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Flight Simulation Modeling Soars at the Laboratory

THE nation has accelerated efforts to begin the next chapter of nuclear deterrence, in which the focus moves beyond the maintenance of aging weapons. The shift has intensified the need to update the enterprise, including a cumbersome and costly flight-test methodology. Answering this need with speed and ingenuity, Livermore's Weapon Technologies Engineering Program (WTE) developed "Sora," an advanced flight simulation package.

Sora gives Lawrence Livermore a new capability and expanded role in the enterprise while reinvigorating external partnerships. WTE's Flight Performance Integration (FPI) lead, Sejin Oh, believes the array of advanced flight simulation modeling capabilities is vital to the updated enterprise. "The country is really out of practice in terms of designing new strategic systems," says Oh. "We are sharpening our pencils and dusting off skills we haven't practiced in a long time because the need is now."

FPI will help streamline a long-standing, costly annual testing regime. Each year, approximately four unarmed Minuteman missiles are flight tested, providing United States Air Force (USAF) and Department of Defense (DOD) contractors test data to run their own flight simulation code. Livermore scientists then use the Laboratory's thermal–structural code to simulate how the warhead responds to loads indicated in the contractors' flight simulations. Historically, the contractors' and the Laboratory's separate simulations were made largely in isolation. Concurrent development of the reentry vehicle and warhead was challenging, and Livermore and DOD contractors exchanged only interface definitions. This methodology was sufficient for stockpile stewardship, but now the enterprise needs better coordinated development of the warhead and reentry vehicle. Sora facilitates that coordination, enabling the Laboratory to study the warhead and reentry vehicle as a coupled system for the first time. "With Sora, we are augmenting the Laboratory's thermal–structural analysis with vehicle modeling," says Brad Perfect, FPI sciences lead. We now understand the why and how of the inputs we are giving the thermal–structural analysts, and we are gaining insights into uncertainties and sensitivities."

Testing with Agility

From the time a reentry vehicle separates from the missile bus exoatmospherically to its descent and to burst, it experiences a multitude of extreme conditions and forces. Sora simulates the flight, vehicle, and nuclear warhead in a complex multiphysics, multiscale environment including hypersonic air chemistry, ablation, heat transfer, structural dynamics, weather, and even cloud microphysics. "FPI has spent several years developing, in this case, an advanced methodology for cheaply obtaining aerodynamics tables for vehicles, which we view as a nation-leading capability," Perfect says. "Sora enables us to generate realistic time-dependent loading environments."

Sora is agile enough to simulate different types of vehicles and different experimental environments. Analysts can tweak even the most nuanced variables. Dan Driver, FPI production lead, says that everything from geography to atmospheric conditions must be taken into consideration. "Understanding how something flies is pretty complicated because you must take into account not only what the vehicle encounters on its flight but also the aerodynamics of the vehicle itself," says Driver. "It's a many-step process we've tried to streamline to focus on uncertainty information."

FPI has made it possible for models to provide high-fidelity loading environments during simulated reentry, an entirely new capability for the national program. The Laboratory's superior large-scale computing capabilities also allow FPI to run calculations and turn them around to analysts quickly. "One of our first 'wins' was to be able to provide 'on-demand' loading boundary conditions for the Laboratory's thermal–structural analysts," says Perfect. Livermore also was able to complete a feasibility study on flying existing warheads on new delivery platforms—in just 60 days. Before FPI, this would have taken several months, if not years, and involved an intricate dance between facilities, contractors, and institutions around the country. With its streamlined simulation modeling production methodology, FPI has turned Lawrence Livermore into a one-stop shop. "This integration has allowed us to move much faster in terms of accounting for the environments the vehicle may travel through," says Carleton Knisely, FPI assessments lead. "Once we can evaluate the current systems, we can take that physics knowledge and go forward with confidence that the new systems will perform as expected."

A New Role for Livermore in Payload Design

With the focus on improving and reimagining the delivery vehicle, enhanced simulation modeling capabilities give the Laboratory a new ability to analyze the vehicle and warhead as a coupled system, yielding a new appreciation for the system's behavior and better information about weight, centers of gravity, and other characteristics. "It's not to say FPI hasn't been informed by legacy simulation systems," says John Miller, the director of the WTE program. "We are just improving upon legacy simulation systems in order to develop technology to access new configurations with the goal of making more informed design decisions."

The FPI team hopes streamlining a previously multi-institutional and lengthy process by creating the one-stop-shop capabilities for the Laboratory will accelerate development and reduce reliance on expensive and time-consuming flight testing. "We are putting a lot of effort into doing what Livermore does best," says Driver, "which is knowing our payloads inside and out."

Vehicle for Partnerships and Collaboration

FPI's immediate success with Sora has contributed to the Laboratory's partnerships across industry and academia. For example, FPI enables the Lab to collaborate with more universities in new ways. Sora is central to Livermore's role in the University Consortium of Applied Hypersonics (UCAH), a collaborative network that aims to advance innovation through projects not requiring security clearance. "UCAH is a deliberate national effort to accelerate our technology and workforce in a very important strategic area," says Perfect, "FPI is simultaneously a resource to universities, a consumer of technology, and a landing place for recent graduates." He adds, "We want to be intentional about funding useful projects that can be transitioned to the national laboratories, industry, or government to harness the power of our universities for workforce development and applied research."

While FPI enables the Laboratory to reduce dependence on external conceptual design, collaboration with the Air Force and Army research laboratories (AFRL and ARL), Air Force Nuclear Weapons Center, and their DOD contractors has

For Coleby Friedland, Eric Albin, Sejin Oh, Raghav Chari, Mona Golbaebi, and Carleton Knisely (left to right) and Flight Performance Integration colleagues, a teamwork style extends to collaboration beyond the Laboratory.

The Lawrence Livermore Flight Performance Integration team (left to right): Oliver Alvarez, Carleton Knisely, Emily Howell, Geoffrey Oxberry, Tuan Ngo, Andy Cook, Daniel Hnatovic, Michael Adler, Hassan Beydoun, Brad Perfect, Lisa Isaac-Diaz, Jeremy Thornock, Bill Nguyen, Siva Movva, Sejin Oh, Yuan Li, Jack Acton, Aric Rousso, Ryan Whitmore, Eileen Perez, and Daniel Driver.

been crucial. FPI's model development is focused within the Laboratory's design space, but as Knisely points out, the system needs to be transferrable to contractors for everyone to benefit. "Our interactions with AFRL and ARL are a good example of technology transfer," says Perfect. "Sora is a vehicle by which we can provide Livermore's nation-leading capacity to government users."

After successfully running FPI capabilities on DOD computer systems in 2022, proposals are planned for expanding the user base. "Working with contractors is important for our project," says Knisely. "We're not responsible for building the vehicles or airframes themselves. That's entirely their wheelhouse, but we do need to interact with them very closely to understand how whatever changes and improvements they make could impact what we contribute and vice versa."

Collaborative Spaces

Even amidst Lawrence Livermore's legacy of teamwork and interdisciplinary science, the new W80-4 life-extension and W87-1 modernization programs (LEP and MOD) put an even higher premium on the importance of strong internal collaborations onsite. "It's not just that FPI allows us to work in close proximity to the other teams onsite," says physcist Joseph Wasem. "It's the confidence we have in knowing exactly what they are working on and how they are doing it through our work together on the MOD and LEP."

To enhance teamwork, the FPI staff is taking a novel approach to day-to-day work. FPI lead Oh says that it's time to rethink how teams work. "We try to have a sort of start-up mindset within our team."

The group has grown since 2019 from 6 to more than 30 contributors, many of them fresh out of graduate school or pursuing Ph.D.s. Knisely says the team's relative youth and experience level free up their approach to problems. "We don't have a lot of preconceived notions based on 'what we've always done,'" says Knisely. "I think it's a big part of the reason we've been so successful."

Wasem describes a kind of "spitballing" of ideas between FPI staff with different training, backgrounds, and experience. "We address problems quicker when we talk and put together like a puzzle all of these incomplete ideas right here at the Laboratory."

Oh is hopeful that this welcoming and collaborative environment in a demanding field will continue to attract new hires to the Laboratory in a highly competitive flight dynamics job market. "As a small group, we're operating efficiently and performing at a high level," Oh says. "Risk taking is encouraged and failures do occur. We're okay with that, and it's risk taking that makes us agile and responsive enough to meet the challenges we face moving into the future of the nation's nuclear deterrent."

—Amy Weldon

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