USA
ADVANCED COMPOSITES
LEADERS GUIDE

MISHAP RISK CONTROL GUIDELINES FOR ADVANCED AEROSPACE MATERIALS

ENVIRONMENTAL, SAFETY, AND HEALTH CONCERNS FOR ADVANCED COMPOSITES

Adapted from USAF Guide

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USACRC
4905 5TH AVE
Fort Rucker, AL 36362

DSN 558-1122
Comm: (334) 255-1122
FAX: (334) 255-9478

TABLE OF CONTENTS

Mishap Risk Control Guidelines: Part I

NOTE:

These guidelines are only general in nature. Specific actions are aircraft and material dependent. Users should contact specific weapon system management offices for specific procedures.

MISHAP RISK CONTROL GUIDELINES
FOR ADVANCED AEROSPACE MATERIALS

Part I

I. Purpose

The purpose of this report is to provide information pertaining to environmental, safety, and health risk control issues for aircraft mishaps involving advanced materials, especially composites. The ultimate goal of this project is to provide information for Army, DOD, federal, and international policies guiding the procedures and precautions recommended for personnel involved in all phases of a composite aircraft mishap response, including fire-fighting, investigation, recovery, clean-up, and material disposal.

II. Scope

In order to limit the focus of these guidelines, only post-mishap response risks associated with a significant release of advanced aerospace/composite materials will be discussed. It should be assumed that this would occur whenever fire or explosions accompany a mishap involving composite aircraft components. Advanced materials are distinguished from their traditional/commodity counterparts by their relative increased cost, performance, and complexity. Composite materials consist of two or more substances combined to produce a material with specific physical characteristics for specialized applications. For the purposes of this report, advanced composites are defined as composite materials applicable to aerospace construction/environments that are comprised of high-strength, high-modulus reinforcement(s) within a generally homogeneous matrix. Yet, because of the extreme diversity of materials and broad spectrum of applications, no single characterization is sufficient.

Composites are often incorrectly described purely in terms of the reinforcement or fiber (i.e. Graphite, boron composites), without reference to the matrix system. However, matrix material information is an essential aspect of mishap risk assessment and will be addressed accordingly. This report will address all material risks, with special emphasis upon carbon/graphite fiber reinforcement and polymer matrix composites (thermoplastic or thermoset) because of their fire/thermal performance.

The guidelines are specifically oriented towards aerospace concerns, although the information is widely applicable to other transportation mediums and mishap scenarios. Likewise, the information could be readily adapted to other military, government, or private applications. By focusing on both base- and command/policy-level needs across all major commands and locations, these guidelines establish minimum safety and health precautions oriented towards the end-users for associated training courses and local aircraft mishap response procedures/protection requirements. However, these guidelines are not intended to be used independently, but as more of a consolidated guidance source. Given the strength-to-weight, cost, and performance advantages of advanced composite materials, their use for production, repairs, and modifications will continue to increase. As advanced composites proliferate, so too must the level of supporting information, guidance, research, and cooperation among end-users.

III. Background

Tremendous liability, skyrocketing health and disability costs, increased environmental responsibility, and loss potential concerns are the driving forces in this emerging area. It should be emphasized that composites are comprised of a complex mixture of materials whose composition, concentration, and toxicity are not always clearly known, especially in a mishap environment. Because of the unknown hazards, diverse locations, and complex scenarios, a high degree of precaution with protective measures is required.

Although on-going research has often been inconclusive, evidence shows that burned or exploded components of composite materials DO cause personnel health and safety problems IF personnel are not properly protected. Numerous accounts of both military and civilian response personnel becoming ill or dying as a result of exposure to toxic gases from the burning plastics/composite materials have been documented. Respiratory irritation and health problems from inhalation of fiber particulates and dust as well as mechanical irritation from dermal contact/abrasion/puncture/sensitization are also noted. Although generally conflicting in nature, specifically regarding graphite as a "nuisance" dust, some health reports and studies have been accomplished. Regardless of their final determinations, all recommend caution and state that unknown health hazards do exist.

IV. Hazard Assessment

In developing procedures to deal with advanced composite material components released from burning and burnt aircraft, the hazards must be assessed as completely and accurately as possible. Likewise, system and equipment vulnerabilities must be identified before any protective techniques and procedures can be applied. Mishaps involving multiple aircraft or in enclosed areas will create a more concentrated and severe environment and should be treated with greater concern. It shall be assumed that any advanced composite material which is intact, as manufactured in the final product, is deemed inert, non-hazardous, and biologically benign. The following hazard information is not all inclusive, although it does emphasize several key areas.

A. Organic Compound/Matrix Hazards

Organic compounds, including resins, adhesives, and other chemicals, used in the manufacturing of advanced composite material products are generally considered inert and harmless when undisturbed in the final product. However, when these substances are subjected to the fire, thermal, and energy extremes of an aircraft crash, these compounds can become unstable, leading to decomposition and chemical reactivity. Resins, such as epoxies, polyimides, phenolics, and thermoplastics, may release harmful or lethal vapors and gases into the air when burned. Polymer matrix composites, because of their dominant use and generally lower temperature constraints are of most concern. Residual solvent contact from the destroyed composite materials and other heavy or radioactive materials also presents important material health hazards. Much research still needs to be conducted on resin vapor release (particularly the newer resin systems) and its short- and long-term effects.

B. Smoke and Fume Hazards

1. Smoke and fumes from burning advanced composite materials should generally be considered toxic. Together with the multitudes of other smoke, fumes, and gases released from burning aircraft, they can have a symbiotic effect. All of these substances are assumed to be both individually and collectively toxic and hazardous to human health. Asphyxiation and acute poisoning can result from sufficient personnel exposure. In general, advanced material gaseous effluent should not be singled out as exceptionally acute within the spectrum of the mishap fire products.

2. The hazards associated with smoke, fumes, and gases from composite materials are greatly diminished or negligible when the fire is extinguished and the debris has been returned to ambient temperature.

C. Reinforcement Hazards

1. During an aircraft mishap, the composite structures are subjected to thermal and mechanical forces which cause them to be broken up into pieces and/or burned. In many cases, the energy absorbing characteristics of composites cause "explosive" fracture or debonding and deformation. The reinforcement fibers, which are very stiff and give the composite material its strength, may be broken into particulate fibers, turned to dust, and protruding from the aircraft part. The fibers sticking out from a part may puncture the skin (boron reinforcement fibers may even penetrate completely through a limb), cause skin and eye irritation, and/or, if in dust form, be inhaled. The diversity of reinforcement materials, primarily in fiber form, creates different hazards at the mishap site. For example, glass and aramid fibers tend to melt under extreme heat, rather than decompose into smaller fibers, whereas both carbon and boron fiber decompose and create some respirable fibers.

2. Much research still needs to be conducted on the long-term effects of inhaling graphite particulate fiber and dust. The toxicology of the particulate fiber and the disease-producing potential associated with exposure to them is a function of three major factors:

(1). The dose or amount of particulates deposited in the lungs.
(2). Physical dimensions of deposited particulates.
(3). Particulate durability (lifetime) in the lung.

3. Although pure carbon fiber is chemically inactive and non-toxic, carbon fibers released from burning composite material are not pure. Because of the absorption and adsorption capabilities of carbon fibers, they absorb pyrolysis products, often assumed to be toxic and hazardous.

D. Specific Carbon Fiber Hazards

1. At the present time, the most widely used advanced composite material system found on aircraft is carbon/graphite epoxy. These material systems, as well as several others are widely used for various applications. to numerous to list. Advanced composite materials are also used for repairs and modifications to the existing aircraft.

2. The hazards associated with free carbon fibers are of a permanent nature requiring special management, procedures, and handling, unlike the shorter-term chemical binder hazards.

3. Carbon fibers in the 3-5 micron range are very light, become easily airborne, and are respirable. Plume dissipation under windy conditions increases the dispersion area. Fire exposed carbon fibers tend to break into shorter lengths and smaller diameters, increasing the probabilities for respirability and ease of transport. Inhaled carbon fiber particulates cannot be expelled efficiently.

4. Absorbed pyrolysis products on carbon fibers allow toxic debris to enter the body, causing possible short-term acute decreases in respiratory system efficiency and passageway irritation. Long-term effects are not known.

5. The combined effect of inherently sharp and stiff individual carbon fibers promotes easy dermal penetration. Partially pyrolyzed fibers easily break into smaller segments. Rubbing of exposed skin areas only increases the problem and spreads the affected area. Typical exposure requires medical attention, usually for dermatitis. The long-term effect of contaminants introduced to the body in this manner is unknown.

E. Electrical Hazards to Equipment

1. Carbon/graphite and boron fibers are electrically conductive. If infiltrated by a sufficient amount or density of fibers, unprotected electrical and electronic equipment may become damaged and/or inoperative. However, the environmental release and downwind cloud density of carbon fibers from burning aircraft wreckage is far less than previously estimated despite their lightweight airborne nature. As such, tests have shown that widespread equipment failure is highly unlikely, with possible exception to the immediate crash site. Although the probability of equipment failure in an mishap scenario is generally, negligible, the risk of equipment failure is always present. The electrical conductivity is not considered to be a direct personal health hazard.

2. Electronic interference is the main utility or facility hazard posed by free carbon fibers. Electric and electronic equipment is potentially at risk when free carbon fibers are deposited in relatively large quantities on unprotected or closely proximal circuits and circuit elements. When settling on electrodes or circuits, conductive carbon fibers may cause:

- Low voltage resistive loading or shunting, causing equipment and digital computer circuit malfunction.
- Short circuits and transient arcs at 10-15 V, possibly blowing fuses.
- Sustained arcs causing shorted transformers and vaporized bus bars above 150 V.
- Corona discharge above 300 V, which damages components and insulation.

3. Carbon fibers are influenced by the presence of electrostatic fields, thereby settling in high voltage areas and reducing the local dielectric properties of free air. In turn, this may cause equipment malfunction or failure.

F. Hazards to the Environment

1. The hazards posed by large amounts of advanced composite material debris to the environment are not known. Although carbon fibers are very stable, pyrolyzed fibers will continually and gradually breakdown and disperse. The long term effects are unknown, although dispersion will cause concentration dilution. Potential impacts on the flora, fauna, animals, food chain, and humans are unknown, but assumed very minimal. In most cases, past mishap sites reveal negligible damage.

V. Introduction to Mishap Risk Control Guidelines

This report is the result of an extensive review of existing and planned guidelines, documents, operating procedures, and technical research in the myriad of areas associated with mishap risk control and advanced aerospace materials. Nevertheless, it is not intended to be used independently, but in conjunction with other sources. Current research reveals a lack of consistent information and a diverse spectrum of understanding and risk control practices. Despite previous policy efforts, the limited guidance on the recommended safety and health procedures dealing with fragmented or burned advanced composite materials often present in aircraft mishaps needs to be updated. Furthermore, according to the Air Standardization Coordinating Committee Advisory Publication 25/XX, many nations do not have adequate written procedures outlining the personnel protection requirements and proper handling procedures. The urgency associated with emergency situations and the potential for hazardous exposures require accurate and accessible information.

Given the existing and projected increases in advanced composites usage for aerospace applications, realistic policies and procedures that focus on minimizing the safety and health hazards of advanced materials are needed. As the knowledge base grows and the mishaps are characterized, the procedures can be situationally optimized in terms of cost and performance while still maintaining a safe public environment.

Based upon the basic hazards already know to exist, and the fact that there are still unknown risks, personnel safety and health precautions are necessary. Administrative controls, including adequate personal protective equipment (PPE) and worker safety practices need to be immediately implemented because the field environment is <u>not</u> conducive to engineering controls. Risk control with an error to conservative measures is essential until a competent authority determines that adverse health hazards are at an acceptable level or no longer exist.

VI. Mishap Response Guidelines and Safety Precautions

Since aircraft crashes occur under a diverse assortment of weather and terrain conditions, with widely varying degrees of airframe destruction, a universally applicable set of risk control precautions is not practical. However, the potentially harmful vapors, gases, composite particulates, and airborne fibers generated from a composite aircraft mishap, whether burning or not, necessitate that several standard safety precautions be observed. Given that secondary exposures due to handling, clean-up, and disposal operations could cause exposures greater than the original incident, situational control is critical to risk control.

A. Initial Survey

Water crashes do not generally constitute a fire hazard until the wreckage has been recovered. For all other cases, a initial survey should be conducted by the fire chief to inspect for:

(1). Signs of fire damage in and around aircraft components known to contain composite materials.

(2). The presence of loose fibers. A distinction should be made between burned and unburned, and their relative condition.

(3). The ease with which burnt fibers become airborne and the prevailing weather conditions/directions.

(4). The degree to which the crash site and surrounding area have been exposed to combustion and explosion/impact processes.

(5). Malfunctioning or abnormal equipment operations.

(6). High carbon fiber concentrations with a "Sniffer" detection device.

(7). Local/proximal equipment/asset damage and danger.

B. Response

Note: The following Paragraphs 1-3 should be emphasized due to their immediate importance to maintaining control during a mishap.

1. Minimize unnecessary personnel. While the aircraft wreckage is still burning or smoking, ONLY fire-fighters equipped with Self-Contained Breathing Apparatus (SCBA) will be in the immediate vicinity of the mishap until the fire chief advises the commander that the area is fire-safe. Advanced fire fighting techniques, equipment, and protection may be required, although the specifics are beyond the scope of this report. Authorized personnel are determined by the on-scene commander. Although proximity suits and SCBA should be adequate protection, fire-fighters should be aware of the potential puncture/abrasion hazards associated with crash/fire damaged composites and any liquified materials/chemicals. Although secondary in importance to fire control and extinguishment, care should be taken to avoid high-pressure water break-up and dispersal of composite structures. Any loose ash or residue should be secured in place with foam as necessary until decontamination procedures are started. Containment of suppression and material effluent may be necessary, as determined by the on-scene authority for individual scenarios. Plastic or burlap lined trenches may be adequate, although waste disposal is of concern.

2. For aircraft mishaps involving a fire/explosion, all unprotected personnel must be restricted from assembling downwind of the aircraft at the crash site and should be prevented from entering the peripheral area. The peripheral area boundary is designated by the safety officer and/or the on-scene commander. As a guide, the peripheral area should be defined as more than 25 feet away from damaged composite parts, however, this distance may vary depending upon environmental conditions (rain,

dry, high winds, remote site etc…) which might help or hinder the situation. The only individuals authorized in the immediate mishap site and peripheral areas will be those that are sufficiently protected.

3. Areas affected by direct and dense fallout from the smoke plume, in the immediate vicinity of the mishap site should be evacuated, including removal of easily mobile, critical equipment. Aircraft exposed to the immediate fallout area should be moved as soon as possible and inspected and cleaned afterwards, along with severely affected equipment.

4. An aircraft specialist (such as a representative from the weapon system manager) should be contacted as soon as possible to identify composite materials and other hazardous materials to the Safety Investigation Board (SIB) and/or mishap response personnel.

5. Helicopters or low flying aircraft should not be used to control or suppress the fire. Likewise, they should not be allowed to fly or hover within 500 feet AGL above the site and an no less than 1000 feet horizontally. Aircraft should be restricted from taxiing near the crash area. Redissemination of the fibers and particulates from rotor or prop wash must be avoided. Also, intake of fibers into the electrical/mechanical systems of the aircraft could cause failure resulting in an additional flight incident.

6. The area should be roped or cordoned off as soon as possible and a single entry/exit point should be established to the mishap site.

7. Avoid excessive disturbance of the dust by walking, working, or moving at the crash site to minimize airborne particulate fibers and dust. All contaminated footwear should be cleaned to limit the spread of debris in the area and inside support vehicles.

8. When exiting the crash site, personnel should use a HEPA filtered vacuum, if available, to remove advanced composite contaminants from their outer clothing, work gloves, boots, headgear, and equipment. If a HEPA vacuum is unavailable, efforts shall be made to wipe or brush off as much contamination as possible.

9. Clean rooms (i.e. tent or trailer) should be set up as practical. All PPE should be donned in the clean room , with the respiratory protection worn under all other equipment so it can be removed last.

10. If the local authorities believe that personnel other than those at the accident site have been directly and significantly exposed to adverse material hazards, the medical staff should be consulted for evaluation and tracking. If time permits, advise the otherwise un-threatened populace in affected or fallout areas to:

- Remain in-doors
- Shut external doors and windows
- Turn off forced air intakes
- Await further notification

11. No eating, drinking, or smoking is permitted within 500 feet of the crash site, or as otherwise determined by the on-scene commander. Personnel must be advised to wash hands, forearms, and face prior to eating, drinking, or smoking.

12. If disposable protective clothing is unavailable, unprotected personnel involved with crash/fire-damaged composite parts should remove non-disposable clothing and launder it according to paragraph 15. Also, personnel should shower prior to going off-duty to preclude injury from loose fibers. Portable showers may need to be provided for this.

13. To protect the medical staff, contaminated victims/response personnel should have their outer garments removed at the scene, if practical. When removal of the outer garments at the scene is not practical, victims shall be covered to prevent dispersion of contaminants while they are transported. At the medical facility, contaminated victim clothing should be carefully handled.

14. Exposed personnel shall be instructed to advise the local medical staff of any ill effects they believe are related to their exposure to the advanced composite materials. Symptoms of ill effects include, but are not limited to:

-Respiratory tract irritation and reduced respiratory capacity
-Eye irritation
-Skin irritation, sensitization, rashes, or infections

15. Disposable protective clothing (coveralls) should be wrapped and sealed in protective plastic bags after use and discarded as routine waste. Severely contaminated clothing should be discarded. Otherwise, launder nondisposable clothing separately. If laundered by a contractor, the contractor should be informed of the presence of composite fibers and the hazard potential. The contaminated clothing should be handled with care and washed separately. Due to the numerous types of composite/hazardous materials that may contaminate clothing, the environmental science (Preventive Medicine Svc.) officer should determine if other special handling or cleaning procedures are required.

C. Containment

1. As previously stated, burned and mobile composite fragments and particulate residue from mishaps involving fire or explosive action should be secured with fire-fighting foam or a fine water mist until a holddown fixant material can be applied to immobilize the fibers. Initial actions should concentrate on debris containment. Two types of fixants are used, one for burned composites and debris, and the other for land surfaces. For open terrain and improved surfaces, such as concrete and asphalt, holddown fixants are usually not necessary unless high concentrations exist. For all other conditions where holddown is required, the following is recommended after obtaining SIB concurrence.

Caution: Wait until the fire is completely out and the wreckage has cooled to perform the following procedures.

(1) Obtain a fixant or "hold-down" solution, such as Polyacrylic acid (PAA) or acrylic floor wax and water. Light oil is not recommended because it may become an aerosol and collect on equipment, hamper material investigations, and present a health hazard. PAA is currently available in either solid or liquid forms, depending upon the desired characteristics. See Appendix 1 for PAA Mixing Procedures. Generic acrylic floor wax, available at a wide variety of stores, should be mixed in a 10:1 water-to-wax ratio.

(2) Apply a heavy coating of the fixant solution to all burned composite materials and to areas containing scattered/settled composite debris. Completely coat the material until wet to ensure the particulate fiber/dust is immobilized. This should contain the release of particulate fibers and/or dust into the air.

Note: Polyacrylic Acid (PAA) fixant, or equivalent, is strongly recommended for use on burned composite debris. Although non-burned composite materials do not generally present as great a fiber particulate or dust hazard as burned materials, fixant application is still recommended. PAA in solution is a combination of two components and is chemically similar to household floor wax. It is transparent and strippable (i.e. chemically removable), when wet or dry, by a dilute solution of household ammonia (about 1% by volume of ammonium hydroxide in water) or trisodium phosphate (approximately one 8 ounce cup trisodium phosphate per 2 gallons of water). See Appendix 1 for PAA Mixing Procedures.

CAUTION: Strippability of fixant coatings is required where coatings are applied to debris that must later undergo microscopic analysis by crash investigators. Care must be exercised in the use of the stripping solutions since they can react with some materials and the process of stripping may damage the part.

(3). Once the coating is dry, carefully wrap the coated parts and/or material with plastic sheet/film or place in a plastic bag that is minimum of 0.006 inches (6 mils) thick. Seal and secure the damaged materials with tape. Generic garbage bags are generally inadequate unless several are used as plies.

(4). Using aircraft preservation tape, apply tape over the non-fire/crash damaged composite parts/material. These parts/materials may be required for investigative purposes. Place the damaged composite part/material in a plastic bag if possible and label as required.

(5) If deemed necessary, soil tackifiers may be used to hold materials on sand or soil. Most solutions, including Polychem, J-Tack, or Terra Tack can be sprayed onto the ground at a rate of 0.5 gal/sq. yd.

(6) Improved hard surfaces (i.e. concrete, asphalt, carrier deck) should be vacuumed (with electrically protected vacuums) or washed down with a detergent and water solution. The effluent should be collected via plastic or burlap coated trenches or drainage ditches. If at sea, wash overboard using proper precautions. Sweeping operations should be avoided as they redisseminate the particulate debris.

(7) To prevent clogging, fixant application equipment should be flushe d out immediately after use with a dilute solvent solution (See Appendix 1) followed by a clean water rinse.

2. All sharp projections from damaged composite parts should be covered and padded to prevent accidental injuries. Damage or abrasion can be minimized by applying foam with tape.

D. Clean-up and Disposal Concerns

1. In contrast to earlier procedures, material disposal must be accomplished according to local, state, federal, and international guidelines. Accordingly, the nearest DOD, government, or private environmental management office should be contacted for relevant disposal procedures for the advanced composite parts/material which do not require accident investigation evaluation, repair, or are not needed. Ensure the SIB or AFR 110-14 board releases the parts before disposal is authorized.

2. Waste material, if deemed hazardous by the environmental engineer, should be placed in sealed drums and disposed of appropriately as hazardous waste. If possible, a HEPA vacuum should be used to clean-up the local area. All crash debris, vacuum bags, coveralls, gloves, and any other contaminated materials should be properly disposed and labeled appropriately with the following:
"Composite Waste. Do not incinerate. Do not sell for scrap. Composite Waste." Any required hazard warnings should also be added.

Note: Demilitarization may be required prior to material disposal if done through private contract. Coordination with the specific aircraft manager is required.

3. 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.

4. If aircraft were subjected to the smoke and debris of the immediately affected area, the following should be undertaken:

(1) Vacuum the air intakes with an electrically protected vacuum cleaner.

(2) For internally ingested smoke, visually and electronically (i.e. "sniffer") inspect all compartments for debris and vacuum thoroughly.
(3) Prior to flying, perform electrical checks and engine run-up.

5. For significantly affected structures and equipment:

(1) Thorough clean all antenna insulators, exposed transfer bushings, circuit breakers, etc. Inspect air intakes and outlets for signs of smoke or debris and decontaminate if necessary.

(2) Consult more detailed electrical reference material and specific decontamination instructions for more information.

VII. Personal Protective Equipment:

The following protective equipment shall be worn by personnel working with or within 25 feet of any burned composite materials. Likewise, if personnel are breaking or cutting either burned or unburned composite parts, the same personal protective equipment (PPE) requirements apply.

1. Respiratory Protection: wear NIOSH approved full-face or half-mask respirators with dual cartridges for organic vapors (for protection from jet fuel) and for dust, mist, and fumes (for airborne particulate fibers and other dust). All personnel must be fit tested and properly trained in the use of respirators. The use of full-face respirators is recommended because they will eliminate the need for safety goggles.

2. Safety goggles (with either no or small vent holes to minimize particulate/fiber entry) shall be worn when a half-face respirator is used. Safety glasses with side shields are not recommended within the 25 ft boundary area of the mishap site.

3. Skin Protection:

(1) Coveralls - Tyvek, coated with 1.25 mil polyethylene, hooded coveralls are required. The coveralls should have a zipper front, elastic sleeves, legs, and drawstring hood. External booties will eliminate possible boot contamination and reduce dermal contact potential. They are recommended when available. Any openings or attachment points, especially at the ankles and wrists, should be sealed with duct-tape to keep out particulates.

(2) Gloves - Puncture resistant leather gloves shall be worn as a minimum. Optimally, Nitrile gloves shall be worn as an insert to the leather glove to protect against blood-borne pathogens, solvent residue,

and fuel spills. Any additional specific requirements will be determined by the installation industrial hygienist.

Caution: Do not wear Nitrile rubber gloves when handling burning or smoking composite materials.

(3) Boots - Steel-toed shoes/boots should be worn.

4. Additional protection (i.e. SCBA, splash suits, as determined by the industrial hygienist, will be worn when jet fuel/hydraulic fluid or other hazards exist. Similarly, when burned composite materials have been coated or set with fixant and the surrounding area satisfactorily sanitized or the parts moved to a new location, only peripheral area protection is required unless otherwise stated.

5. Peripheral Areas

(1) As a guide, the peripheral area should be defined as more than 25 feet away from damaged composite parts, however, this distance may vary depending upon environmental conditions (i.e. rain, dry, high winds, remote site, etc…) which might help or hinder the situation. The on-scene commander shall establish the limits as appropriate.

(2) Peripheral Area PPE shall include a disposable or non-disposable respirator, safety glasses with side shields, BDU s with sleeves worn down, and hard soled shoes. If any debris is to be manipulated, the previously discussed glove ensemble is also required. Likewise, if special conditions exist that would increase the hazard, increased protection is highly recommended. As a general rule, it is easier to protect than correct a health problem.

Note: Disposable respirators generally provide only nuisance dust protection and are not accepted for industrial use. However, for lower-risk peripheral areas, High Efficiency Particulate Absorption (HEPA) disposable respirators may be used when peripheral personnel are not respirator trained. They are not authorized for high-particulate-exposure areas.

The following list contains examples of the recommended/required PPE:

Equipment	NSN
Disposable Respirator	
3M 9970M High efficiency	4240-01-272-1876
3M 9970L High Efficiency	4240-01-272-1877
Comfo II Respirators	
Half-mask Small	4240-01-312-8702
Half-mask Medium	4240-P-479531
Half-mask Large	4240-01-086-7670
Ultra Twin Respirators	
Full-face Small	4240-01-248-9139
Full-face Medium	4240-01-199-0077
Full-face Large	4240-01-248-9140
Filters	4240-01-230-6895
Safety Goggles	4240-00-611-8066
Safety glasses with side shields	4240-00-516-5431
Tyvek coveralls	GSA contract # GS-07F-4403A
Tyvek coveralls w/Hood	8415-01-198-8738
Tyvek coveralls w/Hood and booties (w/Olefin coating)	8415-01-254-0667

Burning/Smoldering Composites

1. SCBA
2. Aluminized Proximity Suits
3. Aluminized/puncture resistant gloves
4. No Rubber gloves

Broken or Splintered Composite Material

1. Full or half face respirator with dual cartridge (HEPA & organic) filters
2. Coated and hooded Tyvek suit with optional booties (Taped seams)
3. Leather work gloves (External)
4. Nitrile gloves (Internal)
5. Hard-soled, leather work boots

Minimal Composite Exposure

1. BDU’s with sleeves worn down
2. Non-disposable/Disposable HEPA respirator
3. Safety glasses with side shields
4. Leather work gloves (External)
5. Nitrile gloves (Internal)
6. Hard soled work boots

Appendix 1

Fixant Mixing Procedures:

Note: The following information has been extracted from TR 81-266 "Revised HAVE NAME Protection Manual" (NSWC, June 81). Also, the "hold-down" solution chosen, polyacrylic acid (PAA), has been shown to be strippable and non-detrimental to the composite fracture surfaces. Thus, use of PAA will not affect mishap investigation proceedings.

The proper mixing procedures for two fixant solutions will be discussed: Polyacrylic Acid and Floor wax.

1. Polyacrylic Acid

a. Polyacrylic Acid (PAA) fixant, or equivalent, is recommended for use on burned composite debris. PAA is currently available in either a solid (Carboset® 525 and Carboset® 515) or liquid (Carboset ® XL-11) form. Both PAA substances can be procured through B.F. Goodrich, Specialty Polymers and Chemical Division, 9911 Brecksville Road, Cleveland OH 44141-3247. (1-800-331-1144). In general, PAA in solution is a combination of two components and it is chemically similar to household floor wax. It is transparent and strippable (i.e. chemically removable), when wet or dry, by a dilute solution of household ammonia (about 1% by volume of ammonium hydroxide in water) or trisodium phosphate (approximately one 8 ounce cup trisodium phosphate per 2 gallons of water). Strippability of fixant coatings is required when coatings are applied to debris that must later undergo microscopic analysis by crash investigators. Care must be exercised in the use of the stripping solutions since they can react with some materials.

b. A typical PAA solution would be Carboset® 525 and Carboset 515®
(B. F. Goodrich), mixed with water in the following proportions:

Carboset® 525	- 5% by weight
Carboset® 515	- 2.5% by weight
Water	- 92.5% by weight

c. The following should be performed to create the PAA solution.

(1) Heat 45 gallons of water in mixing tank to a minimum of 60°C (140°F).

(2) Add ammonium hydroxide to the water until a pH of 8 or higher is obtained. Generally, less than 4 pounds of ammonium hydroxide is required, but the exact amount depends on the water characteristics.

(3) Begin agitation of the water using a propeller mixer.

(4) Slowly add 20 pounds of Carboset® 525 crystals to the water, taking care to keep the crystals suspended. This operation should typically take over an hour. Adding the crystals too rapidly will result in coagulation, greatly slowing their dissolution. Maintain the pH during the mixing process by adding ammonium hydroxide as required.

(5) After the Carboset® 525 is completely dissolved, pour 10 pounds of Carboset® 515 into the solution. Preheating of the viscous liquid will facilitate its handling. Continue mixing until the Carboset® 515 is completely dissolved (approximately 15 minutes).

(6) The mixed solution should be stored at above freezing temperature until needed and it should be replaced annually. Do not use a zinc or galvanized container for storage.

Note: Fixant should be applied as soon as possible to minimize the particulate hazard. The mixing process for dry PAA is generally too long and complex for emergency conditions. Therefore, liquid PAA (Carboset® XL-11) is recommended. The are no limiting shelf-life restrictions, although the solution should be thoroughly mixed after long-term storage. Liquid PAA is susceptible to freezing (32 °F) but may be thawed and used without adverse effect.

2. Floor Wax

a. A suitable fixant solution can be obtained by thoroughly mixing off-the-shelf acrylic floor wax in a 10:1 ratio with water (10 parts water to 1 part floor wax). Because of its widespread availability, floor wax is a very viable fixant alternative. However, strippability concerns may preclude its use when extensive material investigation is required. The empty container, with some remaining solution should be saved in order to aid stripping solvent selection. Nevertheless, fixant application for safety reasons is of higher priority than investigation purposes.

USAF
ADVANCED COMPOSITES
PROGRAM OFFICE

MISHAP RISK CONTROL GUIDELINES
FOR ADVANCED AEROSPACE MATERIALS

RECOMMEDATIONS
AND
ACTION ITEMS

Project Engineer: Lt John M. Olson

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SM-ALC/TIEC
5201 Bailey Loop
McClellan AFB, CA 95652-2514

DSN 633-3810
Comm: (916) 643-3810
FAX: (916) 643-0487

MISHAP RISK CONTROL GUIDELINES
FOR ADVANCED AEROSPACE MATERIALS

RECOMMEDATIONS AND ACTION ITEMS

I. General Recommendations

The following general recommendations are the result of extensive research and experience gained from prior events. There are six primary areas, if included, that would significantly increase not only the quality but the applicability of the original Mishap Risk Control Guidelines for Advanced Aerospace Materials. These areas include: Research, PPE, Implementation, Procedures, Applications Equipment, and Medical Information. Many of these recommendations would substantially increase the crucial database of knowledge in their respective areas.

A. Research:

The complex mixtures, diverse constituent materials, unique processing methods, and varied application environments of composites have limited the amount of readily available data concerning material, performance, health, and flammability characteristics. As such, continued research and testing is essential in order to more accurately characterize many of the materials currently being used. Likewise, once this information is available, communication becomes critical regardless of the medium chosen. The following list is comprised of several of the most critical issues concerning composite aircraft mishaps that require immediate research attention.

1) Fire/Flammability/Thermal Research: In mishap scenarios, flammability is an extremely pertinent topic. MIL-STD-2301 specifies 11 flammability tests for composite materials based upon ASTM and other standards.

MIL-STD-2031 Flammability Test Summary
ASTM D2863 - Oxygen Index ASTM E162 - Flame Spread Index ASTM E662 - Smoke and Combustion-gas Generation ASTM E1354 - Heat Release and Ignitability NIST Quarter-Scale Fire Test NIST Toxicity Test Burn-through Fire Resistance Combustion-gas Measurement Large-scale open-fire test

At a minimum, the following baseline tests need to be accomplished:

a. Fire propagation - whether a material supports combustion, measured by ignitability (ASTM E1354).
b. Fire retardancy - flame spread index (ASTM E162)
c. Fire containment - acting as a barrier to fire
d. Smoke and toxicity - measured by smoke obscurity (ASTM E662)
e. Fire Endurance - maintenance of structural integrity

In terms of Fire/Thermal characterization, research in the following thrust areas is needed:

1. Thermo/Mechanical Properties of Advanced Materials/Composites
2. Fire Modeling
3. Fire/Thermal Testing - New tests and refined testing
4. New Materials - Qualification, development, synthesis
5. Database - Fire/Thermo specific
6. Hazard Assessment - Consolidation of information/techniques
7. Suppression/Mitigation - New procedures, substances, results

Note: Current research indicates that toxin quantities, delamination extent, and other performance characteristics under structural loads during a fire test cannot be extrapolated from a small-scale test to a larger structure. Likewise, 2-D test coupon data may not accurately reflect larger 3-D performance. Finally, the diversity and situationally specific nature of many of the standard test methods complication reproducibility and applicability.

Cooperative research between DOD, federal, and international organizations is required because of cost and time constraints. The establishment of a government and/or industry working group is a critical step. Technology transfer, defense diversification, and mutual partnerships/cooperative ventures/Memorandums of Understanding are viable research program options.

2) Continued research is needed for Systematic Health Effects testing of post-cured composites, with specific emphasis upon irritant and nuisance dust, and burned airborne particulates.

3) Updated and revised Mishap Risk Control Guidelines for Advanced Aerospace Materials should be forwarded for examination and adoption to the Air Standardization Coordinating Committee.

4) Fixant and Stripping Substance analysis is a major area in need of immediate research. Material and safety information are essential elements as well as on-going material compatibility studies. Questions concerning the fixant and stripper effect on material analysis and investigation need to be answered. Additionally, alternative substances should be pursued to ensure that the best substances are being used. Fixant

requirements include: durability, UV and environmental stability, temperature range (useful/storage), cost, local availability, ease of application, and chemical residual effects.

B. PPE Equipment:

1) The Air Force Safety Agency and the Bio-environmental Office need to evaluate, list, contract, and establish training for Personal Protective Equipment (PPE) required for composite mishaps. Most of the equipment is currently in the inventory, although on-going evaluation is required. Likewise, sufficient numbers of personnel need to be trained in the use of the equipment (i.e. respirators) to respond to a composite mishap. Several private PPE supply sources exist from which non-government contract equipment may be obtained.

2) Consideration must also be given to PPE compatibility with existing Nuclear, Biological, and Chemical (NBC) attire. Currently, chemical warfare masks are not effective against airborne composite particulate hazards. As such, SCBA would be required for a composite mishap unless a dual cartridge system was available that protected against all of the hazards.

3) As a general rule, it is far easier and more cost-efficient in the long run to protect, rather the correct health problems. Therefore, when the specific risks are unknown, conservative protection should always be the case.

C. Implementation:

Despite the existing Mishap Guidelines, there is a critical lack of complete background and procedural information throughout the Air Force. In order to consolidate the available information from several sporadic sources and increase the overall level of awareness throughout the force structure, the following recommendations are provided. Although some have been previously presented, all warrant increased attention in order to avoid the disconnects of the past.

1) An Air Force policy must be created with sufficient upper-level backing. As such, a high-ranking person/office must actively endorse and champion this cause. The concept must be actively "sold" to the pertinent parties. The Aircraft Mishap Response Plans (AFP 127-1), job guides, technical manuals, ATC training manuals, and safety notices must reflect the new emphasis, knowledge, and procedures.

2) Coordination needs to be accomplished between all concerned agencies and offices, including oral, written, and personal correspondence. To avoid the previous problem of higher-level endorsement with no lower-level application, the distribution of the available guidelines and recommendations needs to be modified. Information should go to the primary offices/agencies for approval and directly to the end-users as well.

3) A plan of action should be drafted to specifically chart the progress, goals, and requirements of successfully implementing the composite aircraft mishap policies and guidelines.

4) On both a base and a policy-making level, a meeting between the three members of the Response Triad - Safety, Fire Department, and Bio-Environmental, as well as the security police, Environmental Management (EM), and Disaster Preparedness (DP) should be arranged. Situation and requirement specific procedures and information should be discussed.

5) A new Air Force or DOD training program specifically covering Composite Aircraft Mishap concerns during fire-fighting, investigation, recovery, and material disposal should be offered. Personnel from many different locations should be trained with a broad understanding all of the factors involved throughout the post-mishap process.

6) Inter-service and government/private cooperation are essential in order to standardize and share information and procedures. A Tri-service working group and a civilian/government committee or association should also be set-up to facilitate information flow. Training courses, workshops, and conferences would provide an active forum for discussion and pre-emptive mishap preparation.

7) An aircraft/aerospace vehicle-specific list of composite components would greatly assist in mishap characterization and hazard identification. At the present time, the USAF Wright Laboratory Manufacturing Technology Directorate has a book entitled, Composite Materials Applications , which outlines Army, Navy, and Air Force assets containing composite components arranged according to material type (See Reference section). Although similar in concept, a single source vehicle-specific listing of composite components would be much more efficient to use in the event of a mishap. A similar commercial or civilian document would also be very helpful.

D. Procedures:

Given the variability of potential composite aircraft mishap locations, the application of engineering controls under field conditions is usually not feasible. Therefore, administrative controls, including operations, process, and safety controls, must be immediately implemented in a program designed to encompass all personnel associated with the mishap response effort. Likewise, specific procedures need to be developed that minimize confusion and clearly outline required actions.

1) Risk control becomes the key to minimizing the potential safety and health hazards to response personnel. Accordingly, several critical areas need to be addressed. They include:

a. Information regarding the safe handling of material

b. Sufficient training for all personnel involved
c. Isolation of Operations to minimize the exposure to unprotected personnel
e. Proper Personal Protective Equipment (PPE)
f. Personal and Industrial Hygiene
g. Warnings and Labels

2) Despite the great strides made in the quality and availability of Material Safety Data Sheets (MSDS), several problems still exist. As the primary source for transmitting hazardous material information to the end-user, MSDS's are a critical aspect of effective risk control. In the past, MSDS availability in Secret or "black" programs has been a problem. However, the Occupational Safety and Health Administration Hazard Communication Standard, 29 CFR 1910.1200, requires MSDS availability in the workplace for all hazardous materials in all industries. Nevertheless, security measures make this a realistic concern. In the event of an emergency or mishap situation, MSDS information must be available to health professionals, provided certain security restrictions are applied. Accurate information must be available in order to reduce both the human and environmental risks, while still maintaining security.

3) A very clear directive is required concerning the application of fixant/stripper to damaged or destroyed composite materials and components. Previous discrepancies concerning fixant/stripper applications and the associated impact on material analysis and investigation need to be eliminated by testing and research in this area.

4) Specific procedures for the application of fixant and stripper need to be included in any mishap guidelines. The variability of location, geometry, application equipment, and materials requires procedures maximize coverage efficiency. Optimally, the substances will be liberally sprayed-on in a coating sufficiently thick to cover the damaged area and penetrate into difficult 3-D areas.

E. Application Equipment

1) Before any application equipment can be recommended, several different fixant/stripper substances need to be tested and evaluated in order to gain a better the understanding of their characteristics. New fixant/stripper material requirements should include:

- durability
- UV and environmental stability
- Thermal range (useful, storage)
- material compatibility
- availability
- cost
- ease of application
- chemical residual effects

- storage life and ease of storage
- toxicity and health effects

Once suitable fixant and/or stripper materials have been chosen, suitable equipment for mishap site protection and clean-up can be chosen. Three primary substance choices are recommended.

2) Given the diversity of the potential mishap locations, application equipment must be evaluated not only with regards to its performance, but its general availability and accessibility as well. The following list is indicative of equipment that would provide a multiple-use capability.

a. Garden hose/sprayer (controlled stream or wide-head)
b. Portable bug or insecticide sprayer (ensure prior cleaning)
c. Portable car or aircraft wash rack kit
d. Glycol (de-icing) gun

Each of the above recommendations needs to be evaluated with emphasis upon thermal, environmental, geographic, and substance compatibility. Fixant/stripper flow and viscosity concerns should be observed.

3) High-efficiency vacuum systems and sweepers need to be evaluated and tested in order to minimize the safety and health hazards to personnel and the environment in both the immediate crash site and the peripheral area. Availability, flexibility, performance, and cost-efficiency should be the driving concerns.

F. Medical:

In order to better assist mishap response teams and medical response professionals, accurate medical information needs to be available.

1) The on-site exposures need to be determined and defined as soon as possible in order to properly adapt to the specific requirement. Once this has been accomplished, on-scene commanders, health professionals, and bio-environmental personnel should be briefed. Likewise, test data and exposures should be documented and recorded.

2) A complete list of existing reference studies and tests specific to composite aircraft mishap concerns needs to be generated.

3) A list of Points of Contact for information, expertise, and research would be beneficial.

4) Long-term exposure tests should be initiated to provide a database of composite mishap pertinent health and medical information. As the use and application of

composites increasingly proliferate, mishaps will inevitably become more frequent. Cumulative, chronic, and acute data is essential for both preventative and acute care.

5) All personnel using respirators and/or SCBA need to be properly trained and tested for the equipment. Both qualitative and quantitative fit-testing should be required for all personnel.

6) A comprehensive list of applicable base, local, state, and federal regulations should be created for reference.

G. General:

1) Any equipment used on, in, or near aircraft and/or fuel should be explosion-proof electrical equipment and should be grounded while in operation.

2) Fire-fighting equipment should be available during fixant/stripper application, aircraft break-up, and recovery. Advanced fire-fighting equipment needs to be developed and tested to remain abreast of the increasing material performance characteristics of advanced materials.

3) Adequate ventilation should be provided during fixant/stripper mixing operations. Also, if any fuel, hydraulic fluid, fire-suppressant, solvents, or cleaning solutions are present, ventilation is essential.

4) Acid should be added to water, never water to acid. Care should be taken to minimize the acid solution contact with skin or clothing. In case of contact, the affected parts should be flushed with large amounts of water. Eye, glove, and splash-suit protection should always be used when handling these substances (i.e. fixant, stripper).

5) All applicable base, state, and federal regulations should be observed.

6) In order to increase the flow of information, enhance communication, and increase the general level of response team expertise, a CD, tape, or disc containing pertinent composite aircraft mishap information should be developed. Using a portable computer, fire-fighters, investigators, health professionals, bio-environmental engineers, disposal workers, and other individuals could have on-site information regardless of the location. Pertinent information would include:

- Composite Aircraft Mishap Safety and Health Guidelines
- Mishap Checklist
- MSDS information
- Medical information
- Fixant/Stripper solution information
- Application equipment

- Hazard exposure information
- Relevant Personal Protective Equipment (PPE)
- Material compatibility information
- Aircraft or vehicle specific composite part/location data

7) Once the information mishap response information is consolidated, potential international coordination should be investigated. The Canadians and British are currently very interested in this area and have done much work to date. The Israelis, Australians, French, Germans, Swedes, and Russians may also cooperate in an international effort. This would be very beneficial on several accounts, including increased global cooperation, good foreign safety/health policy, and better foreign aircraft disaster preparedness.

8) The safety and health personal protective equipment guidelines and procedures should be implemented, especially for fire battle damage, in both the general and Aircraft Battle Damage and Repair (ABDR) Technical Orders (TO s). Currently, this information is not provided in TO 1-1-690 General Advanced Composite Repair Processes Manual.

II. Recommended Action

Given the widespread interest, technical urgency, and increased proliferation of advanced aerospace materials, the following recommendations should be adopted:

1. Adopt a Risk Control, or preventative post ure, as opposed to a compliance or regulatory one. Be a world class leader in the field.

2. Disseminate the Mishap Risk Control Guidelines across all functional levels, with emphasis upon the lowest, or base and unit, levels of the Air Force.

3. Amend, update, modify, and/or generate command/policy-level action including Aircraft Mishap Response Plans (including AFP 127-1), job guides, technical manuals, training courses, refresher courses, procedural checklists, and Air Standardization Coordinating Committee documents.

4. Develop cooperative, inter-service, technology transfer, and defense diversification efforts in research, planning, and implementation via any suitable means to ensure continuity and consolidation without duplication.

5. Continually solicit input, research, and cooperation and appropriately modify the guidelines to remain abreast of the rapidly advancing technologies and provide an accurate and updated information source..

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