I am submitting herewith a thesis written by John M. Olson entitled "Mishap Risk Control and Response Guidelines for Advanced Composites and Advanced Aerospace Materials". I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

Ralph D. Kimberlin, Major Professor

We have read this thesis and recommend its acceptance:

Mr. Fred Stellar

Dr. Alfonso Pujol, Jr.

Accepted for the Council:

Interim Vice Provost and
Dean of the Graduate School

Mishap Risk Control and Response Guidelines for Advanced Composites and Advanced Aerospace Materials

A Thesis
Presented for the
Master of Science Degree

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John M. Olson

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ABSTRACT

Advanced composites and advanced aerospace materials (AC/AAMs) provide important design, performance, and functionality benefits over other materials options for a variety of ever-increasing applications. In their cured or final design state, these materials are generally considered safe, inert, and biologically benign. However, when damaged by fire, explosion, or high-energy impact, these materials can present unique hazards and concerns. In order to mitigate the potential environmental, safety, and health risks and hazards associated with these events, timely and appropriate mishap response procedures are crucial. Unfortunately, due to the diversity of materials, the complexity of mishap dynamics, and the wide range of response elements involved, current and synergistic mishap response guidance is limited. This is particularly true for mishaps that occur within a controlled or confined space environment. This thesis consolidates the current research and operational experience in this area in order to develop a coordinated, factual, and multi-disciplinary source of information and operational guidance for responding to mishaps involving these materials.

PREFACE

In order to limit the scope, this thesis focuses on the hazards and risks predominantly associated with a significant release of fire, explosion, or high-energy impact damaged advanced composite (AC) materials. Carbon/graphite fiber reinforcement and polymer matrix materials are specifically emphasized. However, other AC materials and advanced aerospace materials (AAMs) are addressed because the response guidance is quite similar. Simple composite materials are specifically NOT addressed as these present greatly reduced hazards and risks compared to their advanced counterparts.

This effort focuses on air and space mishap events. As such, the mishap dynamics will be described within the context of aerospace mishap events, although the information is universally applicable to any AC/AAM mishap scenario with similar elements and dynamics. Special emphasis will also be place on addressing the unique and challenging issues and supporting guidance for a mishap in a controlled or confined space environment.

The information in this document is the product of the most recent, unbiased, majority-consensus research available. However, continued research and emerging technologies, highlighted by the dynamic, complex, multidisciplinary nature of this field, make this work one that is constantly being updated and refined. Likewise, these operational guidelines represent the "current" best practice solution and must be situationally tailored for each particular damage/mishap event, particularly for non-aerospace applications.

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NOMENCLATURE AND DEFINITIONS

Composite Material: A physical combination of two or more materials, generally consisting of a reinforcement and a "binder" or matrix material. Generally, the reinforcements, or load-bearing elements, are fibers, while a resin forms a matrix to hold the fibers and fill the voids. The reinforced matrix structure thereby allows fiber-to-fiber load and stress transfer. Composite materials generally consist of laminates of several layers in varying directions. In many cases, a honeycomb core material is sandwiched between two of the laminates. The name of the composite describes its physical make-up: type of fiber/type of resin.

Examples: Fiberglass (Glass/Epoxy, Glass/Polyester)

Advanced Composite Material: A composite material comprised of high-strength, high-stiffness reinforcement (i.e. fibers) in a matrix (i.e. resin) with properties that can include low weight, corrosion resistance, unique thermal properties, and special electrical properties. Advanced Composites are distinguished from traditional composites by their increased relative performance, cost, complexity, and mishap hazard potential.

Examples: Graphite/Epoxy, Boron/Epoxy, Aramid (Kevlar)/Epoxy, Quartz/Cyanate Ester

Advanced Aerospace Material: A highly specialized material fulfilling unique aerospace construction, environment, or performance requirements.

Examples: Beryllium, Depleted Uranium (DU), Radar Absorbent Material (RAM)

It is essential that a clear distinction be made between Advanced Composites and Advanced Aerospace Materials because of several very specific and unique hazards.

Hazard: A condition or changing set of circumstances that presents a potential for injury, illness, or property damage. Likewise, it can be described as the potential or inherent characteristics of an activity, condition, or circumstance, which can produce adverse or harmful consequences.

Given this definition, the hazards associated with mishap damaged advanced composites and advanced aerospace materials will be addressed with a risk control emphasis.

Risk Control: The process of minimizing accidental and other extraordinary losses by anticipating and preventing unplanned events. It emphasizes the complexities of exposures and encompasses broad areas of risk which are indicative of a mishap scenario. Effective risk management is comprised of both risk control and risk financing in order to control exposures through knowledge, training, preparation, and an understanding of the factors involved. Loss avoidance must be both a pre- and post-mishap effort.

Confined Space: A restricted or limited access area generally small in size, thereby restricting mobility, ease of entry/exit, and resources available. Sometimes describing a controlled volume of space with minimal accommodations, accessibility, or internal/external environmental controls, often times conducive to engulfment or entrapement.

Examples: Mine/Mine shaft, vault, interior of autoclave, hold of a ship, shipping container, empty pressure cylinder

Controlled Space: Similar to a confined space in that it is a restricted or limited access area with restricted mobility, operational contraints, and resources available. Additionally, a controlled space may have unique environmental characteristics including pressurization, temperature control, atmospheric regulation/hazards, and environmental control. Likewise, accessibility would be limited along with availability of resources other than those in the immediate vicinity or space of interest. A controlled environment may also be monitored or regulated both internally and externally.

A controlled space may also be conducive to engulfment or entrapment, especially if volatile, toxic, explosive, or corrosive substances are contained within the same atmospheric confines.

Examples: International Space Station, MIR, submarine, the Euro Tunnel (CHUNNEL)

For the purposes of this work, confined and controlled space will be jointly used as they present similar conditions for mishap responses involving AC/AAMs. However, controlled space hazards can be significantly greater under some circumstances, and will be specifically addressed when appropriate. This is particularly true for pressure vessel applications in austere environments (i.e., space and deep-sea).

LIST OF ABBREVIATIONS

AAM	Advanced Aerospace Material
AC	Advanced Composite material
ACPO	Advanced Composites Program Office
AFFF	Aqueous Film-Forming Form
AGL	Above Ground Level
B/EP	Boron/Epoxy composite
BEE	Bio-Environmental Engineer
CRZ	Contamination Reduction Zone
DEP	Decontamination Exit Point
DOD	Department of Defense
DOT	Department of Transportation
DU	Depleted Uranium
ECP	Entry Control Point
EPA	Environmental Protection Agency
ESH	Environmental, Safety, and Health
FAA	Federal Aviation Administration
FG	Fiberglass
GPS	Global Positioning System
GR/EP	Graphite/Epoxy composite
HAMMER	Hazardous Aerospace Material Mishap Emergency Response
HAZ-MAT	Hazardous Material
HEPA	High Efficiency Particulate Air
HAM	Hazardous Aerospace Material
HIV	Human Immuno-deficiency Virus
IC	Incident Commander
IERA	Institute for Environmental, Safety, and Occupational Health Risk Assessment
LO	Low Observable(s)
LZ	Landing Zone
MSDS	Material Safety Data Sheet
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NBC	Nuclear, Biological, Chemical
NFPA	National Fire Protection Agency
NTSB	National Transportation Safety Board
OSC	On Scene Commander
PPE	Personal Protective Equipment
RAM	Radar Absorbent Material
RCS	Radar Cross Section
SCBA	Self Contained Breathing Apparatus
SP	Security Police
TO	Technical Order
USAF	United States Air Force

CHAPTER 1: INTRODUCTION

Overview

Advanced composites and advanced aerospace materials (AC/AAMs) are pressing the envelope of technology by providing design flexibility and superior performance advantages over other traditional materials for a wide spectrum of applications. Distinguished by high-strength, high-stiffness, low weight, corrosion resistance, and design flexibility, these materials are responsible for significant gains in speed, range, payload, agility, efficiency, and low observability (LO) for aerospace applications. Figure 1-1 highlights the most important benefits of advanced composites.

Not only are AC/AAMs being used on almost every major new aerospace vehicle, but they are also used extensively for repairs and modifications to existing systems as well because of their unique material benefits.

Beneficial Characteristics of Advanced Composites

- **High Structural and Tensile Strength**
- **High Strength-to-Weight Ratio**
- **Generally Corrosion Resistant**
- **Anisotropic Material Properties**
- **Precisely Tailored Reinforcement Capability**
- **Design Flexibility gives Reduced Part Count**
- **Uniquely Designed Performance Characteristics**
- **Small Raw Material Scrap Rate**
- **Highly Energy Absorbent**
- **Unique Electrical Properties for Low Observables and Reduced Radar Cross Section**
- **Safe and Biologically Benign When Cured**

Figure 1-1 Summary of Advanced Composite Characteristics. [1]

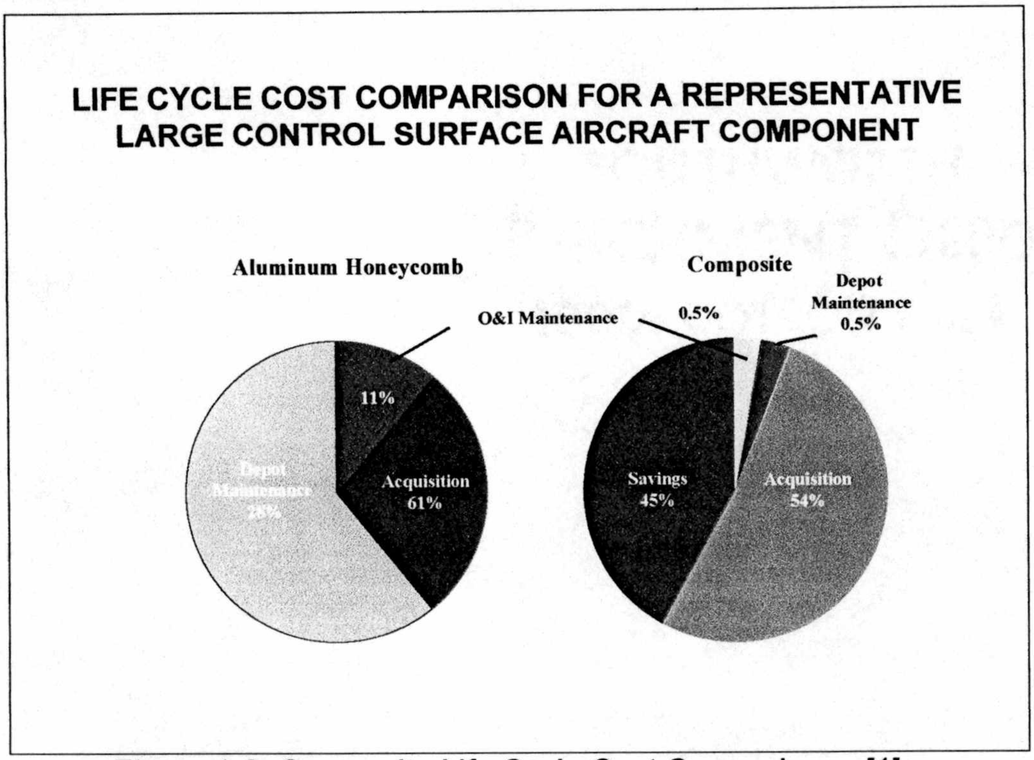

Figure 1-2 Composite Life Cycle Cost Comparison. [1]

Figure 1-2 is representative of the drastic life cycle cost savings that can be realized by implementing composite structures in aircraft applications (in this case, a large control surface) that previously used an aluminum honeycomb construction. Examples of new applications include the B-2 Stealth Bomber, X-33 Joint Strike Fighter, F-22 Advanced Tactical Fighter, V-22 Tiltrotor, Enhanced Expendable Launch Vehicle, Space Shuttle, International Space Station, Airbus A320, and the Boeing 777, just to name a few. The diagrams in Appendix A (Plates A-1 through A-26), graphically depict the types and locations of AC/AAMs within much of the current United States Air Force (USAF) air and space vehicle inventory. Clearly, these materials comprise a substantial component of the overall material content. If trends continue, as all indications portend, the use and exploitation of these materials will continue to rapidly increase.

Applications

Aerospace applications have steadily progressed from early minor control surface applications through recent widespread use in secondary and primary structure. The exponential increase in AC/AAM use in aerospace applications is graphically portrayed in Figure 1-3.

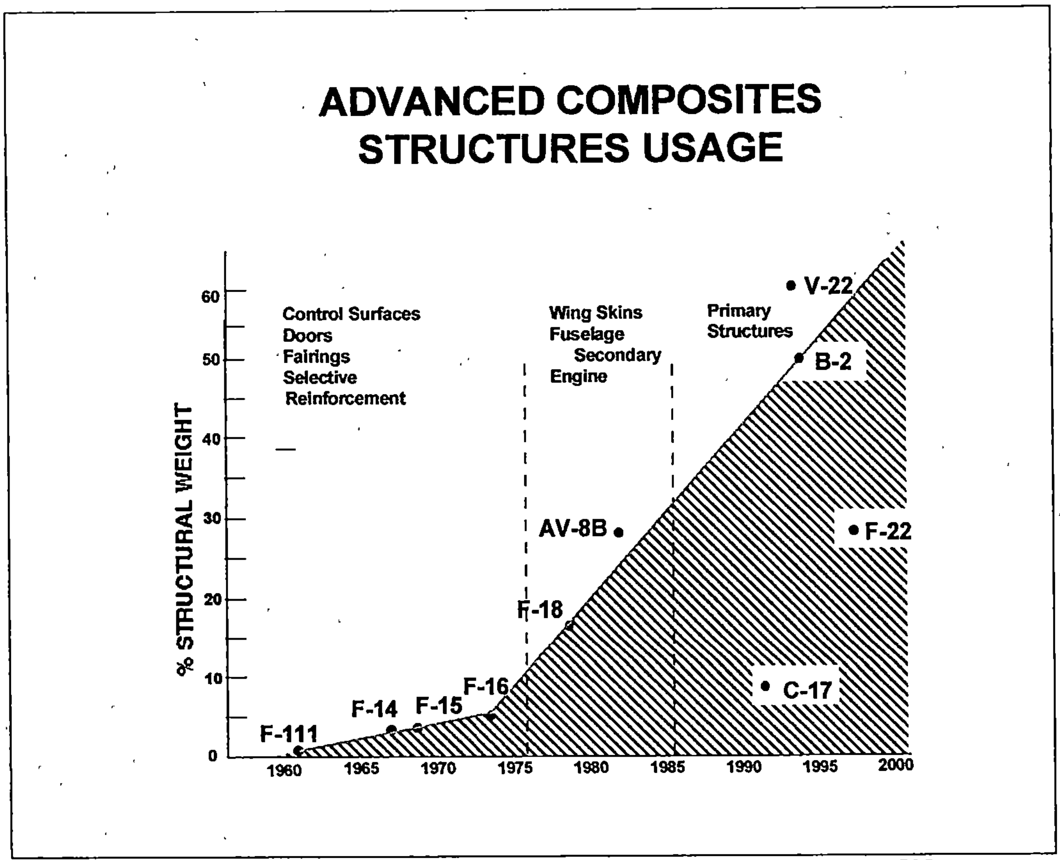

Figure 1-3. Usage Trends for AC/AAM Materials. [2]

Materials technology has opened incredible design and applications opportunities previously deemed impossible. Similarly, the benefits reaped from composite materials and other AAM solutions are being harnessed in almost every major sector of the commercial, industrial, and international marketplace. In the scope of just 10 years, production for composite materials has more than tripled, with gains across a wide spectrum of business sectors as depicted in Figure 1-4.

Materials Information

Inherent in the make-up of AC/AAMs is the virtually limitless combination of matrix and reinforcement options. Coupled with different and distinct

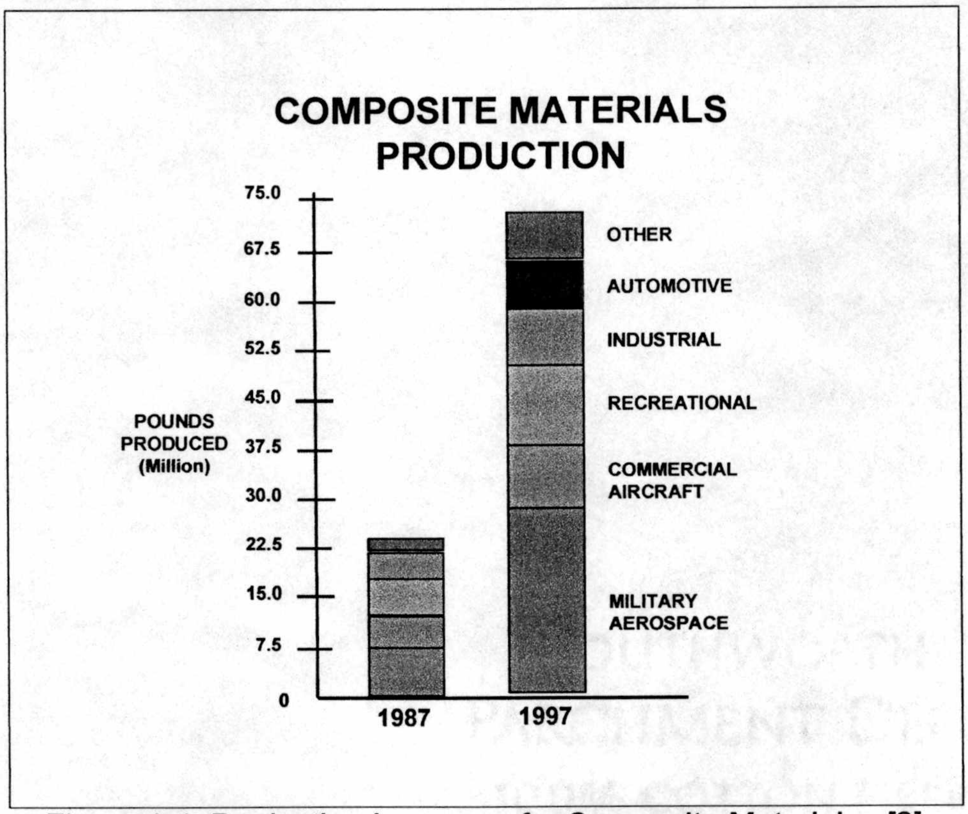

Figure 1-4 Production Increases for Composite Materials. [2]

chemical and industrial processes (often proprietary) for manufacturing these materials, the cumulative diversity of materials for composite fabrication is unlimited. Typical reinforcement constituents for advanced composites include carbon/graphite, boron, aramid (kevlar), and spectra. Similarly, notional organic matrix materials include both thermosets (Epoxies, Polyesters, Bismaleimides, and Polyimides) and thermoplastics (PEEK, Torlon, Ryton).

In their cured or final design state, these materials are *generally* considered safe, inert, and biologically benign [3]. As such, they are designed, built, fabricated, modified, and generally repaired with this mindset. However, AC/AAMs present some life-cycle concerns, particularly in three main areas:

1. Manufacturing – Maintenance – Repair: Raw materials processing (including cutting, sanding, and shaping) as well as curing and autoclaving.
2. Post-Mishap: Non-fire or heat damaged materials.
3. Disposal: Waste stream, recycling, breakdown, and incineration.

In general, the hazards associated with these operations, or life-cycle phases, are fairly well understood and appropriately controlled by existing engineering or administrative means. Further discussion of these areas is beyond the scope of this work.

In the past, a sharply focused emphasis upon performance has been the driver behind technological advancements in materials and applications.

Unfortunately, some materials applications have outpaced the technical community's ability to fully understand and support them throughout the life cycle – particularly in fire and explosion mishaps.

Statement of the Problem

When damaged by fire, explosion, or high-energy impact, AC/AAMs can, and often do, present unique hazards and concerns [4,5,6]. As such, these materials require timely and appropriate responses to mishaps involving these materials in order to mitigate the potential environmental, safety, and health risks associated with these events. The mishap response hazards, and subsequent effort to mitigate them, are complicated by large variations in chemical mixtures, constituent materials, processing methods, application environments, and mishap scenarios. This, coupled with extremely complex burn chemistry and the unpredictable nature of mishap events drive a critical lack of current and consolidated AC/AAM damage information. In turn, this lack of technical information has lead to operational response guidance deficiencies. However, society is no longer willing to accept the benefits of technology without careful observation of the human and environmental effects, both on a short and long-term scale. Tremendous liability, skyrocketing health and disability costs, increased environmental stewardship, and untenable loss consequences in this area make risk management absolutely essential. Furthermore, not only must risk management entail risk control, it must also look at the cumulative tradeoffs for risk financing in terms of cost-benefit relationships. As advanced composites production and usage increases, so too do the tangible and intangible consequences of improperly handled mishaps involving these substances.

Objectives of the Study

The primary objectives for this thesis are focused around two areas:

1) Review, consolidate, and classify the environmental, safety, and health hazards of mishaps involving AC/AAMs in order to develop risk control methods.

Secondary objectives associated with the consolidation of information are to eliminate historical fallacies associated with these types of mishaps and to optimize the response according to the level of risk.

2) Development of current operational mishap response guidelines for incidents involving AC/AAMs.

Secondary objectives associated with the operational guidelines are to emphasize the unique concerns of the mishap response participants and focus upon the unique and challenging controlled/confined space environment.

The overriding goal of the entire effort is to codify a reasonably conservative set of generic operational guidelines which a AC/AAM mishap responder may apply to protect people, property, and the environment given extremely challenging constraints on time, resources, and knowledge.

CHAPTER 2: BACKGROUND

Widespread AC/AAM material usage, particularly in the aerospace industry, has been prevalent for only the past 30 years. Thus, the relative "infancy" of these materials, combined with the lack of detailed mishap information, has contributed to the current level of understanding, and often times, misunderstanding, regarding appropriate AC/AAM mishap response.

Early Fallacies

Early USAF, DoD, NASA, and industry studies [5,7,8] from the 1960s through the early 1980s contributed, in some cases, to several **fallacies** concerning composite mishap damage hazards, including:

- Release of damaged composite material will cause widespread electrical blackout.
- Dispersed composite material causes malignant tumors, among other biological impacts, and should be treated like asbestos.
- Large concentrations of particulates can be carried very long distances downwind in a smoke plume.
- All fractured advanced composites are deadly, razor sharp.
- Extreme personal protection is always required when dealing with AC/AAMs.
- Mishap scenarios with AC/AAMs are always very dangerous.

Fortunately, many of these claims have proven, through modern research and documented operational experience, to be partial-truths, over-reactions, or inaccurate conclusions. The hazards depend on a huge assortment of variables. However, on-going research in many disciplines pertinent to the aerospace AC/AAM damage environment is not yet complete (nor will it ever be), and some results or opinions are conflicting. For example, the Environmental Protection Agency (EPA) does not specifically define burned AC/AAMs as hazardous wastes leading to often times improper handling [3]. Likewise, the National Fire Protection Agency (NFPA) does not have any written guidance on composites in a fire or mishap [3]. Oftentimes, there is a strong climate within the industry that "we make them, you break them", which has lead to post-mishap handling information not being readily available from the manufacturer's. Nevertheless, overwhelming evidence reveals this fact: burned or exploded advanced composites/advanced aerospace materials DO cause environmental, safety, and health problems IF they are not properly addressed [4,9,10,11]. Common throughout the literature, research databases, and annals of operational experience, is the need to exercise caution. Because the composition, concentration, and toxicity of these materials is often unknown in a synergistic mishap environment, they present challenging response scenarios. For this reason, a high degree of precaution with conservative protection is recommended until the hazard exposures and elements involved can be characterized for an "optimal response".

Mishap Characteristics

Damage to AC/AAMs caused by fire, explosion, and/or high-energy impact in a mishap presents unique environmental, safety, and health hazards. In typical aircraft fires, temperatures reach between 1000-2000 °C. Organic matrix materials (i.e., resins and polymers) burn off around 400 °C, creating toxic combustion products and liberating the reinforcement (i.e., fibers) [12,13]. Depending upon the type of AC/AAM, the associated material dynamics and characteristic responses can vary greatly. For example, glass or aramid fiber reinforcements tend to melt under the intense heat, whereas, extreme heat can oxidize carbon or graphite fibers. In turn, oxidation can alter their size, shape, porosity, strength, and impact resistance of the fibers, along with several other characteristics.

Mishap Dynamics

The intense thermal and mechanical forces in a mishap generally cause degradation, debonding, and/or "explosive" fracture of AC structures. While absorbing this fracture energy, the reinforcement, usually stiff and strong, may be broken into particulate fibers, turned to dust, or reduced to a cloth-like consistency. AAMs can produce highly toxic oxides or heavy metal concentrations. A notional collection of thermal degradation products from a current AC/AAM-laden aircraft is described in Table 2-1 on the following page. All of which, in varying concentrations, can be hazardous to human health.

Table 2-1 Representative Thermal Degradation Products [14]

HAZARDOUS COMPOUNDS BY MAJOR SUSTANCE	
Bromides	**Hydrogen Cyanide**
Sulfur Dioxide	**Silicon Dioxide**
Methane	**Formaldehyde**
Hydrogen Fluoride	**Ammonia**
Ketones	**Hydrochloric Acid**
Hydrogen Sulfide	**Isocyanates**
Amines	**Aromatic Compounds**
Heavy Metals: Lead, Manganese, Chromium, Silver, Copper	

Liberated carbon fibers can readily penetrate human skin due to their stiffness, whereas boron fibers can penetrate bone. Furthermore, the adsorbed and absorbed pyrolysis and combustion products (generally toxic) on activated, oxidized fibers can be a very potent injection and inhalation hazard because the toxins can be readily placed and retained in the body. This phenomenon is particularly critical in mishaps involving bloodborne pathogens (i.e., HIV, Hepatitus B) that are present in the debris. In almost all cases, the type, amount, and extent of damage drive the concentration of AC/AAMs at a mishap site. In turn, the concentration of AC/AAMs determine the extent of the hazards. The prevailing weather conditions can also greatly affect the extent of the dispersion of the damaged materials within the vicinity of the mishap, potentially exacerbating the response hazard exposures.

Types of Damage

Fire, coupled with heat, shock, and fragmentation, produces several different types of damage in ACs. Effects can range from a simple reduction in strength, to a loss of LO performance, delamination, debonding, charring, melting, burning, and vaporization [12]. Table 2-2 summarizes the graded extent of possible damage from least to worst. The impact upon AAMs can be just as broad, but is highly dependent upon the type of material. For example, Depleted Uranium (DU) and Beryllium both produce highly toxic oxides when subjected to intense heat (>700-800 °C).

Subsequently, the unique environmental, safety, and health concerns presented by both ACs and AAMs are summarized in Table 2-3, which is found on the following page . Each of these problems will be addressed later, along with the appropriate response precautions or solutions.

Table 2-2 AC Material Damage Types by Increasing Damage Extent.

Damage Extent	**Type of Material Damage**
Least	**Strength Reduction**
↓	**Loss of Coatings**
↓	**Charring**
↓	**Delamination/Debond**
↓	**Melting**
↓	**Burning**
Worst	**Vaporization**

Although AC/AAMs represent only one of the many hazards associated with an aircraft mishap (i.e., fuels, lubricants, exotic metals, and weapons), they do merit increased awareness and informed precautions because of their

Table 2-3 Unique AC/AAM Concerns.

PROBLEM	CAUSE
1. Highly Toxic Smoke	Matrix Offgasing
2. Diverse Fracture or Degradation Mechanisms	Fracture Dynamics
3. Damage Susceptibility	Organic Material Limits
4. Invisible Damage	Internal Delaminations and Debonds
5. Corrosion and Weakening	Material and Fire Agent Incompatibilities
6. Difficulty Assessing Hazards	Complex Cure and Fire Chemistry

increased hazard potential, increasingly widespread use, and persistence or durability. Exposures to potentially harmful vapors, gases, particulates, and airborne fibers generated in a composite mishap need to be controlled because of the combined effects of the dispersion forces and the complex chemical mixtures.

Hazard Exposures

Hazard exposure routes for damaged AC/AAMs include absorption (contact), inhalation (breathing), injection (puncture and tearing wounds), and ingestion (eating, drinking, and smoking). Concentrations are absolutely the key element. Generally speaking, the higher the concentrations, the worse the hazards and the greater the risks. The toxicology of respirable particulates and their disease producing potential is a function of three main variables: 1) the dose or amount of particulates in the lung; 2) the physical dimensions of deposited particulates; and 3) the durability (time) in the lungs [4]. Fire-exposed carbon fibers tend to break into shorter lengths and split into smaller diameters with sharp points, thereby increasing their probability for inhalation and ease of transport [4]. Dry and windy conditions at a mishap site increase the chances for re-dispersion of particulates. Likewise, whether inhaled or injected, ACs are not easily removed nor expelled because of their shape, sharpness, and stiffness [15]. Other potential health and environmental effects caused by AC/AAMs include dermal and respiratory problems, toxic and allergic reactions, contamination, and radiation exposure (for some AAMs). These impacts may be acute or chronic, as well as local or systemic, depending upon the circumstances. Mechanical injection or cuts are the most common skin hazard, although sensitization (acute and chronic) can occur. Irritation to the respiratory tract is also common, much like a nuisance dust irritation hazard. Off-gassing, toxic products in the smoke plume, smoldering debris, and oxidized (fire-damaged) particulates are the primary respiratory hazards. Table 2-4 on the following page highlights the potential environmental, safety, and health (ES&H) effects of composites.

Table 2-4 Summary of Potential ES&H Effects.

MAJOR TYPE	DESCRIPTION
Skin Problems	Acute/Chronic/Local/Systemic
Respiratory Problems	Acute/Chronic
Radiation Exposure	Mild Acute Exposure
Toxic Exposure	Mild to Extreme
Site and Equipment Contamination	Light to Widespread/Unservicable
Noted Carcinogen, Mutagen, and Teratogen elements	
Carcinogen = Cancer causing	
Mutagen = Causes gene mutations	
Teratogen = Causes birth defects	

Electrical Hazards and Risks

Mishaps involving AC/AAMs that are electrically conductive (i.e., graphite or carbon fiber) may present electrical shorting or arcing hazards if very high concentrations exist (usually at the immediate mishap site only). Although rare, this may result in electrical equipment degradation or failure, including communication interference (including radio frequency transmission/reception). However, NASA research has shown that widespread electrical failure due to environmental release and plume dissipation is highly unlikely, except at the mishap site [5]. Disseminated carbon or graphite fibers are influenced by the presence of high voltage or magnetic fields and reduce the local dielectric properties of free air, all of which could can cause equipment malfunctions, although the concentrations of liberated AC/AAMs must be high.

Current Hazard and Risk Classifications

At the present time, several government and private agencies are trying to develop an accurate and coordinated account of the real hazards posed by AC/AAMs in a mishap environment. In order to do this task, the risks must be quantified in terms of exposures. In turn, this requires a fundamental knowledge of the elements involved and the historical, operational, and academic characterizations the hazards themselves. Paramount to this effort is the cooperative work of each of the respective "expertise" agencies within all phases of the AC/AAM product lifecycle.

At the forefront of this effort is the Institute for Environmental, Safety, and Occupational Health Risk Analysis (IERA) with its subgroup, known as the Hazardous Aerospace Material Mishap Emergency Response Integrated Product Team (HAMMER - IPT). At its genesis, this group was designed to first identify all hazardous aerospace material (HAM), as they referred to it, prior to accomplishing a risk characterization [16]. It is important to make a clear distinction of definitions. This document views AC/AAMs as generally safe unless damaged as previously described, versus a definition that immediately labels these materials in a negative tone. It should be emphasized that concentrations are the ultimate driver, with a minority of exceptions. Once a risk characterization is completed (to the best extent of the resources available), the appropriate response precautions, protective equipment, and procedures may be addressed.

The baseline for much of the recent work by the HAMMER-IPT is the 1993 USAF Advanced Composites Program Office (ACPO) Guidelines for Response to Aircraft Mishaps Involving Composite Materials developed by the author [17]. Since their inception, a significant amount of new, updated, and operational verified data is available. Accordingly, the HAMMER-IPT published an Interim Guidance addendum to the original guidelines in 1998 [18]. Again, the rate at which new information was being generated, combined with several operational experiences, has formed the current basis for which these guidelines are being written. Although inclusion of much of the specific data is beyond the scope of this document, the practical and operation application of this consolidated information is the cornerstone of the following mishap response guidelines.

Rationale

Given the existing and projected increases in the usage and applications of AC/AAMs, it is critical to develop realistic policies and procedures that focus on risk control to minimize the environmental, safety, and health hazards associated with an AC/AAM mishap. Huge increases in the variety, type, quantity, and concentrations are again outpacing the preparations for mishaps involving these materials. Likewise, the rapid growth and development of these materials has led to widespread applications in many different sectors, so the need for generalized, multi-disciplinary guidance has increased. No longer an aerospace dominated issue, effective and efficient AC/AAM mishap response is a necessity across the transportation, medical, sporting goods, and commercial arenas. Ultimately, as the associated knowledge base grows, procedures and guidelines can be situationally optimized in terms of cost, safety, and performance.

CHAPTER 3: METHODOLOGY

Risk Reduction Methods

Based upon both existing and yet uncharacterized mishap hazards associated with AC/AAMs, risk reduction measures are necessary. Administrative controls, including adequate personal protective equipment (PPE), training, and safe practices, need to be immediately implemented as this dynamic field environment is not conducive to engineering controls. Conservative, although situationally optimized, risk control measures are essential. Basically, careful and common sense approaches are the best course of action. Because aircraft mishaps occur under extremely diverse weather, terrain, and location conditions, with widely varying degrees of damage, a universally applicable set of risk control precautions is not practical. The numerous variables require conservative protective measures with a complete material lifetime, or "cradle-to-grave", mentality of responsibility. This is true for all phases of a mishap response, ranging from first response and fire fighting, to investigation, recovery, clean up, and disposal. It was originally assumed that the first responders and fire fighters would have the greatest potential risks due to their acute exposure to the hazards. However, experience has shown that the cumulative exposure over a longer duration can have similar, if not worse, effects if appropriate response regimes are not followed. Therefore, diligence is required throughout the response and recovery process until final completion.

Risk Identification

The major issues currently affecting mishap response which involve AC/AAMs are:

1. Fiber dispersion and re-dispersion
   - Includes the mishap dynamics, effective response procedures, and hold-down material (fixant) suitability.

2. Synergistic material and combustion effects
   - The combined effects of multiple materials and varying damage extents.

3. Concentrations and compatibility
   - Exposure limits are not specifically defined. Equipment, procedure, and fire suppression agent compatibility issues also exist.

4. Adsorbed and absorbed pyrolysis and combustion products
   - Impact and extent of the toxin hazard.
   - Characterization of the type, dynamics, and toxicity of components.

5. Site and equipment contamination and decontamination
   - Procedures for effectively and realistically addressing the hazards.

6. Clean-up and disposal complications (including potential classifications as Hazardous Materials {Haz-Mat} depending upon the type and damage of the materials)
   - Determine proper disposal methods and classifications of waste debris.
   - Clarify legal obligations and compliance with applicable regulations.

7. Bloodborne pathogens
   - Examine the potential for Hepatitis B and HIV transmission from injection by contaminated debris.

8. Radiation exposure effects
   - Evaluate extent and results of potential exposures to Depleted Uranium and other radioactive AAMs.

9. Unknown or limited characterization of toxic corridors within smoke plumes
   - Model and sample the smoke plumes from actual and simulated mishaps.

10. Confined space operations for mishap response
    - Analyze effectiveness of mishap response procedures in a controlled environment, particularly under austere conditions.

11. Community preparation and mutual aid issues
    - Disaster preparedness issues including information, shelters, and protection.
    - Training and Awareness of the risks, including outlining resource requirement.

12. Acute toxic exposures to beryllium oxide and other highly dangerous AAMs
    - Evaluate protective measures and protective equipment.

13. Mishap investigation issues
    - Decontamination, storage, and subsequent handling of damaged materials.

14. Training and equipping of response personnel
    - Changing mind-sets, currencies, developing techniques, and resources
    - Standardizing the level of knowledge: DoD, Government, Civilian

Identify Participants

Depending on the location, type, and extent of damage, several different groups of people and response personnel will be affected or involved in a general mishap response effort. In describing the types of response personnel, mishap response must be viewed from a "cradle-to-grave" mishap perspective. Therefore, mishap responders are described as those personnel involved in a complete mishap response, from initial or first responders, to investigation, clean-up, recovery, and disposal. This also includes those people executing, reporting-on, and managing these incidents.

Typically, it can be assumed that innocent onlookers, witnesses, or curious public members will be present at a mishap with the exception of restricted, rural, or remote locations. However, for the purposes of this study, the groups or organizations functionally outlined in Table 3-1 (next page) are the

Table 3-1 Organizations Involved in a Mishap Response.

MILITARY RESPONDERS	CIVILIAN RESPONDERS
Firefighters	Firefighters
Security Police/Military Police	Police Personnel/Sheriff
Safety: Ground, Flight, System, Range	FAA Inspectors*
Bio-Environmental Engineer	Environmental Protection Agency*
Disaster Preparedness Personnel	Community Disaster Relief Agencies
Civil Engineers	American Red Cross
Medical Personnel	Medical Personnel or EMTs
Maintenance Personnel*	Community Leadership*
Weapons Personnel*	News Media*
Engineering Personnel*	Coroner
System Program Office Personnel	Waste Disposal Agency
Chain of Command	Environmental Protection Agency
Public Affairs	
Mortuary Affairs	
* - Denotes likely elements at either event not listed in the other column	

primary mishap response participants. As such, they are key players in any coordinated mishap response effort of a reasonable magnitude. Because of subtle differences in naming conventions between the military and civilian communities, they are organized into two classification groups: military and civilian responders. Nevertheless, all of the organizations listed may or may not be at either a military or civilian mishap event.

CHAPTER 4: DISCUSSION

With the problem clearly defined, the process of integrating all of the stakeholder concerns within the context of the risk reduction methodology became a daunting task primarily because of the technical unknowns and the diversity of the users. Although several efforts at developing mishap response guidelines were by undertaken by the US Navy, the Air Force, the Federal Aviation Administration (FAA), the National Transportation Safety Board (NTSB), and the National Aeronautics and Space Administration (NASA), each of these efforts had shortcomings. Most, if not all, of the guidelines were antiquated due to the rapid advances in materials technology, types of applications, and new research/experimental findings. However, the greatest problem with properly responding to a mishap with AC/AAMs (even with current information) is the variability in both knowledge and procedures for the responders themselves.

Depending upon the source, the guidelines for a mishap response varied widely from one organization to another, and from one area to another, particularly between government and civilian operations. Unfortunately, the ramifications of less than acceptable AC/AAM mishap response are directly manifested in hazards to the safety and health of the mishap response personnel and any bystanders. The risks to responders who are either unaware or ill-informed are untenable, particularly since acceptable procedures for well educated and trained responders mitigate the majority of the risks.

Compounding the problem of less-than-universal knowledge of modern and correct response procedures is the potential for intense public and media criticism. In the digital age, breaking news, such as a mishap, is immediately the focus of attention. Not far behind is the full weight of public scrutiny, blame, and the requisite responsibility. As such, it is critically important that a mishap response be executed in a timely, proper, and effective fashion.

The legal ramifications of variances in mishap response knowledge, training, and preparation are also important. Litigation has become a powerful driver for mandatory compliance and training, with liability assessments driving the responsibility for a safe response. Both civil and criminal legal cases are now commonplace for negligence, product liability, and environmental pollution events. Therefore, structured programs with consistent application are essential.

Expanding on the environmental issue, modern society is much more acutely aware and intolerant of environmental disregard. As evidence of this, legislative and judicial judgements are forcing environmental stewardship towards the forefront of any activity, particularly a mishap, because of the "messy" nature. Often times, the local, state, federal, and international guidelines in this area are very restrictive – particularly with hazardous or toxic waste.

Overall, the cost of risk financing for a mishap response simplifies down to a simple concept – the cost of preparation is always less than the cost of recovering from an inappropriate mishap response. Rephrasing this concept, it will either cost on the front end with training and resources, or it will cost far more on the back end with unanticipated expenditures, emergency spending, possible fines, and huge recovery bills. In most cases, these financial risks are intolerable, or at the very least, greatly debilitating. Likewise, these costs are not only currency related, but intangible as well. The cost of injured workers, affected operations, and irrecoverable resource and asset damage is astronomical. Therefore, risk control through current procedures, guidelines, training, and resources accompanied by exhaustive coordination and dissemination of information is the best recourse for a mishap involving AC/AAMs. Operationally realistic responses optimized to the individual scenario are the pivotal element required to protect people, property, and the environment.

Several agencies, lead by IERA-HAMMER, ACO, the FAA, and the Department of Transportation (DOT), are actively identifying and funding research and testing in several key areas where several mishap unknowns exist. Both laboratory experiments and actual sampling tests at mishap events are essential elements of a coordinated testing effort. Likewise, consolidation of operational experience, interview data, effectiveness reports, field studies, and epidemiological records are important contributors to a greater mishap knowledge database. As budgets shrink and technology proliferates, international cooperative efforts are also becoming increasingly effective. The recent manifestations of global commerce, electronic interconnectivity, and structured technical interchanges have radically increased the depth and breadth of information available to the mishap responder. The key, however, is consolidating the information into a usable tool that is readily available -- in this case, the following mishap response guidelines. Unfortunately, as soon as they are printed, they are no longer the state-of-the-art. Ultimately, a fluid electronic database with adequate data safeguards and sufficient interconnectivity must be developed.

Emerging Technology and Methodology

Advanced Composites and Advanced Aerospace Materials are, and will continue to be, a major portion of a wide spectrum of current and future product applications. Given their relative infancy as high-production-volume structural materials (compared to metals), these materials require a different mindset for all who are affected by them (a substantial group). Likewise, they mandate new procedures, particularly in a mishap response. As part of the on-going effort to systematically uncover the unknowns of the dynamic mishap environment, advances in toxicology, safety, industrial hygiene, fire science and fire modeling, materials science and engineering, plume modeling, medicine, bio-environmental engineering, ergonomics, textiles, and a myriad of other areas are rapidly revealing the information necessary to optimally respond to these incidents. With this new information, training becomes the key.

Aircraft and spacecraft designs, along with the systems that they comprise, make increasingly widespread use of many different materials, manufactured by multiple organizations, with unique processes and varied lots. Configuration control for such complex product and process supply chains becomes an important element which directly affects the mishap responder. The diversity of knowledge and experience required to know what materials are present and what effect or impact they will have on the scenario dynamics requires either the assistance of highly trained personnel or the aid of electronic databases. The material location plates in Appendix A highlight the AC/AAM locations within these vehicles. However, it can be easily seen that any changes, updates, or applications not included in this brief summary would be unavailable for a mishap responder.

The logistics support required to meet the challenges of a AC/AAM mishap response has also changed. Although many existing items can be used, they must often times be employed in more creative ways to meet the immediate needs of the mishap responder. Certainly, new facilities and equipment specifically designed, tested, and intended for composite materials are the ideal solution. In order to maximize the opportunities of this happening, logistics and supportability must be a concern for government, military, and civilian producers alike. Surprisingly, issues such as fire suppression agent and system compatibility have become major concerns. For example, Potassium Bicarbonate dry chemical fire suppression agent is incompatible with some materials because it causes galvanic corrosion, thereby degrading the material. Similarly, some materials are not readily extinguished with some agents. This issue is further heightened by Personal Protective Equipment (PPE) requirements, which will be discussed later.

Clean-up and disposal techniques must continue to evolve to meet the different needs of AC/AAMs. Some of the unknowns surrounding these materials in a mishap have led to inadequate material classifications, difficulty identifying the proper waste disposal stream, and inconsistencies regarding exposure limits. However, great strides have been made towards characterizing the type and extent of the hazards presented by the materials. In turn, this knowledge can be leveraged into prudent waste management operations. Similarly, site remediation technology, combined with a strong focus on "green alternatives" whenever and wherever possible, have yielded substantially improved mishap recovery capabilities. In turn, these efficiencies directly translate into a cost savings for the clean-up, recovery, and disposal phases of the mishap response. The key to realizing these benefits is strict observation and control of the mishap response process at all levels to ensure proper procedures are followed.

Finally, the most important technology and methodology based improvements for mishap response lie with people – the responders themselves and the vast supporting infrastructure. The focus must be upon personnel health and safety concerns for the entire process to mesh. By first realizing that AC/AAMs are different, everyone involved can adapt accordingly. Certainly many of the general elements of a prudent mishap response remain unchanged, but there are several new and different skill requirements presented by these materials. Re-training, coupled with a new mind-set, becomes an important element of the successful response program. At the very core of this program must be the basic knowledge and facts about these materials and their hazards. Building upon this must be a systematic training program, emphasizing recurrent updates, that will instill confidence in the entire response process. Safe and effective protection depends upon these foundations. Once in place, this knowledge and training enables responders to use an educated common sense approach tailored to the unique requirements of each mishap scenario. In this way, the people and the process can evolve to meet the demands of the technology.

Special Focus on Confined Space

Much of the current information on AC/AAMs excludes the challenging and unique demands of a confined or controlled space mishap event. As there are more and more of these specialized applications, the number of mishaps that occur within these types of environments has also continued to increase. Accordingly, special emphasis will be placed upon the added demands, risks, and responsibilities associated with these unique mishap response efforts.

Generally speaking, the added physical and mental demands of more austere and limiting environments exact an exponentially greater human toll than a standard mishap response effort. Fire, smoke, and toxicity (FST) are important concerns that drive the balance between the advantages of AC/AAMs and the risks posed by these elements for egress and life sustainment. As such, the risks, challenges, ramifications, and results become more critical to control. Often times, there is only one opportunity for a correct mishap response. Unfortunately, improper responses or actions can have potentially grave consequences. This is particularly true in areas where people must either remain at the mishap site or revisit it within a short period of time.

A confined/controlled space mishap event involving potentially explosive, asphyxiating, or oxygen enriched atmospheres presents unique challenges to the mishap responder. Under these conditions, combustion reactions are driven by the four elements of the fire pyramid: fuel, heat, ignition source, and oxidizing agent. Various oxygen content atmospheres exhibit combustion dynamics that are characterized by flammability limits, thermal conductivity, ignition energy, burn-through time, burn velocity, flame spread rates, smoke generation, among many factors [19]. For life sustaining controlled space environments, and pressure graded atmospheres in particular, control of the mishap event and the subsequent response efforts must be carefully coordinated to limit rapid oxidation (uncontrolled reaction), yet still sustain life. Essentially, "Fire is dependent on the percent of oxygen in the atmosphere (environment), whereas life is dependent on the partial pressure of oxygen. The two are not synonymous [19]." Expanding on this concept, removal of the nitrogen in diluted or mixed (oxygen-nitrogen) atmospheres causes higher temperature products, faster reaction times, and lower (easier) ignition [19]. These dynamics make controlled space AC/AAM mishaps not only more difficult to immediately respond to, but more hazardous in terms of combustion products throughout the entire response effort. A tragic example of these dynamics is the Apollo 1 launchpad fire incident in which pure oxygen pressure environments were used. Under these conditions, complete combustion occurs much more rapidly than under ordinary atmospheric conditions.

As a result of early lessons learned in fire-safety in both the spacecraft and submarine arenas, much of the information can be successfully tailored to overcome the challenges of AC/AAM applications and their modern mishap response concerns. Currently, many NASA and USAF acceptance tests address the flammability and fire performance characteristics of materials, structures, and components in "worst case" controlled-oxygen atmospheres with an upward flame spread indicative of normal gravity behavior. However, the unique physics of a zero or micro-gravity in which non-buoyant fire and flame characteristics are prevalent require more creative risk control. Research by NASA at Glenn Research Center has shown that flammability and fire-spread rates in low gravity are sensitive (or extremely sensitive) to forced convection (ventilation flows) and the concentration of oxygen within the atmosphere [20]. Therefore, control of these convective atmospheres becomes very important throughout all phases of a mishap response.

Two other elements on the fire pyramid, heat and an ignition source, are extremely important to control in order to effectively respond to mishap within a controlled/confined space. Ignition and heat sources within a confined/controlled space are plentiful, particularly in self-contained environments. Electrical and heating overloads, spills, aerosols, energetic/kinetic activities, friction, volatiles, and auto-ignitions sources, such as trash, represent some of the numerous contributors to an initial fire event, as well as subsequent fire resurgence, exothermic reactions, or smoldering. Similarly, AC/AAMs, under the proper conditions previously discussed, can supply plentiful quantities of fuel.

Therefore, these source elements MUST be identified and controlled in a response event.

The best solution for proper confined/controlled space mishap response is a robust research and technology program that identifies hazards (both individually and synergistically), hones test practices and methodologies, and validates policies and operational practices. Furthermore, a fire prevention strategy should be augmented by a strict fire safety program driven by configuration control. Most well developed confined/controlled space applications already employ this concept. However, detection, intervention, suppression, and recovery capabilities for AC/AAM mishaps in controlled space must still be further developed.

Experimental verifications of theoretical non-buoyant combustion analyses are limited due to the shear difficulty of testing. Nevertheless, the growing body of knowledge relevant to confined/controlled space response has revealed some interesting dynamics. Aerosols or particle clouds (possibly caused by a spill or high-pressure leak) can persist for extended periods in low gravity environments, unlike the rapid settling and dispersal found on earth. Also, due to more uniform dispersal, peak explosion pressures can be greater than under normal gravity conditions [20]. Energy imparted to hot bubbles or droplets from easily vaporized or effervescent materials can lead to unrestricted radial propellant of potential ignition sources in low gravity. Similarly, the localized flame zone found in micro-gravity retains molten fuel near the source, thereby enhancing localized burning rates for metals, plastics, and AC/AAMs. Finally, and potentially most important, is the potential for persistent smoldering in concealed volumes. Not only does the extended production of toxic gases present a substantial hazard in itself, but it also creates the potential for subsequent open flame initiation and ignition of adjacent objects. A probable scenario involving a slow flame spread and low heat release in micro-gravity could propagate, if not dealt with appropriately.

Fortunately, some studies have shown that combustion is actually suppressed in micro-gravity, and that the flammability range is also reduced, particularly for oxygen concentrations less than 30 to 40 percent [20]. However, the same NASA research shows that higher oxygen content atmospheres yield flame spread rates that are independent of the gravity level [20]. As pressure is introduced into the equation for micro-gravity environments, the flame-spread rate rises with pressure, quite unlike normal gravity downward spread behavior. Likewise, flame length was shown to increase with increasing air velocity and preheat temperatures under micro-gravity conditions.

Together, these behaviors demonstrate that pressurized, convective, oxygen-rich atmospheres could be problematic both to initial and follow-on mishap response efforts unless they were controlled. Once controlled, the micro-gravity effects would actually lower the hazard levels. Therefore, the current Space Shuttle and International Space Station employ a strict regime of ignition source minimization, oxygen content control, and sea-level air atmospheres to maximize risk control. Likewise, the use of inherently fire retardant materials such as phenolics and brominated vinyl ester resins, as well as materials with fire retardant fillers (i.e., alumina tri-hydrate), halogens, and additives for excellent FST properties has significantly reduced the hazards for confined/controlled space mishaps [21].

In AC/AAM specific applications, the unique performance characteristics which initially led to a material's selection also reduce the experimental data available for mishap response. For example, thermally thick materials, such as multi-ply ACs require long flame initiation and flame-spread tests and can only be done in space. As such, the volume of data is inherently limited. Also interesting is the micro-gravity combustion performance of thick polymers (plastics). Actual on-orbit tests have shown that combustion produces a thick molten layer with significant deep thermal degradation that causes mobile bubbles to flow to the surface and be released as burning fuel-vapor jets [20]. This phenomenon would certainly hamper AC/AAM containment and particulate dispersion in a controlled space.

Another interesting aspect pertinent to confined/controlled space mishap response is the potential for reduced fire resistance of materials, structures, and components through normal aging and repeated use [20]. Over time, materials modified for fire resistance can lose their effectiveness, quantities of potential ignition and fuel sources can build-up, and people can become complacent. As both the length and complexity of the space missions increase, so too do the cumulative levels of risk for a mishap and an ineffective mishap response. Yet, conservative operational guidelines continually supplemented by an increasing database of results would significantly advance the body of knowledge necessary to optimally respond to an incident regardless of conditions.

As a modern example of positive strides towards this goal, modern FST and qualification testing guidelines for NAVY submarines require that two criteria be established for the use of ACs onboard [22]:

1) The AC system will not be the first source or it will be sufficiently fire resistant not to support spontaneous combustion.
2) Secondary ignition of the AC system will be delayed until the crew or a suppression system can respond to the primary fire source.

As such, for submarines, AC/AAM systems must successfully pass fire performance thresholds based on fire growth, tenability, fire resistance, and structural integrity under fire. However, these performance standards are predicated upon the fact that the fire must not reach a flashover condition where all of the atmospheric gases spontaneously ignite within the confined space prior to fire containment and suppression. Once this condition occurs, the thermal conditions will inevitably ignite all combustible items within the compartment [22].

For space applications, NASA employs even more rigorous testing and qualification requirements. However, multiple research works recommend full scale testing for the most robust fire growth, SFT, fire resistance, fire integrity, and subsequent post-fire modeling [22]. This however, is quite expensive, cumbersome, and time consuming. In many cases, the shear complexities of testing make it impossible. Therefore, conservatively based risk control measures bolstered by the latest technical research and guidance are the absolute key to optimizing the AC/AAM mishap response within a confined/controlled space environment. The challenges are many, but the protection of people, property, and the environment remains a realistic and certainly attainable objective.

CHAPTER 5: RESULTS

Personnel Protective Equipment Guidelines

As the normal first responders, fire fighters are considered the primary response group to a mishap with AC/AAMs, and are therefore subjected to the greatest hazard exposures from the materials. However, they are the best protected responders in all but the most extreme cases. As such, all personnel in the immediate vicinity of an AC/AAM mishap, as well as all personnel subject to the concentrated smoke plume, must wear bunker or proximity suits and Self Contained Breathing Apparatus (SCBA) until the composite material fires have been completely extinguished and cooled to a temperature at or below 300 °F (149 °C) with no intense smoldering. It is important to note that the potential exposure to hazards associated with AC/AAM mishaps may be more severe for secondary exposure groups, including all of the subsequent response operations, than for the initial fire-fighting activities because of the duration of exposure and generally reduced levels of protection. However, the hazard exposures are minimal if the Personal Protective Equipment (PPE) outlined in Figure 5-1 (next page) is properly used. All affected personnel need to know the hazards and the proper response for effective mishap risk control, which makes coordination and communication critical for everyone involved. Preparatory knowledge and training, accompanied by common sense, good judgement, and quick decision making, are crucial for safety and success.

Table 5-1 Personal Protective Equipment (PPE) Requirements.

AC/AAM Mishap Condition	PPE RECOMMENDED
Burning or Smoldering Materials	1. Full Protective Fire Clothing 2. Self Contained Breathing Apparatus (SCBA) 3. Do NOT use rubber gloves
Broken, Dispersed, or Splintered Materials [Damaged Materials] (Post-Fire, Explosion, or High-Energy Impact) • HIGH Concentrations or Substantial Exposure [High concentration determined by Bio-environmental engineer sampling or qualitative assessment]	1. Protective overalls (i.e., Tyvek suit) – coated with hood and foot coverings 2. Full face respirator with High Efficiency Particulate Air (HEPA) and Organic Dust/Mist dual filters (Note: A gas mask with similar filter(s) may be substituted if equipment or respirator-trained personnel are not present) 3. Hard-soled work boots (Impact or Puncture resistant shank/sole) 4. Leather work gloves over long nitrile rubber gloves [no surgical gloves]
Minimal or Limited Exposure to NON-Fire or Heat Damaged Materials following a Mishap • LOW Concentrations with Minimal Exposure to Broken Materials with NO Fire or Heat Effects [Low concentration determined by Bio-environmental engineer sampling or qualitative assessment]	1. Long-sleeves and long-pants for durable work clothing 2. Nuisance dust filter or mask (for large, but airborne particulates) 3. Adequate eye protection (goggles or safety glasses) 4. Hard-soled work boots (Impact or Puncture resistant shank/sole) 5. Leather work gloves over long nitrile rubber gloves [no surgical gloves]

Mishap Risk Control Guidelines

The following guidelines are provided as recommended precautions and procedures for handling a composite mishap response. However, the hazards are dependent upon the type, quantity, damage extent, and mishap scenario. In most cases, the concentration of the materials present drives the level of risk for the potential environmental, safety, and health hazards. Of particular note are the ingestion, inhalation, and absorption health risks.

These guidelines address all phases of an aircraft mishap response, including fire fighting, investigation, recovery, clean up, and disposal. However, they can be universally applied to any application or situation involving these materials. Broad use of the short checklist in Appendix C is also highly recommended. However, the guidelines are general in nature and should be more specifically tailored to individual mishap scenarios as required. They should be a basis for the development of consistent and effective procedures and policies throughout the world in order to maximize risk control and minimize the environmental, safety, and health hazards caused by composite mishaps. Ultimately, the user is urged to supplement this information with new and updated research and operational guidance as it becomes available, although the conservative measures outlined within this document are the best course of action in the absence of specific or concrete data. The photographs displayed in Appendix B, Figures B-1 to B-28 graphically depict the guideline verbiage.

In summary, composite mishap hazards can, in most cases, be efficiently and effectively mitigated with proper training, precautions, and preparation.

Mishap Risk Control Guidelines For AC/AAMs

Immediately after a mishap, the situation should be assessed by answering the following questions:

1) Does the mishap scenario involve advanced composite/advanced aerospace materials? [Conservative presumption – Always assume YES]

2) If yes, where are they located and are they damaged? Reference applicable technical data or other information sources.

   If no, respond to mishap with "normal" or standard mishap response procedures.

3) Who can provide information about the type and content of these materials, and when/where can they be reached for specific questions? Consider acquisition, logistics, contractor, and maintenance personnel.

4) How does the environment affect the situation (check the current and forcast weather and surrounding area typography/geography)? For example, does the weather impact the response, or does the local geography change the response strategy? Are there any population centers or critical assets (such as aircraft, powerplants, or factories) nearby?

Once these basic questions have been addressed, the following steps should be accomplished. The specific response should be tailored to match the extent of the hazards.

1. First responder(s) [usually fire fighters] shall conduct an initial mishap site survey for:
   a. Signs of fire, explosion, or high-energy impact AC/AAMs.
   b. Presence of loose/airborne fibers and particulates, including a preliminary assessment of debris concentrations.
   c. Prevailing meteorological conditions/wind direction, including smoke plume assessment (if any).
   d. Degree of site exposure to fire/impact/explosions.
   e. Local/proximal equipment/asset damage and hazards, including the debris pattern and surrounding assets that were affected.
   f. Exposed personnel and environmental contamination routes.

   Essentially, the first responder(s) will determine the extent of any additional AC/AAM hazards associated with the mishap.

2. Establish control at the site with a clear and direct chain of command. If properly protected personnel are not present, avoid the mishap site until appropriately trained and equipped personnel arrive at the scene. Generally,

the Fire Chief will command the mishap site until the area has been declared fire safe, at which time command may/or may not be transferred to an On Scene Commander (OSC) or Incident Commander (IC).

3. Evacuate personnel from areas in the immediate vicinity of the mishap site affected by direct and dense fallout from the smoke plume, along with easily mobile and critical equipment. Continually move fire fighting equipment in order to avoid the smoke plume, especially in larger scale mishaps involving greater amounts of AC/AAMs. Restrict ALL unprotected personnel from assembling downwind of the mishap site. Use of over-pressurized cab equipped fire vehicles is essential if unable to avoid the smoke plume, although protective gear may be still be required inside the cab in extreme cases. Direct exposure to the smoke plume will require greater de-contamination requirements. Some modern AC/AAMs form combustion and pyrolysis products that are permeable to the protective membranes for ventilation in contemporary fire suit ensembles. Accordingly, contamination, de-contamination, and protection become very important concerns for a small percentage of mishaps, usually involving stealth aircraft. If exposed to either the smoke plume, open fire, or smoldering off-gassing of burned AC/AAMs, fire fighters should monitor their bodies as part of the whole system. This would include checking for any potential chemical burns/irritation at heavy perspiration areas such as the armpits and groin. However, this

phenomenon is very dependent upon rare material concentrations in confined space type environments. Nevertheless, it warrants consideration.

4. Alter or move aircraft and flight operations within the immediately exposed mishap and fallout areas. In general, overflight of the area should be prohibited unless required for rescue or response operations. In that event, no ground or flight operations (specifically helicopters) are to be permitted within 1000 ft above ground level (AGL) of the mishap site and within 1,000 ft horizontally. (This footprint may be increased depending on concentrations and local conditions).

5. Normal fire fighting mishap response procedures should initially be followed, although the special precautions associated with AC/AAMs should be aggressively implemented as conditions permit and warrant. Depending upon the type of materials involved, some equipment-related problems might arise. These include, but are not limited to: dulling of penetrator tools due to the hardness of some advanced composites, inability to penetrate some areas unless the hard-points and emergency penetration points are known, and internally insulated (imbedded) fires that are difficult to suppress. Complex engine inlets and imbedded exhaust areas are particularly challenging for fire suppression because they make access, fire suppression, and cooling difficult. Extreme care should be exercised with these areas because of the inability to visually survey the fire dynamics.

6. Extinguish fire and cool AC/AAMs to below 300 °F (149 °C) at a minimum to avoid endothermic or exothermic fires. Most volatiles will continue to burn off above 200 °F (93 °C) and any material above 100 °F (38 °C) is still quite hot to the touch. Therefore, AC/AAMs should be cooled as much as possible, without unnecessarily breaking up the debris. This can be accomplished by spraying a light mist of water or foam on the affected materials once the major fires are extinguished. In some cases, fire suppression agent compatibility will be an added concern. For example, dry chemical fire suppressant can destroy some advanced composite components, so care should be exercised with small and isolated fires in order to minimize peripheral material damage. Nevertheless, extinguishing all fires is the primary objective. In more extreme cases, known fire suppression agents are somewhat ineffective at extinguishing fires on some rare or exotic AC/AAMs. Extreme caution should be exercised in these very rare scenarios.

7. ONLY fire fighters equipped with Self Contained Breathing Apparatus (SCBA) are authorized in the immediate vicinity of a burning/smoldering mishap site until the Fire Chief declares the area both fire safe and smolder/off-gas hazard safe. If possible, care should be taken to avoid high-pressure water or foam applications due to the high potential for break-up and dispersal of the AC/AAMs.

8. Avoid dragging fire hoses through mishap debris or contaminated areas, as there is a high potential for abrasion and/or equipment contamination. Gear, including the bunker suits and water/air lines, may be snagged by sharp and jagged AC debris. Boots are particularly prone to cuts and penetration where jagged and stiff AC debris is damaged. Likewise, they are potential sources for contamination from particulates, and can transfer some of these contaminants to other areas outside of the immediate mishap vicinity.

9. Cordon or rope off the mishap site and establish a single entry control point (ECP) and a single decontamination exit point (DEP) (not collocated!). Only adequately protected personnel are authorized at the immediate mishap site and peripheral area (contamination reduction zone). The fire chief and bioenvironmental engineer, with the on-scene commander (OSC) or incident commander (IC) designates the peripheral area in a coordinated effort. As a guide, the peripheral area should be defined as approximately 25 feet away from a mishap cordon area containing damaged composite parts, although it will vary based upon local meteorological and geographical conditions.

10. If personnel other than those at the mishap site have been directly and significantly exposed to material and smoke hazards, consult medical personnel for evaluation and tracking. If possible, inform the medical personnel of the type and extent of exposures. Advise and inform the otherwise unthreatened populace of the applicable precautions to take in the

affected mishap site surroundings or in plume fallout areas. Track patient symptoms, treatment, and outcomes for those involved in the mishap.

11. Coordinate with the OSC or IC to provide necessary access to the mishap site for more thorough survey and investigation. For larger scale mishap response scenarios, especially involving modern, highly unique (exotic) AC/AAMs, use of a Hazardous Materials (Haz-Mat) Response unit is recommended because of the added levels of experience and increased capability to control the situation. Given an early assumption that AC/AAMs are present at a mishap site, these units would be initial responders.

12. If possible, toxicology and area studies for dust, inhalable and respirable particulates, and fibers should be conducted by a qualified industrial hygienist or bioenvironmental expert as soon as practical. However, all research personnel must be sufficiently protected. The survey protocol should include a visual observation, personnel, air, ground, and water sampling, and evaluation of the engineering controls and PPE in use at the scene.

13. Identify specific aircraft and material hazards as soon as possible by inspection of the debris and consultation with an applicable, knowledgeable personnel/sources (i.e., crew chief, system managers, reference documents, web sites, contractors, or aircraft specialists). Indicate, or point out, AC/AAM locations and concentrations to all response personnel, as appropriate.

14. Minimize airborne dispersion of particulates/fibers by avoiding excessive disturbance from walking, working, or moving materials at the mishap site. This includes fire suppression equipment whenever possible.

15. Locate, secure, and remove any radioactive AAMs by using a Geiger counter to find any applicable debris or particulates. Contact relevant authorities and dispose of in accordance with strict policies.

16. Monitor entry to the site from the single ECP. Exit from the cordoned site will be accomplished via the DEP to the decontamination site ONLY! The following guidelines apply:

    a. When exiting the mishap site, personnel should follow clearly defined decontamination procedures. These procedures may be optimized for the concentration levels, types of materials, and phase of recovery. Use of a High Efficiency Particulate Air (HEPA) filtered vacuum system with a brush attachment is highly recommended, as this is a very efficient and effective means of decontamination. If possible, remove AC/AAM contaminants from outer clothing, work gloves, boots, headgear, and equipment. If this type of vacuum is unavailable, efforts must be made to rinse, wipe, or brush off as much particulate contamination as possible. One technique that has proven effective is to apply wax (liquid or aerosol) to any remaining external contaminants on the protective suit and subsequently remove the suit by "rolling it off". This "wax and roll" technique not only immediately contains the contaminants, but also eliminates subsequent re-dispersion and run-off collection problems with other decontamination line techniques.

b. Both clean sites (i.e., tent or trailer) for donning of Personal Protective Equipment (PPE) and separately located decontamination line sites (with their associated clean sites) should be set up as soon as practical.

c. No eating, drinking, or smoking is permitted within the exclusion and contamination reduction zones, or as otherwise determined by the IC. Personnel must be advised to wash their hands, forearms, and face with cold water and soap prior to eating, drinking, or smoking.

d. Contaminated protective clothing should be properly wrapped, sealed, and disposed of according to applicable local, state, federal, and international guidelines. Heavy duty garbage bags work well for the initial containment prior to disposal.

e. Personnel should shower in cool or cold water on-site prior to going off-duty to prevent any problems associated with the transfer of loose fibers or particulates. Portable showers may need to be provided.

f. When practical, contaminated outer-garments from victims/response personnel should be removed at the mishap site decontamination area in order to protect the subsequent medical staff. Any ill effects believed to be related to exposure to AC/AAMs should be reported immediately.

Likewise, the local medical staff should be advised of the incident, along with the potential hazards. Symptoms of effects could include:

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

g. All contaminated footwear should be cleaned to limit the spread of debris into clean areas and support vehicles.

h. Materials Safety Data Sheet (MSDS), for the constituent materials should be made available to qualified personnel.

i. Security restrictions may require additional control measures during emergencies, particularly when the area is declared a national security area for the preservation of classified information and materials.

17. Secure burned/mobile AC/AAM fragments and loose ash/particulate residue with plastic, a gentle mist of water or fire-fighting agent, fixant material, or a tent-like structure in order to prevent re-dispersion.

18. Consult the specific aircraft authority and/or the investigators before applying a fixant or hold-down material. However, safety concerns at the immediate mishap site may override any delayed application. Fire-fighting equipment should be available during fixant/stripper application, aircraft break-up, and recovery. Also, any fires must be completely out and the materials cooled to below 300 °F (149 °C). Preferably, the all material and debris will be cooled

as much as possible. Ideally, all of the material should be cooled to less than 100 °F (38 °C). Two types of fixants are generally used: one for burned AC/AAMs and debris, and the other for land surfaces. Fixant is usually not needed for open terrain and improved surfaces (concrete or asphalt) unless very high concentrations exist (subjectively determined or quantitatively measured).

19. Obtain and mix (if necessary) the fixant or hold-down solution such as Polyacrylic Acid (PAA) or acrylic floor wax and water. Do not use light oil because it may become an aerosol and collect on equipment, hamper material investigations, and present a health hazard of its own. Generic acrylic floor wax, which is widely available, should be mixed in an approximate 8:1 or 10:1 ratio (to dilute it and ease spreadability), although this may vary.

20. Apply (preferably spray) a moderate coating of the fixant solution on all burned/damaged AC/AAMs and to any areas containing scattered/settled particulate debris. Completely coat the material until wet to ensure immobilization of the material, then allow the coating to dry in order to maximize the protection.

21. NOTE: Strip-ability of the fixant coating is required where coatings are applied to debris that must later undergo microscopic chemical and material

analysis by incident investigators. Care must be exercised in the use of stripping solutions since they can react with some materials and the process of stripping may damage the parts. PAA may be removed by a dilute solution of household ammonia (about 1% by volume of ammonium hydroxide in water) or trisodium phosphate (approximately one 8 ounce cup of trisodium phosphate per 2 gallons of water).

22. If deemed necessary, agricultural soil tackifiers may be used to hold materials on sand or soil. Most solutions should be sprayed onto the ground at a rate of 0.5 gals/sq. yd.

23. Improved hard surfaces (i.e., concrete and asphalt) should be vacuumed with an electrically protected HEPA closed-system vacuum, if possible. Sweeping operations should be avoided as they re-disseminate the particulates. The effluent from any run-off should be collected via plastic or burlap coated trenches or drainage ditches. NOTE: The entire impact or mishap site must be diked to prevent run-off of fire fighting agent (to avoid additional clean-up or environmental contamination).

24. All fixant application equipment should be immediately flushed/cleaned with a dilute solvent to prevent clogging for future use. Likewise, all fire fighting vehicles and equipment must be decontaminated to the maximum extent possible, at the mishap site. Water and HEPA vacuums may be used.

25. Pad all sharp projections on damaged debris that must be retained so that injuries during handling and analysis can be avoided.

26. Carefully wrap the coated parts and or material with plastic sheeting/film or place them in a plastic bag of approximately 0.006 inches (6 mils) thick. Generic garbage bags are generally inadequate unless they are used in several plies.

27. Conduct all material disposal according to local, state, federal, and international guidelines. Consult with appropriate agencies for relevant procedures and policies for materials that do NOT require mishap investigation analysis or repair. Ensure all parts are released before disposal is authorized. All AC/AAM waste should be labeled appropriately with the type of material followed by the words: “Do Not Incinerate or Sell for Scrap”.

28. Complete all necessary soil and surface restoration as required at the mishap site.

29. Place all hazardous waste material in appropriate containers and dispose of properly according to all applicable regulations.

30. If aircraft, other vehicles, structures, or equipment were subjected to the concentrated smoke plume or debris areas, the following should be accomplished:

   a. Decontaminate the entire aircraft/vehicle/piece of equipment and collect the effluent.

   b. Vacuum the air/ventilation/cooling intakes with an electrically protected, HEPA vacuum cleaner.

   c. For internally affected smoke areas, visually and electronically inspect all compartments for debris and vacuum thoroughly.

   d. Prior to flying, perform electrical and systems checks, as well as an engine run-up.

31. For significantly affected structures and equipment, thoroughly clean all antenna insulators, exposed transfer bushings, circuit breakers, and any other applicable electrical components. Inspect air intakes and outlets for signs of smoke or debris and decontaminate if necessary.

32. Continue to monitor affected personnel, equipment, and mishap site.

Special Considerations for Confined Space

Concentrations of smoke, fumes, toxic products, particulates, and pyrolysis products are much greater in a confined or controlled space mishap environment. This is particularly true if gradients in atmosphere, pressure, temperature, and convective flow are present (and this is typically the case). As such, the associated environmental, safety, and health hazard potentials are greater. So too are the risks greater, therefore additional precautions must be taken to avoid unnecessary assumptions of risk that could otherwise be controlled. Added procedures are also required to mitigate the risks through both sound procedures and optimum PPE. Additional mishap risk control guidance for AC/AAMS in a confined/controlled space follows:

1. A hazard assessment and clearly defined entry regime is the essential first element of a confined/controlled space response (once entry is warranted)

2. If response personnel are already at the scene and within the confines of the mishap space at the time of the event, clearly defined emergency procedures (previously codified and practiced) must be immediately enacted. Practice under simulated duress prior to an actual emergency is critical for effective execution during an actual emergency.

3. Once the scenario is assessed and a proper course of action is undertaken, convective currents, air flows, or winds, if present, should be immediately minimized or eliminated. In low gravity, low pressure, normal atmospheric conditions, if ventilation flow can be stopped (as a first response action), the fire will propagate slowly, if at all. Dispersion and re-dispersion, as well as combustion, flame spread, fire propagation, and off-gassing, must be tightly

controlled. Environmentally isolating the mishap site must be the first point of order. However, extreme caution must be exercised in pressure vessels with high concentrations of oxidizing agent (i.e., oxygen) due to the explosive hazard.

4. Localize and contain the fuel sources and any effluent, particulate, or "drips" so that the fire and smolder reactions may be contained. Post mishap response and clean-up following an event will also be much more efficient if the immediate mishap site is controlled. If possible, open ignition sources or thermally active areas should be moved from critical locations to minimize the potentially greater hazards posed by a pressure vessel breach, an added ignition/fuel source, or irrecoverable damage to a life sustaining system.

5. Use of maximum PPE and administrative controls such as strict personnel exposure rationing and "buddy-system" operations must be employed. Likewise, decontamination efforts must assume the highest contamination concentrations. Accordingly, these processes must be extremely thorough to accommodate the greater than normal levels of people and equipment contamination.

6. Hydration and dissipation of heat for all affected response personnel is paramount, particularly in a stagnant high temperature environment. Exposures requiring maximum PPE must be strictly time limited with

supporting documentation and tracking of exposures. Adequate rest schedules with intense re-hydration and nourishment must be observed. Sweating should be controlled by any means available in order to minimize potential exposures caused by a slippery, ill-fitting masks, wet hands, sweat-filled burning eyes, or abrasion/injection wounds to soft, open pores.

7. Closed system, HEPA vacuums with both narrow and wide-mouthed brushes are invaluable clean-up tools and should be used extensively as conditions permit.

8. Decontamination efforts are difficult to isolate, although heavy gauge plastic films and duct-tape can be used to form particulate and fume resistant barriers for some areas. It should be cautioned that the permeability of the plastic film is dependent upon the types of chemicals present. Nevertheless, a minimum of 6 mil plastic sheeting will provide fair protection from most particulates with a reasonable amount of durability. Fume permeability will vary.

9. Plastic buckets or containers (i.e., 5 gal buckets) are recommended for a space efficient method of forming a decontamination line for people and equipment where working area volume or other elements are limited.

10. Once the immediate mishap response effort is under control, the atmosphere must be ventilated (if safely possible) in order to avoid the build-up of off-gas products, airborne particulates, and other toxins. However, the exhaust ventilation, purge, or scrubber routes must be clearly known, monitored, and controlled in order to minimize compounding the cleanup problems. The filters for these ventilation systems must be handled with care in the same manner as site debris and contaminants. As such, they should be encapsulated via some previously discussed method to eliminate re-dispersion of the particulates.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The development and use of AC/AAMs was investigated in order to characterize the material properties, the hazards associated with a mishap event, the damage effects, the frequency and concentration of exposures, and the risks to mishap responders throughout the life cycle of a mishap response. In summary, the use and exploitation of AC/AAMs is rapidly increasing because of their outstanding material characteristics and benefits. These materials can and often do present environmental, safety, and health concerns when damaged by fire, explosion, or high-energy impact, although the damage mechanisms, frequency of exposure, and concentrations of material determine the hazard levels. Applying proper risk control mechanisms in conjunction with current knowledge, training, and proper resources make mishap response efforts safer, more effective, and less costly on both a tangible and intangible level. Finally, a current, practical, and reasonable set of Mishap Response Guidelines for AC/AAMs was outlined.

Recommendations

1. Incorporate the guidelines into to an ongoing training and education program immediately. Any organization with the potential for exposure to

these types of materials in a mishap response scenario should adopt these risk control guidelines and adapt their operations accordingly.

2. Continue research, testing, and operational modifications in order to continually update and modify these guidelines. Particular emphasis should be placed on understanding the dynamics involved and systematically addressing each of the relevant areas as new technologies and methodologies evolve.
3. Share and communicate the latest developments pertinent to effective risk control and safe mishap response via sustained training, sharing of information, global interconnectivity, cooperative research, and joint testing. Continually inform the community and professionals within mishap response organizations of not only the hazards of a mishap with AC/AAMs, but also the merits and safety of an effective mishap response. Continually educate the populace to foster confidence in their safety while instilling appropriate respect for the hazards. Ultimately, a heightened understanding of the life cycle issues associated with AC/AAMs must permeate to a greater extent throughout our modern society since these are the materials of choice for many applications.

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APPENDICES

APPENDIX A – PLATES WITH AIRFRAME MATERIALS LOCATIONS

AH-64A.5

AIRFRAME MATERIALS

AH-64A

T.O. 00-105E-9

1. AIRFRAME MATERIALS

a. Main Rotor Blades (not pictured) are constructed of stainless steel, aluminum, fiberglass, and nomex honeycomb.

b. Cockpit flooring (not pictured) is constructed of Boron armor

c. Crew seats (not pictured) are contructed of Kevlar/Boron carbide and nylon.

d. Tail Rotor hub forks (not pictured) are contructed of Titanium

e. Both aircraft engines (T700-GE-701-C) are contructed with Titanium/Carbon/ Nickel Graphite.

f. Battery (not pictured), located on the right side is a Fiber Nickel-Cadmium battery.

LEGEND

Graphite Composite

Kevlar/epoxy Composite

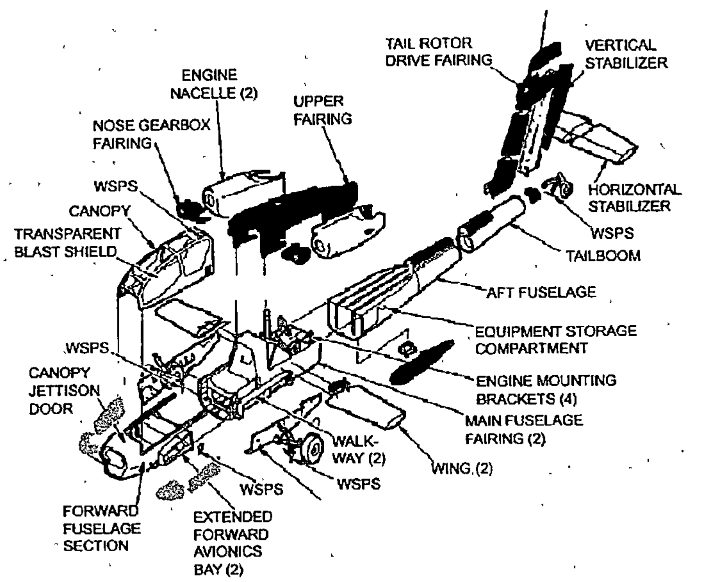


Plate A-1 Airframe Materials Locations for the AH-64A. [23]

AH-64D5

T.O. 00-105E-9

AIRFRAME MATERIALS

AH-64D

1. AIRFRAME MATERIALS

a. Main Rotor Blades (not pictured) are constructed of stainless steel, aluminum, fiberglass, and nomex honeycomb.

b. Cockpit flooring (not pictured) is constructed of Boron armor.

c. Crew seats (not pictured) are contructed of Kevlar/Boron carbide and nylon.

d. Tail Rotor hub forks (not pictured) are contructed of Titanium.

e. Both aircraft engines (T700-GE-701-C) are contructed with Titanium/Carbon/ Nickel Graphite.

f. Battery (not pictured), located on the right side is a Fiber Nickel-Cadmium battery.

LEGEND

Graphite Composite

Kevlar/epoxy Composite

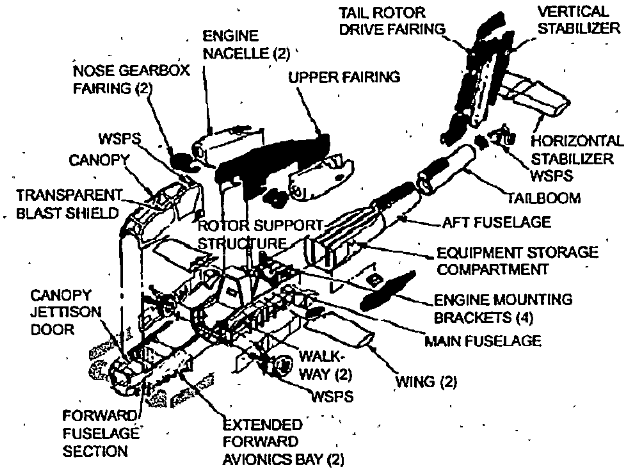


Plate A-2 Airframe Materials Locations for the AH-64D. [23]

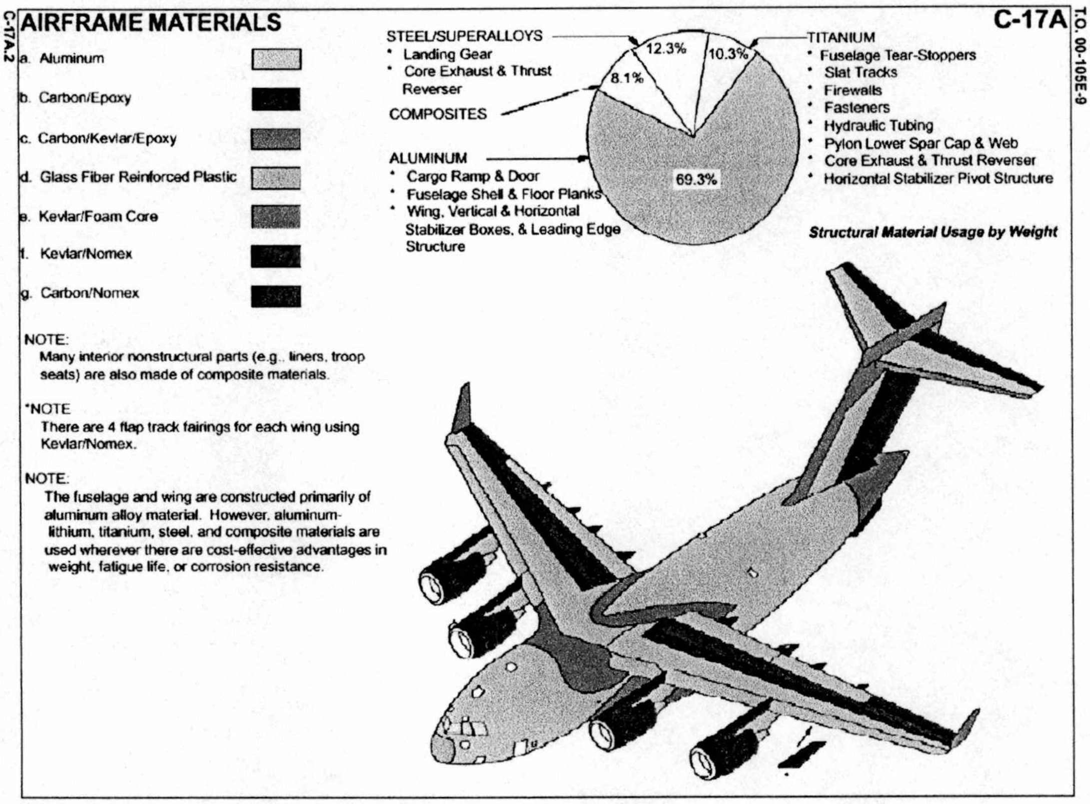


Plate A-3 Airframe Materials Locations for the C-17A.

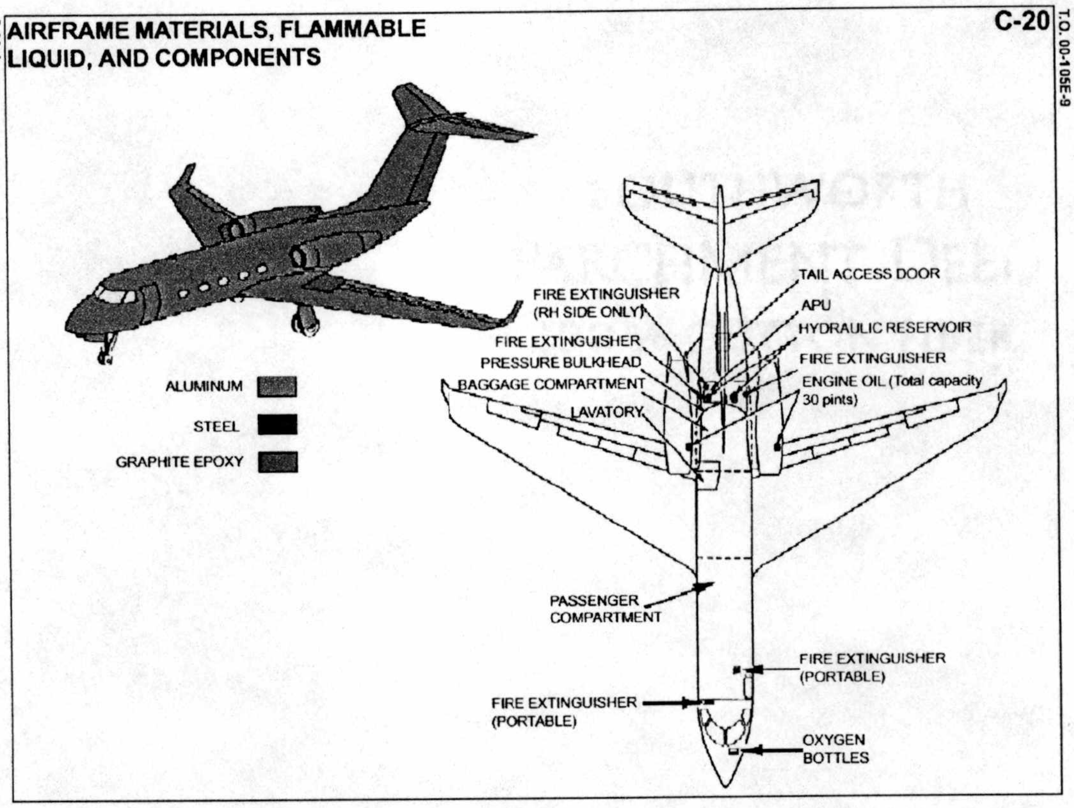


Plate A-4 Airframe Materials Locations for the C-20. [23]

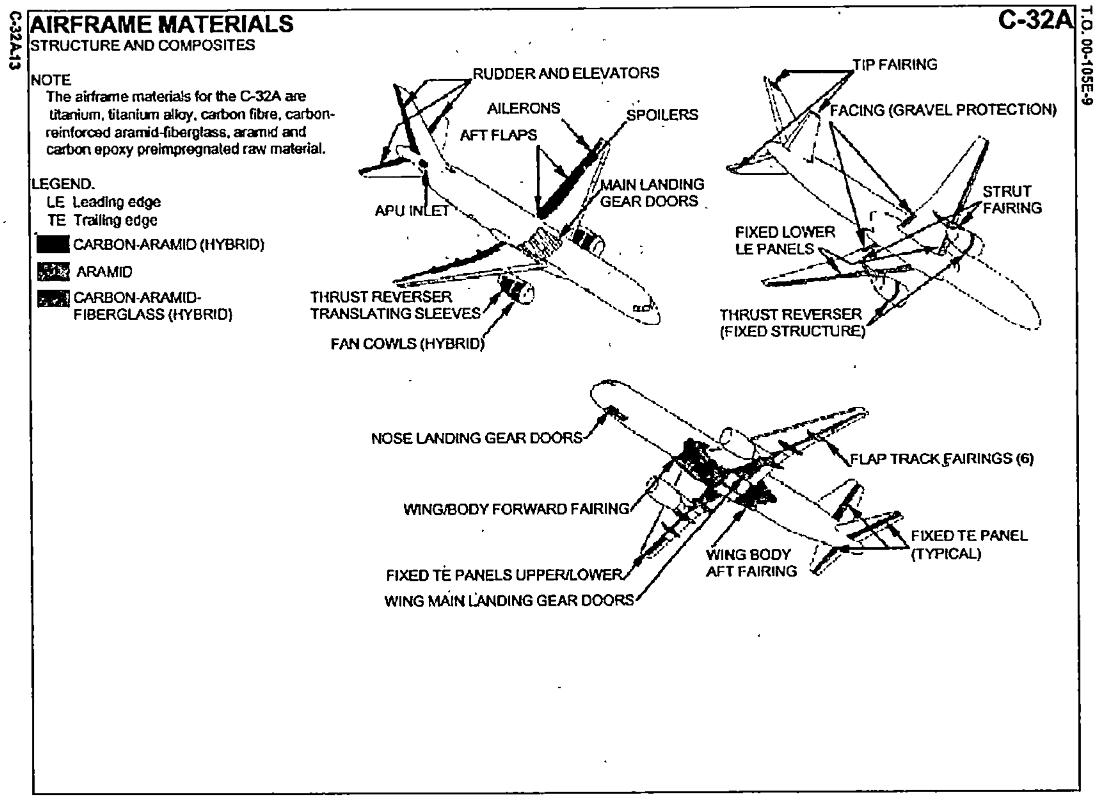


Plate A-5 Airframe Materials Locations for the C-32A. [23]

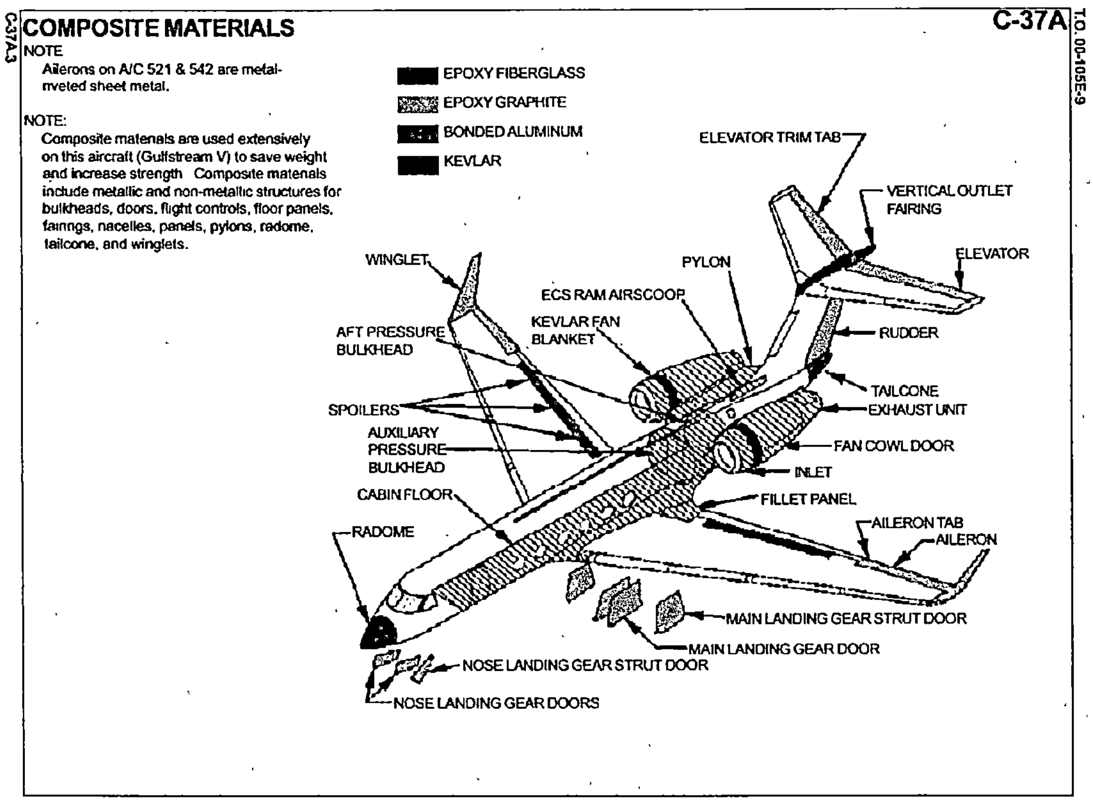


Plate A-6 Airframe Materials Locations for the C-37A. [23]

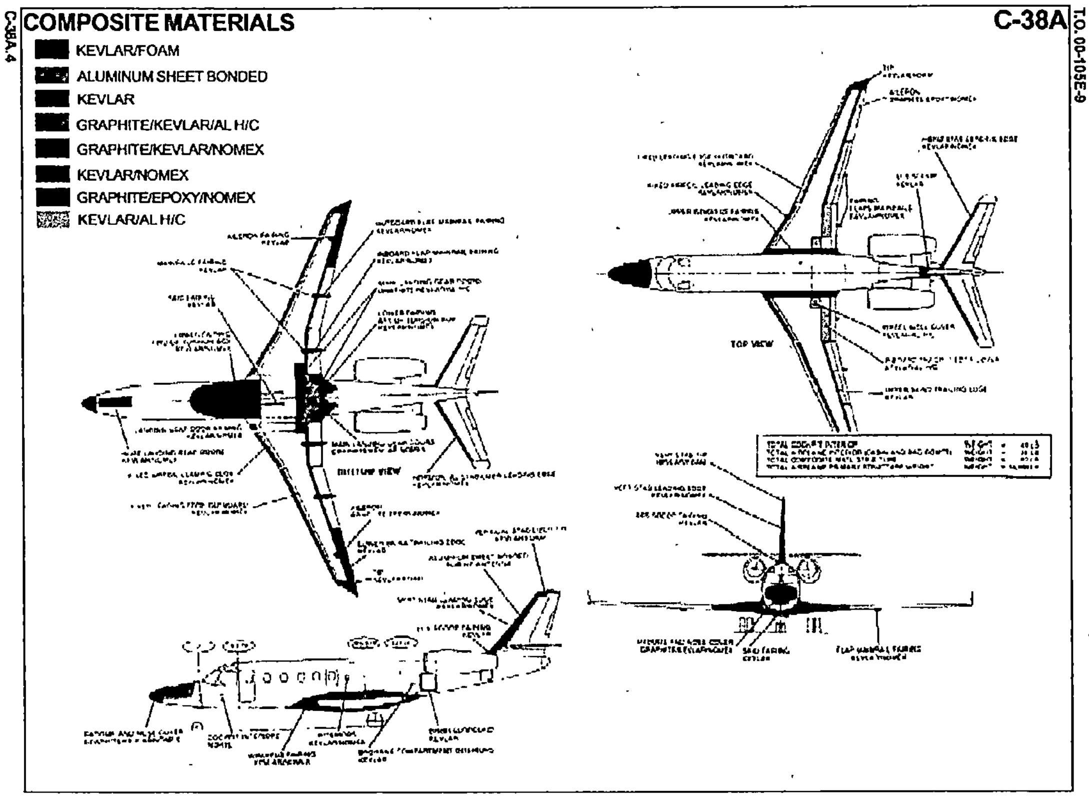


Plate A-7 Airframe Materials Locations for the C-38A. [23]

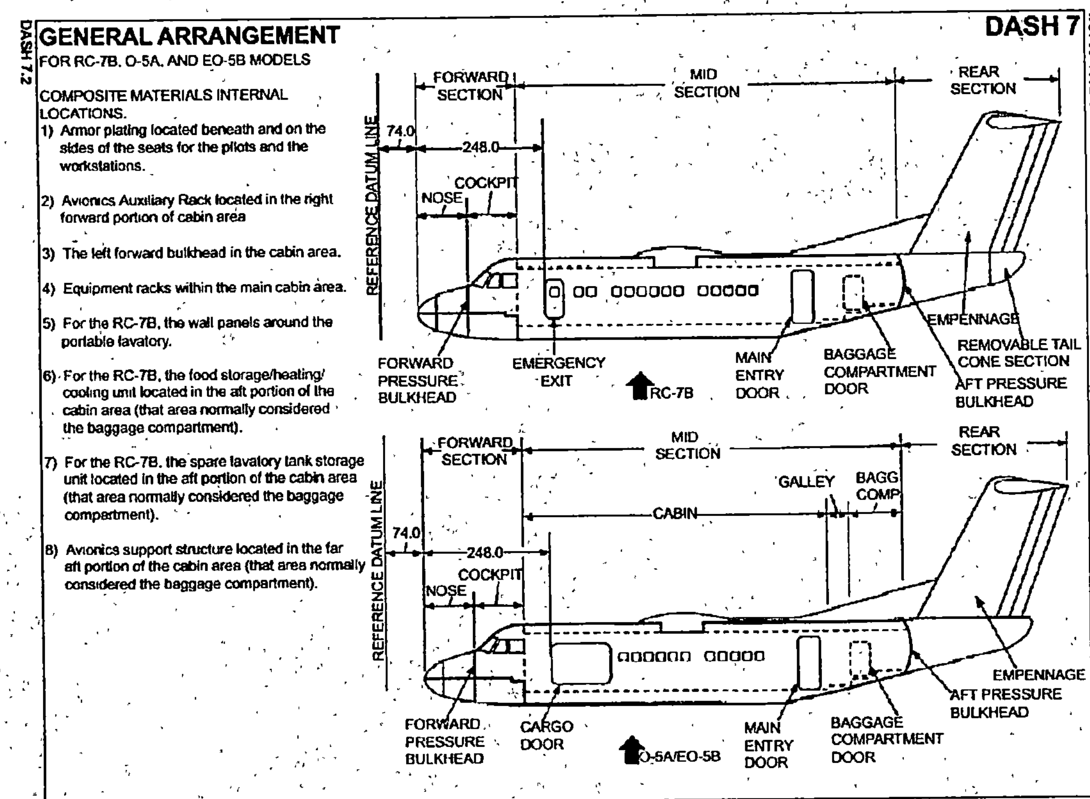


Plate A-8 Airframe Materials Locations for the DASH 7. [23]

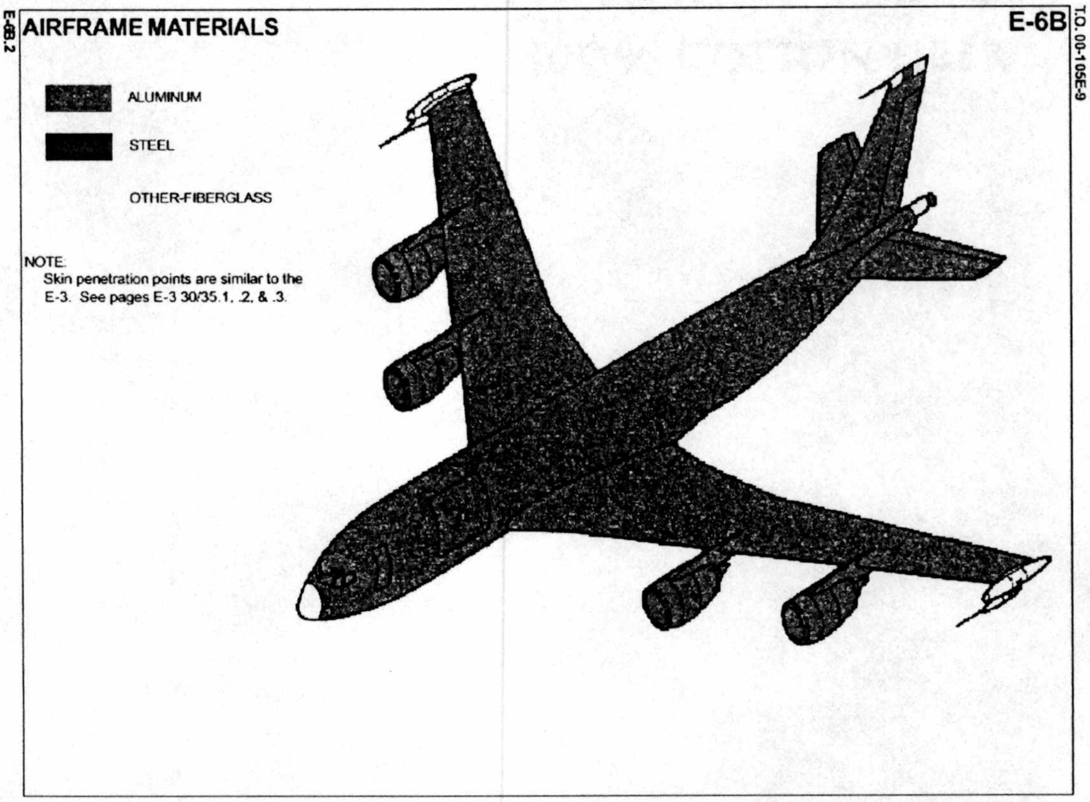


Plate A-9 Airframe Materials Locations for the E-6B. [23]

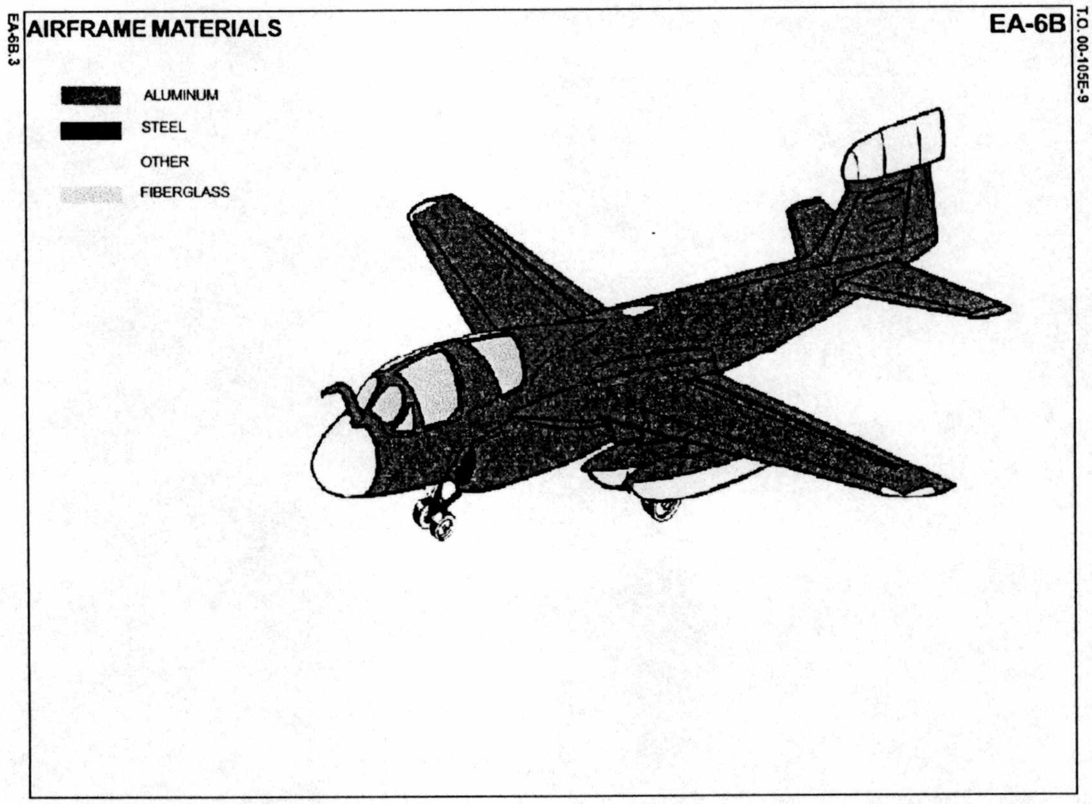


Plate A-10 Airframe Materials Locations for the EA-6B. [23]

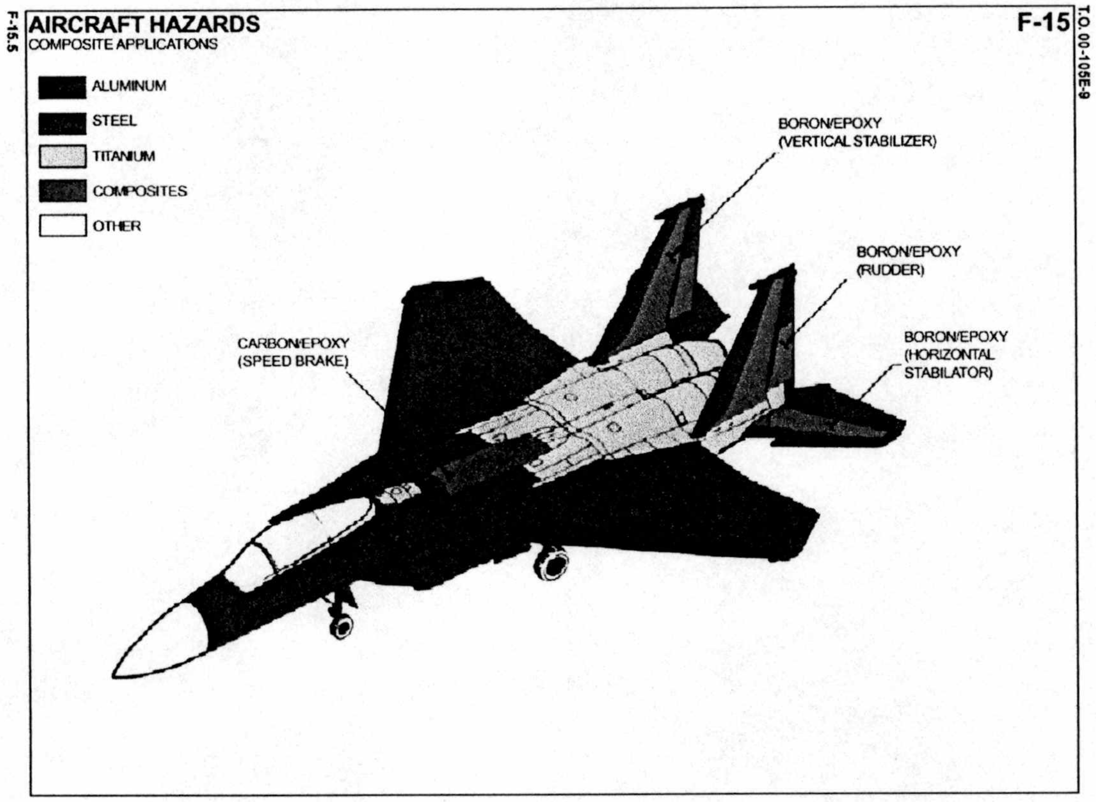


Plate A-11 Airframe Materials Locations for the F-15. [23]

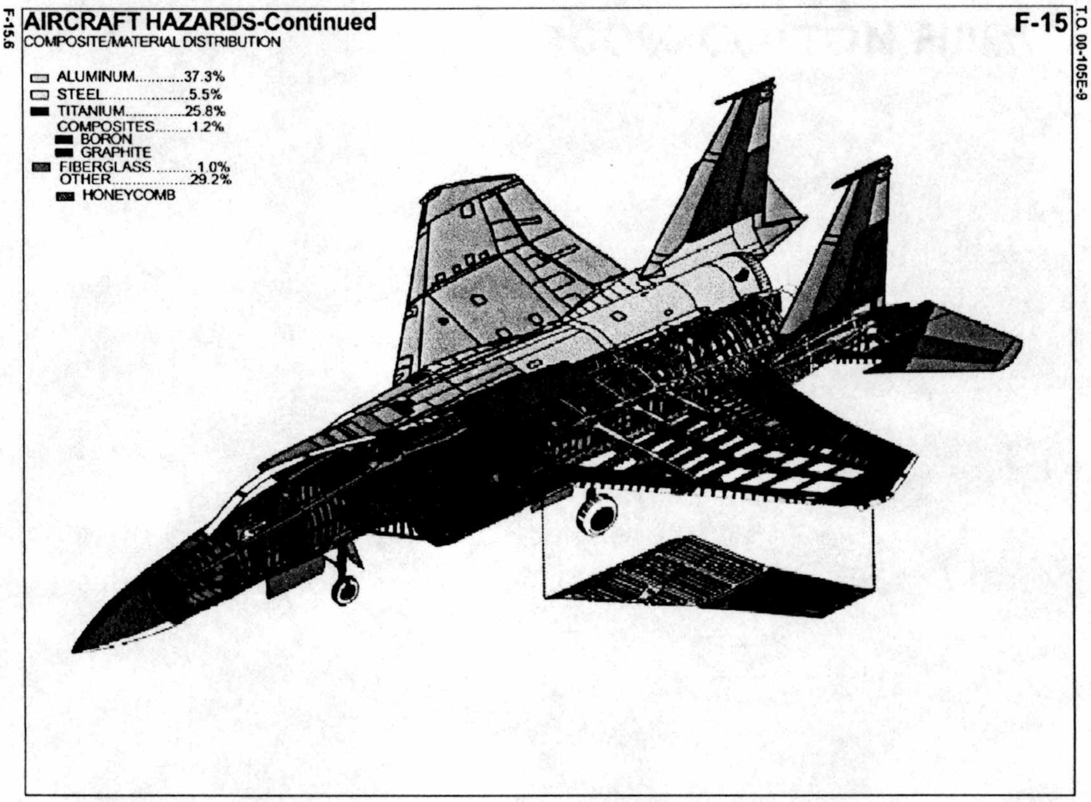


Plate A-12 Airframe Materials Locations for the F-15, Continued. [23]

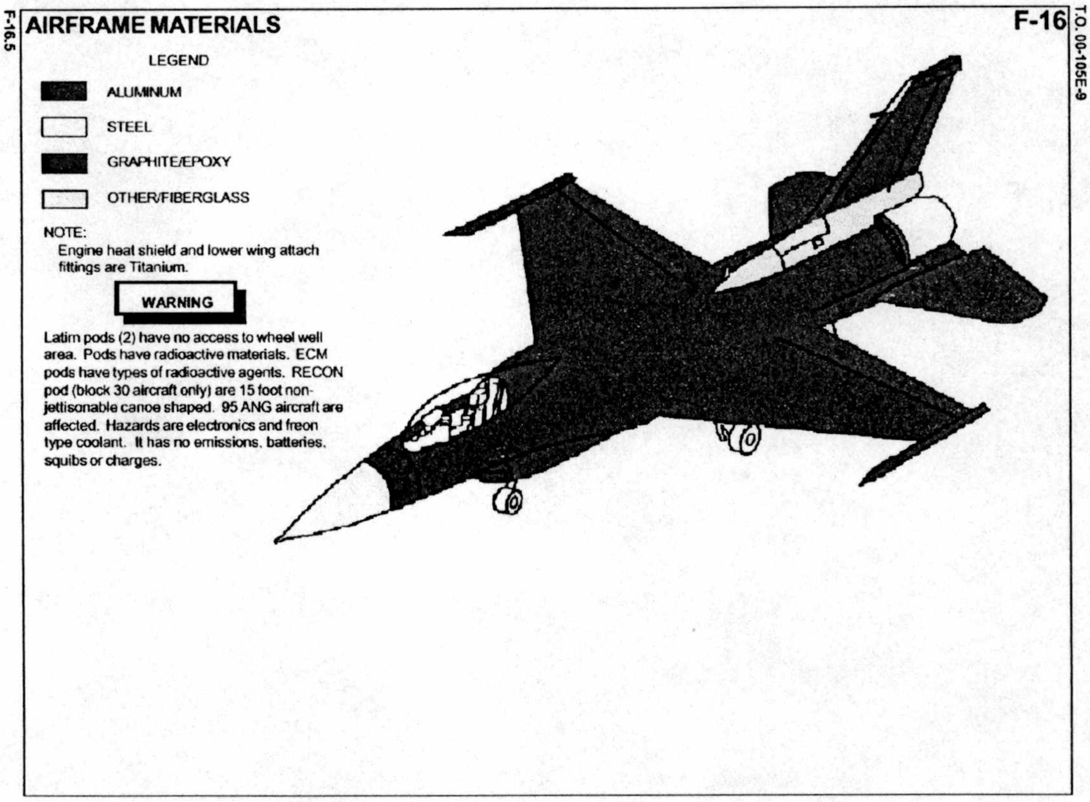
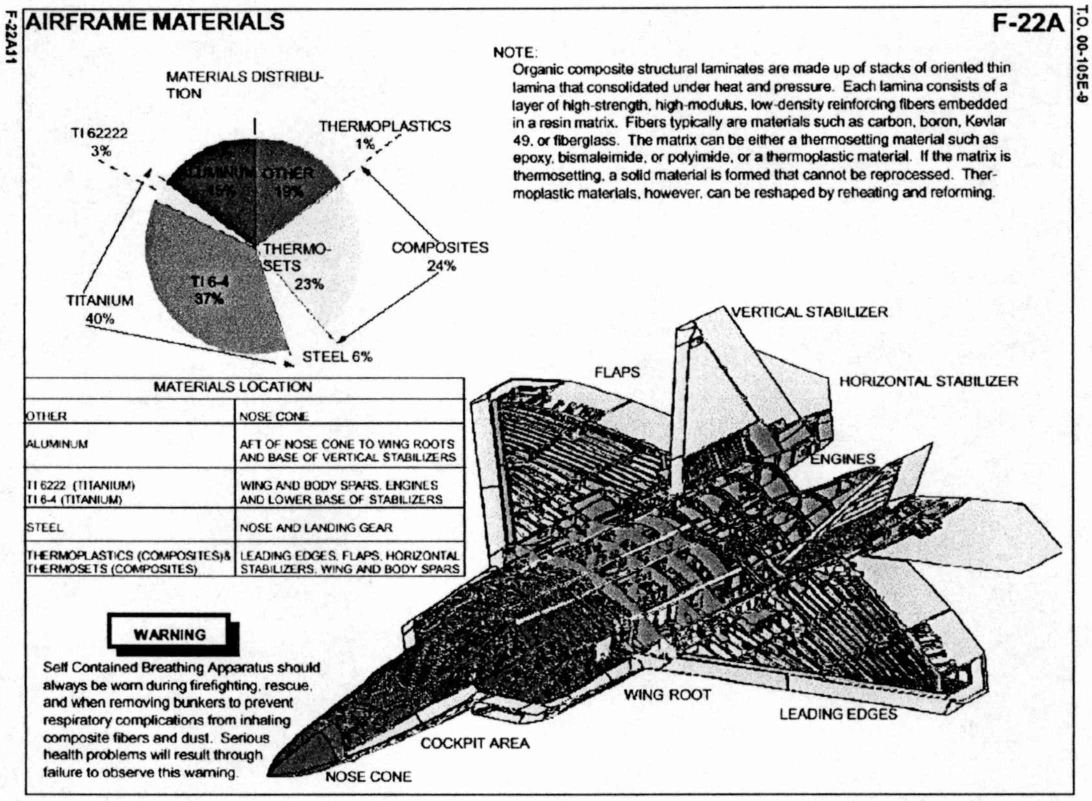


Plate A-13 Airframe Materials Locations for the F-16. [23]



T.O. 00-105E-9

F-22A11

AIRFRAME MATERIALS

F-22A

NOTE:

Organic composite structural laminates are made up of stacks of oriented thin lamina that consolidated under heat and pressure. Each lamina consists of a layer of high-strength, high-modulus, low-density reinforcing fibers embedded in a resin matrix. Fibers typically are materials such as carbon, boron, Kevlar 49, or fiberglass. The matrix can be either a thermosetting material such as epoxy, bismaleimide, or polyimide, or a thermoplastic material. If the matrix is thermosetting, a solid material is formed that cannot be reprocessed. Thermoplastic materials, however, can be reshaped by reheating and reforming.

MATERIALS LOCATION	
OTHER	NOSE CONE
ALUMINUM	AFT OF NOSE CONE TO WING ROOTS AND BASE OF VERTICAL STABILIZERS
TI 6222 (TITANIUM) TI 6-4 (TITANIUM)	WING AND BODY SPARS, ENGINES AND LOWER BASE OF STABILIZERS
STEEL	NOSE AND LANDING GEAR
THERMOPLASTICS (COMPOSITES)& THERMOSETS (COMPOSITES)	LEADING EDGES, FLAPS, HORIZONTAL STABILIZERS, WING AND BODY SPARS

WARNING

Self Contained Breathing Apparatus should always be worn during firefighting, rescue, and when removing bunkers to prevent respiratory complications from inhaling composite fibers and dust. Serious health problems will result through failure to observe this warning.

Plate A-14 Airframe Materials Locations for the F-22A. [23]

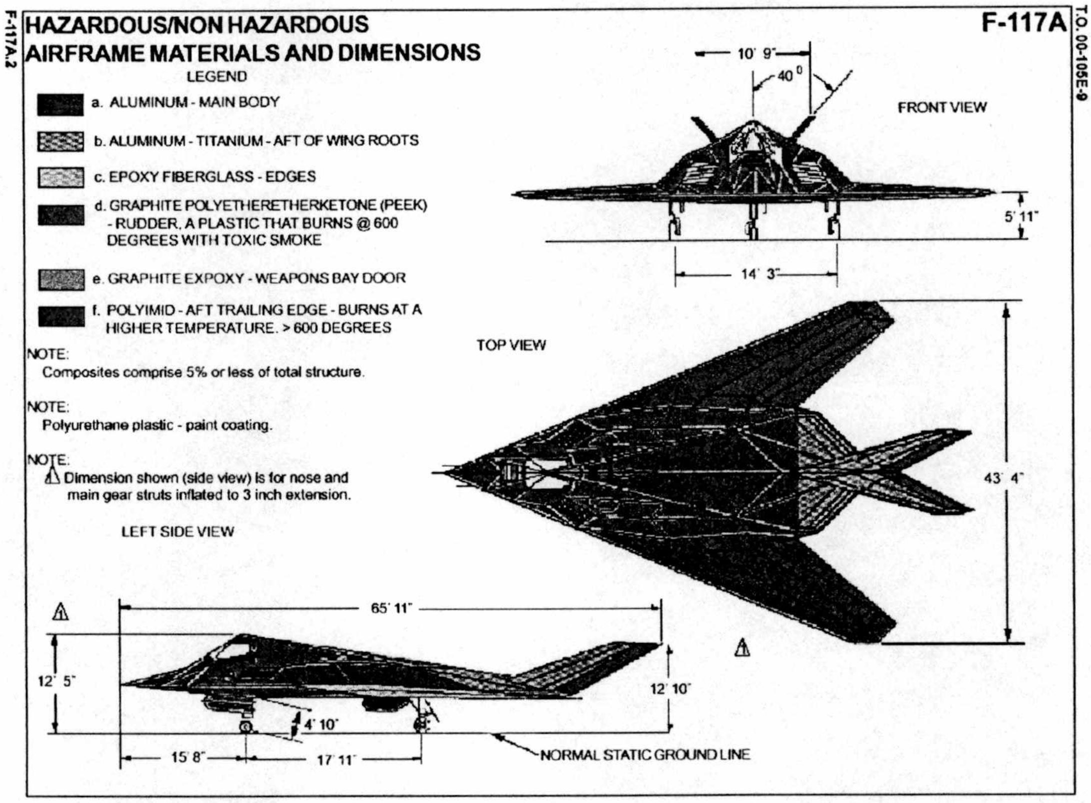


Plate A-15 Airframe Materials Locations for the F-117A. [23]

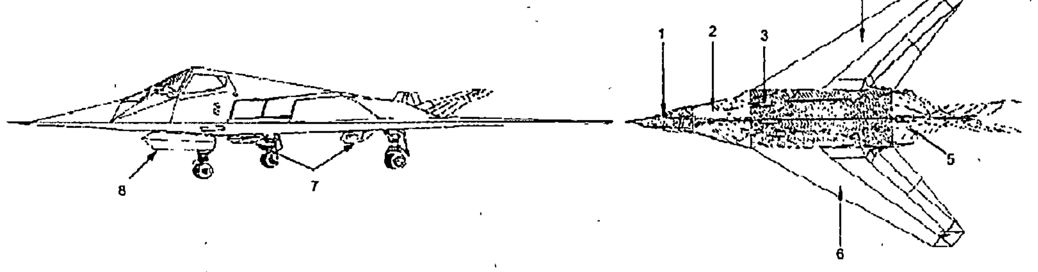
F-117A-3

T.O. 00-105E-9

HAZARDOUS BYPRODUCTS OF BURNING WRECKAGE

NOTE:
Aircraft areas identified by numbers 1 through 8

F-117A



GENERAL MATERIAL	SPECIFIC MATERIAL	AREA USED ON AIRCRAFT	BYPRODUCT
Fuel Hydraulic fluids Lubricants	Fuel, JP8 Oil, low temperature Oil, synthetic Molybdenum disulfide Grease, various types Fluid, hydraulic, various types	3,4,5,6,7,8	Carbon monoxide Carbon dioxide Sulfur oxides Polynuclear aromatic hydrocarbons Phosphorus oxides
Rubber (gaskets and tires) Honey comb core Plastics (gaskets, sleeving, electrical and thermal insulations, tubing, canopy, sheets, and parts	Neoprene Chloroprene Silicones Fluorosilicones Nitriles Polyvinyl chloride Nylons Polyolefins Teflons Polyurethanes Acrylic - polycarbonate Viton, Phenolics, Bismaleimides, Epoxies, and Polysulfide	Throughout aircraft	Carbon monoxide Carbon dioxide Polynuclear aromatic hydrocarbons Hydrochloric acid Hydrofluoric acid Nitrogen oxides Hydrogen cyanide Phosgene Formaldehyde Sulfur oxides

Plate A-16 Hazardous Byproducts of Burning Wreckage for the F-117A. [23]

HAZARDOUS BYPRODUCTS OF BURNING WRECKAGE-Continued

F-117A

GENERAL MATERIAL	SPECIFIC MATERIAL	AREA USED ON AIRCRAFT	BYPRODUCT
Fabrics and fibers, natural and synthetic	Wool Kevlar Carbon fibers - epoxy coated Glass fibers - aramid, epoxy, teflon, and polyester coated Polyetherether ketone Polysulfide Cellulose	1,2,3,4,5,6	Hydrogen cyanide Nitrogen oxides Sulfur oxides Carbon monoxide Carbon dioxide Polynuclear aromatic hydrocarbons Hydrochloric acid Hydrofluoric acid Phosgene Formaldehyde
Metal alloys - structural, fillers, bonding, and welding	Aluminum, Chrome, Copper, Gold, Iron, Steel, Lead, Silver, Tin, Titanium, Zinc, and Trace metals	Throughout aircraft	All may melt and resolidify. No hazardous emissions.
Blanket insulation and other ceramics	Fiberfrax, Fused ceramic powders	1,3,5	None
Adhesives Sealants Paint Coatings	Polysulfides Silicones Flourosilicones Epoxy Polyurethane Buena - N Iron Silver Silicon dioxide Strontium chromate Lead chromate	Throughout aircraft	Hydrogen cyanide Nitrogen oxides Sulfur oxides Carbon monoxide Carbon dioxide Polynuclear aromatic hydrocarbons Hydrochloric acid Hydrofluoric acid Phosgene Formaldehyde

Plate A-17 Hazardous Byproducts of Burning Wreckage, F-117A, Cont'd. [23]

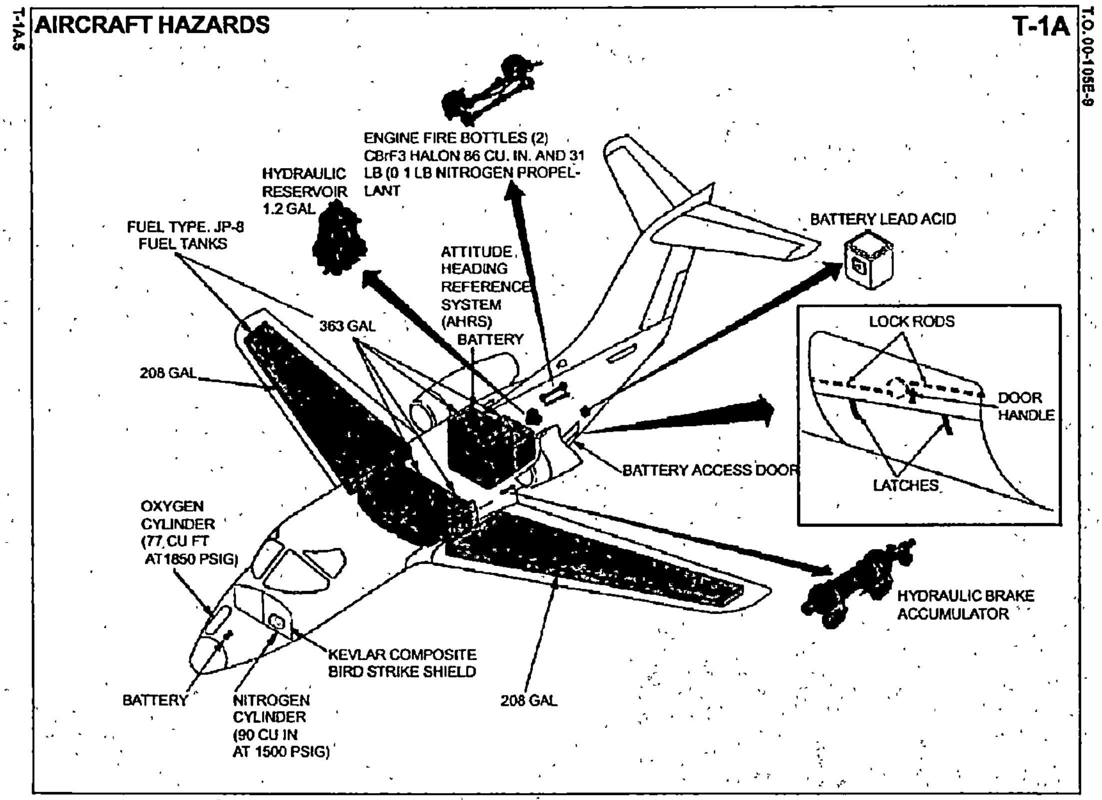


Plate A-18 Aircraft Hazard Locations for the T-1A. [23]

MD-11

AIRCRAFT GENERAL INFORMATION

MD-11

T.O. 00-105E-9

GENERAL INFORMATION FOR ALL MODELS

NOTE:
AIRCRAFT DIMENSIONS
Length 201' 4"
Wing Span 169' 10"
Height 57' 9"

1. The MD-11 Series and variants: is a medium/long range DC-10 follow on. Seating for 323 two class passengers and a maximum of 410. Two crew flightdeck. Crew door and three passenger doors each side, all eight of which open sliding inward and upward. Two freight holds in lower deck, forward and aft of wing, and one bulk cargo compartment in rear fuselage. Power plant is three Pratt & Whitney PW4460 turbofans or three General Electric CF6-80C2D1F turbofans

2. MD-11-Combi is a cargo/passenger version. Seating for 168 to 240 passengers and 4 to 10 pallets. Common configuration 214.

3. MD-11CF is a convertible freighter. Main deck cargo door at front on port side.

4. MD-11F is a all-freighter version.

5. MD-11C&D are tentatively planned for increased capacity.

6. AIRCRAFT STRUCTURE
Composites used in virtually all control surfaces, engine inlets and cowlings, and wing/fuselage fillets; wing has two-spar structural box with chordwise ribs and skins with spanwise stiffeners; upper winglet of ribs, spars and stiffened aluminum alloy skin with carbonfibre trailing edge; lower winglet carbonfibre; inboard ailerons have metal structure with composites skin; outboard ailerons all composites; inboard flaps composites-skinned metal; outboard flaps all-composites; spoilers aluminum honeycomb and composites skin; tailplane has CFRP trailing edge; and elevators CFRP.

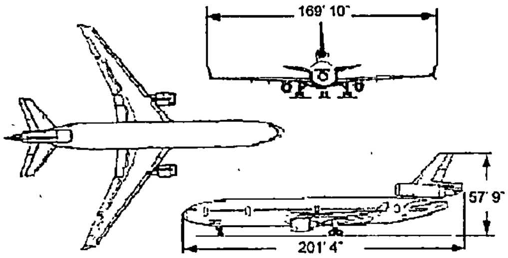


Plate A-19 Aircraft General Information for the MD-11. [23]

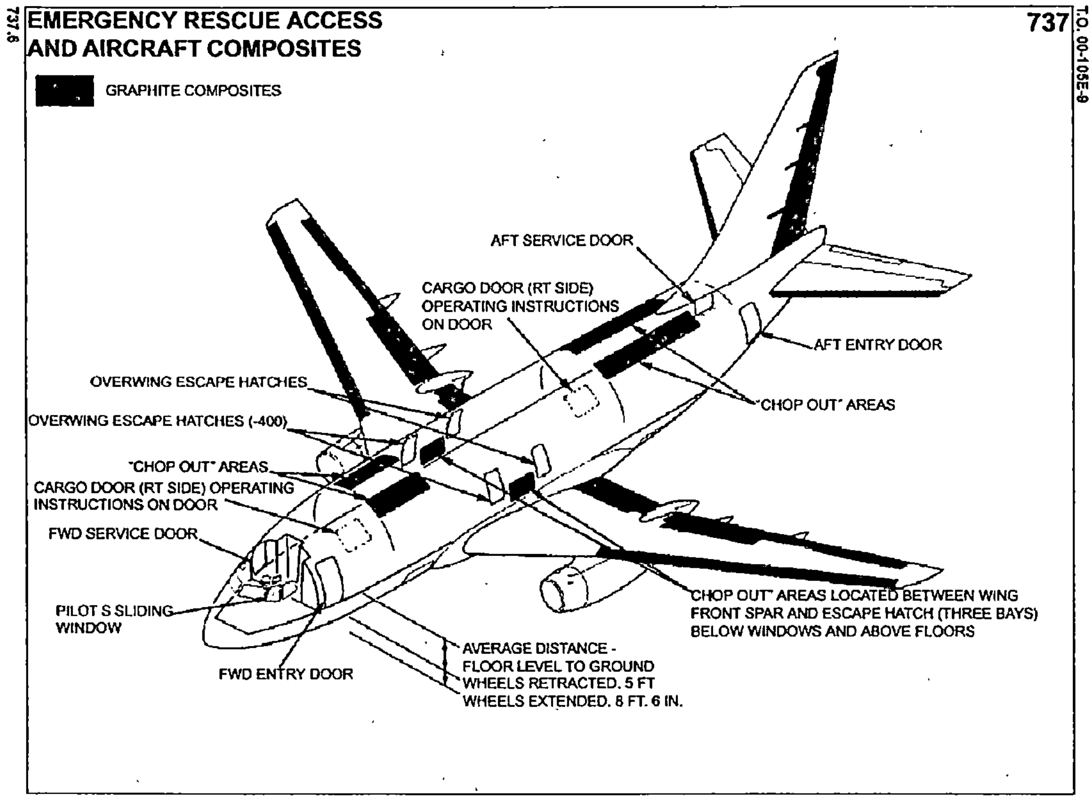


Plate A-20 Emergency Rescue Access and Aircraft Composites for the 737. [23]

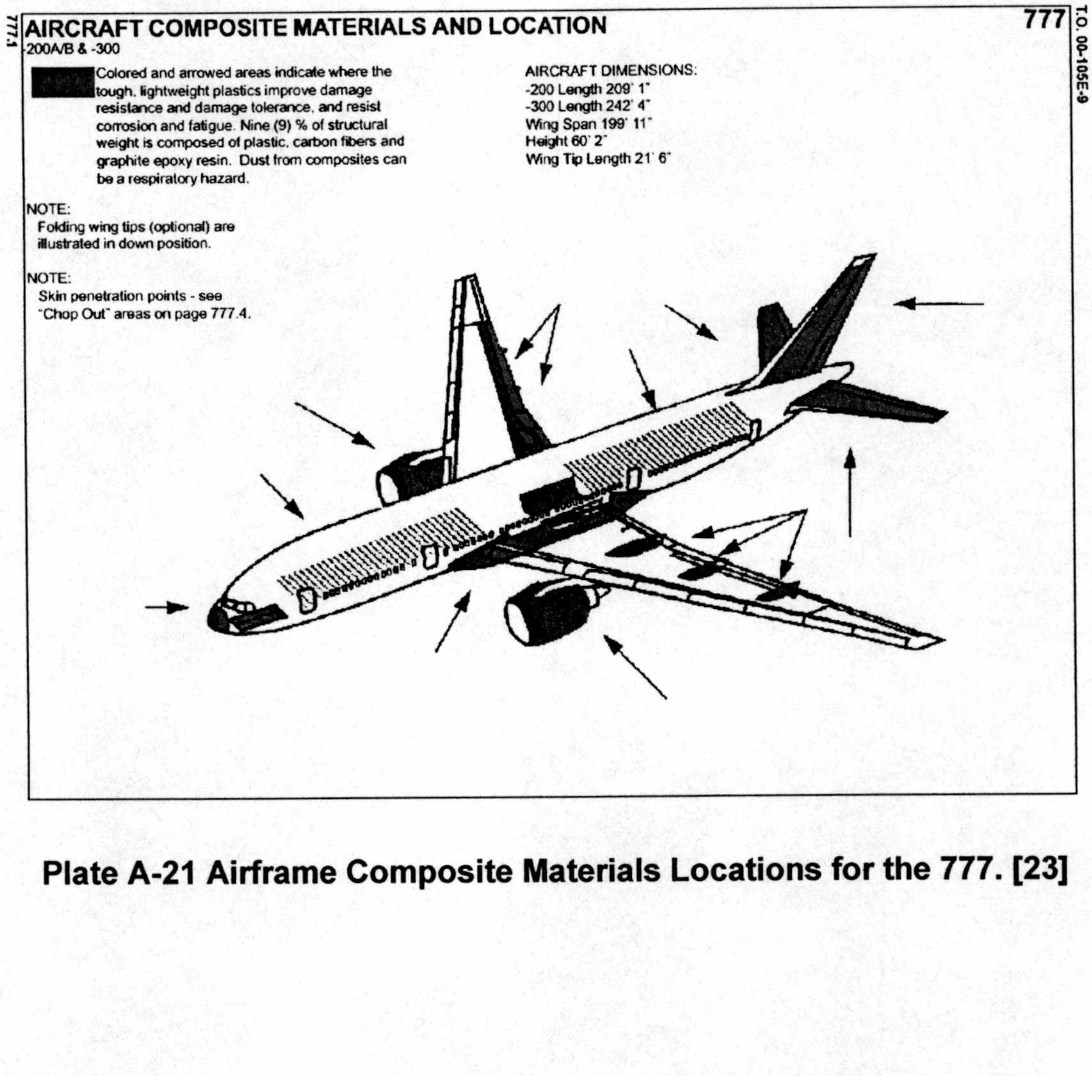


Plate A-21 Airframe Composite Materials Locations for the 777. [23]

OV-18

T.O. 00-105E-9

DANGER AREAS/SAFETY PRECAUTIONS
HAZARDOUS MATERIALS, FLUIDS & GASES

OV

DANGER AREA	PERSONNEL ACTION
CAUTION Monomethylhydrazine (CH3NHNH2) in contact with metallic oxides or other oxidizing agents can ignite. NOTE: Nitrogen tetroxide (N2O4) and monomethylhydrazine may be venting through the relief valves unless each system has been safed.	Do not park vehicles over metal drains. Stay upwind of venting gas. Wear protective clothing and recommended air breathing device.
Forward and aft reaction control subsystem (RCS) thruster nozzles and relief valve vent ports.	Stand clear.
Main landing gear/tires/wheels could explode. Peak temperatures may not be reached for 45 minutes.	Do not approach from the sides.
Main landing gear tire fire. Peak temperatures may be reached 45 minutes after a hard-braking landing which could ignite the rubber tires.	Approach upwind and apply large amounts of water to cool the brakes and to extinguish the burning tires.
Metals (composites) Beryllium: windshield frames, ET doors, and brake structure Aluminum boron: truss members in the wing feed-through section Epoxy boron: truss members of the main propulsion system thrust structure, aft fuselage Although not easily ignited, these metals will burn at elevated temperatures and produce toxic compounds that are hazardous to health.	MET-L-X may be used on brake fires. Exercise caution. Although small amounts of water accelerate these types of metal fires, rapid application of large amounts of water is effective in extinguishing these fires because of the cooling effect of water. If water or foam is used, wear complete protective clothing and NIOSH-approved positive pressure breathing equipment.
Fluids/gases are flammable and hazardous.	Exercise caution to prevent exposure.
External surfaces will be at elevated temperature.	Wear proper clothing to prevent injury.
Hydrogen overboard vents, 8-in. fill and drain, and 17-in. Orbiter/external tank (ET) disconnects. Autoignition may result from high surface temperatures. Note that the flame of pure hydrogen is invisible.	Exercise caution.
Switches.	Do not operate any switch other than those specifically identified.
Emergency egress window that is to be jettisoned (all vehicles).	Move to position out of range of debris.
Emergency jettison of the side entry/egress hatch (all vehicles).	Move to position out of range of jettisoned hatch.
Inadvertant deployment of drag chute after rollout (all vehicles).	Avoid area 10 degrees left and 47 degrees right of Orbiter centerline and 100 feet aft until pyrotechnic circuits are safed.

Plate A-22 Danger Areas/Safety Precautions for Hazardous Materials, Fluids & Gases for the Orbiter Vehicle (OV). [23]

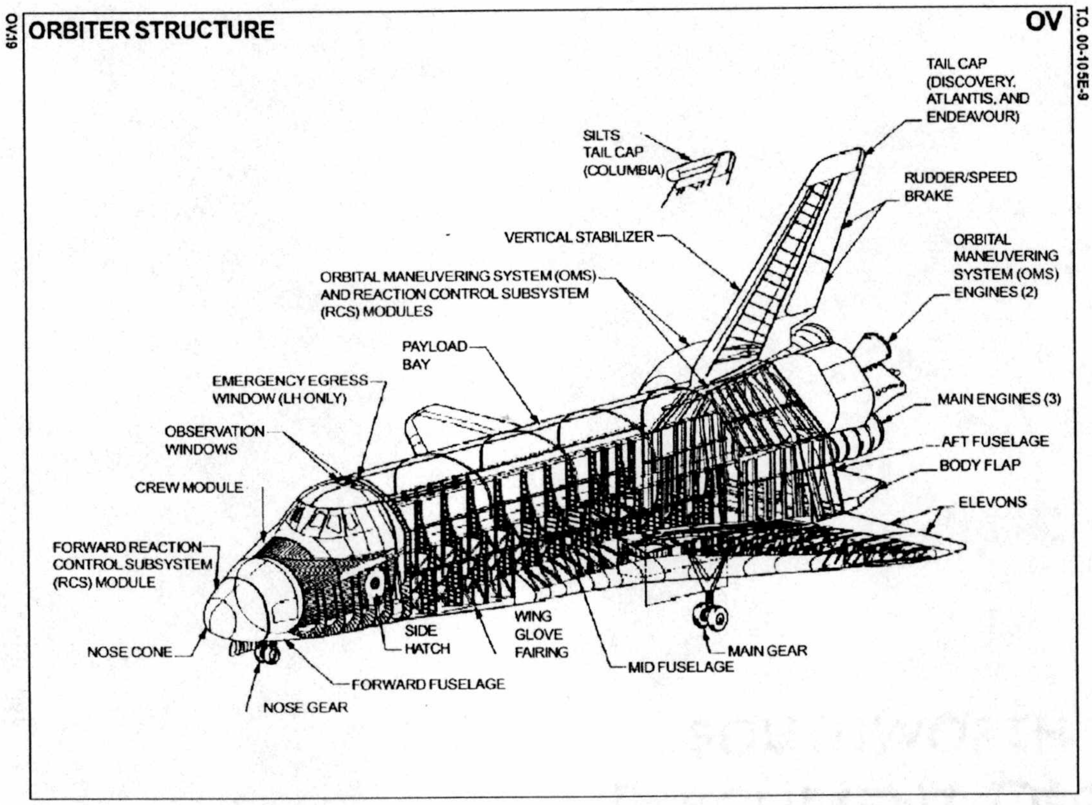


Plate A-23 Airframe Locations for the Space Shuttle Orbiter Vehicle (OV). [23]

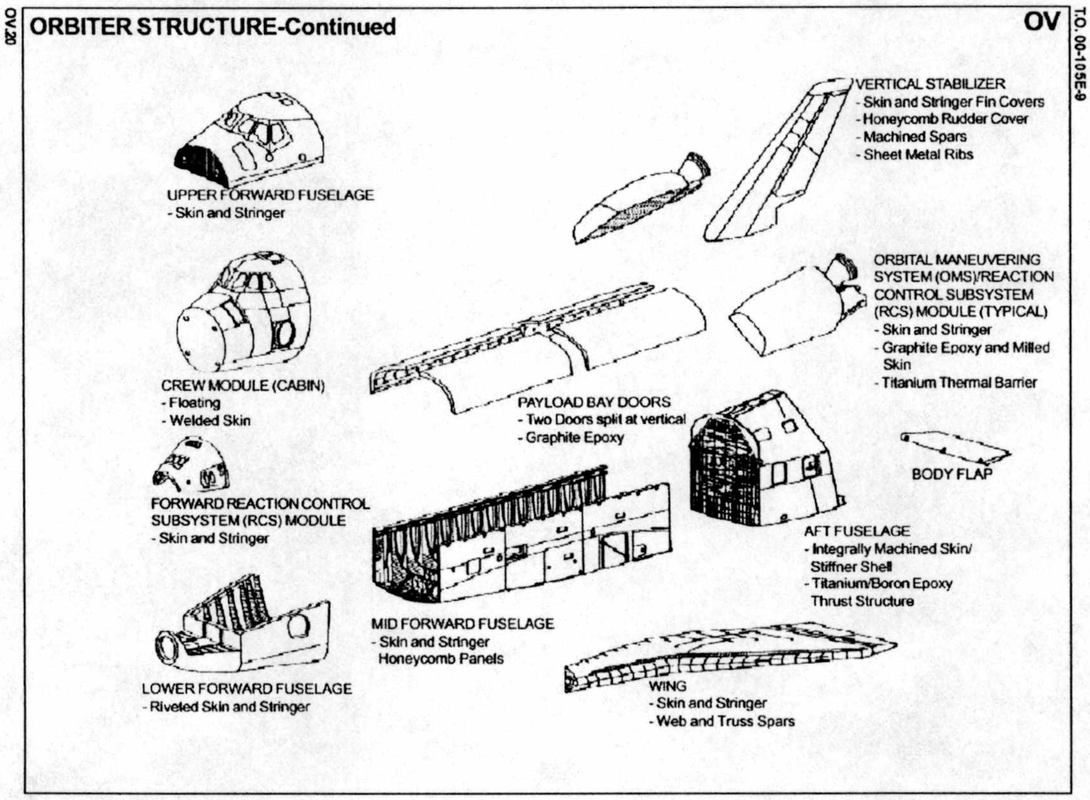


Plate A-24 Locations on the Space Shuttle Orbiter Vehicle (OV), Cont'd. [23]

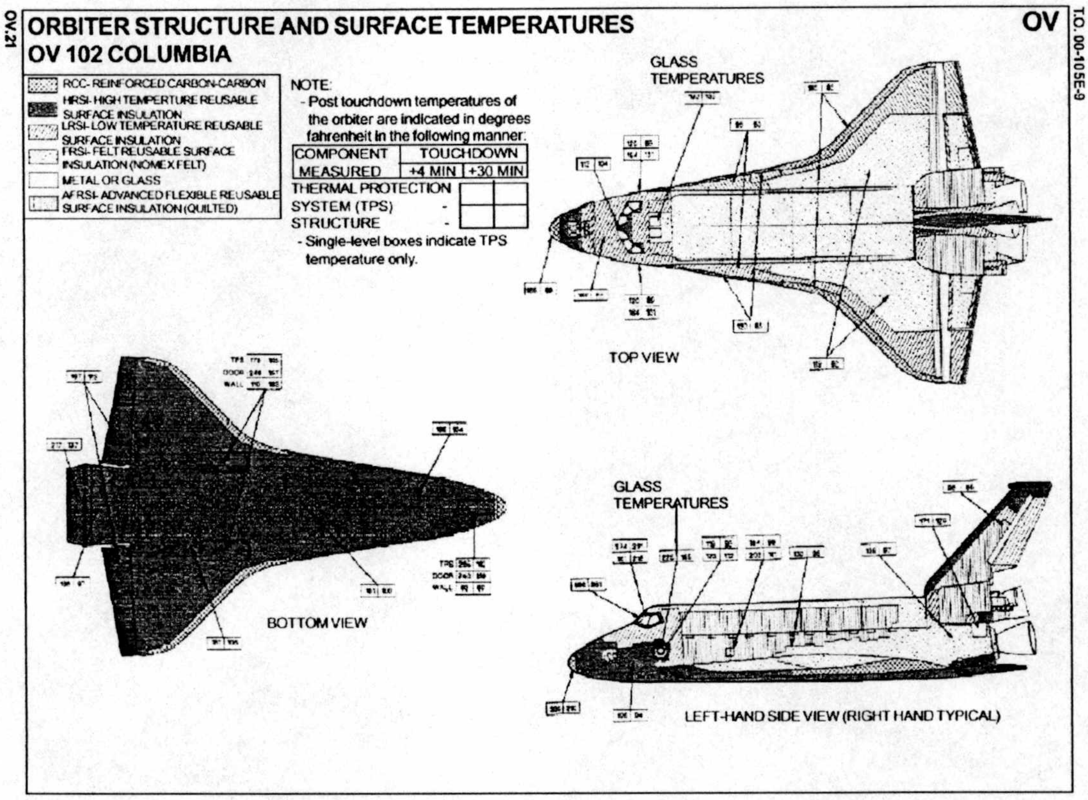


Plate A-25 Orbiter Structure and Surface Temperatures for Columbia. [23]

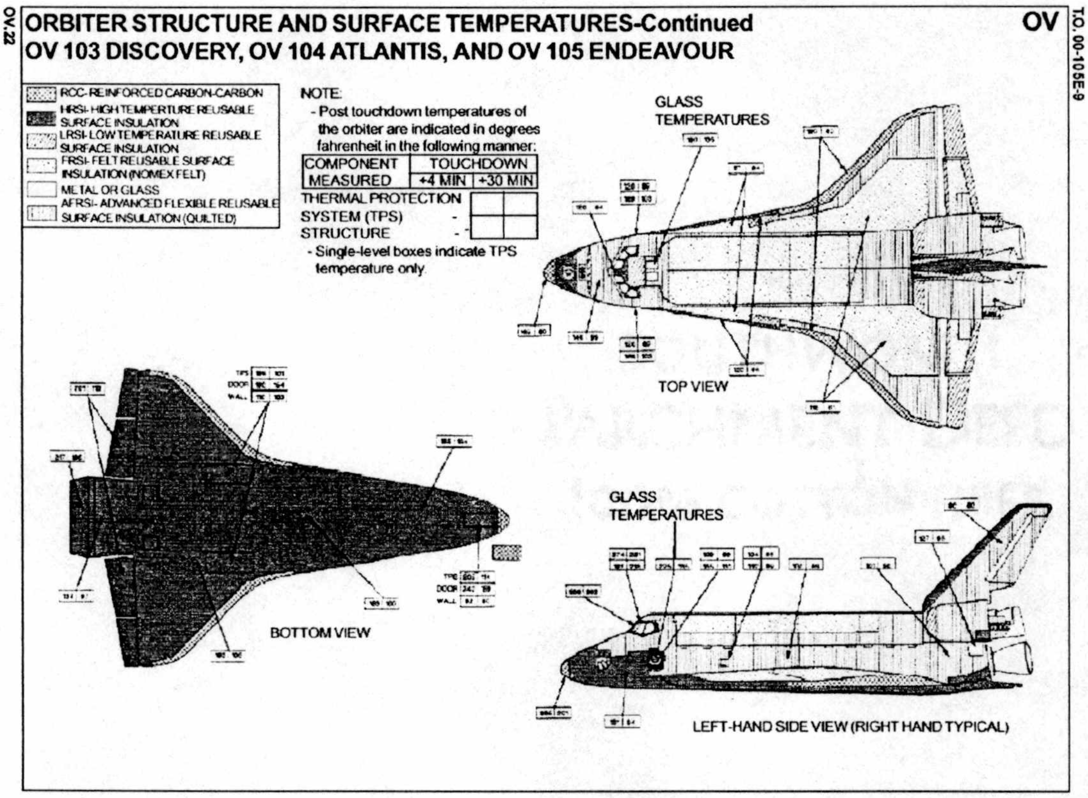


Plate A-26 Orbiter Structure and Surface Temperatures for Discovery, Atlantis and Endeavour. [23]

APPENDIX B - PHOTOGRAPHS

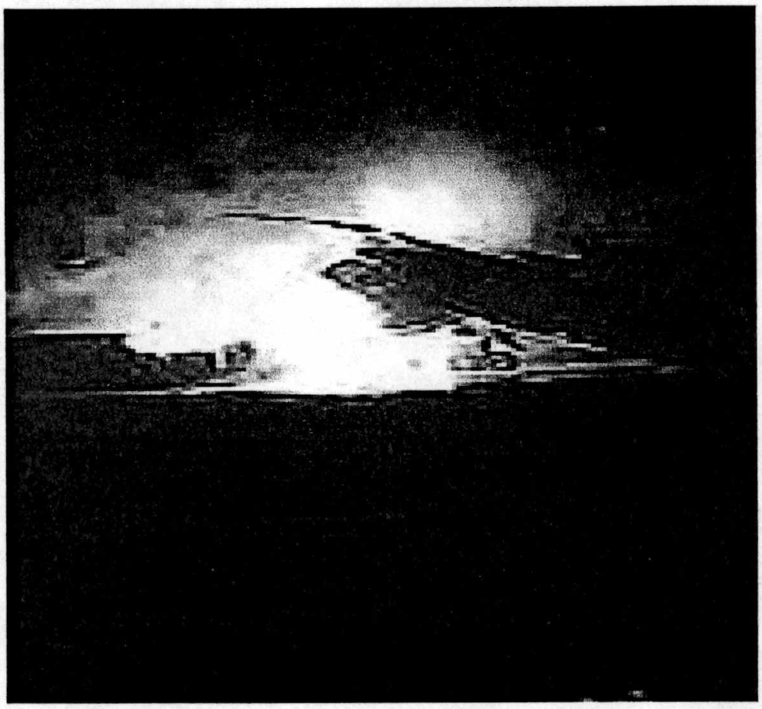


Figure B-1 Representative Mishap Damage Mechanisms. (Fire, Explosion, High-Energy Impact, Heat, Shock, Fragmentation.) B-1A Aircraft Mishap with AC/AAMs.

Figure B-2 Explosive Impact and Fire Damage Mechanisms. Includes Shock and Thermal Loading Exacerbated by High Energy Impact on a Composite Ground Target.

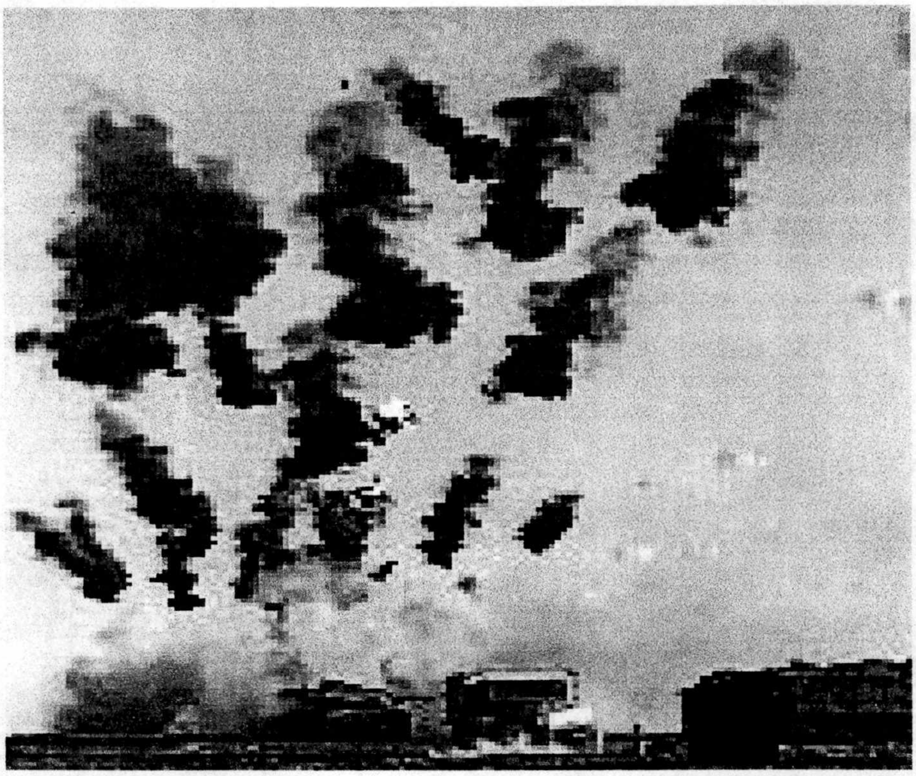


Figure B-3 Representative Mishap Damage Mechanisms. (Fire, Explosion, High-Energy Impact, Heat, Shock, Fragmentation.)

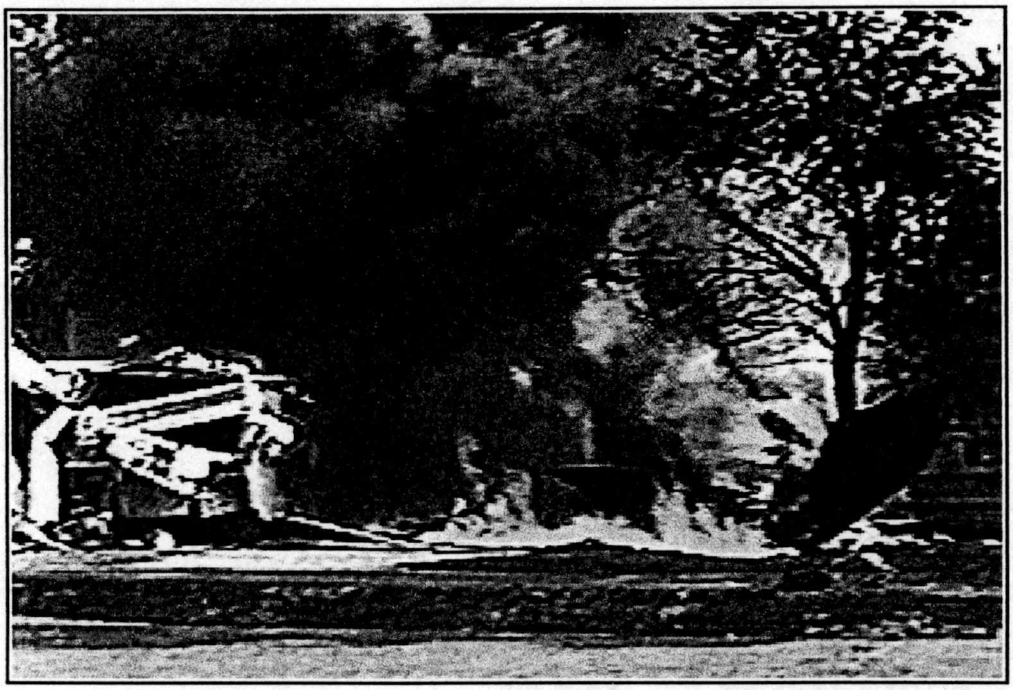


Figure B-3 Mishap Site, Wreckage, and Ensuing Fire from a crashed USAF F-117A Stealth Fighter.

Figure B-4 Mishap Site and Wreckage from a downed USAF F-117A Stealth Fighter. Unprotected Serbian onlookers in background. AC/AAMs were present at this mishap site.

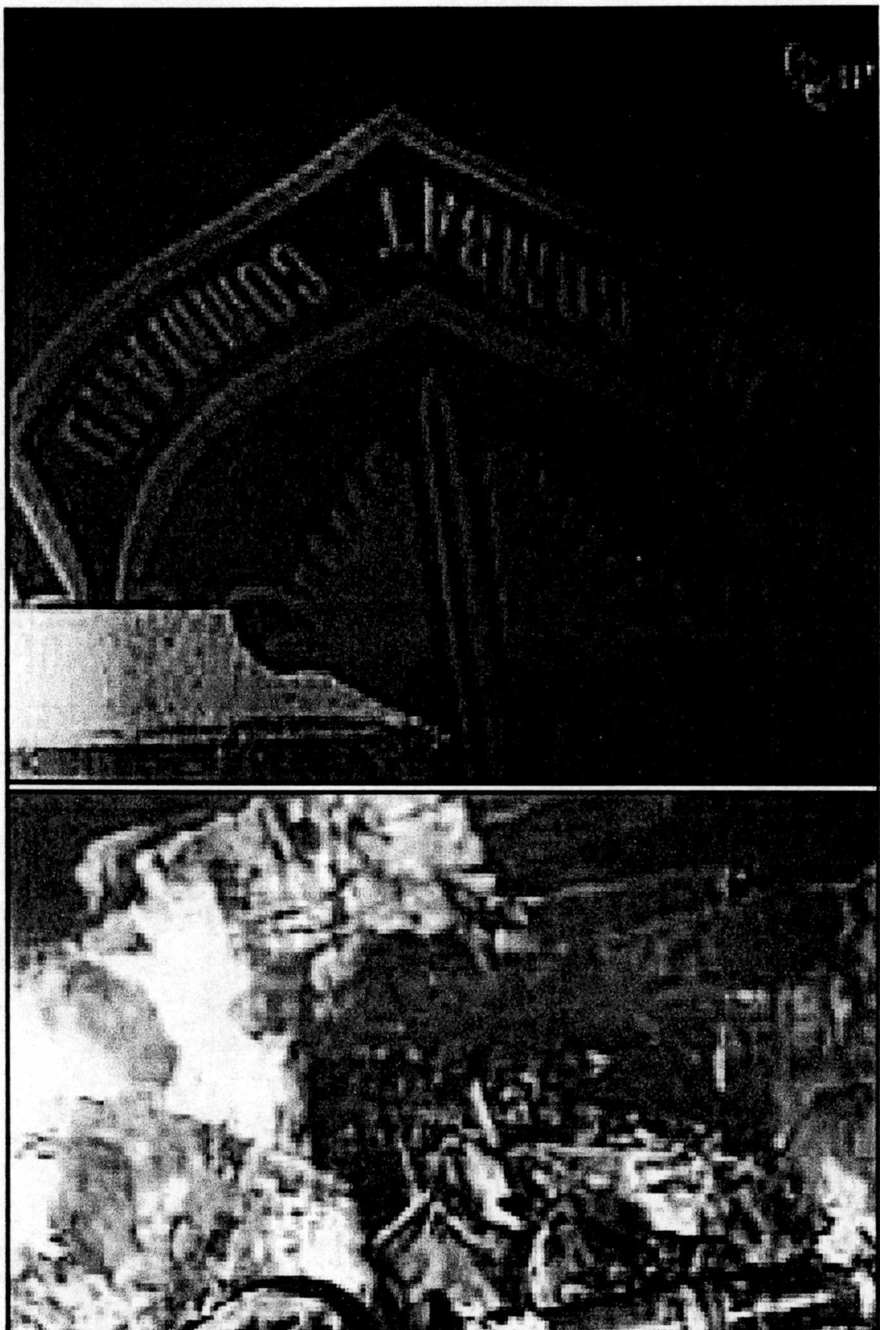


Figure B-5 More Mishap Footage of Downed F-117A in Kosovo Conflict. Damaged AC/AAM Visible.

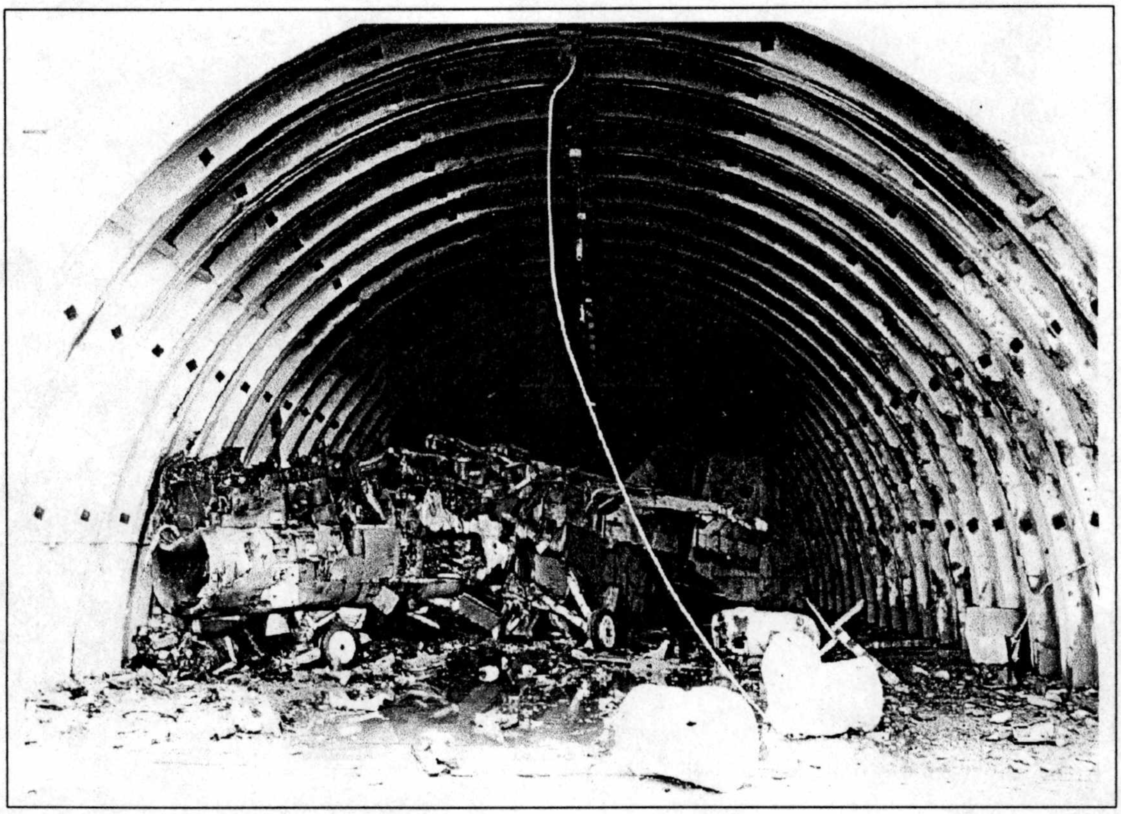


Figure B-6 Damaged Aircraft Within a Controlled/Confined Space. AC/AAMs were damaged within this aircraft bunker.

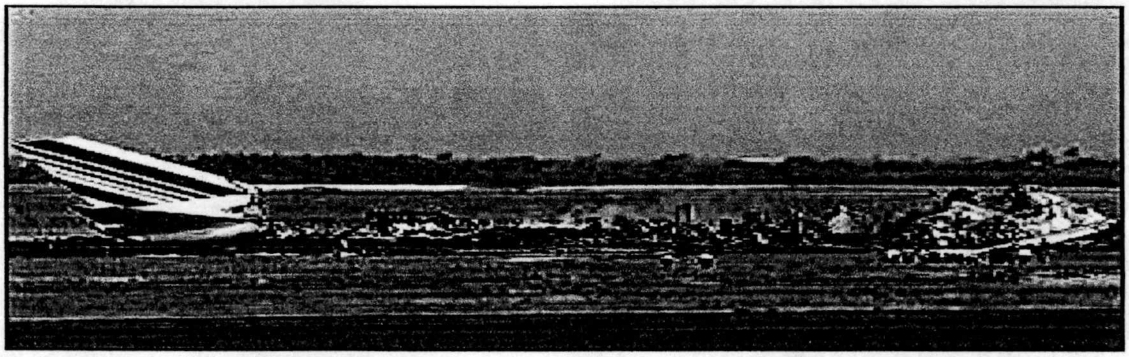


Figure B-7 Smoldering Remains of Large Aircraft with AC/AAMs.

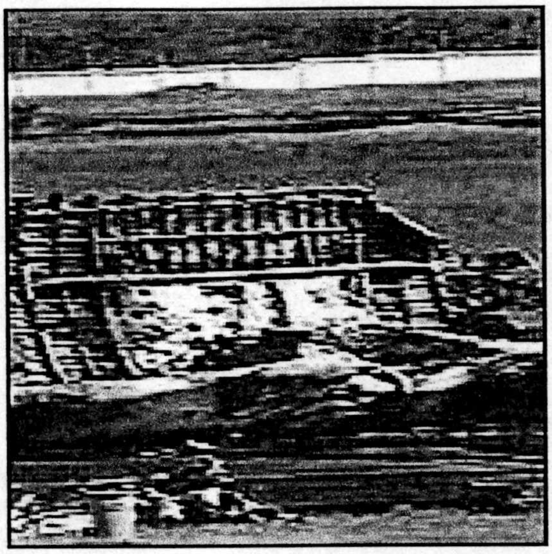


Figure B-8 Damage Advanced Composite Remains of Large Aircraft. Fixant Material Applied.

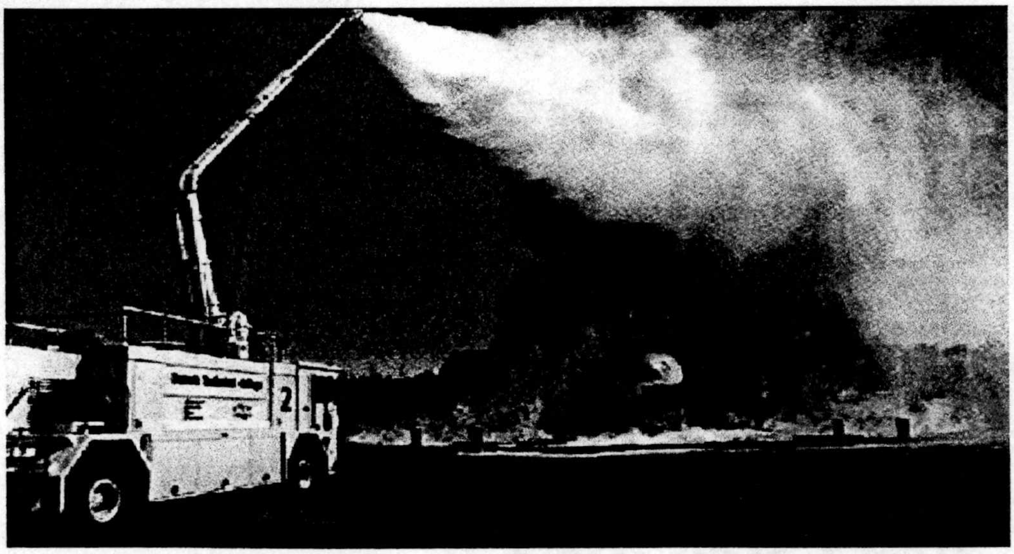


Figure B-9 Fighting an Aircraft Fire Involving AC/AAMs.

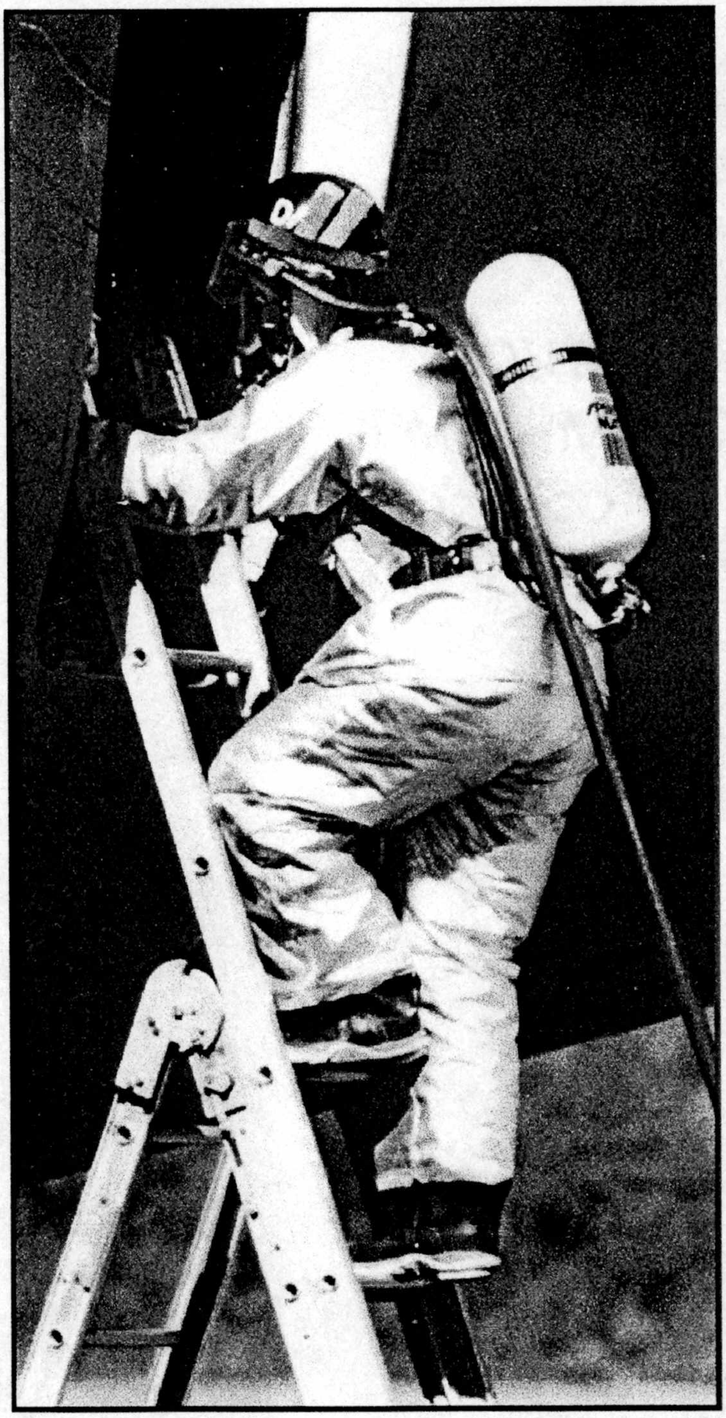


Figure B-10 Complete Fire Protection Ensemble with Self Contained Breathing Apparatus.

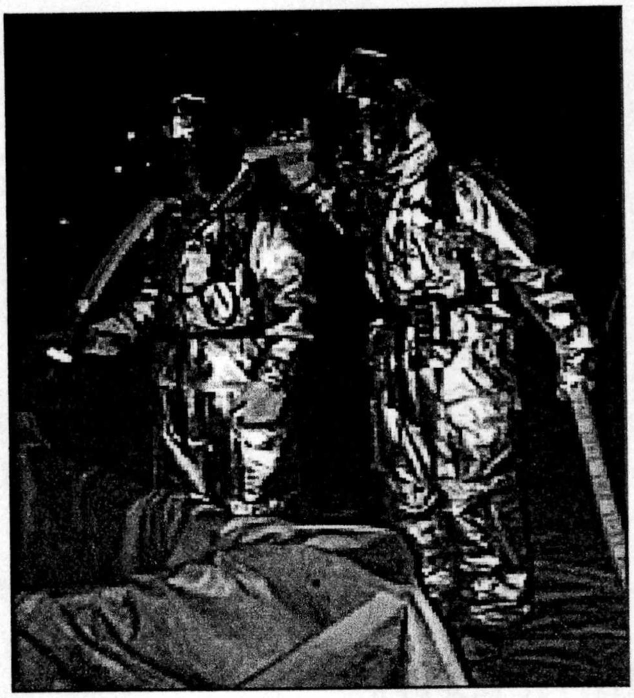


Figure B-11 Firefighter Team Decontanimation with Full Ensemble and Breathing Apparatus.

Figure B-12 Advanced Concept Fire Protection Ensemble for Fire, HazMat, and Structural Protection.

Figure B-13 Mishap Response Personnel During Transport Aircraft Post-Mishap Recovery.

Figure B-14 Equipment Decontamination Following Exposure to Damaged AC/AAMs.

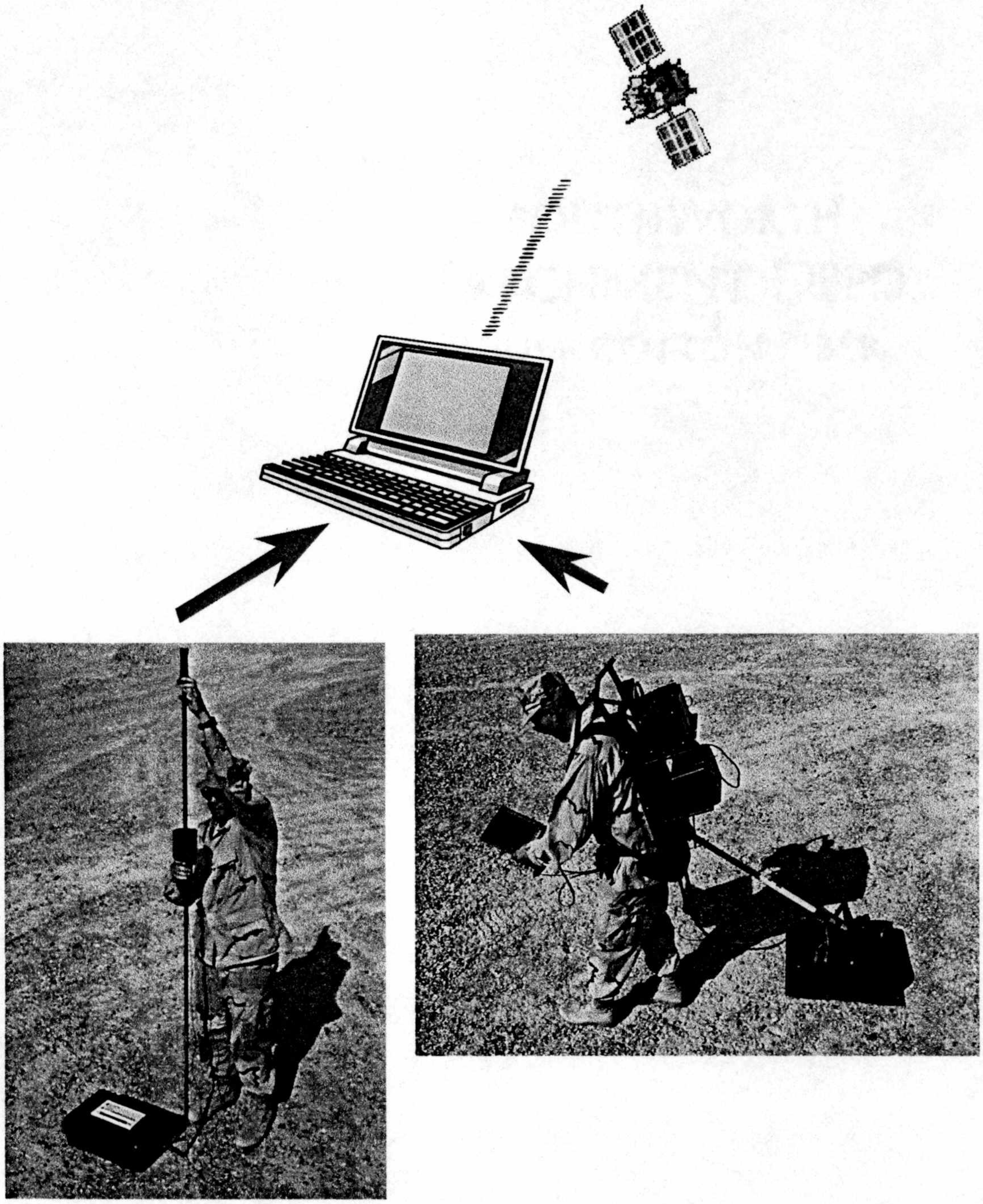


Figure B-15 Mishap Site Mapping and Characterization in the Field.

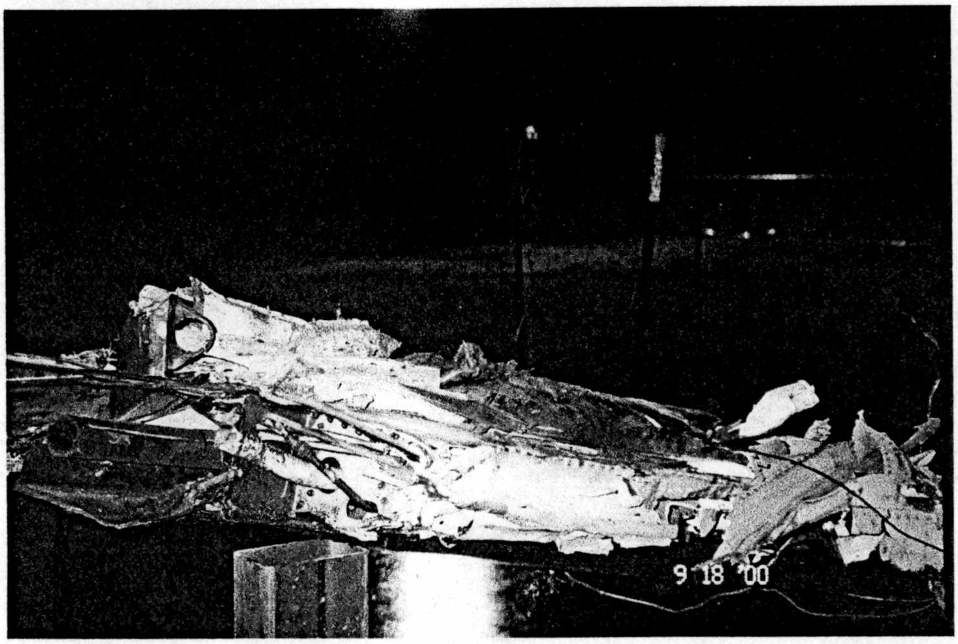


Figure B-16 Damaged Composite Wing (Pre-burn) in a Controlled Fire Test (Inside an Aircraft Shelter)

Figure B-17 Damaged Composite Wing and Personnel in Protective Equipment (Pre-Burn) Inside an Aircraft Shelter.

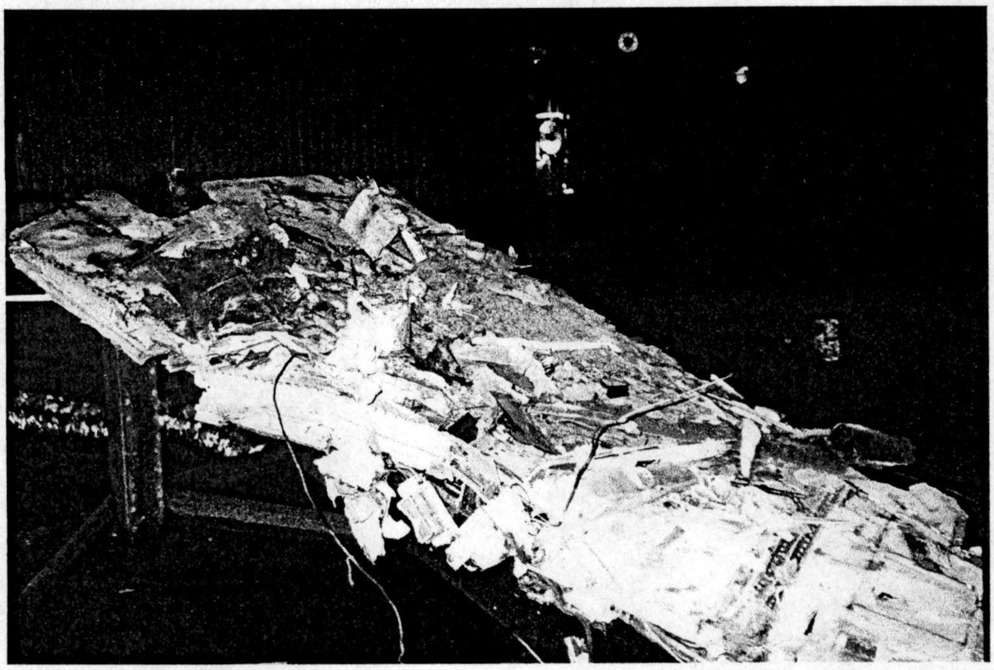


Figure B-18 Close-Up View of Damaged Composite Wing (Pre-Burn).

Figure B-19 Mishap Response Team in Full Personal Protective Equipment Moving Damaged Composite Wing Structure.

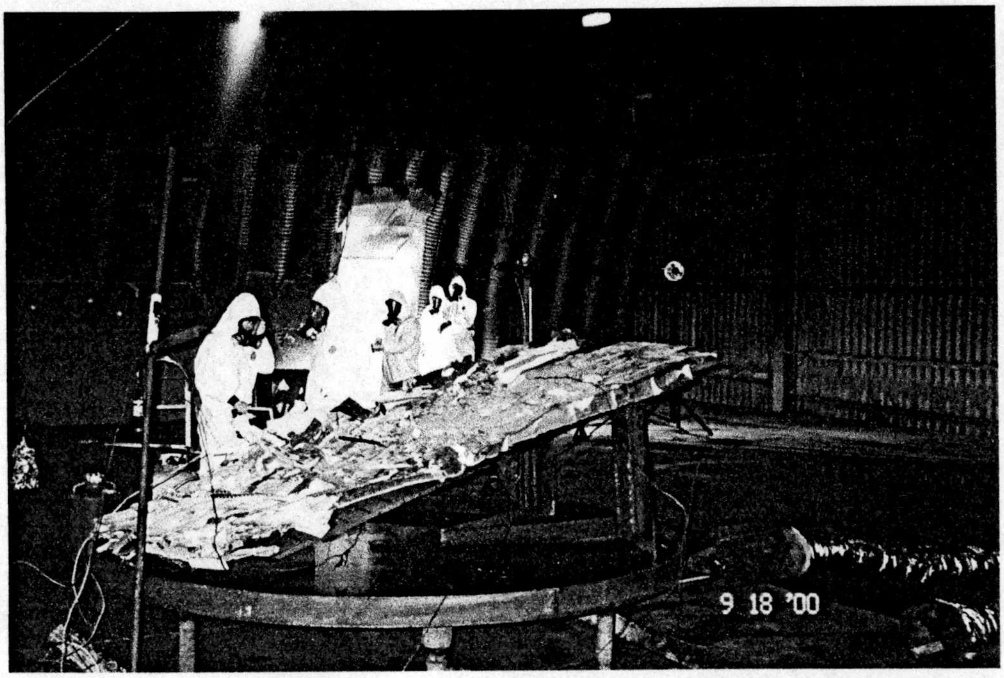


Figure B-20 Overview of Composite Fire Test Within an Aircraft Shelter.

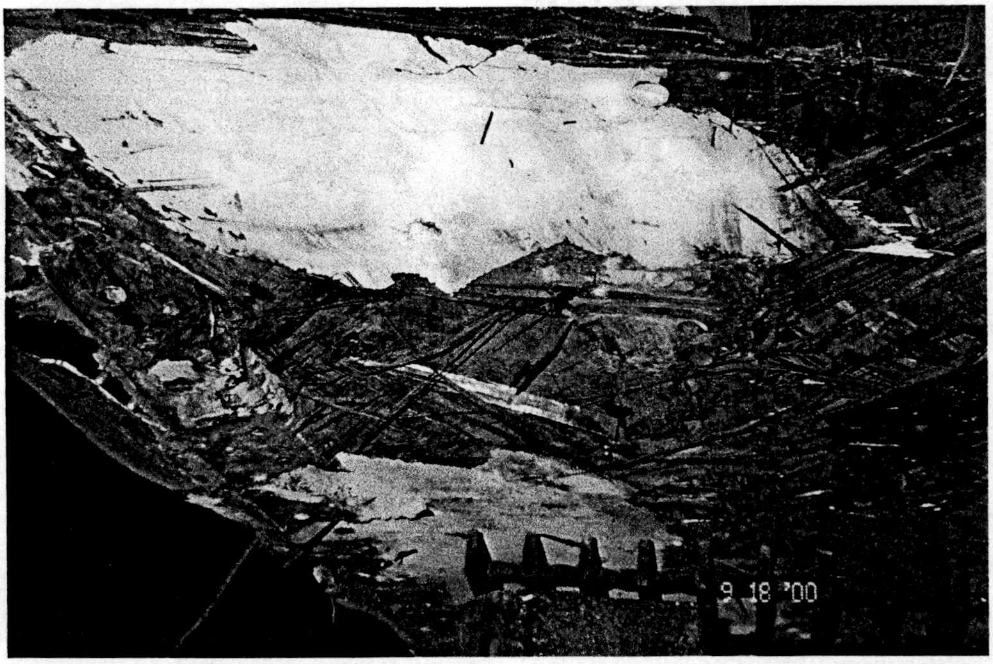


Figure B-21 Fire Damaged Composite Material Showing Multiple Levels of Burn Damage.

Figure B-22 Post Burn Fire Damaged Composite Wing Structure.

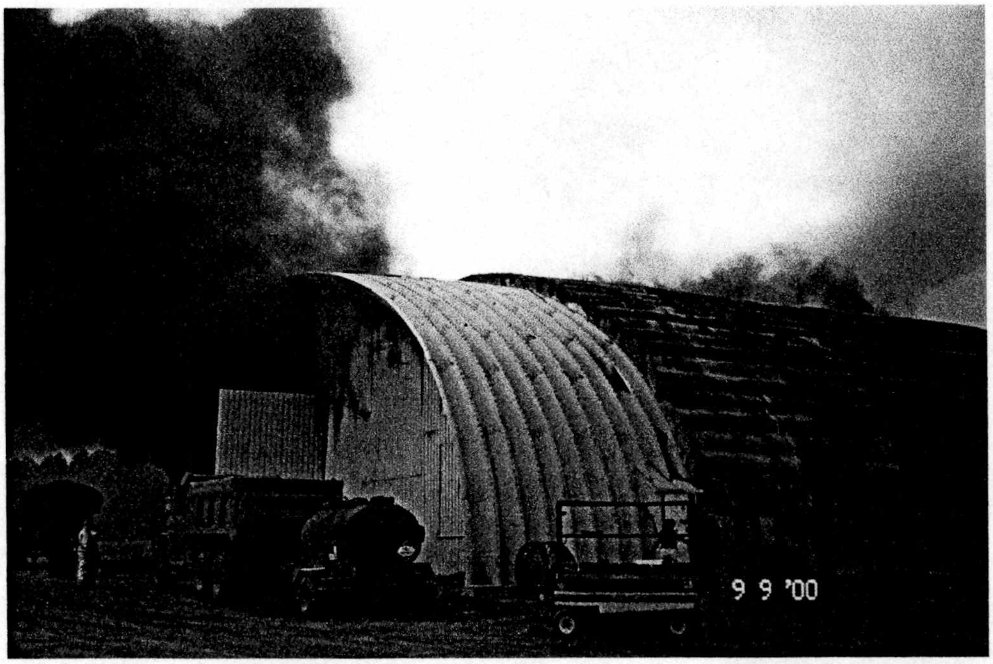


Figure B-23 Outside View of Aircraft Shelter Used for Composite Wing Burn Test with Small JP-8 Fuel Fire Inside.

Figure B-24 Close-Up of Post-Burn Composite Wing Structure.

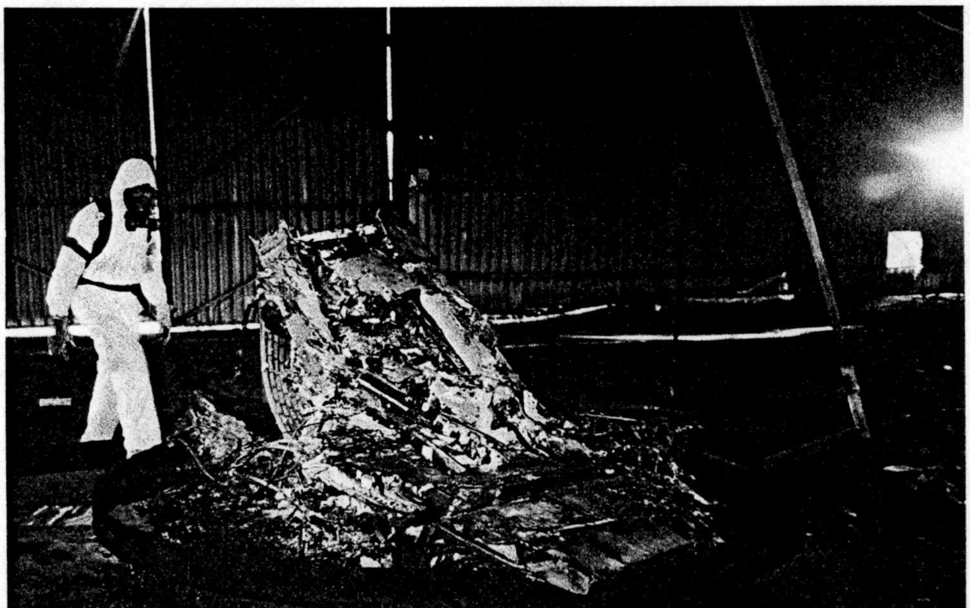


Figure B-25 Mishap Responder in Full Protective Equipement Following a Composite Wing Burn Test.

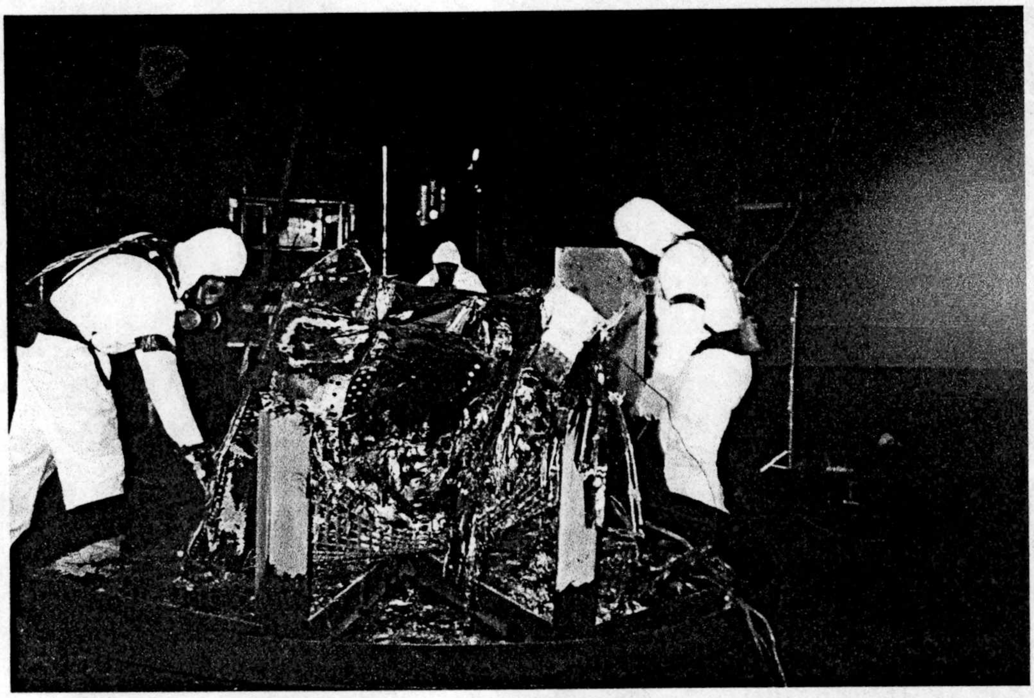


Figure B-26 Clean-Up and Recovery Crew Working On Fire Damaged Composite Wing Structure.

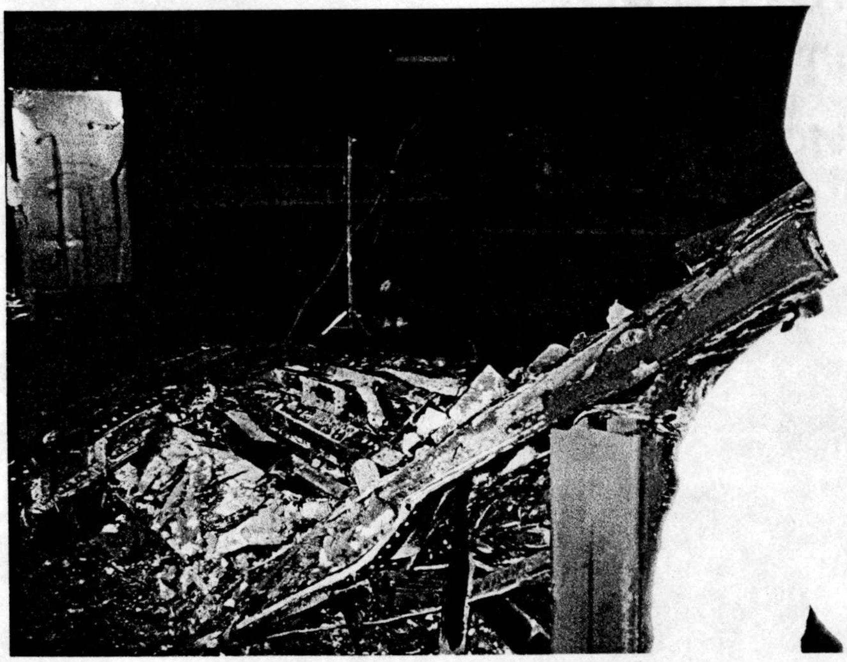


Figure B-27 Top View Looking Down Onto Fire Damaged Composite Wing Burn Test Area.

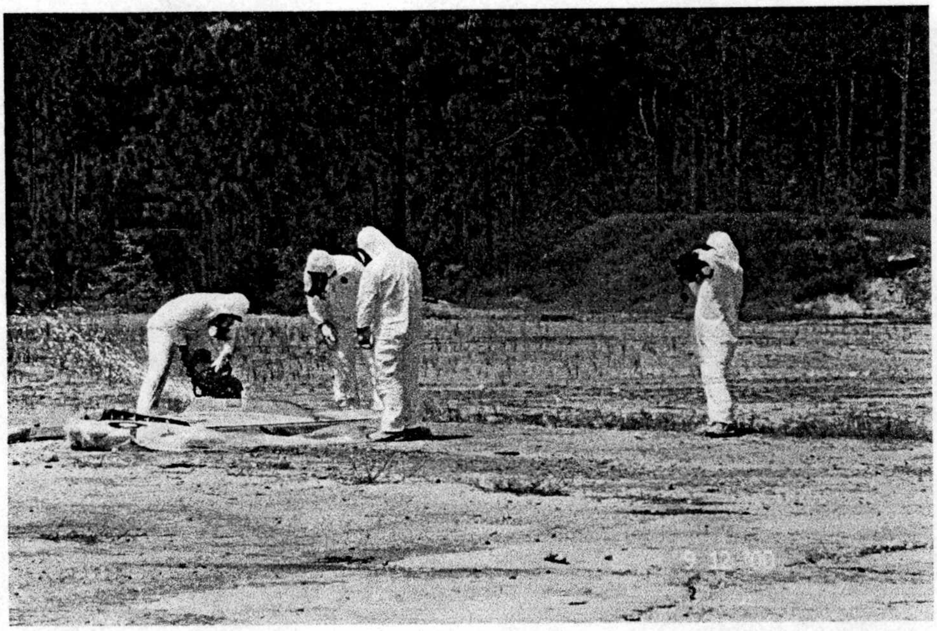


Figure B-28 Mishap Response Personnel in Full Protective Equipment Cutting a Composite Wing with a Diamond-Coated Disk on a Rotary Disk Saw.

APPENDIX C - RAPID RESPONSE CHECKLIST

GENERAL RAPID RESPONSE CHECKLIST FOR AC/AAM MISHAPS

- [ ] Conduct the Initial Mishap Site Survey
- [ ] Establish Control at the Mishap Site with a Clear Chain of Command
- [ ] Evacuate Personnel From the Immediate Mishap Site Vicinity. *Restrict ALL unprotected personnel from assembling downwind of the mishap site.*
- [ ] Restrict Ground and Flight Operations As Appropriate for Conditions
- [ ] Extinguish Fire and Cool AC/AA Materials to below 300 °F (149 °C)
- [ ] Cordon Off the Mishap Site and Establish a Single Entry and Single Exit Point
- [ ] Consult Medical Personnel for Evaluation and Tracking of Exposed Personnel
- [ ] Coordinate a Thorough Survey of the Mishap Site with an Incident Commander (IC)
- [ ] Conduct Expert Toxicology and Area Studies With Survey Protocols
- [ ] Identify Specific Aircraft and Material Hazards
- [ ] Avoid Excessive Disturbance of the Mishap Site
- [ ] Locate, Secure, and Remove Radioactive AAMs; Contact Relevant Authorities and Dispose of In Accordance with Strict Disposal Policies
- [ ] Monitor Entry at the Single Entry Control Point (ECP) – Establish a Single Exit to the Decontamination Area
- [ ] Secure Burned/Mobile AC/AAM Fragments and Loose Ash/Particulate Residue
- [ ] Consult Aircraft Authorities Before Applying Fixants or Hold-Down Materials
- [ ] Obtain and Mix a Fixant or Hold-down Solution
- [ ] Apply/Spray the Fixant Solution on Burned/Damaged AC/AA Materials
- [ ] Use Strippable Fixant Coating Where Coatings are Applied
- [ ] Use Agricultural Soil Tackifiers If Necessary
- [ ] Vacuum Improved Hard Surfaces with a HEPA Filtered Vaccum
- [ ] Flush/Clean the Fixant Application Equipment With Dilute Solvent
- [ ] Pad All Sharp Projections On Damaged Debris
- [ ] Wrap Coated Parts and/or Material with Plastic Sheeting/Film
- [ ] Dispose of Material According to Local, State, Federal, and International Guidelines
- [ ] Complete Soil and Surface Restoration
- [ ] Continue to Monitor Affected Personnel and Sites

VITA

John Michael Olson graduated from the United States Air Force Academy in 1992 with Bachelors of Science degrees in Engineering Sciences and Mechanical Engineering, with a minor in German. He was commissioned as a 2nd Lieutenant in the U.S. Air Force and went to the University of Illinois at Champaign/Urbana where he earned a Master of Science degree in Materials Science and Engineering with an emphasis in composite materials in 1993. Upon completion, he worked as an advanced composites engineer and flight test liaison officer at the Air Force Advanced Composites Program Office at McClellan AFB, CA. In 1995, he attended Pilot Training at Reese AFB, TX. From 1996 to 1997, he was in charge of all special operations flight testing on the AC-130H and MC-130E aircraft at Hurlburt Field, FL. During this period, he completed all his pre-medical requirements at the University of West Florida and the University of Wisconsin-River Falls. He also obtained his commercial, multi-engine, and instrument pilot ratings. He then attended the Defense Language Institute at the Presidio of Monterey from 1997 to 1998 where he completed the French course and learned Russian for Astronauts. Following this program, he attended the United States Air Force Test Pilot School at Edwards AFB, CA and graduated in June of 1999. He then proceeded to his current position as the Chief of the Airborne Test Branch at Eglin AFB, FL, where he is responsible for testing air-to-ground precision guided weapons on the F-16 and F-15 aircraft. He has been and remains deeply involved in mishap response issues involving advanced composites, particularly in air and space-related endeavors.