ADVANCED AEROSPACE MATERIALS / COMPOSITES:

POST-MISHAP
ENVIRONMENTAL, SAFETY AND HEALTH CONCERNS

REQUIREMENTS AND RECOMMENDATIONS

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RECOMMEDATIONS AND REQUIREMENTS

I. Purpose

To provide recommendations and requirements for further research and information pertaining to environmental, safety, and health risk control issues for aircraft mishaps involving advanced aerospace materials, especially advanced composites.

II. Definitions

For the purposes of this report, the following working definitions may be broadly applied.

Composite: A physical combination of two or more materials.
Example: Fiberglass

Advanced Composite: A Composite Material made with high strength/high stiffness reinforcement (i.e. fibers) in a matrix (i.e. resin).
Examples: Graphite/Epoxy, Kevlar/Epoxy, Quartz/Cyanate Ester, Boron/Epoxy

Advanced Aerospace Material: A highly specialized material used to fulfill unique aerospace construction, environment, and/or performance requirements.
Examples: Radar Absorbent Material (RAM), Beryllium, Depleted Uranium

In this report Advanced Composites will be abbreviated, AC, Advanced Aerospace Materials, AAM, and they will be jointly referred to as AM/C.

Advanced materials/composites are distinguished from their more traditional or commodity counterparts by their increased relative performance, cost, and complexity. Additionally, they tend to present a greater mishap hazard potential. Therefore, the focus of these recommendations is on AM/C's. However, it is absolutely essential that a clear distinction be made between Advanced Composites and Advanced Aerospace Materials.

III. General Information

Advanced Materials/Composites in their cured, or final form, are *generally* considered inert, biologically benign, and safe. However, environmental, safety, and health hazards arise when these materials are damaged by:

1. Fire
2. Explosion
3. High-Energy Impact

Mishap events may exhibit one or all of these damage mechanisms. In most cases, the material hazards are dependent upon the amount or concentration of damaged materials.

The inherent diversity of AM/C's, underscored by the varied chemical mixtures, constituent materials, processing methods, application environments, and mishap scenarios, has limited our understanding of these materials. The extent of the hazards posed by a mishap are largely dependent upon:

1. Type and amount of AM/C's involved
2. Type and extent of the damage
3. Prevailing weather and environmental conditions
4. Geographic location
5. Methods of response
6. Understanding of the event and response effort dynamics

After looking at all the factors involved, it is apparent that the relative "infancy" of these materials and a lack of mishap information forms a gap in the AM/C knowledge base. A total emphasis on performance has been the driver behind technological advancements in materials that have outpaced our ability to fully understand and support them. Often times this has resulted in **non-existent, inconsistent, or conflicting information** necessary to effectively mitigate the hazards of an AM/C mishap. This report outlines several key areas in which **more information, research, experience, or action is needed.**

These areas can be broadly categorized into the following: Mishap Dynamics, Safety Issues, Environmental/Disposal Issues, Equipment, Policy and Procedures, and Health Information.

1. Mishap Dynamics:

Research and testing are essential in order to more accurately characterize the hazards and gain a better understanding of the contributing information. The following list is comprised of several of the most critical issues concerning composite aircraft mishaps that require immediate research attention.

1.1 Fiber and Particulate Dispersion and Re-Dispersion
- Type, size, aspect ratio, and quantities of particulates released
- Response operation impact on re-dispersion
- mechanisms of dispersion

1.2 Plume Characteristics
- Loft Distance
- Weather Interactions
- Concentrations

1.3 Synergistic Material Effects - Interaction among Constituents
- Effects on individual materials and overall structure

1.4 Synergistic Combustion Effects - Complex Chemical Interactions
- Off-gassing concerns: type, amount, concentrations, scenarios

1.5 Concentrations

- Quantitative and qualitative characterization
- Establishment of "safe" or "contamination reduction zones"
- Conductive effects: Establish threshold values - Electrical, communications

1.6 Fire/Flammability/Thermal Research:

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

Current research indicates that some toxin quantities, delamination extents, 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 complicate reproducibility and applicability.

Flammability characterization is covered in MIL-STD-2301 Flammability Test Summary, which specifies 11 flammability tests for composite materials based upon ASTM and other standards.

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

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

2. Safety Issues:

The following Safety Issues cover hazards that are attributed to the materials themselves and the safety concerns both during and after a mishap.

2.1 Containment of Material/Debris
- Determine best methods
- Evaluate effectiveness and suitability
- Continually evaluate alternatives

A fixant is a substance used to contain or "hold down" damaged AM/C particulate debris in order to reduce the dispersion hazard. Stripper is a substance used to take the fixant off. A very clear directive is required concerning the application of fixant/stripper to damaged or destroyed composite materials and components.

2.2 Testing and Evaluation of several different fixant/stripper substances
- Understand 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

2.3 Fixant and Stripper Compatibility
- Does it damage or react with debris?
- Effect on microscopic material analysis and crash investigation
- Determine the effectiveness

2.4 Fixant/Stripper Application Procedures
- Take into account location, geometry, available equipment and materials
- Evaluate spray coverage - efficiency, 3-D coating

2.5 Suppression Agent Compatibility
- Is the agent compatible with the materials/stealth or heat coatings/engines?
- Does it corrode or damage? Determine the extent.
- Clear directive when to use

2.6 Maintenance Operations and Concerns
- Determine necessary precautions
- Evaluate equipment and PPE needs
- Integration into operating procedures and training

3. Environmental and Disposal Issues:

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

3.2 Site Contamination and Decontamination
- Evaluate EPA considerations
- Determine type and extent of contamination
- Review decon options
- Validate ability to effectively decontaminate

3.3 Containment of Material and Debris
- Determine when necessary and to what extent
- Is it effective?
- Review best methods

3.4 Clean-up Complications
- Determine clean-up requirements
- Develop specific procedures
- Evaluate methods of clean-up for cost, effectiveness, efficiency

3.5 Disposal Concerns - Classifications (Haz-Mat?)
- Verify disposal container suitability for AM/C's
- Classify types of debris
- Determine appropriate disposal schemes
- Follow all laws, rules, guidelines: generate new ones as appropriate

3.6 Impact on Waste Stream
- Evaluate the cumulative effect from all sources
- Determine impact
- Review waste minimization options
- Investigate re-mediation

4. Health Information:

Accurate health and medical support information has not kept pace with the application of advanced materials technology on our weapons systems. Sufficient information needs to be available to assist mishap response teams and medical response professionals, as well as provide a foundation for operational guidelines and protective equipment. The following are guidelines and recommendations to expand the knowledge base.

4.1 Complete List of Reference Studies and Tests
- Develop and update
- Cover information specific to AM/C mishap concerns
- Make list of Points of Contact, expertise, and relevant research

4.2 Determine and define on-site exposures ASAP
- Brief commanders and key personnel
- Develop procedures for obtaining data and using it immediately
- Tailor response to specific requirements

4.3 Test Data and Exposures - History/Database
- Immediately take data at mishap site
- Monitor site, personnel, and equipment
- Archive and disseminate results

4.4 Develop emergency respirator and/or SCBA training and fitting procedures
- All personnel must be trained and tested for equipment
- Do both qualitative and quantitative fit testing
- Determine stocking requirements

4.5 Mechanical or Dermal Irritation
- Methods: Absorption, contact, injection, abrasion, cuts
- Examine extent
- Examine sensitization
- Outline effects and PPE requirements

4.6 Respiratory and Ventilation Concerns
- Cutting, machining, sanding, and break-up dispersion of particulates
- Review collection methods and effectiveness

4.7 Bloodborne Pathogen Exposure Concerns
- Due to the injection wounds caused by fractured advanced composites
- Injection of toxins directly into body (Hepatitis B, HIV)
- Research effects and amounts
- Provide protection information

4.8 Systematic Health Effects testing of post-cured composites
- Emphasis upon irritant and nuisance dust and burned airborne particulates.

4.9 Short/Long-term exposure tests should be initiated.
- Provide a database of AM/C mishap health and medical information
- Cumulative and chronic data is essential for preventative and normal care
- Acute effects are necessary to develop appropriate response efforts

Material Safety Data Sheets (MSDS) are an important method of communicating hazardous material information. Accordingly, quality and availability are key. In the past, MSDS availability in secret or "black" programs has been tightly restricted. 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. 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.

4.10 Inadequacies of MSDS Information
- Cured composites often times are chemically altered from their constituents so the MSDS information would not be correct. The fire damage further alters the chemical nature so the MSDS information may be non-applicable.

4.11 EPA Classifications and Requirements
- Specific AM/C waste materials needs to be classified so appropriate response and clean-up systems can be applied
- EPA requirements need to be addressed

4.12 Exposure Limits
- Specific AM/C limits need to be determined for both cured and burned AM/Cs

Risk control becomes the key to minimizing the potential safety and health hazards to response personnel.

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

5. Equipment:

When the specific risks are unknown, conservative protection should be the rule.

5.1 Equipment Contamination and Decontamination
- Extent, type

- What methods are appropriate?
- Is it effective?

5.2 Suitability of PPE

- Appropriate agencies need to evaluate, list, contract for Personal Protective Equipment (PPE) required for composite mishaps
- Training is required in proper use
- Most is currently in inventory - Updates and on-going evaluation needed
- Sufficient numbers needed for AC mishap

5.3 PPE compatibility with existing Nuclear, Biological, and Chemical (NBC) gear, procedures, and environments

5.4 Protection and Clean-up equipment

- Compatibility with fixant/stripper chosen
- Evaluate performance, availability, and accessibility within thermal, environmental and geographic constraints.

The following list is indicative of fixant application 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

5.5 High-efficiency vacuum systems (HEPA filters) and sweepers

- Evaluate and test: Minimize hazards to people and environment
- Useful for both immediate mishap site and large area.
- Concerns: Availability, flexibility, performance, and cost-efficiency

6. Policy and Procedures:

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.

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.

6.1 Official Policy

- A clear, powerful, and well supported stance with solid backing is needed
- Amend, update, modify, and/or generate commander policy-level action
- Include in Mishap Response Plans, job guides, Technical Orders, training courses, refresher courses, checklists, and Air Force Instructions (AFIs), Safety notices, and technical updates

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.

6.2 Money for Programs, PPE, Training, Testing, and Equipment

- Funding is absolutely key
- It is cheaper in the long run to pay for prevention

6.3 Liability and Litigation Concerns

- Minimize losses
- Fulfill legal obligations
- Reduce liability

6.4 Repair and Battle Damage Repair Concerns

- Develop information tailored to the unique concerns

6.5 Existing Myths and Fallacies

- Provide facts, eliminate incorrect information
- Continually update and revise guidance and procedures

6.6 Cooperative research between DoD, federal, and international organizations

- Necessary because of cost and time constraints
- Establish a government and/or industry working group

6.7 Provide updated and revised AM/C mishap risk control information to:

- Air Standardization Coordinating Committee.
- Other DoD groups
- NATO and other allies

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.

6.8 Coordination needs to be accomplished between all concerned agencies and offices

- Oral, written, and personal correspondence.

-Information should go to the primary offices/agencies for approval and directly to the end-users as well.

6.9 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.

6.10 Develop an aircraft/aerospace vehicle-specific list of composite components

- Assist in mishap characterization and hazard identification
- Single source vehicle-specific listing of composite components
- A similar commercial or civilian document would also be very helpful.

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

6.12 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.

6.13 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.

6.14 Use State-of-the-art Media to increase the flow of information, enhance communication, and increase the general level of response team expertise

- Make AM/C Mishap hazard Videotapes
- Utilize multi-media, interactive laser disc training
- Develop a CD, tape, or disc containing composite aircraft mishap information
- 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

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 posture, 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..