H2. IMPACT ANALYSIS

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H2. Mishap Number: 261766

Mishap Aircraft: B-2A, 89-0127

Mishap Date: 23 Feb 08

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Initial ground contact occurred when the left wing tip hit the ground causing fracture damage to the wing tip and wing tip support structure. The aircraft continued upwind then descended to hit the ground with the nose gear and then the left main landing gear. Upon ground impact, the left main landing gear separated from the aircraft releasing fuel. This caused a fireball to travel upwind scorching an area of approximately 29,517m^2. The left main landing gear rested 475m from the final position of the aircraft. The bomb bay and nose landing gear doors, located at 350 – 400, from the aircraft, showed signs of physical damage with little or no scorch markings. Ground scars show the aircraft came to rest 717m from initial ground contact. The pilot (left) seat rested 458m from the aircraft. The co-pilot seat rested 431m from the aircraft. The hatches were located 568m and 578m from the aircraft. The debris field was comprised of random pieces and fragments of composite materials ranging in size and shape with very few metal pieces found. Most of the aircraft structure remained intact but with severe impact damage as it came to rest on its bottom outer mold line. The survey determined the debris field area was 18, 964m^2.

The base fire department had 13 fire fighters on call at the time. It was Saturday and the fire department had no knowledge of any B-2A flying activity scheduled for that day. The fire department had water on the fire 2 minutes and 53 seconds after the aircraft crashed. Thirty minutes after the fire started, there were a total of 53 fire fighters (every fire fighter the base could recall) and every available truck on the scene. An off-base fire department brought 3 vehicles and 5 personnel to aid in extinguishing the fire. The Navy sent 4 fire fighters and a truck to the base station to respond to any other on-base calls. A 1000ft cordon was established during the initial response and held until the aircraft was in the recovery phase thirteen days later.

At take off, the aircraft contained approximately 20,735 gallons of fuel. As the aircraft came to rest, pooling fuel burst into flames. Burning reached a steady state level within seconds of impact and continued for approximately 4-6 hours before transitioning to a cool down phase. The complete combustion event did not end until day two and possibly three. In total, the fire department used 83,000 gallons of water containing 2,500 gallons of aqueous film-forming foam (AFFF) with not much success in completely putting out the final combustion stage. Low hydrant pressure in the area required fire trucks to leave the scene to get more water. Fire trucks ran out of water approximately 4 or 5 minutes into the scenario then had to ferry back and forth to refill. A constant supply of water to completely cool the aircraft and shorten the overall response time was needed.

There was a change in the nature of burning as JP-8 was consumed. The aircraft structure continued to burn. The fire scenario could be explained in four distinct combustion stages: 1) 20-30 minutes for the JP-8 flaming combustion, 2) 4-6 hours for aircraft structure flaming combustion which transitioned to intermittent flare up at random locations across the aircraft, 3) 24 hours into the initial response, cool down was taking place through-composite-thickness with indications of internal deep-seated smoldering and 4) 48 hours into the initial response, the final cool down stage was reached with a hint of light smoke being released. A hundred gallons of dust hold-down solution (fixant) was then sprayed on the leading edge of the aircraft

Smoldering and intermittent flaming at random locations across the aircraft and deep-seated smoldering combustion continued for approximately 24-48 hours. An infrared (IR) gun was used on surfaces that showed signs of smoldering and white smoke. The gun registered between 75-85°F. Unlike metals, temperature (heat, cool) penetrates composite structures layer-by-layer. Time at high temperature produce the conditions for deep-seated smoldering within the composite and surface layers cool before the layers within the composite structure. This observation demonstrates the IR gun cannot detect deep-seated smoldering.

Standard fire fighting tactics were used during the first and second phase. The aircraft came to rest with the nose facing in the upwind direction allowing the fire fighting response to attack in the downwind direction concentrating the flow of fire fighting agent on the center wing box and crew station. This angle of attack turned out to be beneficial to cooling and protecting crucial evidence. To combat intermittent flare up and smoldering, the tactics changed to structural fire fighting techniques on the wing box.

The B-2A was designed with approximately 80% composite material and 20% aluminum and titanium as the substrate materials. The carbon fiber / epoxy composite system is the primary composite materials system; although there are other composite systems found in small quantities like fiberglass / PMR-15. JP-8 pool and fireballs can create flame temperatures in excess of 2000°F and "time at temperature" determines the degree of damage for these materials. As the flame-front penetrates through the composite thickness, layers burn and metals melt. The wreckage showed varying degrees of impact and thermal damage. The B-2A aircraft sustained severe thermal damage.

Aircraft materials show signs of thermal damage that help to determine what the temperatures could have been. Melting point, color change and recognition of surface feature changes were used to evaluate the wreckage. The following materials were used as indicators of temperature exposures: carbon fiber, glass, titanium, aluminum, silver, nickel, iron, copper, epoxy and polyurethane coatings, and polycarbonate. The inboard and outboard wing assembly, wing tips, leading and trailing edge showed signs of thermal exposure of at least 1700°F. The crew station assembly showed signs of at least 1200-1500°F. The center body was at least 1200°F. The aft wing assembly, GLAS, hot trailing edge and decks were exposed to at least 900-1100°F. The bottom outer mold line condition will remain unknown until the wreckage is moved.

JP-8 fuel produced dense black sooty smoke. The wind conditions were 13 knots down the flightline and lofted the dense plume downwind (opposite the takeoff direction). No buildings or personnel were in the downwind direction at the time of the incident. Soot was carried in the thermal column, became diluted and dispersed downwind. No downwind plume exposures were reported. The initial response did not report seeing lingering airborne carbon fibers. After the fire was extinguished and the site determined safe for mishap operations, cordons were reduced to encompass the debris field and burn area.

A screening sample, for fibers by NIOSH Method 7400 and for total particulates by NIOSH Method 500, was taken 5 hours into the response approximately 1.5 miles downwind from the aircraft at rest. Results were non-detect for a 15 minute sampling time. Twenty-four hours after flame out, a preliminary site evaluation was made. Responders were protected wearing level C protective gear and were fitted with air sampling pumps for fibers and particulate collection. Fibers and particulate were detected for one responder who walked in the field behind and around the aircraft for 108 minutes. The results were an order of magnitude lower than an asbestos exposure limit. Area and occupational health monitoring continued for operations distributing, handling, or moving the damage/burnt wreckage.

Initial site assessment was delayed due to difficulty acquiring and understanding current composite information. Once T.O. 00-105E-9, Chapter 3 was obtained, personal protective evaluations were made for each phase of the mishap. Safety and health exposure decisions were based on the information gathered during the initial site survey, specific activities to be performed and the composite guidance. Because the aircraft caught on fire and burned for hours, the exposure potential was determined to be airborne particulate, dust and fibers, sharp objects and protruding impact damaged fiber bundles or fragments at the wreckage. There were no lethal hazards to report after the fire was extinguished. Residual fuels on the ground and possibly in the hydraulic lines were present and operations were "saved" for that concern. Initial assessment determined to minimize wind disturbances across the wreckage by spraying the wreckage with dust hold down solution (50% fixant) then covering with tarps.

Following debris field analysis, surveying and removal of random pieces and fragments of composite materials, the cordon was progressively reduced. Aircraft recovery phase began 13 days from the mishap event. The cordon was reduced to 50ft based on the spread and handling of debris at the wreckage. When the wind blew over the wreckage, dust/fibers/particulate was generated from severely burnt composite layers flapping in the wind. Dust/fibers/particulates were generated when handling the burnt debris. Dust/fibers/particulate was generated when cutting through the structure. Level C protection was required inside the cordon, work cycles were established based on the heat index and a decontamination line was setup appropriate for dust/particulate/fiber exposure concern. Aircraft recovery time was increased due to the preparation for donning and doffing personal protective equipment (PPE).

Discussion

The length of time needed to extinguish the fire and cool the aircraft was unexpected. It took approximately six hours to put the fire out (flames) with pockets of smoldering occurring for 24-48 hours. The lengthy response required trucks to leave the scene to re-supply, interrupting the suppression or cool down process, allowing heat to continue to penetrate and burn through thickness (layer-by-layer). Without having adequate water pressure or a water source near by, the structure was not continuously cooled through-composite thickness (layer by layer) flare-ups continued to occur.

Knowing how composites are made will help explain why the initial response took longer and required more extinguishment. Composites are a system of materials and are manufactured layer by layer to a desired shape and thickness. Each layer is made up of resin-coated fibers. Flame and heat penetrate layer by layer burning through thickness. Cooling or flame suppression occurs in the same manner.

During the initial response, the aircraft composite material concern is the resin, not carbon fiber. Aircraft composite materials (resins, coatings, adhesives, caulking) are a source of fuel. The B-2A contains ~80 composites by weight. Of the 80%, ~35% will be resin (mainly epoxy). A thicker structure means more fuel to burn and the B-2A has thick structural members. Once the JP-8 fuel fire is out, composites will continue to burn through-thickness which was observed. As heat penetrates each fiber layer heating the resin, the resin catches on fire. If not completely cooled, flare-ups continue to occur that transition to deep-seated smoldering which was also observed. Flare-up and smoldering is a combustion stage, producing heat and gases that require proper personal protection. Once the fire is out the composite concern now becomes lingering carbon fibers and dust around the wreckage. The fibers and dust caused by flaming combustion will settle out or blow downwind. Extinguishing the fire quickly and wetting down the aircraft and surrounding area will reduce the lingering fiber concerns.

The B-2A aircraft experienced severe thermal damage. Damage and loss could not have been prevented regardless of the number of fire fighters or vehicles that responded. The damage had been done before the initial response arrived. The value of fire fighters is realized when they arrive to find a situation they can do something about (minimize loss or damage). Fire fighters call this "early intervention." In this case, there was nothing the firefighters could do to minimize damage. In such cases, the primary goal of the fire fighters is to protect exposures, such as adjacent aircraft. The Air Force accepted this principle in the 2007 CONOPS. Although in this mishap we couldn't minimize damage, the aggressive fire fighting effort allowed the investigation to retrieve crucial evidence. That is one of the two main reasons for attempting to put out the fire, save the evidence. The other reason is to minimize the extent of damage with the purpose of minimizing health exposures during the handling operations conducted by the follow-on response for aircraft recovery and disposal.

Observations/Recommendations

1. Without specific "mishap composite" knowledge it can be challenging to determine what exposures may be encountered at each phase of the mishap. The situation is very controllable with specific knowledge that is found in T.O. 00-105E-9, Chapter 3, *Hazardous Materials and Mishap Hazards*. Chapter 3 contains composite guidance for each phase of the mishap response including the fire behavior of burning composites. Chapter 3 is not known to exist by many in the mishap community and is not widely used. Firefighting and Bioenvironmental training should consider incorporating information found in T.O. 00-105E-9, Chapter 3.

2. Air sampling, after the fire was extinguished, "close-in" to the damaged/burnt wreckage shows Level C protection is prudent.

3. Aircraft composite fires differ from metal aircraft fires because they add fuel to the fire by increasing the fuel load. In order to extinguish a composite fire, fire fighters have to consider composite thickness and maintaining a continuous supply of agent. Fires involving thick composite fires will require extensive time to extinguish. Therefore, agent conversation is essential to sustain fire fighting operations.

4. Although the Air Force provides significantly more agent than NFPA 403 requires, strict agent conversation measures are required to provide sufficient agent to extinguish thick composite structure fires. Turrets should be used only briefly (usually <1 minute) to knock down large fires that involve the aircraft's fuel. Remaining fire fighting should be accomplished with hose lines. Only by using hose lines can fire fighting be sustained. Using turrets can exhaust the vehicle's agent in about 3 minutes while hose lines can be sustained almost indefinitely. Moreover, hose lines are more effective at reaching fires concealed by debris that turret streams cannot reach.

5. Part of the solution to fighting composite fires is to develop new tactics and fire fighting strategies specific to composite aircraft fires.

6. Infrared guns did not detect deep-seated smoldering. Detection of deep-seated smoldering will require new techniques.

7. Aircraft recovery units responsible for composite aircraft will need to have appropriate tools to cut composites. It can not be an afterthought.

8. With a larger number of aircraft being constructed out of composite materials (both civilian and military), airport/airfield fire departments need to start training to this new type of fire threat.

9. The airfield that the B-2A crashed upon has a known problem of low water pressure at the underground hydrants. The closest good pressure water lines were approximately ½ mile away from the scene. With effective agent conservation tactics that relies predominately on hose lines; such fire fighting operations can be sustained more effectively, even with low flow hydrants.

10. The fire department did not have knowledge that four B-2A's were flying on the day of the accident. They also did not know if there was any hazardous cargo onboard. Having a daily flying schedule could ensure the fire department maintains the appropriate number of fire personnel on hand based on the flying and cargo/weapons requirements.

11. An aircraft's home base should stand up its emergency operation center (EOC) after a deployed aircraft accident to offer an open line of communication between them and the accident site. This will allow the accident responders to have a straight-forward way of getting answers quickly and correctly.

12. The Bio-Environmental Engineering unit had all the sampling equipment needed for day-to-day operations but they did not have enough air sampling pumps for an aircraft accident of this magnitude.

13. Most bases do not keep large stock of PPE on hand except that which is needed for day-to-day operations. Bases should have a good plan developed for how to acquire large quantities of PPE in times of emergency. Whiteman AFB should prepare a contingency kit to supplement day-to-day crash recovery equipment.

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