THE REAL-TIME ENDGAME ANALYSIS OF THE LETHALITY INDUCED BY THREAT EFFECTS (REALIT-E) CONCEPT

John K. Manion
SURVICE Engineering Company
Belcamp, MD, USA

Abstract

This paper presents a concept of integrating information from ballistic vulnerability testing and analysis with high-fidelity man-in-the-loop flight training simulators to increase the accuracy and confidence in vulnerability analyses and improve the quality of training of aircrew. This concept is called the Real-time Endgame Analysis of the Lethality Induced by Threat Effects (REALIT-E) process.

The REALIT-E process provides a framework to enhance two seemingly disparate areas, vulnerability analysis and aircrew training. This process improves vulnerability analysis by providing real aircrew responses to a given set of damage and improves the training process by exposing aircrews to realistic and threat specific damage. It opens the door for additional cross-fertilization between the vulnerability and training communities that can improve aircraft design, tactics, and mission rehearsal and ultimately result in more survivable aircraft. The full extent of the benefits of the REALIT-E process has yet to be realized.

Introduction

The U.S. Department of Defense has developed sophisticated test and evaluation mechanisms to support the development and fielding of survivable weapons systems. These mechanisms include the live-fire test and evaluation (LFT&E) process. Live-fire testing matches expected threats with a full-up combat ready weapon system or representative subsystems in a testing environment and evaluates the damage mechanisms and failures that result. In support of LFT&E efforts vulnerability analyses are used to evaluate damage effects and explore conditions not tested due to resource constraints. In LFT&E vulnerability analysis for aircraft, the test-derived failures are compared to aircraft performance requirements to estimate the ultimate effect of the failures on the aircraft's ability to maintain controlled flight and/or continue its mission. A critical element in determining the end effect of threat-induced damage is the aircrew's response. With certain damage, the crew's response directly determines the outcome. Obviously, the LFT&E testing process cannot directly measure crew responses due to personnel safety issues. The final evaluation often estimates crew response based on crew interviews, historical data, and/or operational documents. However, each of these sources is, in itself, insufficient in providing a definitive answer.

The results of the tests and vulnerability analyses have a significant impact on the development of the weapons system to ensure that both the equipment and the crew are protected to the maximum degree possible. It is therefore paramount to ensure that all of the elements of the vulnerability analysis and testing processes are as accurate as possible. Improvements to the accuracy of determining crew response to damage are therefore necessary to ensure adequate vulnerability reduction measures are designed into the system.

The use of high-fidelity simulation devices to support training results in crews more capable of successfully completing their mission and surviving to fight again. A crucial element of that training is the ability to generate realistic failures and malfunctions. Typically, failures are introduced at the discretion of the simulator instructor and tend to have little or no correlation with actual threat effects. While this type of training is useful in addressing normal operational malfunctions, it does little to prepare the student for actual combat damage. Real threats can cause multiple failures, which can be exacerbated by inappropriate crew action. To ensure that crews are trained and ready for combat, it is necessary to include realistic damage and failures into the simulated mission.

The REALIT-E concept enhances both the vulnerability analysis and training processes by merging the strengths of each. Through the REALIT-E process, the damage generated from vulnerability testing and analysis is integrated into the high fidelity training simulator giving aircrews realistic cues to threat induced damage. The results of the aircrew responses to damage help fill the vulnerability data voids and allow a better evaluation of the end effects of the damage.

Vulnerability Assessment Process

Description

As illustrated in Figure 1, the LFT&E vulnerability assessment process focuses on the endgame portion of the threat engagement scenario.

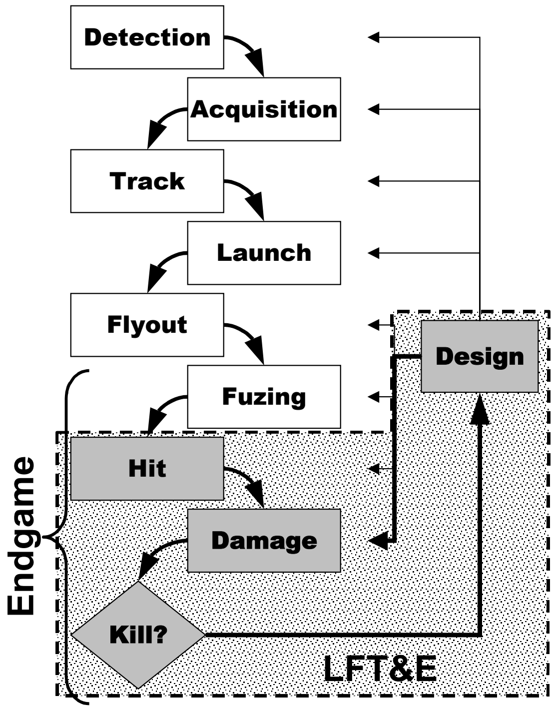

Figure 1. Elements of an Engagement

The challenge of the LFT&E process is to investigate all of the possible hit locations by all of the possible threats that can be encountered in combat. Of course, this cannot be completely evaluated through testing alone. Only by including analysis can the complete picture be obtained. The success of the LFT&E process is a result of the test, analysis, and design loop, as shown in Figure 2.

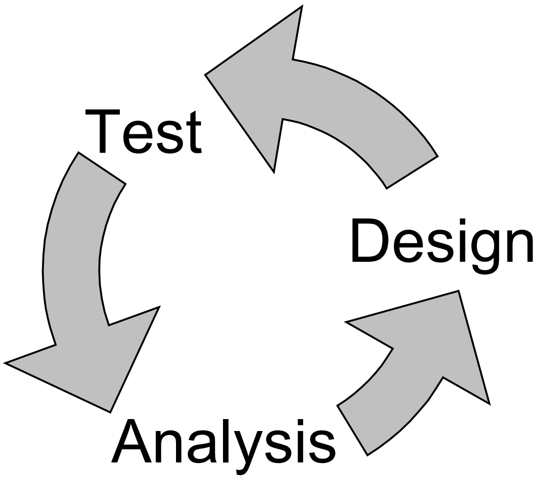

Figure 2. LFT&E Process

The results of the LFT&E process clearly have a significant impact on the development of the weapons system. The vulnerability analysis portion of the LFT&E cycle attempts to quantify the threat's effects on the system by investigating all of the possible encounter conditions and determining the system response to each encounter. If the system response to a threat is negative in a significant number of cases, then a design change is implemented and tested. Sophisticated tools and processes have been developed over the years to support vulnerability analyses.

The elements of the vulnerability analysis process are shown in Figure 3.

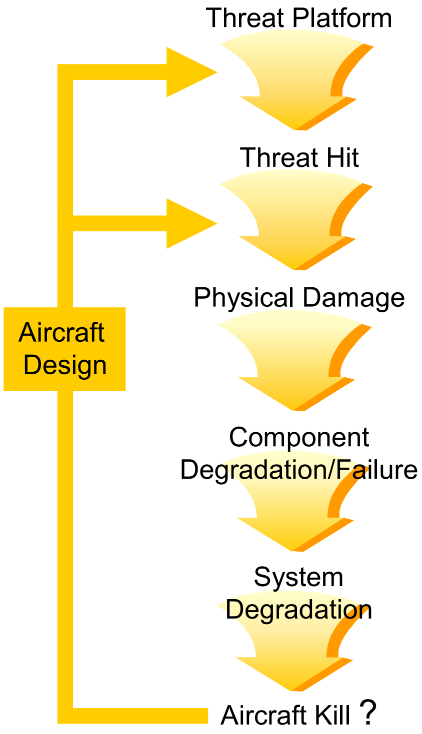

Figure 3. Elements of Vulnerability Analysis

The vulnerability analysis starts with the assumption that the aircraft has been hit by the threat. Of course, the susceptibility considerations determine likely areas of hit that influence the initial conditions of the vulnerability analysis. As shown in Figure 3, a hit results in physical damage to the platform. The vulnerability analysis utilizes testing, modeling, simulation, and existing data to determine the expected damage that results from various hits on the platform. The physical damage affects the platform's components by either degrading them, failing them completely, or causing them to become threats themselves (e.g., burning fuel). Again, testing and experimentation of damaged components combined with modeling and simulation provide the tools necessary to support the vulnerability analysis. The degraded components, likewise, degrade the overall system performance. The vulnerability analyst can determine the system-level degradation through testing and experimentation, through aircraft design and performance information, and through modeling and simulation. The last step in the vulnerability analysis process is determining the impact of the system-level degradation on aircraft performance requirements and assessing whether or not a kill has occurred. Some system-level responses are clearly a kill, such as the aircraft exploding in a fireball. But some system-level responses are not as easily resolved into a kill or no-kill condition. For example, the loss of a single engine in a twin-engine helicopter while in hover could cause the aircraft to impact the ground and result in a forced-landing kill. But if the crew responds quickly enough, they may be able to transition the helicopter to forward flight without losing too much altitude, thus avoiding the forced-landing kill. Clearly in this case, the crew response is key in determining the probability of the resulting forced-landing kill.

Issues

The process of estimating the end effect of the failures on aircraft performance often must consider the crew's reaction and response to the damage. Crew reaction is typically addressed by reviewing historical data on combat incidents, interviewing aircrews, reviewing aircraft flight manuals, and reviewing aircraft specifications.

Historical combat data are useful in that they relate real combat damage to loss or recovery of aircraft. The limitations of these data are that details of the threat engagement tend to be sketchy at best and any survivable combat damage is, understandably, fixed quickly without much record of the original damage.

Interviews with aircrews are useful in that the perspective of the pilot is directly integrated into the analysis. Their experience and knowledge is extremely valuable for assessing the impact of damage and failures. The limitation of these data is that pilot responses tend to be optimistic and may underestimate the potential for aircraft loss due to a number of factors including task saturation and loss of situational awareness.

The emergency procedures in the aircraft flight manuals are another useful source of data. They clearly describe the procedures to follow given sets of damage. The limitation of this information is that it is developed for latent failures expected to be encountered based on reliability considerations. The multiple, cascading, and time-dependent failures associated with combat damage are not considered.

Aircraft specifications contain information on expected performance under certain conditions and provide a useful tool in determining system response to some failures. The limitation of these data is that the specifications do not consider all of the potential changes in aircraft performance that can result from combat damage.

All of these data sources, while valuable in supporting the decision of determining aircraft kill are insufficient in giving a complete answer. In the end, the analyst and/or engineer must decide the impact of crew reactions to damage on aircraft survivability.

Manned Simulator Training Process

Description

A typical simulation-based training scenario is illustrated in Figure 4.

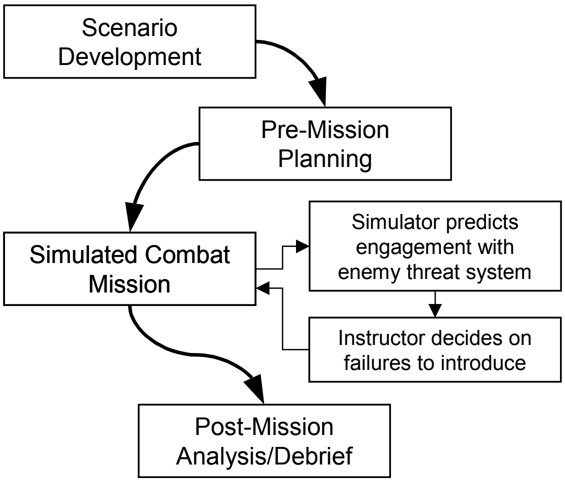

Figure 4. Simulation-based Training Process

The instructor pilot develops the training scenario by considering the training requirements, tactics to be tested, systems involved, and pilot experience. For this task, the instructor relies on training and aircraft manuals, doctrines, and flight records. After the instructor defines the mission and scenario, the crew performs the pre-mission planning by considering the mission goal and profile, tasking, assets involved, threat profiles, and system capabilities. After the plans are made, the crew enters the simulator and flies the mission. During the mission, the simulator models aircraft performance, environmental effects, and interactions with threat systems. The crew responds to all of the stimuli in an attempt to successfully complete the mission. If a threat system engages the aircraft, the crew responds to try to avoid the hit. Some mission level simulators will even fly out the missile and determine if a hit occurs. Upon receiving the hit, the instructor may introduce failures and observe the crew response. Often these failures are introduced at the discretion of the instructor with little or no considerations for the threat, attack aspect, or hit point. Upon mission completion, or termination, the instructor debriefs the crew. This debrief includes discussion of the mission performance, systems management effectiveness, and effectiveness of crews reactions and contingencies.

Issues

A crucial element of simulation-based training is the ability to generate equipment and system failures or malfunctions that require the crew to analyze the source of the failures and take appropriate steps to initiate a corrective action. These failures typically have little or no correlation with actual threat effects. While this type of training tests the ability of the student to exercise the Emergency Procedures (EP) in the context of a mission, it does little to prepare the student for the actual damage effects caused by real threats. Real threats differ in that they may cause multiple failures that are seemingly unrelated and create cascading, time-dependent, and/or crew-action-dependent failures.

REALIT-E Concept

Description

The REALIT-E process is designed to address the vulnerability analysis and manned simulator training process issues by taking advantage of the strengths of each process. For vulnerability analysis, REALIT-E directly addresses the aircrews' responses to damage by using the information available from multiple manned flight simulator sessions. This provides statistically significant information to support the determination of the end effects of damage for vulnerability analysis. In return, REALIT-E provides realistic damage cues to the aircrew during the mission, which enhances crew training.

The REALIT-E process starts by compiling the LFT&E information and historical data offline to generate a matrix of possible system and component failures based on threat type and engagement parameters. To create this matrix, vulnerability data are generated and formatted for the threat systems of interest using standard vulnerability analysis processes. Vulnerability analysis determines probable damage and failure mechanisms for a given threat endgame condition. The endgame condition is defined as direction of impact with respect to the aircraft, inherent threat properties (e.g., mass, warhead properties, etc.), and threat properties as a result of the engagement (e.g., velocity, orientation, hit point, etc.). For a given endgame condition, component failures are determined and the respective system-level degradations are identified. Through the REALIT-E process, these derived threat effects are mapped to the available simulator malfunctions to allow a real-time implementation in the simulator. If, during a simulated mission, a threat engagement leads to a "hit" the pre-mapped malfunctions will be injected based on the threat and endgame conditions. The inserted malfunctions will allow for the consideration of time dependency of failures, failures caused by subsequent crew actions, and cascading effects. The REALIT-E process will still allow for the instructor to inject his/her own sets of malfunctions or he/she can select from a predefined list of realistic, threat-specific failures. Through REALIT-E's automated data acquisition software, parameters of the engagement will be measured, collated, and stored into a pilot and aircraft response database. This database will enhance post-mission debriefs and will directly support vulnerability analysis by providing a statistically significant database of crew responses to damage. A concept of the simulation-based training process that includes REALIT-E is shown in Figure 5, where the REALIT-E specific elements are shown as shaded boxes.

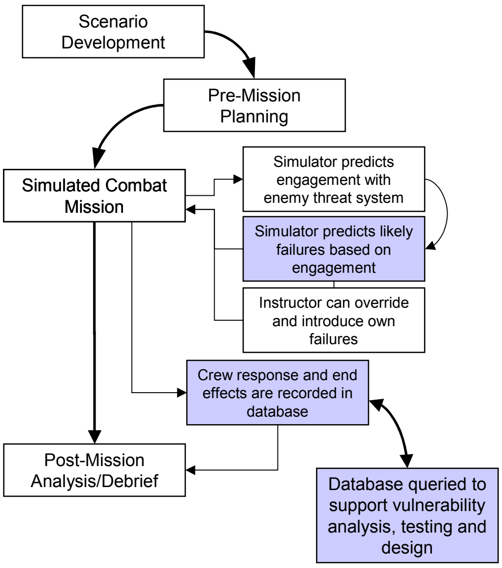

Figure 5. Simulator Training Process Using REALIT-E

Developing the vulnerability data and matrix of system failures does not require the development of any new tools. It simply uses the standard tools and processes in place for over 30 years. The process of mapping the system failures to simulator malfunctions will require coordination between the vulnerability engineers and simulator engineers and will most probably require software modifications to the simulator. Other aspects of implementing the REALIT-E process that will require simulator software modifications are for automatic insertion of failures and automatic data acquisition. Additional offline software tools are also required for the post mission analysis and integration back into the vulnerability analysis process.

Benefits

Clearly, the most direct benefit of the REALIT-E process is on aircrew training. This process exposes crews to realistic damage effects in the context of real mission profiles. It trains the aircrews to think beyond the standard emergency procedures in the heat of the battle. It also exposes the crew to the realistic cues of damaged systems and the degraded performance characteristics. This results in a level of realism that currently can only be experienced during combat. This gives the aircrew an expanded understanding of their aircraft, which provides the edge to allow the crew to continue the fight and/or safely return to base.

The second benefit, which is actually what spawned the REALIT-E concept, is the improvement to the LFT&E vulnerability analysis process. The data from the REALIT-E database will directly support vulnerability evaluations by providing real aircrew responses to real damage. This information will allow for the final determination of the impact of the damage on aircraft performance. This will give more accurate and defendable evaluations of aircraft vulnerability, which will result in more survivable aircraft.

Other Potential Uses of REALIT-E

The REALIT-E process will provide benefits throughout the design and life-cycle of the weapons system. The support for LFT&E will enhance the engineering and manufacturing development phase by providing better data to reduce aircraft vulnerability in the design. During operational testing (OT), the data generated and lessons learned will be available to the OT aircrews to support their assessment of the platform and development of tactics, techniques, and procedures (TTPs). REALIT-E also has the potential to enhance emergency procedures by including battle damage. During the operational deployment of the aircraft, the REALIT-E process will enhance advanced training and mission rehearsal. It will support studies on proposed design changes throughout the life-cycle of the platform.