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On the cover:
A KC-10 Extender Prepares to Refuel a B-2 Spirit *(U.S. Air Force Photo by SrA Keith James).*

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For far too long now, radio frequency (RF) helicopter modeling and simulation (M&S) have been grossly inadequate to achieve statistically relevant outcomes for developers or tacticians. This capability gap has been well known throughout the rotary-wing survivability community, but ad hoc models have thus far provided limited results. Accordingly, members of the Susceptibility Reduction Working Group (SRWG), a cohort of rotary-wing developmental modeling and tactical experts, have been collaborating with the Air Force Life Cycle Management Center/Systems Analysis and Training Systems Division (AFLCMC/EZJ) to develop a new framework and graphical user interface (GUI), conforming current M&S tools for low-altitude rotary-wing aircraft operating in clutter.

In 2015, the Deputy Secretary of Defense tasked the Joint Staff to improve requirements for weapon systems cybersecurity, which resulted in adding a Cyber Survivability Endorsement (CSE) to the Joint Capabilities Integration and Development System (JCIDS) Manual's System Survivability Key Performance Parameter (SS KPP). The tasking was driven by the 2015 Director of Operational Test and Evaluation (DOT&E) annual report, which highlighted the same high-risk vulnerabilities being found in almost every tested system, and these repeated vulnerabilities should have been fixed prior to operational test and evaluation (OT&E).

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FROM THE DIRECTOR'S DESK

by Dennis Lindell

Thank you for your readership and support of the *Aircraft Survivability* journal.

For more than 50 years, the Joint Aircraft Survivability Program (JASP) has supported the research, development, test, and evaluation (RDT&E) of combat-proven aircraft survivability capabilities for the U.S. military. First chartered as the Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS) in 1971 in response to the high aircraft loss rates the U.S. was suffering in Southeast Asia, the JTCG/AS focused the community on *susceptibility reduction* (design characteristics that make an aircraft harder to detect) and *vulnerability reduction* (design characteristics that give an aircraft the ability to withstand a hit). Later, *modeling and simulation* (M&S) for survivability assessment and the *establishment of aircraft survivability as a formal design discipline* became additional focus areas of the JTCG/AS.

Rechartered as JASP in 2005, the group has continued its mission to "achieve increased affordability, readiness, and effectiveness of tri-Service aircraft through the joint coordination and development of survivability (susceptibility and vulnerability reduction) technologies and assessment methodologies." To accomplish this mission, JASP focuses on:

- Exchanging aircraft survivability information with the Services to increase the combat effectiveness of military aircraft in threat environments.
- Identifying aviation capability gaps that require aircraft survivability RDT&E and ensuring the gaps are addressed in a joint warfighting context.
- Implementing RDT&E that complements Service aviation survivability programs.
- Investigating and reporting on combat damage incidents, through the Joint Combat Assessment Team (JCAT).
- Instilling a common understanding of aircraft survivability concepts, methods, and tools in current and future analysts, developers, and leaders. (One method is through support of aircraft combat survivability education—such as from the Naval Postgraduate School and Air Force Institute of Technology—for military, Department of Defense [DoD] civilian, and DoD contractor personnel.)
- Interfacing with other DoD programs, the intelligence community, other federal agencies, and industry to improve military aircraft survivability.

The JASP mission also requires the ongoing coordination and funding of many technical projects. Our coordination focuses on facilitating information exchange and education and aligning efforts toward common goals. The primary vehicles we use for this coordination are the following:

- **Online and Print Publications**
  - The JASP website (for public release information; see http://jasp-online.org)
  - The JASP space on DoDTechipedia (for public release and controlled unclassified information [CUI]; see https://www.dodtechipedia.mil/dodwiki/x/IYY8KQ)
  - The Aircraft Survivability journal (for public release information; published three times/year)
  - *The Fundamentals of Aircraft Combat Survivability* textbook
  - *The JASP Specialist Directory* (online in the JASP space on DoDTechipedia)
- **Training**
  - JCAT Threat Weapons Effects (TWE) Training
  - Aircraft Combat Survivability Short Course
- **Sponsored Joint Meetings**
  - JASP Model Users Meeting
  - JASP Program Review
  - JASP Proposal Review Meeting
  - Susceptibility Reduction Working Group
  - M&S Configuration Control Boards (for SLATE, BRAWLER, COVART, BlueMax, and Next Generation Fire Model)

- **JASP RDT&E Documents**
  - ~500 reports since 2003 entered in the Defense Technical Information Center (DTIC)
  - >86% project publishing rate
  - JASP M&S tools archived in the Defense Systems Information Analysis Center (DSIAC)
- **Aircraft Survivability Working Groups**
  - Vulnerability Assessment and Reduction
  - Susceptibility Assessment and Reduction.

The relevancy of JASP and its efforts can be seen daily as U.S. forces execute their important missions on battlefields around the globe. In addition, the progression of aircraft survivability understanding and capability in the face of ever-capable threats and complex, multidomain theaters of operation demonstrates both the success of the aircraft survivability community in the past and the challenges we are charged to address in the future. Admittedly, some of these challenges are large, but so is JASP's resolve to continue to provide a focal point across the DoD to identify and develop the tools, techniques, and technologies needed to address them.

In conclusion, as you read through this issue of *Aircraft Survivability*, I hope you'll find the content to be informative, interesting, and useful. The journal is intended to provide an ongoing opportunity for aircraft survivability practitioners to share ideas, recognize accomplishments, and coordinate efforts across our common areas of interest. It's also a real-time reflection of the remarkable ingenuity, dedication, and professionalism of our aircraft survivability community. And it's not possible without your participation. Therefore, I want to challenge each reader to share an article in this issue with a colleague, as well as to submit his/her own article for publication in 2023.

Sincerely,

Dennis Lindell

NEWS NOTES

by Dale Atkinson and Eric Edwards

2022 AIRCRAFT SURVIVABILITY SHORT COURSE HELD IN VIRGINIA

At the end of May, approximately 100 Government and industry students attended a 3-day short course in aircraft combat survivability at the new headquarters for the Institute for Defense Analyses (IDA) at Potomac Yards in Alexandria, VA. This classified short course—which was sponsored by the Joint Aircraft Survivability Program (JASP) and Office of the Director, Operational Test and Evaluation (DOT&E)—featured speakers, presentations, demonstrations, and discussions from across the aircraft survivability community. The purpose of the annual course is to help military aviation developers, testers, researchers, program management and acquisition personnel, pilots, and other practitioners better understand how to increase the survivability and combat effectiveness of manned and unmanned air platforms.

The keynote address for this year's course was given by retired Gen. Norton Schwartz, former Air Force Chief of Staff and current IDA president and CEO. Other presentation topics included:

- Integrated Survivability Assessment, Survivability Testing, and Trade Studies
- Kill Chain; 1v1, Mission, and Campaign Survivability; System Safety
- Survivability Enhancements
- Live First Test and Evaluation/Joint Live Fire
- Joint Combat Assessment Team/ Aviation Survivability Development and Tactics
- Analysis of Air Combat Data
- Current Threats Intelligence/ Surface-to-Air Fires Threat Analysis
- Aircraft Cyber Combat Survivability
- Susceptibility Overview, Threat Operations, Acoustics, and Visual Signatures
- Susceptibility Radar Signature, Electronic Warfare
- Susceptibility Infrared Signatures
- IR Engine Signatures
- Vulnerability Overview, Threat Effects, and Damage Processes
- Critical Components and Vulnerability Assessment
- Vulnerability Reduction Technology
- Force Protection and Recoverability
- Army and Navy Rotary-Wing Tactics
- Fighter Aspects of Survivability
- Aircraft Survivability Design and Optimization and Basic Design Process

Special thanks are extended to Dr. Mark Couch from IDA for arranging this year's host venue and keynote speaker. For more information on the 2022 short course or to inquire about being a part of next year's course, please contact Prof. Christopher Adams at the Naval Postgraduate School at caadams@nps.edu.

U.S. Army Photo by CW2 Cameron Roxberry

NEW AJEM VERSIONS RELEASED

In May, the U.S. Army Combat Capabilities Development Command (DEVCOM) Analysis Center (DAC) released v4.22.2 of the Advanced Joint Effectiveness Model (AJEM). The release includes new capabilities and corrective updates to improve and advance methods used in the ballistic vulnerability/lethality (V/L) analyses of Department of Defense (DoD) air, ground, sea, and soldier systems. Most notably, v4.22.2 integrates the latest version of the Operational Requirements-based Casualty Assessment (ORCA) model (v4.62.2).

Additionally, AJEM v4.22.3 is planned for release this fall and is expected to enable users to more seamlessly integrate AJEM analysis results into analyses of higher-level effectiveness models. For example, v4.22.3 will provide DEVCOM Armaments Center the ability to integrate AJEM into its Performance Related and Integrated Suite of Models (PRISM) software. PRISM is a mission/engagement-level simulation tool that can incorporate physics-based and statistical models to feed data into campaign-level models.

For more information about AJEM and these versions, readers are encouraged to contact the AJEM Model Manager, Ms. Marianne Kunkel, at marianne.kunkel.civ@army.mil. To obtain the latest version of AJEM, qualified users should contact the Defense System Information Analysis Center at *https://dsiac.org/models/ajem/*.

U.S. Air Force Photo by TSgt. Matthew Fredericks

FIRST RED HAWK TAKES FLIGHT

In April, the first unit of the Air Force's new jet trainer, the T-7A Red Hawk, rolled off the production line at Boeing's manufacturing facility in St. Louis, MO. The jet is the Service's first new advanced trainer since the T-38 Talon entered service more than 60 years ago. In addition, the plane is said to be the first aircraft to be fully digitally designed, moving from computer screen to first flight in 36 months.

The Red Hawk, whose name and distinctive color were chosen in honor of the famed Tuskegee Airmen "Red Tails" of World War II, is expected to be much more adaptable than it predecessors. Its open-architecture software will accommodate the addition of new capabilities and training elements to keep pace with ever-changing Air Force requirements and technologies. Furthermore, the jet's high-end performance is expected to make the aircraft suitable for other roles beyond just pilot training, including potential adaptation and exportation as a light fighter. The Red Hawk is currently scheduled to reach initial operational capability in 2024, with the Air Force planning to buy at least 351 units.

HISTORIC HYPERSONIC TEST CONDUCTED

In May, the Air Force successfully tested the first air-launched hypersonic weapon, releasing an AGM-183A Air-launched Rapid Response Weapon (ARRW) from a B-52H Stratofortress flying off the California coast. During the test, the ARRW—or "Arrow"—demonstrated its booster ignition and burn capabilities and achieved hypersonic flight speeds 5 times greater than the speed of sound.

The historic flight was executed by the 419th Flight Test Squadron and the Global Power Bomber Combined Test Force, based at Edwards Air Force Base, CA. The ARRW is being designed to give U.S. military leaders the ability to hold fixed, high-value, time-sensitive targets at risk in contested environments from extreme stand-off distances, as well as extend the U.S. military's rapid-response, precision-strike capabilities against heavily defended targets all across the world.


U.S. Air Force Photo by Christopher Okula

U.S. Air Force Photo by SSgt. Max Daigle

FIRST OSPREY REFUELING FROM A KC-46 TANKER

In June, a KC-46 Pegasus tanker was used to successfully refuel a CV-22 Osprey tilt-rotor aircraft in flight near Cannon Air Force Base, NM. The first-of-its-kind refueling used a centerline hose and drogue system (which is used mainly for helicopters, U.S. Navy/Marine Corps aircraft, and foreign aircraft) instead of a boom-type refueling system (which is used for most U.S. Air Force aircraft). The accomplishment not only adds yet another aircraft to the new tanker's potential support inventory but also demonstrates the expedited Osprey refueling process that the use of the Pegasus promises. Traditionally, the process has required multiple trips by an MC-130J to fly to a tanker to get fuel and then fly to the Osprey to transfer it. ASJ

HEARD ANY NEWS?

If you know of a community-related event, announcement, or other news item that you would like to submit for consideration as a News Note, please contact Mr. Dale Atkinson at daleatk@gmail.com.

JCAT CORNER

by Capt. Daniel Adducchio, CDR Joseph Walker, and Bart Schmidt

The Joint Combat Assessment Team (JCAT), composed of U.S. Army, Navy, and Air Force contingents, continues to train aircraft combat damage assessors in anticipation of future requirements to gather evidence from aircraft hostile fire incidents, provide immediate threat data to combatant aircraft unit commanders, and make data available for engineering improvements to reduce the loss of lives and aircraft.

Since our last update, 20 JCAT student assessors completed Phase II and III training required to qualify as trained aircraft combat damage assessors. In March, the Navy hosted JCAT Phase II training at Naval Air Weapons Station (NAWS) China Lake, CA. During Phase II training, JCAT trainees from the Navy, Army, and Air Force applied threat knowledge and forensic assessment principles that were learned in Phase I at Fort Rucker last January to complete a number of practical field exercises in the Navy's combat damage boneyard. The exercises, which included a night assessment, helped advance the students' ability to gather data and make systematic conclusions on actual threat damage in a variety of field conditions. Additionally, a weapons demonstration provided immediate effects for students to take advantage of increased knowledge of weapons engagements.

The capstone event of JCAT training, JCAT Phase III, is the annual Threat Weapons Effects (TWE) seminar. TWE draws information from threat exploitation, live fire testing, and combat experience to provide a comprehensive picture on threat lethality. This year, Navy JCAT hosted the TWE seminar at Eglin AFB, FL, in May, bringing together more than 200 military and civilian subject-matter experts in the fields of

survivability, intelligence, and aircraft operation fields. Briefing topics included:

- Modern Integrated Air Defense System (IADS) Threats
- Russia/China/Iran Air Defense Artillery
- An Update on Man-Portable Air Defense Systems (MANPADS)
- Warhead Design, Effects, and Future Trends
- Directed Energy Weapons
- Live, Virtual, Constructive Capability
- Overviews on Surface-to-Air Missiles.

In addition, a keynote address was provided by retired Air Force Col. Travis Willis on his perspectives as an F-111 pilot in the Gulf War.

Navy JCAT also coordinated a live fire demonstration with the 96 OSS at the Eglin test range consisting of two static detonations of two surface-to-air warheads in proximity to two F-15 vertical stabilizers. The aircraft components were put on display outside the briefing hall for participant and transported to the Army Combat Forensics Lab at Fort Rucker, AL, to use as training devices during JCAT Phase I training. The dates, location, and registration details for next year's TWE, which will be hosted by the Air Force, will be provided through the Defense Systems Information Analysis Center (DSIAC) at a later date.

With the completion of the JCAT phase training class of 2022, 20 Joint personnel are now fully qualified JCAT assessors. Of particular note, Air Force 2nd Lt. Kervin Reyes-Lozada, who is currently in an on-alert status and ready to deploy in support of battle damage repair, completed training with this class and now stands ready to provide JCAT duties in addition to battle damage repair.

Lastly, the Army JCAT team would like to welcome CW4 Richard Barnett in joining the team and to bid a fond farewell to CW3 Paul Olson, CW4 Mark Chamberlain, and CW5 Tyson Martin. Paul's and Mark's diverse backgrounds

Photo by SGT Igor Paustovski, Courtesy of Wikimedia Commons

as former infantrymen and aviators will be greatly missed as they begin well-earned retirements. As for Tyson, he is off to Joint Base Lewis-McChord, WA, assigned to the 16th Combat Aviation Brigade. The entire JCAT would like to thank all three of these individuals for their service to JCAT, the Army, and the country, and we wish them and their families the best of luck on their next adventures. ASJ

JOINT AIR THREAT MODEL SIMULATION VALIDATION: DEALING WITH THE CLUTTER IN ROTARY-WING M&S

by Bart Schmidt

Photo by MSG Becky Vanshur, Idaho Army National Guard

For far too long now, radio frequency (RF) helicopter modeling and simulation (M&S) have been grossly inadequate to achieve statistically relevant outcomes for developers or tacticians. This capability gap has been well known throughout the rotary-wing survivability community, but ad hoc models have thus far provided limited results. Accordingly, members of the Susceptibility Reduction Working Group (SRWG), a cohort of rotary-wing developmental modeling and tactical experts, have been collaborating with the Air Force Life Cycle Management Center/Systems Analysis and Training Systems Division (AFLCMC/EZJ) to develop a new framework and graphical user interface (GUI), conforming current M&S tools for low-altitude rotary-wing aircraft operating in clutter.

The SRWG is working to develop a new framework and GUI, conforming current M&S tools for low-altitude rotary-wing aircraft operating in clutter.

As a result of this working group's efforts, several tools have made remarkable advances in rotary-wing M&S capabilities [1]. These include:

- **BlueMax** – a point-mass flight dynamics simulation used to construct realistic air-vehicle time, space, position information (TSPI) data for input into other models, analysis tools, and environments for the purpose of conducting aircraft susceptibility analyses [2].

- **Enhanced Surface-to-Air Missile Simulation (ESAMS)** – a tool used to model the interaction between an airborne target and radar surface-to-air missile (SAM) systems. ESAMS has begun incorporating rotary-wing models, including dynamic radar cross section, Doppler effects, chaff and clutter effects, and improved radar features for RF SAM threat systems.
- **REACTr** – a multispectral data fusion tool providing ESAMS with near-truth chaff cloud characterization. REACTr's novel technique greatly improves the capability to capture the dynamic characteristics of chaff flow fields and bloom rates that affect the spatial and spectral chaff characteristics over time with regard to the threat aspect.
- **Joint Anti-Air Model (JAAM)** – a tool used to develop and validate operational tactics for aircraft and weapons. JAAM enables test personnel to evaluate weapon system effectiveness from weapon launch through target intercept by displaying results in a graphical 3D environment. In part because of the SRWG, the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME) has now incorporated rotary-wing requirements into the next-generation JAAM v6.0.

In addition, AFLCMC/EZJ has executed numerous JASP JTCG/ME projects to combine these and other tools, develop an intuitive interface, and provide the rotary-wing survivability community with enhanced capability in the form of the Survivability and Lethality of Aircraft in Tactical Environments (SLATE) framework [3]. The SLATE application supports constructive, batch, virtual, post-test event, and virtual test ranges. On a small personal computer, developers and Warfighters alike can conduct analysis regarding product design and tactics. SLATE leverages the Air Combat Effects Library (ACEL), the same math and data module that drives the next-generation JAAM v6.0 application. The SLATE simulation provides the user with both rotary-wing and fixed-wing aircraft operating at high, medium, and low altitudes, including clutter effects.

Unlike with an open-air test, SLATE features a user-friendly interface to give users access to complex simulations to evaluate interactions between an aircraft and threat system throughout the majority of the kill chain. Even more importantly, SLATE users will be able to run these engagements thousands of times from innumerable starting conditions to glean lessons learned that were previously unthinkable.

One of the SRWG's major goals is to prove that most developmental work can be completed in a digital environment, thereby reducing expensive range costs and driving down timelines, while also protecting sensitive operational capabilities that could be exposed in open-air test environments. Upon completion of the Joint Air Threat Model Simulation Validation (JATMS-V), users of SLATE will have a validated simulation environment for single-rotor aircraft—the UH-60M—against a set of RF threat systems. In addition, future JATMS-V events will continue to grow this capability to other aircraft while also adding new threats as they become available.

Over the next few years, rotary-wing engagement scenarios will be evaluated in both constructive and virtual simulations to assess recommended TTP capabilities, ASE, and developmental aircraft survivability nuances against various RF threats.

U.S. Marine Corps Photo by Sgt. Hailey Clay

In May 2022, the SRWG met at the Institute for Defense Analysis (IDA) to discuss and build the Design of Experiment (DOE) for JATMS-V. The group collectively agreed that a DOE using JMP software would be the best methodology to accomplish its test goals, which are to determine with statistical significance (80% power and 80% confidence) that the rotary-wing models are, or are not, valid. A subissue crosswalk was then constructed, connecting 22 test subissues to critical DOE factors (variables). The group further discussed each of these factors, values, confidence levels, constraints, and necessary excursions to achieve a successful test.

IDA analysts are now ingesting this information into JMP to develop the DOE. The DOE report will provide the necessary data to shape the test plan, including number of runs, relationships, statistical relevance, and confidence. The team will continue to shape the test plan and coordinate test range/ assets, aircraft, expendables, and team training. Test execution is projected for March 2023.

In the end, ensuring that these models are valid is critical. Over the next few years, rotary-wing engagement scenarios will be evaluated in both constructive and virtual simulations to assess recommended tactics, techniques, and procedures (TTP) capabilities, aircraft survivability equipment (ASE), and developmental aircraft survivability nuances against various RF threats. In these environments, the maneuvers can be flown by a provided script (constructive) or pilot-in-the-loop (virtual) and repeated numerous times with controlled variables. Data extracted from multiple executions will inform tactics development, ASE research and development, and acquisition decisions of key attributes in breaking the kill chain prior to live test runs. These efforts will ultimately help reduce cost; schedule; and, most importantly, the loss of lives. ASJ

ABOUT THE AUTHORS

Mr. Bart Schmidt is the Training Specialist (Survivability) on the Aviation Survivability Development and Tactics Team and is the Co-Chairperson for SRWG's JATMS-V effort. With 26 years in the U.S. Army and 17 years as a UH-60 Black Hawk pilot, he also has been an aviation mission survivability officer, a combat forensics officer, and a subject-matter expert in aviation susceptibility and vulnerability. Mr. Schmidt holds a bachelor's degree in professional aeronautics from Embry-Riddle Aeronautical University.

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[1] Schmidt, Bart, and Warren Whitmire. "Susceptibility Reduction Using Modeling and Simulation." *Army Aviation*, p. 40, October 2019.

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[3] Air Force Life Cycle Management Center. "Survivability and Lethality of Aircraft in Tactical Environments (SLATE)." Wiki page, https://www.dodtechipedia.mil/dodwiki/display/JAS/SLATE, accessed on 24 May 2022.

DoD SYSTEMS NEED CYBERSECURITY AND CYBER RESILIENCY TO ACHIEVE CYBER SURVIVABILITY

by Steve Pitcher

In 2015, the Deputy Secretary of Defense tasked the Joint Staff to improve requirements for weapon systems cybersecurity, which resulted in adding a Cyber Survivability Endorsement (CSE) to the Joint Capabilities Integration and Development System (JCIDS) Manual's System Survivability Key Performance Parameter (SS KPP). The tasking was driven by the 2015 Director of Operational Test and Evaluation (DOT&E) annual report, which highlighted the same high-risk vulnerabilities being found in almost every tested system, and these repeated vulnerabilities should have been fixed prior to operational test and evaluation (OT&E).

This situation happened because requirements documents did not include contractually binding cybersecurity and cyber resiliency threshold performance requirements and instead relied on compliance with Federal Information Security Management Act (FISMA), National Institute of Standards and Technology (NIST), Committee on National Security Systems (CNSS), and Department of Defense (DoD) guidance. Because the only cyber threshold requirement for legacy systems was for enough cybersecurity compliance to obtain an Authorization to Operate (ATO), the DOT&E had again identified significant cyber risks that would require reengineering to mitigate or remediate them. Unfortunately, the recommended remediation efforts were frequently too costly or performance-robbing to yield operationally acceptable levels of performance and mission assurance.

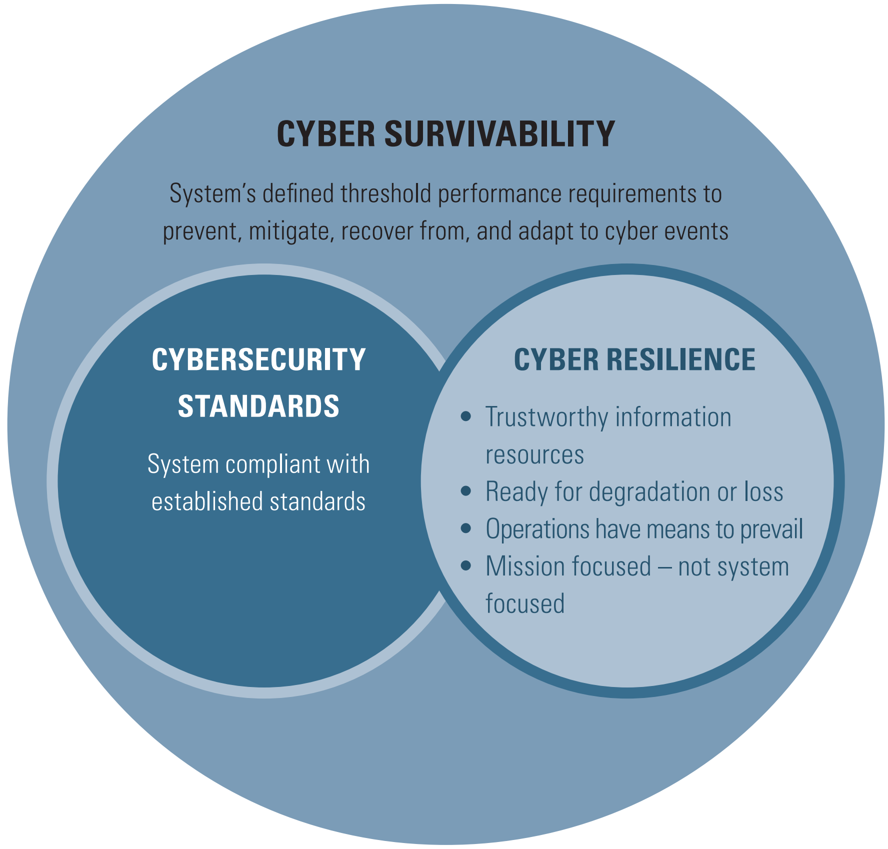

Figure 1. The Holistic Relationship of Cyber Survivability to Cybersecurity and Cyber Resilience.

A focus on cyber survivability ensures Warfighter systems are designed with sufficient cybersecurity and cyber resilience to prevent, mitigate, recover from, and adapt to cyber events by applying a risk-managed approach to building and maintaining systems, as stated in the 2021 JCIDS Manual. As illustrated in Figure 1, cyber resiliency and cyber survivability are closely related concepts, sharing similar technologies and practices; but cyber survivability holistically includes both cybersecurity requirements and cyber resiliency constructs.

Although compliance with the DoD's Risk Management Framework (RMF) remains compulsory, compliance with RMF isn't sufficient to achieve and maintain an operationally relevant cyber risk posture, or a resilient, survivable capability for mission assurance. JCIDS is transforming acquisition, with CSE guidance placing cybersecurity and cyber resiliency minimum viable requirements on equal footing with all other system performance requirements, during cost, schedule, and performance risk trade-space decisions. Program Managers (PMs) can use Cyber Survivability Attribute (CSA) threshold requirements to justify (resourcing) specific technical controls from FISMA, NIST, and CNSS, but RMF guidance doesn't define how a linkage to the CSAs could be used to support a PM's efforts in pursuit of cyber survivability. In addition, requirements for obtaining a continuous ATO (cATO) or implementing Zero Trust could also be contractually defined by the CSAs.

CSE provides exemplar language for 10 holistic CSAs to support a resource sponsor's tailoring of cyber performance requirements associated with the 4 pillars of the SS KPP. The Adapt pillar was added to proactively respond to cyber risks throughout a capability's life cycle. All 10 CSAs must be considered early in a capability development effort to effectively understand the mission and resource risk implications for that capability. Selecting and tailoring a subset of the CSAs will assist in

A focus on cyber survivability ensures Warfighter systems are designed with sufficient cybersecurity and cyber resilience to prevent, mitigate, recover from, and adapt to cyber events by applying a risk-managed approach to building and maintaining systems.

U.S. Air Force Photo by SrA Beaux Hebert

defining the threshold performance requirements most critical to the capability's survivability and its move, shoot, and communicate functions.

CSE targeted the inability of cybersecurity processes to build-in sufficiently robust capabilities to prevent (resist/anticipate), mitigate (absorb/withstand), recover from, and adapt to the spectrum of cyber-events in plain language requirements that a PM can understand. The Services have developed System Security Engineering (SSE) guidance to decompose that plain language into cybersecurity technical controls for fielding survivable capabilities and have begun developing metrics for testing to define a system's Cyber Survivability Risk Posture (CSRP).

This CSE Implementation Guide (CSEIG) is purposely not prescriptive on how to determine a CSRP, but it has provided information to allow the Services and Agencies to mature their own processes. These Agency and Service efforts—including the Office of the Under Secretary of Defense for Acquisition & Sustainment Deep Cyber Resiliency assessment, Army Cyber Operations Rapid Assessment-Platform, Air Force Measures of Performance Report, Air Force SSE Cyber Guidebook, Naval Air System Command's SSE Process Guide, DoD Cybersecurity Test & Evaluation

> CSE's cyber threshold performance requirements have the potential to support the acquisition of capabilities with acceptable levels of cyber resiliency and survivability, as well as sufficient operational performance.

Guidebook, DoD Cyber Table Top Guide, MITRE's work with the Air Force Research Laboratory's CSA Tool, and the System Engineering Research Center's Cyberattack Resilient Systems Report—are not sufficient to define a measurable CSRP for the DoD. However, they all contribute to the effort for maturing the measurement of cyber resiliency and survivability. This work is planned for inclusion in CSEIG version 4 to share their contributions toward a CSRP metric for cyber risk posture.

CSE does not identify any new cybersecurity requirements. The CSE process helps requirement sponsors better understand the cyber risks to the capability's mission-critical functions and provides exemplar performance requirements to state those cybersecurity and cyber resiliency requirements as a set of cyber survivability threshold performance requirements. These requirements are identified early enough in the acquisition process to inform engineering decisions and enable programs to include them during operational risk trade-space decisions for fielding a survivable minimum viable capability.

Requirement sponsors and PMs need to make defendable operational risk trade-space decisions. CSE associates cyber technical controls with the CSAs to help them identify controls that will be most beneficial for that system's survivability and its move, shoot, and communicate functions. Operational forces need systems that meet mission requirements and are survivable in their intended operating environment. The Warfighter needs and deserves cyber survivable capabilities, and, as mentioned, the CSE framework supports creation of threshold performance requirements to prevent, mitigate, recover from, and adapt to cyber events by applying a risk-managed approach to building and maintaining systems.

Even though CSE is only mandatory for capability developments that are subject to the JCIDS process, the Services have seen resource and mission risk benefits to justify including cyber survivability requirements in capabilities using all acquisition pathways. CSE is particularly well suited to the higher technology readiness levels associated with rapid acquisition capabilities. Conversely, if alternative acquisition pathways, such as Middle Tier of Acquisition and Joint Urgent Operational Needs, do not effectively consider cyber survivability threshold performance requirements, they are at risk of not providing a survivable operational capability. Programs going through all acquisition pathways consider, and sufficiently apply, the concepts outlined in the CSEIG to field survivable DoD capabilities.

CSE can reduce total life cycle costs (acquisition and sustainment) and improve mission assurance. This is counterintuitive, as the cost of implementing cybersecurity into legacy weapon systems has, at times, been found to be costly in both money and system performance. However, these outcomes were driven by the need to repeat the design and testing phases for flawed capabilities. When included in system design decisions, and made contractually binding, CSE's cyber threshold performance requirements have the potential to support the acquisition of capabilities with acceptable levels of cyber resiliency and survivability, as well as sufficient operational performance.

ABOUT THE AUTHOR

Mr. Steve Pitcher is the Senior Cyber Survivability Analyst for the Joint Staff J6; Command, Control, Communications, Computers/Cyber (C4/Cyber) Directorate. He previously completed a 20-year career in the Air Force and then served as a civilian in the Missile Defense Agency before joining the Joint Staff in 2006. As part of the Joint Staff, he has focused on developing approaches to support coalition interoperability, data service, and hybrid mission planning and execution, and, more recently, has worked to define and promote properly articulated cyber survivability performance requirements to support system acquisition and to balance cyber security and cyber resiliency requirements with other functional requirements during operational risk trade-space decisions. Mr. Pitcher holds a B.S. in computer science and math from the University of Puget Sound and an M.B.A. from Embry-Riddle Aeronautical University. He is also a graduate of the Air Command and Staff College and Air War College and is a Certified Information Systems Security Professional (CISSP) and Certified Ethical Hacker (CEH).

COVER STORY

THE RAPID STRUCTURAL VULNERABILITY TOOLKIT: ENHANCED VULNERABILITY ASSESSMENT FOR DIGITAL ENGINEERING

by Neil Berg and Stephen Rosencrantz

U.S. Navy Photo by SN Taylor Parker

Aircraft vulnerability analysis is critical to understanding the combat survivability of both an aircraft and its crew. However, it's often too late to do anything about aircraft vulnerability when aircraft are already fielded and pilots are already flying in harm's way. Live fire test and evaluation (LFT&E) is performed to provide insight into the vulnerability of an aircraft, but it often takes years, costs millions of dollars, and can start late in the design process.

Historically, live fire tests have been used to analyze structural vulnerability for a number of different aircraft. These tests require expensive physical test articles, which can be time-consuming to obtain and are often usable for only a limited number of tests. Therefore, structural live fire test programs usually consist of a small number of damage events (threat/shotline combinations).

More recently, structural live fire test data have been supplemented with data from high-fidelity finite element analysis (FEA) simulations. While these simulations and analyses have been helpful in filling some data gaps and validating a handful of live fire tests, they are also time-consuming, often taking weeks or months to set up. And the data set they provide is limited, requiring a fair amount of engineering judgement to generalize results to other locations and threat/shotline variables.

> RSVT enables analysts to rapidly determine the residual strength and even time-to-kill of damaged structures, including fixed-wing and rotary-wing aircraft, while taking into account damage propagation and dynamic loads.

In addition, understanding the structural vulnerability of modern aircraft often requires an understanding of the effects of many damage events and needs to account for propagating damage and dynamic loading. But to date, there has not been an effective tool to adequately address these requirements.

THE RSVT SOLUTION

To reduce the time and effort needed to understand the structural vulnerability of aircraft, and to help fill the data gaps, Skyward, Ltd. has been developing the Rapid Structural Vulnerability Toolkit (RSVT). RSVT enables analysts to rapidly determine the residual strength and even time-to-kill of damaged structures, including fixed-wing and rotary-wing aircraft, while taking into account damage propagation and dynamic loads.

RSVT represents a vast improvement in speed over traditional residual-strength analyses. As mentioned, high-fidelity simulation can take days or weeks to set up and run, while live fire tests can take even longer. Conversely, the toolkit provides the capability to simulate thousands of damage events per hour. It also has the versatility to run on Windows, Mac, and Linux and is scalable from a laptop to a supercomputer.

RSVT has been developed over the past few years with help from both a Small Business Innovation Research (SBIR) project and a Joint Aircraft Survivability Program (JASP) project. SBIR efforts have focused on developing the tool, while the JASP project has focused on demonstrating the capabilities of RSVT and developing strategies for using RSVT output data in standard Department of Defense (DoD) vulnerability tools, such as the Advanced Joint Effectiveness Model (AJEM) and the Computation of Vulnerable Area Tool (COVART).

USE CASES

RSVT is applicable to a variety of use cases. The basis of the toolkit is the use of beam theory to rapidly apply loads and propagate damage. As a result, RSVT is applicable to beam-like structures, which includes almost every part of an aircraft (such as wings, tails, and fuselage), some sections of a helicopter (such as tail booms and rotor blades [shown in Figure 1]), and even buildings and bridges. In addition, RSVT can apply damage effects such as failure, deformation, and thermal damage from a variety of military threats (such as blast, penetration, fire, hydrodynamic ram, and directed energy weapons), as well as nonmilitary threats (such as bird strikes and unconstrained engine debris).

Vulnerability Assessment Support

The toolkit can be used in several ways. The most common use is performing vulnerability assessments (illustrated in Figure 2), which involve applying damage along thousands of shotlines to generate residual strength or probability of component dysfunction given a hit ($P_{cd|h}$) data. The resulting data can then be used with systems engineering, vulnerability, or wargaming tools.

Battle Damage Assessment

Additionally, RSVT can be used for battle damage assessment (illustrated in Figure 3), where the user can, in a matter of seconds, determine the residual strength of damaged (produced by physical tests or high-fidelity FEA) structures. This rapid

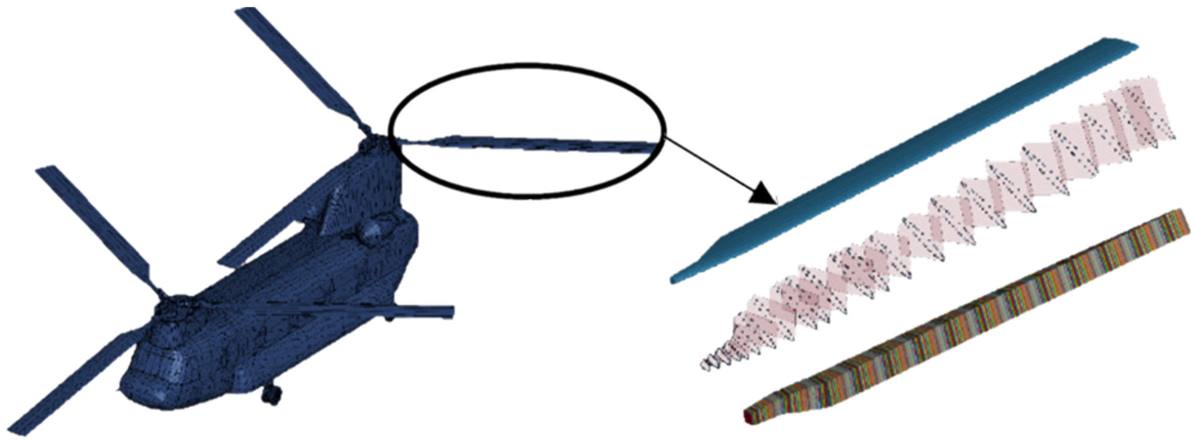

Figure 1. The Applicability of RSVT to Beam-Like Structures, Such as a Helicopter Blade.

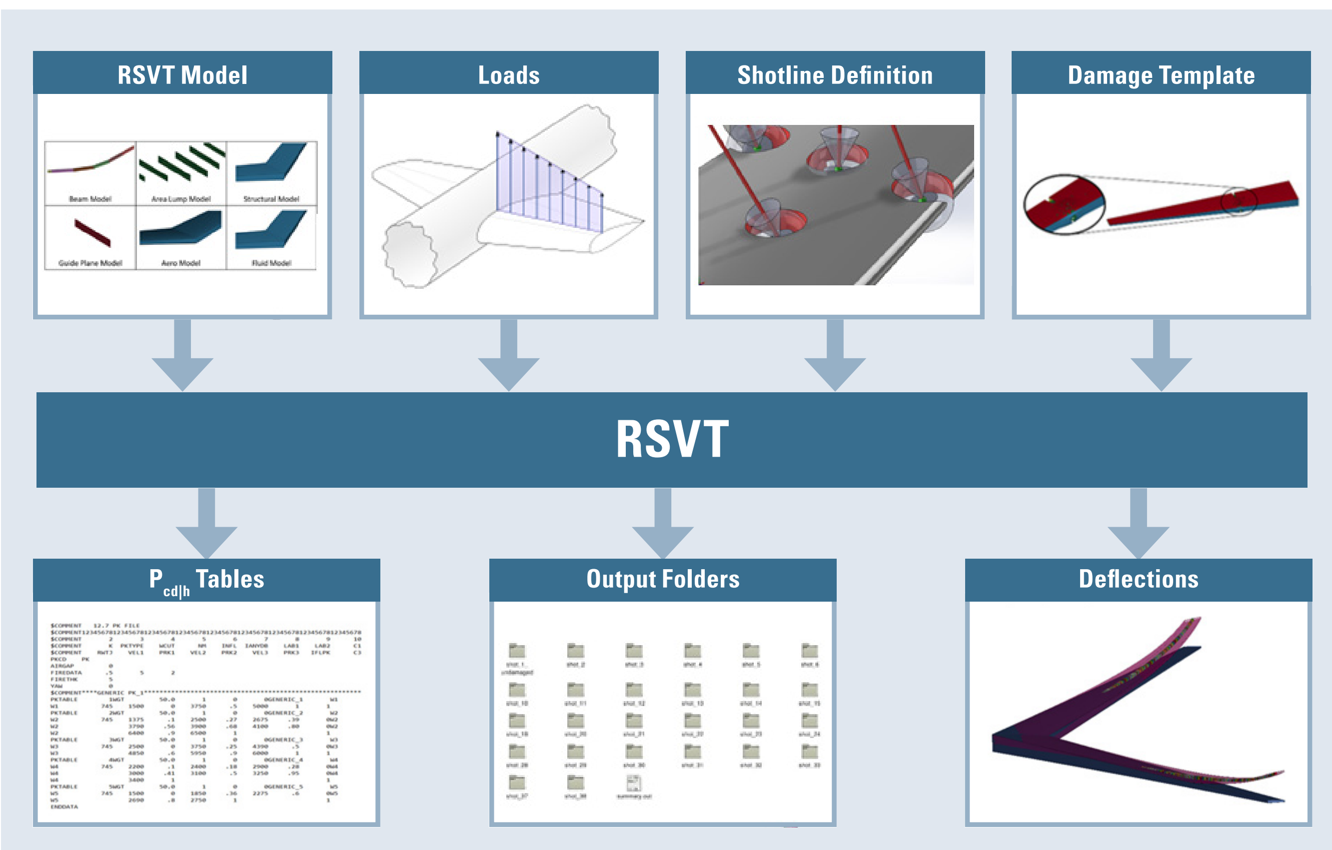

Figure 2. Performing Vulnerability Assessments.

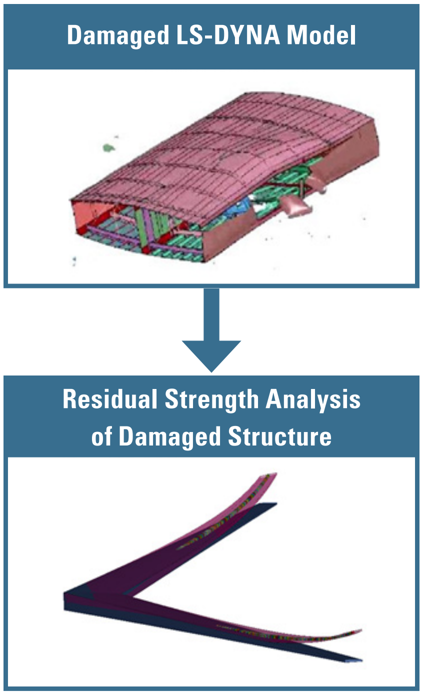

Figure 3. Rapidly Determining the Residual Strength of Damaged Structures.

RSVT provides the capability to simulate thousands of damage events per hour.

battle damage assessment can also quickly help determine the airworthiness of a combat-damaged structure in the field.

FEA Input Generation

RSVT can also be used to set up high-fidelity FEA simulations (illustrated in Figure 4). This use case can be particularly helpful when analyzing the results of a structural vulnerability assessment conducted by RSVT. The results of the RSVT structural vulnerability assessment may point out damage events of interest. These events can then be turned into matching LS-DYNA simulations for in-depth analyses.

Digital Engineering

As the DoD moves toward a digital engineering environment, it is important to account for structural vulnerability throughout the design cycle of the aircraft (illustrated in Figure 5). RSVT helps to realize this goal, as all of the aforementioned use cases allow structural vulnerability assessments to be performed much earlier in the design cycle of an aircraft than previously possible. An analysis using RSVT can help discover

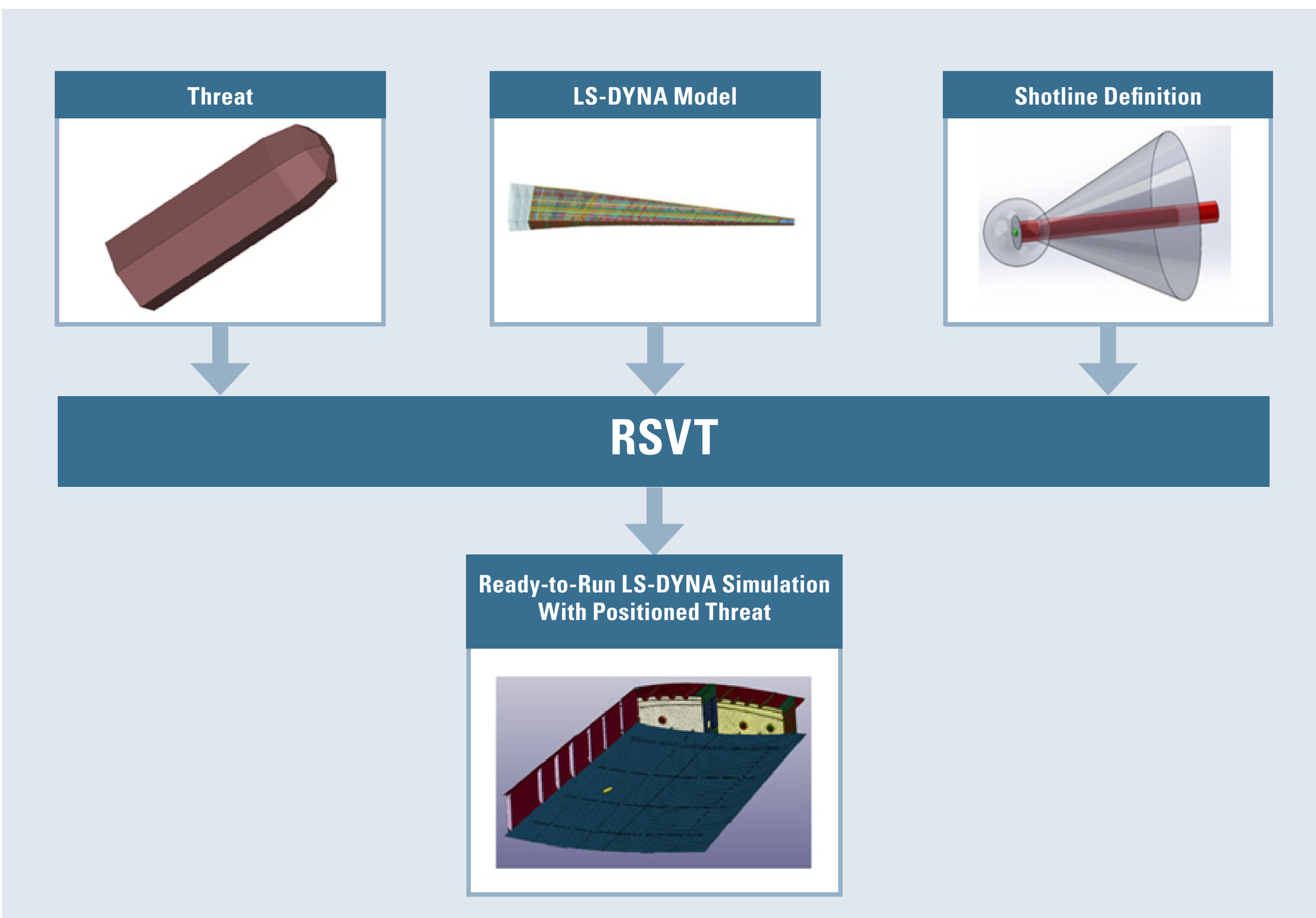

Figure 4. Generating Ready-to-Run High-Fidelity FEA Simulations.

Figure 5. Using RSVT in the Digital Engineering Life Cycle, Long Before LFT&E Would Normally Occur.

RSVT can help discover structural vulnerabilities in a design before the concept moves to LRIP.

structural vulnerabilities present in a design before the concept moves to low-rate initial production (LRIP). This capability could thus enable improvements that could lead to safer, more survivable aircraft, designed at digital engineering speeds.

THE RSVT METHODOLOGY

As mentioned, RSVT takes advantage of beam theory principles to rapidly apply loads and propagate damage for beam-like structures (a structure whose cross section is small compared to its length). Four inputs are required to run a structural vulnerability analysis: (1) the RSVT model, (2) shotlines, (3) a damage template, and (4) the flight loads. For each shotline, RSVT applies damage to the RSVT model, then propagates the damage by incrementing the loads.

CREATING THE RSVT MODEL

RSVT uses a custom model to apply the loads and propagate the damage for a damage event. The RSVT model can be automatically generated using shell models, such as those used in traditional high-fidelity FEA tools.

Three shell models can be imported to create the RSVT model: (1) the structural model, consisting of all the structural members; (2) the aerodynamics model, consisting of the aerodynamic surfaces (for computational fluid dynamics [CFD]); and (3) the fuel model, defining the extents of the fuel location. An example of these shell models is shown in Figure 6. The shell models, along with other user inputs (such as material properties), consist of everything needed to automatically generate the RSVT model. This RSVT model can then be used as input to the various RSVT run modes.

SPECIFYING THE SHOTLINES

Shotlines can be easily described using the records available in RSVT. The shotline parameters can be split into two groups: (1) the target, and (2) the threat. For the target, the parameters include target orientation (direction of gravity) and fuel level. For the threat, the parameters are the orientation (azimuth and elevation), velocity, and the impact location. The

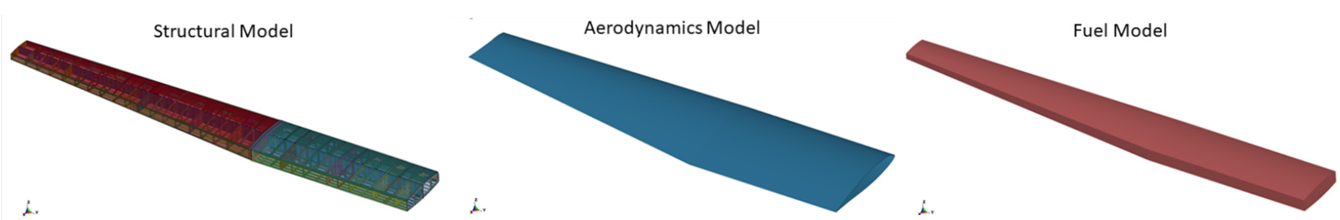

Figure 6. Example of Shell Models Imported Into RSVT.

Instead of simulating a threat impacting and damaging the RSVT model, RSVT relies on the use of damage templates to apply the damage.

available shotline records allow users to quickly specify anywhere from a single shotline to millions of shotlines in a matter of minutes.

APPLYING THE DAMAGE

Instead of simulating a threat impacting and damaging the RSVT model, RSVT relies on the use of damage templates to apply the damage. Damage templates are a set of records that describe the shape and probability of the damage caused by a given threat. These shapes get combined into a single damage template. The damage templates can fail, deform, or change the temperature of elements in the RSVT model, providing the user the capability to represent such damage as impact, blast, hydrodynamic ram, fragmentation, fire, and directed-energy weapons.

Under the JASP project mentioned previously, four damage templates are under development, each representing a different ballistic threat. These templates were generated by using available live fire test data and high-fidelity simulations to develop a description of the damage caused by each threat applied along any shotline. A comparison between a damage template and the damage caused during a live fire test is shown in Figure 7. The damage templates for each of the four threats considered for this JASP effort compare well with available test and high-fidelity data.

Current development efforts are under way to improve damage template creation, by adding a machine learning (ML) process, which involves training using live fire test and high-fidelity simulation data. This ML damage template will be able to apply the damage for a specific threat without relying on the user to have in-depth knowledge of the potential damage. Damage templates provide a rapid method to apply damage to the structure, allowing users to run RSVT at a rate of thousands of shotlines per hour.

LOADING THE MODEL

Loads can be easily specified and applied to the shell elements of the RSVT model or, in the dynamic case, can be automatically calculated using paneling method CFD tools. RSVT can represent aerodynamic loads, fuel and/or structure weight, and even mass from, say, engines or other structures attached to a wing. The loads can also be applied in both the static and dynamic run modes.

These four inputs—(1) the RSVT model, (2) the loads, (3) the shotlines, and (4) the damage templates—represent all the information needed to run any of the RSVT modes. The shotlines are used to position the damage template and set analysis parameters. The damage template is then applied to the RSVT model. The loads are then used either statically or dynamically depending on the mode, and the damage is propagated until the residual strength or time-to-kill of the structure is determined.

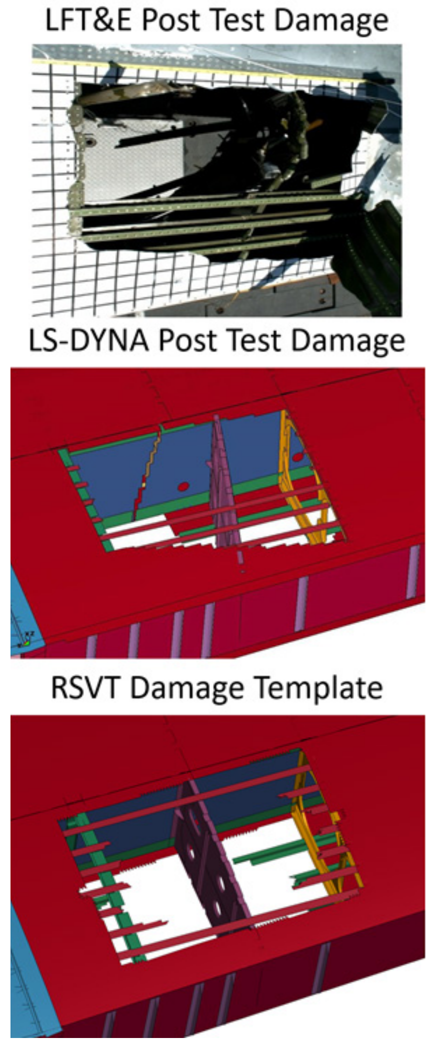

Figure 7. Comparison Between Live Fire Test, LS-DYNA, and RSVT Damage Representations.

OUTPUTS

As shown in Figure 8, RSVT provides a wide range of outputs. The results from each shotline/damage event include stresses, strains, and margins of safety, as well as deflections, residual strength, time-to-kill, and probability of kill. These outputs can be used to explore areas of interest on the structure and perhaps inform shotlines that would be interesting for live fire testing or high-fidelity

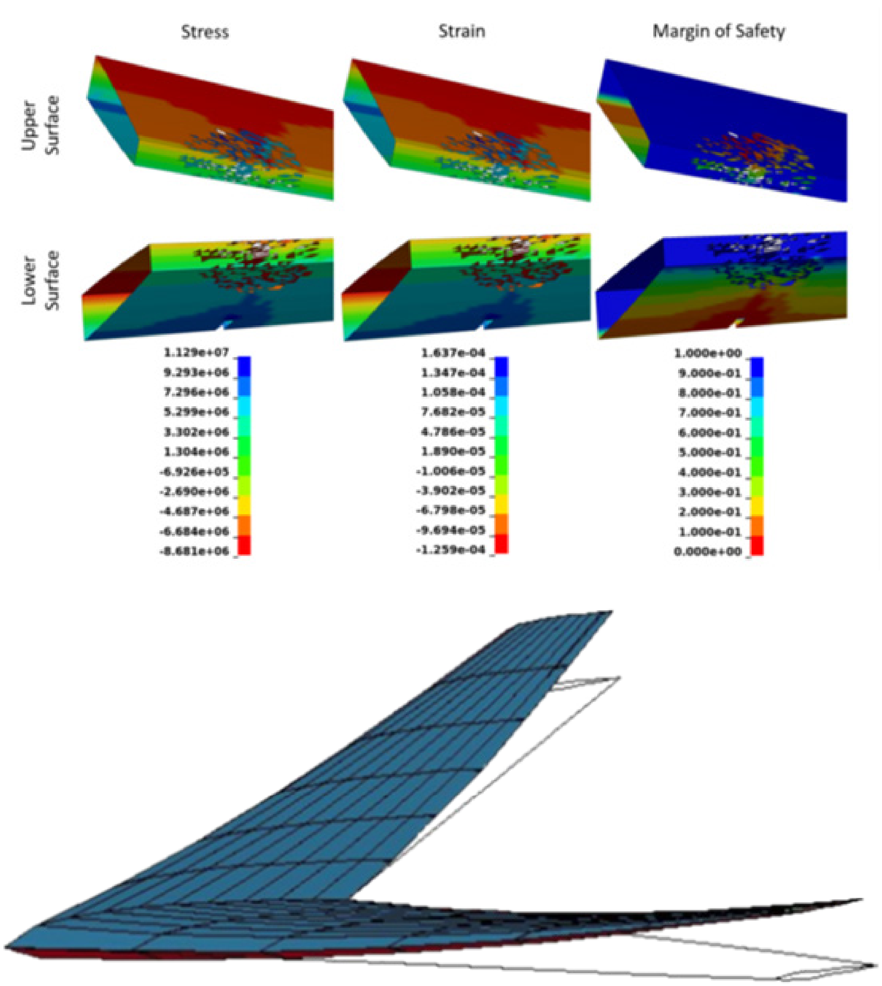

Figure 8. RSVT Outputs, Including Deformation, Propagated Damage, Residual Stress, Strain, and Margin of Safety.

The outputs from RSVT allow users to fully analyze their aircraft for structural vulnerabilities much earlier in the design cycle of the aircraft.

simulation. Additionally, by the end of the current development efforts, there will be a strategy for the implementation of RSVT results into DoD vulnerability tools, such as AJEM and COVART, as well as the Endgame Framework. The outputs from RSVT allow users to fully analyze their aircraft for structural vulnerabilities much earlier in the design cycle of the aircraft.

DEVELOPMENT AND FUTURE WORK

The development of RSVT began with the previously mentioned SBIR contract, including Phase I and II efforts. These efforts helped to develop the groundwork for RSVT, resulting in a toolkit of software algorithms that could rapidly determine residual strength of damaged structures and could be run using a command-line interface.

An additional SBIR effort enabled the development of a tool for applying dynamic loads to a structure while allowing for damage propagation. This effort resulted in a tool for determining time-to-failure of structures by applying dynamic loading for subsonic cases.

Current efforts to enhance RSVT include more SBIR development and the JASP project. The result of the SBIR efforts will be a fully functioning RSVT, including a command-line interface and a graphical user interface that can determine both residual strength and time-to-kill for damage structures. This effort will also include improvements to a variety of the features in RSVT, including additional material models, advanced failure modes, and dynamic loads in supersonic, hypersonic, and even rarified atmosphere.

The goals of the JASP project are to demonstrate the capabilities of RSVT and to develop a strategy to leverage the results of an RSVT analysis in DoD vulnerability tools, such as AJEM and COVART.

These efforts are expected to continuously enhance the toolkit to rapidly determine residual strength and time-to-failure of beam-like structures and to further demonstrate its capabilities. And while the capabilities of RSVT are certainly not a replacement for live fire tests and high-fidelity FEA, they promise to be an increasingly valuable component in improving the knowledge gained from traditional structural analysis methods and higher-level simulations and in filling in the remaining data gaps that can result from time and/or budget constraints.

ABOUT THE AUTHORS

Mr. Neil Berg is an engineer at Skyward, Ltd., leading the technical development of RSVT. With extensive expertise in developing simulation tools and analyzing aircraft vulnerability and weapons effects, he is currently developing tools to rapidly evaluate the effect of aircraft structural damage on flightworthiness, performing coupled Euler-Lagrange simulations, and designing an improved test device for evaluating structural joints subject to hydrodynamic ram. Mr. Berg holds a B.S. in aerospace engineering from the University of Cincinnati.

Mr. Stephen Rosencrantz is the Director of Modeling and Simulation (M&S) at Skyward, Ltd. He has more than 22 years of experience leading and executing machine learning (ML), software engineering (SE), FEA, and synthetic-aperture radar (SAR) simulation projects. He is currently leading and growing Skyward's M&S group as they develop RSVT; develop ML algorithms and software for automatic dependent surveillance-broadcast/EO/infrared/lidar anomaly detection and digital engineering solutions; and provide simulation support to DoD programs. Mr. Rosencrantz holds a B.S. in aeronautical and astronautical engineering from the University of Washington and an M.S. in mechanical engineering from Wright State University. ASJ

EXCELLENCE IN SURVIVABILITY: ROBERT LYONS

by Dennis Lindell

The Joint Aircraft Survivability Program (JASP) is pleased to recognize Mr. Robert Lyons for his Excellence in Survivability. Currently serving as the Technical Director of the Joint Aircraft Survivability Program Office (JASPO), Robert has been providing critical test and program management support for weapon system survivability for almost 40 years. During this time, he has distinguished himself as a leader in multiple survivability disciplines, including live fire test, survivability flight test, research and developmental test, and program management for the Navy, Air Force, and JASP. And the impact of his work on the nation and its Warfighters is undeniable, ultimately improving U.S. military capability and saving lives.

A California native and 1983 engineering graduate of the University of California, Robert began his survivability journey in the California high desert as a live fire test engineer at the Naval Weapons Center (NWC) in China Lake, CA. He was responsible for ballistic vulnerability testing of Navy aircraft subsystems, including structures, flight controls, and fuel systems on the F/A-18A, A-6E, and prototype V-22. He also led the F/A-18 Joint Live Fire (JLF) program and the first lethality live fire test and evaluation (LFT&E) test of the Advanced Medium-Range Air-to-Air Missile (AMRAAM). During his 6 years at NWC, Robert gained a detailed understanding of aircraft subsystems, vulnerability, and lethality; and he honed his expertise in the preparation and coordination of test plans, execution, evaluation, and documentation. In addition, the data he collected and lessons he learned on these programs continue to be reflected in the advanced capabilities, performance, and survivability of the current Navy aviation fleet, particularly the F/A-18, V-22, and AMRAAM.

Always looking forward to new experiences and challenges, Robert then joined the 420th Test Squadron at Edwards AFB in 1990. As the B-2A bomber survivability flight test lead, he headed and managed the B-2 Spirit detectability/survivability developmental test and evaluation (DT&E) flight testing. Robert's only condition for joining the test squadron was not to be called "Bob." Thus, he was promptly given the call sign "Not Bob." Leading large, diverse, multidiscipline teams of technicians and engineers, he was instrumental in the success of the B-2 Spirit development program, providing critical information to the upper levels

> The longstanding success of the B-2 Spirit bomber is an ongoing testament to the skill and expertise of Robert and the other program developers and testers.

of the Air Force and Office of the Secretary of Defense (OSD), including the Director of Operational Test and Evaluation (DOT&E). His "been there, done that" expertise on the testing of the effectiveness of observables (radio frequency [RF], electro-optical/infrared [EO/IR], electronic warfare [EW]) vs. foreign threat systems was critical to the B-2A defensive avionics DT&E and B-2A operational test and evaluation (OT&E). Robert also applied the experience and knowledge gained in the B-2A program to develop survivability test approaches for numerous follow-on high-priority aircraft, and the longstanding success of the B-2 Spirit bomber supporting U.S. operations across the globe is an ongoing testament to the skill and expertise of Robert and the other program developers and testers.

Never one to rest on his laurels, "Not Bob" and his career took a major turn in 1998, when he joined the Space & Naval Warfare System Command (SPAWAR) in San Diego to be the Program Manager and Test Director for the AN/SRS-1A(V) Combat Direction Finding (CDF) tactical cryptologic program. Here, he oversaw the development and implementation of a major software and hardware upgrade on 24 Arleigh Burke-class guided missile destroyers and 7 Wasp-class amphibious assault ships. His responsibilities included development and management of program plans and budgets, as well as internal and external organization coordination and oversight of Government and contractor teams. Robert's hard work and diligence helped the team overcome significant schedule and technical hurdles to complete a successful test program, including the first ever "mixed-mode" direction finding testing, which greatly increased the understanding of this important capability. These systems were a major capability upgrade to the Navy's surface fleet, providing long-range hostile target signal acquisition and direction finding to detect, locate, categorize, and archive data into the ship's tactical data system. CDF greatly improved warship commanders near-real-time indications and warning, situational awareness, and cueing information for targeting systems. In addition, Robert would be able to apply the program management, software development, and configuration management expertise that he gained during his time at SPAWAR in numerous future assignments.

In 2005, Robert moved to the East Coast and joined JASPO. Filling one of two Navy representative positions, he initially applied his survivability test and program management expertise to leading the JASP Susceptibility Reduction program. In this role, Robert brought together a diverse tri-Service team of aircraft susceptibility reduction engineers, testers, and modelers to tackle some of the formidable foreign threat weapon challenges facing U.S. aviators on current and future battlefields. Leveraging the modest JASP susceptibility reduction budget with other Service and OSD funding, the team was able to significantly advance the technologies and techniques to counter stressing EO/IR and RF guided threats, ultimately transitioning those capabilities into programs of record, including, but not limited to, the Common Missile Warning System, Common Infrared Countermeasures, Distributed Aperture Infrared Countermeasures, Suite of Integrated Radio Frequency Countermeasures, and Integrated Defensive Electronic Countermeasures programs.

In 2010, Robert served as a key author of the JASP-led Study on Rotorcraft Survivability, a highly acclaimed report to Congress on the history, current state, and recommendations for survivability improvements regarding rotary-wing aircraft. This report was key in establishing a baseline on current fleet survivability, securing additional funding for implementation of critical life-saving technologies in rotorcraft operating in USCENTCOM, and achieving a significant and lasting impact on the ability of our forces to safely complete their missions. Moreover, this effort was accomplished in a short 9-month suspense, requiring the leadership and

close coordination of a tri-Service working group of representatives from more than a dozen organizations. Once again, Robert's keen organizational and analytical skills were instrumental in the identification and improvement of the nation's military aviation capability.

From 2009 to 2016, Robert took on the leadership of DOT&E's Joint Live Fire – Aircraft Systems (JLF-Air) program. As Joint Test Director, he coordinated test programs to address observed shortfalls in LFT&E assessment methodologies, system vulnerabilities, and other gaps in previous aircraft LFT&E programs. His responsibilities included issue development, annual program plan establishment, financial management, and cross-Service coordination between the Army, Navy, and Air Force deputies. He also provided decision-makers with critical survivability information; maintained close relationships with DOT&E action officers; and supplied time-critical feedback to the Army Shoot Down Assessment Team, supporting investigations of combat loss events.

Under Robert's leadership, JLF-Air provided a significant benefit to the T&E and operational communities through the first comprehensive Man Portable Air Defense System (MANPADS) threat characterization for vulnerability assessment models. This characterization greatly improved the understanding of the damage mechanisms of this increasingly prolific threat, ultimately providing a higher level of realism and confidence in LFT&E and survivability modeling and simulation (M&S).

Throughout his tenure as the JLF-Air Joint Test Director, Robert also made it his mission to publish all the program's test plans and reports in the Defense Technical Information Center's Online Access-Controlled (DOAC) library, providing ready access of live fire test data to the aircraft survivability community. He increased the number of accessible reports by 100 (including an F/A-18A JLF test report he'd originally written as a young test engineer at NWC 20 years earlier). This notable effort preserved the knowledge gained through tens of millions of dollars' worth of investment for use in determining future requirements and developing and validating M&S.

In 2016, Robert took on his current role of JASPO Technical Director, promoting the interchange of information on aircraft survivability requirements, capabilities, deficiencies, and technologies across the aircraft survivability community. In his 6 years in this position, he has led JASP through several aircraft survivability gap assessment and prioritization efforts, clearly defining future initiatives and the application of JASP resources to solving pressing aircraft survivability shortfalls. He also has mentored new JASPO Deputy Program Managers and project engineers, readily sharing his many lessons learned and enabling the success of other programs and projects. Simply put, with an eye ever toward continuous self and organizational improvement, Robert has been critical to the success of JASP in its ongoing mission to improve aircraft survivability.

With an eye ever toward continuous self and organizational improvement, Robert has been critical to the success of JASP in its ongoing mission to improve aircraft survivability.

Congratulations, Robert, on this well-deserved and long overdue recognition of your many contributions to the survivability community. Your longstanding dedication and professionalism have brought great credit to yourself, the community, and the many programs you've supported. And your expertise and efforts will continue to contribute to the protection of our combat operators and the success of the U.S. military for many years to come. ASJ

ABOUT THE AUTHOR

Mr. Dennis Lindell is the Director of JASP. He has more than 30 years of experience in aircraft survivability, including almost 20 years in JASPO.

WPAFB TEST CHAMBERS REACH NEW HEIGHTS IN ALTITUDE AND AIRCREW RESEARCH

by Eric Edwards

U.S. Air Force Photo by Jason Schaap

It's something aviators have known for a long time. What works down on the ground doesn't always work up in the air. Especially when it's 50,000 or 100,000 ft up in the air. High altitude can negatively affect not only the inflight performance of components and equipment but also the cognitive and physical abilities of the aircrews who operate them. And when one further adds the inherent pressures of fast-paced, advanced combat operations into high-flying environments, the effects on performance can be even worse.

Accordingly, in May of last year, the Air Force Research Laboratory (AFRL) officially opened the doors to its four new Research Altitude Chambers (RACs) at Wright-Patterson Air Force Base (WPAFB), OH. The chambers, managed by AFRL's 711th Human Performance Wing, were established to help researchers better understand and mitigate the effects associated with high-altitude flight operations. And in less than a year, this unique collection of state-of-the-art, computer-controlled test facilities has already reached new heights in altitude research on aircrews and equipment [1, 2].

50,000 FT AND CLIMBING

This spring, three of AFRL's new RACs were certified for manned studies up to 50,000 ft. This man-rating certification is unequalled throughout the Department of Defense (DoD) and distinguishes the testing facilities as a key resource to support the ever-rising manned-flight altitude requirements of both the Air Force and Space Force. And researchers aren't stopping there. With the addition of some new equipment, the manned altitude ceiling is expected to soon rise to 60,000 ft [1, 2].

High-altitude research and training are helping to ensure U.S. personnel and equipment are ready for the fight no matter the height.

AFRL's four RACs (shown in Figures 1–4) were each designed and built with different purposes and capabilities in mind [3].

- RAC 1 can hold up to 20 people and is primarily used to study high-altitude hypoxia, human performance effects, fatigue, and decompression sickness on aircrews. It can also simulate heights up to 100,000 ft to test unmanned equipment.
- RAC 2 is the biggest of the altitude chambers and is used to test aircraft life support systems and large equipment (up to the size of a Humvee). It too can support 100,000-ft unmanned equipment

Figure 1. RAC 1 *(U.S. Air Force Photo by Jason Schaap).*

Figure 2. RAC 2 *(U.S. Air Force Photo by Jason Schaap).*

Figure 3. RAC 3 *(U.S. Air Force Photo by Richard Eldridge).*

Figure 4. RAC 4 *(U.S. Air Force Photo).*

testing and can vary temperatures between -67 and 150 °F and humidities between 2 and 98%.

- RAC 3 specializes in simulating the effects of rapid decompression (as fast as 0.04 s) on the body, as well as other kinds of related research. It too is temperature-controlled.
- RAC 4, at 45 ft^3, is the smallest chamber. It is used to study rapid decompression (at a rate of 8,000 to 23,000 ft in 0.04 s), durability, and other effects on small equipment, such as cellphones, computers, and medical equipment up to 100,000 ft.

As a group, these chambers are continuing to provide aviation and aerospace researchers, manufacturers, testers, military planners, and others with important physiological and operational data and insights not otherwise available. Furthermore, the high-altitude training they offer aircrews is helping to ensure U.S. personnel and equipment are ready for the fight no matter the height.

In spatial disorientation, the normal forces of flight and the body's sensory receptors/ responses can trick even a good pilot into believing the aircraft is doing something it's not.

PUTTING SOME SPIN ON IT

Of course, it's not just altitude that can affect an aviator's ability to perform his/her high-flying, fast-moving missions. Today's operational environments can, with little or no notice, thrust aircrews into extreme drops, climbs, turns, and spins, suddenly applying acceleration forces that can severely disorient and/or disable them. Thus, complementing AFRL's new RACs at WPAFB are several other unique pieces of equipment to help researchers and aircrews prepare for some of these harsh effects.

One such piece of equipment is AFRL's human-rated centrifuge, which has been in operation since 2018. Said to be the world's most advanced (and the DoD's only) human-rated centrifuge, this spinning beast has the capability to apply up to 9 g's (9 times the normal force of gravity). This capability allows researchers to measure the often-debilitating high-g effects on personnel, as well as provides those personnel with an opportunity to experience the effects in a controlled, safe environment and to learn how to counteract them and remain conscious and in control of their aircraft. Moreover, the centrifuge is configurable to test not only jet pilots (who feel g forces mostly through the top of their heads in the z axis) but also astronauts (who feel g forces mostly in their chest in the x axis) [4].

An even more radical—and some might say tortuous—piece of equipment at WPAFB is the Kraken spatial disorientation device (shown in Figure 5). Spatial disorientation is the leading aeromedical causal factor in Class A aviation mishaps (incidents that destroy or cause more than $2 million in damage to the aircraft or result in a fatality or permanent total disability to personnel). With this phenomenon, the normal forces of flight and the body's sensory receptors/responses can trick even a good pilot into believing the aircraft is doing something it's not (such as turning, pitching up or down, rolling, or even flying straight and level). And in an attempt to "correct" these misperceived motions/orientations, a pilot can take actions that can have potentially fatal results [5,6].

Accordingly, the Kraken device is a 245,000-lb machine developed in 2016 by the Naval Medical Research Unit Dayton (NAMRU-D), one of AFRL's partners in aerospace physiology research, to simulate and study the kind of forces and spatial disorientation that can get aircrews into trouble. This one-of-kind device—named after the mythical, multi-tentacled sea monster—has a six-axis range of motion, including 360°+ in the pitch, yaw, roll, and planetary directions, 33 ft of horizontal travel, and 6 ft of vertical (heave) travel. As such, it can simulate the behavior and acceleration forces (of up to 3 g's) of essentially any air, ground, sea, or space vehicle in existence (not to mention the wildest amusement park ride imaginable) [5, 7, 8].

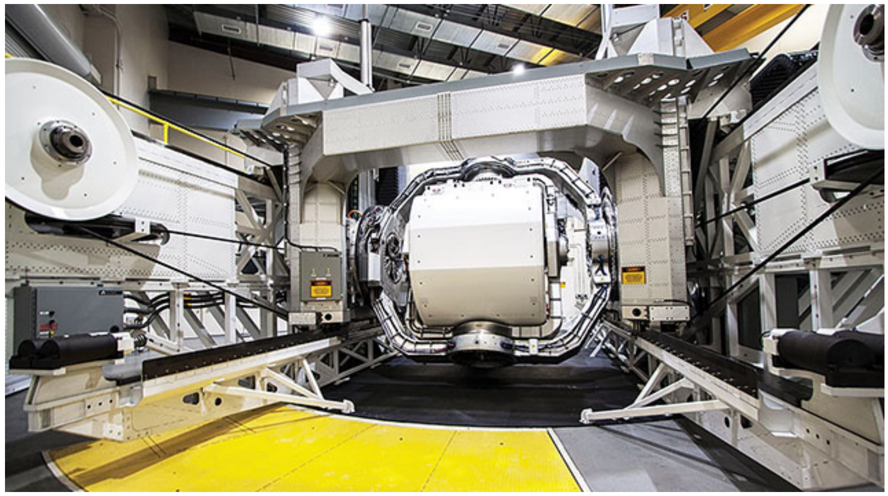

Figure 5. The Kraken Spatial Disorientation Device *(U.S. Navy Photo by Megan Mudersbach).*

CONCLUSIONS

Clearly, the flight path of current and future U.S. air and space operations is one that will require our forces to fly higher, faster, and in more challenging situations than ever before. And just as clear is the fact that aerospace physiology testing and research—such as that being conducted at WPAFB—will continue to be vital for understanding and addressing the effects of these uncharted skies on the aircrews and equipment that venture into them. ASJ

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CALENDAR OF EVENTS

SEPTEMBER

AAAA Aircraft Survivability Equipment Symposium
12–13 September in Lexington, KY
https://www.quad-a.org/Public/Events/AAAA_Events/Public/Events/Upcoming_Events.aspx

VFS Development, Qualification, and Affordability of Complex Systems Technical Meeting
13–14 September in Huntsville, AL
https://vtol.org/complex

Fundamentals of Random Vibration and Shock Testing Open Course
13–15 September in Longmont, CO
https://equipment-reliability.com/open-courses/training-in-fundamentals-of-random-vibration-and-shock-testing-september-13-15-2022/

2022 Future Force Capabilities Conference
19–22 September in Austin, TX
https://www.ndia.org/events/2022/9/19/2022-future-force-capabilities-conference-and-exhibition

JAS Program Review
27–29 September at Nellis AFB, NV
https://www.jasp-online.org/event/fy22-jas-prm/

OCTOBER

2022 Insensitive Munitions & Energetic Materials Technology Symposium
18–20 October in Indianapolis, IN
https://www.ndia.org/events/2022/10/18/3550---imem-tech-symposium

Precision Strike Technology Symposium
18–20 October in Laurel, MD
https://www.ndia.org/events/2022/10/18/3pst---precision-strike-technology-symposium-psts-22

59th AOC International Symposium & Convention
25–27 October in Washington, DC
https://www.crows.org/mpage/2022HOME

2022 Military Sensing Symposium Joint (BAMS and NSSDF) Conference
31 October to 4 November in San Diego, CA
https://mssconferences.org/public/meetings/meetinglist.aspx

NOVEMBER

NDIA Aircraft Survivability Symposium
1–3 November in Monterey, CA
https://www.ndia.org

25th Annual Systems & Mission Engineering Conference
1–3 November in Orlando, FL
https://www.ndia.org/events/2022/11/1/3870---sme-conference

I/ITSEC 2022
28 November to 2 December in Orlando, FL
https://www.iitsec.org/

DECEMBER

HELMOT XIX Helicopter Military Operations Technology Meeting
7–8 December in Hampton Roads, VA
https://vtol.org/helmot

JANUARY

AIAA SciTech Forum
23–27 January in National Harbor, MD (and Online)
https://www.aiaa.org/scitech

MARCH

IEEE Aerospace Conference
4–11 March in Big Sky, MT
https://www.aeroconf.org/

Note

The inclusion of an event in this calendar does not necessarily reflect the endorsement of that event or its sponsoring organization(s) by the Joint Aircraft Survivability Program Office or the Defense Systems Information Analysis Center.

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

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