

AIRCRAFT SURVIVABILITY

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Surviving Space

Ensuring Aerospace Systems Survivability in the Final Frontier



Winter 2000



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Newsletter & Cover Design
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About the cover: This digital artist's concept shows the International Space Station after assembly is completed in 2006. The completed station will be powered by almost an acre of solar panels. The pressurized volume of the station will be roughly equivalent to the space inside two jumbo jets.

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Editor's Notes

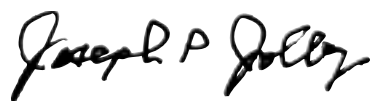
The JTCG/AS has traditionally focused on making **Aircraft** more survivable. It has only been over the past two years or so that we have begun to look at **Spacecraft** Survivability.

Our involvement in Space began when Dr. Joel Williamsen of the University of Denver Research Institute suggested several Space-related initiatives. Over time, the JTCG/AS Principal Members Steering Group (PMSG) has made certain decisions. Our vision statement was broadened to address aerospace systems in stead of aeronautical systems and we co-sponsored a Space and Air Survivability Workshop with the AIAA and the University of Denver Research Institute, held last June at the Air Force Academy in Colorado Springs, Colorado. We also funded a project in Spacecraft Survivability. Based on these activities and the level of interest that exists, we decided to devote this issue of Aircraft Survivability to Spacecraft Survivability.

Some insight into future attention to Space, not just for our organization but for all of DoD, might be gained from the Report of the Commission to Assess United States National Security Space Management and Organization dated 11 January 2001. The first of five major unanimous conclusions of the commission was that U.S. national security Space interests be recognized as a top national security priority. In the context of the growing commercial and national security use of Space, the report further states that U.S. assets are an inviting target, even calling the U.S. an attractive candidate for a "Space Pearl Harbor." Considering the Commission Chairman was the Honorable Donald H. Rumsfeld, it was interesting to read the last sentence of the report's executive summary which stated, "The Secretary of Defense should establish a Major Force Program for Space." The full report is available on the Web at www.space.gov.

Our Pioneer in Survivability feature article recognizes the outstanding achievements of Dr. Joel Williamsen in manned spacecraft survivability. Dr. Williamsen is credited with developing original spacecraft and crew survivability software for the International Space Station and for bringing the aircraft and spacecraft survivability communities together.

We hope you enjoy this issue and encourage feedback. Our E-mail address is on the inside front cover. The next issue of Aircraft Survivability will be published in the Spring 2001. The theme will be S&T Initiatives in Survivability.



An F-16C/J Falcon, U.S. Air Force photo by TSgt Brad Fallin.

Letter to the Editor

Dear Mr. O'Bryon,

I greatly enjoyed your article, "Tearing the Walls Down to Achieve Greater Aircraft Survivability." Your article highlights a number of observations and experiences that are all too familiar to me. Let me briefly give you some background on where I'm coming from and then make some closing comments.

For the past 25+ years I've been working in areas including exploitation, real time crew in the loop simulation (SAM, AAA, aircraft, etc.), RF and EO countermeasures, human operator modeling (aircraft and threat), and open air flight testing. As you might be able to deduce, my emphasis has been crew centered; additional evidence of these efforts can be found in the human operator models developed through JTCG/AS for the TAC ZINGER and P001 models, although the crew component representations have since been deleted for the ESAMS and RADGUNS upgraded models.

Having said that, let me comment on some additional walls that have been built over the years that might need "tearing down" as well; security concerns preclude me from providing the specifics. First, there is a wall between the hardware and human operator communities, and while there is a door, it is locked. This door allows the human operator community to enter the hardware community if and only if a comprehensive, validated model of

human operators is used as the "key" to enter. Lacking any entries, the hardware community will continue to estimate warhead fragment patterns out to the fourth decimal place of accuracy, launch/fire every 2 seconds because "we don't know when they would actually hit the fire button," and basically assume that it is adequate for any crew function to be implicitly represented within hardware representations.

Second, there is a wall between what we know and what we think we know. For unexplained reasons, combat experiences, exploitation efforts, crew in the loop laboratory simulations, and the results of field tests do not seem to be getting to the training, T&E, design, and M&S communities. I know there is a lag in the "system," but data and information available from the 70s is still not in places where it needs to be. Hence, when I hear of a 35+ year old system downing one of our F-16s or F-117s, I wonder if "lessons learned" from the past are in fact "observations" since nobody seems to have changed their behavior.


Third, there is a wall between the Red and Blue "operators." Everybody seems to subscribe to the notion that the most critical subsystem is the human operator, the most critical countermeasure is the crew member, and so forth. But it seems these beliefs are held for our cockpits and not the systems on the ground—the shooters.

Well, I better stop there, I could go on and on about even more walls that exist, let alone the ones that are still under construction, but it might be more productive for me to work on tearing down the walls instead. Again, thank you for an excellent article that I hope will reach the ears of those who need it most. It has given me encouragement to continue chipping away at the mortar...

Evan P. Rolek

NDIA Combat Survivability Award Winner—David Bonnesar

Editor's note: In the Spring 2000 issue of Aircraft Survivability, we omitted recognizing the recipient of NDIA's Combat Survivability Technical Award for 1999. We apologize for this oversight and are providing the following recognition in this issue.

 In November 17, 1999, the National Defense Industrial Association (NDIA), hosted their annual symposium at the Naval Postgraduate School in Monterey, California. The symposium theme for 1999 was "Aircraft Survivability 1999—Challenges for the New Millennium." At this symposium, Mr. David Bonnesar was awarded the NDIA Combat Survivability Technical Award for 1999. This prestigious award was given in recognition of Mr. Bonnesar's achievements over the past twenty years in the field of low observable (LO) mission planning. For over twenty years, Mr. Bonnesar worked for what is now known as Lockheed Martin Corporation. During this time, he was largely responsible for development of the hardware and software for the F-117 threat avoidance system, later named the Mission Data Processing System (MDPS). His primary responsibilities in the MDPS group were the design and development of mission planning technology to accommodate 3-D signature management, real-world constraints, low observable technology, vehicle performance data, and advanced optimization techniques in order to maximize the combat survivability of the F-117 Stealth Fighter. The late Mr. Ben Rich, legendary leader of Lockheed Martin's Skunk Works, talked about this achievement in his book titled, *Skunk Works*. During his last two years at Lockheed, Mr. Bonnesar contributed technical expertise to the conceptual design and development of the F-117 Offensive Combat Improvement Program (OCIP). OCIP incorporated into the F-117 aircraft a digital moving map display and a flight management system that increased pilot situational awareness and reduced pilot workload.

Mr. Bonnesar left Lockheed in June of 1989 and in 1990 founded his own company named BONN Corporation. With his new company, he has continued his work under contract to the Air Force, to optimize the F-117 aircraft's automated mission planning system. The



Lockheed F-117 Stealth Fighter. Photo by Eric Schulzinger.

F-117 was extensively employed in combat for the first time during Desert Storm demonstrating impressive combat survivability and mission effectiveness. After Desert Storm, Mr. Bonnesar continued to optimize and improve the MDPS by correcting deficiencies identified during Desert Storm. One reason for Mr. Bonnesar's success has been his commitment to involving the user in all phases of product development. In doing so, he gained a thorough understanding of the user's needs and was consequently able to deliver an operationally effective product.

Throughout his professional career, Mr. David Bonnesar has demonstrated marked creativity and innovation in developing planning and analysis tools that have increased the survivability and enhanced the mission effectiveness of the F-117 Stealth Fighter. There is little doubt that pilots operating the F-117 aircraft today have significantly improved capability for surviving combat missions as the result of Mr. Bonnesar's sustained efforts to improve their mission planning capabilities. In summary, he has devoted his professional life to supporting the Warfighter with singular success in first developing and then extending the state-of-the-art of LO mission planning. ■

Surviving Space

An Overview of Results from the Space and Air Survivability Workshop 2000

by Dr. Joel D. Williamsen

Space systems, commercial and military, are proliferating throughout the world... Indeed, so important are space systems to military operations that it is unrealistic to imagine that they will never become targets.

– U.S. Space Command Vision for 2020, February, 1997

At the core of U.S. national security strategy is a simple fact—that the U.S. has a critical need to control outer space in order to ensure U.S. battlefield dominance. Government and commercially-operated space systems (including satellites, ground stations, uplinks, and downlinks) provide essential command, control, communications, and intelligence (C3I)-gathering capa-

bilities during times of war, and enhance our economic competitiveness in times of peace.

However, with this increased dependence on space systems comes an increased vulnerability to attack (i.e., direct threats) and to the already harsh environment of space (i.e., hazards). Some of these space system hazards and threats are represented in Figure 1—note that for the most part, these early hazards can be thought of as either electromagnetic or kinetic in nature. Electromagnetic hazards include cosmic rays, solar flares, and trapped particles from the Van Allen radiation belts. Kinetic hazards include meteoroids (ice and dust particles impacting spacecraft as Earth's orbit crosses ancient comet tails at tens of kilometers per second) and atomic oxygen (molecules from Earth's extreme upper atmosphere impacting spacecraft surfaces). Electromagnetic threats can include lasers, high-powered microwaves, and radio frequency (RF) jamming. Kinetic threats include orbital debris (man-made particles crossing the orbits of satellites) and kinetic energy anti-satellite (KE-ASAT) warheads with fragments that impact spacecraft at speeds from 5 to 15 kilometers per second. These threats are similar to air combat threats in that they are often highly directional in nature (approaching generally from the front, sides, or bottom of the spacecraft), inflict predictable levels of damage to the target, and affect different spacecraft subsystems with varying levels of success.

On June 12–14, the JTCG/AS and the American Institute of Aeronautics and Astronautics (AIAA) joined together to sponsor the Space and Air Survivability Workshop at the U.S. Air Force Academy. The purposes of the workshop were (1) to summarize space environment hazards and directed threats to commercial and military spacecraft performance, (2) to discuss spacecraft survivability analysis methods, tools, and test techniques, and (3) to explore how aircraft survivability methodologies and enhancement techniques could be applied to improve spacecraft survivability. The 65 workshop attendees heard fourteen presentations from

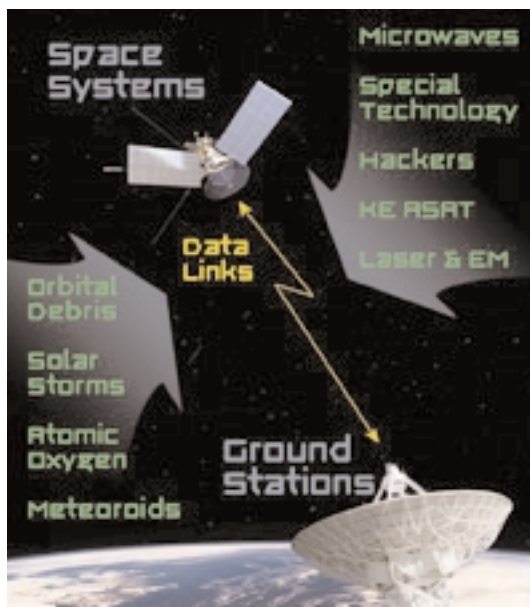


Figure 1. Space System Hazards and Directed Threats

DoD, NASA, academia, and industry on a variety of aircraft and spacecraft survivability topics, and followed these with an afternoon of workshop discussions. A summary of some of the important findings from this conference are summarized below.

Differences and Similarities in Air and Space Survivability. Satellites differ in their construction from aircraft in many ways. Spacecraft operate at longer ranges from directed threats than aircraft. They are generally less maneuverable, more fragile, and much more



Figure 2. Common Factors Affecting Space and Air Survivability

predictable in their movements over enemy territory. Because the threats to spacecraft differ significantly from aircraft, the actual target effects (i.e., the target and threat interaction, failure modes, effects of loss on the end user, etc.) differ widely between aircraft and spacecraft. However, similarities also exist. Both systems are designed to maximize performance while minimizing weight. Both have intricate and redundant guidance, power, communications, cooling, and propulsion subsystems that are distributed throughout the airframe.

Despite their differences, Figure 2 shows that we can approach space and air survivability in very similar ways. Though the nature of the threat or hazard varies, their interaction with the target and its components can be represented through a geometric model, along with their probabilities of occurrence and effects on the end user. The similarity in survivability outputs shown in Figure 3 between a high performance fighter aircraft penetrated by warhead fragments, and the International Space Station being penetrated by orbital debris is quite remarkable. In this case, the International Space Station utilized survivability analysis techniques pioneered by aircraft survivability analysts. Application of these aircraft survivability tech-

niques to other space system threats should show similar space system survivability benefits.

Commercial Spacecraft Survivability. As the Department of Defense increases its dependence on space systems for C3I (with little or no major budget increases on the horizon), it must turn to commercial space systems to provide major portions of these vital services. Commercial spacecraft have been designed with various levels of protection against the natural space environment, although their specific protection levels are often unknown to the government agency procuring their services. However, commercial providers do not design against directed threats to their systems—it is simply not part of their “business case,” and their multinational ownership makes regulation difficult. It may be possible, however, to determine the level of protection afforded by commercial spacecraft against these threats, as long as some form of compensation (tax incentives, increased user fee, etc.) and protection of proprietary data is offered to the owner/operators of these commercial space systems.

Lack of Interservice Approach to Spacecraft Survivability. Since its formation, the JTCCG/AS has been tasked with the development, validation, verification, and distribution of aircraft vulnerability models, methodologies, and test techniques for increasing the survivability of military aircraft in the combat environment that are applicable to more than one service. Sadly, this type of inter-service organization is not available to the spacecraft survivability community. The joint nature of an organization such as the JTCCG/AS may offer advantages in preventing the waste inherent in the development and proliferation of a multitude of spacecraft vulnerability models and methodologies. At the workshop, the JTCCG/AS expressed strong interest in fostering an inter-service approach to spacecraft protection analysis and test support, and in studying the applicability of aircraft vulnerability modeling techniques currently under development [such as the Advanced Joint

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Spacecraft Survivability to Kinetic

by Dr. Jeffery R. Calcaterra

The problem of spacecraft protection is quite complex and difficult to thoroughly discuss. Current spacecraft are typically not protected against intentional threats. This is not because spacecraft are easily replaceable or unimportant, but simply because there has been no active threat, and therefore no proven need for protection. There are significant hurdles that must be overcome before military satellites are designed to be as survivable as military aircraft.

In many ways there are significant parallels between the state of aircraft at the outset of World War I and the current state of spacecraft. The first biplanes were used primarily to provide reconnaissance. The primary use of spacecraft worldwide is communication, (Figure 1), but the primary advantage for the United States military is better reconnaissance.

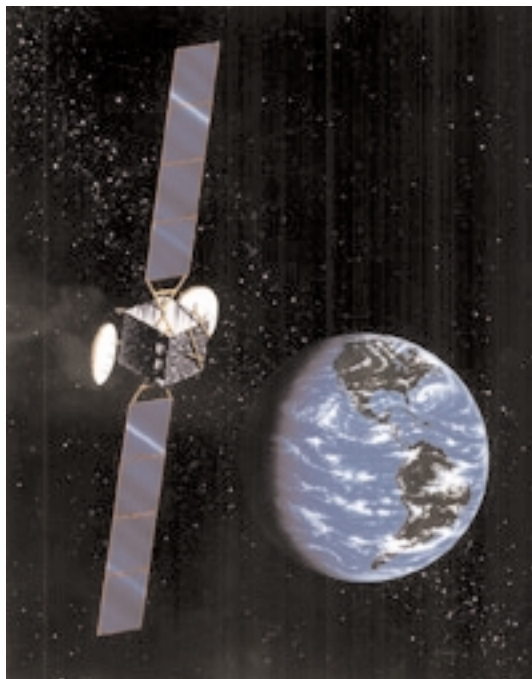


Figure 1. Galaxy IV Communication Satellite

World War I era aircraft were lightly armored simply because state-of-the-art propulsion systems of the time were barely sufficient for flight. The same can be said for modern spacecraft. Finally, the aircraft was not viewed as a primary military asset at the outset of the war. Many feel the same way about spacecraft. However, the United States has fought two wars in the past decade where space assets played a major role. The importance of spacecraft during these conflicts has helped to change the perception of spacecraft as a simple support asset.

Our enemies in the past two wars were not technologically capable of threatening spacecraft, which serves to reinforce the view of space as a sanctuary. Yet in many ways these countries never posed a significant threat to some of our air assets, and air is certainly not viewed as a sanctuary. The fact is that spacecraft threats already exist. These threats can be classified into two different categories—unintentional and intentional. In this article, the discussion will be limited to unintentional kinetic energy threats. These threats are often referred to as hazards by industry and include things like micrometeorites and man-made space debris. Kinetic energy hazards are fairly well characterized and industry designs include features that mitigate the impact of this threat. However, the United States typically does not require military satellites to be designed with features to mitigate intentional threats. The reason is that extra protection is viewed as being too costly for the perceived importance of the threat. However, there is no doubt that capable enemies who wish to deny the United States the use of space will target our assets.

The number of potential enemies with this capability is larger than most people think. According to Jane's *Intelligence Review*, there are approximately 20 countries with rocket technology mature enough to reach low-earth orbit. All of these countries could deploy a kinetic energy anti-satellite weapon in the form of an explosive warhead. This type of device could threaten spacecraft by placing small particles in a colliding orbit with a satellite. Many of these 20 countries have sufficient technology to place a kinetic energy device into low earth orbit without detonating the device. This is typi-

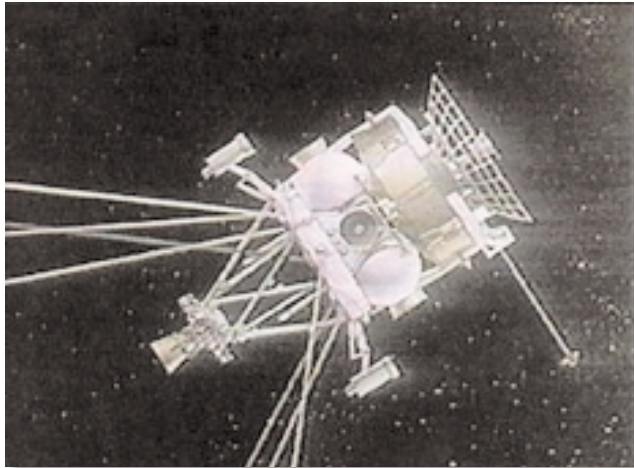


Figure 2. Notional Co-orbital Interceptor

ally referred to as a co-orbital interceptor and a notional example is shown in Figure 2.

Interceptors can maneuver to the appropriate orbit and specifically target key assets. As the number of advancing countries continues to grow, so will the threats to our assets. The question of war in space is more likely "when" than "if." The JTCG/AS has taken leadership of tri-service spacecraft protection. To ensure spacecraft superiority into the next millennium, the JTCG/AS must continue to fight for inclusion of survivability features on spacecraft and to develop novel spacecraft protection systems. With these efforts, the spacecraft survivability community will hopefully be better prepared than the aircraft survivability community was at the beginning of World War I. ■

Dr. Jeff Calcaterra is the lead spacecraft survivability engineer for the 46th Test Wing's Aerospace Survivability Flight. His responsibilities include spacecraft vulnerability analysis, warhead lethality studies and system level damage characterization. Dr. Calcaterra has extensive experience in the damage mechanics, fatigue behavior and reliability analysis of advanced materials and structures. He has authored over 20 conference and journal publications in these areas. He is the Technical Chairman for the Space and Air Survivability Workshop in June 2000. He may be reached at Jeffrey.Calcaterra@wpafb.af.mil.

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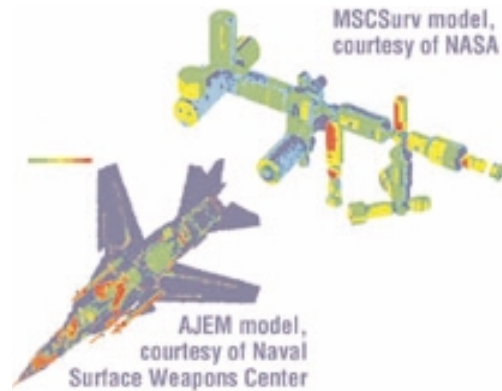


Figure 3. Similarity in air and space survivability modeling techniques. At left, a high performance aircraft is penetrated by warhead fragments. At right the International Space Station is penetrated by orbital debris particles. In both models, higher "probability of kill" areas are shown in red. Effectiveness Model (AJEM)] to selected aspects of the spacecraft survivability issue.

For those interested in further information on the results of the Space and Air Survivability Workshop 2000, please feel free to contact the University of Denver Space Survivability Web site at www.spacesurvivability.du.edu. We are looking forward to supporting the JTCG/AS and the AIAA as they continue to examine how air combat survivability methods may be applied to the benefit of space systems. ■

Dr. Joel Williamsen is currently serving as the Director of Space Systems Survivability at the University of Denver Research Institute, where his responsibilities include space vehicle survivability and lethality analyses, system simulations, hypervelocity impact testing, and damage modeling in support of NASA, Air Force, and commercial spacecraft clients. Prior to joining DRI, he was lead engineer for the design, analysis, and repair of space station meteoroid and orbital debris protective structures at NASA-Marshall Space Flight Center. Dr. Williamsen is currently serving as the secretary of AIAA Working Group for Survivability Technical Committee, and as the chairman of the AIAA Working Group for Spacecraft Survivability. He may be reached at jowillia@du.edu.

SURVIVABILITY

by Mr. Robert E. Ball and Mr. Mathias L. Kolley

Aircraft combat survivability can be defined as the capability of an aircraft to avoid or withstand a man-made hostile environment. While the concept of aircraft combat survivability is not new—going back to World War II—only in the past thirty years has it become recognized and established as a formal discipline. The driving force behind this institutionalization was the extremely heavy losses suffered by fixed and rotary wing aircraft in the Vietnam War. Initially, aircraft survivability implied survivability against man-made threats in a combat environment. While the definition of aircraft survivability has changed slightly over time to include natural as well as man-made hostile environments, the same fundamental concepts apply.

Can these concepts be extrapolated and applied to space-based systems? In an article in *Aviation Week & Space Technology*, April 12, 1999, General Richard B. Myers, commander-in-chief of the U.S. Space Command, made the following comment: “High-cost orbiting resources have become critical to national and economic security... Today, though, those space assets are vulnerable and too tempting a target for terrorism or adversarial military operations.” Given this comment, it is certainly appropriate to consider this question.

Aircraft survivability is a function of two factors—susceptibility and vulnerability. Susceptibility refers to the system's inability to avoid being hit by a threat in a hostile environment while vulnerability refers to the inability of that system to withstand the damage caused by the threat it could not avoid. Both of these factors apply to spacecraft as well as aircraft. However, when looking at space systems, the number of hostile environments (threats) increases significantly. Aircraft

threats are typically man-made—penetrators, blasts, lasers, high power microwave (HPM)—and delivered by a hostile enemy. Birds at low altitude are a notable exception. Space-based assets also face natural and man-made threats, and in greater numbers. Natural threats include meteoroids, solar storms, and atomic oxygen. Additional man-made threats include orbital debris, anti-satellite missiles (ASAT), communications links threats, such as electronic interference and electromagnetic pulse (EMP) caused by an exoatmospheric nuclear detonation, as well as ground element threats, such as terrorists attacks or sabotage.

All of the hostile environments mentioned previously—both man-made and natural—can produce varying degrees of system “kills.” Two types of aircraft kills are **attrition kill** and **mission kill**. Attrition kill results when the aircraft falls out of control within some time period after a hit due to a loss of one or more essential functions for flight (lift, thrust, control), resulting from the permanent loss of one or more critical components due to damage. Mission kill results from the loss of one or more mission critical components due to physical damage. Types of space kills also include attrition (hard) kills and mission (soft) kills. However, these kills apply to any of the components in the space system, such as the satellite itself, ground elements, or the communications links. An attrition kill occurs when the satellite or ground element is unable to perform one or more essential functions after being hit. A mission kill can occur when the satellite or ground element is unable to perform one or more essential functions during the hit because of a temporary loss of one or more mission-critical components due to the hit. This includes the loss of communications links.

Traditional aircraft survivability concepts have revolved around the reduction of aircraft susceptibility and vulnerability. Susceptibility reduction has emphasized the avoidance of being hit. Techniques and processes which have enabled this to occur include the following—

- ▶ Threat warning



It's Not Just for Aircraft Anymore

- Noise jamming and deceiving
- Signature reduction
- Expendables
- Threat suppression
- Weapons and tactics, flight performance, and crew training and proficiency

Vulnerability reduction has emphasized those techniques which provide for a “harder” aircraft. These techniques provide the aircraft with the capability to take a hit, withstand the effects of that hit, and complete its mission. Vulnerability reduction features include—

- Component redundancy, with separation
- Component location
- Passive damage suppression
- Active damage suppression
- Component shielding
- Component elimination

These same concepts can be applied to spacecraft systems. Noise jamming and deceiving apply equally well in both environments. A similar comment can be made for threat suppression. Any type of active defense can protect the on-orbit satellite as well as the ground element and communication links of the entire space system. Spacecraft susceptibility reduction can also be achieved by providing the on-orbit satellite with some type of maneuver capability (spacecraft tactics). The ability to change orbit will allow the spacecraft to avoid getting hit by large pieces of orbital debris and meteoroids and help defeat accurate foreign tracking/orbit determination. Accurate foreign tracking/orbit determination capability is one of the biggest threats to U.S. space systems. Any effective foreign space object identification program will allow a potential enemy to possibly engage in a denial and deception program. This in turn could negate the effectiveness of U.S. reconnaissance assets and result in a mission kill without attacking any of the elements in the space system.

Reducing the vulnerability of a spacecraft involves the same fundamental concepts as hardening an aircraft. Systems are developed which are more tolerant of the many and varied threat effects. Component redundancy with appropriate separation applies to both air and space systems. However, for space systems, the ability to have a constellation of satellites provides an opportunity to dramatically utilize this particular vulnerability reduction technique. Space systems are even more sensitive to weight considerations than aircraft.

Therefore, aircraft vulnerability reduction techniques such as component shielding and damage suppression typically do not extend into the space arena.

After an aircraft has been detected and taken a hit, battle damage repair is required to bring the aircraft back to an operational status. This same concept applies to spacecraft. The reconstitution of space systems is the space analog to aircraft battle damage repair. Replacing the heat protection tiles on space shuttles is a common example of the reconstitution concept. An example of an on-orbit reconstitution was the work performed by space shuttle astronauts when they corrected the “blurry vision” of the Hubble Space Telescope.

As shown above, many of the survivability concepts developed for aircraft apply to spacecraft as well. Given the increasing importance of space based assets, it is mandatory that designers of space systems apply these concepts to reduce the susceptibility and vulnerability of current space systems as well as insure the survivability of future systems. ■

Dr. Ball received his B.S. and M.S. degrees in Civil Engineering from Northwestern University in 1958 and 1959 and a Ph.D. in Structural Mechanics in 1962. He authored “The Fundamentals of Aircraft Combat Survivability Analysis and Design” and established the American Institute of Aeronautics and Astronautics (AIAA) Technical Committee on Survivability. In 1996, he was awarded the AIAA Survivability Award. He may be reached at reball@redshift.com.

Mr. Kolleck is a senior associate with Booz·Allen & Hamilton. He has 14 years experience as a Survivability/Vulnerability Engineer. For the past seven years, he has been supporting the Joint DoD/FAA Halon Replacement Program for Aviation. Mr. Kolleck earned his B.S. in Aerospace Engineering from the University of Cincinnati and his M.B.A. in Finance and M.S. in Economics from Wright State University. He may be reached at kolleck_matt@bah.com.

Directed Energy Attack on Spacecraft

by Mr. Michael Black

The possibility of directed energy attack on spacecraft has increased significantly with the commercial development of radio frequency (RF) and laser technologies. It is now within the economic and technical reach of many adversaries to develop weapons that deny and disrupt communications and imaging satellites. Directed energy could significantly affect spacecraft operations. These affects include the potential to deny operations, penetrate the satellite command uplink, insert false instructions, degrade signal-to-noise from spurious or spoofing signals, or deny an area due to dazzling or blinding. The affects depend on the attacker's capabilities and intent.

As reported in *Space News*, in an exercise recently conducted for a space-dedicated war

game sponsored by the U.S. Army, commercial satellite services were degraded or destroyed to prevent the other side from utilizing these important resources. The result of such a military conflict would be the disruption of commerce and other civilian activity dependent on commercial satellites.

Some top-level government officials recognize directed energy weapons as a potential threat to our information infrastructure. General Richard Myers, vice chairman of the Joints Chiefs of Staff, has been quoted as saying,

"Although right now space is a peaceful medium, our dependence on it and its vulnerability to evil intent make space systems all too tempting a target for terrorism or hostile military operations. We've already seen the development of satellite-blinding lasers, missiles capable of dispersing shrapnel into low-Earth orbit and GPS jammers."

CONCERNS	Air	Space	Implication
Mission duration	Hours	Years	High reliability/auto repair
Maintenance intervals	Weeks/Months	None	High reliability/auto repair
Resupply	Hours	None	Reusable rather than expendable
Vehicle trajectory	Highly Variable	Highly Stable	Short term track denial not effective
Vehicle speeds	~ 600 mph	0(GEO)-17000 (LEO) mph (Rel)	Predictable
Threat Engagement Range	Feet to 100s of miles	Feet to 10,000s of miles	Power/sensitivity drivers
Threat exposure times	Minutes to 10s of minutes	10s of minutes to continuous	Continued coverage for long periods
Threat spectrum	Some agility for modest range	Routine use of UHF	Track denial must be multispectral
Thermal profiles	-60° C to 100° C	-200° C to 200° C	Harsher extremes than airborne profiles
Vibration profiles	Continuous vibration	Launch impulse	
Radiation profiles	EMP/lighting	EMP/e/p/photon bombardment	Shielding/grounding more critical
Power availability	100s to 1000s of watts	10s to 100s of watts	Low power
Volume	Cubic feet	Cubic inches	Compact
Weight	10s to 1000s of pounds	1s to 10s of pounds	Low power
Shape	Driven by vehicle	Driven by spacecraft	Deployed shape very flexible
Number of threats	Many	Many	Focused concepts are viable
Threat knowledge	Much data	Little data	Robustness of concepts is critical
Assessment tools	Many SW/lab test assets	Some partial software tools	Reliance on technical judgement
Command and control	Mostly manned	All remote/autonomous	Command, control & communication (C3) critical

Figure 1. Air and Space Differences

Electrical Power

- Total Dose Degradation
- Neutron Degradation
- Laser Damage
- SGEMP X-ray Response

Staring Sensors

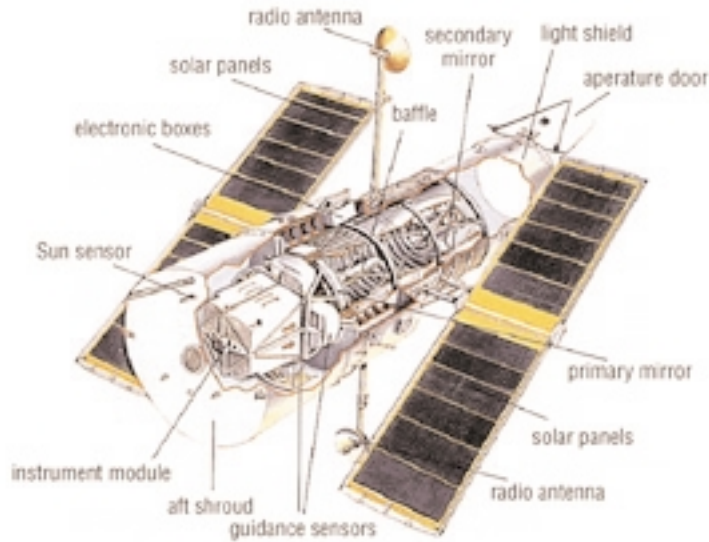
- Laser Blinding
- RF Coupling
- Dose Rate (x- & g-ray) Upset
- Total Dose Degradation

Thermal Control

- Laser Thermal Loading

Scanning Sensors

- Laser Blinding
- RF Coupling
- Dose Rate (x- & g-ray) Upset
- Total Dose Degradation



Structure

- Radiation Shielding
- SGEMP X-ray Response
- Laser Thermal Loading

Signal Processing

- Total Dose Degradation
- Neutron Degradation
- Dose Rate (x- & g-ray) Upset
- IEMP Response

Guidance & Control

- Laser Blinding
- RF Coupling
- Total Dose Degradation
- Neutron Degradation
- Dose Rate (x- & g-ray) Upset

Communications

- RF Jamming
- Nuclear-induced Scintillation

Figure 2. Satellite Systems Vulnerabilities

The methodology for aircraft survivability is virtually the same for spacecraft survivability (Figure 1). The differences in the environments change the implications for survivability. For instance, the available power, weight, and volume constraints in a spacecraft are severely limiting. Also, the inability to repair spacecraft damage, limits options for any survivability techniques utilized.

Also, potential vulnerabilities show up across a variety of subsystems (Figure 2). It is important to build multi-threat survivability and understand the effects from such threats. Making a system invulnerable to laser effects might make the spacecraft vulnerable to RF attacks. It is important to recognize that different directed energy threats attack a variety of subsystems to obtain different effects.

Commercial space assets are playing an ever-increasing role in our national economy and our national defense. Space business revenues for 1998 were estimated at 88 billion dollars and are projected to grow to 450 billion dollars by the end of 2003. Satellite communications, weather, navigation, and surveillance and reconnaissance operations have become an integral part of everyday life from Global Positioning System (GPS) receivers to weather data on the 6 o'clock news. Spacecraft have also become critical to our military's information warfare program. Due to budget constraints, the majority of the military's remote sensing

and satellite communications capabilities may soon have to be met by commercial assets. As the U.S. military increases its reliance on space as a force multiplier, threats to space assets become more inevitable.

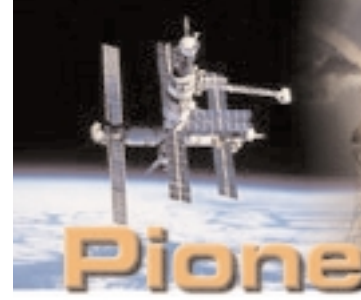
The economic dollar impact of a hostile attack on commercial satellite assets with a focus on economic disruption has not been made. In terms of military support, an attack on space information assets will help a potential adversary take away one of the important advantages we rely upon to conduct military operations. The leveling of the battlefield will result in more U.S. and allied casualties. ■

Mr. Michael Black works for Ball Aerospace as the head of the Spacecraft Protection Group in Albuquerque, New Mexico. He has been involved in developing spacecraft protection technologies to a variety of threats (nuclear, laser, RF, debris and natural). These include threat warning and attack reporting to provide threat knowledge, research and development on protection modifications to a variety of subsystems, and response modeling to calculate satellite vulnerabilities and their impact on the mission. He may be reached at mblack@ball.com.



Dr. Joel E. Williamsen

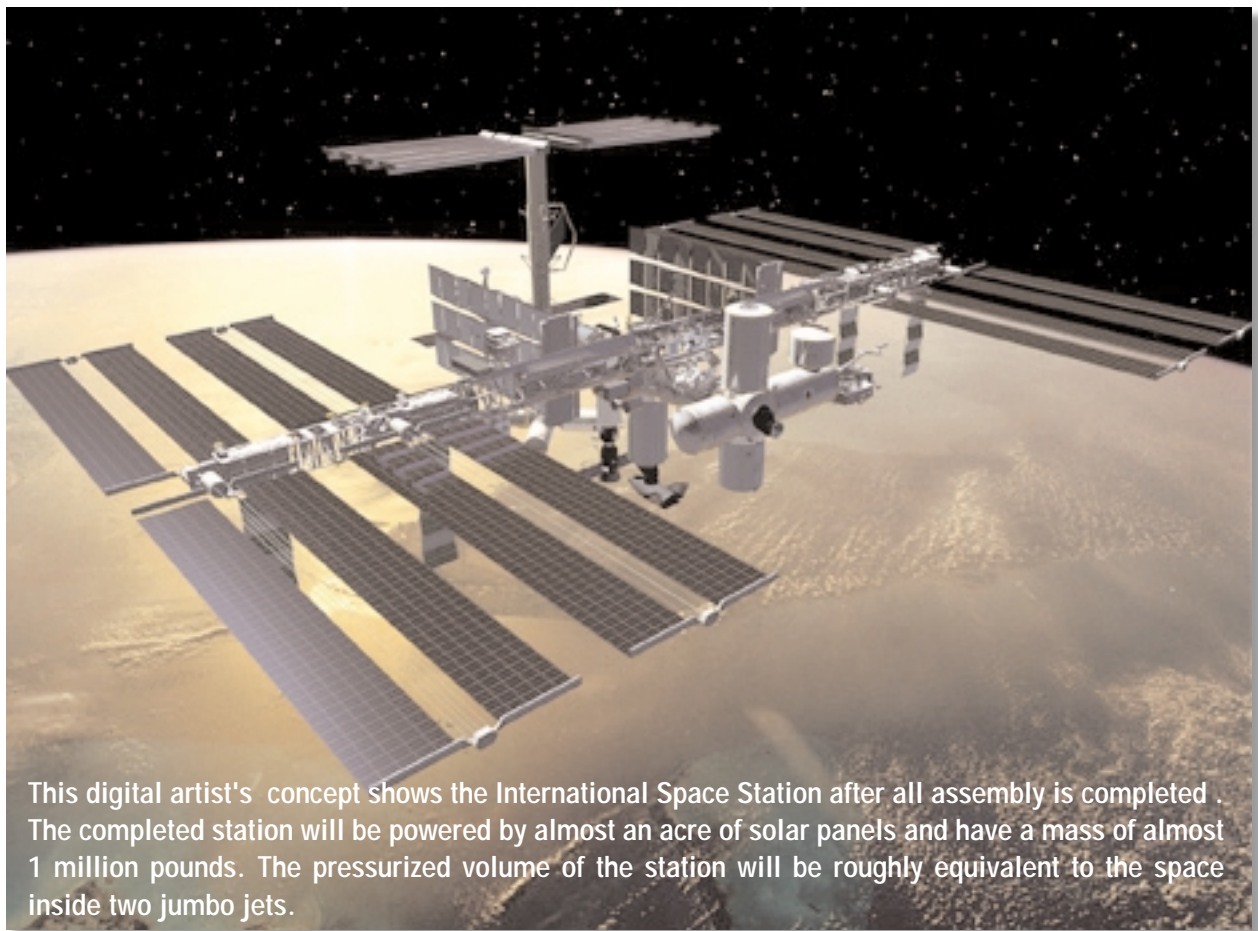
by Mr. Carl Lyday



Dr. Joel Williamsen is a pioneer in the field of manned spacecraft survivability. Thanks to Joel's work while at NASA and later at the University of Denver Research Institute, the International Space Station (ISS) crew will be in less danger from the hazards of meteoroids and orbital debris. Joel has led the way in determining the effects on the space station in the event a meteoroid or a small object in orbit should strike and penetrate one of the pressurized modules. As more and more satellites and other spacecraft have been launched over the past four decades, the flux of orbital debris has increased dramatically, presenting a severe hazard to any spacecraft in low earth orbit. The hazard increases proportionally with the size of the spacecraft and the duration of its mission. In the case of the International Space

Station (ISS), the crew modules sweep out an area of 300 square meters. This, coupled with its 15-year mission duration, substantially increases the likelihood a dangerous penetration will occur.

Dr. Williamsen developed the original version of a software tool called Manned Spacecraft & Crew Survivability (MSCSurv) for the ISS Program. This software program models and analyzes the effects on the spacecraft and crew should a penetration occur. It then evaluates how the damage to the vehicle or injury to the crew can be avoided or minimized by making changes in the spacecraft's design and/or in the crew's operational procedures. Dr. Williamsen's expertise in hypervelocity impact phenomena has been used to develop material damage models that he incorporated into MSCSurv. Since his original work, he has co-developed several subsequent versions of MSCSurv and has performed studies that have greatly enhanced ISS and ISS crew safety. For example:



This digital artist's concept shows the International Space Station after all assembly is completed. The completed station will be powered by almost an acre of solar panels and have a mass of almost 1 million pounds. The pressurized volume of the station will be roughly equivalent to the space inside two jumbo jets.



1. The thickness of the rear wall of the NASA module was increased when MSCSurv results indicated that this change would dramatically reduce the risk of critical cracking (unzipping) if the wall were to be penetrated by orbital debris.
2. Analyses using a modified MSCSurv showed that if leak detectors were strategically placed on the NASA portion of the station, millions of dollars would be saved over placing the detectors in every module, with no compromise in safety.
3. Testing showed that the hole size created by a penetration would be dramatically reduced if the Multi-layer Insulation (MLI) were relocated so that it does not lie directly against the pressure wall. This testing and analysis led to another design change that will increase ISS and crew safety.

In April of 1999, Dr. Williamsen was again called upon to support a Russian technical interchange meeting on the Russian module. Dr. Williamsen presented the results of the latest survivability calculations for the ISS and crew in the event of orbital debris penetration. His presentation provided convincing rationale that continued survivability analyses are vital to the overall safety of the ISS and its crew. Before the 1990's, orbital debris analyses did not go further than assessing the probabilities of penetration. Now, largely through the efforts of Dr. Williamsen, the space community is recognizing the value of extending this analysis to include the effects and consequences of a penetration. With the long duration and large exposed areas of ISS, penetration by orbital debris is no longer an unlikely event. Dr. Williamsen's work has contributed significantly to the reduction of risk to the mission and crew of the ISS.

Dr. Williamsen has done much to bring the aircraft and spacecraft survivability communities together. He has long been convinced that many of the survivability methodologies are similar and that much synergism would be achieved with greater interplay between the

fields. One of the biggest steps in uniting these communities was taken last June when Joel sponsored an Air and Space Survivability Workshop at the U.S. Air Force Academy, attracting over 50 people from the two fields. The excellent papers presented at that conference are available at URL <http://spacesurvivability.du.edu>.

Dr. Williamsen has authored numerous papers and holds 4 patents and 3 invention registrations involving warhead design, spacecraft shielding design and spacecraft repair. ■



Dr. Williamsen stands by the barrel of the University of Denver Research Institute's 2-stage light gas gun, which is used to fire small projectiles at hypervelocity speeds into various spacecraft materials. Results of these tests are used to design shielding to protect spacecraft against orbital debris.

Mr. Lyday has been the director of the University of Denver Research Institute since 1996. He graduated from the USAF Academy in 1965 followed by a 29-year career as a fighter pilot and experimental test pilot. In his last three years in the Air Force, Mr. Lyday was the commander of a 700-person research, development, and testing organization located at Holloman AFB, NM.

Natural Hazards of the Space Environment

by Dr. Steven W. Evans

Spacecraft in Low Earth Orbit (LEO) are subject to numerous environmental hazards. Here I'll briefly discuss three environment factors that pose acute threats to the survival of spacecraft systems and crew: atmospheric drag, impacts by meteoroids and orbital debris, and ionizing radiation.

Atmospheric drag continuously opposes the orbital motion of a satellite, causing the orbit to decay. This decay will lead to reentry if not countered by reboost maneuvers. The drag deceleration is directly proportional to the density of the thin atmosphere through which the spacecraft passes. During the maximum in the 11-year solar activity cycle, increased solar ultraviolet radiation heats the atmosphere causing it to expand and increase the density at a given altitude. Figure 1 shows solar activity during the past thirteen years.¹ The mean density at a given altitude tracks this solar activity curve. Meteoroids and orbital debris (M/OD) pose the obvious hazard of penetrating spacecraft surfaces producing—

- Damage to external and internal equipment
- Decompression of manned modules, propellant tanks and lines, and batteries
- Generation of plasma pulses that can lead to failure of electronic components not directly penetrated.

Meteoroids arrive from the zenith hemisphere, while the Earth provides shielding to the satellite from below. There are two meteoroid components: the so-called sporadics, which produce a constant background flux of particles, and the streams, which produce the meteor showers seen regularly on certain dates throughout the year. Most meteoroids are small, low-density (~1 g/cm³) objects, but they impact at high speeds—from 16 to 72 km/s—and so may have high kinetic energy.

Orbital debris is a by-product of man's activities in space, and consists of objects ranging in size from miniscule paint chips to spent rocket stages and dead satellites. As a collision threat, debris is always present, and debris objects are most likely to arrive roughly in the local horizontal plane of a satellite, with peaks in the flux distribution at about 30 to 60 degrees either side of the satellite's velocity direction, as shown in Figure 2. Debris particles are modeled as having the

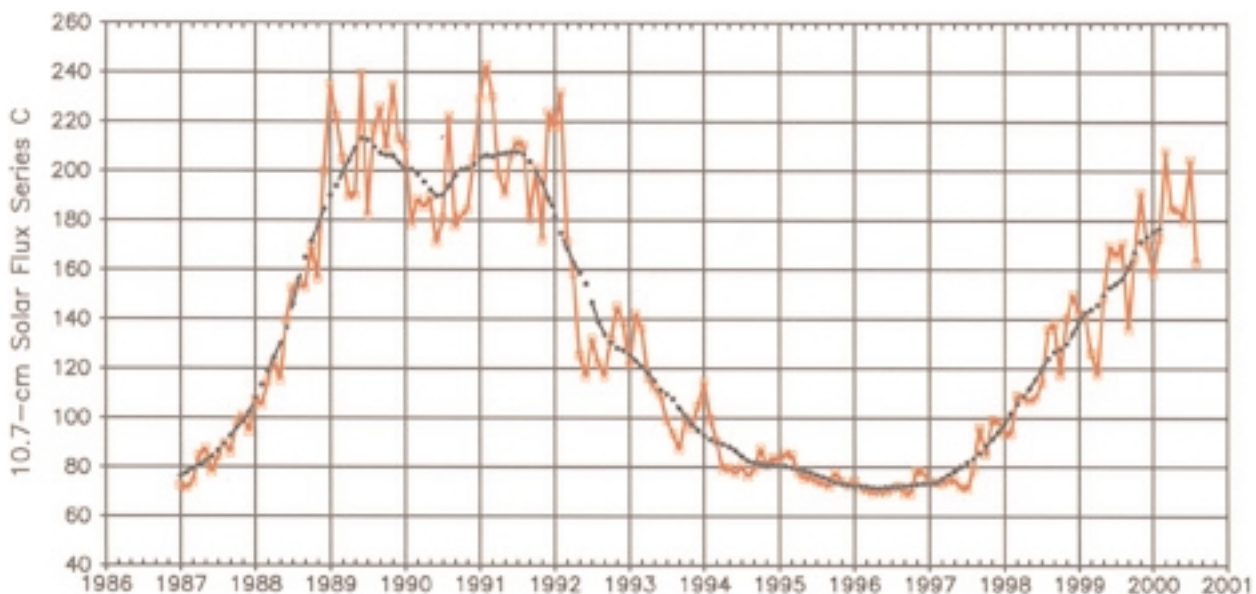


Figure 1. Monthly Mean and 13-Month Smoothed solar flux at 10.7 cm since 1987.

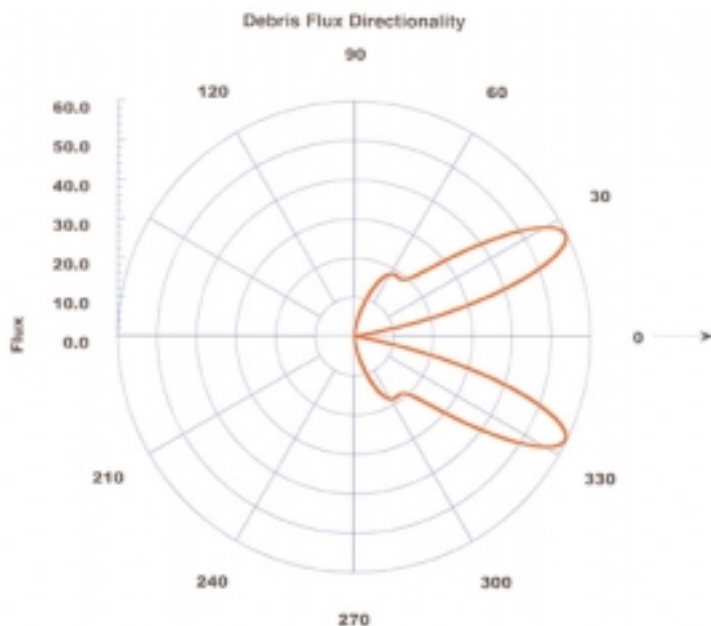


Figure 2. Orbital debris directionality: case at 51.6 degrees inclination and 400 km altitude. Zero degrees marks the satellite velocity direction.

density of aluminum, 2.7 g/cm³, and having collision velocities from 2 to 14 km/s. The spatial density of debris particles at a given altitude will vary with the atmospheric density at that altitude, and so will be a complex function of the solar activity cycle and the rate of debris introduction from above (by orbital decay) and from debris producing events, such as collisions.

The countermeasure to both meteoroids and debris is to furnish spacecraft with shields to break up the incoming particles before they can penetrate important structures. These shields may be of several types, from the simple Whipple shield—a thin “bumper” layer of metal placed at a standoff distance from a thicker back wall (a pressure vessel or component wall), to more sophisticated multi-shock blankets. Debris objects large enough to be tracked by radar (~10 cm or larger) can be avoided by propulsive maneuvers.

Ionizing radiation experienced in LEO has several components—geomagnetically trapped protons and electrons (Van Allen belts); energetic solar particles; galactic cosmic rays; and albedo neutrons. These particles can have several types of prompt harmful effects on equipment and crew, from single-event upsets, latchup, and burnout of electronics, to lethal doses to crew. Ionizing radiation is an omnipresent, omnidirectional threat, but exposures to these types of radiation will be

increased through repeated passage of the spacecraft through the South Atlantic Anomaly (a region where the trapped radiation approaches the Earth's surface more closely than elsewhere), or by solar eruptive events such as flares and coronal mass ejections (CME's). Individual flares and CME's are unpredictable, but their frequency increases during times of maximum solar activity. Countermeasures to ionizing radiation consist of providing sufficient shielding mass to attenuate the flux to sensitive components and personnel; building electronics and other equipment that has an inherently low vulnerability to radiation damage (hardening); and limiting the exposure time of crew members.

All three types of prompt threat show some dependence on the solar activity cycle. Atmospheric drag mitigation and large debris avoidance require propulsive maneuvers. M/OD and ionizing radiation require some form of shielding for crew and sensitive equipment. Limiting exposure time is a mitigation technique for ionizing radiation and meteor streams. ■

Dr. Steven W. Evans is an aerospace engineer with the Environments Group at Marshall Space Flight Center. He received his B.S. in physics (1973) and his M.A. in astronomy (1975) from the University of Texas at Austin. He earned his Ph.D. in aerospace engineering from Mississippi State University in 1991. He recently completed compilation of the environment definition document for the Next Generation Space Telescope and is the MSFC lead for meteoroid/orbital debris hazard assessment for the International Space Station. Dr. Evans represents Marshall on the Inter-Agency Space Debris Coordination Committee, an international agency tasked to coordinate orbital debris hazard mitigation/reduction efforts among space-faring nations. He may be reached at steve.evans@msfc.nasa.gov.

Endnote

1. H. Euler and S. Smith, “Future Solar Activity Estimates for Use in Prediction of Space Environmental Effects on Spacecraft,” September 2000, <http://sail.msfc.nasa.gov/nse/solar.html>.

Meteoroid & Orbital Debris Survivability & Vulnerability

by Mr. Russell Graves and Mr. Justin Kerr

The International Space Station (ISS) will be the largest man-made satellite to date upon its completion in 2006. The vehicle's surface area will be roughly 12,000 m², with a design life of 15 years. At assembly completion in 2006, it will be capable of supporting a crew of seven. An artist's rendition of the "assembly complete" configuration is shown in Figure 1.

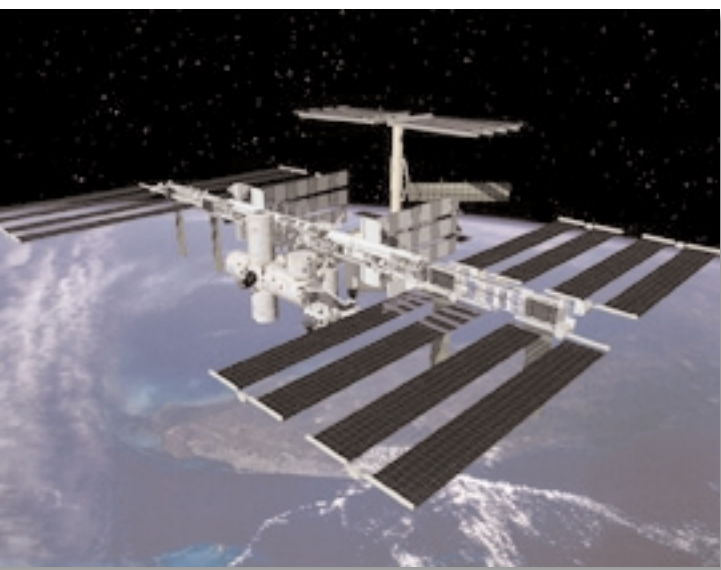


Figure 1. An artist's rendition of the "assembly complete" configuration.

Large area, extended exposure, man-rated—all of these considerations make survivability for the international space station one of the primary, if not most important design considerations. Of all of the "natural" space environments, three elements—ionizing radiation, meteoroids and orbital debris—were identified as potentially harmful threat environments. Based on specified requirements, the ionizing radiation threat could be fully mitigated by design. However, the meteoroid and orbital debris environments could not be fully mitigated by design—the result was a probabilistic requirement set for pressurized element penetration and vehicle or crew loss.

The space station program utilized the meteoroid and orbital debris (M/OD) environment models defined in NASA's document SSP 30425, *Natural Orbital Environment Guidelines for Use in Aerospace Vehicle Development*, for its shielding design. NASA has also developed an updated orbital debris environment model (ORDEM96, in NASA Technical Memorandum 104825). In the threatening particle size—nominally 1 cm diameter—the original design environment is slightly more harsh than the updated version. Figure 2 gives a description of the environment models used for space station and generalized descriptions of the associated threats.

The three probabilistic design requirements defined for space station are a Probability of No Penetration (PNP), a Probability of No Catastrophic Failure (PNCf), and a Probability of No Subcomponent Penetration (PNSP).

The PNP is a measure of the inherent penetration resistance of the spacecraft's structure to the impacts that the space station must endure during its orbital life. The space station, taken as a whole, is required to exceed a PNP of 0.76 for 10 years—that is, the probability of one or more penetrations must be less than 0.24 over this period. For the case of no penetration, the reliability equation reduces to $PNP = e^{-N}$, where N = number of perforations defined by the specified PNP. It has been formulated such that it can be specified for hardware providers with sufficient detail for hardware development. These probabilities can be assessed using the reliability function shown above, with one exception—the "expected number" of impacting particles (N) are reduced by the number that can be "filtered out" using shielding (to obtain PNP) or that would cause catastrophic loss (to obtain PNCf).

The PNCf is an assessment of the potential loss risk of the vehicle and/or one or more crew members. This measure of risk includes assessments of the effects of a penetration on the vehicle and its crew. Depressurization rates, equipment response, and crew response (per procedure as applicable) are included in this assessment.

The PNSP is assessed in the same way as the PNP. Unique failure criteria have been developed for these important, but non-critical components—such as avion-

ics cabling—that clearly do not immediately affect the crew’s safety as the result of an impact. The failure criteria for these components are typically those determined (by test and analysis) to be an impact event that would cause the assessed subcomponent to fail in providing its specified function to its subsystem. An additional probabilistic metric that has been used on the space station is the Probability of No Impact (PNI). It is identical in formulation to PNP except that the probability of impact rather than actual shield penetration criteria for particle sizes larger than a specified size is assessed. The utility of a PNI analysis is primarily a simplified bounding assessment.

This categorization among “no failure” probability requirements—PNSP, PNP, and PNCF—provides a clear distinction between a potential catastrophic loss of vehicle (PNP, PNCF) versus a level of reduced subsystem performance or reduced redundancy (PNSP)...in much the

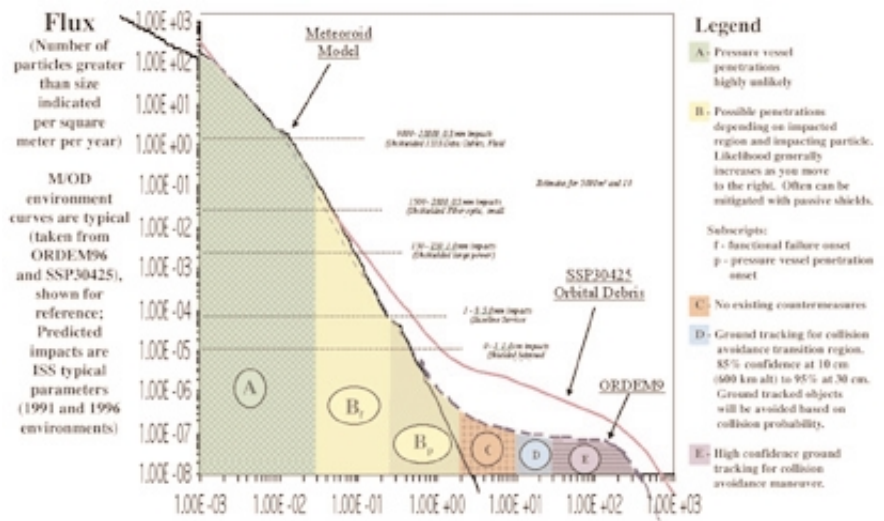


Figure 2. Comparative Orbital Debris and Meteoroid with SSP 30425 Orbital Debris Environment Shown.

same way as aircraft survivability engineers refer to Ph and Pk.

The assessment method used for space station M/OD risk determination was “analysis supported by test.” Hypervelocity impact tests were primarily utilized for the development of “ballistic limit equations.” A set of ballistic limit equations were established for each shield

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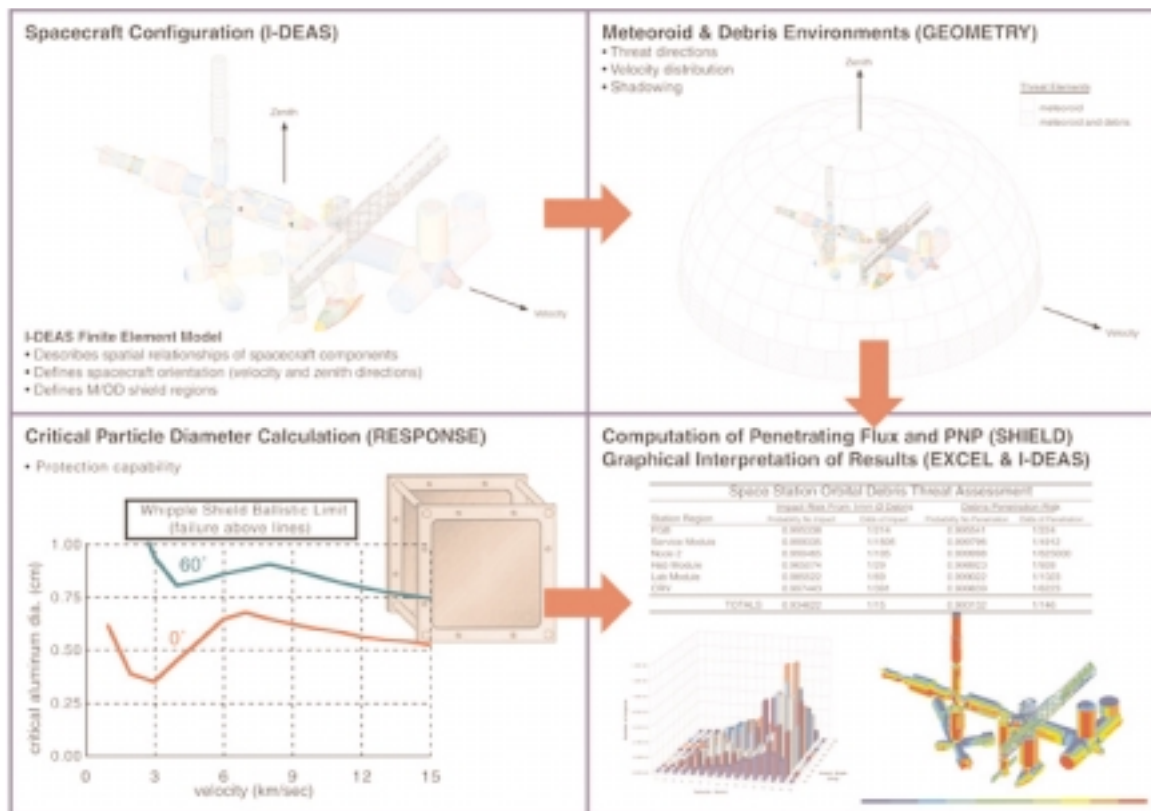


Figure 3. NASA/JSC Bumper-II Meteoroid/Debris Threat Assessment Code.

Aircraft Survivability Equipment & Avionics AAAA Symposium 2000

by Dr. Steven Messervy and Mr. Tommy Atchley



This year's Aircraft Survivability Equipment (ASE) and Avionics Army Aviation Association of America (AAAA) symposium was conducted at Fort Monmouth in Eatontown, New Jersey, 26–28 September hosted by the Fort Monmouth Chapters of the AAAA and the Association of Old Crows. This year's theme explored "Electronic Combat and Aircraft Survivability: Achieving Full Spectrum Dominance for the 21st Century."

The symposium consisted of a classified session on 26 September at the Fort Monmouth Meyer Center and two open sessions on 27–28 September at the Sheraton Eatontown Hotel. In addition to these sessions, a classified training forum specifically tailored for attending U.S. Army Electronic Warfare Officers (EWO) was conducted on the 28th at Ft. Monmouth.

The classified session focused on results of the Suite of Integrated Infrared Countermeasures (SIIRCM) testing to date. It provided a first hand look at the flight test results as well an insight to future capabilities of advanced Infrared (IR) imagery threats. The session concluded with briefings on laser technologies that will have the capability to counter advanced IR threats.

On 28 September, MG Joseph Bergantz, USA Program Executive Officer-Aviation, Redstone Arsenal, Alabama, kicked off the session with an overview of Army aviation and how ASE and avionics will enhance Army Aviation's transformation to support the Army Chief of Staff's vision of a lighter, more responsive fighting force. The remainder of the morning session provided an in-depth look at the Advanced Threat Infrared Countermeasures (ATIRCM) program, Suite of Integrated Radio Frequency Countermeasures (SIRFC) program, and advanced IR munitions, followed by an insight into Anti-Helicopter Mine Systems.

The lunch speaker was Mr. Anthony Grieco, Deputy Director for Electronic Warfare (EW), Office of the Under Secretary of Defense for Acquisition and Technology. He spoke on the current and future state of electronic warfare.

The afternoon session covered the AVR-2A laser warning system, the ASET-IV system for EW training, the evolution and skill requirements of the Electronic

Warfare Officer (EWO), and related topics. LTC Schwarz of the JTCG/AS Central Office presented a briefing on the survivability efforts funded by the JTCG/AS across all services. The session concluded with briefings on advanced laser detection technologies.

The AAAA banquet conducted on Wednesday evening featured BG Virgil "Duz" Packett, Deputy Commanding General, U.S. Army Aviation Center, Fort Rucker, Alabama as the guest speaker. He presented the Avionics and ASE Awards to Mr. Arlie Kiester from the Army Aviation Electronic Combat Project Mangers Office and LTC Jeff Crabb from the Office of the Assistant Secretary of the Army for Acquisition, Logistics, and Technology.

On the morning of September 28th, Mr. Paul Bogosian, Deputy Program Executive Office-for Army Aviation, opened the Avionics session and gave an overview of the organization and how the PEO plans to support the transformation of the Army through modernization and re-capitalization. The avionics session provided an overview of Aviation Mission Planning System, Improved Data Modem, Global Positioning System (GPS), and communications.

The luncheon address was provided by COL (P) Roger Nadeau, Deputy for Systems Acquisition-U.S. Army Aviation and Missile Command, Redstone Arsenal, Alabama. He spoke on digitization's role in supporting the Army transformation. The afternoon session provided an overview of the Common Transponder program, the Open Avionics Architecture, Horizontal Technology Insertions, and concluded with the Joint Tactical Radio System.

This years symposium clearly emphasized the vital role in which ASE and avionics must play in "Achieving Full Spectrum Dominance for the 21st Century." All the presentations may be downloaded at the Fort Monmouth AAAA Chapter Web site: www.aaaamonmouthchapter.org. ■

Dr. Steven Messervy is the Project Manager, U.S. Army Aviation Electronic Systems (AES) and Chairman of the Principal Members Steering Group of the JTCG/AS. He may be reached at 256.313.4650, E-mail messervys@peoavn.redstone.army.mil.

Tommy Atchley is a lead engineer in the Technical Management Division of the AES Project Office. He may be reached at 256.313.4441.

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configuration on the space station. Additional testing was performed with inhibited shaped charge tests (at velocities higher than we could achieve with light gas guns to further validate the established failure characteristics. The resulting ballistic limit equations were coded into Bumper-II and MSCSurv. Bumper-II was used for assessment of PNI, PNP, and PNSP. MSCSurv was used for assessment of PNCF. An overview of Bumper-II and MSCSurv is shown in Figure 3.

With the developed methodologies and installed passive shielding, the space station is being deployed with the M/OD environments sufficiently mitigated. These developed methodologies and shield techniques are now beginning to be utilized for other spacecraft applications. ■

Editor's Note: in the aircraft survivability community, PNI is somewhat analogous to probability of hit [P(hit)], PNP is analogous to probability of penetration [P(pen)], PNCF is somewhat analogous to probability of kill [(Pk)], and PNSP is somewhat analogous to probability of mission kill [P(mission kill)].

Mr. Russle Graves works for The Boeing Company. He has been responsible for passive M/OD shielding of the International Space Station to help ensure survival and reduce its vulnerability from impacts since Boeing's selection as the space station prime contractor in 1993. He is a graduate of the University of Tennessee with a M.S. in Engineering Science and Mechanics ('89) and a B.S. in Mechanical Engineering ('85). He may be reached at Russell.Graves@SW.Boeing.com.

Mr. Justin Kerr is the manager for hypervelocity impact testing at the NASA Johnson Space Center Hypervelocity Impact Technology Facility. He is also responsible for Space Shuttle meteoroid/orbital debris mission risk assessments and post mission damage reporting. He is a graduate of the The University of Texas at Austin with an M.S. in Mechanical Engineering ('95) and a B.S. in Aerospace Engineering ('93). He may be reached at 281.244.5071 or justin.h.kerr1@jsc.nasa.gov.

A Synopsis of JTTCG/AS & JLF/AS Programs

by Mr. Joe Jolley and Mr. Robert Wojciechowski

The JTTCG/AS is chartered by and reports to the Joint Aeronautical Commanders Group (JACG). In accordance with its charter, the JTTCG/AS Principal Members Steering Group (PMSG) is responsible for reviewing and approving JTTCG/AS financial and research and development plans. The Office of the Secretary of Defense, Operational Test and Evaluation, Live Fire Test and Evaluation (OSD/DOT&E/LFT&E) funds the JTTCG/AS.

To execute its responsibility, the PMSG holds an annual meeting to approve the execution of funds for the upcoming year. Before the PMSG meeting however, the three JTTCG/AS Subgroups (Vulnerability Reduction, Susceptibility Reduction and Survivability Methodology) meet to review the projects submitted by their various committee members. At that meeting, the subgroups create a program plan for presentation at the PMSG meeting where the Subgroups' proposed programs are reviewed and one final list of projects is approved for funding.

Projects funded by the JTTCG/AS are normally proposed by Service laboratory engineers who sponsor them to the JTTCG/AS through the Subgroups where they compete with other nominations for submittal to the PMSG for funding. Prerequisites for project approval include interest by more than one Service in the proposed research and that the work be non-system specific. Projects, with few exceptions, average three to four years in duration and roughly \$100-\$200K per year. The FY01 program resulted in fifty-one approved projects with funding going to five Air Force activities, two Army activities, six Navy activities and one intelligence activity. This mix of participants changes from year to year. In addition, most projects involve more than one Service activity with one engineer assigned as project engineer. Every effort is

made to leverage JTTCG/AS funding with Service funds. This process of coordination between the Services in the execution of joint research is a key benefit the JTTCG/AS organization provides the military aircraft design and acquisition community. Following is a description of some areas of investment.

Vulnerability Reduction Technology

In the area of Vulnerability Reduction, the JTTCG/AS is making a significant commitment in the area of vulnerability reduction technologies to counter the MANPADS threat. In FY00, the Advanced Survivable Rotorcraft project was initiated to identify opportunities to improve rotorcraft survivability against MANPADS. The MANPADS Threat Characterization project will provide high-quality test data for accurate threat characterization.

The Weapons Bay Ablative Protection "Proof of Concept" project is starting in FY01. It will propose a low weight combination of ablative and intumescent materials to protect the weapons bay against ballistic impacts to internally carried munitions. This project will recommend designs for weapons bay protection,



Top: Lockheed Martin's JSF lifts off on its new flight. Bottom: Boeing JSF Concept Demonstrator Completes First Flight.

based on the severity of munitions reactions and the area to be protected. It will culminate in full-scale ballistic tests with live munitions in late FY01.

The JTCG/AS has recently completed initial development and demonstration of engine computer software capable of detecting, identifying and mitigating engine damage. This technology could be considered for use in the Joint Strike Fighter (JSF) engine development program.

Susceptibility Reduction Technology

In the area of Susceptibility Reduction, the JTCG/AS is sponsoring projects to improve aircraft survivability when exposed to radio frequency (RF), electro optic (EO) and infrared (IR) tracking systems and guided threats. Projects are intended to advance the technologies that could improve pilot and flight crew situational awareness to the various threat radars, sensors, and surface-to-air and air-to-air missiles, and provide techniques to counter the threats so that they do not engage or impact the aircraft.

Projects are being funded to enhance RF jamming capability in a network centric environment. An Air Force project in wide band mode former technology is being supported by the JTCG/AS in keeping with its interest in developing RF sensors that are more accurate, and smaller in size and weight than existing sensors. The Subgroup is also supporting a Navy project to evaluate the ability to miniaturize countermeasure (CM) equipment to fit and work on unmanned air vehicles (UAVs).

MANPADS are either EO or IR guided threats. The Subgroup continues to invest in projects that attempt to determine the weaknesses of these guidance systems and to develop advanced CM techniques, both on-board and expendable, that will exploit these weaknesses.

Survivability Methodologies

The JTCG/AS has four major focus areas in survivability methodology:

Survivability Model & Simulation Credibility—

The JTCG/AS has established the Joint Accreditation Support Activity (JASA) to assess, improve and document the credibility of approved survivability models available through the Survivability/Vulnerability Information Analysis Center (SURVIAC). One particular example, the Enhanced Surface to Air Missile Simulation (ESAMS), has been identified as an impor-

tant simulation for both the operational and acquisition communities. An ESAMS Cooperative Assessment Team, which includes JASA representatives, has been appointed to investigate and report on its credibility.

Transition to a New Modeling Architecture—

The Joint Modeling and Simulation System (JMASS) is a new architecture for engagement-level models. The JTCG/AS is supporting migration of legacy models into the JMASS architecture. The long-term distribution and configuration management of JMASS models is also of interest to the JTCG/AS.

Fielding a New Physics-Based Ballistic Vulnerability Simulation—

The JTCG/AS, in cooperation with the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME) and the Army Research Laboratory, has developed a new physics-based simulation to assess the vulnerability of a wide range of targets as well as the lethality of many types of munitions. The Advanced Joint Effectiveness Model (AJEM) has the capability to calculate damage effects on a target system and determine the impact of that damage on the ability of the system to function. The current method of aggregating results of engagement models for use in mission and campaign simulations is inadequate to make design trade-offs between survivability enhancement features.

Developing an integrated survivability assessment process—

The JTCG/AS is investigating approaches for developing an Integrated Survivability Assessment process to allow for balanced and robust modeling and simulation across the survivability spectrum at the engagement, mission and campaign levels.

Joint Live Fire Air Systems (JLF/AS)

In addition to its role as advocate for aircraft combat survivability, the JTCG/AS active-



A sequence taken from an IR video camera of this year's Joint Live Fire test at China Lake, California, where a foreign (shoulder-fired IR) missile was fired into an F-16. Sequence from left to right: Missile plume behind aircraft engine plume, missile plume with the missile nearly at impact, and detonation of the warhead.



Another sequence taken from a conventional camera. Missile warhead detonates and then two more exposures in that sequence. These photographs were taken by the light of the detonation (at night).

ly participates in the air portion of the Joint Live Fire (JLF) program under OSD/DOT&E.

The Joint Live Fire Air Systems (JLF/AS) program was first chartered in 1984 and has as its objective the conduct of full-up system-level testing of fielded U.S. and foreign air-system platforms and aircraft munitions. During FY00, the JLF program funded vulnerability tests on the F-14 Tomcat, the F-16 Fighting Falcon, the CH-47D Chinook, and the C-130 E/H Hercules. In addition to these full-scale tests, the JLF program also funded comparative testing of fuel tank filler technologies that may reduce the vulnerability of aircraft to ullage fires and explosions.

The JLF Air program has contributed significantly to the understanding of damage inflicted to aircraft as a result of a MANPADS impact (other threat types as well). Whereas the

JTCG/AS focuses on emerging technologies to reduce the vulnerability and susceptibility to MANPADS, the JLF Air program concentrates its resources on the conduct of full-scale, realistic testing of MANPADS threats versus aircraft platforms. One such test conducted during FY00 consisted of a MANPADS launch (conducted as a training exercise for U.S. Marines) at a realistic engagement range against an operating (static, tower mounted) F-16 aircraft. This dynamic test resulted in an increased awareness of the types of damage that can be expected from a MANPADS hit. Additionally, this test also provided a real-world opportunity for the U.S. Air Force's Aircraft Battle Damage Repair team to hone their skills. This type of testing is the hallmark of the JLF Air Systems Program.

Both the JTCG/AS and the JLF Air Systems Programs solicit proposals for new projects each year that compete for funding. This has been a brief overview to cover

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Battle Damage Assessment and Repair (BDAR)

by Mr. Richard Jackson

Since its inception in the early 1980s, the U.S. Army Aviation Logistics School (USAALS) has participated in Battle Damage Assessment and Repair (BDAR). Initially, the USAALS participated with the Aviation Applied Technology Directorate (AATD) research and development programs for the development of BDAR procedures, technical manuals, and kits. The school has always provided BDAR instruction to aviation basic noncommissioned officers and aviation maintenance technicians.

In 1996, the Office of the Secretary of Defense, Live Fire Test and Evaluation (OSD, LFT&E) invited USAALS to participate in their AH-1 live fire test at China Lake, California. The purpose of the test was to characterize damage from a ballistic impact on a dynamically loaded rotorcraft blade as well as to demonstrate the test methodology. The USAALS formed a BDAR team with representatives from the USAALS, the Ordnance School, and the Corpus Christi Army Depot. The USAF provided personnel from Robins Air Force Base, Georgia, McClellan Air Force Base, California, and Hulburt Field, Florida. Initially the China Lake Weapons Station personnel briefed their test plans and their accomplishments to date. Worth noting is the fact



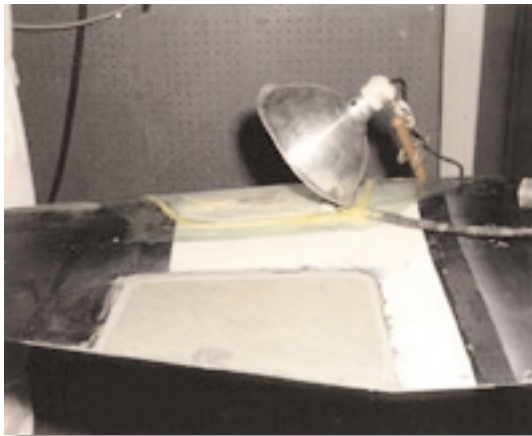
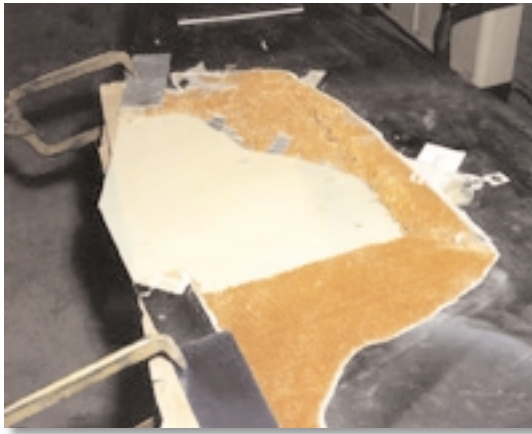
Figure 1. Blade number one had damage to the trailing edge of 19x24 inch at BS 205 to 239. This blade was repaired using standard blade repair materials. The blade was operated on the test helicopter for 30 minutes with no excessive vibrations.



Figure 2. Blade number two had damage to the leading and trailing edges. Damage to the leading edge spar was located at BS 227 to 232. This damage was repaired with non-standard material, as there is no doctrinal/approved SPAR damage repairs. This blade also had damage to the trailing edge at BS 227.5 to 232.5, seven inches deep. The damage was repaired by forming a basil wood plug and sealing the hole with adhesives. The blade was operated on the test helicopter for 30 minutes with no excessive vibrations.

that no blade design engineers participated in the assessment. Live fire was then conducted on AH-1 helicopters.

After the test, the BDAR team's initial assessment was that of the nine blades damaged by the 11 shots fired, none were repairable in a conventional sense. However, their assessment was that two of the blades were repairable using BDAR procedures. The procedures and materials used to repair the damage were limited to materials available in a combat situation. A successful BDAR was defined as "returning the helicopter to mission capable status for 100 flight hours or until a permanent repair can be accomplished, whichever occurs first." The team selected two blades to be repaired.



In addition to the BDAR repairs, a third blade set—blade number three/four—were simulated to be from a helicopter recover procedure. Thirty one inches were cut off the end of each blade. The exposed surfaces (blade tips) were then taped using “hundred mile an hour tape.” These blades were operated on the test helicopter for 30 minutes within the operating envelope of a 9000 pound AH-1 with no excessive vibrations.

USAALS personnel then participated in the follow-on test for the AH-1 power train system. The USAALS BDAR team accomplished BDAR repair to drive shafts, intermediate gearboxes, tail rotor gear boxes and transmission components. Some of these components had been damaged twice, but were successfully repaired. The repaired components were then operated on the test helicopter for 30 minutes with no excessive vibration or leakage.

The repairs developed by this team were not approved by an aeronautical engineer or depot level personnel and, therefore are not appropriate for use on any U.S. Army aircraft.

USAALS continues to participate in the live fire program by providing support to the Army Research Laboratory at Aberdeen Proving Grounds, Maryland as they conduct live fire tests on the AH-1, OH-58D, CH-47F, RAH-66, AH-64, and UH-60M helicopters. The USAALS role in this program is to determine the extent of damage and recommend a BDAR repair. Listed below are a few examples of the damage we have assessed for BDAR repair in the past two years—

- Evaluated damage to the AH-1 power train drive shafts—determined repairable.
- Evaluated the OH-58D main rotor blades for damage by using the latest nondestructive test equipment (x-ray, bond master). The damage to these blades was to the main SPAR—determined non-repairable.
- Evaluated damage to RAH-66 structure in the tail section—determined repairable.
- Evaluated damage to CH-47F fuel lines and components—determined repairable using BDAR fuel cell repair kit.

The highlight of USAALS participation in this program occurred in October 2000, when the USAALS provided 13 advanced individual training (AIT) soldiers to provide BDAR support for the CH-47F Live Fire Program. As their situational training exercise, these 68G military occupation skill (68-G structural repair)

calendar of events

FEBRUARY

12-15 — Reno, NV

Modeling and Simulation, Acquisition,
Testing and Evaluation

Contact: 760.939.8474, Dave Hall

MARCH

13-15 — San Diego, CA

EW and SA for Survivability Symposium
and Expo

Sponsored by NAVAIR, EWAT

Contact: assenmachtetj@navair.navy.mil
301.342.0026

26-29 — Long Beach, CA

NDIA National summit on Defense
Acquisition and RDT&E

Sponsored by NDIA

Contact: Sam Campagna, 703.247.2544
R. Seymour, 703.614.3991

APRIL

30-3 May — Dayton, OH

JMASS Customer's Conference

Contact: 937.255.4840, Donna Egner, SURVIAC

JUNE

12-15 — Colorado Springs, CO

JMUM 2001

Contact: 937.255.4840, Donna Egner, SURVIAC

soldiers accomplished battle damage repair to the CH-47F structure and fuel cells, post live fire. This was the first use of the AIT soldiers in a BDAR program. The AIT students were able to apply their training skills and knowledge while the USAALS and the Army demonstrated their least experienced 68G soldiers could successfully accomplish BDAR procedures.

The Live Fire Program benefits DoD, the U.S. Army, and the USAALS. All agencies reap the benefit of applying and testing current systems against live fire. Additionally, doctrinal BDAR techniques are tested and verified and USAALS instructors and students receive invaluable hands-on experience. ■

Mr. Jackson is the Deputy Director, Department of Aviation Trades Training, United States Army Aviation Logistics School. He has 39 years of aviation maintenance experience. He has been working with BDAR for more than 20 years to include 26 months in Vietnam.

JTCG/AS and JSF/AS Programs

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some of the projects in which the JTCG/AS and JLF/AS invest their resources. If you would like more detailed information about specific projects being funded, please contact Mr. Joe Jolley at the JTCG/AS Central Office at 703.607.3509 ext. 14 or E-mail jolleyjp@navair.navy.mil. For JLF/AS assistance, please call Mr. Robert Wojciechowski at the Office of the Secretary of Defense, 703.6143991 or E-mail rwojciechowski@dote.osd.mil. ■

Mr. Jolley is the Deputy Director of the JTCG/AS Central Office and the Army Civilian representative. He may be reached at jolleyjp@navair.navy.mil or 703.607.3509, extension 14.

Mr. Wojciechowski became a member of the permanent staff in office of the Director, Operational Test and Evaluation, Office of the Secretary of Defense in January 2000. His primary duties include mission area coordinator for Live Fire Testing of air systems and anti-air weapons, DOT&E representative for the Joint Technical Coordination Group for Aircraft Survivability (JTCG/AS) and Joint Live Fire (JLF) Air Systems, and serving as a member of the executive board for the NDIA Combat Survivability Division. He can be reached at 703.614.3991 or wojo@dote.osd.mil.

Information for inclusion in the
Calendar of Events may be sent to:

SURVIAC
Washington Satellite Office
Attn: Christina McNemar
3190 Fairview Park Drive, 9th Floor
Falls Church, VA 22042
PHONE: 703.289.5464
FAX: 703.289.5467

12-15 February 2001, Reno, NV

Assuring M&S Credibility for Defense Acquisition and T&E

Survivability, Lethality and System Effectiveness



<http://www.nawcwpns.navy.mil/~jasa>

*A Workshop Sponsored by JTCG/AS and JTCG/ME
in Cooperation with DOT&E and NDIA*



Who Should Attend—Senior Executives from Government & Industry responsible for system acquisition programs, Acquisition Program Managers using M&S to support program milestones, Government & Industry Analysts concerned with M&S use in system acquisition, T&E professionals concerned with M&S in use in T&E.

Survivability, lethality and mission effectiveness models and simulations (M&S) form a core of support to acquisition program milestones. Heavy reliance on M&S has resulted in an ever-increasing emphasis on the ability to demonstrate their credibility. Recent studies have shown, however, that DoD and Service M&S initiatives neither

provide for long-term support of these critical M&S, nor assessment of their credibility. This workshop will identify the unique problems faced by acquisition programs using these M&S and explore potential solutions to these problems. The program is divided into three sessions with an optional tutorial on Monday afternoon—

- 12 Feb—Tutorial: Lessons Learned in M&S Credibility for Acquisition Programs
- 13 Feb—Session I: OSD View of M&S Use in Acquisition
- 14 Feb—Session II: Acquisition Program View
- 15 Feb—Session III: Test & Evaluation Community View

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