

AI copilots set to engage the future of air combat

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The X-62A Variable Stability In-Flight Simulator Test Aircraft, or VISTA, flies over Palmdale, California, on Aug. 26, 2022. The APL-supported Defense Advanced Research Projects Agency Air Combat Evolution program used the VISTA to test and evaluate artificial intelligence and autonomy. Credit: U.S. Air Force/Kyle Brasier

The future of military conflict is inseparable from the development of artificial intelligence (AI). The battlefield of the future will be redefined by the fielding of intelligent autonomous systems operating at machine speed and with machine precision. As the National Security Commission on Artificial Intelligence stated bluntly in its [2021 final report](#): "Defending against AI-capable adversaries operating at machine speeds without employing AI is an invitation to disaster."

"We need to keep human warfighters in control of the future battle, and that means investing in efforts to catalyze [human decision-making](#) with the advanced computing power of AI," said Tom Urban, who supervises the Intelligent Combat Platforms Group at the Johns Hopkins Applied Physics Laboratory (APL) in Laurel, Maryland. "APL is involved in a number of efforts to do that by providing humans with intelligent virtual assistants."

Building on more than a decade of pushing the boundaries of what AI can do in air combat, APL engineers and air combat specialists have made significant progress in creating a copilot that will grant the power, speed and precision of machine computation to human fighter pilots.

A software wingman

Most work in this domain, like the XQ-58A Valkyrie, the Air Force's experimental pilotless aircraft, is focused on creating advanced autonomous fighter aircraft.

Researchers at APL, however, have their sights set on augmenting human decision-making with the computational power of AI. Rather than seeking to replace pilots, APL researchers aim to help them succeed by enhancing and complementing their abilities, intuition and experience

with machine speed and precision.

To that end, the team has created—over three years of painstaking development—an AI teammate dubbed VIPR. Short for Virtual Intelligent Peer-Reasoning agent, VIPR serves a pilot in three critical capacities: as a situationally-aware peer, a performant wingman and a cognitive support assistant.

John Winder, a computer scientist in APL's Force Projection Sector who co-leads the project with Urban, likens VIPR to R2-D2, the pilot-assisting droid from "Star Wars."

"It can hang back and provide support by maintaining [situational awareness](#), tracking blind spots and alerting the pilot when needed, or it can step up and play the role of the pilot, flying the plane and taking actions to save the life of its human pilot," he said.

Tracking cognitive blind spots

Another way to think about VIPR is as an extremely advanced GPS and navigation assistant, there to help the driver overcome blind spots. But where a driver's blind spots are visual, the fighter pilot's blind spots are primarily cognitive.

"Fighter pilots are, by nature, very confident people," said Winder. "That's a professional necessity and an asset, but it can also lead to a kind of tunnel vision that might prevent them from taking on critical new information in the heat of combat."

One of VIPR's most important functions, therefore, is to actively track the cognitive state of the pilot. It has to understand the pilot's intentions, know what the pilot knows and reason about what the pilot understands, so that it recognizes when the AI and the pilot are no longer on the same

page.

"Besides looking 'outward' to track and predict adversary threats, VIPR also has to look 'inward' to understand the human pilot's intentions, objectives and modes of behavior, all on a second-by-second basis," Winder said. "And when the pilot has missed something critical during combat, VIPR has to inform them of that in a timely, actionable manner to help them survive the engagement."

The VIPR prototype is capable of doing all of this in an interactive real-time simulation, responding to the pilot's voice commands, switching roles between full pilot and copilot fluidly and seamlessly—and if that weren't enough, it can also pilot multiple autonomous squad mates, or collaborative combat aircraft. In this mode, the human pilot can act like the quarterback on a football team, directing the objectives of a VIPR-controlled team.

After three years of development, the APL team is preparing to more formally evaluate its AI prototype with human pilots. But anecdotally, at least, the initial response has been promising.

"We have some former pilots on our team, and they've all walked away from engaging in the simulation with smiles on their faces," Winder said. "And as a non-pilot myself, when I engage in the simulation scenario unassisted, I survive for maybe eight seconds. With VIPR, I'm able to survive and win."

"Obviously, we have much more rigorous testing to do before this can be fielded, but we're optimistic based on what we've seen so far."

New challenges, new technology

Developing VIPR has taken a concerted effort on the part of APL

scientists and engineers, necessitating multiple major breakthroughs in AI and machine learning techniques.

Three particularly significant advances are crucial to understanding what makes VIPR unique.

The first was the creation of recurrent conditional variational autoencoders (RCVAEs)—essentially, machine learning models capable of encoding the (often implicit) observations, beliefs and decisions of a human pilot. RCVAEs are multimodal and probabilistic, meaning they have to infer and incorporate multiple variables from a variety of data sources and make decisions based on intelligent approximations, all at lightning speed.

This breakthrough is what enables VIPR to develop something like an "intuitive," structured understanding of the [pilot](#)'s intentions and beliefs.

The second was applying graph [neural networks](#) (GNNs) to the problem of modeling adversary behavior. GNNs are a type of neural network that can be directly applied to graphs to predict the future states of anything that can be depicted on a graph—analogous to how a large language model can be used to predict and generate text.

The application of GNNs is what allows VIPR to predict complex adversary behaviors and coordinated maneuvers with high fidelity in a 3D space.

Notably, these first two breakthroughs have general applicability beyond the problem space of air combat, and are already being leveraged for other efforts at APL.

The third critical enabler was the development of a novel, advanced neural network known as a State-Time Attention Network (STAN) for

deep multi-agent reinforcement learning.

Based on the same Transformer architecture used by ChatGPT—GPT stands for "generative pretrained transformer"—and many other generative AI tools, STAN enables VIPR to scale its "awareness" to a variable number of entities and to learn a wider variety of multi-task behaviors.

"Neural networks generally assume a fixed-size input and can't handle a dynamically changing set of observed variables. With STAN, VIPR can rapidly adapt to new scenarios it has never seen before as well as switch smoothly among several tasks. STAN is a novel APL contribution, and one that's truly necessary to advance the state of the art in the space of AI decision-making," Winder said.

A history of pushing the boundaries

VIPR—and the larger effort that produced it, known as Beyond Human Reasoning—is the latest in a long line of APL innovations in AI for air combat, going back more than a decade.

This history includes serving as technical lead and host of the AlphaDogfight Trials, in which AI agents went head-to-head with human F-16 pilots; building the Colosseum, a virtual environment to support the Air Force Research Laboratory's Golden Horde program to create the next generation of autonomous weapons systems; and supporting the Defense Advanced Research Projects Agency's Air Combat Evolution program by developing infrastructure and autonomous solutions to enable AI agents to control a full-scale fighter jet.

More broadly, APL is engaged in a number of efforts to promote seamless teaming and collaboration with AI-enabled systems at every level of the battle—from individual soldiers to battlefield commanders

and decision-makers.

This work was made possible in part by APL's Innovation program, and in particular Project Catalyst, an initiative that allows staff members to compete for significant funding, sometimes over a period of years, to test critical assumptions, investigate phenomena and push the boundaries of our current knowledge.

Provided by Johns Hopkins University

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