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Survivability/Vulnerability Information Analysis Center

SURVIAC is a U.S. Department of Defense Information Analysis Center (IAC) sponsored by the Defense Information Systems Agency (DISA), Defense Technical Information Center (DTIC).

The Joint Live Fire (JLF) Program

The Joint Live Fire (JLF) Program was chartered in 1984 by the Office of the Under Secretary of Defense, Director Defense Test & Evaluation (OUSD/DDTE), as a Joint (Air Force, Army and Navy) Test and Evaluation (JTE) Program. The purpose of the JLF Program is to test and evaluate "fielded" U.S. systems (air, land and sea) and U.S. weapons against actual foreign threats and foreign targets (air, land and sea) encountered in combat (i.e., "Better to sweat in peace, than to bleed in combat.").


Foreign Rotorcraft Testing - APG, MD

The original four objectives of the JLF Program have not changed. They are to:

1. Gather empirical data on the vulnerability of U.S. systems to foreign weapons and on the lethality of U.S. weapons against foreign targets;
2. Provide insight into design changes necessary to reduce vulnerabilities and improve lethalities of U.S. weapon systems;
3. Enhance the database available for battle damage assessment and repair; and
4. Validate/Calibrate current vulnerability and lethality methodologies.

The JLF Program continues today under the leadership of the Office of the Deputy Director, Operational Test and Evaluation/Live Fire Testing (DOT&E/LFT), which also oversees the congressionally mandated Live Fire Test (LFT) Program for U.S. systems and U.S. weapons in the "acquisition" process. DOT&E/LFT provides test execution funding and provides technical and financial oversight. The Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS) and the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME) are the executive agents for the JLF program, while the Services execute and support the tests under joint leadership. JLF has three components that are used to address air, ground and sea systems.

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NDIA Presents Survivability Awards

2001 Survivability Achievement Award Recipients

(Pictured left to right) Jerry Wallick, CSD Award Committee Chair; Alan Wiechman, Technical Achievement Award; James Sinnett, Leadership Award; Prof. Robert Ball, Lifetime Achievement Award; RADM(R) Bob Gormley, CSD Chair

At the annual Aircraft Survivability Symposium held at the Naval Postgraduate School in Monterey, California, 5-8 November 2001, the National Defense Industrial Association (NDIA) Combat Survivability Division presented three awards for survivability achievements.

Mr. Alan R. Wiechman received the Combat Survivability Award for Technical Achievement in recognition of his contributions as a pioneer in low observables (LO) aircraft design. Alan has worked on a number of classified programs, including Have Blue, the F-117, and Sea Shadow, as well as more recent programs for Boeing. Mr. Wiechman works at The Boeing Company, St. Louis, Phantom Works as Director, Signature Design and Applications, Advanced Military Aircraft and Missiles, with responsibility for signature design throughout the corporation. While the specifics of his technical contributions remain classified, it can be stated that, in the future, most aircraft will be comprised of vehicles benefiting from advances that he pioneered. As a recognized national expert, he personally pushed the state of the art in LO design and greatly enhanced the national defense posture of the United States.

Mr. James M. Sinnett, Boeing, received the Combat Survivability Award for Leadership in recognition of his vision and the willingness to take risks at a critical time in the development of modern day combat aircraft. He was one of the few to immediately grasp the significance of the nascent low observables (LO) technology and the benefits that could be attained from its incorporation in aircraft. Mr. Sinnett championed development of next generation survivability technologies within The Boeing Company and throughout the military aircraft industry as a whole. He directed large research and development investments for which there was, at the outset, little assurance of a positive return. These included far-reaching classified technology demonstrations, the successful completion of which elevated his team to a position of leadership in the industry. Jim built a research and development infrastructure that facilitated the efficient design and

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NDIA Survivability Awards continued from page 3

demonstration of LO air weapon systems. He also willing served the country as a member of preminent natinal study teams, study boards and advisory panels. He chaired NASA's Aerospace Technology Advisory Committee, served as Vice-Chairman of the Naval Research Advisory Committee, and is an influential member of the Naval studies Board of the National Academy of Sciences.

While details of technical achievements of team working under his aegis must remain classified, his leadership ability, foresight, perseverance, and personal integrity were clearly evident, thereby earning him the respect and admiration of his peers throughout the survivability community and the military aircraft industry.

Dr. Robert E. Ball received the Combat Survivability Award for Lifetime Achievement in recognition of his contributions to the enhancement of aircraft survivability and national security.

Prof. Ball was among the first to note that aircraft losses during the Vietnam War were heavily influenced by aircraft design. Recognizing that survivability considerations should be given more attention during the system design process, he saw that formal education could play a beneficial role and provide engineers with the tools needed to design more survivable aircraft. As a consequence, he developed and gained approval for the first ever college-level course on aircraft survivability, which was incorporated into the regular aeronautical engineering curriculum at the Naval Postgraduate School in 1977.

Prof. Ball also developed a short course in aircraft survivability fundamentals suitable for presentation in a nonacademic setting, which some 4,000 individuals from government and industry have attended.

In the mid-1980s Prof. Ball authored the first textbook of its kind on overall aircraft survivability. This book, "The Fundamentals of Aircraft Combat Survivability Analysis and Design," was published by the American Institute of Aeronautics and Astronautics (AIAA) and is widely recognized as a major factor in establishing combat survivability as a key design discipline among military aircraft engineering professionals.

This award for lifetime achievement acknowledges his lasting contributions to aircraft combat survivability and to the nation.

Please join us in congratulating all three of these deserving award winners.

For more information on the Survivability Achievement Awards, please contact:

Mr. Jerry Wallick, (703) 845-2353, or
E-mail, jwallick@ida.org.

JMUM 2002

25-28 June 2002
U.S. Air Force Academy
Colorado Springs, Colorado

The 7th Annual combined users meeting is called the Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS) Model Users Meeting (JMUM).

This meeting includes users of the following models: AJEM, ALARM, BLUEMAX, BRAWLER, COVART, ESAMS, FASTGEN, MIL AASPEM, RADGUNS

For more information, please contact Mr. Paul Jeng, SURVIAC, (937) 431-2712, E-mail: surviacmodels@bah.com

JLF/Air

The Aircraft Systems component of JLF (JLF/Air) has, and continues, to test aircraft such as the Air Force's C-130, F-15 and F-16; the Army's AH-1S, AH-64, CH-47 and UH-60; and the Navy's AV-8B, F-14 and F/A-18. Threats tested against these aircraft include small arms/automatic weapons (SA/AW), antiaircraft artillery (AAA), surface-to-air missiles (SAM) including man-portable air defense systems (MANPADS), air-to-air missiles (AAM) and directed energy weapons (DEW). JLF/Air is also responsible for conducting tests to evaluate the lethality of fielded U.S. air-to-air munitions such as the Sidewinder air-intercept missile (AIM-9) and the 20mm PGU-28/B SAPHEI projectile against foreign fixed and rotary-wing aircraft. In recent years, JLF/Air has begun to address the issue of MANPADS against U.S. aircraft in support of the warfighter. A number of tests utilizing MANPADS threats against U.S. aircraft have been completed.

JLF/Ground

The Armor, Anti-Armor/Ground Mobile component of JLF (JLF/Ground) began as the Armor/Anti-Armor effort to address the vulnerability of U.S. Army and Marine Corps armored systems such as the M1 Abrams, M60, and M48 main battle tanks; M2/M3 and LAV 25 fighting vehicles; M113 personnel carrier; and AAVP-7 landing craft to foreign threat munitions. Battle Damage and Repair (BDAR) processes and techniques were institutionalized during these early JLF/Ground tests and lessons learned continue today. JLF/Ground also focuses on the lethality of the U.S. large caliber tank-fired, medium caliber auto-cannon, and the antitank guided missile against former Soviet Union armored platforms including main battle tanks and the BMP series of fighting vehicles. In 1998, the scope of JLF/Ground was expanded to include all ground mobile systems including air defense systems, surface-to-surface missile launchers, and logistics vehicles. Besides expanding the suite of platforms and munitions addressed, JLF/Ground conducts tests to support the Air Force in

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C-130 Wing Hydrodynamic Ram Testing - Wright-Patterson AFB, OH

developing requirements for munitions lethality and fosters international collaboration on selected programs.

FSU T-72 MBT Testing - APG, MD

JLF/Sea

The Sea Systems component of JLF (JLF/Sea) was initiated in FY01 with initial funding received in FY02. JLF/Sea will address the vulnerability of fielded surface and submarine combatants including attack gun-boats and will also address the lethality of fielded U.S. threats against foreign sea systems. Like its predecessors (JLF/Air and JLF/Ground) experience gained and lessons learned from JLF/Sea vulnerability and lethality test programs will be utilized for designing more survivable U.S. sea systems and more lethal U.S. sea weapons in the future. This information will also be utilized for mission planning and for developing warfighter tactics, techniques and procedures.

Impact on Next-Generation U.S. Systems and Weapons

While JLF does not, and never was intended to, replace, or fund, congressionally mandated live fire testing of developmental systems and munitions, a key feature of the JLF Program has been the sharing of data and test resources with the development community. For example, lessons learned from structural evaluations conducted following JLF/Air tests conducted on the AV-8B, F-15, F-16 and F/A-18 wings and empennages, particularly the composite assemblies, are being directly applied to the F/A-18E/F, F-22, and the Joint Strike Fighter (JSF). Similarly, lessons learned from JLF/Air post-test evaluations of fuel systems, propulsion, flight controls, crew stations and munitions stowage are being factored into newly designed fixed and rotary-wing systems, including the F/A-18E/F, F-22, JSF and Comanche helicopter. Data collected and lessons learned from JLF/Air lethality test programs are being applied to the development of the AIM-9X as well as to future 20mm projectiles being developed by the Army (e.g., Comanche Gun System), Navy (e.g., PGU-28 A/B projectile) and Air Force (e.g., 20mm replacement projectile).

JLF/Ground vulnerability tests, beginning with the M113, M2/M3, and M1 Abrams, concentrated on identifying parameters influencing platform vulnerability and crew casualties. These tests demonstrated the value of compartmentalization of stowed ammunition for large caliber rounds as well as medium caliber cartridges and antitank guided missiles. Stowage of hazardous materials, in general, and of ammunition, in particular, was shown to have a major impact on damage and damage mitigation. These tests demonstrated the importance of fuel tank/fuel line location, fire suppression system design and layout, spall liners, electrical system redundancy, the elimination of brittle materials for mechanical components, and combat overrides for critical fire control and weapon firing safety devices. Lessons learned from JLF/Ground tests have been applied to the systems tested as well as to next generation systems. From the viewpoint of munitions development, results from on-going JLF/Ground tests of fielded U.S. weapons against foreign targets have been shared with ammunition designers of new and/or improved weapons during engineering and manufacturing design to allow them to improve their designs prior to milestone, MS III (now MS C). These tests have also been used to generate full-up system lethality data for candidate off-the-shelf munitions being considered for lethality upgrades to Army and Marine Corps fighting vehicles. More specifically, these tests have given munition designers insight into tandem warhead parameters affecting defeat of explosive reactive armor. Similarly, tests of kinetic energy penetrators against actual armor installations have provided key insights into post-perforation damage mechanisms as well as penetration performance.

Impact on Vulnerability Reduction Technologies

The focus of JLF is on fielded systems, but the program has included leveraging with "proof-of-concept" vulnerability reduction technologies - as long as their use does not interfere with the original objectives of the JLF Program. JLF/Air Test Programs have leveraged "proof-of-concept" technologies such as reactive fuel tank fire and explosion suppression systems, engine nacelle fire detection and extinguishing systems and reactive hydraulic fluid flow-sensing shut-off valves. Data collected and lessons learned from these tests demonstrate that significant fuel fire/explosion and hydraulic system protection is feasible for both "fielded" and "future" fixed and rotary-wing aircraft systems. JLF/Air tests utilizing MANPADS missiles against U.S. aircraft were leveraged with the FBI to obtain data that would be useful in forensic investigations of terrorist missile attacks. These same tests are being used to help identify vulnerability reduction technologies that may be effective against the MANPADS threat.

JLF/Ground has encouraged leveraging its test programs to obtain data of interest to other elements of the RDT&E community. For example, impact signatures of munitions attacking armor platforms during day, night, and obscured visibility conditions as they appear to the naked eye and through platform sights collected during JLF tests have proven useful for realistic training. Comparisons of platform signatures from before and after damage have also been used to develop battle damage assessment procedures. Data have been collected inside and near target vehicles to determine radiation levels and contamination due to depleted uranium munitions.

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Impact on Modeling & Simulation

The value of testing complemented with modeling has been demonstrated through years of JLF test experience. Modeling is used to support test planning and design by eliminating shots producing no useful information and extending test results to conditions not tested. Test results, on the other hand, are invested in model development and are key to system-level model validation. As part of the effort to address the MANPADS threat, DoD and industry aircraft vulnerability experts meet on an annual basis to review and discuss: 1) Existing MANPADS damage prediction methodologies which can be used for vulnerability reduction design; warfighter tactics, techniques and procedures; and mission planning; and, 2) How to enhance these methodologies utilizing test data from completed and future JLF/Air MANPADS tests. When applicable, the JLF Program leverages their tests in support of JTCG/AS and JTCG/ME modeling and simulation related efforts.

JLF Contributions to Military Operations

During the build-up for Operation Desert Storm, JLF/Ground test data provided soldiers crucial information on the lethality of specific munitions against specific targets. JLF munitions lethality tests provided critical insights into the combat effectiveness of various antiarmor munitions. During Operation Desert Storm, JLF/Air was called upon to investigate the vulnerability of F-15 and F-16 aircraft carrying extended-range external fuel tanks (i.e., could they be protected for safe carriage through the combat zone?). JLF/Air personnel were able to complete a thorough test program within 30 days to address this issue. Test results and recommendations on how to proceed were provided to Air Combat Command in support of the warfighter, prior to the completion of the air campaign. Aircraft battle damage assessment and repair (ABDAR) techniques and technical order (T.O.) repair limits verified and validated during the JLF/Air Program were invaluable to ABDR technicians during Operation Desert Storm. In fact, upon


SCUD Testing - Chicken Little, Eglin AFB, FL

returning from Operation Desert Storm, a number of the ABDR technicians interviewed placed great value on the realistic training they had received from participating in the JLF/Air Program.

Summary

Knowledge gained and lessons learned from the JLF Program have helped to reduce U.S. casualties in Operation Desert Storm (Kuwait/Iraq), Operation Allied Force (Kosovo) and the current campaign against terrorism - Operation Enduring Freedom (Afghanistan). Prior to entering combat, the U.S. Military can continue to test its fielded systems and munitions against the ever-changing threats and weapon systems they will face in combat through the JLF Program. Knowledge gained and lessons learned prior to combat will not only help reduce U.S. "high-value" system losses, it will more importantly reduce U.S. Military and innocent civilian casualties, while maximizing the losses for our enemies.

Note: The author would like to acknowledge inputs received from Messrs. Dennis Bely, Lex Morrissey, John Murphy, Steve Polyak, Al Wearner, Tracy Sheppard, Larry Eusanio and Dale Atkinson for this article. Their inputs are greatly appreciated.

SURVIAC is tasked to provide data management support to the JLF Program Office and serve as the JLF data repository. SURVIAC assists in establishing data reporting guidelines to assure uniformity in planning, data collection and data processing. SURVIAC also assists in revising/updating JLF documents. If you'd like to learn more about the JLF Program, or wish to review test data and lessons learned, you can contact Mr. Jeffrey Wuich, SURVIAC/Booz Allen Hamilton, (937) 255-4840 Ext. 259 or E-mail: jeffrey.wuich@wpafb.af.mil.

SURVIAC Aberdeen Satellite Office Celebrates Tenth Anniversary in a New Facility

For SURVIAC's Aberdeen Satellite Office (ASO), 2001 has been an especially exciting year. At the end of August, just a few weeks shy of its 10-year anniversary, the office was part of the relocation of the SURVICE Engineering Company's corporate headquarters to a brand-new facility overlooking the Bush River in Belcamp, Maryland.

Located approximately three miles from its previous site and five minutes from Aberdeen Proving Ground, SURVICE is the first tenant of the Water's Edge Corporate Campus, a $63-million Class A office park. The new 20,000-square-foot building features enhanced office, storage, and conference facilities; wireless computing capabilities; consultant/client workstations; and special project and team rooms.

In addition, the expanded library houses over 12,000 survivability-related technical reports, manuals, military standards/specifications, directives, books, videos, and computer tapes, as well as a wide variety of networked survivability, vulnerability, and weapon systems effectiveness databases.

For more information about the SURVIAC ASO, contact Mr. Art LaGrange at 410-273-7794 or art@survice.com. For driving directions, visit the SURVICE web site at www.survice.com.

Protecting Our Defenders With Technology

While our Service men and women defend our Nation both at home and abroad, the survivability community does their part by continuing to develop technologies to protect our warfighters. When the Services have been presented with challenges to weapon system survivability, the survivability community has responded and risen to the challenge with a solution. These solutions have potentially saved the lives of untold numbers of Service men and women. The survivability community has adapted to the advances in threats, missions, and weapon system design. Technologies have been and are being developed to meet current and future challenges. This article describes some of those activities that are underway in the field of fire protection technologies.

Background

In most cases, fire is either the primary cause, or a contributing factor, to loss of aircraft assets. This includes combat and noncombat situations. In many instances, injuries to personnel and loss of mission capability accompany a fire event. Aircraft fires are a significant cost to the Department of Defense. Methods and technologies to mitigate them or "design them out" are imperative, not only to save aircraft, but also to save lives and prevent property damage.

Fire prevention efforts on military aircraft are focused on the engine nacelles (the region surrounding the exterior of the jet engine case, shrouded by an outer cover, and typically ventilated), the dry bays (which can include wing leading/trailing edges, landing gear, avionics, and weapons bays), and the fuel tanks. Historically, fuel fire and explosion has been a major cause of aircraft losses in combat. Data from Southeast Asia showed that over half of the aircraft combat losses involved fuel fire and explosions where the combustion overpressure generated exceeded the structural strength of the tank. To help address this problem, fuel tank protection systems are used on military aircraft to protect the ullage (the void space above the fuel level in a fuel tank). Ullage can have a potentially explosive fuel-air mixture. If initiated by a combat threat, an explosion can result.

A survivability enhancement feature (either integral or retrofit) is any particular aircraft characteristic, piece of equipment, or design technique that reduces the susceptibility and/or the vulnerability of the aircraft. The goal of the survivability discipline is the early identification and successful incorporation of those survivability enhancement features that are cost-effective and allow the weapon system to accomplish its mission. Alternatively, if the loss of the aircraft is inevitable, the survivability enhancement features should allow a graceful degradation of system capabilities, giving the crew additional time to depart the hostile area.

There are three main categories of fire protection systems: passive, active, and reactive. Passive protection systems (which generally require no electronics, wiring, brackets/hardware, power, or crew interface) are activated upon the initiation of a fire event. Passive protection technologies usually only mitigate the potential for fire ignition not extinguish it. If passive systems are unsatisfactory, then it may be necessary to consider an active fire suppression system. Active systems respond to the activation of a fire through the use of fire detectors. However, these systems require that the crew is notified that a fire exists and must take additional time to discharge the fire extinguisher. This valuable time could increase the damage to the aircraft. The final option is the use of reactive systems, which react to the initiation of an explosion and automatically discharge a substance which is intended to suppress the explosion by either physical or chemical means. Reactive systems monitor the occurrence of fire, and upon detection, release an extinguishing agent. However, reactive suppression systems can be complex and must integrate numerous subsystems. Often, there are increases in cost, weight/volume penalty, and the potential for failure/false alarms exists. As a result, some aircraft programs have been forced to forego needed fire protection and accept their fire vulnerability.

The following table shows some fire protection related survivability enhancement technologies developed in the last half century. The rest of this article is devoted to the newer technologies shown below that are currently being investigated.

	Engine Fire Protection	Dry Bay Fire Protection	Fuel Tank Protection
Passive	* Intumescent material * Hot surface ignition mitigation	• Firewalls • Self-sealing fuel lines • Powder packs • Ballistic foam * Intumescent material * Simple Passive Extinguisher (SPEX)	• Self-sealing fuel tanks • Reticulated foam * Ionomer self-healing fuel containment
Active	• High rate discharge fire extinguisher	• High rate discharge fire extinguisher • Gas generator	• Venting • Ullage inerting (inert gas) • Tank depressurization • Fuel tank cross feed
Reactive	* Bis(aminotetrazolyl)tetrazine (BTATZ)	* Bis(aminotetrazolyl)tetrazine (BTATZ) * Reactive powder panels	* Linear Fire Extinguisher (LFE) * Parker Hannifin Reactive Explosion Suppression System (PRESS)

* Newer technologies

Intumescent Materials

SURVIAC has been exploring the strategic placement of intumescent materials (a passive technology) within the aircraft engine nacelle for fire protection. Intumescent materials respond to the impingement of a fire by swelling and forming a protective char (coating) to physically and thermally protect the coated structure. Intumescent materials come in several different forms that include coating/paint, tape, caulk/sealant, and putty. The char thickness may range between two and 80 times that of the original material and result in an expansion amount of between one to 30 inches. The char thickness can be characterized by either high (>15 fold), moderate (3 to 15 fold), or low (<3 fold) volume expansion. Intumescent coatings activate in a temperature range of 270 to 500°F.

The intumescent coating can be applied as a very narrow and thin strip in a form of one or more closed rings on the exterior of the engine core. These rings are located to swell against the enclosure at locations where clearance is minimal. If a fire occurs in an engine nacelle the resulting flame would impinge onto a portion of the intumescent material, which upon heating would swell several orders of magnitude beyond its original thickness. This swelling would block the downstream airflow path in the vicinity of the fire, depriving it of a steady flow of oxygen and facilitating self-extinguishment (Figure 1). If the blockage is only partial, and the flame follows the redirected airflow around the sealed-off area, the local intumescent-covered portion in that region would also swell, sealing off the perimeter of the machinery space and depriving oxygen flow until the fire self-

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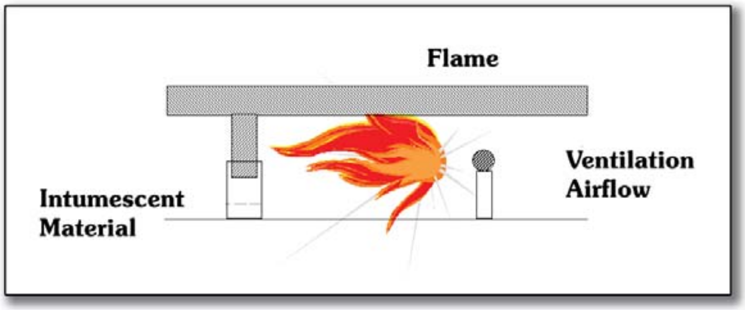

Figure 1. Flame impinges onto the intumescent material

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extinguishes. In this manner, a series of "fire-walls" can be formed using a minimal quantity of intumescent material. If an extinguishing system is also used, the intumescent material can improve its effectiveness, or permit smaller systems, by weakening the fire and reducing the airflow dilution of the extinguishant. Previous analysis performed by the USAF suggested feasible application for engine nacelle spaces. Intumescent materials have been used (or investigated for use) in various military platforms for all three Services and for various commercial applications.

The intumescent coating may only be needed in a limited region of the compartment where the origin of fires is most likely. The intumescent material could also be mounted on the enclosure interior side if it is deemed beneficial. If the gap is relatively large between the engine and the enclosure, then a strip of coating may be placed on both the enclosure and engine surfaces, which upon expansion could meet in the middle.

This technique may be sufficient in many cases to permit the omission of an extinguishing system altogether. This could prove enticing to platforms with weight/volume restrictions such as the Joint Strike Fighter and unmanned aerial vehicles. The option of fire containment/management may be better than no system.

Intumescent materials have properties that can influence their effectiveness for fire suppression (e.g., expansion factor/amount, density, protection hours, activation/maximum temperature, physical forms, char characteristics, etc). Trade-offs must be made depending upon the requirements most important to the platform. The material properties can be engineered to meet these requirements and designed around aircraft specific problems. The main concerns are: potential toxicity, fragility of char, response in a high humidity environment, installation in highly cluttered areas, and early expansion due to low activation temperature.

In a recent study, relevant intumescent data gathered included the following: activation temperature, methods to increase char strength, toxicity, heat exposure limits, fragility of char, installation techniques, humidity limits, current applications (military and commercial), suitable protected areas, common hazards protected against, expected expansion factor and resulting expansion amount based upon original thickness, durability of the coating, adhesiveness and vibration-resistance of the expanded char following activation by fire, and physical properties of the expanded char. Current aircraft engine nacelle configuration data were obtained and used to analyze the physical and functional limitations of these intumescent materials in a notional fighter aircraft. These data included aircraft operating conditions, engine materials, and areas of minimal clearance and other dimensional data. The analyses included: weight impact due to addition of intumescent material, requirements of resistance of intumescent material to airflow environment, and expected reduction in suppressant amount required due to presence of intumescent material.

This study showed the feasibility of utilizing strategic placement of intumescent materials within the ventilated aircraft engine nacelle to reduce the amount of suppressant needed. For full exploitation of this technology, an experimental program was recommended. Because of this, current efforts are underway to demonstrate and optimize the utilization of intumescent materials. Additionally, the project will investigate their use in improving the performance of extinguishing systems. The following technical issues will be addressed: width of intumescent strips necessary to resist shear force of airflow while sealing, resistance to expansion from engine heat, tolerance of aircraft environment; and total expansion heights possible to seal against surrounding structure. The project will test and demonstrate an intumescent configuration to provide decision makers with a lower cost/weight option. The project will also develop and document design criteria for customers to use when utilizing intumescent materials.

Hot Surface Ignition Mitigation

The ignition of leaking fluids (from battle damage or otherwise) onto hot components (such as a bleed air duct in an engine nacelle) can be a significant contributor to fires and results in asset losses. Testing of this phenomenon has been shown to be extremely difficult to replicate consistently. In addition, existing techniques (such as the use of insulation) to mitigate hot surface ignition are heavy and costly. The preferred fire suppression approach is to keep fire from starting.

A new concept of micro-cavities (stamped, forged, rolled or molded) on hot components to control heat transfer and boiling ignition processes is being studied and will be demonstrated on a bleed air duct. The concept will demonstrate that suspended fuel over these micro-cavities will reduce the amount of direct contact and therefore reduce heat transfer and also promote more benign forms of boiling to dissipate heat. The surface ignition mitigation concept is shown in Figure 2. The concept is practical for aircraft without fire systems, or to reduce the amount of extinguishant required.

Current efforts underway are identifying parameters that dictate the conditions suitable for ignition on a hot surface and optimizing surface micro-cavity configuration to increase a safe operating temperature range. These efforts will deliver a protocol to predict hot surface ignition temperature based on the operating conditions and demonstrate a component surface treatment to mitigate ignition.

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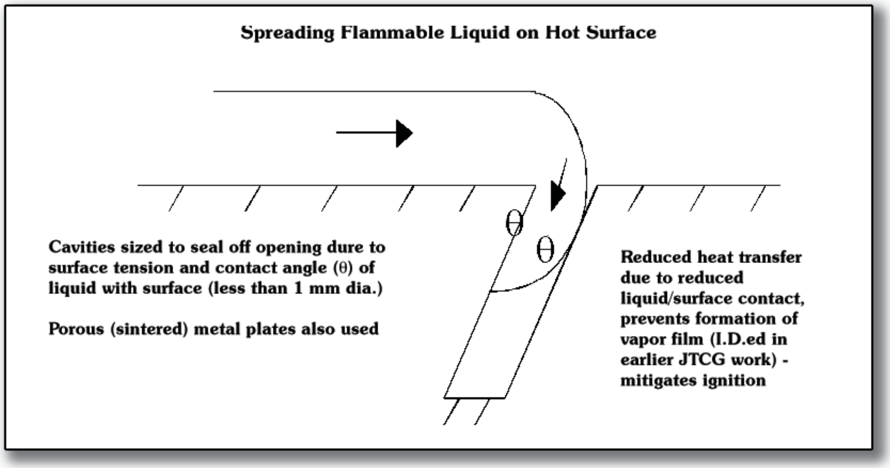

Figure 2. Surface Ignition Mitigation

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BTATZ

The Los Alamos National Laboratory discovered a new rocket propellant – Bis(aminotetrazolyl)tetrazine (BTATZ). It is a nonexplosive, nonpyrotechic, inflammable solid, that decomposes rapidly without flame (low temperature gas) and produces nitrogen. This nitrogen production is highly efficient with 90 percent of the propellant converted to gas. BTATZ is impact insensitive and does not react immediately. Because of this, BTATZ has been identified as a composition highly suitable for fire suppression applications.

The potential for its use provides possibilities of entirely new "outside of the box" fire suppression systems. The properties of BTATZ suggests that system simplification and lightweight packaging are possible. This could be accomplished using vacuum packed molded bricks, powder packs, or conceivably even no packaging (with the use of propellant paint, etc.). The propellant would be installed in dry bays near fire prone regions. Heat from the dry bay fire results in the propellant activation and fire extinguishment.

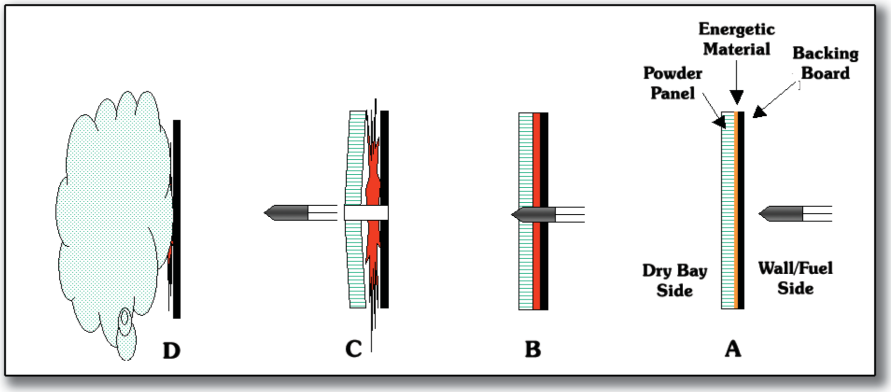
BTATZ is a relatively new composition. Several issues need to be resolved before applying it in "real world" situations. The effluent may be toxic with the potential from the production of hydrogen cyanide since it contains carbon, nitrogen, and hydrogen. The impact of the hydrogen production – the quantity, flammability characteristics, and ability to be reduced – needs to be examined. Other issues include long term stability (shelf life) and sensitivity to initation from static sparks.

Current NAVAIR work is underway to address the BTATZ issues. Work currently sponsored by the DDR&E Next Generation Fire Suppression Program (NGP) is investigating propellant "scale-up" production methods, effluent analysis and species measurement, and chemical suppression enhancement/additives. Additional work currently sponsored by the JTCG/AS is investigating application of BTATZ as a powder pack enhancement and further development of BTATZ "paint." Additional work was cosponsored by V-22 research and development to investigate the powder pack enhancement (with the use of BTATZ), to include a conductive binder (to reduce static sensitivity), to produce test quantities of the propellant, and to demonstrate the concept in a full scale aircraft fire scenario. BTATZ will also be investigated for its ability to withstand the aircraft engine nacelle environment.

Reactive Powder Panels

Current powder pack technology includes a lightweight, brittle, honeycombed panel filled with a fire suppressant powder (usually aluminum oxide). The panel is normally affixed to a dry bay wall adjacent to a fuel tank. Projectile damage to a powder pack results in release of some powder into the dry bay to prevent ignition of leaking fuel. However, some limitations exist with this current design. Fire suppressant powder is dispersed solely through kinetic energy transfer from the projectile to the powder panel. The amount of dispersed powder is limited to the region of projectile penetration. Most of the suppressant can remain encased within the powder panel, unused and "wasted." Fuel and incendiary dispersion can be much more extensive than the powder dispersion. The application of powder packs must then usually be restricted to smaller dry bays, with little or no airflow. Usually, additional passive technologies (such as self-sealing fuel cells) are combined with the powder packs to achieve a more effective protection level. This results in increases in cost and weight penalties.

The Naval Air Systems Command (NAWD-WD, China Lake) is currently investigating the concept of reactive powder panel design (Figure 3). This design would incorporate a small amount of impact sensitive pyrotechnic (BTATZ) thinly painted on the surface of the panel. The powder panel is then affixed on top of this painted surface. When a round impacts the panel, the pyrotechnic is initiated and results in removal, breakup, and discharge of the "entire" powder panel from the wall. Pyrotechnic gases effectively disperse the fire suppressant powder.



A) Small amount of impact sensitive pyrotechnic is thinly painted on surface of supporting backing panel. Powder panel is affixed on top of this painted surface.

B) Round impact results in initiation of pyrotechnic.

C) Pyrotechnic activation results in removal, breakup, and discharge of "entire" powder panel from wall.

D) Fire suppressant powder effectively dispersed by pyrotechnic gases.

Figure 3. Reactive Powder Panel Enhancement Concept

To be effective, BTATZ must be initiated by bullet impact almost simultaneously along its entire surface. However, BTATZ is impact insensitive and does not react immediately. To solve this problem, a dual layer of BTATZ and an additional impact sensitive initiator material can be sandwiched between the powder panel and the dry bay wall. This energetic initiator activates on impact and initiates the entire surface of the BTATZ. The initiator also provides some added energy to assist in the break-up (crack) of the powder panel. The energetic initiator must be applied as a very thin sheet or paint; be sensitive enough to be initiated by the projectile (fragment) impact; and rapidly react to initiate the BTATZ main propellant charge along the majority of its surface. The energetic initiator should provide some energy to assist in shattering the powder panel, but must not be overly energetic to result in damage to the supporting aircraft structure or result in severe injury from accidental activation. Also, the energetic initiator should create only a minimal, low-temperature, flame (if any).

Ballistic testing of the reactive powder panels has been completed in FY01. Baseline powder panel tests were performed for comparison to the enhanced (reactive) powder panels. Testing of "first look" energetic initiators was also completed. Fire protection demonstration tests will occur in FY02. This testing will include demonstration testing of the concept versus actual dry bay simulator fires.

Simple Passive Extinguisher (SPEX)

The Simple Passive Extinguisher (SPEX) concept focuses on fire protection system simplification with minimal, or no supporting subsystems. An ideal application of the SPEX concept would simply place an agent (such as BTATZ) within the volume to be protected. The agent would be a reactive agent is sensitive to the characteristics of a

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fire (heat, smoke, and potentially light). Exposure to the fire would result in agent activation to extinguish the fire.

Commercially-off-the-shelf (COTS) fire suppression agents may be applied to the SPEX concept. Several fire suppression vendors have products already designed to utilize heat as a primary (not backup) activation mechanism. COTS technologies can be applied to SPEX at the simplest system level – heat reactive fire bottles, and pyrotechnic suppressors with heat sensitive initiators. System retrofit would merely involve installing SPEX fire suppression canisters or bottles near fire-prone regions. These kits could be installed at the squadron maintenance level. Heat from the fire would result in the discharge of agent and fire extinguishment.

Dry bay clutter (obstructions), geometry, or internal airflow may require some modification of SPEX to include a heat sensitive initiator "fuze" that would expand the fire detection coverage area and activate a multiple SPEX packet. An ideal fuze material would be quick reacting and flameless (potentially BTATZ).

Assuming the benefits (due to lack of detector, activation hardware) of the SPEX/BTATZ concept, the fire suppression system could be approximately one-sixth the weight of an equivalent active system. Since the SPEX/BTATZ concept has not been commercially produced to date, the cost benefits are unknown but should be similar. Using a SPEX/BTATZ concept with a chemical suppression additive could result in a synergistic enhancement. The fire suppression system could be approximately one-twelfth the weight of an equivalent active system.

The SPEX concept can be applied now with commercially available technologies, and emerging technologies promise even greater system simplification to enhance SPEX benefits.

Linear Fire Extinguisher (LFE)

Projectile-induced ullage explosions are usually generated by a specific sequence of events. The elapsed time from ballistic impact to a fully developed explosion occurs within milliseconds. The LFE system, initiated by detection of projectile function or fragment impact flash, operates within the same millisecond time frame and is expected to create a "protected" ullage space before damaging overpressures are developed from the ensuing explosion. The parallel explosion-development/system-activation sequence is as follows:

Projectile penetration causes an incendiary flash and the subsequent detonation disperses incandescent particles and fragments within the threatened fuel tank, beginning the process of explosion development.

Optical sensors respond to the incendiary flash, triggering a detonator to activate the extinguisher(s).

The extinguisher(s) discharges an explosion inhibiting agent that suppresses the explosion, thus negating development of damaging overpressures.

The LFE system consists of an optical sensor, a hollow thin-wall stainless steel tube for extinguishant storage, and a combination detonator and flexible linear shaped charge (FLSC) mounted over the exterior of the tube for extinguishant discharge initiation (Figure 4).

An active explosion suppression system is feasible, but dependent on the suppression agent used. Some of the extinguishing agents tested include: distilled water; aqueous film-forming foam (AFFF) and water solution; water, AFFF, and Halon 1301; water and monoammonium phosphate powder; 30 percent calcium chloride and water solution; 50 percent ethylene glycol and water solution; 70 percent ethyl alcohol and water solution; Halon 1301 and water mixture; propane; monoammonium

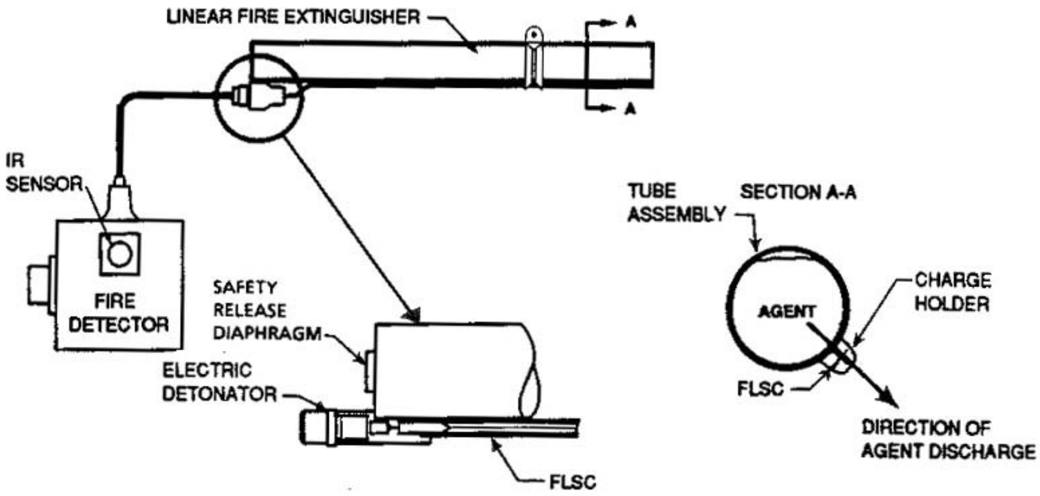

Figure 4. Linear Fire Extinguisher (LFE)

phosphate powder mixed with Halon 1301; FC-218; HFC-227ea; HFC-125; and Pentane.

Some advantages of the LFE system include: speed (response within five milliseconds), suppressant speed – 1000 ft/sec, detectors, one channel IR fiber optic, efficient distribution, and low weight (mostly suppressant).

Some disadvantages of the LFE system include: power consumption, detector technology lags, ullage overpressure with halon, and reaction forces from tube.

The following items must be addressed:

- Compatibility of the suppressant with the environment and the fuels requiring protecting, especially considering alternative suppressants.
- Reactive loads that are imposed on the aircraft structure when the LFE is discharged.
- Installation and operation issues of the finalized system.
- Concerns of overpressures must be addressed. Pyrotechnic devices in air craft fuel tanks also present a potential risk to the aircraft.
- Effects of discharging the LFE when completely submerged in fue, and the ability of successfully dispersing the agent into the fueled areas.

Discussions with Government personnel indicate that a LFE test program is scheduled to be performed at Wright-Patterson AFB, Ohio. The test program will not only address the LFE, but will also attempt to quantify the previously described reactive loads, if possible. In later studies, methods to mitigate these loads will be explored.

Parker Hannifin Reactive Explosion Supperssion System (PRESS)

The Parker Reactive Explosion Suppression System (PRESS) is designed to be installed in aircraft fuel tanks and react to and suppress fuel tank explosions. It consists of an optical detector, transmission lines and a suppression tube(s) containing a water/brine solution. This system is designed to respond within a few milliseconds to engage the flame front and reduce pressures below damage causing levels. After detection, the transmission lines transmit a signal to the suppression tube, which initiates an exploding bridgewire circuit. This, in turn, initiates a detonating cord and propellant internal tube, creating a high pressure expulsion force to expel the adjacent bladder filled with water. The water exits through orifice holes, is transmitted through radial channels in the external nozzles and released as five-micron-thick sheets. These sheets break up into

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ten-micron droplets which absorb thermal energy released by the explosion. This process occurs in its entirety within a few milliseconds.

Some advantages of the PRESS system include: fastest responding system – allows less suppressant, lighter weight, system designed for liquids like water, tank overpressure problem not evident, and nozzles allow directed flow of suppressant.

Some disadvantages of the PRESS system include: requires large scale proof-of-concept testing, more complex system – chance for malfunction despite high reliability components, and possible expense in manufacture.

The following items must be addressed:

- Use of explosives and chemical propellants inside fuel tanks to suppress a fuel explosion.
- Introducing water into a fuel system.
- Introducing a chloride brine into a fuel system.
- Ultra-fast suppressant dispersion raises concerns about mounting bracket reaction loads.
- Resistance to battle damage.
- Discharge of suppressant when the dispersion tube is submerged in fuel (potential of producing a hydraulic ram effect).
- Installation of the PRESS system in small cluttered compartments would be difficult and costly. Also detection would be difficult since the detectors are typically line of sight.

Discussions with Government personnel indicate that technical complications prohibited demonstrating the effectiveness of PRESS for suppressions of fuel vapor explosions. These discussions indicated that the PRESS nozzle design was too complex and required very tight tolerances (which prohibited a low cost manufacture). To alleviate this problem, conventional nozzles were used in a radial fashion to generate the same effect.

Parker Hannifin representatives stated that the PRESS technology has been shelved due to technical and funding issues. The technical issues included the nozzle technology development. Several different approaches were attempted. In their opinion, nozzle technology has not advanced to a state that would allow the PRESS technology to be further pursued by Parker Hannifin.

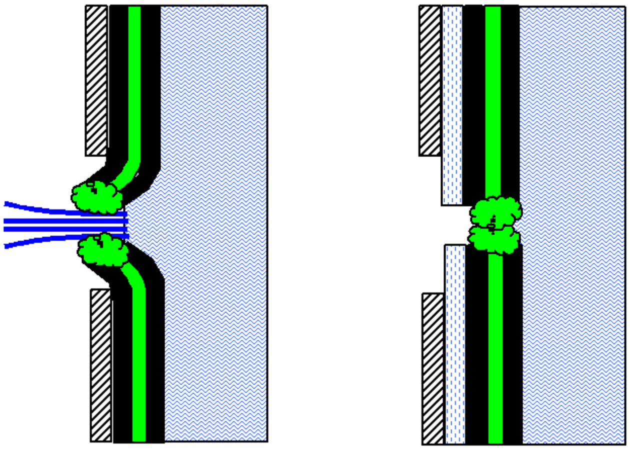
Ionomer Self-Healing Fuel Containment

The ionic forces in ionomer plastics provide a “self healing” capability. When these forces are destroyed at impact, they instantly reform in a similar manner as when a bullet passes through water. This lends itself to fluid (fuel, oil, hydraulic) containment applications.

An ionomer is an ion-containing polymer. Such a thermoplastic resin has ionic bonds between the polymer chains. Ionic crosslinks occur randomly between the long-chain molecules. Typical properties of ionomers include:

- High impact strength at low temperatures,
- Puncture and abrasion resistance,
- High melt elasticity,
- Good thermoforming properties,
- Low sealing temperatures,
- High sealing seam strength, and
- Resistance to grease, oil, and solvents.

Current materials used in “self-sealing” backing boards adjacent to fuel tanks incur some damage (a “hole”) after a ballistic impact (Figure 5.). This may allow fuel leakage into the dry bay through this hole. An ionomer backing board would be expected to “self-heal” after impact, and may thus provide additional containment of fuel from a wounded self-sealing fuel cell.



a) Fuel cell unsupported due to structural damage. Wounded area is not flat and cannot meet to seal.

b) Backing board provides support to the fuel cell in the structurally damaged area. Wound is flat and can meet to seal.

Figure 5. Ionomer "self-healing" fuel containment fuel cell backing board.

This may provide for expanded applications including backing board fuel containment of nonself-sealing fuel cells, or self-healing ionomer fuel cells. Other potential applications include: self-healing fuel lines, self-healing hydraulics containment covers/linings, and self-healing gearbox oil containment covers/linings.

The objective of this effort is to develop and demonstrate a simple and low-cost alternative/enhancement to current self-sealing fuel cell technologies. Commercially available ionomers (properties, types, and suppliers) are being investigated, materials are being acquired, the ballistic response and containment are being tested and the analysis and results are being documented.

Recent events have demonstrated the need for cockpit hardening of aircraft. The high impact strength of ionomers also suggests possible applications in cockpit hardening. Should time and funding permit, additional testing may be conducted to evaluate ionomer's resistance to bullet impact as a function of its thickness and layers.

Summary

The responsibility of the survivability community is to protect our defenders by providing them with survivable aircraft. In the past half century, many technologies have been developed and fielded to fulfill this responsibility.

To all the Service men and women who defend us, thank you for giving us – the survivability community – the opportunity to help protect you. May we be ever diligent to make the weapon systems you use to defend us more survivable.

We salute you.

Acknowledgements

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- NAWD-WD, China Lake – Joseph A. Manchor
- NAWD-WD, China Lake – Richard B. Mueller
- 46th Test Wing, WPAFB – Mike Bennett

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Component Vulnerability Analysis Archive (CVAA) Workshop Held

A Workshop to introduce the first release version (5.0) of the Component Vulnerability Analysis Archive (CVAA) was held on 11 December at the Booz Allen Hamilton facility at Ashford Center in Beavercreek, Ohio. The Workshop consisted of a morning of lectures covering the CVAA history as well as details and examples of the database construction, procedures for searching for data and data entry procedures. The afternoon was devoted to 'hands on' work with CVAA with practice exercises involving finding specific data and entering new data in a local CVAA version.

Attendees were John Barber (Bell Helicopter Textron), James Cole (Naval Surface Warfare Center – Dahlgren), Ron Dexter (SURVICE Engineering), Scott Frederick (Skyward Ltd.), Dustee Hata (Boeing Company), Kelly Kennedy (ASC/ENMM), Jerry Kitchen (AFOTEC/TSE), Leanne McKay (SURVICE Engineering), and Earl Wilhelm (Boeing Phantom Works). Lecturers and administrators were Gerald Bennett (SURVIAC), Geraldine Bowling (SURVIAC), James Davis (SURVIAC), Dennis Gorman (SURVIAC), Paul Jeng (SURVIAC) and Eric Scarborough (Applied Research Associates Inc.). Copies of the CVAA Workshop notes and the CD ROMs containing the 5.0 version and the lectures will be available through SURVIAC. Pictured below are the CVAA Workshop attendees, lecturers and administrators.

Version 5.0 of the CVAA was released at the Workshop. The CVAA is in the process of being reviewed for entry into SURVIAC. In the interim it may be obtained through SURVIAC as a non-SURVIAC product at a cost of $150.

For more information on CVAA, please contact
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E-mail: bennett_gerald@bah.com

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POC: Joe Moravec, (810) 978-3106, E-mail: moravec_joseph@bah.com

Advanced Technology Electronic Defense Systems (ATEDS) Program Review
8-11 April 2002
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POC: Jack Kress, (812) 330-1800, E-mail: ATEDS@teklaresearch.com,
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JMASS Customer Conference
8-11 April 2002
Virginia Beach, Virginia
POC: JMASS Program Office, Jennifer Turso, (800) 810-4333 or (732) 981-3428,
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Aircraft Fires & Explosions: Accidents, Combat and Terrorist Attacks
16-19 April 2002
Cambridge, Massachusetts
POC: BlazeTech, (617) 349-0700, E-mail: firecourse@blazetech.com, http://www.blazetech.com

Global Air & Space International Business Forum and Exhibition
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46th Annual Fuze Conference - The World of Fuzing
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