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Composite Material Hazard Assessment at Crash Sites

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14. ABSTRACT
This revised special report updates and supersedes the 2001 report, published as document number IERA-RS-BR-TR-2001-0009. Advanced composite material use in the military and private sector is increasing. As a result, personnel responding to a crash site should be able to assess the hazard and determine a category of high or low exposure risk. The information in this technical report provides valuable details to help Air Force Bioenvironmental Engineering personnel develop local response plans for composite materials at aircraft crash sites. This special report serves, in part, as a foundational document for the United States Air Force School of Aerospace Medicine's Composite Materials Field Guide.

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SUMMARY OF CHANGES FROM IERA-RS-BR-TR-2001-0009

This revised special report updates and supersedes the 2001 report, published as document number IERA-RS-BR-TR-2001-0009. Changes include significant updates to style and formatting throughout the report. Specific changes are as follows:

- Paragraphs 4.8, 4.9, and 4.10 a. These discuss three additional crash summaries: 1) a B-2A in 2008, 2) an F-22 in 2009, and 3) a C-17 in 2010, respectively. These additional entries also update Tables 1 & 3 by increasing the summaries of crashes to nine and add the B-2 and C-17 airframes to the corresponding tables.

- Paragraph 6.4. Minimizing Personnel Exposures.

Minimize the number of people at the site to only those necessary to perform required tasks and operations. The U.S. Air Force Advanced Composites Program establishes guidelines for minimum safety and health protection requirements for firefighters, investigators, and cleanup crews in accidents involving aircraft with advanced composite materials. All personnel involved in rescue in close crash-site proximity are required to wear self-contained breathing apparatus, chemical protective clothing, leather gloves, and neoprene coveralls to minimize exposure to all airborne species. Personnel engaged in investigation, recovery, and removal of fragmented composite parts should wear, at a minimum, NIOSH approved half-mask respirators with cartridges for organic vapors and fumes, and carbon fibers and dusts.

- Paragraph 8.3. Synergistic Interactions (Carbon Fiber Adsorption Effects and Mitigation)

Air sampling at a crash site should include, but not be limited to, specifically characterizing exposure to composite materials. The long-term, toxicological effects due to inhalation of micron-sized carbon fibers contaminated with adsorbed organic chemicals and byproducts generated in composite fires are largely unknown. Chemical extraction analyses indicate a significant number of toxic substances are adsorbed onto the fibers, several of which are known carcinogens. No epidemiological data on burning composites are available on the extent of personnel exposure to such combustion products. Similarly, no studies have assessed the toxicology of the carbon fibers generated in a fire scenario with extended post-exposure duration. Synergistic interactions between the solid, vapor, and gaseous combustion products continue to be an enigma. Research and experience during several crash responses indicate composite fiber release has been relatively low. The intent of the air sampling guidance in this document is to aid BE planning and actions during emergencies and recoveries involving composite materials. Until there are adequate assessments, the use of personal protective equipment must be relied upon for crash rescue personnel and investigators.

1.0 INTRODUCTION

This revised special report updates and supersedes the 2001 report, published as document number IERA-RS-BR-TR-2001-0009. Advanced composite material use in the military and private sector is increasing. As a result, personnel responding to a crash site should be able to assess the hazard and categorize the exposure risk. The information in this technical report provides valuable details to help Air Force Bioenvironmental Engineering personnel develop local response plans for composite materials at aircraft crash sites. This special report serves, in part, as a foundational document for the United States Air Force School of Aerospace Medicine's (USAFSAM) *Composite Materials Field Guide* by providing a detailed background and discussion of the guiding principles.

2.0 PRE-MILLENIAL CRASH RECOVERY ILLNESSES

In the late 1980s, a Navy F-18 fighter aircraft crashed on Santa Catalina Island. Two search and rescue personnel who were exposed to ash and debris subsequently experienced persistent reduced breathing capacity and heightened reactivity to histamine challenge. There is no documentation indicating what personal protective equipment (PPE) these two search and rescue personnel wore.

In 1990, a Royal Air Force (RAF) GR.5 Harrier mishap occurred in Denmark. The RAF recovery team reported eye, respiratory and skin irritation. Unfortunately, the RAF recovery team's wear of PPE was also undocumented in the historical documentation. The local firefighters that responded to this mishap did not present with injuries. As a result of this incident, the RAF imposed more stringent PPE documentation requirements.

In 1997, after responding to a USAF F-117A mishap, 22 Baltimore area firefighters reported labored breathing, eye and skin irritation, nausea, and headaches.

While smoke inhalation at an aircraft crash fire is a clear health hazard, determining the relative risk and hazard attributed specifically to composite materials in the smoke is difficult to determine, and has been a topic of study for many years. The next section looks at the various sources of exposure from aircraft mishaps, including but not limited to fires, and the efforts to study the hazardous aerospace materials (HAM) on Air Force weapons systems.

3.0 HAZARDOUS AEROSPACE MATERIALS

Advanced composites are organized into three classifications based on the composition of the matrix phase. The classifications are polymer matrix composites, ceramic matrix composites, and metal matrix composites. Advanced composites use various resin systems including polyester, epoxy, as well as other proprietary and specialized resins. Along with a catalyst or curing agent, a fiber structure, such as glass or carbon, encompasses the complete resin system matrix. For advanced composites, the fiber element has a length to width ratio that is very high, but it can be as low as 3 to 1. During manufacture, the fiber reinforcement materials provide strength to the finished product. Advanced composite composition is derived from a wide variety of resins, reinforcing materials, hardeners, curing agents, and aromatic amines [1]. During an aircraft accident/mishap it is important to know that transformative processes take place and chemical byproducts are formed. The transformative process may create toxic materials that were not part of the original manufacture of the advanced composite. Chemical extraction analyses indicate a significant number of toxic substances are adsorbed on the fibers, several of which are known carcinogens [2].

3.1 Sources of Exposure

Aircraft crashes often initiate or accompany a fire. The air contaminants resulting from a fire are a mixture of gases, vapors and particulate matter. The composition depends on the materials burned, blaze intensity, and its growth rate. Broadly classified polycyclic aromatic hydrocarbons (naphthalene), nitrogen-containing aromatics (aniline), and phenol-based organic compounds have been detected during studies of composite material combustion byproducts [2,3]. Firefighting personnel may be exposed to toxic gases and particulates during both firefighting and rescue operations. Recovery team members may be exposed to particulates/fibers when moving or modifying aircraft parts (e.g., cutting, breaking, twisting, or hammering). Puncture injuries are also possible since the fibers can penetrate PPE. Health care providers and safety personnel frequently note reports of hand, splinter injuries. When assessing unprotected worker exposures, expect skin and/or eye irritation symptoms.

3.2 Hazardous Aerospace Material Mishap Emergency Response (HAMMER) Program

The HAMMER program addresses safety and health issues related to aerospace vehicle mishap response, investigation, recovery, cleanup and disposal. The goals of the HAMMER program are to identify and inventory all HAM on Air Force weapons systems, and ensure the Air Force has procedures in place to protect personnel from the hazards associated with these mishaps. The following summarizes some of the HAMMER program accomplishments:

3.2.1 Aircraft Mishap Investigation and Prevention (AMIP) Course. USAFSAM offers the AMIP course. The course prepares flight surgeons, aerospace physiologists, and aviation psychologists to assist with aircraft accident investigations. The course includes a briefing that informs students about the types of hazards they may encounter when responding to an aircraft mishap.

3.2.2 Burn Study/Actual Crash Site Experience. The HAMMER program conducted a large-scale aircraft burn study in September 2000 (see section 4.7 below for details). This involved multiple burns of large composite (graphite/epoxy) boxes. Aircraft recovery crews practiced simulated recovery efforts. The results from these tests, along with other previous sampling efforts, determined appropriate protective equipment and respiratory protection at mishap sites [4].

4.0 ACTUAL AND SIMULATED CRASH SITE EXPOSURE ASSESSMENTS

A review of the previous work indicates the airborne levels have been relatively low [5-8]. The preferred fiber sampling method in available studies was the National Institute for Occupational Safety and Health (NIOSH) Method 7400, *Asbestos and Other Fibers,* which was used during some of the events noted in Table 1. The following table summarizes sampling efforts to quantify HAM exposures between 1986 and 2010.

Table 1. HAM TWA Exposure Concentrations during Recovery Operations

Aircraft	Crash Date	Composite Type	Task	Sample Type	Particulate (mg/m^3)		OEEL 8-h TWA (mg/m^3)
					Task	8-h TWA	
F-14	1986	Boron	Crash pit work	Total dust[a]	2.5-4.3[a]	0.318-0.636	10.0
F/A-18	1989	Graphite	Heavy equipment operator	Total dust	NA	15.9-18.3	10.0
			Mishap investigator		NA	24.1	10.0
F-16	1999	Graphite	Spraying, pickup, wrapping	Inhalable[a]	0.046-1.324[a]	NR	10.0
				Respirable[b]	0.053-0.785[b]	NR	2.0
F-16	1998	Graphite	Spraying, pickup, wrapping	Inhalable[a]	0.450-2.61[a]	NR	10.0
				Respirable[b]	0.23-0.695[b]	NR	2.0
F-16	1998	Graphite	Spraying, pickup, wrapping	Inhalable[a]	0.059-1.11[a]	NR	10.0
				Respirable[b]	0.012-0.36[b]	NR	2.0
F-16	1999	Graphite	Spraying, pickup, wrapping	Inhalable[a]	0.89-19.2[a]	NR	10.0
				Respirable[b]	0.08-5.73[b]	NR	2.0
Wing (crash simulation)	2000	Graphite	Simulated recovery, cleanup, cutting, wrapping	Total dust[a]	0.003-0.004[a]	0.001-0.0012	10.0
				Respirable[c]	0.0004-0.001[c]	0.0001-0.0003	2.0
B-2A	2008	Graphite	Downwind observer	Total dust[d]	ND[d]	NR	10.0
C-17	2010	Graphite	Cutting, grinding, pickup, wrapping	Inhalable[a]	1.45-2.22[a]	NR	10.0

Notes: OEEL = occupational and environmental exposure limit; NA = not available; NR = not reported; ND = non-detect.

[a]NIOSH Method 7400 reported Total Dusts and Inhalable results using a 0.8-um mixed cellulose ester filter.

[b]NIOSH Method 600 reported Respirable results using a respirable dust 10-mm nylon cyclone MSA or the aluminum cyclone (SKC).

[c]NIOSH Method 7402 was used. See para 4.7 for more detail on the simulation and para 8.1 for more details.

[d]NIOSH Method 500 reported Total Particulates and was utilized along with Method 7400 during the 2008, B-2A aircraft mishap.

4.1 F-14 Crash, 1986

On 25 June 1986, a Navy F-14 crashed in Dixie Valley, Nevada.[1] The F-14 presented potential exposures to boron composite material. The F-14 does not have published composite material weight or percentages by weight for the frame. Personnel from Naval Air Station Miramar; Naval Air Detachment Fallon; Naval Safety Center, Norfolk; and Naval Hospital, Oakland initiated the salvage operation. An on-site industrial hygienist provided observations, indicated potential problem areas, and provided recommendations based upon sampling results. The industrial hygienist collected samples from selected personnel working at the site during removal of aircraft debris and parts. Safety personnel placed monitors on the pit workers and the crane operator during salvage of the wreckage to determine personal exposures to airborne fibers and dusts. Personnel analyzed airborne fibers collected on 37-mm mixed cellulose ester (MCE)

[1] Memorandum from Commanding Officer, Naval Hospital to Commander, Carrier Airwing Reserve 30, Industrial Hygiene Assist at Dixie Valley F-14 Crash Site, 25 Jun 1896.

filters and analyzed per the NIOSH Method 7400 fiber counting method. Pre-weighed 37-mm polyvinyl chloride (PVC) filters captured total particulate concentrations.

4.2 AV-8B Crash, 1987

On 12 January 1987, an AV-8B aircraft mishap at Marine Corps Air Station, Cherry Point, North Carolina, prompted a Navy Environmental Health Center industrial hygienist to conduct a comprehensive occupational health survey of the aircraft accident investigation and cleanup, which occurred from 13 to 17 January 1987. [2] The AV-8B contains 1,317 pounds of ACM, 26% of the aircraft by weight. The industrial hygienist collected airborne and bulk samples. Sixty firefighters and crash and rescue personnel responded to a grass and fuel fire caused by the aircraft accident. These personnel applied floor wax to larger pieces of wreckage. Two individuals performed spill control by building a dike around the aircraft fuselage to contain any leaking. Prior to reclamation, personnel collected bulk samples. Results from these samples indicated an order of magnitude increase for chromium and elevated levels of acenaphthylene, a polycyclic aromatic hydrocarbon (PAH) in three of four samples when compared to raw graphite cloth. The source of chromium was undetermined; however, the PAH source was believed to have been the jet fuel used in the aircraft, JP-5. The Naval Safety Center accident investigator and Emergency Reclamation Team proceeded with retrieval of pertinent aircraft components by digging, moving, and collecting components. Personnel conducted air sampling during these activities on 15 January 1987 using DuPont P2500 pumps. The pumps operated at 2.0 liters per minute (lpm) with open-faced MCE filters (37-mm diameter and 0.8-µm pore size). They also collected samples on closed-face matched weight cassettes. On 16 January 1987, personnel removed aircraft components and conducted site cleanup operations. A crane turned over the fuselage during recovery of the debris. Personnel collected air sampling during these activities.

4.3 AV-8B Crash, 1988

A Naval Medical Command industrial hygienist conducted sampling on 13 July 1988 at the mishap site of an AV-8B Harrier II stationed at Marine Corps Air Station, Cherry Point, North Carolina.[3] The aircraft suffered a systems failure and crashed a few miles from the runway in a small clearing. The hygienist utilized NIOSH Method 7400 using 0.8-µm pore MCE filters in 25-mm cassettes open-faced collection mode with electrostatic extension cowls. Personnel used DuPont P2500A and P2500B personal sampling pumps with flow rates of 1.9 - 2.1 lpm. Personnel also collected area samples on the first day after the crash. Responders applied fixative to large areas of damaged ACM before cleanup began. Personnel collected area and personal samples from 14 to 18 July during debris removal and site cleanup. On the second day after the crash, rigorous handling of debris occurred because of personnel movement through the area. Site safety monitors obtained breathing zone samples from Marines actively tearing apart large pieces of debris by hand while searching for electronic parts. The third day after the

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[2] Marine Corps Air Station, Industrial Hygiene Survey Report for AV-8B Mishap, Navy Environmental Health, Cherry Point, NC, Jul 1987.

[3] Marine Corps Air Station, Industrial Hygiene Survey Report for AV-8B Mishap, Navy Environmental Health, Cherry Point, NC, Jul 1988.

mishap, personnel used shovels and rakes to remove contaminated soil. Personnel continued moving, stacking, and loading large parts onto a flatbed for wrapping during the final stages of the recovery effort. Moving and shifting damaged ACM resulted in significantly higher airborne concentrations of fibers; however, applying fixative moderately reduced the generation of airborne fibers.

4.4 F/A-18 Crash, 1988

An F/A-18 aircraft crashed into an irrigation pipe located on the edge of an onion field and an adjacent barley field.[4] The F/A-18 is composed of ten percent composite material by weight. The aircraft mishap occurred in June 1988. Responders used the results from personal and area sampling accomplished after the AV-8B aircraft crash in 1987 as a basis for comparison of this F/A-18 incident. Both aircraft contain the same type of composite material, but with different percentages (AV-8B and F/A-18 are by weight twenty-six percent and ten percent ACM, respectively). Response personnel collected air samples during crash site cleanup and jet fuel removal operations. Samples takers collected from the front of the tractor cab at the height of the driver's breathing zone. The sample media consisted of open-face, 37-mm cassettes with 0.8-µm pore MCE filters, using an air pump operated at 2.0 lpm during plowing operations in the morning and in the afternoon.

4.5 F/A-18 Crash, 1989

Air sampling characterized the response personnel exposure to particulates after the crash and subsequent burn of an aircraft with 590 kg of carbon fiber composites [3]. The F/A-18 crashed in a desert bombing range north of Yuma, Arizona. Laboratory analysis processed the air samples via gravimetric analysis and optical microscopy. Other samples utilized optical microscopy on 0.8-µm MCE filters in open-face cassettes. Technicians collected gravimetric samples on previously prepared 5-µm pore size PVC filters. Personnel used personal cascade impactors. however no results were published. Sampling started approximately thirty hours after the crash. Soon after the mishap occurred and before the sampling began, responders applied polyacrylic acid fixative to larger debris pieces to lessen fiber release. The day after the crash site monitors took air samples. On the fourth day after the crash, personnel groups A and B were performing recovery procedures (sorting through wreckage and cutting into metal). Personnel in group C, the primary mishap investigator, was turning pieces of wreckage over and kicking through debris. On the sixth day after the crash, safety personnel remediated the site and buried the aircraft on site. Personnel in group D operated the earthmover to open a trench, place materials in the trench, and then close the trench. Personnel in group E directed and assisted group D personnel. Other personnel collected area samples.. The majority of the samples were well below the Navy's recommended exposure limits for the total airborne material from aircraft mishaps (i.e., the short-term exposure limit (STEL) of 7.0 mg/m^3 and time-weighted average (TWA) of 3.5 mg/m^3). Of all the samples collected and analyzed, only three samples were above the Navy STEL of 7.5 mg/m^3; these samples impacted groups C, D, and E. It was determined at

[4] Memorandum from Commanding Officer, Navy Environmental Health Center to Commander, Light Attack Wing answering the request for advisory opinion concerning the crash of an F/A-18 aircraft into an onion field, Jun 1988.

the time that the sample results were of total dust, which included significant amounts of ambient (background) environmental aerosol particulate.

4.6 F-16 Crashes, 1998 and 1999

The Bioenvironmental Engineering Flight (BEF) at Luke Air Force Base (AFB), Arizona, performed air monitoring at several mishap sites between 26 October 1998 and 26 March 1999.[5] The exact locations of the aircraft mishaps are unknown; however, since the local BEF performed the sampling, the crash sites were proximate to Luke AFB. The F-16 aircraft has four different models, and the average weight of composite material for these F-16 models is approximately 200 pounds. This report includes sampling results at four of six separate mishap sites monitored by the BEF at Luke AFB. The BEF sampled only four incidents sampled, since the aircraft structures at the other two sites were still intact. They used personal air sampling to determine the crash recovery worker's exposure to potential inhalation hazards from composite fiber materials. Crash site operations included initial fixant spraying over the debris; aggressive handling of materials by lifting, wrapping, and loading; and final cleanup. The initial spraying and parts movement involved spraying all exposed composite materials with a water-based wax solution. Wrapping included heavy plastic sheets and duct tape to cover and secure aircraft structures. Aircraft structures were loaded onto a flatbread truck in preparation for disposal. Final cleanup involved picking up and bagging the remaining littered composite debris. Results from personal sampling indicated the concentrations of composite materials were less than 1.0 fibers per cubic centimeter (f/cc).

4.7 HAMMER Burn Study, 2000

The September 2000 HAMMER Burn Study simulated crash response and composite material mishap recovery activities [4]. The purpose was to determine the level of exposure to composites for personnel involved in mishap response operations. The Tyndall AFB, Florida, burn study used large graphite/epoxy composite boxes in a fire science hangar. There were three composite material burns including a small 20-pound piece cut out from a wing box, a 316-pound composite box, and a 287-pound composite box. Air sampling consisted of both area and personal samples and quantified exposures for fibers, volatile organic compounds, phenol, particulates, and aromatic amines. PPE recommendations for crash site recovery operations used sample results for determination. Responders formulated a worst-case exposure scenario by not taking into consideration the application of aqueous film-forming foam (AFFF) to extinguish the JP-8 fire and not considering the application of a wax fixant to the composite boxes before handling by the recovery workers. Analysis indicated all exposures below USAFSAM-recommended OEELs and exposure guidelines for the substances analyzed.

4.8 B-2A Crash, 2008

A B-2A aircraft crashed during take-off at Andersen AFB, Guam, on 23 February 2008. The aircraft released aircraft fuel (JP-8) upon ground impact; a fireball engulfed the aircraft and traveled upwind, scorching a large area of the flightline [9]. Thirteen firefighters responded immediately to the crash site and sprayed water to put out the aircraft fire within 3 minutes of the

[5] Memorandum for AFIERA/RSHI from 56 AMDS/SGPB, Aircraft Mishap Composite Fibers Air Sampling Results.

crash. Within 30 minutes after the crash, 53 firefighters responded to the crash site and fought the fire. The aircraft continued burning for approximately 4 to 6 hours; 83,000 gallons of water and 2,500 gallons of AFFF extinguished the fire. Initial response established a 1,000-foot cordon. The recovery phase later reduced the cordon to 50 feet, which lasted 13 days. Personnel collected two 15-minute screening samples approximately 1.5 miles downwind 5 hours after the aircraft crash. Analysis incorporated one sample for fibers per NIOSH Method 7400 and another sample used total particulates per NIOSH Method 0500. The results of these two samples were non-detect. Personnel also collected a personal air sample for a crash recovery worker who performed debris collection in the field behind the aircraft for 108 minutes. Results from personal sampling indicated the concentrations of composite materials were less than 1.0 f/cc. SAF/AQRT conducted an impact analysis of the crash and concluded that the BEF had all the sampling equipment needed for day-to-day operations but did not have enough air sampling pumps for an aircraft accident of this magnitude [9]. See Appendix A for more details of the report and the B-2 crash.

4.9 F-22 Crash, 2009

An F-22 aircraft crashed off base at Harper Lake, California, on 25 March 2009. The BEF from Edwards AFB responded to the crash site the day of the incident and performed air sampling daily until28 April 2009, as long as military and Department of Defense (DoD) civilians were at the crash site engaged in crash recovery operations.[6] In total, The BEF collected and analyzed 50 samples per NIOSH Method 7400 for fibers. The results for these 50 samples indicated: 34 samples were non-detect for fibers and 16 samples were less than 1.0 f/cc.

4.10 C-17 Crash, 2010

A C-17 aircraft from Elmendorf AFB, Alaska, crashed off base at a remote location on 28 July 2010. Firefighters sprayed a fixant solution of water and wax on any parts that appeared to be ACM. Due to the austere conditions and frequent rain, BEF collected no personal air samples; however, direct reading instruments (DRIs) measured particle and aerosol mass concentrations. A condensation particle counter and optical particle counter were the DRIs measured particle and aerosol mass concentrations, respectively [10]. Sampling continued for 3 days of crash site recovery operations in close proximity to workers who were engaged in cutting operations on the vertical and horizontal stabilizers of the aircraft. The average particulate mass concentration as measured by the DRIs over the 3 days was 1.71 mg/m^3, which is less than USAFSAM's recommended OEEL for respirable particulate of 3.0 mg/m^3. Measured concentrations reported for the DRIs include background ambient aerosol particulate, which would also include particulate from the diesel exhaust of an excavator and other equipment operating at the crash site. See Appendix B for pictures of the crash site.

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[6] Memorandum for Record from 95th AMDS/SGPB, After Action Report, F-22 Crash Recovery/Response, Harper Lake, May 2009.

5.0 COMPOSITE HAZARD ASSESSMENT

Conduct a composite material risk assessment at each crash site. The assessment should begin immediately upon arrival and continually be adjusted even when the crash site is deemed safe for entry by the fire department, Explosive Ordnance Disposal, and other response personnel (e.g., hydrazine response team). Along with the other hazardous risk considerations, categorize the site as posing a high or low composite material exposure risk. Take the following parameters into consideration when conducting an assessment.

5.1 Visual Assessment

A visual assessment of the composite material should include the following:

5.1.1 Identification and Location of Composite Materials. Knowing where composites are located on the operational aircraft is the first step in determining where the composites are at a crash site. Resources to determine the pre-crash location of potentially harmful materials include T.O. 00-105E-9 and other weapon system specific T.O.s. The weapon systems maintenance personnel, crew chiefs, and Crash Recovery Team are also invaluable sources of information when collecting information during an assessment.

5.1.2 Nature and Extent of Damage. Factors impacting composite material dispersion include speed, ground impact angle, aircraft failure mode, promulgation of fire, and terrain topography. While surveying, assess if the composite material exists throughout the crash site. Also, assess if the material has both physical and fire damage.

5.2 Duration and Location of Fire

Fire increases risk to composite dust/fiber exposure because the resin will burn off and leave ACM and fibers exposed. These fibers can become airborne if disturbed and may also be spread throughout the site depending on the environmental conditions. An extended duration fire increases the risk of spreading fibers and dust. The quantity of fuel, intensity, and oxygen availability at the geographic location are also key factors when assessing fire duration. A fire will normally not be evenly distributed across the aircraft; rather, there will be a gradation of fire damage for the various aircraft parts. If the composite components receive no or very little fire damage, the exposure risk is minimal.

5.3 Physical Damage

Physically damaged ACMs have increased exposure risk associated with them. Composite materials located primarily in the rear of the aircraft (stabilizers) with little to no damage at a crash site have low adverse health exposure risk.

5.4 Aircraft Type/Quantity of Composite Material

There has been a significant increase in the use of composite materials on Air Force aircraft. ACM use has increased with each new weapon system. Refer to Table 2 for more detail [11]. Some aircraft should automatically be in the high-risk category due to the high percentage or large quantity of composite materials within the airframe. For example, the B-2, F-22, AV-8B, and F-35 would be in this category.

Table 2. Composite Material Composition of Selected Military Aircraft

Aircraft Type	Percent Composite Material by Weight
F-15	2
C-17	8
F-16	13
AV-8B	26
B-2	37
F-22	38
F-35	42

5.5 Terrain and Environmental Conditions

Aircraft have crashed into mountains, oceans, and deserts. A plane that crashes into swampland will present a lower composite dust risk than one that crashes into a hot, dry desert. Other factors to consider are wind and precipitation (rain). Both wind speed and direction may affect the risk category. A high wind speed may carry dust and fibers away from the site and reduce the dust and fiber concentrations at the site. Precipitation will tend to mitigate exposure and associated risks.

5.6 Phase of Response/Recovery

As a general rule, the risk should be set conservatively high and downgraded only after an appropriate assessment and controls have been considered and/or implemented. The use of PPE alone should not permit a site to be categorized as a low exposure risk.

6.0 RISK MITIGATION MEASURES

6.1 Applying Fixant

Spraying an aircraft fire with dust suppression agent (water, foam, or floor wax) is precautionary when there is concern about particulates in the air (like any other fire) [12]. Using a fixant (floor wax) only provides a surface coating that can easily become ineffective as a control measure once the coating is disturbed. Do not apply fixant unless permission to do so is granted by the president of the mishap investigation board. In certain circumstances, spraying fixant may interfere with the analysis of evidence. After immediate life-saving efforts have ceased, the investigative effort is always the top priority at a crash site as compared to recovery operations. Studies have shown that the efficacy of floor wax is inconclusive and requires further research [4,13]. However, from a risk assessment perspective, if a fixant cannot be utilized, then a crash site should remain in the high-risk category. Personal protective equipment control measures are largely implemented as the only means to safeguard personnel.

6.2 Wrapping

Wrapping in plastic is an effective control measure for identified composite materials. Use plastic sheeting/film or plastic bags with a minimum thickness of 6 mil (0.006 inch). Do not perform wrapping unless the president of the mishap investigation board approves.

6.3 Establishing Zones

An additional control measure can be the establishment of operational exposure zones. The zones would delineate PPE requirements whenever personnel performed work while within a given radius of the damaged composite material. This control requirement will only be effective if the damaged composite material is restricted to well-defined areas at the crash site.

6.4 Minimizing Personnel Exposures

Minimize the number of people at the site to only those necessary to perform required tasks and operations. The U.S. Air Force Advanced Composites Program establishes guidelines for minimum safety and health protection requirements for firefighters, investigators, and cleanup crews in accidents involving aircraft with ACMs. All personnel involved in rescue in close crash-site proximity are required to wear self-contained breathing apparatus, chemical protective clothing, leather gloves, and neoprene coveralls to minimize exposure to all airborne species. Personnel engaged in investigation, recovery, and removal of fragmented composite parts should wear, at a minimum, NIOSH-approved half-mask respirators with cartridges for organic vapors and fumes and carbon fibers and dusts [2].

7.0 PERSONAL PROTECTIVE EQUIPMENT

7.1 Selection Factors for PPE

Base PPE selection on two factors: 1) the task performed and 2) the composite material exposure category. Often hazards at the crash site other than composite fibers drive PPE selection criteria. The complete risk assessment task incorporates an initial composite material hazard assessment. The Crash Recovery Team, maintenance personnel, bioenvironmental engineer, and a Safety Board representative should accomplish this assessment together. The health and safety representatives are always responsible for maximizing personnel protection based upon the local and total health hazard assessment evaluation on scene.

7.2 Respiratory Protection

Personnel who disturb composite material resulting in the potential release of particulates should wear at a minimum a NIOSH-approved N95 filtering face piece device. Personnel wearing any respirator must meet all the program requirements such as medical clearance; compliance with a written program; training on the use, maintenance, and storage of respirators; fit-testing; etc. Reference Air Force Occupational Safety and Health (AFOSH) Standard 48-137 for additional guidance and requirements [14].

7.3 Hand Protection

Always recommend wear of leather gloves when handling crash debris to reduce the risk from physical hazards of puncture and abrasion from sharp objects. Remember that certain composite materials, such as the boron fibers in an F-15, can easily penetrate the gloves and skin. Take extra precaution when handling these materials. Nitrile rubber gloves can be worn underneath the leather gloves to provide chemical hazard protection. The inner nitrile rubber gloves are only required when preventing worker exposure to liquids such as jet fuel, hydraulic fluid, biological fluids, and other hazardous liquids that may be encountered.

7.4 Coveralls

Wear disposable Tyvek® coveralls where the potential exists for composite fibers to be airborne and deposited on clothing. For example, coveralls should be worn when damaged composite materials are being disturbed due to either handling or environmental conditions (i.e., high winds).

7.5 Eye Protection

Recommend goggles whenever material or debris is disturbed such that material can potentially become airborne. Refer to pictures of the F-22A debris in Appendix C.

8.0 AIR SAMPLING

8.1 Historical Review

A historical review of sampling results, the composite material combustion byproduct studies, and sampling results from relatively recent aircraft crashes indicate single fiber concentrations are very low [9,15].[7] Historically, assessors detected higher concentrations of non-fibrous particles and fiber clumps in these results. When response forces sampled for fibers, NIOSH Method 7400, *Asbestos and Other Fibers by Phase Contrast Microscopy (PCM)*, was utilized most often. This method counts all fibers that meet the established criteria (i.e., length, width, aspect ratio). This method was acceptable since it was reasonable to assume that all of the fibers collected were from composite materials at the aircraft crash sites. Additionally, this analytical method was less expensive than NIOSH Method 7402, *Asbestos by Transmission Electron Microscopy (TEM)*. Assessors used NIOSH Method 7402 during the HAMMER burn study because there was a validated need to measure fiber concentrations and to evaluate fiber characteristics. The following summarizes lessons learned regarding NIOSH Method 7402.

8.2 NIOSH Method 7402, *Asbestos by Transmission Electron Microscopy (TEM)*

During the preparation steps of NIOSH Method 7402, *Asbestos by Transmission Electron Microscopy (TEM)*, there may be a gain or loss of fibers. The loss of fibers can occur during the ashing/etching phase. The ashing/etching step strips the top layer of the filter to expose small fibers embedded in the filter. Fibers on the surface may be oxidized or reduced in diameter because of the conditions during etching. Fiber counts can also be artificially increased during the re-deposition phase. During this phase, portions of the filter are placed in glass bottles and rinsed off with water. The solution is then ultra-sonicated, which tends to break up fiber clumps into individual fibers. Fiber clumps are not respirable; therefore, by breaking individual fibers loose, the respirable fiber concentration can be positively skewed during analysis [16]. The clearing step, which is required for both NIOSH methods, 7400 and 7402, involves exposing the filter to a solvent such as dimethyl formamide. This step collapses the filter from a thickness of 60 µm to 15 µm. This step should not affect the fiber counts.

Because all particles have an electrical charge, when sampling using NIOSH Methods 7402 or 7400, some of the fibers may become statically collected onto the wall of the cowl. There are different interpretations as to the health significance of these deposited fibers. The NIOSH position is that if the material deposited on the wall of the cowl, those particles would not have been inhaled; therefore, do not make any effort to remove these fibers for subsequent analysis. The primary purpose of the cowl is to protect the filter and the deposited fibers are not relevant.

[7] Memorandum for Record from 95th AMDS/SGPB, After Action Report, F-22 Crash Recovery/Response, Harper Lake, May 2009.

8.3 Synergistic Interactions (Carbon Fiber Adsorption Effects and Mitigation)

Air sampling at a crash site should include, but not be limited to, specifically characterizing exposure to composite materials. The long-term, toxicological effects due to inhalation of micron-sized carbon fibers contaminated with adsorbed organic chemicals and byproducts generated in composite fires are largely unknown. Chemical extraction analyses indicate a significant number of toxic substances are adsorbed on the fibers, several of which are known carcinogens. No epidemiological data on burning composites are available on the extent of personnel exposure to such combustion products. Similarly, no studies have assessed the toxicology of the carbon fibers generated in a fire scenario with extended post-exposure duration. Synergistic interactions between the solid, vapor, and gaseous combustion products continue to be an enigma [2]. Research and experience during several crash responses indicate composite fiber release has been relatively low. The intent of the air sampling guidance in this document is to aid BE planning and actions during emergencies and recoveries involving composite materials. Until there are adequate assessments, use of PPE must be relied upon for crash rescue personnel and investigators [2].

9.0 EXPOSURE STANDARDS

Occupational and environmental exposure limits are the Air Force specific exposure levels used by BEFs to describe an exposure limit and control health risk. The OEELs are commonly adopted from established recognized standards (when possible) such as the Occupational Safety and Health Administration (OSHA) permissible exposure limits (PELs), the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit values (TLVs), or a limit noted in an AFOSH standard or Air Force instruction. The approach for comparing composites to particulates not otherwise specified (PNOS) is also consistent with NIOSH's health hazard evaluations of composite material hazards [17]. USAFSAM maintains the recommendation for comparing composite material exposures to the PNOS OEEL as long as the following ACGIH Appendix B criteria still apply for the particulates:

(1) do not have an applicable TLV [or other OEEL],
(2) are insoluble or poorly soluble in water (or aqueous lung fluid), and
(3) have low toxicity (i.e., are not cytotoxic, genotoxic, or otherwise chemically reactive with lung tissue, and do not emit ionizing radiation, cause immune sensitization, or cause toxic effects other than inflammation or the mechanism of "lung overload") [18].

While fiberglass is one specific type of composite material, it is the only type of composite material for which there is a standard measured in f/cc. All other composite standards use a gravimetric sample analysis and are reported in mg/m^3. The recommended exposure limits for composite material during repair and maintenance operations are presented in Table 3 [18-20]. Sampling for composite materials during crash and recovery operations is challenging due to the non-specificity of the gravimetric sampling method. It is difficult to distinguish composite material from other airborne confounding particulate matter present during a mishap.

Table 3. Exposure Limits for Composite Materials

Composite Material	8-h TWA ACGIH TLV (mg/m^3)	8-h TWA OSHA PEL (mg/m^3)
Graphite (all forms except graphite fibers) (respirable particulates only)	2.0	5.0
All Other Respirable Composite Materials [PNOS] (i.e., aramid, boron, carbon, or combination)	3.0	5.0
All Other Inhalable Composite Materials [PNOS] (i.e., graphite, aramid, boron, carbon, or combination)	10.0	15.0
Continuous Filament Glass Fibers (i.e., fiberglass)	1.0[a]	--

[a]Measured in f/cc.

For additional information on the behavior of composite materials during a crash, contact the Composites Branch, Structural Materials Division, Materials & Manufacturing Directorate, 2941 Hobson Way, Bldg. 654, Wright-Patterson AFB, OH 45433-7750, or call direct at commercial 937-255-3811.

10.0 OTHER POTENTIAL HAZARDS

Aircraft crash sites have numerous potential hazards. The types of hazards vary depending on the type of aircraft, whether or not casualties were involved, type of cargo, whether or not fire was involved, etc. If a fire was involved, more toxic substances will be created and released than a crash not involving a fire. The Senior Inspector of Accidents stated, “The main problem that we face is identifying the chemicals likely to be present after a ground fire. It is difficult enough to obtain information about what is built into an aircraft, never mind what is likely to happen to it in a fire” [21].

Potential contaminants/hazards include the following: jet fuel, unexploded ordnance, isocyanates, blood-borne pathogens, radioactive material, plastics, polymers composed of organic material, and composite fibers. Aircraft structural alloys include, but are not limited to, beryllium, aluminum, zinc, hydrazine (F-16), magnesium, titanium, and copper released in the form of metallic oxides, which pose an inhalation hazard to unprotected responders. Potential exposure to the civilian population depends upon their proximity to the crash site and is typically minimal due to exposure time and distance considerations when compared to exposures to response and investigation team personnel. See Table 4 for selected general aircraft mishap-related hazardous materials concerns.

Table 4. Selected General Aircraft Mishap Related Hazardous Materials Concerns

Hazardous Material	Physical Description	Health Hazard	Aircraft	Quantity/Location
Hydrazine	Clear, oily, liquid with an odor similar to ammonia; combustible and explosive	Can cause severe local damage or burns with contact to skin and eyes; vapor causes local irritation to eyes; if inhaled, vapor causes irritation to the respiratory tract and systemic effects	F-16	6.8 gal/emergency power unit
Beryllium	Dust or powder form, silvery and resembling aluminum powder	Toxic respiratory carcinogen and eye irritant; if introduced under skin through cuts or punctures, slow-healing ulcers may develop; exposure to beryllium particles can cause chronic beryllium disease	C-5, F-100, A-7D	C-5 brake pads, F-100 wing tip areas and around cockpit, and the A-7D landing gear bushings
Lithium thionyl chloride	Soft, silvery highly reactive metallic element	Reacts violently with water; serious injury to personnel can occur if incorrect fire suppression procedures are employed	C-17	Used in onboard computer batteries
Pressurized tanks and aircraft parts	Compressed liquids and gases (oxygen); tires	Physical and chemical hazards from projectiles and release of materials	All	Interior and exterior
Strontium	Radioactive material used in aircraft construction	Internal and external hazard; beta radiation dose reduced 10% by wearing leather gloves	Helicopters	Anti-ice detectors and blade integrity indicators
Depleted uranium	Radioactive heavy metal used as a ballast or counterweights in aircraft gyroscopes, flight controls, helicopter blades, and aileron balances; chemical and radiation hazard	Inhalation is the most significant mode of entry. If involved in fire, depleted uranium will release very toxic particles depositing in the respiratory tract, which are then absorbed into the blood stream and deposited in internal organs. This deposition causes intense ionization by alpha particles resulting in severe localized damage to cells.	A-7	Two weights, one in the cockpit and one in the lower part of the vertical stabilizer
			A-10	30-mm ammunition
			C-5	Aileron and elevator counterweights
			C-130	Aileron, elevator, and rudder counterweights
			F-16	Gun pods on certain models

10.1 T.O. 00-105E-9, Reference for Hazardous Aerospace Materials by Airframe

The Air Force Civil Engineer Support Agency's Fire Protection Division compiled data and developed AF T.O. 00-105E-9. The types of aerospace vehicles included in this document are U.S. fighter, cargo and bomber aircraft, helicopters, North Atlantic Treaty Organization aircraft and helicopters, and commercial airliners. This T.O. is an invaluable tool for development of local emergency response guidance as well as for a response team to identify hazards associated with post-crash recovery activity. The T.O. also provides illustrations, which assist in locating and identifying various components of each aircraft. For example, the exterior composition of the C-17 aircraft is detailed in Figure 1, which has been incorporated from T.O. 00-105E-9. For example, the C-17 contains approximately 15,000 pounds of ACM. Also, T.O. 00-80C-1, *Crashed, Damaged, Disabled Aircraft Recovery Manual*, is a reference for post-crash activities.

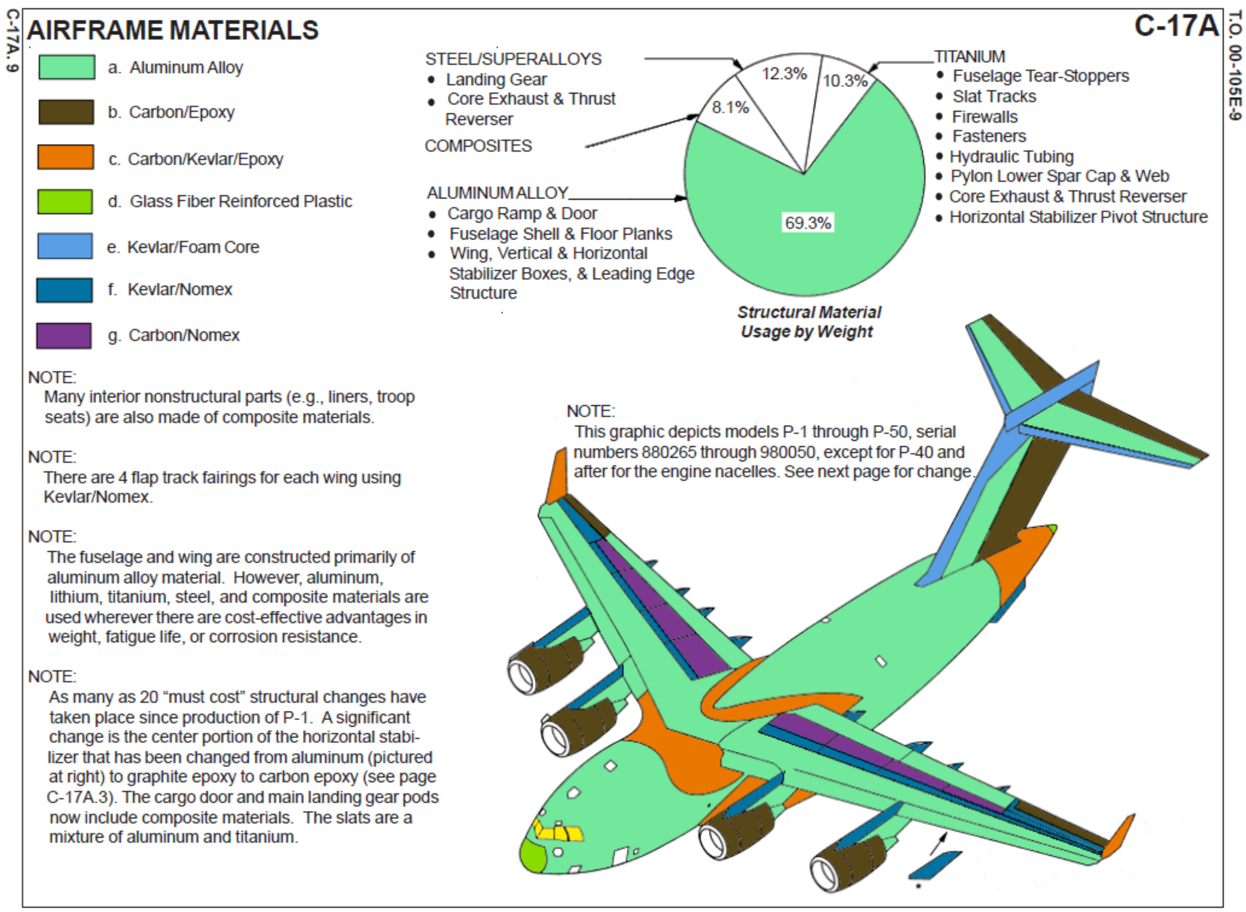

Figure 1. External Material Composition of the C-17 [22]

11.0 HAZARDOUS WASTE

11.1 Test burned composite material for disposition purposes. Tests for organics, inorganics, and metals have typically shown no detectable levels.

11.2 Additional guidance may be found in the following documents:

- DRMS-I 4160.14, Volume II, Chapter 4**,** paragraph 18, “Composite Fiber Property,” 19 June 2008
- DoD 4160.21-M, Attachment 1, Chapter 10, Section 5, “Carbon Composite Fiber Material,” August 1997

11.3 Accomplish the demilitarization of materials for final disposition in the following ways:

- Treat with a fixative (water and floor wax solution).
- Bag in durable plastic or cover with shrink wrap.
- Seal and label appropriately prior to disposal.

12.0 STORAGE AND FINAL DISPOSITION CONSIDERATIONS

Mishap investigators will typically keep aircraft wreckage in storage for 1 year after the mishap. The material must be available for follow-up analysis. Investigation team and recovery site workers wrap materials in plastic for preservation and to prevent future potential exposures if they are disturbed. The wreckage should be sorted by systems and/or materials such as avionics, hydraulics, composites, etc. If the material is not sorted initially, then all the materials will have to be handled again. This will potentially cause unnecessary exposure and subsequent risk. The Defense Reutilization and Marketing Office requires that materials be packaged together for disposal, segregating and grouping according to material type. Labeled crates brought out to the crash site for recovery will aid in storage and disposal procedures of the wreckage.

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APPENDIX A: B-2A CRASH (89-0127) ON 23 FEB 2008

1. The following two pictures show the debris from the B-2A crash.

Source: Federal Aviation Administration (FAA)
http://www.fire.tc.faa.gov/ppt/materials/June09Meeting/hode-0609-CompositeFuselageFirefightingWork.ppt

2. A video of the crash showing the smoke plume is available at the following site:
http://www.acc.af.mil/shared/media/document/AFD-080605-049.wmv

3. The following is a description of the investigation of the crash quoted from the accident report by SAF/AQRT [9]:

> 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 29.517 m^2. The left main landing gear rested 475 m 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 717 m from initial ground contact. The pilot (left) seat rested 458 m from the aircraft. The co-pilot seat rested 431 m from the aircraft. The hatches were located 568 m and 578 m 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 carne to rest on its bottom outer mold line. The survey determined the debris field area was 18,964 m^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 1000 ft 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 JP-8 burning over time. As 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 intema1 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 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 firefighting tactics were used during the first and second phase. The aircraft came to rest with the nose facing in the upwind direction allowing the firefighting response to attack in the downwind direction concentrating the flow of firefighting 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 firefighting 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 1200-1 500°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 l.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 damaged/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 (SO% 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 clays from the mishap event. The cordon was reduced to 50 ft 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 beat to continue to penetrate and burn through thickness (layer-by-layer). Without having adequate water pressure or a water source nearby, 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 bum 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). Firefighters 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 firefighters 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 firefighting 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 firefighting 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 firefighting should be accomplished with hose lines. Only by using hose lines can firefighting 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 firefighting 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 cannot 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 1/2 mile away from the scene. With effective agent conservation tactics that relies predominately on hose lines; such firefighting operations can be sustained more effectively, even with low flow hydrants.

10. The fire department did not have knowledge that four B-2As were flying on the clay 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.

APPENDIX B: PICTURES OF THE C-17 CRASH FROM 28 JULY 2010

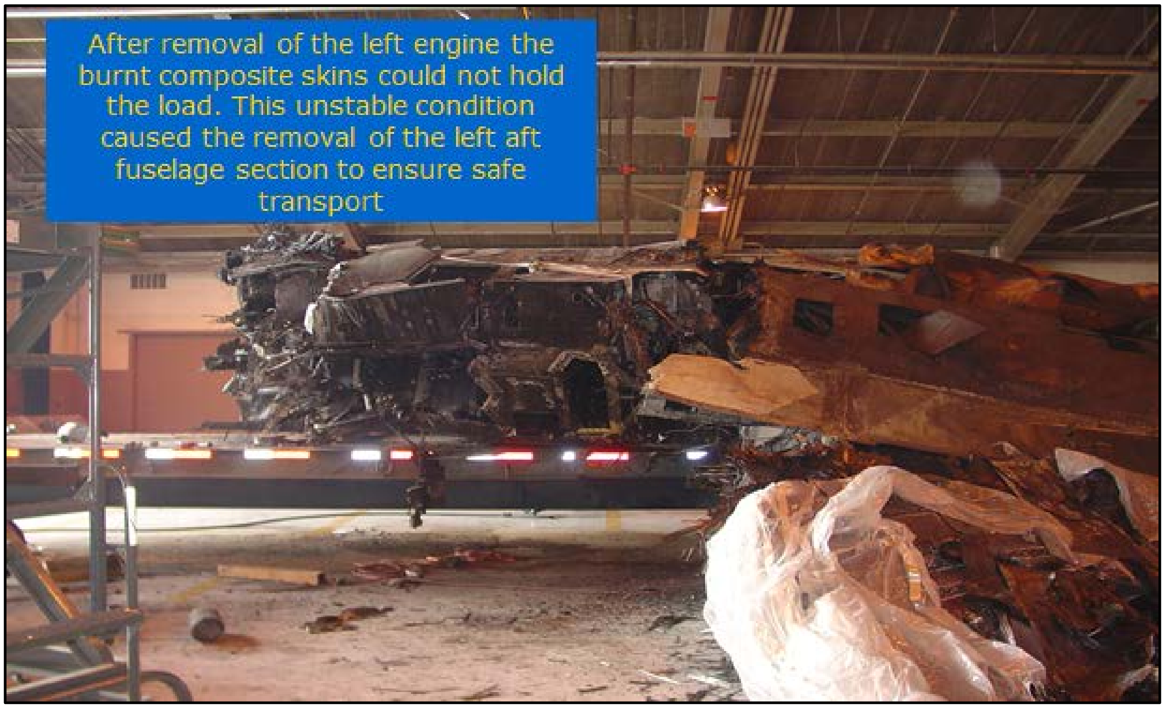
JOINT BASE ELMENDORF-RICHARDSON, AK

-- The wreckage of a 3rd Wing C-17 that crashed shortly after take-off at about 6:14 p.m. (Alaska time) during a local training mission July 28, 2010.

-- The four crew members on board were killed in the crash (Air Force photos/Senior Airman Cynthia Spalding).

APPENDIX C: PICTURES OF THE F-22A TEARDOWN

SOURCE: A. Sloper, "649 CLSS F-22A Teardown 14 June 2006," F-22A Program Development slide presentation, Hill AFB, 2006.



SOURCE: A. Sloper, "649 CLSS F-22A Teardown 14 June 2006," F-22A Program Development slide presentation, Hill AFB, 2006.

APPENDIX D: AIRCRAFT COMPOSITE MATERIAL LOCATIONS

Composite Materials Field Guide

Aircraft	Location	Composite Fibers/Matrix *								No Composite
		AR/EP	B/EP	C/EP	C/BMI	GR/EP	GR/BMI	GL/EP	GL/BMI	
A-10C	Leading Edges	X				X				
B-1B	Ailerons					X				
	Fairings					X				
	Longeron		X							
	Weapons Bay Doors					X				
B-2A	Control Surfaces							X		
	Ducting					X				
	Leading Edges							X		
	Trailing Edges							X		
	Wing Skin/Substructure					X				
B-52H	Radome							X		
C-130 All Variants	Radome							X		
C-130J	Radome							X		
	Trailing Edge Panels					X				
C-17A	Ailerons					X				
	Wing Fillet Panels					X				
	Landing Gear Doors					X				
	Vertical and Horizontal Stabilizer Leading Edges**					X				
	Nacelle Access Doors					X				
	Radome							X		
	Rudders					X				
	Spoilers*					X				
	Horizontal Stabilizer					X				
	Wing Trailing Edge Panels**					X				
	Wing Leading Edge Access Panels*					X				
	Main Landing Gear Pod					X				
	Elevators					X				
	Tailcone					X				
	Upper Pylon Fairing**					X				
	Winglets					X				
	*= graphite/epoxy face sheets and Nomex core (sandwich panel)									
	**= Kevlar foam core (sandwich panel)									

AR/EP = Aramid/Epoxy
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C/EP = Carbon/Epoxy
C/BMI=Carbon/Bismaleimide
GR/EP = Graphite/Epoxy
GR/BMI = Graphite/Bismaleimide
GL/EP = Fiberglass/Epoxy
GL/BMI=Fiberglass/Bismaleimide

Aircraft	Location	Composite Fibers/Matrix *								No Composite
		AR/EP	B/EP	C/EP	C/BMI	GR/EP	GR/BMI	GL/EP	GL/BMI	
C-20B	Rudder					X				
	Flaps					X				
C-20C	Rudder					X				
	Flaps					X				
C-20E	Rudder					X				
	Flaps					X				
C-20H	Rudder					X				
	Flaps					X				
C-21A										X
C-32A/B	Control Surfaces	X		X						
	Aft Flaps	X		X						
	Spoilers	X		X						
	Main Landing Gear Doors	X		X						
	Thrust Reverser Translating Sleeves	X		X						
	Fan Cowls	X		X						
	Tip Fairing	X								
	Facing	X								
	Strut Fairing Fixed Lower LE Panels	X								
	Thrust Reverser (Fixed Structure)	X								
	Nose Landing Gear Doors	X		X				X		
	Wing/Body Forward Fairing	X		X				X		
	Fixed TE Panels Upper/Lower	X		X				X		
	Wing Main Landing Gear Doors	X		X				X		
	Wing Body Aft Fairing	X		X				X		
	Flap Track Fairings	X		X				X		
	Fixed TE Panel (Typical)	X		X				X		
C-37A/B	Winglets					X				
	Control Surfaces					X				
	Main Landing Gear Doors					X				
	Nose Landing Gear Doors					X				
	Radome							X		
	Tailcone							X		
	Vertical Outlet Fairing							X		
C-38A		X		X		X				

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Aircraft	Location	Composite Fibers/Matrix *								No Composite
		AR/EP	B/EP	C/EP	C/BMI	GR/EP	GR/BMI	GL/EP	GL/BMI	
C-40B/C	Radome							X		
	Inboard Fixed Leading Edge Lower Skin Panel							X		
	Inboard and Outboard Fixed Trailing Edge							X		
	Outboard Fixed Leading Edge							X		
	Wing-to-Body Fairing							X		
	Flap Track Fairings							X		
	Ailerons							X		
	Dorsal Fin							X		
	Aileron Tabs					X				
	Trailing Edge Panels							X		
	Rudder					X				
	Tailcone							X		
	Elevators					X				
	Nose Landing Gear Doors					X				
	Winglets					X		X		
C-5 All Variants	Radome							X		
C-9C	Radome							X		
CV-22	Airframe Materials					X		X		
E-4B										X
E-9A										X
F-15 All Variants	Horizontal Stabilizer		X							
	Rudder		X							
	Vertical Stabilizer		X							
	Speed Brake			X						
	Radome							X		
F-16 All Variants	Horizontal Stabilizer			X						
	Vertical Stabilizer			X						
	Rudder			X						
	Ventral Fin							X		
	Radome							X		

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GL/BMI=Fiberglass/Bismaleimide

Aircraft	Location	Composite Fibers/Matrix *								No Composite
		AR/EP	B/EP	C/EP	C/BMI	GR/EP	GR/BMI	GL/EP	GL/BMI	
F-22A	Edges				X					
	Horizontal Stabilizer - pviot shaft, ribs & spars			X						
	Vertical Stabilizer - upper & lower spars, rear spar			X	X					
	Wing Skins									
	Wings Intermediate Spars				X					
	Fwd Fuselage Chine Beam				X					
	Fwd Fuselage Fuel Tank Walls			X						
	Mid Fuselage Upper Longerons				X					
	Mid Fuselage Shear Webs			X						
	Mid Fuselage Keel Beam				X					
	Ducting			X						
F-35A	NLG Doors					X				
	Gun Bump					X				
	Ducting					X				
	Weapons Bay Doors					X				
	Lower Panels and Skins					X	X			
	Boom Upper/Lower Skins						X			
	Lower Engine Covers						X			
	Nacelle Liner						X			
	Wing to Body Fairing					X				
	MLG Door					X				
	Rudder Skins						X			
	Horizontal Stabilizer						X			
	Leading Edge Flap					X			X	
	Flaperon						X			
	Vertical Stabilizers Skins						X			
HH-60G	Cockpit Surface	X								
	Main Body					X				
KC-10A	Radome							X		
KC-135 All Variants	Radome							X		
MQ-1	Outer Fuselage	X		X						
	Landing Gear			X						

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GL/BMI=Fiberglass/Bismaleimide

Aircraft	Location	Composite Fibers/Matrix *								No Composite
		AR/EP	B/EP	C/EP	C/BMI	GR/EP	GR/BMI	GL/EP	GL/BMI	
MQ-9	Outer Fuselage	X		X						
	Landing Gear			X						
	**Other composite materials not be classified under the existing columns were found									
RC-135 All Variants	Radome							X		
RQ-4B	Aft Fuselage					X				
	V-tail Skins					X				
	V-tail Spar					X				
	Ruddervators					X				
	Wing Skins					x				
	Wing Spars and Ribs					X				
	Leading/Trailing Edges					X				
	Ailerons					X				
	Spoilers					X				
	Engine Fairing Pan						X			
	Wing Fuel Baffles							X		
	Radomes							X		
T-1A	Bird Strike Shield	X								
T-38A/C										X
T-53	Fuselage							X		
	Elevator Tip							X		
	Rudder Horn							X		
	Horizontal Stabilizer							X		
	Wing							X		
	Wing Tip							X		
	Engine Cowl							X		
	Wing Spar					X				
	Cabin Doors					X				

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GL/EP = Fiberglass/Epoxy
GL/BMI=Fiberglass/Bismaleimide

Aircraft	Location	Composite Fibers/Matrix *								No Composite
		AR/EP	B/EP	C/EP	C/BMI	GR/EP	GR/BMI	GL/EP	GL/BMI	
T-6A/B	Outboard Gear Doors					X				
	Cowling Inlet Lip					X				
	Air Conditioner Compressor Bump on the Forward Cowl					X				
	Wing Tip Fairings							X		
	Dorsal Fairing							X		
	Strake Fairings (Horizontal Stabilizer)							X		
	Glare-shield							X		
	Tailcone							X		
TG-16A	Fuselage							X		
	Empennage							X		
	Winglets							X		
	Wings			X						
TH-1H	Radome							X		
U-28A	Ventral Strakes	X								
	Dorsal Fin	X								
	Fairings							X		
	Engine Cowling							X		
	Wing Tips							X		
T/U-2S	Rudders					X				
	Elevators					X				
	Vertical Stabilizer Leading Edge	X						X		
UH-1 All Variants	Propeller							X		
UV-18B										X

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GL/EP = Fiberglass/Epoxy
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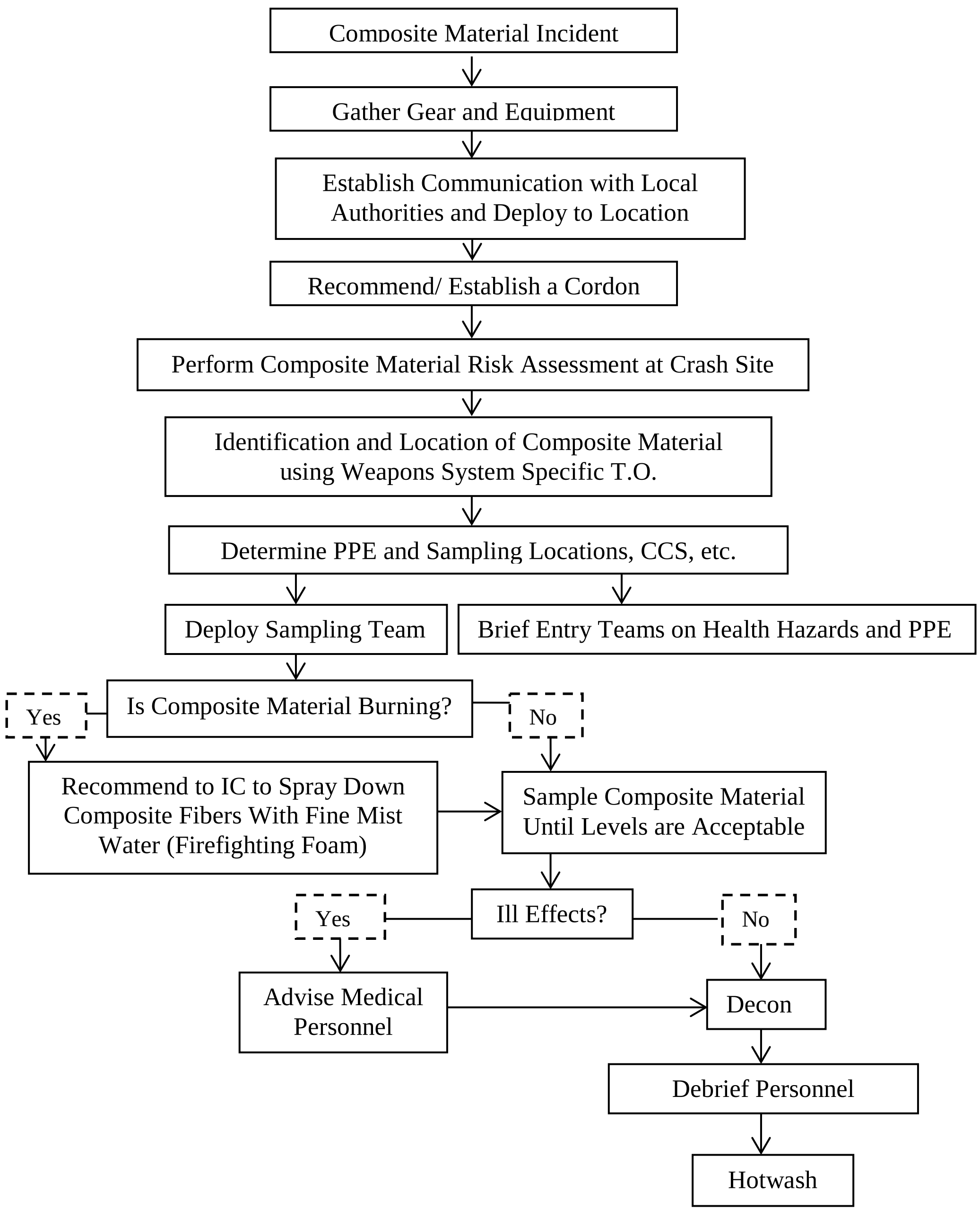
APPENDIX E: CHECKLIST FOR RESPONSE TO AIRCRAFT MISHAPS INVOLVING COMPOSITE MATERIALS

(adapted from [6])

ALL PURPOSE CHECKLIST	PAGE 1 OF 6 PAGES		
TITLE: Bioenvironmental Engineering (BE) Checklist - Aircraft Composite Fiber	**OPR**	**DATE**	
ITEM	**Y**	**N**	**N/A**

Composite Material Incident Flow Chart



ALL PURPOSE CHECKLIST		PAGE 2 OF 6 PAGES	
TITLE: Bioenvironmental Engineering Checklist - Aircraft Composite Fiber			
ITEM	**Y**	**N**	**N/A**
PURPOSE: To provide BE flight personnel critical response procedures for aircraft mishaps involving composite materials, in order to minimize associated environmental, health, and safety hazards. **INITIAL ACTIONS:** a. Load the following equipment, if available, into the response vehicle: 1) Full-face air-purifying respirators with N, R, or P100 filters 2) Coated Tyvek® suits with hoods and booties 3) Leather work gloves 4) Nitrile gloves (inner) 5) Hard-soled, steel-toed boots (safety-toe, reinforced shank, if boron composites involved) 6) Air sampling pumps (low flow) 7) Air flow calibrator 8) Analytical balance with 1 mg sensitivity (possible locations: PMEL, Fuels Lab) 9) Applicable sample media for hazardous aerospace material of concern 10) Tygon/rubber tubing 11) Tripod or mounting stand for area samples 12) NIOSH Manual of Analytical Methods 13) Maps (base grid, area, topographical) 14) Portable lights/flashlights for night operations (with extra batteries) 15) Wet Bulb Globe Temperature (WBGT) Meter b. Once the type of aircraft involved in the mishap is known, check APPENDIX D, AIRCRAFT COMPOSITE MATERIAL LOCATIONS to obtain information on the potential locations of aircraft components that may contain composite fibers. c. Consider wind direction and speed when establishing a safe route to the scene and for an upwind recommendation for the entry control point. d. Notify downwind areas to keep windows/doors shut and tell the population to remain indoors if they are not evacuated due to fire and smoke plume effects. e. Restrict helicopters from the area to avoid fiber and dust re-suspension.			

ALL PURPOSE CHECKLIST		PAGE 3 OF 6 PAGES		
TITLE: Bioenvironmental Engineering Checklist - Aircraft Composite Fiber	**OPR**	**DATE**		
ITEM		**Y**	**N**	**N/A**

RESPONSE SITE ACTIONS:

a. Senior BE representative reports to Incident Commander (IC) or Emergency Operations Center (EOC), if applicable; otherwise, senior officer and enlisted should report to the ECP.

b. Attend initial situation briefing and record available information, typically located at the ECP or alternate location. If necessary, ensure that location meets criteria for protection against fibers.

c. Recommend establishing a controlled area to the IC. Typically, the controlled area is a minimum radius of 25 feet from damaged composite parts; this distance can vary depending upon environmental conditions (rain, dry, high winds, wind direction, remote site, etc.).

d. Recommend that only firefighters and other IC directed personnel equipped with self-contained breathing apparatus (SCBA) inside the controlled area while there are burning/smoking components at the mishap site or until the incident commander declares the area fire-safe. Since respiratory irritation and health problems from inhalation of fiber particulate and dust are a major concern, take care to avoid high-pressure water break-up and destruction of composite structures. If structural break-up is occurring, recommend to the IC to have the firefighters control their high-pressure water spray so break-up and dispersal of the composite structures is mitigated.

e. Brief the entry team personnel on the potential hazards involved with recovery operations:

1) Exposure to fibers and respirable/inhalable dusts created by parts being moved, cut, hammered, etc.
2) Break up and air dispersal of fibers.
3) Generation of dust and noise from mechanical equipment and actions.
4) Handle composite fiber carefully to avoid piercing protective equipment and unprotected skin.
5) Move parts with extreme caution/care following good ergonomic practices to avoid back and muscle strains.
6) Avoid rubbing exposed skin to minimize dermal problems.
7) Secure burned and mobile composite fragments and particulate residue with firefighting foam or a fine water mist until a hold-down fixate material can be applied to immobilize the fibers.

f. Develop and air-monitoring strategy, to include personnel and area samples, to document exposure to response and recovery personnel.

g. Calibrate air sampling equipment, setup WBGT unit, as needed, and continue recording data/observations on a Chronological Log of Events sheet.

h. Initiate the air sampling plan.

ALL PURPOSE CHECKLIST		PAGE 4 OF 6 PAGES		
TITLE: Bioenvironmental Engineering Checklist - Aircraft Composite Fiber	**OPR**	**DATE**		
ITEM		**Y**	**N**	**N/A**
i. Until air sampling data on the hazards present during recovery operations are obtained, initial entry and eventually recovery personnel disturbing or moving aircraft parts should wear the following recommended protective equipment: 1) Respirator: As a minimum, a NIOSH-approved full-face, negative pressure respirator with N, R, or P100 filters 2) Coveralls: Tyvek® suit with hood 3) Gloves: Inner nitrile (disposable or reusable) with outer leather 4) Shoes: Steel-toed work boots (safety-toe, reinforced shank recommended if boron composites involved) 5) Hearing protective devices				
j. Only enter the site when required and always wear the PPE stipulated in the site safety plan. Note: Although BE flight personnel normally do not enter the controlled area until the area is declared safe by the fire chief (and Explosive Ordnance Disposal, if applicable), BE flight personnel may enter the area to collect environmental samples.				
k. Collect a roster of all response personnel and entry teams for future medical monitoring.				
l. If conducting ACM field analysis of gravimetric samples, return samples to an environmentally controlled area and follow NIOSH Method 0500 or 0600 (as applicable). NOTE: For additional assistance beyond the scope of this guide or for expedited analytical support, additional information can be gained by contacting the ESOH Service Center at DSN 798-3764, 1-888-232-ESOH (3764) or esoh.service.center@wpafb.af.mil.				
m. Instruct entry/reentry personnel to: 1) Carefully remove loose fibers from contaminated clothing before removing the contaminated clothing. When exiting the crash site, personnel may use a high efficiency particulate air (HEPA) filtered vacuum, if available, to remove advanced composite contaminants/fibers from outer clothing, gloves, boots, etc. Possible sources for HEPA vacuums are the Asbestos Removal Team and Structural Maintenance. In addition, personnel should shower using tepid to cool water after removal of the protective clothing to help prevent dermal irritation.				

ITEM	Y	N	N/A
2) Advise the local medical staff of any ill effects they believe are related to exposure to the composite materials or to the recovery operation. Symptoms of ill effects include, but are not limited to: a) Respiratory tract irritation and reduced respiratory capacity b) Eye irritation c) Skin irritation, sensitization, rashes, or infections			
n. Recommend eating and drinking only within designated areas outside the contaminated area. Note: No eating, drinking, or smoking within a minimum of 25 feet of the contaminated area or as otherwise determined by the IC to prevent ingestion of fibers.			
o. Identify other potential hazards as part of an all hazards response team (AHRT) approach (e.g. jet fuel or hydraulic fluid; radioactive components, such as depleted uranium counterweights, isotopes associated with inertial navigational equipment, etc.; and any explosive components such as ammunition or explosive bolts.)			
p. Establish clean rooms (e.g., tents or trailers) with IC direction. When available, all personal protective equipment should be donned in a clean room, with the respiratory protection worn under all equipment so it can be removed last. If possible, the clean rooms should have incorporated shower facilities.			
q. Prevent contamination spread: Remove outer garments from contaminated patients at the scene, if practical, before transporting them to the medical treatment facility. If removal of outer garments at the scene is not in the patient's best medical interest, cover the patient to prevent the dispersal of contaminants. Inform the receiving medical facility that contaminated patients are on the way and they should possibly activate their decontamination team to prepare the fiber-contaminated patients for treatment.			
r. Work with the IC and other response site representatives to minimize re-entrainment of airborne fibers and dust using recovery techniques (generally the wet method) that avoid excessive disturbance of the dust and material at the crash site.			
s. Monitor the waste stream generation resulting from the crash response effort. Ensure disposable protective clothing (coveralls and gloves) are wrapped and sealed in protective plastic bags after use and are discarded as waste. Carefully launder non-disposable, reusable clothing. If laundered by a contractor, coordinate with JA (legal) to inform the contractor of the presence of composite fibers and the potential fiber hazard.			

ALL PURPOSE CHECKLIST		PAGE 6 OF 6 PAGES		
TITLE: Bioenvironmental Engineering Checklist - Aircraft Composite Fiber	**OPR**	**DATE**		
ITEM		**Y**	**N**	**N/A**
CLEANUP AND DISPOSAL: a. Work with civil engineering to place hazardous waste material, based upon RCRA criteria, in sealed drums and dispose as a hazardous waste. If possible, use a HEPA vacuum to clean up the fibrous debris in the local area. Once the mishap debris has been cleared for release by the mishap investigation board, plus the vacuum bags, coveralls, gloves, and other contaminated materials, work with the environmental flight to dispose of the items. The items should be labeled with the following: "Composite Waste. Do not incinerate. Do not sell for scrap. Composite Waste." Any required hazard warnings should also be added. b. Brief entry team personnel on the potential hazards involved with the recovery operations: 1) Exposure to fibers and respirable/inhalable dusts created by parts being moved, cut, hammered, etc. 2) Break up and air dispersal of fibers. 3) Generation of dust and noise from mechanical equipment and actions. 4) Handle composite fiber carefully to avoid piercing protective equipment and unprotected skin. 5) Move parts with extreme caution/care following good ergonomic practices to avoid back and muscle strains. 6) Avoid rubbing exposed skin to minimize dermal problems. 7) Secure burned and mobile composite fragments and particulate residue with firefighting foam or a fine water mist until a hold-down fixate material can be applied to immobilize the fibers. c. Coordinate the final remediation process with the environmental flight or its equivalent and assist the IC in coordinating with the federal, state, and local environmental authorities. For open terrain mishap areas, the surface should be sprayed with a final foam application and plowed under after all necessary/possible material collection actions have been completed. d. Determine what types of environmental monitoring samples need to be collected, develop the sampling plan and work with the environmental flight or its equivalent, as necessary, to arrange for the analysis of the samples.				

LIST OF ABBREVIATIONS AND ACRONYMS

ACGIH .... American Conference of Governmental Industrial Hygienists
ACM .... advanced composite material
AFFF .... aqueous film-forming foam
AFOSH .... Air Force Occupational Safety and Health
AFB .... Air Force Base
AMIP .... Aircraft Mishap Investigation and Prevention
BEF .... Bioenvironmental Engineering Flight
ESOH .... Environmental, Safety, and Occupational Health
DoD .... Department of Defense
DRI .... direct reading instrument
f/cc .... fibers per cubic centimeter
HAM .... hazardous aerospace materials
HAMMER .... Hazardous Aerospace Material Mishap Emergency Response
HEPA .... high efficiency particulate air
IC .... Incident Commander
IERA .... Air Force Institute for ESOH Risk Analysis
lpm .... liters per minute
MCE .... mixed-cellulose ester
NIOSH .... National Institute for Occupational Safety and Health
OEEL .... occupational and environmental exposure limit
OSHA .... Occupational Safety and Health Administration
PAH .... polycyclic aromatic hydrocarbon
PEL .... permissible exposure limit
PPE .... personal protective equipment
PVC .... polyvinyl chloride
RAF .... Royal Air Force
STEL .... short-term exposure limit
TLV .... threshold limit value
T.O. .... technical order
TWA .... time-weighted average
USAFSAM .... United States Air Force School of Aerospace Medicine