

Published by the Joint Technical Coordinating Group on Aircraft Survivability

# AIRCRAFT SURVIVABILITY



Summer 2000

## Live Fire Test & Evaluation

Advancing Warfighter  
and Aircraft Survivability



# Report Documentation Page

Form Approved  
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE <b>2000</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-2000 to 00-00-2000</b>	
4. TITLE AND SUBTITLE <b>Aircraft Survivability: Live Fire Test &amp; Evaluation, Summer 2000</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>JAS Program Office, 200 12th Street South, Crystal Gateway #4, Suite 1103, Arlington, VA, 22202</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			



*Aircraft Survivability* is published three times a year in the Spring, Summer, and Fall by the Joint Technical Coordinating Group on Aircraft Survivability (JTCCG/AS). The JTCCG/AS is chartered by the Joint Aeronautical Commanders Group.

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**About the cover:**

Photographs (clockwise) top: V22 Osprey tiltrotorcraft, CH-47F Chinook, a replica C-130J wing leading edge dry bay test without fire extinguishing agent (baseline test), and F/A-18E ullage explosion in fuel tank 1.

# Contents

<b>DOT&amp;E Support for Survivability Testing and Evaluation</b>	4
<i>by Mr. Philip E. Coyle III</i>	
<b>Tearing the Walls Down to Achieve Greater Aircraft Survivability</b>	7
<i>by Mr. James F. O'Bryon</i>	
<b>V-22 Aircraft Battle Damage Repair</b>	12
<i>by Mr. Bob Matthews</i>	
<b>C-130J Live Fire Test &amp; Evaluation</b>	14
<i>by Mr. John J. Murphy and Mr. John M. Vice</i>	
<b>F/A-18E/F Aircraft Live Fire Testing Program</b>	16
<i>by Mr. J. Hardy Tyson</i>	
<b>National Live Fire Test and Evaluation Workshop</b>	18
<i>by Mr. Tracy V. Sheppard</i>	
<b>Aircraft Crew Casualty Issues</b>	19
<i>by Dr. Lowell H. Tonnessen</i>	
<b>CH-47F Chinook (Improved Cargo Helicopter) Live Fire Test and Evaluation</b>	22
<i>by Mr. Dennis S. Lindell</i>	
<b>Advanced Joint Effectiveness Model</b>	24
<i>by Mr. Thomas L. Wasmund</i>	
<b>Pioneers of Survivability: Donald J. "Jerry" Wallick</b>	26
<i>by Mr. Dale B. Atkinson</i>	
<b>Professor Ball Receives Art Stein Award</b>	30
<i>by Mr. Dale B. Atkinson</i>	
<b>Calendar</b>	32

# Editor's Notes

If you are a fan of Live Fire Test and Evaluation (LFT&E), you should enjoy this Summer issue of *Aircraft Survivability*. We are fortunate to have Mr. Philip E. Coyle III, Director, Operational Test and Evaluation, Office of the Secretary of Defense, share his views on aircraft survivability. His words are more than informative—Mr. Coyle challenges the survivability community and the JTTCG/AS and ME, in particular, to take action in several key areas.

Following Mr. Coyle's article is an interestingly written article by Mr. James O'Bryon, Deputy Director under Mr. Coyle responsible for LFT&E. Mr. O'Bryon's article enumerates eight major areas where the survivability community can improve its working relationship with other disciplines to the ultimate benefit of the warfighter. Mr. O'Bryon's office has funding and technical oversight of the JTTCG/AS.

Following the two lead articles are a series of four informative articles written by the senior survivability engineers responsible for conducting recent LFT programs. The authors describe highlights of LFT on the F/A-18E/F, V-22, CH47, and C-130 aircraft.

Dr. Lowell Tonnessen then provides a thought-provoking article that poses several questions on aircraft crew survivability issues—or "user" survivability as he identifies it.

To round out this issue, you will find three articles, one on the status of the Advanced Joint Effectiveness Model (AJEM) that is planned for release within the next few weeks, an overview of the recent National LFT Conference held last May in Austin, Texas, and our Pioneer in Survivability article, recognizing Mr. Jerry Wallick.

One final note, for the past year, the JTTCG/AS has supported, both financially and through its network of survivability experts from all services, the Joint Test and Evaluation (JTE) nomination titled, Joint Aircraft Survivability to MANPADS (JASMAN). The Air Force is lead service for this JTE. Mr. Ralph Lauzze, Dr. Kristina Langer and Major Robert Mann are the team leaders responsible for JASMAN. On 13 July 2000, after many weeks of preparation and briefings to senior level Defense Department officials, JASMAN passed a major hurdle when it was approved by the JTE Program Senior Advisory Council (SAC), to proceed to the Joint Feasibility Study (JFS) phase. For the next year, JASMAN will work to further define the specific joint test plans and objectives prior to

being considered for Chartering as a Joint Test and Evaluation program. The JTTCG/AS plans to continue its support to JASMAN.

As always, we welcome your comments or feedback related to the articles or the newsletter in general. Our E-mail address is on the inside front cover.



## AIAA Survivability Award for 2000 Presented to Jerry Wallick

The American Institute of Aeronautics and Astronautics (AIAA) 2000 Survivability Award was presented to D. Jerry Wallick for pioneering efforts in the development of survivability as a design discipline, including battle damage assessment and repair (BDAR), and their application to the A-10 and other combat aircraft designs. The AIAA Survivability Award is presented biennially to an individual or a team to recognize outstanding achievement or contribution in design, analysis, implementation, and/or education of survivability in an aerospace system. Mr. Wallick has made major contributions to the establishment of survivability as a design discipline for over 30 years, in both government and industry positions. The award was presented on April 4, 2000, at a National AIAA meeting in Atlanta, Georgia. The JTTCG/AS congratulates Jerry on this outstanding achievement and is pleased to highlight him as one of the Survivability Pioneers in this issue.

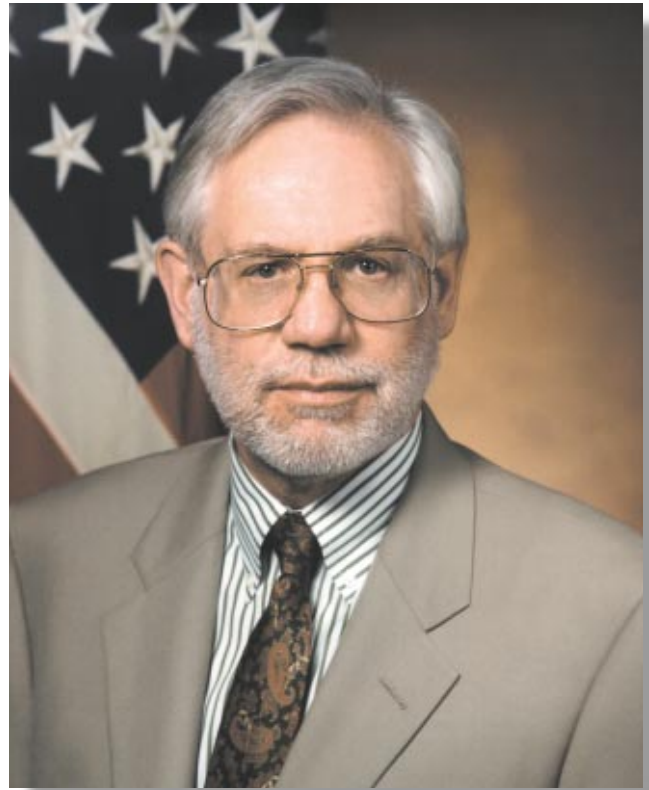
# DOT&E Support for Survivability Testing and Evaluation

by Mr. Philip E. Coyle III

I appreciate the opportunity to present my views regarding aircraft survivability and the new relationship between my office and the Joint Technical Coordinating Group on Aircraft Survivability (JTCCG/AS). In June 1999, the Secretary of Defense approved a reorganization of test and evaluation within the Office of the Secretary of Defense (OSD). We are pleased to have been assigned the responsibility for sponsorship and oversight of the JTCCG/AS and of the JTCCG for Munitions Effectiveness (JTCCG/ME). In addition, the Secretary transferred the preponderance of test and evaluation functions and resources to my office, including stewardship of the Services' test ranges and facilities, test investment, and sponsorship of other test-related programs. This reorganization will dramatically improve the ability of my office to address the declining state of test and evaluation capability in the Department of Defense (DoD), and to strengthen survivability test and evaluation.

A key role for my office is to provide oversight for the Operational Test and Evaluation (OT&E) and the Live Fire Test and Evaluation (LFT&E) programs. In fiscal year 1999 (FY99), my office provided oversight for 210 programs, including 80 with LFT&E. Most of these programs have involved test and evaluation for survivability and/or lethality. These activities are closely related to the missions of the JTCCG organizations. Consequently, it is appropriate and advantageous for our office to assume the stewardship of the JTCCGs. Even though a primary motivation for the changes was to streamline test and evaluation activities within OSD, we see the new organization as an opportunity to achieve a closer working relationship with the JTCCGs. The JTCCG organizations have had a long, productive history, and we look forward to working with them.

Among the JTCCG/AS accomplishments that I find particularly noteworthy is the establish-



**Mr. Coyle is the principal advisor to the Secretary of Defense and the Under Secretary of Defense for Acquisition and Technology on operational test and evaluation in the DoD.**

ment of survivability as a design discipline. The survivability methodology, models, textbook, design standards, handbooks, and short courses sponsored by JTCCG/AS have had a profound impact on the survivability of today's aircraft and those we are developing for the future. I also am impressed by JTCCG/AS contributions to the development of countermeasures and vulnerability reduction features. JTCCG/AS has, in my opinion, successfully coordinated the activities of the small survivability communities in each Service to achieve much more than the Services would have achieved on their own. It also has provided some degree of stability during Service budget fluctuations.

One of the biggest challenges facing us is to improve aircraft survivability in the low altitude battle space. Today, the battle space considered "low altitude" is large and growing larger with the proliferation of a more

capable generation of man-portable air defense systems (MANPADS) and other air defense weapons. We will continue to require operations in this battle space for identification of friend-or-foe, targeting, accurate battle damage assessment, minimization of collateral damage, combat search and rescue, and even the mission to destroy these more capable MANPADS weapons. Our ground forces also rely on rotary wing aircraft for support during their operations. We will not be able to avoid operating in this battle space. Due to the relatively close engagement conditions, susceptibility reduction, defensive systems, and tactics alone are not able to adequately achieve the desired level of survivability for our aviation forces.

At the JTCCG/AS Principal Members Steering Group meeting in January 2000, Mr. James O'Bryon, Deputy Director, OT&E (Live Fire Testing), articulated our goals in the oversight of JTCCG/AS. I would like to highlight these goals. We plan to—

- Work with the JTCCGs to develop a common vision and to implement new plans and priorities in our ever-changing defense environment
- Participate with the JTCCG/AS in its annual strategic planning exercises
- Be a strong advocate for the JTCCGs before the Congress and DoD
- Energize the Operational Users Group to assure that JTCCG/AS efforts and products are focused on the warfighter as the end user
- Ensure that models and simulations promulgated by the JTCCGs are representative of reality, and if they are not, publish limitations and correct flaws
- Invigorate the Survivability/Lethality Information Analysis Center (SURVIAC) charter to capture combat and accident/incident data
- Expand JTCCG/AS activities into space system survivability
- Gain broad access to the testing and training data being generated throughout DoD
- Place greater emphasis on evaluating and reducing aircraft user casualties
- Broaden survivability assessments to include less traditional emerging threats
- Examine commercial aircraft vulnerabilities to selected threats in coordination with the Federal Aviation Administration.

For several years, my annual reports to the Congress have highlighted the needs of test and evaluation centers and test ranges across the country. In my FY99 annual report to the Congress, I called attention to the fact that we have been developing new technologies for weapons but have not funded research and development of testing technologies. I am hopeful that the JTCCGs will develop new test techniques and methods to address the testing challenges imposed by new weapons technology and the challenges imposed by the need to make test and evaluation more realistic with fewer resources. To illustrate, I would like to offer two examples.

The JTCCG/AS and the Joint Live Fire (JLF) program, in coordinated efforts, have taken on the challenge of developing methods for realistically and economically testing aircraft vulnerability to MANPADS weapons. The MANPADS threat has proliferated extensively and has not been adequately reflected in survivability requirements or adequately addressed in test and evaluation. Over the past few years, JTCCG/AS and JLF have initiated additional efforts to rectify this situation, as reported in the Summer 1999 edition of *Aircraft Survivability*. Among these efforts is an investigation of various methods for testing MANPADS, including free flight, sled tracks, and gas gun. My office expects to use the results of these investigations to make recommendations to acquisition programs concerning the best ways to test aircraft vulnerability to MANPADS. Without this information, program managers will not have the tools they need to perform realistic tests against MANPADS and might risk destroying a valuable test article without capturing the required data.

As a second example, the concept of full-up, system-level testing was developed in conjunction with ground vehicle vulnerability testing to achieve greater realism. The Congress always envisioned that the Live Fire Test legislation would apply to aircraft vulnerability testing. However, initial attempts were frustrated because such testing was deemed too expensive and impractical. Even though

LFT&E began in the mid-1980s, the first fixed-wing aircraft program was not completed until 1995 (the C-17). We have since completed LFT&E on the B-1 and the F/A-18E/F. All three of these aircraft had received waivers from full-up, system-level testing, which allowed them to conduct their Live Fire programs on less realistic test articles. However, during this period, the state of the art has evolved to the point where the next new aircraft, the Joint Strike Fighter (JSF), will undergo full-up, system-level testing. The V-22, F/A-18E/F, and F-22 LFT&E programs demonstrated that the costs of LFT can be greatly reduced through multiple use of test articles; that is, test articles built and tested for other purposes can be effectively used to obtain live fire data. The V-22 and F/A-18E/F LFT programs went beyond testing individual components to testing more extensive articles and demonstrated that there is much to be learned from such tests. The new technology and integrated systems on the JSF require full-up, system-level testing. Testing JSF vulnerability to the MANPADS threat also will require large test articles. The JSF program is taking advantage of the experience on these earlier programs by including in its planning the use of a flight test vehicle for full-up, system-level LFT after its flight testing is complete. I am asking the JTCG/AS and JLF to investigate and recommend methods for realistically and efficiently testing the vulnerability of the JSF in the full-up, system-level tests.

We currently address vulnerability and susceptibility in a somewhat disjointed manner. I believe we need a more integrated approach to these two elements of survivability. For example, susceptibility is often determined in one set of tests and vulnerability, "given a hit" is determined in a separate set of tests. In some cases, the disjointedness allows important factors (such as fuzing, and a realistic distribution of impact points and impact angles) to fall through the cracks. We should strive toward more integrated approaches for testing and evaluation of survivability. As a further example, current high-level mission and campaign models treat susceptibility and vulnerability in



a gross, aggregate manner, often with unequal resolution. As a result, the models may underestimate the benefits of survivability features in cost-benefit and trade-off studies, making it difficult for these features to "buy their way" onto the aircraft. The unequal treatment of susceptibility and vulnerability reduction features in the models can also lead to designs that do not have a robust combination of susceptibility and vulnerability reduction features.

At times, survivability has taken a back seat to other performance considerations. Some designs have relied heavily on either low observability, countermeasures, or vulnerability reduction alone, rather than a robust combination of the three. In this age, where we intend to attain virtually zero casualties, we must renew our efforts to achieve high levels of survivability through more balanced designs and the application of new technology while working within budgetary constraints. I believe that realistic test and evaluation is important to achieving this goal. JTCG/AS has played an important role in aircraft survivability in the past, and I expect it will have an even greater impact in the future. I look forward to working with JTCG/AS to make it so.

*Mr. Philip Coyle was confirmed by the Senate as the Director, Operational Test and Evaluation (DOT&E), in the Department of Defense (DoD) on September 29, 1994. In this capacity, he is the principal advisor to the Secretary of Defense and the Under Secretary of Defense for Acquisition and Technology on operational test and evaluation in the DoD. Mr. Coyle is the principal operational test official within the senior management of the DoD. Mr. Coyle has 20 years experience in testing and test-related matters. Mr. Coyle graduated from Dartmouth College with a B.A. (1956) and an M.S. in Mechanical Engineering (1957).*

# Tearing the Walls Down to Achieve Greater Aircraft Survivability

by Mr. James F. O'Bryon

Exactly 13 years ago today,\* on June 12, 1987, then President Ronald Reagan stood eye to eye with former Soviet Premier Gorbachev at the Berlin Wall. The Berlin Wall stood for the better part of three decades as the world's icon of the division between East and West, between the oppressed and the free, between the Warsaw Pact and the United States and its NATO allies. On that day, quite unexpectedly, President Reagan stood there and challenged Mr. Gorbachev to "TEAR THIS WALL DOWN." Although the Wall had stood for years dividing East and West, few had ever so boldly challenged the Soviets to physically remove it.



**East and West German guards converse at the newly created opening in the Berlin Wall after a crane removed a section of the structure beside the Brandenburger Gate. Photo by SSGT Lee Corkran.**

As history has since shown, this Reagan challenge gave momentum to the democracy movements in a number of Eastern European nations, and less than 3 years later, the Berlin Wall was torn down without a shot being fired, again reuniting those who for so long had been divided by this man-made obstacle.

Much like this seminal event 13 years ago, a number of walls have also been erected over the years dividing the various organizations and disciplines contributing to aircraft survivability. Unlike the Berlin Wall, howev-

er, the walls I am speaking of were not built by human hands but rather by a combination of management decisions, organizational charts, budgetary constraints, policies, and attitudes. Let me address some of these "walls" and discuss how tearing them down will yield significant benefits for the air survivability community and, ultimately, the warfighter.

## Tear Down the Wall Between Safety and Survivability

Historically, survivability has been considered the purview of the program manager, assuring that, if an aircraft is hit in combat, sufficient testing has been conducted and adequate robustness has been built into the aircraft to allow it to withstand its expected threat set. On the other hand, the safety community has been, and continues to be, organized primarily around peacetime operations, looking at losses to crew and aircraft due to non-combat situations. These losses result from hard landings, bird strikes, wire strikes, foreign object damage (FOD) ingestion, lightning strikes, midair collisions, controlled flight into terrain, and other such reasons. Their budgets, management, and timetables are very different. Program managers tend to finish their business upon aircraft fielding, unless there is an immediate significant problem noted in the early fielding of the system. The oversight of aircraft safety often begins at fielding or first unit equipped.

Consider how many aircraft we have lost over the past decade during training versus the number of aircraft (and pilots) lost to threat damage. Our losses due to safety-related accidents in training and other non-combat situations have exceeded losses due to military combat by a factor of 10! Even during Desert Storm, there were slightly more U.S. troops lost to safety-related incidents than due to threat weapons. The safety and survivability

\* This article is based on the keynote speech given by Mr. James F. O'Bryon at the Air and Space Survivability Conference, held at the Air Force Academy, June 12, 2000.



communities must work closer together earlier to ensure that total aircraft life-cycle losses are minimized, regardless of whether they result from a threat encounter or a safety-related source.

What is not often realized is that damage from peacetime accidents can often mimic the kinds of damage that also occur in combat. Ingestion of a bird into a high-performance jet engine can sometimes look much like a missile fragment hit. Fires in a wing leading edge caused by the impact of some foreign object damage can be very similar to fires caused by the impact of an armor-piercing projectile. If these two communities could tear down the organizational wall between them and work in real time together, survivability enhancements to the aircraft, which perhaps could not be justified solely on the basis of improving safety or improving combat survivability, might be justified based on their benefit in both environments.

## **Tear Down the Wall Between Testing and Training**

The wall between testing and training is primarily organizational. It stems from the fact that the mission of testing has been viewed historically as an integral part of the research, development, test, and evaluation



**A USAF T-38 Talon Instructor Pilot during an annual air defense exercise. Official DoD photo by SRA Andy Dunaway.**

(RDT&E) function, while training has been viewed as a combat readiness issue. The two missions have been viewed, historically, as relatively unrelated due, in part, to their time phasing. The testing community's job has been to make sure that the combat equipment worked and was delivered on time. After that, the training community's job was to make sure that our combat forces knew how to use the equipment provided. In fact, testers have historically viewed trainees with some suspicion since they could possibly threaten the desired outcome of a test, especially if trainees were still on the steep part of the learning curve.

Trainers, likewise, have shown some resistance over the years to having testers "keeping book" on them when they are out in the field trying to get the hang of their equipment, even possibly posing a career threat if performing poorly.

However, with the advent of the requirement for realistic live fire and operational testing, we are realizing that there are opportunities for obtaining valuable training earlier during testing. These opportunities include learning battle damage repair techniques during live fire testing; learning command, control, communications, and intelligence (C3I) protocols and techniques during operational test and evaluation (OT&E); and a host of others. Similarly, excellent testing insights can be gained during training when testing is done without interfering with the training tempo. Moving the testing and training communities closer together, cooperating where they can, is one of the Secretary's major themes. Potential areas of cooperation between these communities include joint use of ranges, threat targets, M&S, joint experimentation, and other related opportunities.

In fact, the Live Fire Testing and Training Initiative is in its fourth year and has embarked on nearly 20 projects benefiting both the testing and the training communities across all of the military services.

## **Tear Down the Wall Between Testing and Modeling/Simulation**

There is a widely held misunderstanding that testing and M&S are on opposite sides of the balance scale and that one must make a choice between modeling and testing. Nothing could be further from the truth. Testing and M&S are inseparable. They are intertwined. They are both integral parts of the scientific method. Neither is sufficient without the other.

Before any test, modeling should be performed to predict what the test is expected to reveal. Following the test, the results must be carefully compared to model predictions, correcting the model where deficiencies are found. The notion that M&S is competing with testing runs against scientific logic. They are partners.

## **Tear Down the Wall Between the Aircraft PM and the Munitions PM**

Program managers of aircraft have their hands full. Similarly, program managers for munitions, missiles, and other ordnance have a full plate when it comes to getting their systems through the acquisition wickets. Even though the aircraft carry the items of ordnance, they often do not share in the integrated project teams (IPT) that permit cross-pollination of ideas on how weapons lethality (including insensitive explosives or low vulnerability ammunition) might affect a carrying aircraft's vulnerability.

The Live Fire Test legislation (Title 10, United States Code, Section 2366) requires that aircraft that are under the LFT&E requirement include testing of the entire combat-configured aircraft, including carried ordnance.



**The F/A-19E “Super Hornet” completing its first in-flight tests with ordnance. Official DoD photo by Vernon Pugh.**

If one looks at the organizational charts within the services, the aircraft program managers have few, if any, formal requirements to interact with the program managers of aircraft ordnance, other than to be sure that their form, fit, and function are compatible.

The missiles, bombs, smart weapons, and flares carried by aircraft are developed with little to no measure of merit given to their relative impact on the total vul-

nerability of the aircraft that will carry them. Typically, it is not until one reaches the Assistant Secretary of any given military service that the paths of the aircraft program managers and the weapons program managers formally cross. This is too late. These program managers must be in each other's IPTs, ensuring that measures of merit rewarding the optimization of overall aircraft survivability are applied and rewarded from the earliest stages of aircraft integration. If this does not happen, we will continue to suboptimize the overall survivability of the combat-configured aircraft.

## **Tear Down the Wall Between Aircraft Susceptibility and Aircraft Vulnerability**

The wall discussed above, between the munitions PMs and the platform PMs, creates another problem, given that the demands of stealth, radar cross-section, and low-drag have forced these munitions to be stowed inside the aircraft, thereby adding to the potential for increased aircraft damage if hit. Recent studies have shown that aircraft with internally stowed ordnance are many times more vulnerable than those with the same munitions carried on external pylons.

The stealth, low-observable community is a highly active and relatively well-funded community, having spent tens of billions of dollars over the past decade to reduce detectability. The vulnerability reduction community involves another active, albeit smaller, group of dedicated professionals who are trying to reduce aircraft vulnerability to a hit. Both avoiding a hit and withstanding a hit are important to overall aircraft survivability. Unfortunately, there is little design-changing dialogue between these two communities to enable realistic trade-offs to be made, if indeed, improving one parameter degrades the other. A vital part of tearing down this wall would be to embark on the development of a realistic risk-benefit approach that would enable these trade-offs to be made without prejudice.



An F-16 Fighting Falcon pilot “checks his six” after taking off. Official DoD photo by SRA Jeffrey Allen.

## **Tear Down the Wall Between the Survivability of the Aircraft and the Survivability of the Pilot**

It continues to amaze me that there is so much attention to aircraft survivability and so disproportionately little to pilot survivability. Even if pilot survivability is considered, the pilot’s vulnerable area is simply added in with the other predicted vulnerable areas with no greater weighting for the pilot than for a piece of wing or a fuel tank.

The thinking in some corners has been that “you can always eject.” The problems with this approach are several. First, the assumption is implicit that the pilot will have the option to eject. This might not be true, especially if the pilot is incapacitated or at an altitude or attitude that would prevent a safe ejection. Second, the assumption is that ejection is relatively safe. The fact is that ejection from a fast-moving fighter aircraft is not as safe as one would be led to believe. A significant proportion of pilot ejection deaths are attributable to hitting the canopy, hitting a vertical stabilizer upon ejection, flailing to death, chute failure to properly deploy, injury due to

enemy fire on descent, drowning at sea, or capture upon successful descent.

For many years, the pilot’s life was considered more valuable than that of the aircraft. Hence, the pilot’s attitude was that it’s his life, and what happened to him was either his decision, fate, or bad luck. Now, the value of both the aircraft and pilot have increased dramatically. The latest performance fighter aircraft now cost as much as their weight in gold. Without putting a dollar value on human life, we can say that the political (and hence strategic) cost of a pilot has increased dramatically. Air power increasingly is being used prior to, or in place of, any commitment of ground troops. The political implications of captured pilots or of casualties in the early stages of conflicts, even at relatively low casualty levels, have inflated the value of the pilot’s life. We must be concerned about the survivability of both the pilot and the aircraft, regardless of whether pilots express a willingness to risk their lives.

Another issue relates to the ability of the pilot to survive if the aircraft can withstand its maneuver envelope. For many years, the pacing structural problem with aircraft was the aircraft’s ability to withstand the high-acceleration environment. Today, the issue is just the reverse. We now have aircraft that can withstand higher “g” forces than the pilots who fly them. This is not an indictment of the pilots, but rather recognition that while aircraft structural strength has increased, the strength of the human body has not. Because of this, pilots are losing consciousness at an unacceptable rate when performing high-g maneuvers. In fact, controlled flight into terrain (CFIT) (many of these caused by loss of consciousness due to maneuver) is the largest contributor to loss of United States fighter aircraft.

We must address this important issue of loss of aircraft due to pilots’ physical limitations and tear down the wall that has existed for so long between aircraft and pilot survivability assessment. Fortunately, there are potential solutions that can virtually eliminate losses of this type. In fact, in September 1999, I experienced the performance of a software solution called AGCAS, or automatic ground collision avoidance system. As I flew over the Edwards Air Force Base desert in the back seat of an F-16, the pilot was intentionally repeating the flight paths of actual fatal accidents to challenge the AGCAS system to take control of the aircraft as it headed on various collision courses with the ground, on occasion reaching as much as 7.8 g’s.

The issue now is not whether we can eliminate this type of aircraft and pilot loss. The issue is whether the military services will make this system a priority in upgrading current aircraft, as well as embedding it in our developmental aircraft. Saving one aircraft and/or pilot might potentially pay for hundreds of upgrades of this type. It would also enable pilots to maneuver with impunity, knowing that if they did lose consciousness, the aircraft could fly itself until the pilot's consciousness and motor skills returned.

## **Tear Down the Wall Between Ballistic and Nonballistic Threats**

Historically, aircraft vulnerability testing has been confined to ballistic, explosive, and incendiary threats. Hence, we have focused on building aircraft, which have redundant fuel lines, fire suppression systems, hydraulic lines, structural paths, and other similar physical characteristics.

With the advent of directed energy threats, our vulnerability reduction measures must take on a new dimension, moving from hard kills to soft kills, from mechanical and chemical energy to light and electrical energy. There is no question that the United States is more computer-dependent than any other nation on Earth, and this is reflected in our military equipment as well. The threat community and T&E community must join hands in ensuring that we conduct a complete and balanced assessment of aircraft survivability, ensuring that our reliance on high technology will not expose a soft and vulnerable underbelly.

## **Tear Down the Wall Between Aircraft and Spacecraft**

Aircraft survivability has made significant progress over the past several decades, and the test methodology, test resources, and facilities have moved ahead. With the launching of Sputnik and Explorer in the late 1950s, we ushered in another source not only of combat surveillance and capability but also of another potential survivability concern.

While there is disagreement as to how many spacecraft of various kinds are orbiting the Earth, the numbers are in the thousands and are expected to grow exponentially as other nations become launch capable. This man-made cluttering of the Earth's exosphere, coupled with the preponderance of high-velocity space debris, give impetus to the need to add physical protec-



**A satellite in orbit over Earth.**

tion to our high-value space assets to mitigate potential loss due to both random hits and purposeful threat attack. The aircraft survivability community has much to offer in its modeling and test data base, which could and should be very helpful in improving the survivability of the spacecraft that we are increasingly dependent on not only for our national defense but also for our economic welfare.

## **Summary**

History has shown the tremendous benefit that tearing down the Berlin Wall has had for the entire world. My hope is that, together, we can work to remove some of the barriers that currently exist organizationally, budgetarily, technically, and politically to improving aircraft and spacecraft survivability.

We cannot afford to work on half the problem, achieving local maxima solutions. We cannot afford to do as one man did, pawn his television so he could pay his cable bill.

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# V-22 Aircraft Battle Damage Repair

## Improving the Operational Effectiveness of the Warfighter

by Mr. Bob Matthews

**D**espite improvements in tactics, performance, and survivable designs, combat vehicles will see battle damage. If we expect these vehicles to return to combat in time to contribute to the outcome of a conflict, they must be damage tolerant and our operational commanders must have enablers to quickly assess and repair their equipment.

While each Service approaches battle damage assessment and repair differently, all program managers must strike the balance between tactics, performance, survivability, and repair that provides the most combat-effective and affordable weapon system. That balance can be achieved through the use of technology and techniques for preventing or responding to detection and damage by either passive or active means. While the title “battle damage assessment and repair” implies a responsive approach, if combat repairability is integrated with performance and survivability requirements early in design, it can produce a weapon system requiring fewer repairs.

Through interaction with design and survivability teams, the repair development team provides a critical feedback loop for live fire tests to ensure that damage can be repaired without critical loss to combat effectiveness. If combat effectiveness is compromised because repair is determined to be impossible or impractical, the feedback provides the information necessary to reduce damage and susceptibility or improve repairability. The resulting synthesis of prevention and response across product teams yields a weapon system that is more likely to complete the mission, make it back to station, and return quickly to battle.

### The V-22 Advantage

The V-22 tiltrotor has a tremendous speed and range advantage over today’s helicopters, without the takeoff and landing requirements

of fixed-wing aircraft. With reduced signatures, night and all-weather capability, and countermeasures, the V-22 has multiple layers of protection to avoid or suppress threats. When those layers are degraded or insufficient and damage occurs, ballistic tolerance and system protection measures work to maintain capability and survivability. With the mission completed or aborted and the aircraft back at station, it is the job of V-22 aircraft battle damage repair (ABDR) to restore combat capability.

Because the concept of repairability, including battle damage, was addressed in the operational requirements document for the V-22, the aircraft can continue to operate without repair for minor battle damage or can be repaired quickly through removal and replacement of components using peacetime repair methods. As the severity of damage and the complexity of repair increase, the V-22 ABDR development program will provide the last layer of response in a comprehensive and systematic approach to maintaining combat effectiveness.

The objective of V-22 ABDR development is to maximize the amount of combat damage that can be repaired at the organizational level of maintenance without unique support requirements and to return to combat within 24 hours (12 hours desired). The ABDR development program is intended to give the operational commander the maximum flexibility to decide whether and how to use an aircraft with battle damage. This philosophy generates ABDR products that determine remaining capability, assist in prioritizing repairs to restore needed functions, and provide rapid troubleshooting and repair procedures.

### Assessment and Repair

The first step in the ABDR process is to assess the aircraft and determine what capability remains. If sufficient capability remains to perform a mission, the operational commander may choose to perform no repairs and return immediately to combat. When a required capability has been lost, the V-22 ABDR manual will identify the repairs that are needed to restore functionality.

For ABDR purposes, the V-22 can be divided into three primary elements: structures, electrical wiring, and

systems. Each element holds unique challenges and opportunities, requiring different types of analysis and products to provide maximum flexibility to the operational commander.

## Structures

All structures have two inherent repair damage limits. The first limit is the damage that can be sustained without having to perform any repair, known as the unrepaired damage limit (UDL). The second damage limit is the maximum damage that can be repaired without adversely affecting the designed load distribution around the repair; this is known as the repairable damage limit (RDL). During peacetime, repairs and unrepaired damage must not degrade the performance or the life of the component. For the V-22, that means that any repair is good for the life of the aircraft with a 1.5 factor of safety.

Unfortunately battle damage does not restrict itself to peacetime limits. In order to maximize the UDL and RDL for combat, ABDR does not require that the components last for the life of the aircraft, although it does require that they last for at least for the next 100 flight hours. UDLs can be expanded further if mission loads are reduced with flight restrictions on nacelle angle, sink speed, air speed, or gross weight. Even greater UDLs are established for ferry flights when repair is not possible or practical at the aircraft's present location. Presented in matrix form, these limits now give commanders options, allowing them to select the appropriate amount of repair based on the condition of the aircraft, the time available for repair, and the mission requirement. As a final contingency, when damage is beyond all limits, there are provisions for rapid disposition and repair of the aircraft by a depot field team.

## Electrical

Troubleshooting and repair of electrical wiring can consume 90 percent of the maintenance downtime involved in ABDR. The V-22 has an advantage in that a number printed on the cable uniquely identifies each wire harness and each individual wire. To aid in assessing electrical wiring, two matrices were developed that correlate the signal function of a wire to its unique wire or harness number. These matrices allow an assessor to quickly identify a critical wire or harness and restore needed functionality without unnecessary maintenance.

## Systems

Damage limits are not particularly effective for aircraft systems in combat. A system either works or it does not. When a system is damaged, the most prudent maintenance may be to isolate and disable nonessential systems. When a required system is inoperative, spares may not be available, or time may not permit removal and replacement (R&R). Assessment tools must provide alternatives when R&R is not an option. The V-22 ABDR team is pursuing an innovative assessment tool that will provide critical insight to the operational commander. The V-22 damage versus derived function matrix (DVDFM) provides single-source information for component redundancy, backups, and interchangeability, letting commanders know if they can rely on other systems or quickly swap out a required component. The DVDFM also provides alternative repairs, workarounds, and operational checks and shows the effects or restrictions for each failure mode of the component. If system safety has been compromised to below peacetime levels (loss of redundancy, fire hazard, etc.) those risks are identified to help the commander determine an appropriate level of risk for the situation. When used in concert with the structural and electrical matrices, the DVDFM completes a comprehensive ABDR program for rapidly assessing and repairing a V-22 with combat damage.

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# C-130J

## Live Fire Test & Evaluation

by Mr. John J. Murphy  
and Mr. John M. Vice

**C**-130J acquisition by the Air Force is taking place in a nontraditional manner. As a commercial off-the-shelf system, this latest version of the venerable C-130 aircraft presents new issues concerning whether or not it is covered by the live fire test and evaluation (LFT&E) requirements of Title 10 United States Code (USC) Section 2366 and Department of Defense (DoD) Regulation 5000.2-R.

The LFT&E statute ties the Live Fire Test (LFT) program to formal milestones found in standard DoD acquisition programs. However, the C-130J acquisition is not structured according to these milestones because of the nontraditional acquisition approach. To preserve the spirit of LFT&E and “do the right thing,” the Air Force and the Office of the Secretary of Defense (OSD), Director, Operational Test and Evaluation (DOT&E), jointly committed to a C-130J LFT&E program that meets the intent of a high-quality LFT&E program, whether or not this is required by law. This commitment was formalized in a memorandum signed by both agencies in March 1998.

The backdrop for the joint Air Force and DOT&E memorandum is a C-130H and C-130J vulnerability analysis completed in 1996. This analysis identified the major ballistic vulnera-

bility contributors and areas where data voids existed. In response to the study findings, the Air Force structured a multiphase C-130 Vulnerability Reduction Program (VRP) to better quantify the aircraft’s vulnerabilities and investigate the feasibility of vulnerability reduction approaches. In addition, DOT&E and the Air Force agreed on other vulnerability areas to investigate under a C-130J LFT&E.

The outcome of discussions between the Air Force and OSD is the C-130J LFT&E program depicted in Figure 1. The Air Force agreed to fund the VRP and other testing and analysis efforts that would have been conducted as part of the C-130J acquisition. OSD agreed to fund the hydrodynamic ram testing and a mission abort study through its Joint Live Fire (JLF) program. All of the LFT&E program elements were added to the C-130J Test and Evaluation Master Plan. As the elements are completed, the results will be reported to DOT&E and included in the reports required by the LFT law. Through this spirit of doing the right thing, the USC Section 2366 requirements will be met, a more survivable weapon system will result, and the lives of operators will be protected to the maximum extent possible.

Figure 2 shows a top-level schedule for the ballistic testing and analysis portions of the LFT&E program. The wing dry bay fire-extinguishing agent evaluation has been completed. Testing began in the fourth quarter of fiscal year 1998 and concluded in September 1999. Fire-extinguishing agents examined in the VRP

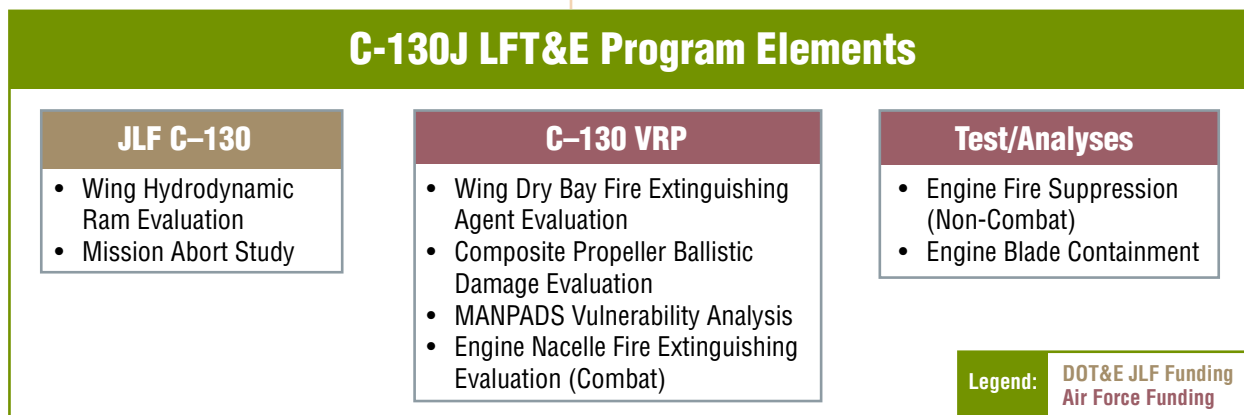


Figure 1. C-130J LFT&E Program Elements

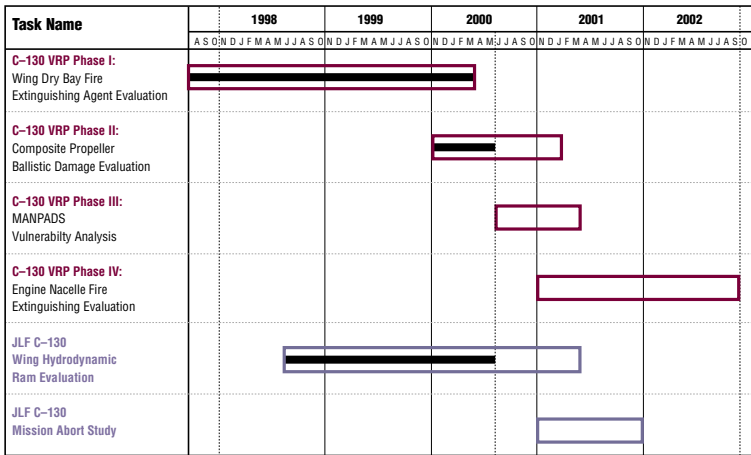


Figure 2. C-130 LFT&E Program Schedule

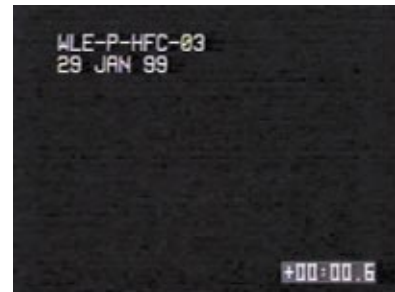


Figure 3. C-130 Wing Dry Bay Fire Extinguishing Agent Evaluation

testing included pentafluoroethane (CHF<sub>2</sub>CF<sub>3</sub>), designated HFC-125, and solid propellant gas generator (SPGG) agents.

Wing leading edge, engine area, and trailing edge dry bay replica and C-130H production wing sections were used for testing. Over 150 tests were conducted, including LFT tests on production test articles without the use of fire-extinguishing agents. Figure 3 shows images from a video camera located in the wing leading edge dry bay during typical agent tests. The final fire-extin-

Table 1. Summary of Test Series Results—Valid API Tests

	Replica Test Article		Production Test Article	
	# API Shots	Weight Selected (lbs)	# API Shots	Demonstrated Weight (lbs)
<b>Wing Leading Edge</b>				
HFC-125	28	2.16	5	2.16
★ SPGG	10	0.93	4	0.93
<b>Wing Engine Area</b>				
HFC-125	17	2.80	2	2.80
SPGG	8	0.93	2	0.93
<b>Wing Trailing Edge</b>				
HFC-125	16	—	0	—
SPGG	8	1.38	2	1.86

\* Wing Leading Edge SPGG testing included FS01-40 and PAC-3302 agents

guishing agent masses developed and validated in the testing for armor-piercing incendiary projectiles are shown in Table 1. The C-130 VRP demonstrated that the candidate agents in active fire-extinguishing systems can feasibly extinguish ballistic threat-induced C-130 wing dry bay fires.

Ballistic testing for the wing hydrodynamic ram evaluation is under way, and planning has commenced for the composite propeller ballistic evaluation. The remaining elements

of the C-130J LFT&E program will be completed as shown in Figure 2.

Overall, the C-130J LFT&E program is an example of how the acquisition and test communities can cooperate and do the right thing to ensure the survivability of our nation's critical defense weapon systems.

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# F/A-18E/F Aircraft Live Fire Testing Program

by Mr. J. Hardy Tyson

The F/A-18E/F aircraft was recommended as a candidate system for live fire test (LFT) in July 1991. Early program direction received by the vulnerability team before the release of the operational requirements document (ORD) in April 1997 required that the vulnerability of the F/A-18E/F version of the aircraft be as good as or better than that of the earlier variants of the F/A-18. An aggressive LFT strategy was developed to meet these requirements, using the waiver path, which included an alternate test plan for other than a full-up, combat-configured aircraft and munitions.

The F/A-18 E/F testing approach was built on the early F/A-18A vulnerability reduction program and the F/A-18 Joint Live Fire (JLF) program. It made use of mishap and combat lessons learned, trade studies, analysis, and component and full-scale testing. The program also employed a building-block approach to testing, a controlled approach that began with less complex test setups and continued with a gradual increase in test complexity while limiting test variables. This approach provided timely input for design decisions during engineering and manufacturing development (EMD) of the aircraft and also provided risk mitigation near the end of testing.

This article provides an overview of the F/A-18E/F LFT program, which began in 1993 and ended in December 1999. A complete description of the test program is contained in Naval Air Warfare Center Weapons Division report NAWCWD TP 8462, dated March 2000. Testing was sponsored by the Naval Air Systems Command, PMA-265 Code AIR-4.1.1. Mr. J. Hardy Tyson was the Navy's senior LFT engineer for the F/A-18E/F. Mr. Chuck Frankenberger was the responsible engineer for propulsion-related testing. Ms. Susan Hennigan supported Mr. Tyson in documenting the test program.

Threats that the operational F/A-18E/F aircraft is likely to encounter are described in the System Threat Assessment Report (STAR) for the F/A-18E/F of February 1997. Data from this

STAR was used to develop a list of existing and future threats for the F/A-18E/F LFT program.

The success of the F/A-18E/F LFT can be attributed in part to the JLF testing of the already fielded F/A-18 aircraft conducted from 1985 –1992. This testing was funded by the Office of the Secretary of Defense for Development, Test and Evaluation (OSD-DT&E), now organized under OSD/DOT&E/LFT&E. Testing under this program addressed every major system on board, including the crew station, structure, hydraulics, propulsion, flight controls, fuel system, and weapons stores. Shortcomings uncovered during this testing provided the contractor with valuable information when the Navy decided to proceed with a follow-on variant of the aircraft. Approval to develop the variant aircraft gave the Navy-contractor team the opportunity to correct the identified deficiencies and produce a more survivable aircraft.

Trade studies performed before the EMD phase of aircraft development involved selection of cost-effective vulnerability reduction features that would ensure that the aircraft design would meet the specification requirement for vulnerable areas. The fuel system was a primary focus of these trade studies. Areas of interest included fuselage fuel tank inerting, the incorporation of an active dry bay fire suppression system, and a foam explosion suppression system in the wing. Vulnerability reduction features selected on the basis of the studies to meet the ballistic vulnerability design requirements for the aircraft's Detail Specification SD-565-3 are as follows—

- Addition of dry bay fire protection beneath fuel tanks 2, 3, and 4
- Redesign of the horizontal stabilator outer bearing attach point
- Relocation of the primary and secondary heat exchanger aft, allowing rerouting of the hot-air bleed duct
- Relocation of hydraulic reservoirs to the bottom fuselage and reduction in length of previously vulnerable hydraulic lines routed vertically between the reservoir and pumps
- Improved materials layout for the engine air-inlet duct/fuel tank common wall
- Further separation of flight control system hydraulic lines between the vertical tails
- Continued use of explosion suppression foam in the wing



**Figure 1. Ullage explosion setup in Tank 1**

- Elimination of the mechanical backup flight control system and replacement with the horizontal stabilator fault management system
- Substitution of polyalphaolefin (PAO) radar cooling fluid for the older, even more flammable fluid.

These features were incorporated into the final aircraft design. An aggressive LFT program was completed to ensure that these features provided the required protection to the aircraft in the ballistic environment.

The aircraft Test and Evaluation Master Plan contained specific questions about the aircraft's vulnerability. The LFT program was designed to address each of these questions.

- Have the vulnerabilities of the F/A-18 series aircraft discovered in the JLF program been corrected in the F/A-18E/F, and are the vulnerability design features effective?
- What is the likelihood of initiating a fire or explosion in fuselage fuel tank ullage spaces and of such a fire or explosion causing injury or death of a crew member either directly or indirectly?
- What are the vulnerability differences of the F/A-18E/F from previous models as a result of configuration changes?
  - Structure of the wing
  - Change in the skin materials
  - Changes in the ECS and flight control systems
- What is the vulnerability of the F414 engine in comparison with the F404 engine? Are there engine failure modes that can propagate to the other engine, to other flight critical systems, or to the crew, either directly or indirectly?
- Are there significant vulnerabilities in the F/A-18E/F discovered by analysis or testing conducted under the F/A-18E/F LFT&E program (i.e., unexpected results from testing)?

The engine and fuel systems in the F/A-18E/F received special attention during the LFT program. For the engine,

blade containment, fuel ingestion, and afterburner and variable exhaust nozzle (VEN) ballistic tolerance were items of special interest. Fuel ingestion was identified as a critical issue during JLF testing of the F/A-18C/D and in that aircraft's vulnerability assessment. The vulnerable area associated with fuel ingestion was recognized to constitute a large portion of the aircraft's total vulnerable area; therefore, the fuel ingestion issue had to be addressed for the F/A-18E/F.

As mentioned, the LFT program used a building-block approach. This approach began with small components and built on test successes into larger components, culminating in full-scale testing. This approach reduced the risk of failure for the full-scale tests and of data loss if a piece of hardware shared with other test agencies became unavailable. As testing progressed, vulnerability issues were continually addressed in analyses conducted parallel to LFT. The changes in assessed vulnerable areas were tracked and reported. Compliance with the specification was accomplished by a manual assessment process because the computerized geometric description of the aircraft was not available until later in the program and program requirements necessitated continuous

*continued on page 31*

**Table 1. Summary of F/A-18E/F Live Fire Tests**

Test Title	Test Article	No. of Tests
Halon replacement (dry bay)	Simulator	30
Fuel Cube	Simulator	26
Material Comparison	Test Stand	8
Inlet Duct/Fuel Tank Damage Control	Simulator	30
Engine Bay Fire Extinguishing	Simulator	303+
Dry Bay Phase I	3 Surrogate, F/A-18	14
Engine	Surrogate, F404	14
Dry Bay Phase II	3 Surrogate, F/A-18A J Simulator	16, 22
Blade Containment I	F414	1
Wing Torque Box Test	Pre-Production Wing	4
Blade Containment II	Component	1
Fuel Ingestion/Bare Engine	F414	105
Dry Bay Phase III	Surrogate, F/A-18A	5
Fuel Cell Qualification I	SV52, EMD Aircraft	10
Tank 4 Ullage Vulnerability	SV52, EMD Aircraft	4
Empennage (horizontal stabilator)	SV52, EMD Aircraft	5
Wing Leading Edge Fire	SV52, EMD Aircraft	3
Fuel Ingestion/Engine Ballistic	SV52, EMD Aircraft	7
Dry Bay Fire Suppression	SV52, EMD Aircraft	5
Ullage Explosion in Fuel Tank 1	SV52, EMD Aircraft	1
Fuel Cell Qualification II	Simulator	5
	SV52, EMD Aircraft	3
<b>TOTAL</b>		<b>622+</b>

# National Live Fire Test and Evaluation Workshop

by Mr. Tracy V. Sheppard

- When does the Service's LFT report have to be submitted to the Congress?
- The LFT&E law requires pretest predictions for all live fire testing (T or F?).
- Under what conditions can a system get grandfathered from LFT&E?
- What percentage of programs going through LFT&E have failed LFT&E?

Those are just 4 of the 20 questions and True/False statements put to the audience during "LFT&E Mythology: Setting the Record Straight," Mr. Jim O'Bryon's closing general session of the National Live Fire Test and Evaluation (LFT&E) 2000 Workshop. I won't go into the percentages of right and wrong answers to this pop quiz (<10 right earned you the advice, "enjoy the conference food"), but suffice it to say, we all learned something... and we had a little fun too.

That was the National LFT&E 2000 Workshop: learning, sharing, camaraderie, and a little fun. This biannual national workshop was held May 8-12, 2000, at the Pickle Research Campus of the University of Texas at Austin. It all started with an electronic call for papers from Jim O'Bryon and culminated with 5 content-packed days of LFT&E. Over 80 abstracts were received, representing the work of over 125 authors and coauthors. The 5-day agenda contained over 100 speakers, representing the armed Services and many of the nation's most prominent defense contractors.

As with prior LFT&E events, this workshop was sponsored by the National Defense Industrial Association. The cosponsor was the University of Texas at Austin. The workshop was conducted in cooperation with the Office of the Secretary of Defense. Honorary chairpersons were Senator Kay Bailey Hutchison of Texas and Dr. Juan Sanchez, Vice President for Research, University of Texas at Austin.

The 5-day agenda began on Monday, with tutorials. These teaching sessions covered topics such as Joint Live Fire, the Live Fire Testing and Training Initiative, directed energy weapons, and the Survivability/Vulnerability Information Analysis Center (SURVIAC). Twelve sessions occupied the next 4 days. These sessions provided an opportunity for program managers and their prime contractors to express their viewpoints on LFT&E; for test centers to present their vast and diverse capabilities; and for the air, land, and sea communities to get together to discuss the intricacies and achievements of their LFT&E programs. Other sessions allowed the presentation of papers on such topics as the airborne laser and the Comanche helicopter. Still other sessions provided an opportunity to discuss emerging threats and emerging technologies in the field of reduced vulnerability. Intermixed throughout the agenda were paper presentations covering such topics as the role of warfighter utility in live fire test design and analysis, aircraft ballistic vulnerability, and, a cost-effective vulnerability/lethality assessment of the role of full-up, system-level test and evaluation. The final session of the conference, following Jim's "Setting the Record Straight" session, was a practical application exercise of the LFT&E legislation and requirements, involving a fictional acquisition program. In this exercise, three teams each prepared a strawman LFT&E strategy for the fictional program, applying the rules and requirements of LFT&E as interpreted by each. Would you be surprised if each team had a different approach to meeting the requirements? Probably not. But that is fine too. After all, we know that live fire is not pass or fail. Live fire is about understanding and uncovering vulnerabilities and about understanding lethality.

This national workshop met its objectives. It brought the live fire community together in an open environment in which learning, sharing, and camaraderie could take place. It also fostered cooperation and commitment across all spectrums of the LFT&E community: cooperation in pursuing the best, most effective means of accomplishing the goals and objec-

*continued on page 21*

# Aircraft Crew Casualty Issues

by Dr. Lowell H. Tonnessen

## Crew Casualties— An Element of Survivability?

**T**raditionally, survivability has been partitioned into two elements: susceptibility and vulnerability. Another approach has been to portray the elements of survivability as a number of atoms or bubbles. Either approach can be valid, depending on the context of the discussion.

Rather than argue the merits of either approach, I would like to present a slightly expanded conception of survivability and discuss why it is needed: Survivability consists of platform (aircraft) survivability and user survivability.

In the following discussion, I sometimes use the more common term “crew casualties” instead of “user casualties.” The scope of this discussion, however, includes occupants of the aircraft who are not part of the crew.

The reason for emphasizing user survivability at this time is that recent conflicts have not been wars of platform attrition. The potential for incurring casualties has affected decision makers at least as much as the potential for losing systems through attrition.

This change in attitude has not come from our pilots. I do not believe our pilots are less brave now than they were in World War II, Korea, Vietnam, or Desert Storm. It is our society that has become less tolerant of casualties, in part because our national survival has not been at stake in recent conflicts.

## Crew Casualties— Someone Else’s Concern?

In the past few months, I have become aware that the aircraft survivability community does not always include crew casualties within the scope of aircraft survivability. “Crew casualties” and “user survivability” typically are not included among the lists or figures displaying the elements of aircraft survivability.

Living to fight another day, however, applies both to the aircraft and to its crew. Both are factors in managed attrition, in which the mission may be sacrificed to reduce losses of aircraft or personnel.



An F-16 Fighting Falcon pilot waits to start engines before flying a mission. U.S. Air Force photograph by SRA Jeffrey Allen.

There can be legitimate differences of opinion about whether crew casualties should be considered part of aircraft survivability and should be addressed by the Joint Technical Coordinating Group on Aircraft Survivability (JTCCG/AS). There should be no question, however, that casualty reduction is a legitimate part of live fire test and evaluation (LFT&E), given the wording of the LFT&E legislation and Department of Defense (DoD) regulation. Consider the following excerpts from the DoD Regulation 5000.2-R, and note that crew casualties require explicit reporting by the Director, Operational Test and Evaluation:

*“At the conclusion...the Director shall prepare an assessment report...stating the opinion of the Director as to whether the live fire test and evaluation performed were adequate (i) to provide information to decision-makers on potential user casualties... and (ii) to ensure that knowledge of user casualties...is based on realistic testing....”*

There is a reason that the LFT&E law applies specifically to user-occupied systems: Congress and the nation are interested in reducing casualties. Yet our current vulnerability assessment methodologies make no essential distinction between an unmanned aerial vehicle (UAV) and a piloted aircraft. The outcome is expressed in terms of the mission or attrition status of the system, not in terms of the survivability of the crew and other occupants.

It is ironic that our interest in aircraft survivability exists primarily because of the people on board, yet we do not seem to want to assess the survivability of the people on board. We may account for them, as we do the status of an engine or a fuel tank, but we do not usually include casualties in our reporting.

## **What Are the Overarching Casualty Issues for Aircraft?**

A reasonable interpretation of the requirement for LFT&E is that programs have the responsibility to identify design features that serve to reduce casualties, to provide any evidence from the test programs concerning the

effectiveness of those design features, and to provide an estimate of expected casualties. I believe we have made some progress in this direction, but our assessment tools do not allow us to address these issues directly.

## **What Are Current Limitations in Our Treatment of Casualties?**

Personnel casualties fall naturally into three categories: crew casualties that contribute directly to aircraft attrition, crew or passenger casualties that do not prevent safe landing of the aircraft, and casualties that result from the inability to land the aircraft safely (e.g., casualties resulting from ejection or crash landing).

Assessments of the first kind of casualty could be derived from current methodologies, because flight-critical personnel are included as aircraft critical components. The methodologies could be modified relatively easily to permit reporting of this kind of casualty. The second kind of casualty also could be derived from current methodologies, if passengers are defined as critical components for the purpose of calculating casualties.

The third kind of casualty, however, would require development of new capabilities to expand our assessment methodologies. I believe we can go as far as to say that, if ejection seats were not already on most fixed-wing fighter and attack aircraft, they could not be justified using current assessment methodologies, because ejection seats do not affect aircraft probability of kill.

## **How Can Casualty Assessment Be Improved?**

As a first step, LFT&E strategies should explicitly include user casualty issues, patterned after the overarching casualty issues mentioned above. If user casualties are included among LFT&E issues, then creative thinking will be directed toward addressing these issues through test and evaluation.

These issues cannot be addressed adequately unless expected casualties (EC) are used as a survivability measure. The EC measure would not replace the aircraft kill measure but would supplement it. User casualties are much too important to be folded into a measure that basically addresses survivability of the aircraft, with only a tangential link to its occupants. The EC measure would give credit for aircraft design features that prevent casualties by keeping the aircraft in flight or reduce casualties when the aircraft is downed.

EC already is a standard measure in assessing armored land systems but typically is not reported in aircraft vulnerability analyses. The EC measure would be especially important in trade studies of design features that might affect both attrition and user casualties. Shouldn't we know, for example, how many casualties should be expected per 1,000 sorties (or per hit), just as we are interested in how many aircraft will be lost per 1,000 sorties (or per hit)? Attrition kill and expected casualties are likely to be positively correlated, but not under all conditions.

### What Role Can JTCG/AS Play?

Should crew casualties be a concern of the JTCG/AS? I do not believe there is an easy answer, but I believe it would be appropriate at some level of effort. A first step would be to develop and document methodologies for estimating expected casualties, both for fixed-wing aircraft and for helicopters.

The LFT&E mission can play a role. Several years ago, the Director of Live Fire Testing of the Office of Secretary of Defense called for the formation of a Crew Casualty Working Group (CCWG) under the auspices of the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME), with funding and participation by the JTCG/AS. Since its inception, the CCWG has made significant progress on injury from direct threat effects, such as fragment penetration, blast, fire, burns, toxic fume inhalation, and blunt trauma, and from acceleration loss-of-consciousness. The CCWG might be the appropriate forum for addressing casualties resulting from a full spectrum of aircraft-specific effects.

Obviously, some of the issues raised in this article relate to crashworthiness and safety, as well as to survivability. However, we should not assume that the crashworthiness and safety communities will address these issues, or that they will be sensitive to combat-specific concerns. Rather, we should integrate our efforts with theirs to achieve the common goal of reducing both aircraft losses and user casualties.

*Dr. Lowell Tonnessen is a Research Staff Member and Project Leader for Live Fire Test and Evaluation at the Institute for Defense Analyses. He looks forward to comment, feedback, and continued discussion of these issues at 703.845.6921, or by E-mail at ltonness@ida.org.*

## National LFT&E Workshop

*continued from page 18*

tives of the LFT&E program; commitment to ensuring that we all do our utmost to provide the most survivable and lethal weaponry we can to our warfighters.

*Tracy Sheppard is the Technical Director of the Live Fire Test Office, Center for Professional Development and Training, University of Texas (UT) at Austin (Washington DC office). Prior to joining the research faculty of UT, Tracy served for over fifteen years within the Department of Defense, first as a Marine and then in positions at Aberdeen Proving Ground and within the office of the Deputy Director for OT&E/LFT in the Pentagon. Tracy received his AS and Bachelor of Electrical Engineering degrees from the Johns Hopkins University in Baltimore, Maryland. He can be reached at 202.955.9472, or by E-mail at [tracy.sheppard@iat.utexas.edu](mailto:tracy.sheppard@iat.utexas.edu)*

# Aircraft Survivability 2000

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# CH-47F Chinook (Improved Cargo Helicopter) Live Fire Test and Evaluation

by Mr. Dennis S. Lindell

The CH-47F (Improved Cargo Helicopter) is a service-life extension program for 300 of the U.S. Army's 431 CH-47D Chinook helicopters (Figure 1). The core CH-47F program features are an airframe life extension, airframe tuning, and a cockpit avionics upgrade, including a 1553 digital data bus. Also incorporated, but under a separate CH-47D fleetwide program, is an upgrade to more powerful full-authority, digital electronic control (FADEC) equipped T55-GA-714A turboshaft engines. These features are designed to improve the helicopter's range and lift capability, provide connectivity on the digital battlefield, and reduce fleet operational and support costs.



**Figure 1. CH-47D Chinook Helicopter**

In April 1998, the CH-47F program successfully passed Milestone II and entered the engineering manufacturing and development phase. Two CH-47D helicopters were inducted into the program in 1999 and are scheduled to roll out in 2001 as CH-47F models. Those aircraft will support contractor and government combined developmental and operational testing in 2001 and 2002. The program's Milestone III review is scheduled for January 2004. Once approved, CH-47F production will proceed at 26 aircraft per year until 2015.

In 1997, the CH-47F Product Manager (PM) and the U.S. Army Test and Evaluation Center/Army Evaluation Center chartered a survivability/vulnerability integrated project team (S/V IPT) to work on CH-47F live fire test and evaluation (LFT&E) issues. The S/V IPT included representatives from the U.S. Army Research Laboratory (ARL), the Army Aviation Center, the Deputy Under Secretary of the Army (Operations Research) [DUSA(OR)], and the Office of the Director, Operational Test and Evaluation.

To support the MS II decision process, the S/V IPT developed an alternate plan for a component-level live fire test (LFT) to accompany the program's waiver request from a full-up LFT. The alternate plan and waiver request were approved by the Under Secretary of Defense in March 1998.

In 1998, the S/V IPT developed an LFT&E strategy for the CH-47F based on ballistic vulnerability modeling and component and system-level live fire testing. Because very little ballistic vulnerability test data were available for the CH-47D Chinook helicopter, the strategy encompassed CH-47D legacy and new CH-47F regions and/or subsystems. The regions and subsystems included—

- Cockpit region
- Fuel subsystem
- T55 turboshaft engine
- Engine nacelle fire detection/suppression
- Tunnel region (rotor drive, mechanical and hydraulic flight control subsystems).

To maximize the information gain from the test program, the LFT&E strategy begins with component-level technical tests and progresses to subsystem- and system-level tests. In association with the LFT&E program, the DUSA(OR) and the Office of the Secretary of Defense/Deputy Director, Operational Test and Evaluation, agreed to support ballistic vulnerability testing of the CH-47D/F composite rotor blades under the Joint Live Fire (JLF) test program. The LFT&E strategy was approved in January 1999.

As the Army's primary source for helicopter ballistic vulnerability analysis and testing, ARL's Survivability/Lethality Analysis Directorate (SLAD)

assumed responsibility for the planning, performance, and reporting of the CH-47F LFT. Due to the specialized experimental facilities that support its research mission and aviation vulnerability experience, SLAD has the unique role of conducting LFT&E of Army rotorcraft. SLAD began developing detailed test plans following approval of the LFT&E strategy. Test plans for the cockpit region, fuel subsystem, and T55 turboshaft engine were completed in 1999.

In 1998, a crash-damaged CH-47D helicopter was designated by the PM for use as the LFT ground test vehicle (GTV) and shipped to Aberdeen Proving Ground, Maryland. The aircraft (Figure 2) was repaired to a ground-run state (i.e., fully operational, but not flightworthy), a remote control system was installed, and the aircraft was ready to support testing in April 1999.



**Figure 2. LFT&E Ground Test Vehicle**

To support the LFT&E program, the PM and SLAD found a number of functional, but not flightworthy, CH-47D parts in the Army supply and reutilization system. SLAD also provided a partial YCH-47A fuselage and several T55-L-711B model turboshaft engines to support component and subsystem-level testing. These additional resources have helped keep the test program on schedule and within budget.

LFTs began in May 1999, with Phase IA of the cockpit region test program, an investigation of threat projectile function on new CH-47F cockpit structural materials. Testing continues as materials become available and is scheduled to finish this summer.

The fuel subsystem and T55 engine programs started with nondestructive controlled damage test phases in February 2000. Testing of these subsystems will

continue this summer, with component-level ballistic testing, and will culminate with subsystem level test events in the fall.

In 2001 and 2002, the LFT program will focus on the engine nacelle fire detection/suppression subsystem, cockpit components and crew, and the tunnel region of the aircraft. After completion of the live fire tests, the GTV will be made available to JLF in 2002 for dynamic rotor blade testing.

Three sequential phases of rotor blade ballistic vulnerability testing are planned: I-Static, II-Quasi-Static, and III-Dynamic. Phase I, consisting of ballistic shots on unloaded blade sections, was conducted in June 1999. In Phase II, blade sections will be shot while loaded statically to represent in-flight forces and moments. The damaged sections will later undergo laboratory testing to determine changes in structural properties and evaluate remaining fatigue life. Phase II is scheduled to start this summer and to finish in 2001. In Phase III, complete blades will be shot on the GTV while operating under conditions representative of hover flight. Test Phase III will enable observation of blade damage dynamic response and the consequences of blade damage to the coupled rotor and helicopter system.

The CH-47F program will enhance the Chinook's capability to support the Army's heavy lift requirements well into the 21st century. The LFT&E program, by finding and addressing system vulnerabilities, will enhance the Chinook's future combat survivability.

*Mr. Lindell received his B.S. in Aerospace Engineering & Mechanics from the University of Minnesota in 1988. He has worked in the field of helicopter vulnerability test and analysis at the U.S. Army Research Laboratory, Survivability Lethality Analysis Directorate (ARL/SLAD) since 1989. Mr. Lindell is currently serving as the SLAD System Leader for the CH-47F Chinook (Improved Cargo Helicopter). He may be reached at 410.278.2468 or lindell@arl.army.mil.*



## Advanced Joint Effectiveness Model

by Mr. Thomas L. Wasmund

The release of version 1.0 of the Advanced Joint Effectiveness Model (AJEM) gives the aircraft vulnerability analyst a new tool, with new capabilities that can provide more realistic estimates of aircraft vulnerability and survivability. AJEM has been jointly developed by the Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS), the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME), and the U.S. Army Research

new physics-based target interaction models that are under development.

AJEM incorporates the capabilities of the COVART vulnerability/lethality (V/L) model and the JSEM endgame model, and adds considerably more. It combines the elements of target modeling, threat modeling, encounter geometries and kinematics, generation of weapon burst positions from proximity or contact fuzing, propagation of damage mechanisms to the target, damage mechanism/target interaction (penetration, fire, blast, etc.), target system relationships (functionality, redundancy, etc.), and target remaining capability or loss of function. AJEM produces results that are applicable during all phases of weapon system acquisition, from research, design, and development to production, test and evaluation. It provides results that are observable or measurable for comparison through testing and real-world events. In addition, it is a tool that can be used to provide input for a number of analysis types.

AJEM's software structure comprises three separate modules. Each module is distinct and runs as a separate process in a UNIX environment. These modules are—

- The AJEM Graphical User Interface,
- The AJEM Encounter Module, and
- The AJEM Vulnerability/Lethality (V/L) Module.

These separate processes communicate with each other and share common data files that contain information about the target description and threat, as well as output from an analysis. The AJEM user interface (shown in Figure 1) helps the analyst manage the various input files required for an assessment and controls the operation of the Encounter and V/L modules. It provides access to a number of tools, including detailed documentation and references in HTML format; a dynamic, color-coded text file editor; a final results post-processor; a vulnagram utility, an encounter visualization tool (EVT); and the BRL-CAD modeling and visualization tool MGED (shown in Figure 2) developed and maintained by ARL/SLAD.

The input information is stored in several files. The "g" file contains the BRL-CAD description of the target being studied. AJEM is designed to run using BRL-CAD geometries. However, the recent release of BRL-CAD 5.1 includes FAST-GEN primitive support—and the AJEM user interface is designed to support FASTGEN files and seamlessly convert

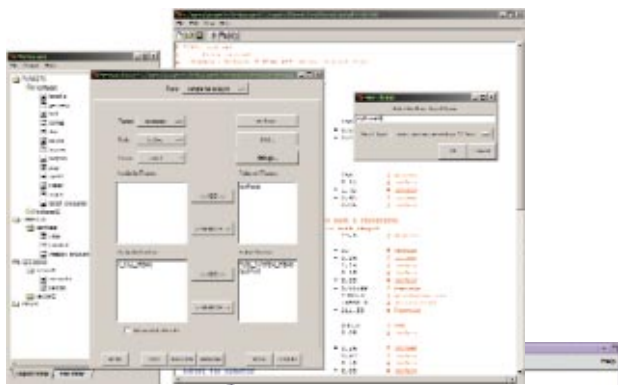


Figure 1. AJEM 1.0 User Interface



Figure 2. MGED released with BRL-CAD 5.1

Laboratory Survivability/Lethality Analysis Directorate (ARL/SLAD). AJEM is planned to be DoD's standard computer simulation for evaluating the lethality and terminal effectiveness of munitions and the vulnerability of aircraft, missiles, and ground systems. It combines the capabilities of a number of the models that it will replace and provides an architecture for adding

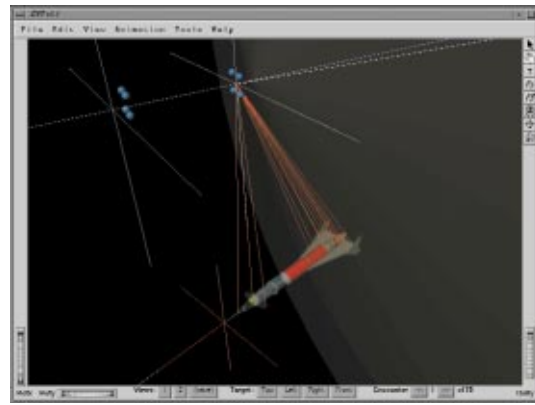
to BRL-CAD format behind the scenes. Additional input files contain all of the material properties, threat characteristics, fault trees, and other information required for a vulnerability/lethality analysis. In addition, a converter is included to convert existing COVART inputs to AJEM format.

The Encounter Module is a separate endgame program that can be executed in a stand-alone mode or transparently via the AJEM user interface. It has the ability to use various fuze models and interacts with the BRL-CAD target description to predict burst points. Once the burst points are determined, the Encounter Module provides the option of running the V/L Module to determine target Pk. The EVT can read the inputs and outputs of the Encounter Module and animate the encounter to help the analyst visualize the results of a run (as shown in Figure 3).

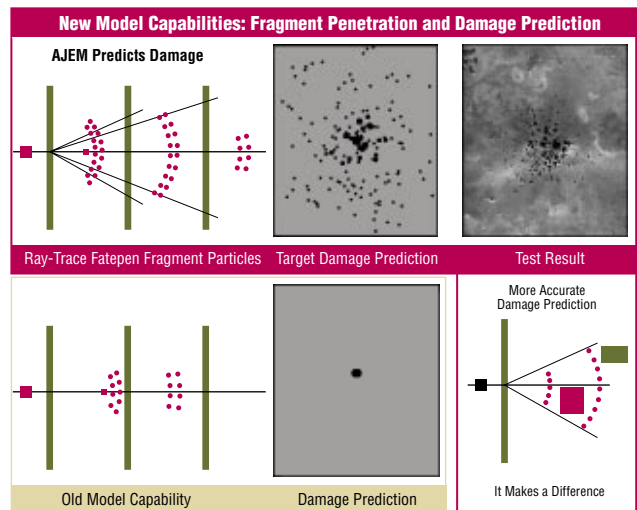
At the heart of AJEM is its V/L Module, the U.S. Army Research Laboratory's Modular UNIX-based Vulnerability Estimation Suite (MUVES). It provides all of the vulnerability analysis capabilities for API and HEI projectiles, fragments, and blast and analyzes missile body hits, missile debris, and warhead effects after a burst point has been determined by the Encounter Module. The model includes penetrator path deflection, ricochet, and the tracing of fragment debris particles, and is currently being updated to predict penetration and fuzing of Man Portable Air Defense Systems (MANPADS). Additionally, MUVES provides the capability of adding new physics-based target interaction models as linked libraries. One of these is the FATEPEN penetration and damage model, which allows realistic analysis of fragments, projectiles, and long rods. A comparison of traditional- and FATEPEN-predicted fragment damage with test results is shown in Figure 4.

The capabilities of AJEM 1.0 are summarized in Table 1. For access to the latest AJEM developments, documentation, and more, visit the AJEM Web site at [www.ajem.com](http://www.ajem.com).

*Mr. Wasmund received his B.S. in Electrical Engineering from the University of Washington, and B.S. and M.S. degrees in Aerospace Engineering from the Naval Postgraduate School. He is a Senior Scientist in the Lethality and Weapons Effectiveness Branch of the Missile Systems Division, NSWC, Dahlgren Division. He has 29 years experience in air target vulnerability analysis, testing, and technology development, primarily working with foreign air targets and supporting missile warhead development. He is the Functional Area Coordinator for Air Targets for the Vulnerability Working Group of JTCC/ME, a co-chair of the Vulnerability Committee of the JTCC/AS Survivability Methodology Subgroup, and the AJEM Model Manager. He may be reached at [wasmundTL@nswc.navy.mil](mailto:wasmundTL@nswc.navy.mil) or 540.653.8692.*



**Figure 3. AJEM Encounter Visualization Tool (EVT)**



**Figure 4. FATEPEN Damage Prediction**

General Capabilities
Graphical User Interface
Stochastic Variability
Parallel Raytracing
Point-Burst Raytracing
Missile Fuzing
Conversion Utilities (data & target geometry)
Interaction/Evaluation Capabilities
AP and API Projectiles
HE and HEI Projectiles
Fragments
Warheads
External Blast
Missile Debris
Fire Initiation (Air-Gap Tables)
Output Capabilities
Damage States/Vectors
Presented Area (Ap)
Vulnerable Area (Av)
Probability of Kill (Pk)
Target Pk Plots (Vulnagrams)
Detailed Individual Shot Analysis

**Table 1. AJEM 1.0 Capabilities**

# Pioneers of Survivability

## Donald J. “Jerry” Wallick

by Mr. Dale B. Atkinson

**O**ur Survivability Pioneer article for this issue spotlights Donald J. (Jerry) Wallick, who has held various positions directly related to survivability since 1967 and I have known Jerry since that time. When asked, “Why are you still working?” His answer was, “Because the job isn’t done yet.” Followed by, “And because I need a few more sailing lessons before Marge and I can retire to the life of our preference.”

Jerry married Marge Melich, his high school sweetheart, in 1958, three years before he graduated from Fenn College in Cleveland, OH, (now Cleveland State University) with a Bachelor of Mechanical Engineering degree. As luck would have it, his job offer from North American Aviation was withdrawn two months before graduation due to the cancellation of the DynaSoar Program. Fortunately, their marriage still survives.

In June of 1961, Jerry accepted a position as a project engineer for propulsion and power subsystems, at the Air Force’s Aeronautical Systems Division (ASD), Wright Patterson Air Force Base (AFB), Ohio. He was responsible for the development of specifications and qualified products lists for various hydraulic and pneumatic components and subsystems. In 1964, he received a Presidential Citation from Lyndon B. Johnson for his outstanding contribution in creating considerable savings to the Government by conducting and implementing results of a flight test program on the B-52 constant speed drive (CSD) systems that economized oil usage and logistics support. What Jerry remembers most about this program is that the B-52 flight test being flown out of Homestead AFB, Florida was abruptly curtailed by events in Dallas on November 23, 1963, resulting in a long, arduous trip home to Ohio.



**Marge and Jerry Wallick**

Jerry was selected to attend the Air Force Institute of Technology (AFIT) in 1965. After 21 months holed up in his basement study, emerging only to attend class, eat, and sleep, he was granted a Master of Science in Aerospace Engineering degree in 1967. At this point, Jerry embarked on his career in survivability with his selection to a position as Project Engineer and Technical Specialist for Nonnuclear Survivability in the Deputy for Engineering at ASD and promotion to GS-13. Jerry’s responsibilities included nonnuclear survivability engineering support for UH-1, CH/HH-3, F-4, F-105, F-111, A-10, F-15, and B-52. His first task on this job was final coordination on implementing results of Project 5105, a program to identify and correct aircraft vulnerability problems manifesting themselves in heavy losses of airplanes in Southeast Asia. Project 5105 came out of some unconventional intervention in Southeast Asia by an Air Force Flight Dynamics Laboratory team. The fixed wing aircraft phase of the project had been completed just before Jerry was appointed. His job was to coordinate the rotary wing phase. A young Air Force lieutenant by the name of Levelle Mahood had this novel idea that stuffing the fuel tanks of a Jolley Green Giant helicopter with foam would help reduce explosions in combat, and it worked. Other folks Jerry worked with in those days,

and who he also credits with unconventional ideas that worked include; John Kneubuehl, Jim Hodges, Gerry Bennett, and Don Voyls from the Air Force; Roland Bernier, Don Mowrer, Bob Walther, Bob Mayerhoffer, and Walt Thompson from the Army; and Hugh Drake and Millard Mitchell from the Navy. Jerry is quick to point out that he's sure there were others just as influential as these in the survivability business at the time, but these were the main people with whom he worked.

Spurred by the emphasis of the Southeast Asia conflict and the success of the ideas of the above people, the Deputy for Engineering survivability organization grew over the next few years from three people, Paul Gray (nuclear engineering), John Kneubuehl (survivability policy and instructions), and Jerry (nonnuclear survivability), to a branch headed by Dick Bachman, from the structures organization, who had participated in the nuclear atmospheric testing in the Pacific. Engineers and analysts were pulled from the survivability, structures, and avionics organizations to form the Branch with a Nuclear Survivability Group and a Nonnuclear Survivability Group.

In 1976, Jerry became chief of the Branch of thirty military and civilian scientists and engineers working in the areas of aircraft and missile survivability, vulnerability, and logistics support aspects of sortie generation. The Survivability Branch mission included survivability design engineering, digital computer simulation, modeling, and data base development and maintenance. The systems supported included A-10, F-15, F-16, B-1, T-46, HH-60, Air Launched and Ground Launched Cruise Missiles, and the Advanced Tactical Fighter (which became the F-22). Support to the A-10 program included development and implementation of the use of live fire testing within the Air Force to incorporate vulnerability reduction techniques as an integral part of aircraft design. Jerry attributes much of the success of the A-10 survivability program to the unrelenting efforts of Capt Joe Pharmer and his memorable "Pharmergrams." Recruits Jerry brought to the Branch, who remain distinguished members of the survivability community, include Hugh Griffis, Marty Lentz, Matt Kolleck, Manny Rodriguez, and Jordan Wescott. In an effort to solve the hydrodynamic ram analysis problem on the original B-1A, the Air Force and Rockwell brought in a structural analysis expert, a Dr. Robert E. Ball, from the Naval Postgraduate School. Jerry points out that they really didn't solve the problem, but he

hoped they provided a sufficient challenge and incentive for Bob when he was later asked to write a book on design for aircraft combat survivability by the JTCCG/AS. Jerry was also the ASD representative on the implementation team led by Don Voyls for the Combat Data Information Center (CDIC), the forerunner of the Survivability/Vulnerability Information Analysis Center (SURVIAC). Jerry also remembers participating in some of the organizational meetings for the Joint Technical Coordinating Group on Aircraft Survivability (JTCCG/AS) in 1971. His memories are particularly clear on one particular meeting where the Principal Members were to choose their chairman. In order to show Air Force commitment, Jerry was to propose that the Air Force Systems Command Principal, Col Lyle Cameron, be appointed chairman. Needless to say, he failed as Col Cameron's campaign manager, and the Navy's CDR



**In 1976, Jerry became chief of the Branch of 30 military and civilian scientists and engineers working in the areas of aircraft and missile survivability. Systems supported included the A-10, F-15, F-16, B-1, and T-46. Official DoD photo by SMSGT Owen Clouss.**

"Moose" Johnson came out of the meeting as chairman. A few years later, Jerry had his turn and served as chairman of the Methodology Subgroup and later as the Air Force Systems Command's Principal Member. Jerry was the first chairman of the newly formed Methodology Subgroup which combined the Vulnerability Analysis Subgroup and the Survivability Analysis Subgroup. Not everyone

was in favor of combining these two sub-groups, but Jerry's leadership made it work, resulting in a more rational way to work the methodology problems.

In early 1984, Jerry and Marge had successfully raised their two children, Tim and Christine, so they decided to try some new challenges and moved to Long Island where Jerry accepted a position as a survivability technical specialist with Grumman Aerospace Corporation. At Grumman, Jerry was made part of the team led by Dr. Vincent Volpe that was to establish system survivability as an engineering discipline within the System Engineering Directorate. He worked on the F/EF-111 Combat Survivability and Vulnerability Evaluation and Enhancement program and on the F-14 Upgrade Advanced Development (Tomcat-21) program. Other assignments at Grumman included development of survivability and battle damage assessment and repair (BDAR) requirements for research and development of advanced composite structures, smart structures, and advanced avionics; implementation of survivability programs for A-6, F-14, and Joint-STARS aircraft; and survivability analyses into



**As a survivability technical specialist with Grumman Aerospace Corporation, Jerry worked on the F-14 Upgrade Advancement Development (Tomcat-21) program. U.S. Navy photograph of an F-14 Tomcat.**

support proposal efforts including Control Reconfigurable Combat Aircraft, Advanced Tactical Fighter, Space Based Radar, and Space Based Neutron Beam Missile Defense System. While at Grumman, Jerry maintained ties to the JTCG/AS by serving as chairman of the Industry Advisory Group to SURVIAC.

By 1990, Jerry decided they had fulfilled their commitment to the New York State and Suffolk County property tax syndicates and moved to Virginia where he accepted a position as a Research Fellow at the Logistics Management Institute (LMI). Jerry said that access to open water sailing was not so great from Herndon, Virginia, but the tax structure was much better. At LMI, Jerry was the Project Leader for LMI's weapon system BDAR projects sponsored by the Office of the Under Secretary of Defense for Acquisition and Technology (OUSD(A&T)), the JTCG/AS, the Director, Operational Test and Evaluation (DOT&E), and the U.S. Marine Corps. He developed system acquisition guidelines and standards, system evaluation methods, design criteria and guidelines, technology research and development strategies, integration of BDAR issues into the OT&E process, and BDAR doctrine, training, and materiel requirements for ground combat vehicles. These projects brought Jerry into renewed relationships with folks like Don Voysl and into new relationships with folks like Dick Hoy, Dick Jackson, Joe Jolley, RADM Bob Gormley, USN (Ret), and Tom Julian. He had joined the American Institute for Aeronautics and Astronautics (AIAA) and the American Defense Preparedness Association (ADPA), the predecessor of the National Defense Industrial Association (NDIA), and became known as the BDAR advocate in both the AIAA Survivability Technical Committee (STC) and in the NDIA Combat Survivability Division (CSD). Bob Gormley was so impressed by Jerry's knowledge of BDAR, that he asked him to organize the first DoD/NDIA symposium focused solely on BDAR, which was very successful. Also, in 1995, the AIAA Survivability Technical Committee elected him chairman. Jerry did a super job on both groups and he felt these were very gratifying experiences that he thoroughly enjoyed.

In 1997, the Institute for Defense Analyses (IDA), thanks to the move of Don Ockerman to Florida and the retirement of Paul Okamoto, was in search of someone to become a member of their project team for supporting aircraft Live Fire Test and Evaluation (LFT&E)



**As a member of the Air Team, Jerry is the IDA lead for LFT&E on the B-1, B-2, F-22 and C-130J. Official DoD photograph by Staff Sgt. David J. McCarrison.**

and the Joint Live Fire (JLF) program. Being one who was always in search of a longer commute, Jerry applied for air team membership and was accepted. So, since the Spring of 1997, Jerry has been a member of the research staff at IDA. As a member of the Air Team led by Larry Eusanio, he is the IDA lead for LFT&E on B-1, B-2, F-22, and C-130J, and the alternate for the Joint Strike Fighter (JSF). He also participates on the IDA planning and reporting team supporting the Joint Live Fire (JLF) program. Jerry feels that this position gives him the opportunity to get more involved in the overall survivability community while still retaining contact with BDAR, since he also serves as the IDA focal point for BDAR. IDA also allows him to maintain AIAA/STC and NDIA/CSD participation. He is currently chairman of the AIAA/STC Test & Evaluation Working Group and has recently been appointed chairman of the Awards Committee of the NDIA/CSD.

When asked what stands out the most in the 32 years since he became involved in survivability and what still needs to be done, Jerry remembers an interesting question from the audience during his first JTCCG/ME conference in 1968 that seems painfully appropriate yet today. He doesn't know for sure who asked it, but thinks it was Dr. Joe Sperrazza (see Pioneer Article on Hugh Drake in the Spring 1999 issue of *Aircraft Survivability*). The question was, "We have been doing this aircraft vulnerability analysis methodology development for twenty years now, why are you still arguing over component Pk/h?" Unfortunately that twenty years is now fifty and people are still arguing. Jerry

believes the root of the problem is two-fold. First, the pace of technology development is such that component Pk/h values have an extremely short half-life. Materials and architectural characteristics for both components and threats change drastically from one system to the next, even from one system model to the next. This renders the component Pk/h obsolete very quickly. Second, the priority given to appropriate test and analysis to maintain component Pk/h databases is totally inadequate. Jerry also feels that an unfortunate situation has developed that goes well beyond component Pk/h data. He sees drastically unbalanced funding lines favoring what he calls modeling and simulation for the sake of pretty displays versus scientific analysis. He is concerned that graphical user interfaces (GUIs) seem to be more convincing to the decision-makers than valid databases. Jerry would like to see more funding and priority put on component testing and analysis to provide valid component Pk/h data to support new materials and designs for modern aircraft.

I have known Jerry for 32 years and have always been impressed by his technical and leadership capabilities as well as his cooperative attitude. Jerry was one of the reasons the JTCCG/AS worked in the first place. He always put the aircraft survivability design discipline and interservice cooperation ahead of his own personal interests. He was truly one of the Pioneers of Survivability.

*Dale Atkinson is a consultant in the aircraft combat survivability area. He retired from the Office of the Secretary of Defense in 1992 after 34 years of government service and remains active in the survivability community. Mr. Atkinson played a major role in establishing survivability as a design discipline and was a charter member of the tri-service JTCCG/AS. He was also one of the founders of the DoD sponsored Survivability/Vulnerability Information Analysis Center (SURVIAC). He may be reached at 703.451.3011 or via E-mail at dba@erols.com.*



## Professor Ball Receives Art Stein Award

by Mr. Dale B. Atkinson

Professor Bob Ball received the Art Stein Award at the Live Fire Test and Evaluation National Workshop, held at the University of Texas in Austin on May 8–12, 2000. Mr. Jim O'Bryon, the Deputy Director, Operational Test & Evaluation/Live Fire Testing, Office of the Secretary of Defense, presented the award to Professor Ball during an awards luncheon at the workshop. The award is an engraved silver stein named after an early pioneer in the vulnerability area from the Ballistic Research Laboratory (BRL), who was well respected by everyone in this field. Mr. O'Bryon's citation of Professor Ball, presented in conjunction with the award, read as follows:

I am very pleased to present the Art Stein Award to Distinguished Professor Robert E. Ball. Bob has been a major force in efforts to establish survivability as a design discipline for many years. The JTCG/AS, established in 1971 as a result of the very large number of U.S. aircraft lost in Vietnam, had a primary goal of establishing aircraft combat survivability as a design discipline. Bob believed that in order for combat survivability to become an accepted design discipline, an educational program must be developed. In 1977, while on the faculty of the Department of Aeronautics and Astronautics at the Naval Postgraduate School (NPS), he developed the first combat survivability course ever to be offered at an educational institution as part of its regular curriculum. Survivability is now a part of the educational skill requirements for the NPS Aeronautical Engineering Curriculum.

Professor Ball has written the only textbook on survivability, *The Fundamentals of Aircraft Combat Survivability Analysis and Design*. His textbook was sponsored by the JTCG/AS and published in 1985 by the American Institute of Aeronautics and Astronautics (AIAA) as part of its educational series. AIAA has sold approximately 10,000 copies (with over 3,000 going to DoD), and the book has been a best seller for the AIAA

for many years. The book has been widely recognized as a major factor in formally establishing survivability as a design discipline and has been used throughout the survivability design, analysis, and test community, both government and industry, as well as in educating program managers and other high-level acquisition community members. For example, NPS Superintendent RADM Mercer sent a copy of the book to the Secretary of Defense in 1993 as an example of the goals and vision of NPS.

In addition to his for-credit course, Professor Ball presents a 5-day short course and a 3-day shorter course on survivability that have been taught over 60 times throughout the United States, at NATO in Europe and Canada, in Greece, and in Great Britain. A typical 1-week short course at NPS is attended by 150 students. Since 1977, Professor Ball has taught approximately 4,000 U.S. military officers, DoD civilians, and personnel in the U.S. aircraft industry, the fundamentals of the discipline. He is the only individual in the world who teaches all aspects of survivability.

As a result of the concern of the U.S. Congress about the vulnerability of U.S. military aircraft and other platforms, Congress passed legislation in fiscal year 1987, known as the Live Fire Test (LFT) law, that requires realistic vulnerability testing of major weapons systems in acquisition before they can proceed beyond low-rate initial production. As a result of the controversy that developed concerning the LFT law, the Office of the Secretary of Defense requested that the National Research Council (NRC) conduct a review of the current methodology for the vulnerability assessment of aircraft and the DoD Live Fire Test and Evaluation (LFT&E) program. In May 1991, NRC created the Committee on Weapons Effects on Airborne Systems to conduct the study, and Bob was appointed as the Chair of the committee. The committee's report, *"Vulnerability Assessment of Aircraft: A Review of the Department of Defense Live Fire Test and Evaluation Program,"* was very well received and led to a wider acceptance of live fire testing as a contribution to aircraft acquisition. The Service LFT&E programs were significantly changed and the guidelines were rewritten as a result of this study.

Professor Ball has always been a strong supporter of other JTCG/AS educational and informational efforts, organizing survivability workshops and symposia and serving as the edi-

tor of the JTTCG/AS Newsletter for many years. In 1989, Professor Ball established the Survivability Technical Committee in the AIAA. In 1994, he was given the title of Distinguished Professor at NPS, and in 1995, he was presented with the Survivability Award by the AIAA. In December 1997, Professor Ball served as an expert witness in the National Transportation Safety Board's public hearing on the TWA 800 mishap. He presented an hour-long lecture on the aircraft combat survivability discipline, with particular emphasis on how the military services protect the fuel tanks from fires and explosions. His lecture was televised live by CSPAN, and portions of it appeared on CNN.

Professor Ball retired from the Naval Postgraduate School in November 1998 as a Distinguished Professor Emeritus. He works as a consultant and is continuing work on the second edition of his survivability textbook for the JTTCG/AS, as well as occasionally presenting his 1-week short course in survivability. For his pioneering efforts in establishing survivability as a design discipline, Professor Robert E. Ball is presented the Art Stein Award for the year 2000.

I think that I speak for the total survivability community in congratulating Bob and saying that this award is extremely well deserved. Bob has been a major factor in establishing survivability as a design discipline and continues to be a mainstay in this area as the discipline moves into the 21st century. Bob, from the total survivability community, thanks for everything you have contributed! We appreciate you!

*continued from page 17*

tracking of aircraft vulnerable areas. Table 1 summarizes the F/A-18E/F live fire tests conducted.

## **For the Record**

Although specific results are classified, it can be said that the Live Fire Test program results confirmed that the F/A-18E/F aircraft is more survivable than any of its predecessors.

Probably the most noteworthy accomplishment of the F/A-18E/F total LFT test program was the successful integration of the dry bay fire suppression system. This system uses solid propellant gas generators to store and disperse the inert agent in selected dry bay areas of the aircraft. The first three phases of the test produced many lessons learned with respect to integrating such systems into an aircraft. These three phases had the following objectives—

- **Phase I**—Demonstrate the effectiveness of the system against both missile fragment and HEI (High Explosive Incendiary) projectile impacts.
- **Phase II**—Determine the optimum quantity, distribution, and duration of inert gas for suppression of dry bay fires started by HEI projectiles and demonstrate that redesigned wire bundles and a fore-aft/aft-fore feed concept would be effective.
- **Phase III**—Determine the inert gas concentration, distribution, and duration of the 189-gram generators that would suppress HEI-initiated fires; measure the pressure produced by the generated gas on the aircraft structure; and demonstrate that the improved Fire Suppression Control Alarm hardware and software would operate correctly in a dynamic operational setting.

The final test, performed on the full-scale test article, successfully demonstrated the effectiveness of the full-up, active dry bay fire suppression system in extinguishing ballistically induced fires initiated by a variety of threats.

The F/A-18E/F LFT program demonstrated through test and analysis that this aircraft meets the goals of the ORD. Testing and analysis have also shown that the F/A-18E/F design meets the SD-565 specification requirements and has fulfilled the requirements of the Test and Evaluation Master Plan. The LFT of the SV52 test article was possibly the largest single sequence of ballistic tests performed by the Department of Defense. This background of testing, in combination with the F/A-18's combat experience, makes the F/A-18E/F aircraft the most aggressively protected, and probably the most thoroughly tested, tactical aircraft in the United States military inventory. Results of the LFT program clearly demonstrate that this newest version of the aircraft is more likely to survive combat damage than any of its predecessors.

*Mr. J. Hardy Tyson has worked in Survivability Division at the Naval Air Warfare Center Weapons Division for 17 years. He has supported many aircraft vulnerability reduction and Live Fire Test programs, including AV-8B, V-22, A-12, F/A-18, and JSF. He may be reached at tysonjh@navair.navy.mil*



# calendar of events

## SEP

**25–29 — Wright Patterson AFB, OH**

**Survivability Shortcourse Workshop**

Sponsored by SURVIAC

Course given by Professor Bob Ball

Contact: 937.255.4840, Kevin Crosthwaite

## OCT

**31– 2 Nov — Williamsburg, VA**

**9th Helicopter Military Operations**

**Technology HELMOT National**

**Specialists Meeting**

Sponsored by the American Helicopter Society

Contact: 757.874.8522, Richard Stoessner

## NOV

**13–16 — Monterey, CA**

**Aircraft Survivability 2000—  
Science and Technology Initiatives**

Sponsored byNDIA

Contact: adekleine@ndia.org

**14–16 — Eglin Air Force Base, FL**

**Joint Interim Mission Model  
(JIMM) Meeting**

Sponsored by SURVIAC

Contact: Linda Hamilton, 937.431.2721 or  
Paul Jeng, 937.431.2712

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

SURVIAC

Washington Satellite Office

Attn: Christina McNemar

3190 Fairview Park Drive, 9<sup>th</sup> Floor

Falls Church, VA 22042

PHONE: 703.289.5464

FAX: 703.289.5467

**27–30 — Orlando, FL**

**Interservice/Industry Training,  
Simulation and Education Conference  
2000**

Sponsored by IST, NDIA, NTSA

Contact: Barbara McDaniel, 703.247.2569

**28–30 — Las Vegas, NV**

**BRAWLER and ESAMS Meeting**

Sponsored by SURVIAC

Contact: Linda Hamilton, 937.255.4840

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