AFRL-SA-WP-SR-2014-0010

Bioenvironmental Engineering Guide for Composite Materials

Maj Jon Black
Maj Richard Yon
Capt Timothy Batten
Mr. David DeCamp
Dr. Gregory Schoeppner

March 2014

Air Force Research Laboratory
711th Human Performance Wing
School of Aerospace Medicine
Occupational & Environmental Health Dept
2510 Fifth St.
Wright-Patterson AFB, OH 45433-7913

NOTICE AND SIGNATURE PAGE

AFRL-SA-WP-SR-2014-0010 HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION IN ACCORDANCE WITH ASSIGNED DISTRIBUTION STATEMENT.

//SIGNATURE//	//SIGNATURE//
DR. DAVID R. CARPENTER Senior Technology Consultant	COL MARK E. SMALLWOOD Chair, Occupational & Environmental Health

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From – To)*
31 Mar 2014	Special Report	June 2013 – March 2014

4. TITLE AND SUBTITLE

Bioenvironmental Engineering Guide for Composite Materials

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Maj Jon E. Black
Maj Richard Yon
Capt Timothy Batten
Mr. David DeCamp
Dr. Gregory Schoeppner

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

USAF School of Aerospace Medicine
Occupational & Environmental Health Dept
Consultative Services Division (USAFSAM/OEC)
2510 Fifth St.
Wright-Patterson AFB, OH 45433-7913

8. PERFORMING ORGANIZATION REPORT NUMBER

AFRL-SA-WP-SR-2014-0010

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Distribution A: Approved for public release; distribution is unlimited. Case Number: 88ABW-2014-2687, 3 Jun 2014

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This guide will provide base-level Bioenvironmental Engineering (BE) personnel a comprehensive baseline for identifying, evaluating, and controlling occupational and environmental hazards associated with composite fibers and materials. The expectation of this guide (in conjunction with other technical order driven directives) is to assist commanders with operational risk management procedures when responding to composite materials in aircraft repair and maintenance and crash and recovery operations. The BE should be able to identify potential inhalation and dermal hazards, recommend personnel protection options and decontamination procedures, recommend environmental controls and cordons, and select the appropriate sampling strategies and methodologies for the most suitable scenario. Specific recommendations are made to provide guidelines in the absence of established exposure standards and choosing the appropriate personal protective equipment in both the industrial and crash response and recovery settings based on the recommendations of the following technical reports: *Assessing Worker Exposures During Composite Material Repair, Industrial Hygiene Technical Report for Bioenvironmental Engineers* and *Assessment of Composite Material Hazards At Crash Sites: Industrial Hygiene Technical Report for Bioenvironmental Engineers*.

15. SUBJECT TERMS

Composites, composite materials, advanced composite materials, ACM, fiberglass, aircraft battle damage repair, ABDR, crash site, recovery operations, aircraft mishap, Maintenance Operations Crash Recovery Team

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Col Mark E. Smallwood
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(include area code)*
U	U	U	SAR	39	

This page intentionally left blank.

TABLE OF CONTENTS

LIST OF FIGURES

Figure **Page**

LIST OF TABLES

Table **Page**

1.0 INTRODUCTION

The use of composite materials is on the rise, as shown by the Air Force sponsored project to fly in 2009 an experimental military cargo aircraft composed of primarily composite materials [1]. Aircraft are not the only items with composite materials. The Air Force is also planning on using fiber-reinforced composite materials in rapid-assembly tactical shelters for deployments [2]. This guide captures the information located in Air Force Technical Order (T.O.) 00-105E-9, Aerospace Emergency Rescue and Mishap Response Information (Emergency Services), which is summarized in Appendix A. NOTE: T.O. 00-105E-9 has a restricted distribution classification F, which is controlled by the Air Force Civil Engineer Center; therefore, it is not reprinted in whole or in part with this document. T.O. 00-105E-9 can be obtained at https://www.dodffcert.com/00-105e-9/. The website also has a composite materials awareness course, which is summarized in Appendix B.

This guide is written to provide base-level Bioenvironmental Engineering (BE) personnel a comprehensive baseline for identifying, evaluating, and controlling occupational and environmental hazards associated with composite fibers and materials. The expectation from this guide (in conjunction with other T.O.-driven directives) is to assist commanders with risk management decisions when responding to composite materials in (1) aircraft repair and maintenance and (2) crash and recovery operations. BE personnel should be able to identify potential inhalation and dermal hazards, recommend personnel protection options and decontamination procedures, recommend environmental controls, and select the most suitable sampling strategies and methods for a given scenario. Specific recommendations are made for exposure standards and guidelines in the absence of established exposure standards and choosing the appropriate personal protective equipment in both the industrial and crash response and recovery settings based on the recommendations of the following technical reports: *Assessing Worker Exposures During Composite Material Repair: Industrial Hygiene Technical Report for Bioenvironmental Engineers* and *Assessment of Composite Material Hazards at Crash Sites: Industrial Hygiene Technical Report for Bioenvironmental Engineers*. A basic background of the composition of composite materials and a general toxicology understanding are helpful to BE personnel to better characterize the potential hazards created when fibers are released.

There are two primary scenarios that may require BE personnel to assess exposures to composite materials. This guide will address the most essential evaluation techniques encountered during routine health risk assessments accomplished in (1) aircraft repair and maintenance operations and (2) aircraft crash and recovery operations. The basic skills needed to identify, evaluate, and control composite hazards complement one another. BE personnel should be prepared to follow up routine health risk assessments by identifying and capturing hazardous processes that involve inhalation and dermal exposures to composite materials and fibers. Typically, this can be accomplished by incorporating air sampling strategies into special workplace surveillance during repair and maintenance operations. BE personnel may also be called upon to provide risk management recommendations to incident commanders in response to aircraft crash and recovery operations that involve physical damage and/or combustion of aircraft parts. The risk for exposures to composite materials varies by the technology, type, and age of the aircraft, and specific information about the aircraft of concern can be found in the applicable T.O.

1.1 Description of Composite Materials and Fiberglass

Generally, the term "composite materials" refers to fibers bound with a resin in a polymer matrix. The fibers within composites are the load-bearing elements, while the resin molecules fill the voids and transfer the stress from fiber to fiber. Composite materials are "advanced" if the material has properties of high strength, high stiffness, low weight, corrosion resistance and, in some cases, special electrical properties. Industry uses a variety of fibers and binders in the fabrication of composite materials. The most common composite fibers encountered in the Air Force are glass, boron, carbon/graphite, and aramid (commonly known as Kevlar®). Glass fibers can be bound together by polymer resin to form fiberglass composites. The terms "graphite fibers" and "carbon fibers" are often used interchangeably from one reference to another. This may be because both materials are made from the same base material – carbon. The distinction between graphite and carbon fibers depends on the purity of the carbon contained in the fiber and in the manufacturing methods used to refine the carbon into a composite material. Additionally, there are composite materials that blend two or more basic fiber types into a blended hybrid material, such as "carbon-aramid-fiberglass" composite materials. The Air Force Research Laboratory continues to research new materials such as aluminum-carbon nanofiber composites and boron nitride nanotubes [3,4]. Furthermore, an aircraft structure can be composed of numerous types of composites and metals as shown in Figure 1. This type of structure is known as a hybrid structure. While there is a variety of fibers and fiber blends used in the Air Force, health risks are primarily associated with the inhalation and the contact hazard exposure pathways.

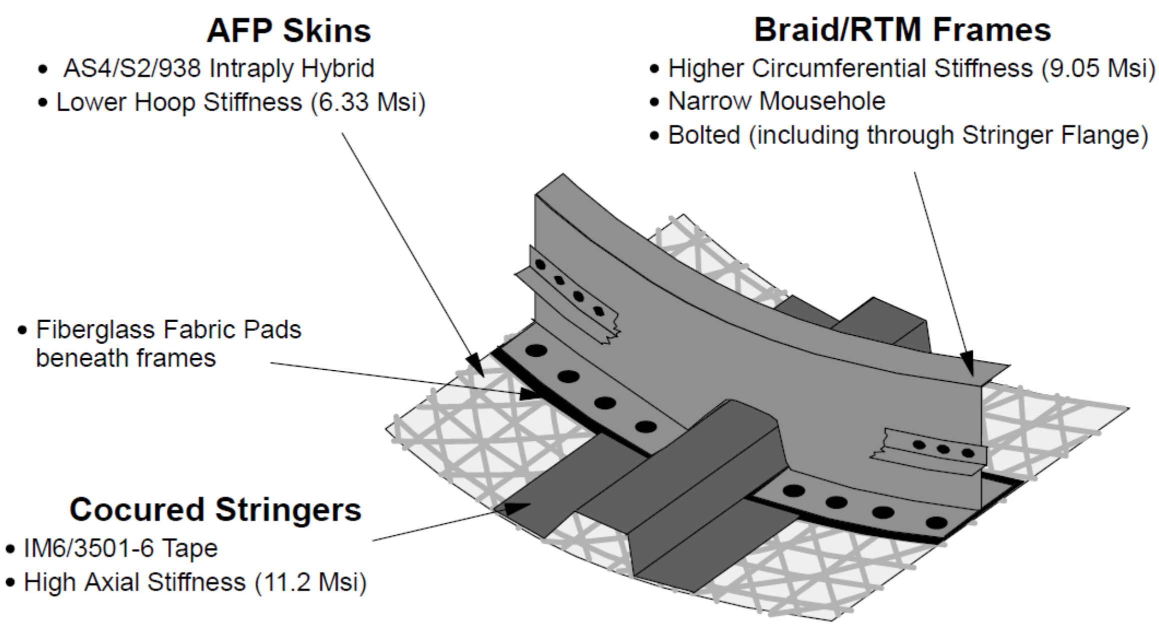


Figure 1. Hybrid Structural Configuration from MIL-HDBK-17-3F

1.2 Toxicology

Although some studies show composite fibers to be a potential health risk, other studies show the risk to be relatively less than that of asbestos or silica [5-7]. To date, a limited number of studies on the toxicology of inhaled carbon fibers have been conducted. A few studies have been conducted that relate to exposure from fibers and dusts in the workplace. These studies concluded that no long-term health risks have been associated with exposure to raw carbon fibers under occupational conditions [5]. Some animal studies with raw carbon fibers and composite dust have also been conducted. It was concluded that carbon fiber and composite dust are significantly less toxic than crystalline silica dusts and fibers, such as asbestos, although more research was suggested to verify these findings [5]. Additional research is needed to address the toxicity to composite fibers and their matrices.

1.3 Inhalation Hazards

Airborne composite materials and fibers have the potential to be hazardous to the respiratory system. The Mine Safety and Health Administration (MSHA) defines respirable dust as the fraction of airborne dust that passes a size-selecting device having the characteristics found in Table 1 [8].

Table 1. MSHA's Respirable Dust Characteristics

Aerodynamic Diameter (µm) (Unit Density Spheres)	Percent Passing Selector
2.0	90
2.5	75
3.5	50
5.0	25
10.0	0

Even though compliance agencies such as MSHA and the Occupational Safety and Health Administration (OSHA) specify a 50% cutpoint of 3.5 microns, the American Conference of Governmental Industrial Hygienists (ACGIH) specifies a 50% cutpoint of 4 microns [9]. This is in accordance with the International Organization for Standardization/European Standardization Committee (ISO/CEN) protocol [10,11].

Generally, dust and fibers that meet the aerodynamic characteristic described in Table 1 penetrate the airway beyond natural clearance mechanisms (cilia and mucous) and can become trapped within the alveoli of the lungs (sedimentation) [12]. Any time a foreign product is introduced into the respiratory tract, a risk exists of pulmonary scarring or other long-lasting respiratory damage. Because these particles enter where the gas exchange takes place within the lungs, other complications can arise as a result of exposure to the toxic products of combustion [12].

1.4 Dermal Abrasion/Puncture Hazards

The second specific hazard associated with composite materials is the puncture and irritation of the skin from exposed fibers on fragmented composite components. The dermal hazard risk is greater at an aircraft crash and recovery operation than under the controlled environment at a Maintenance Operations Low Observables/Composites facility; however, the BE technician should be aware of dermal hazards in each case. Skin irritation is possible because fragmented composites often have sharp, needle-like edges that can easily penetrate the skin. If a person should sustain a puncture, a composite splinter will tend to crumble, break apart, and stay below the surface of the skin. Composite splinters tend to fester and may cause sores, often disintegrating when attempts are made to remove them from the skin [13]. Research shows that irritation from the splintered fibers increases as the fiber's diameter increases [14]. Fibers that pose a dermal hazard are larger in diameter and length than airborne respirable fibers [5]. Exposed fibers from fragmented boron composites are suggested to present the most severe dermal puncture hazard. This is because the boron fibers are much larger in diameter (100 to 140 µm) than other fibers such as carbon fibers [14]. When fragmented, boron fibers also tend to form long, sharp, needle-like structures. No studies were identified that address the toxicology of skin punctures by exposed composite fibers at an aircraft crash and recovery operation.

1.5 Exposure Standards

1.5.1 Unchanged Exposure Standards. Occupational and environmental exposure limits (OEELs) are the Air Force specific exposure levels used by Bioenvironmental Engineering Flights to describe an exposure limit and control health risk. The OEELs are commonly adopted from established recognized standards (when possible) such as the OSHA permissible exposure limits (PELs), the ACGIH threshold limit values (TLVs), or a limit noted in an Air Force Occupational Safety and Health Standard (AFOSHSTD) or Air Force Instruction. In the 1999 technical report titled "Assessing Worker Exposure during Composite Material Repair: Industrial Hygiene Field Guidance for Bioenvironmental Engineers," the authors recommend using the *particulate not otherwise specified (PNOS)* standards for airborne composite hazards. As of March 2014, the current PNOS standard's values have not changed from those published in the original technical report. The approach for comparing composites to PNOS is also consistent with the National Institute for Occupational Safety and Health's (NIOSH) health hazard evaluations of composite material hazards [15]. The U.S. Air Force School of Aerospace Medicine (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)
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") [9]

1.5.2 Updated Exposure Standards. While the gravimetric PNOS standard has remained unchanged as the OEEL for composite materials, there is a significant change regarding the fiber per cubic centimeter (f/cc) OEEL. The previously mentioned 1999 technical report included an 8-h time-weighted average OEEL of 1.0 f/cc for all types of composite fibers "by analogy to synthetic vitreous fibers," i.e., the fiberglass OEEL. In essence, this promulgated a blanket comparison of all composite fibers to the fiberglass standard of 1.0 f/cc. Controlling occupational exposures of all composite compositions to the fiberglass standard is neither supported in the peer-reviewed literature nor regulatory guidance. 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 composites are measured using a gravimetric sample analysis and reported in milligrams per meter cubed (mg/m^3). The recommended exposure limits for composite material during repair and maintenance operations are presented in Table 2 [9,16]. 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. Under most circumstances, comparing gravimetric samples from an aircraft mishap to the exposure limits in Table 2 would present high uncertainty to provide a valid risk assessment.

Table 2. Exposure Limits for Composite Fibers during Repair and Maintenance Activities

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

[a]Units f/cc.

2.0 REPAIR AND MAINTENANCE OPERATIONS

2.1 Air Sampling Strategies for Repair and Maintenance Operations

2.1.1 Introduction. With the basic foundation from section 1.0 established, a framework can be built regarding the more specific assessments for evaluating either repair and maintenance operations or aircraft crash and recovery operations. Section 2.0 will focus on air sampling and controls of composites during repair and maintenance operations, while section 3.0 will similarly detail assessments at an aircraft crash and recovery operation.

2.1.2 Use of T.O. 00-105E-9 for Locating Specific Composite Materials during Repair and Maintenance Activities. Repair and maintenance processes involving the potential exposure of composite fibers are characterized according to the specific type of composite material. The BE technician can reference T.O. 00-105E-9 when performing exposure assessments and health risk assessments for composite material and fiber exposures encountered in industrial activities. T.O. 00-105E-9 provides the location and types of composite materials on most aircraft in the Air Force inventory [17]. The T.O. information is based on source data that are provided by System Program Offices (SPOs) for specific weapons systems or aircraft manufacturers. The System Program Offices decide if modifications to their weapon system warrant sending new information to update T.O. 00-105E-9. Classified and some unclassified sensitive information are in T.O. 00-105E-9. The information in T.O. 00-105E-9 may not be current for all aircraft.

The exact location and composition of composite material between multiple aircraft of the same weapon system could vary depending on the scheduled changes through depot level repair and maintenance.

Process information/details can be obtained from the Maintenance Operations Low Observables/Composites shop supervisors. Knowing the composite matrix during sanding, grinding, scarfing, and depainting allows for the selection of the appropriate sample and analytical method. This is important because gravimetric analytical methods cannot separate composite species directly; therefore, either the repair and maintenance technician or the BE technician will have to determine through T.O. what composites are being characterized in the air sampling narrative. This is needed specifically in the case of graphite, which has a lower TLV than other respirable particulates. The recommended OEELs for repair and maintenance activities are presented in Table 2 [18].

2.1.3 Advanced Composite Material Repair and Maintenance Processes of Concern. Repair activities that pose a concern for composite material release are as follows: depainting, drilling, cutting, grinding, routing, sanding, or grit blasting. The recommended air sampling methodology for these activities is presented in Table 3 [18]. Consult the USAFSAM laboratory sampling guide for appropriate procedures for requesting analytical services.

Table 3. Recommended Sampling Methodology for Composite Material Repair

Substance	Sampling Method	Sampling Media	Sampling Flowrate (lpm)	Equipment
PNOS, Respirable	NIOSH 0600	Pre-weighed, 5.0-µm polyvinyl chloride, 37-mm cassette with cyclone	1.7 (nylon) 2.5 (aluminum)	Cyclone, sample pump, tubing, calibration unit, blanks

2.1.4 Fiberglass Repair and Maintenance Processes of Concern. Processes that involve depainting, drilling, cutting, grinding, routing, sanding, or grit blasting of fiberglass are of concern for inhalable fiber release. The recommended air sampling methodology for fiberglass is presented in Table 4 [18]. Ensure the NIOSH 7400 analysis is conducted under the alternate counting rules for non-asbestos fibers, designated as the B rules.

Table 4. Recommended Sampling Methodology for Fiberglass Repair

Substance	Sampling Method	Sampling Media	Sampling Flowrate (lpm)	Equipment
Synthetic Vitreous Fibers	NIOSH 7400 B Rules	0.8-µm mixed-cellulose ester filter, 25-mm cassette with conductive cowl	2.0	Sample pump, tubing, calibration unit, blanks

2.1.5 Aircraft Battle Damage Repair (ABDR). The same general processes concerning composite material repair and maintenance are performed in a traditional Maintenance Operations Low Observables/Composites shop as those performed during ABDR. Likewise, the recommended air sampling for composites found above in Tables 3 and 4 applies equally to those processes when performed during ABDR [18]. The only difference for ABDR from traditional repair and maintenance operations is the use of the M-50 protective mask during chemical, biological, radiological and nuclear training operation. The M-50 protective mask shall not be used for controlling occupational exposures to hazardous chemicals of any type and may only be used for training scenarios for which respiratory protection is not required.

2.2 Engineering Controls

2.2.1 Crossflow Sanding Booths. Fiberglass repairs typically take place in crossflow sanding booths because most aircraft fiberglass parts are relatively large. Most crossflow sanding booths in the Air Force are essentially paint booths in which sanding/grinding is done. There are, however, commercially available sanding booths designed specifically for composite repair; one example is the Torit® Power Module. Sanding booths are not as effective at controlling particulates as downdraft tables, hand-held vacuum hoses, moveable exhaust hoods, and ventilated tools, which capture particulates at the source of generation. Workers frequently position themselves between the part being sanded/scarfed and the exhaust location, causing contaminants to pass through their breathing zone and increasing their exposures. Sanding booths can be effective in reducing exposures if used in conjunction with some of the other systems listed below. There are no current guidelines in the industrial hygiene literature on effective ventilation rates for crossflow sanding booths.

2.2.2 Hand-Held Vacuum Hoses. Workers occasionally hold a vacuum hose near the part being scarfed to collect particulates generated. The hose is typically attached to a vacuum equipped with a high-efficiency particulate air (HEPA) filter. This system is more effective than a crossflow sanding booth because it collects particulates closer to the point of generation, but can cause significant fatigue for the workers since workers are holding the hose in one hand and the pneumatic tool in the other. Holding the hose with the free hand also results in the workers' breathing zones being physically closer to the point of contaminant generation, increasing exposures. Hand-held vacuum hoses should have air flows similar to those for moveable exhaust hoods.

2.2.3 Downdraft Tables. Downdraft tables have grilles on the table surface through which particulates are drawn. Downdraft tables usually have back and side shields to enclose the operation as much as possible. Air is drawn by a fan through a filter bank and exhausted either into the same room the booth is in or to the outside of the building, depending on the design. Positioning of the part on the table can influence the ability to collect particulates depending on the design of the table because air velocities can vary widely across the table surface. Air velocities should be measured across the surface of the downdraft table. Sufficient measurements should be taken to estimate the average flow. An air flow of 150-250 cubic feet per minute (cfm) per square foot of table surface area is recommended [19,20].

2.2.4 Moveable Exhaust Hoods. Moveable exhaust hoods generally have flexible exhaust ducts connected to a relatively small exhaust hood. A hinged arm may support the hood to allow positioning of the hood near the source of dust generation. Ensure the hood is placed within a few inches of the work surface and positioned toward the direction particulates are being thrown. The effective maximum distance of the hood from the source varies depending on the type of hood (e.g., a flanged slot typically performs better than a hood without a flange) and the velocity of the particulates emitted. As a rule of thumb, the maximum capture distance should not be more than 1.5 times the duct diameter. Air velocities should be measured across the face of the exhaust hood. Sufficient measurements should be taken to estimate the average flow. A minimum volumetric air flow of 400 cfm with a minimum duct velocity of 4000 feet per minute is recommended [19,20].

2.2.5 Ventilated Pneumatic Tools. Ventilated sanders and grinders typically have a number of holes located in the rotary disc through which particulates are drawn. The tool may also have a ventilated shroud (or extractor hood) covering the disc. The tools attach via a hose to either a vacuum containing a HEPA filter or a central vacuum system located in the shop. Ensure the sandpaper the workers use is compatible with the sander; the sandpaper should have the same number of holes as the sander and the holes should be properly aligned. Some sanders come with locking discs, while others have adhesive on the back of the sandpaper. Locking discs ensure proper alignment of the sandpaper with the holes. Measure the air velocity at the holes and multiply by the area of the holes. If the tool has a shroud, measure velocities at several places around the shroud and multiply by the area through which the air is drawn; add this value to the air flow through the holes. Sanders should have a minimum air flow of 10 cfm per inch of disc diameter; grinders should have a minimum air flow of 25 cfm per inch of disc diameter [19,20]. A portable HEPA vacuum will, in most situations, provide ventilation rates much lower than recommended; a central vacuum system, if properly operating, will probably provide better ventilation rates.

To achieve the right surface finish manually, workers inevitably tilt the sander away from the surface, which breaks the vacuum seal and allows dust to escape into the shop environment. When advanced engineering controls are needed to control exposure, pneumatically powered mechanical arms connected to pneumatic-ventilated sanders can reduce the instances of the need to break the vacuum seal to achieve the correct surface finish. These types of devices also are used to reduce the risks of repetitive stress and vibration-induced injuries.

2.3 Personal Protective Equipment (PPE)

Recommendations for PPE worn during common composite material repair processes should be based on the exposure assessment and the confidence in the controls. Assessments should focus on processes for which sanding or grinding of the composite materials is performed. Respiratory protection should only be considered following an evaluation of engineering and administrative controls. Personnel wearing any respirator must meet all the program requirements such as medical clearance; written program; training in the use, maintenance, and storage of respirators; fit-testing; etc. See AFOSHSTD 48-137, *Respiratory Protection Program* [21], for additional guidance and requirements. The use of non-latex rubber gloves should take into account both the composite fiber hazard as well contact hazards from related chemicals to include resins, epoxies, and solvents. However, the appropriateness of the glove material should be evaluated based on the specific solvents used to ensure permeation/breakthrough will not be an issue. If other factors such as abrasion and puncture resistance need to be considered, the use of multiple layers (e.g., double gloving) can increase thickness and/or provide the desirable properties of different materials. Coveralls may reduce skin exposure; however, contaminants may get under the coveralls by entering any loose areas around the neck and wrists. Taping closed the seams around the neck and wrists may help reduce contaminant intrusion under the coveralls. Goggles should be worn whenever material is being aerosolized from grinding or sanding processes in the absence of a full facepiece respirator.

3.0 AIRCRAFT CRASH AND RECOVERY OPERATIONS

3.1 Air Sampling Strategies for Aircraft Crash and Recovery Operations

Today's airframes have not only a variety of composite materials but may often have hybrid blends of composite materials. Therefore, referencing the specific aircraft's composite material makeup and utilizing Air Force T.O. 00-105E-9 can give BE personnel valuable insight to the relative composite hazards within most Air Force airframes. A historical review of sampling results from aircraft crashes and composite material combustion byproduct studies indicates single fiber concentrations after a crash are very low [6]. Therefore, if air sampling is being considered during an aircraft crash and recovery operation, the health risk exposure assessment should not center on composite fibers as the primary concern. Additionally, air sampling at a crash and recovery site for composite materials is confounded by non-composite particulate matter typically airborne at an aircraft crash and recovery site. Therefore, comparing the gravimetric result of a mixture of particulates to exclusively that of a composite material standard would grossly overestimate the composite material exposure assessment. A general checklist and flowchart for responding to an aircraft crash and recovery operation involving composite materials is provided in Appendix A [12].

3.2 PPE

PPE recommendations should be tailored to the specific hazardous aerospace material present and the site. Information regarding the location and type of hazardous materials (to include composites) on military aircraft is included in T.O. 00-105E-9 also known as *NATO Standardization Agreement 3896* [22].

3.2.1 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; written program; training in the use, maintenance, and storage of respirators; fit-testing; etc. Reference AFOSHSTD 48-137 for additional guidance and requirements [21].

3.2.2 Gloves. Leather gloves should be worn when handling crash debris to reduce the physical hazards of puncture and abrasion from sharp objects. It is important to remember that certain composite material, such as the boron fibers in an F-15, can easily penetrate the gloves and skin. Extra precaution should be taken 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.

3.2.3 Coveralls. Disposable Tyvek® coveralls should be worn 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).

3.2.4 Eye Protection. Goggles are recommended whenever material is disturbed such that material can potentially become airborne.

4.0 CONCLUSION

This guide focuses on the specific hazards directly from composites encountered during repair and maintenance operations and during aircraft crash and recovery response. By no means are composite materials the only chemical hazards in either of these scenarios. During repair and maintenance operations, there can be additional hazards from solvents, epoxies, and resins before and/or after the processes described in section 2.0 of this guide. Further information regarding these hazards can be found in "Assessing Worker Exposure during Composite Material Repair: Industrial Hygiene Field Guidance for Bioenvironmental Engineers" [18]. Likewise, composite materials are only one of many potential chemical inhalation hazards at an aircraft crash and recovery operation. There can be hazards from JP-8, polycyclic aromatic hydrocarbons and, in some cases, hydrazine. Each crash and recovery operation is unique. Experience and professional judgment, in conjunction with pre-planning and response exercises, will be needed for an effective response posture. Further information regarding response hazards can be found in "Assessment of Composite Hazards at Crash Sites: Industrial Hygiene Field Guidance for Bioenvironmental Engineers" [7]. In either case, additional information can be gained by contacting the Environmental, Safety, and Occupational Health Service Center at DSN 798-3764, 1-888-232-ESOH (3764) or esoh.service.center@wpafb.af.mil.

5.0 REFERENCES

1. Russell J. Advanced composite cargo aircraft proves large structure practicality. High-Performance Composites 2010 Jan. Retrieved 3 January 2014 from http://www.compositesworld.com/columns/advanced-composite-cargo-aircraft-proves-large-structure-practicality.
2. Air Force selects fiber-reinforced foam core for shelter contract. 2010. Retrieved 3 January 2014 from http://www.compositesworld.com/news/us-air-force-picks-webcore-for-next-generation-composite-shelters.
3. Sylvain DC. New Hampshire Ball Bearing, Astro Division, Laconia, New Hampshire, August 1996. Cincinnati, OH: NIOSH Publications Office; 1996. Health Hazard Evaluation Report 95-0207-2592.
4. Kim MJ. Collaborative research and development (CR&D). Delivery order 0056: novel nanotube synthesis. Wright-Patterson AFB, OH: Air Force Research Laboratory, Materials and Manufacturing Directorate; 2008 Feb. Report No. AFRL-RX-WP-TM-2010-4091.

5. Gandhi S, Lyon RE. Health hazards of combustion products from aircraft composite materials. Washington DC: Federal Aviation Administration, Office of Aviation Research; 1998 Sep. Report No. DOT/FAA/AR-98/34.
6. Kimmel EC, Reboulet JE, Courson DL, Whitehead GS, Still KR, Alexander WK, et al. Airway reactivity response to advanced composite material (ACM) combustion atmospheres: B2-ACM. Wright-Patterson AFB, OH: Naval Health Research Center Detachment Toxicology; 2000. Report No. TOXDET-00-02
7. Hinojosa M, Costantino J, Jarbeau JJ Jr., Hintz TJ. Assessment of composite hazards at crash sites: industrial hygiene field guidance for bioenvironmental engineers. Brooks AFB, TX: Air Force Institute for Environmental, Safety and Occupational Health Risk Analysis; 2001 Aug. Report No. IERA-RS-BR-TR-2001-0009.
8. Martin Marietta Corporation. Dust control handbook for minerals processing. Baltimore, MD: U.S. Department of the Interior, Bureau of Mines; 1987 Feb. Retrieved 3 January 2014 from https://www.osha.gov/dsg/topics/silicacrystalline/dust/dust_control_handbook.html.
9. American Conference of Governmental Industrial Hygienists. 2013 TLVs and BEIs. Cincinnati, OH: ACGIH; 2013.
10. International Organization for Standardization. Air quality--partical size fraction definitions for health-related sampling. Geneva: ISO; 1995. ISO 7708:1995.
11. European Committee for Standardization. Workplace atmospheres--size fraction definitions for measurement of airborne particles. Brussels: CEN; 1993. European Standard EN481.
12. Wright MT, Luers AC, Darwin RL, Scheffey JL, Bowman HL, Davidson RA, et al. Composite materials in aircraft mishaps involving fire: a literature review. China Lake, CA: Naval Air Warfare Center Weapons Division; 2003 Jun. Report No. NAWCWD TP 8552.
13. Anderson J, Hawkins J, Gill R. Aircraft accidents: a practical guide for responders. Independence, KY: Cengage Learning; 2007.
14. Seibert JF. Composite fiber hazards. Brooks AFB, TX: Air Force Occupational and Environmental Health Laboratory; 1990 Dec. AFOEHL Report 90-226EI00178MGA.
15. Durgam S, de Perio MA. Evaluation of potential exposures during composite grinding at an aircraft manufacturing plant. Cincinnati, OH: NIOSH; 2010. Health Hazard Evaluation Report HETA 2007-0344-3104.
16. Occupational Safety and Health Administration. Personal sampling for air contaminants [Updated 2014 11 Feb]. In: OSHA Technical Manual (OTM). Washington, DC: U.S. Department of Labor, Occupational Safety & Health Administration; 1999. OSHA Instruction TED 01-00-015 [TED 1-0.15A]. Retrieved 15 February 2014 from https://www.osha.gov/dts/osta/otm/otm_ii/otm_ii_1.html.
17. Warner Robins Air Logistics Complex. Aerospace emergency rescue and mishap response information (emergency services). Robins AFB, GA: WR-ALC; 2011. Technical Order 00-105E-9/STANAG 3896.
18. Carlton GN, England EC. Asssessing worker exposures during composite material repair: industrial hygiene field guidance for bioenvironmental engineers. Brooks AFB, TX: Institute for Environmental, Safety and Occupational Health Risk Analysis; 1999 Aug. Technical Report No. IERA-RS-BR-TR-1999-0010.
19. American Conference of Governmental Industrial Hygienists. Industrial ventilation: a manual of recommended practice for design, 28th ed. Cincinnati, OH: ACGIH; 2013.
20. American Conference of Governmental Industrial Hygienists. Industrial ventilation: a manual of recommended practice for operation and maintenance. Cincinnati, OH: ACGIH; 2007.

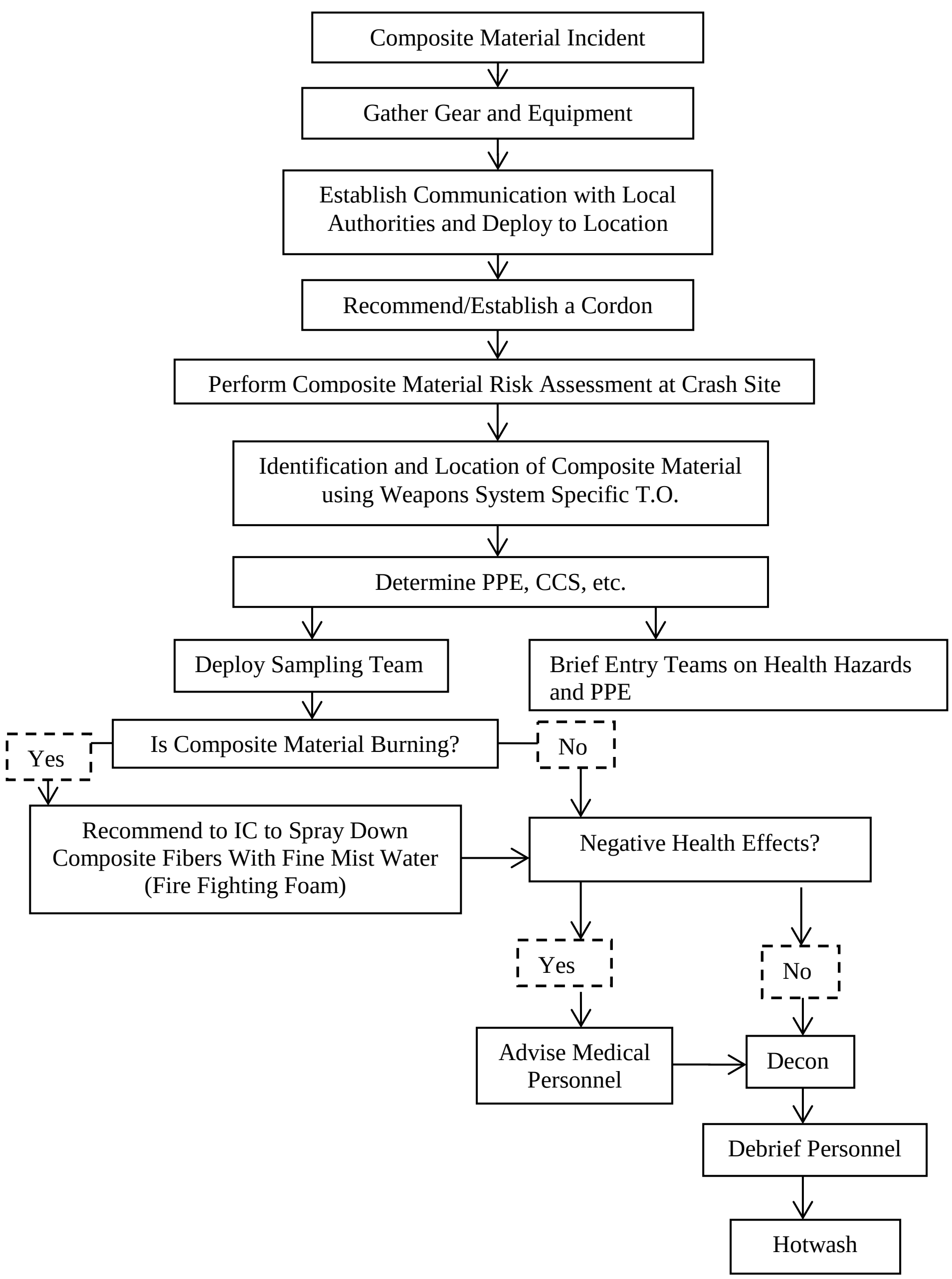
21. U.S. Air Force. Respiratory protection program. Washington, DC: Department of the Air Force; 2009 Apr 7. Air Force Occupational Safety and Health Standard 48-137.
22. Chairman of the Joint Chiefs of Staff. Operations in chemical, biological, radiological, and nuclear environments. Washington, DC: CJCS; 2013 Oct. Joint Publication 3-11.

APPENDIX A

Checklist for Response to Aircraft Crash and Recovery Operations Involving Composite Materials [12]

ALL PURPOSE CHECKLIST (This should be page 1 of Appendix A)	PAGE 1 OF 12 PAGES		
TITLE: Bioenvironmental Engineering (BE) Checklist – Aircraft Composite Fiber	**OPR**	**DATE**	
ITEM	**Y**	**N**	**N/A**

Composite Material Incident Flow Chart



ITEM	Y	N	N/A
PURPOSE. To provide BE flight personnel critical response procedures for composite hazards at aircraft crash and recovery operation to minimize associated environmental, health, and safety hazards. This checklist is intended to supplement local response checklists, which address the non-composite material hazards unique to the local mission, aircraft, and environmental conditions. **INITIAL ACTIONS:** a. Load the following equipment, if available, into the response vehicle: 1) Respirator: As a minimum, a NIOSH-approved N95 respirator 2) Tyvek® suits 3) Tape 4) Leather work gloves 5) Nitrile gloves (inner) 6) Hard-soled, steel-toed boots (safety-toe, reinforced shank, if boron composites involved) 7) Maps (base grid, area, topographical) 8) Portable lights/flashlights for night operations (with extra batteries) b. Once the type of aircraft involved in the mishap is known, check **Tables A1-A6** to obtain information on the potential locations of aircraft components that may contain composite fibers. c. Wind direction and speed should be considered for establishing a safe route to the scene and for an upwind recommendation for the entry control point. d. Downwind areas may need to be notified to keep windows/doors shut and remain indoors if not evacuated due to fire and smoke plume. e. Low altitude helicopters should be restricted from the area to avoid fiber and dust re-suspension.			

ITEM	Y	N	N/A

Table A-1. Composite Material Locations on Selected Aircraft

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
B/EP = Boron/Epoxy
C/EP = Carbon/Epoxy
C/BMI=Carbon/Bismaleimide
GR/EP = Graphite/Epoxy
GR/BMI = Graphite/Bismaleimide
GL/EP = Fiberglass/Epoxy
GL/BMI=Fiberglass/Bismaleimide

TITLE: Bioenvironmental Engineering Checklist – Aircraft Composite Fiber

ITEM	Y	N	N/A

Table A-2. Composite Material Locations on Selected Aircraft

Aircraft	Location	Composite Fibers/Matrix *								No
		AR/EP	B/EP	C/EP	C/BMI	GR/EP	GR/BMI	GL/EP	GL/BMI	Composite
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				

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

TITLE: Bioenvironmental Engineering Checklist – Aircraft Composite Fiber

ITEM	Y	N	N/A

Table A-3. Composite Material Locations on Selected Aircraft

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		

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

ITEM	Y	N	N/A

Table A-4. Composite Material Locations on Selected Aircraft

Aircraft	Location	Composite Fibers/Matrix *								No
		AR/EP	B/EP	C/EP	C/BMI	GR/EP	GR/BMI	GL/EP	GL/BMI	Composite
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						

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

TITLE: Bioenvironmental Engineering Checklist – Aircraft Composite Fiber

ITEM	Y	N	N/A

Table A-5. Composite Material Locations on Selected Aircraft

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				

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

ITEM	Y	N	N/A

Table A-6. Composite Material Locations on Selected Aircraft

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

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

ALL PURPOSE CHECKLIST		PAGE 9 OF 12 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, if applicable, otherwise, senior officer and enlisted should report to the entry control point. 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. As guide, the controlled area should be a minimum radius of 25 feet from damaged composite parts; this distance can vary depending upon environmental conditions (rain, dry, high winds, remote site, etc.). d. Only firefighters and other IC-directed personnel equipped with self-contained breathing apparatus should be inside the controlled area while there are burning/smoking components at the crash and recovery site or until the fire chief declares the area fire safe. Since respiratory irritation and health problems from inhalation of fiber particulate and dust are a major concern, care must be taken to avoid high-pressure water breakup and re-entrainment of composite structures. If structural breakup is occurring, recommend to the IC to have the firefighters control their high-pressure water spray so breakup and dispersal of the composite structures do not occur. e. Entry team personnel shall be briefed 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.				

ALL PURPOSE CHECKLIST		PAGE 10 OF 12 PAGES		
TITLE: Bioenvironmental Engineering Checklist – Aircraft Composite Fiber	**OPR**	**DATE**		
ITEM	**Y**	**N**	**N/A**	

f. Recovery operations pertaining to initial entry and for personnel disturbing or moving aircraft parts should wear at a minimum the following protective equipment:

1) Respirator: As a minimum, a NIOSH-approved N95 respirator
2) Goggles
3) Coveralls: Tyvek®
4) Tape
5) Gloves: Inner nitrile (disposable or reusable) with outer leather
6) Shoes: Steel-toed work boots (safety-toe, reinforced shank recommended if boron composites involved)

g. BE flight personnel normally do not enter the controlled area until the area is declared safe by the fire chief (and Explosives Ordnance Disposal, if applicable). BE flight personnel may enter the area to collect environmental samples. When entry is required, BE flight personnel should wear the above listed minimum recommended PPE.

h. A roster of all response personnel and entry teams should be collected for future medical monitoring.

i. Instruct entry/reentry personnel to:

1) Carefully remove loose fibers from their contaminated clothing before removing the contaminated clothing. When exiting the crash site, personnel could use a HEPA-filtered vacuum, if available, to remove advanced composite contaminants 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.

2) Advise the local medical staff of any ill effects that are believed to be 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

j. Recommend no eating, drinking, or smoking within a minimum of 25 feet of the crash site, or as otherwise determined by the IC, to prevent ingestion of fibers.

ALL PURPOSE CHECKLIST	PAGE 11 OF 12 PAGES			
TITLE: Bioenvironmental Engineering Checklist – Aircraft Composite Fiber	**OPR**	**DATE**		
ITEM		**Y**	**N**	**N/A**
k. Identify other potential hazards, such as spilled jet fuel or hydraulic fluid; location of radioactive components associated with the aircraft, such as depleted uranium counterweights, isotopes associated with inertial navigational equipment, etc.; and any explosive components such as ammunition or explosive bolts.				
l. Recommend to the IC to establish clean rooms (e.g., tents or trailers). All PPE 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 also contain shower facilities.				
m. 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 the facility should possibly activate the decontamination team to prepare the fiber-contaminated patients for treatment.				
n. 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.				
o. Wrap and seal disposable protective clothing (coveralls and gloves) in protective plastic bags after use and discard as routine waste. Severely contaminated non-disposable clothing should also be discarded. For other non-disposable clothing, carefully launder. 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 12 OF 12 PAGES		
TITLE: Bioenvironmental Engineering Checklist – Aircraft Composite Fiber	**OPR**	**DATE**		
ITEM		**Y**	**N**	**N/A**
CLEANUP AND DISPOSAL: a. Place hazardous waste material, based upon Resource Conservation and Recovery Act 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 crash and recovery 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. Entry team personnel shall be briefed 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. 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. 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. 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.				

APPENDIX B

Summary of Composite Material Awareness Course

Conditions to consider in terms of fire damage to composite materials

Fireball

- Sudden dispersal of ignited fuel vapor over a large area
- Very hot flame temperatures (≥ 2400°F)
- May completely miss large portions of the debris
- Very short duration
- The extent of composite damage that can be caused by fireballs varies depending on where the debris lands after impact
- A severe impact followed by extensive fire damage will NOT leave many large fragment pieces around the crash and recovery site
- The path of the fireball may miss the pieces completely, cause slight surface scorch, or engulf the debris entirely
- Inside a fireball, the composite system falls apart because the resin combusts, leaving behind only fiber layers

Fireball Damage • Debris shows some slight surface scorch and is fairly large • This picture is typical for composite structures that have been only partially engulfed by a fireball • If a piece is entirely engulfed inside a fireball, the composite system falls apart and only fiber layers are left behind	
Pool Fires • Quantity of fuel that has collected in a relatively small area and ignited • The flaming combustion stage of a pool fire can be much longer than for a fireball because the fuel is not used up as rapidly • Toxic smoke is generated • May produce the conditions for a smoldering combustion stage	  

Pool Fire Damage

- Due to the long duration and high temperature of a pool fire, it is the scenario that can create the greatest amount of fire damage
- More time at high temperatures allows the flame and heat of a pool fire to penetrate many more composite layers, causing more damage
- Increased time in the flame means there is a potential for the release of carbon fiber
- A pool fire will spread composite strips and clusters around the site

Low Temperature Heating

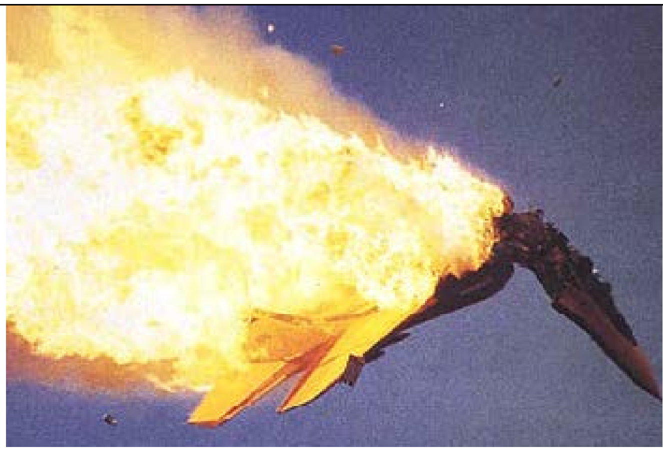
- Occurs when the ignition source, such as a heated wire, causes slow heating at low temperatures over a certain period of time
- A restricted air supply, as in a closed compartment or a small space within a damaged composite part, will promote a smoldering combustion that may go undetected for a long time
- Smoldering combustion is combustion with little or no visible smoke and no flame
- Smoldering smoke is toxic -- requires respiratory protection
- Cannot see internal composite smoldering or carbon fiber combustion; surface temperature can be cool with much higher internal temperature

- Composite structures are especially prone to smoldering because many of them are made with epoxy resin
- The heat from a smoldering pile of composite debris may cause nearby pressurized bottles to explode
- Epoxy smoldering is not expected to occur for thin laminates because heat is not retained in the material
- Epoxy smoldering may occur within piles of debris, and most organic core material will smolder
- Most epoxy formulations will start to decompose around 440-500°F

- As the very hot fuel flame penetrates the layers of this type of composite, the epoxy decomposes in a matter of seconds
- After the flame ceases, thick epoxy structures can begin to smolder
- Smoke from epoxy smoldering is barely visible; smoldering composites are dangerous because the condition can go undetected
- Smoldering epoxy is not sensitive to wind and does not spread to areas that did not previously experience an increase in temperature

In-Flight Fire

- Enough smoke can be generated during an in-flight resin fire to obscure vision immediately
- While visibility is impaired by the smoke, the rapid generation of acutely toxic compounds presents an even greater danger
- The confined space of the aircraft cockpit will increase the toxicity of the fumes because the limited ventilation increases the concentration of toxic gas



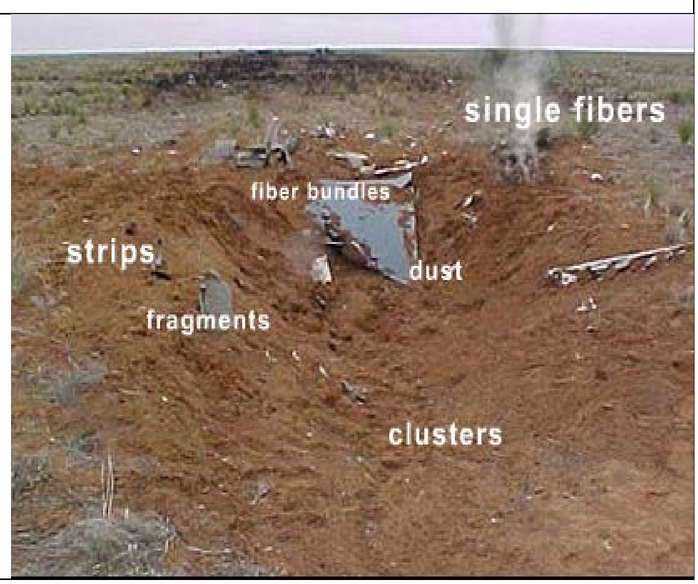
- If a rapid generation of toxic gases in a confined space ignites, a very rapid and destructive fire can result
- The distinct odor produced by burning composites also will be noticeable right away

Mishap Composite Recognition

- Mishap damage to a composite will generally reveal the composite structure of the part
- When a composite is damaged, materials within the damaged composite system begin to separate

Categories of composite debris

- Fragments
- Strips
- Clusters
- Fiber bundles
- Single fibers
- Dust
- Strands



<table>
<tr>
<td>

Strips

- Single laminate layers that have been separated from the whole laminate as a result of damage
- A strip created from physical damage will be found near the fragment from which it was generated
- It will also have resin attached to the fibers except at the fractured ends of the piece
- Strips that have been generated by fire damage will be found both within and outside the combustion zone
- Strips produced in a fire may have some resin or char material attached

</td>
<td>

</td>
</tr>
<tr>
<td>

Fragments (Bulk pieces)

- Large piece of composite laminate debris
- Because of its weight, an impact fragment will not travel far from its initial contact with the ground
- Fragments will be found within the emergency response cordon in the impact crater or in the debris field some distance from the crater
- Fragments have jagged edges that may cause puncture wounds

</td>
<td>

</td>
</tr>
</table>

• Layer separation, which is called delamination, may or may not occur within a fragment piece	
Fiber Bundles • Broken sections of fibers, attached with resin • Created by physical damage • When the composite piece breaks under physical stress, the fiber and resin matrix cracks, creating the broken pieces • The fibers are still held together by the matrix, creating the bundles • Found on or near fractured composite surfaces or along the path the tumbling composite took before it came to rest • If the fracture is severe, the bundles will be dispersed in the immediate vicinity of the damaged debris	 • Fiber bundles have jagged edges and vary in size • Some fiber bundles may not be visible to the naked eye
Clusters • Group of hundreds or thousands of unattached long fibers • Resemble a clump of hair • Generated from unidirectional tape or filament wound layers that have been exposed to fire • Clusters are different than fire damage strips because clusters have been exposed to fire for a longer period of time • Have very little resin or char holding the fibers together, so the fibers are free to move	

<table>
<tr>
<td>

- Because of this, clusters are lightweight and may be found dispersed around the crash and recovery site and outside of the combustion zone
- Clusters may be found attached to strips
- Will not remain airborne, do not cause puncture wounds, and are friable (i.e., clusters turn to ash when touched)

</td>
<td>

</td>
</tr>
<tr>
<td>

Dust

- Generated from shattered or crushed resin fragments, crushed fiber fragments, resin char, and fuel soot.
- Not fibrous, as opposed to fiber bundles, and will vary in size.
- Particles generated from a cracked or fractured composite matrix will have an irregular shape.
- Particles composed of resin char and soot will be spherically shaped.
- Dust is found on and near damaged composite surfaces.

</td>
<td>

- The more severe the damage, the greater the dust generation will be

</td>
</tr>
<tr>
<td>

Single fibers

- Small enough to become airborne
- Can be generated by either physical or fire damage
- Depending on their size, single fibers may not be visible to the naked eye
- Physical damage causes fiber sections to pull out of the resin matrix

</td>
<td>

- Fire will thermally damage the resin matrix, separating it from the fibers
- Fire damage may contribute free floating fibers, depending on the nature of the composite and the mishap scenario
- If the fire was not extinguished, carbon fiber particles may linger in the post fire area

</td>
</tr>
</table>

LIST OF ABBREVIATIONS AND ACRONYMS

ABDR	aircraft battle damage repair
ACGIH	American Conference of Governmental Industrial Hygienists
AFOSHSTD	Air Force Occupational Safety and Health Standard
BE	Bioenvironmental Engineering
CEN	European Standardization Committee
cfm	cubic feet per minute
f/cc	fiber per cubic centimeter
HEPA	high-efficiency particulate air
IC	Incident Commander
ISO	International Organization for Standardization
lpm	liters per minute
mg/m^3	milligram per meter cubed
MSHA	Mine Safety and Health Administration
NIOSH	National Institute for Occupational Safety and Health
OEEL	occupational and environmental exposure limit
OSHA	Occupational Safety and Health Administration
PEL	permissible exposure limit
PNOS	particulate not otherwise specified
PPE	personal protective equipment
TLV	threshold limit value
T.O.	Technical Order
USAFSAM	U.S. Air Force School of Aerospace Medicine