrounding LC17 burned naturally before development of CCAS. Shrubs such as saw palmetto (*Serenoa repens*), live oak (*Quercus virginiana*), red bay (*Persea borbonia*), nakedwood (*Myrcianthes fragrans*), and tough buckthorn (*Bumelia tenax*) have sprouted in the burned patches of vegetation.

The Delta II launch of January 9, 1998 produced effects that differed from all previous Delta launches. The pad perimeter fence in line with the flame trench was knocked down by the launch. Outside the perimeter fence, vegetation was impacted in a plume zone. Two large red bay trees were uprooted. Limbs were broken on large red bays and live oaks. Heavy acid deposition, similar to that found in the near-field plume zone of Space Shuttle launches (Schmalzer et al. 1985), also occurred in this area and killed leaves on live oak, red bay, saw palmetto, wax myrtle (*Myrica cerifera*), and nakedwood. Some heat scorching may have been involved. Lighter acid deposition extended east of the launch complex, crossing the coastal strand/coastal dunes vegetation east of Pier Road but stopping short of the beach.

The flame trench of LC17B had been modified recently, and this was the first launch using the modified flame trench. It appeared to channel the launch plume toward the east to a greater extent than happened before. These modifications were made in preparation for launches of the new Delta III rocket. More deluge water was also used on this launch.

Atlas

Twenty-two Atlas launches occurred between May 1995 and December 1997 from LC36, 12 from LC36B and 10 from LC36A. These included 3 Atlas I, 12 Atlas IIA, and 7 Atlas IIAS rockets (Table 4). All Atlas launches produced vegetation scorching in an area near the pad in line with the flame trench. At LC36A, species with leaves scorched by launch exhaust have included live oak, buckthorn, saw palmetto, nakedwood, wax myrtle, Florida privet (*Foriestiera segregata*), rapanea (*Rapanea punctata*), varnish leaf (*Dodonaea viscosa*),

Table 4. Environmental conditions and effects of observed Atlas launches.

Date	Launch Vehicle	Launch Pad	Launch Time	Wind Direction	Wind Speed (m/s)	Relative Humidity (%)	Vegetation Scorching	Acid Deposition	Particulate Deposition
May 23, 1995	Atlas I	LC36B	0146	NW-N	2.1-3.1	70	Yes	No	No
May 31, 1995	Atlas IIA	LC36A	1127	SW-W	4.1-4.6	63	Yes	No	No
July 31, 1995	Atlas IIA	LC36A	1934	SSE	5.1-7.7	N/A	Yes	No	No
August 28, 1995	Atlas IIAS	LC36B	2053	W	1.0	81	Yes	No	Yes
October 22, 1995	Atlas IIA	LC36A	0400	NE	3.1-6.6	N/A	Yes	No	No
December 2, 1995	Atlas IIAS	LC36B	0308	N-NE	2.0-4.5	91	Yes	No	Yes
December 14, 1995	Atlas IIA	LC36A	1923	N/A ¹	N/A ¹	N/A ¹	Yes	No	No
January 31, 1996	Atlas IIAS	LC36B	2015	W	2.0	80	Yes	No	Yes
April 3, 1996	Atlas IIA	LC36A	1801	NE	3.1	58	Yes	No	No
April 30, 1996	Atlas I	LC36B	0031	N/A ¹	N/A ¹	N/A ¹	Yes	No	No
July 25, 1996	Atlas IIA	LC36A	0842	SW	1.5	91	Yes	No	No
September 8, 1996	Atlas IIA	LC36B	1749	S-SE	3.6	69	Yes	No	No
November 21, 1996	Atlas IIA	LC36B	1544	W-NW	1.5	65	Yes	No	No
December 17, 1996	Atlas IIA	LC36A	2057	SE	3.6	84	Yes	No	No
February 16, 1997	Atlas IIAS	LC36B	2042	NW	3.0	91	Yes	No	Yes
March 8, 1997	Atlas IIA	LC36A	0101	E	5.1	61	Yes	No	No
April 25, 1997	Atlas I	LC36B	0149	SE	2.1	83	Yes	No	No
July 27, 1997	Atlas IIAS	LC36B	2115	SE	2.1	90	Yes	No	No
September 4, 1997	Atlas IIAS	LC36A	803	NW	2.1	96	Yes	No	Yes

Table 4. (Continued)

Date	Launch Vehicle	Launch Pad	Launch Time	Wind Direction	Wind Speed (m/s)	Relative Humidity (%)	Vegetation Scorching	Acid Deposition	Particulate Deposition
October 5, 1997	Atlas IIAS	LC36B	2101	E	7.2	67	Yes	No	Yes
October 24, 1997	Atlas IIA	LC36A	2046	SE	5.1	76	Yes	No	No
December 8, 1997	Atlas IIA	LC36B	1852	SE	2.0	78	Yes	No	No

N/A¹: data not available

Hercules club (*Zanthoxylum clava-herculis*), tallowwood (*Ximenia americana*), beauty berry (*Callicarpa americana*), and Brazilian pepper (*Schinus terebinthifolius*). At LC36B, species affected included willow (*Salix caroliniana*), sawgrass (*Cladium jamaicense*), arrowhead (*Sagittaria lancifolia*), castor bean (*Ricinus communis*), and various herbs. Some launches ignited small grass fires, but none of these spread to surrounding vegetation. No Atlas launches produced acid deposition (Table 4). Atlas I and Atlas IIA rockets do not employ solid rocket boosters; therefore, no acid deposition from HCl is expected. The Atlas IIAS employs solid rocket boosters, but no acid deposition has occurred. Atlas IIAS launches have produced particulate deposition not observed from Atlas I or Atlas IIA. These particulates appear to be primarily sand grains, either quartz grains or shell fragments, consistent with the composition of coastal sands near LC36. None of the particulate deposition was similar to the powdery aluminum oxide material formed by Space Shuttle launches. After some Atlas IIAS launches, we have seen chunks of fused slag material near the pad perimeter fence. Similar material has been seen after Titan launches. Particulate deposition, when it occurred, caused no apparent damage to vegetation.

We mapped effects for 20 of 22 launches; the two launches in May 1995 were not mapped, because the aerial photography of the LC36 region was not yet available. Particulate deposition occurred at least once in an area of 171,629 m² (17.1 ha) around LC36; particulate deposition has extended up to 542 m from LC36A and 241 m from LC36B (Figure 7, 8). Vegetation scorching occurred at least once in an area of 6,247 m² (0.64 ha) around LC36; scorching has extended up to 139 m from the LC36B and 64 m from LC36A (Figure 7, 8). Repeated vegetation scorching was restricted to small areas near the pads.

No animal mortality has been observed after any Atlas launch. Three to four Florida Scrub-Jay territories have been present within a 1 km radius of LC36 during this study. Scrub-Jays have been observed after 20 of 22 launches. High temperatures or winds limited detection after the other two launches. Behavior of Scrub-Jays after launches has been normal. These Scrub-Jays had not been studied or colorbanded previous to this project. Some colorbanded Scrub-Jays have been observed after launches since December 1995 (16 of 22 launches). Vegetation scorching from Atlas launches has not extended into any Scrub-Jay territories. Particulate deposition from one Atlas launch (Atlas IIAS, September 4, 1997) affected a portion of one territory but caused no discernable vegetation damage.

Titan

Eight Titan launches occurred between May 1995 and November 1997, five from LC40 and three from LC41 (Table 5). Of these, two were Titan IVB launches, both from LC40. Vegetation scorching and particulate deposition have occurred

Figure 7.
Atlas Launch Effects

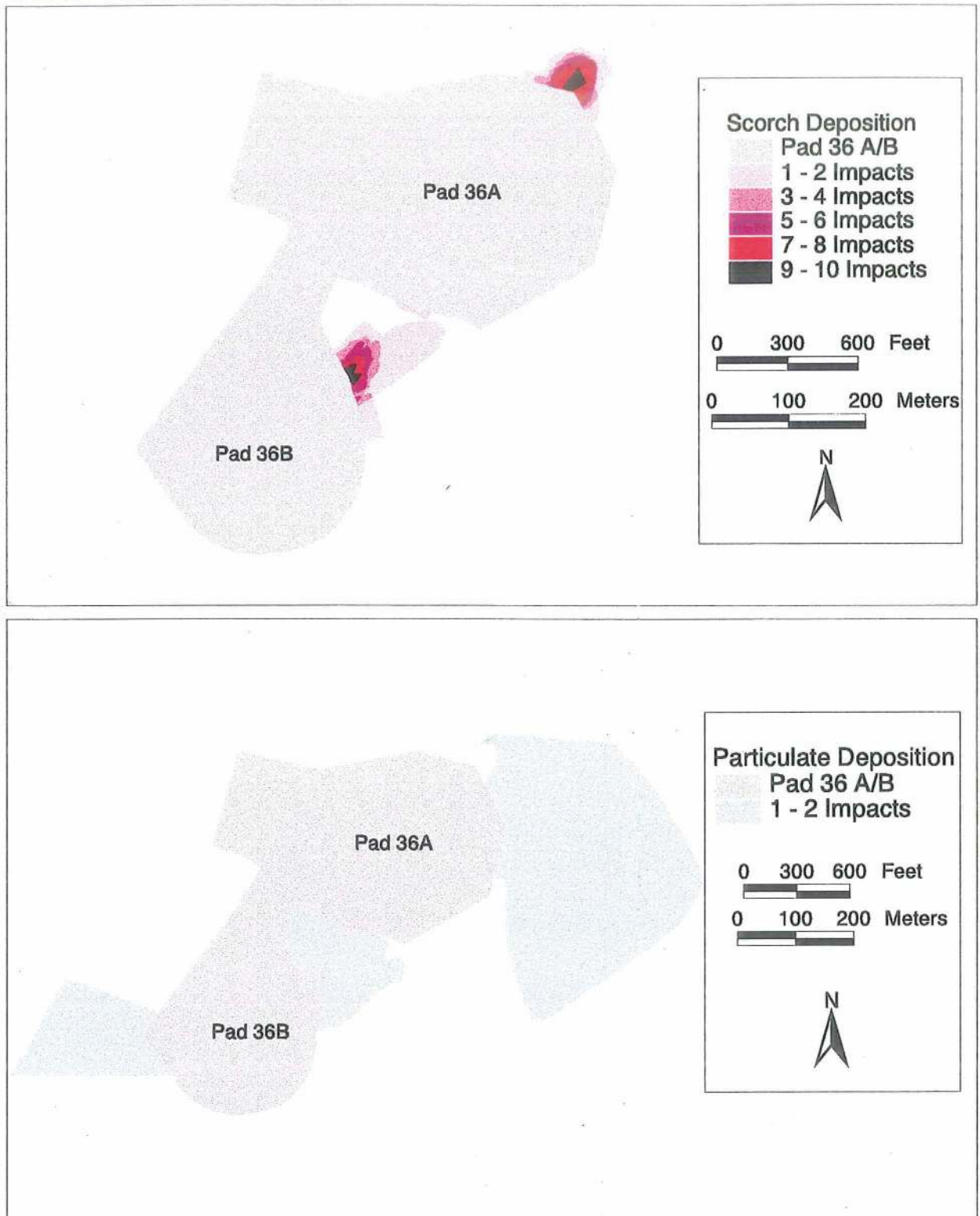
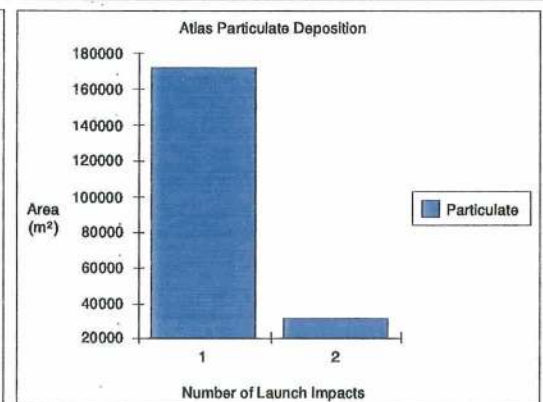
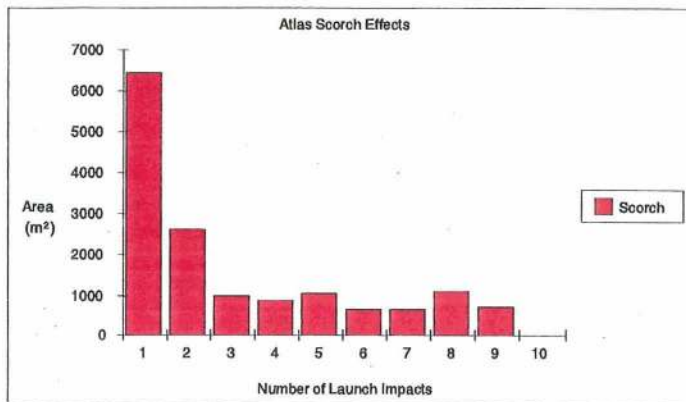
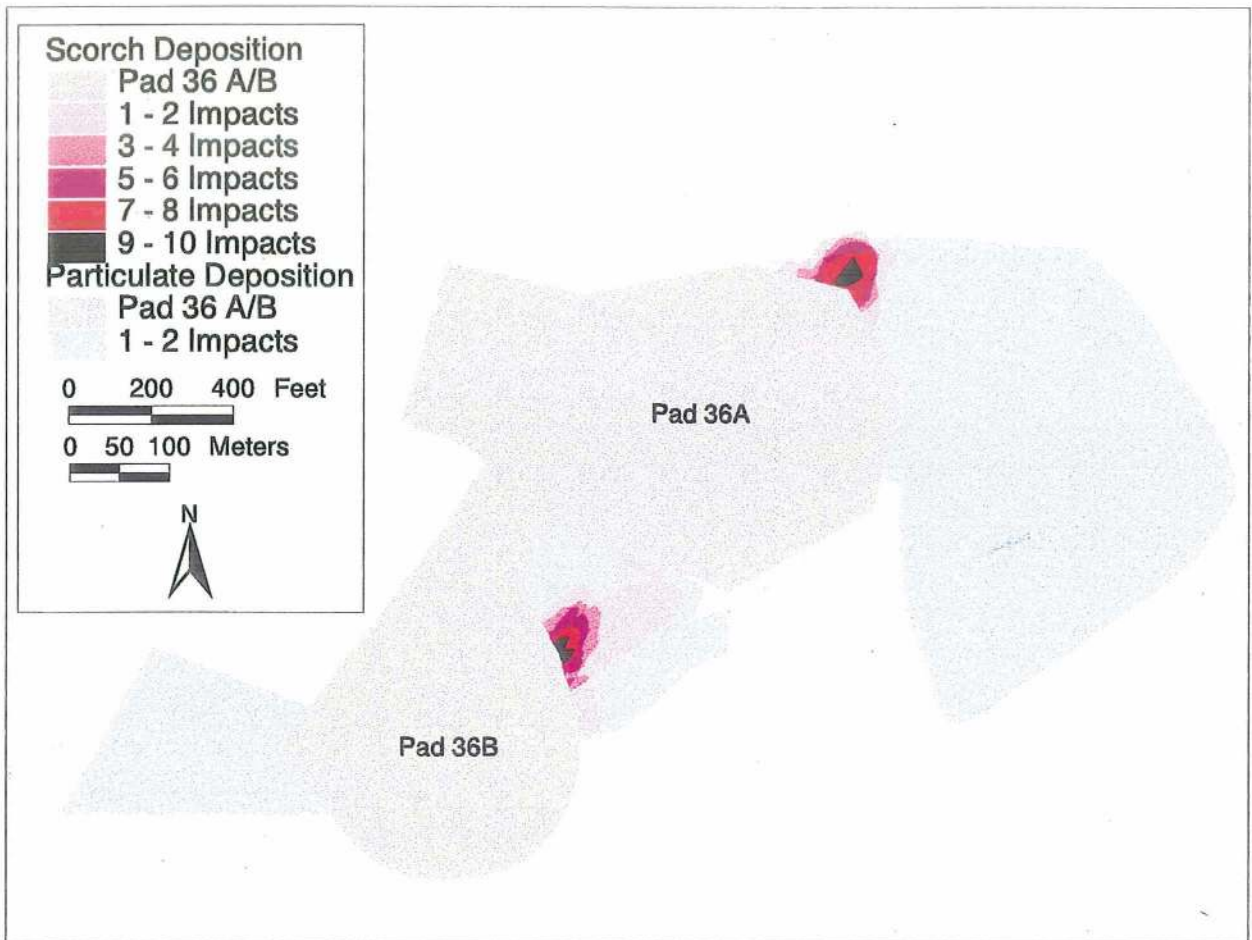


Figure 7. Atlas rocket launch effects for twenty launches from July 31, 1995 through December 8, 1997. This figure shows separately the cumulative distribution of vegetation scorching and particulate deposition. Deposition types are defined as the following: scorch refers to area impacted by flames; particulate refers to area impacted by small particulate deposition. Patterns were determined by overlaying maps of individual launches using a geographic information system.

Figure 8.
Atlas Launch Effects



Impacts	Scorch (m ²)	Particulate (m ²)
1	6428	171918
2	2635	3214
3	996	
4	907	
5	1071	
6	679	
7	668	
8	1103	
9	729	
10	38	

Figure 8. Atlas rocket launch effects for twenty launches from July 31, 1995 through December 8, 1997. This figure shows the cumulative distribution of vegetation scorching and particulate deposition together. Patterns were determined by overlaying maps of individual launches using a geographical information system.

Table 5. Environmental conditions and effects of observed Titan launches.

Date	Launch Vehicle	Launch Pad	Launch Time	Wind Direction	Wind Speed (m/s)	Relative Humidity (%)	Vegetation Scorching	Acid Deposition	Particulate Deposition
May 14, 1995	Titan IV	LC40	945	W	3-4	72	Yes	Yes	Yes
July 10, 1995	Titan IV	LC41	838	SW-W	4-7	87	Yes	Yes	Yes
November 6, 1995	Titan IV	LC40	0015	NE-E	1.5-3.6	86	Yes	Minor	Yes
April 24, 1996	Titan IV	LC41	1937	N	N/A ¹	N/A ¹	Yes	Yes	Yes
July 2, 1996	Titan IV	LC40	2031	S-SW	3.1-6.7	87	Yes	Yes	Yes
February 23, 1997	Titan IVB	LC40	1520	N-NE	5.1-10.3	75	Yes	N/D ²	Yes
October 15, 1997	Titan IVB	LC40	0443	NE-ENE	3.1-8.8	70	Yes	Yes	Yes
November 10, 1997	Titan IVA	LC41	2105	W-NW	4.1-10.3	72	Yes	No	Yes

¹ N/A : not available, rawinsonde data not received

² N/D: not determined, Shuttle launch STS-82 (Feb. 11, 1997) produced acid deposition in area

from all Titan launches; we detected acid deposition from every launch except the Titan IVB launch of February 23, 1997 where extensive deposition from a Space Shuttle launch 12 days before the Titan launch prevented determination of acid deposition from the Titan launch (Table 5). All Titan launches employ solid rocket boosters that produce HCl as an exhaust product. Acid deposition observed after these launches consisted of acid spots on leaves of sensitive species (e.g., beggar's ticks); this deposition was similar to the acid, far-field deposition of Space Shuttle launches (Schmalzer et al. 1986). After two launches (Titan IV, July 2, 1996; Titan IVB/Cassini, October 15, 1997), we found acid deposition distant from the launch complex but not near it. This has not been observed for Shuttle launches.

We have observed two types of particulate deposition. Some particulate deposition consisted of brown to gray powdery material similar to the particulate, far-field deposition of Space Shuttle launches (Schmalzer et al. 1986). The second type of dry particulate deposition differed from far-field Shuttle deposition; it consisted of sand grains entrained in the cloud and other particulate matter some of which appeared fused by the heat of the launch. We have observed larger pieces of fused slag material near the pad perimeter fences after launches.

We mapped effects for all eight Titan launches. Particulate deposition occurred at least once in an area of 2,365.7 ha; particulate deposition extended up to 14,615 m (14.6 km) from LC40 and up to 9,221 m (9.2 km) from the LC41 (Figure 9, 10). Acid deposition occurred at least once in an area of 17.22 ha. Continuous acid deposition extended up to 703 m from LC40 and up to 301 m from LC41 (Figure 9, 10). Isolated acid deposition occurred at a distance of 9.3 km from the launch site during the Titan/Cassini launch; this acid deposition was not mapped separately from the particulate deposition mixed with it. Vegetation scorching occurred in an area of 0.95 ha; scorching extended up to 138 m from LC40 and up to 141 m from LC41 (Figure 9, 10).

No animal mortality has been observed after any Titan launch. Twenty-one to twenty-five Florida Scrub-Jay territories have been present within an area from 1 km south of LC40 to 1 km north of LC41 during this study. Scrub-Jays have been observed after all eight launches, and the behavior of Scrub-Jays after launches has been normal. Scrub-Jays in the LC40/LC41 area have been studied since 1990 (Larson et al. 1993). Vegetation scorching from three Titan launches extended into Scrub-Jay territories. Particulate or acid deposition from six Titan launches affected Scrub-Jay territories but caused no discernible vegetation damage.

Figure 9.
Titan Launch Effects

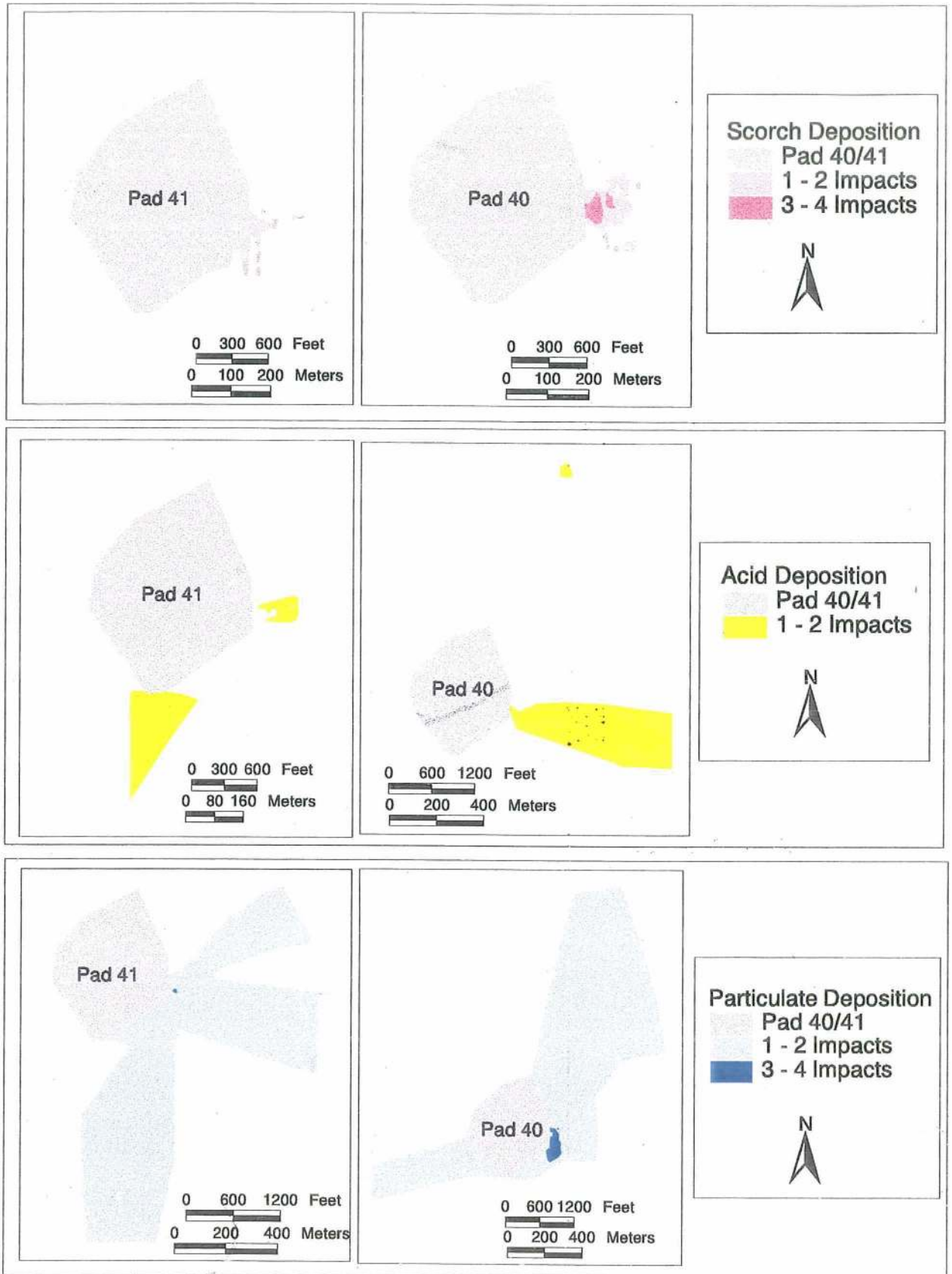
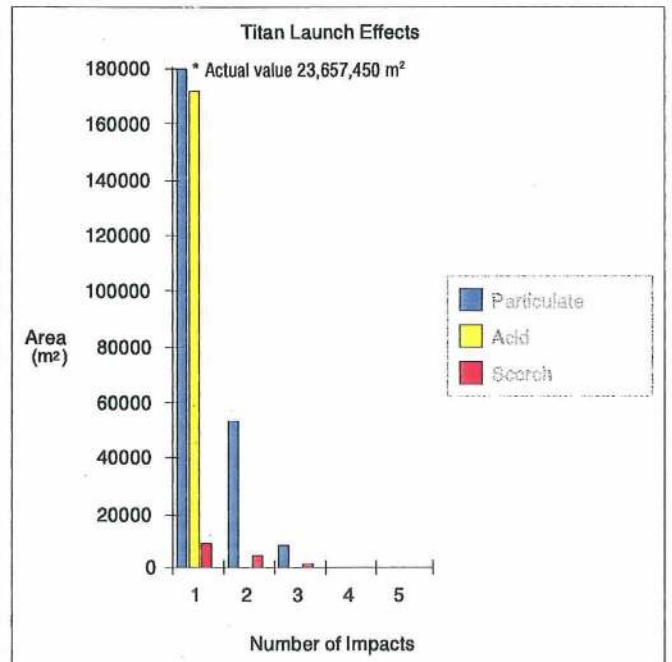
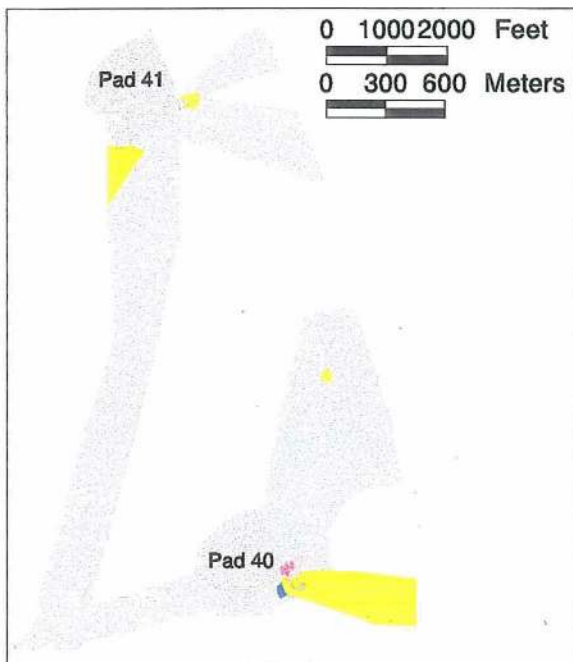
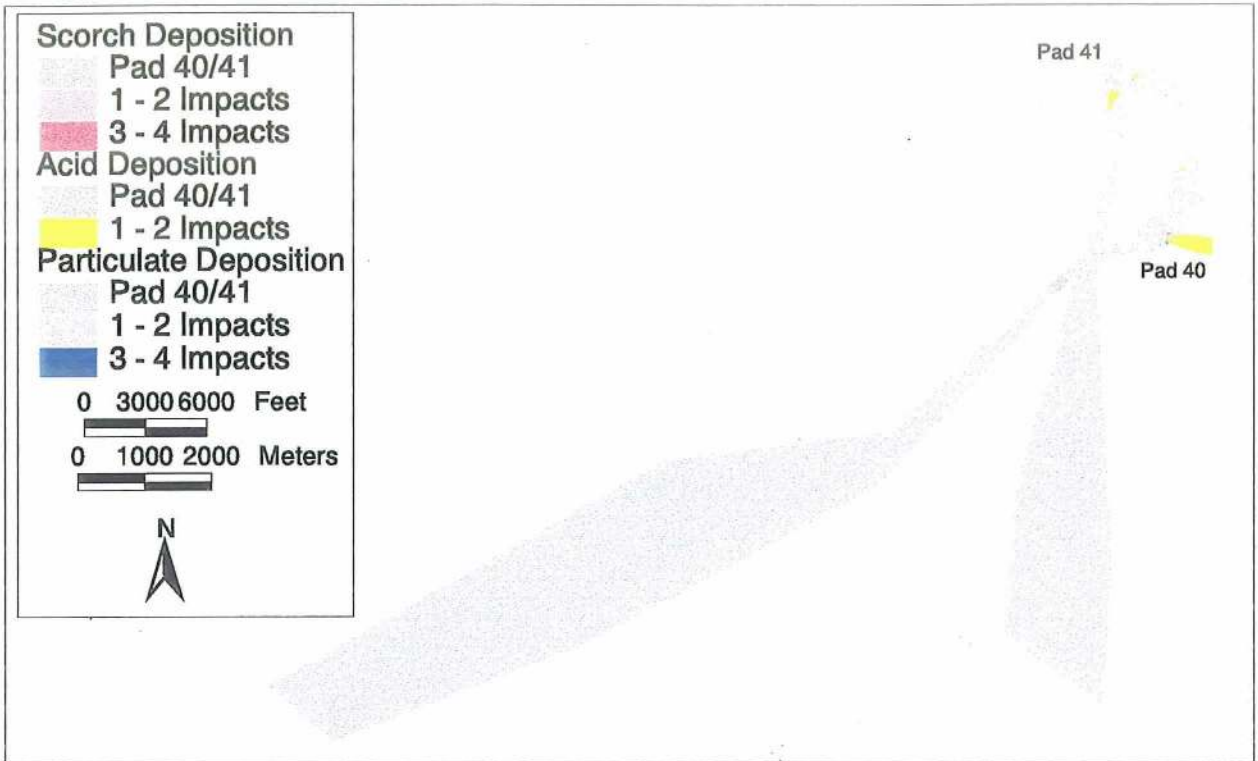


Figure 9. Titan launch effects for eight launches from May 14, 1995 through November 11, 1997. This figure shows the cumulative distribution of vegetation scorching, acid deposition, and particulate deposition for each pad, 40 and 41. Patterns were determined by overlaying maps of individual launches using a geographic information system.

Figure 10.
Titan Launch Effects



Impacts	Scorch (m ²)	Acid (m ²)	Particulate (m ²)
1	9529	172214	23657450
2	4987	0	53521
3	2311	0	8926
4	266	0	1007
5	0	0	0

Figure 10. Titan launch effects for eight launches from May 14, 1995 through November 11, 1997. This figure shows the cumulative distribution of vegetation scorching, acid deposition, and particulate deposition together. Patterns were determined by overlaying maps of individual launches using a geographic information system.

Discussion

Delta

We expected Delta II rocket launches to produce some acid and particulate deposition similar to Space Shuttle launches but much less in intensity and spatial scale. Observations of 14 normal launches confirmed this expectation. Acid deposition occurred at most launches and particulate deposition at all launches. Areas affected by acid and particulate deposition were small and relatively close to the launch complex. The spatial scale was much less than that of the Space Shuttle (Table 6). Additional launches would increase the total area affected by Delta launches, but the relative scale would probably not change greatly.

Table 6. Comparison of areas affected by different launch systems.

Launch System	Number of Launches	Area of Scorch (ha)	Area of Acid Plume (ha)	Area of Acid Deposition (ha)	Area of Particulate Deposition (ha)
Delta	14	0	0	7.1	45.8
Atlas	20	0.64	0	0	17.1
Titan	8	0.95	0	17.2	2365.7
Space Shuttle ¹	49	0	139.9	19397 ²	19397 ²

¹ Duncan and Schmalzer (1994)

² Far-field deposition, acid and particulate not separated

However, the Delta launch of January 9, 1998 showed that this rocket can produce more intense local effects. With changes to the flame trench configuration and use of more deluge water, substantially greater blast and acid deposition impacts occurred. Repeated launches with this system may produce a zone devoid of tree and shrub vegetation, as has occurred from the Space Shuttle (Schmalzer et al. 1985, 1993). The spatial scale should remain less than that of the Space Shuttle.

The explosion of the Delta rocket caused significant damage to facilities and structures. However, its impacts to the natural environment were limited. Vegetation burning occurred, but fire is a natural process in coastal scrub and strand vegetation. Surveys could not be conducted immediately after the event due to safety considerations, and this limited any assessment of direct animal mortality. Scrub-Jay territories around the launch complex remained occupied. An extensive cleanup of the debris left by the explosion was conducted, reducing any long-term threat posed by this material.

Atlas

We expected Atlas I and IIA launches to produce flame or heat impacts; Atlas IIAS launches might also produce acid and particulate deposition due to their use of solid rocket boosters. All Atlas launches have caused heat scorching of vegetation or small fires. However, none of the seven Atlas IIAS launches observed produced acid deposition. Although particulate deposition occurred from Atlas IIAS launches, it differed from that of the Space Shuttle or Delta launches. Particulate deposition from Atlas IIAS launches was primarily sand grains entrained by the launch cloud.

Areas near the flame trenches of LC36A and LC36B that are repeatedly defoliated by heat scorching have lost shrub vegetation, and this area appears to increase gradually over time with frequent launches. The spatial scale of Atlas launch effects remains small (Table 6).

Titan

Titan launches produced heat scorching, acid deposition, and particulate deposition. The spatial scale of particulate deposition exceeded that of the other expendable launch systems but was less than that of the Space Shuttle (Table 6). Titan launches are less frequent than the other launch systems, and cumulative effects from repeated heat or acid defoliation have not been observed.

Titan launches produce acid deposition distant from the launch pad under some meteorological conditions. The Titan IVB/Cassini launch of October 15, 1997 did not cause acid deposition near the launch complex, but acid deposition occurred at the KSC Industrial Area, 9.3 km from LC40. This deposition appeared to result from the interaction of the launch cloud with a localized shower or cloud containing sufficient moisture to cause HCl deposition. Conditions required to produce acid deposition from relatively dry launch clouds may be uncommon. However, such events could occur and not be detected if the acid deposition was very light or occurred in inaccessible areas.

Summary

Expendable rockets have been launched from Cape Canaveral Air Station since the 1950s. However, monitoring of their direct effects on the local environment has been limited. In this project we:

1. Reviewed previous reports, environmental assessments, and environmental impact statements for Delta, Atlas, and Titan vehicles and pad areas to clarify the magnitude of potential impacts;
2. Summarized observed effects of 15 Delta, 22 Atlas, and 8 Titan launches between May 1995 and December 1997; and
3. Developed a spatial database of the distribution of effects from individual launches and cumulative effects of launches.

The review of previous studies indicated that impacts from these launches can occur from the launch exhaust heat, deposition of exhaust products from the solid rocket motors, and noise. The principal effluents from solid rocket motors are HCl, Al_2O_3 , H_2O , H_2 , CO, and CO_2 . The exhaust plume interacts with the launch complex structure and water deluge system to generate a launch cloud. Fall out or rain out of material from this cloud can produce localized effects from acid or particulate deposition. Delta, Atlas, and Titan launch vehicles differ in the number and size of solid rocket boosters and in the amount of deluge water used. All are smaller and use less water than the Space Shuttle. Acid deposition can cause damage to plants and animals exposed to it, acidify surface water and soil, and cause long-term changes to community composition and structure from repeated exposure. The magnitude of these effects depends on the intensity and frequency of acid deposition. Plants differ in resistance to acid damage. Soils of the coastal barrier island are alkaline with high buffering capacity. Noise could affect wildlife species independent of exposure to rocket exhaust products.

We monitored the effects of 15 Delta, 22 Atlas, and 8 Titan launches between May 1995 and December 1997. Delta launches produced acid and particulate deposition. All Atlas launches caused heat scorching, and Atlas IAS launches also caused particulate deposition. Titan launches caused heat scorching, acid deposition, and particulate deposition. Acid deposition was similar to the far-field deposition from the Space Shuttle. However, acid formation is sensitive to the amount of deluge water and the interaction of the launch plume, pad structure, and deluge water. The first launch of a Delta II rocket in January 1998 from the modified LC17B produced an impact area similar though smaller than the Shuttle near-field impact area.

The Delta II rocket launched January 17, 1997 exploded at an altitude of about 484 m. Although there was significant damage to facilities and structures, impacts to the natural environment were limited. Burned vegetation is recovering.

No animal mortality has been observed that could be attributed to launches. Behavior of Scrub-Jays observed after launches has been normal, indicating no noise-related effects.

We mapped effects for 14 Delta, 20 Atlas, and 8 Titan launches and developed a Geographic Information System database for these effects. Vegetation scorching has been limited to small areas (<1 ha) close to (<150 m) the launch complexes for Atlas and Titan launches. Acid and particulate deposition for Delta launches has extended less than 1 km from the launch complex and affected relatively small areas, 7.1 and 45.8 ha, respectively. For Titan launches, continuous acid deposition has not exceeded 1 km from the launch complex. However, isolated acid deposition has occurred up to 9.3 km from the launch site under certain meteorological conditions, apparently due to interaction of the launch cloud and rainfall or other clouds. Particulate deposition from Titan launches has occurred over larger areas (2,366 ha) and up to 14.6 km from the launch site. No discernable vegetation or other environmental damage appears to be caused by this particulate deposition. The spatial scale of effects from Delta, Atlas, and Titan launches is substantially less than that from the Space Shuttle.

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