(Editor's notes are provided for clarification and enhancement within the lesson learned. They will always appear as italicized words bordered by parentheses.)

Lessons Learned System Number: EXT-10-001
Lesson Date: August 9, 2010
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Title of Lesson Learned:
Safety Lessons Learned Following Commanded Aborts and Vehicle Crash

Abstract:
Following two commanded aborts, resulting in both a software driven command to terminate motor thrust and a direct emergency vent actuation, the vehicle ceased powered flight and crashed. Liquid hydrogen peroxide (H2O2) escaping through the emergency vent provided thrust opposite to the main engine, causing the vehicle to act like a large version of a water rocket during the abort sequence. Following the crash, several people rushed out of the bunker to observe the wreckage. Shortly after the observers arrived at the crash site, hydrogen peroxide began raining down on the observers, equipment, and vehicles, starting a small fire and partially bleaching the hair of several people.

Triggering Event:
On March 20th, 2010, during the descent portion of a reusable launch vehicle (RLV) free-flight (at approximately 800 feet above ground level), the vehicle operator sent two abort commands after the vehicle became unstable. Both aborts, a software driven command to terminate thrust and a direct emergency vent actuation, functioned properly, stopping the engine's thrust and opening the emergency vent.

The vehicle uses a large emergency vent, located on top of the vehicle, opposite the engine's nozzle. I have safely and effectively fired this vent hundreds of times. Firing the emergency vent is the normal way to depressurize the vehicle after tests to prove the emergency abort system works. In free fall with the motor off, the escaping pressure caused the vehicle to thrust away from the vent. This thrust drove all unused liquid propellant into the vent, creating a H2O2 water rocket. Following the rapid descent and crash, I and several others exited the bunker to view the wreckage as the fire crew hosed the vehicle down. Shortly thereafter, approximately 60 lbs. of H2O2 began raining down on the group, giving several people blonde highlights. It took a long time for the cloud to rain out. H2O2 also landed on a wooden box in the back of a pickup truck, setting it on fire. The fire crew found and extinguished the fire within 60 seconds.

The distance from the launch point to the viewing bunkers is approximately 700 feet. During the abort sequence, the venting H2O2 drove the vehicle off its planned course and toward the bunkers. As a result the vehicle impacted

between 1/2 and 2/3 of the way to the bunkers *(approximately 230 to 350 feet from the bunkers)*. The bunkers are behind concrete and dirt beams with more than 12" of steel reinforced concrete overhead.

Lesson(s) Learned:

1. Even if operators exercise safety equipment on the vehicle every time it is flown and tested, it may operate differently during an actual in-flight emergency. The design of this vehicle's emergency vent system intentionally opposes motor thrust. However, if BOTH safety aborts are activated, there is no motor thrust.
2. Not every hazard falling from the sky during a crash is hard (i.e., *vehicle fragments)*. Even after all hard pieces of debris have landed there may still be hazards *(e.g., hydrogen peroxide)* falling from the sky.
3. *(During hard aborts, i.e., thrust termination aborts)* the vehicle's abort system should not provide thrust. In this case, the thrust provided by the emergency vent pushed the vehicle closer to the viewing bunkers.

Recommendation(s):

1. When designing abort systems consider all combinations of abort-initiating events and combined abort system responses.
2. Establish safety procedures which limit risk to personnel from falling debris following a crash or safety event. Accident sites and vehicle wreckage present several hazards and should only be approached by those familiar with the vehicle, its systems, and unique hazards.
3. When designing the vehicle's abort system *(i.e., thrust termination abort)*, design it in a manner so as not to provide thrust.

Questions regarding this lesson learned should be directed to the point of contact.

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