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David L. Thirtyacre
Embry-Riddle Aeronautical University, thirtyad@erau.edu

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Remotely Piloted Aircraft C2 Latency during Air-to-Air Combat

David L. Thirtyacre

Remotely piloted aircraft command-and-control latency could play a significant role during beyond-line-of-sight engagements in future conflicts. As the Air Force prepares to use these systems and artificial intelligence in within-visual-range combat, it must understand the effects of latency, or missing sensor data, during a dogfight. Research indicates technology-based latency influences the engagement outcome geometry similar to a slow decision-making cycle—foundational to the understanding of Boyd's Observe, Orient, Decide, Act (OODA) Loop. This study adds depth to the theory illustrating technology-induced latency has a similar effect as slow human decision making resulting in lower performance. Therefore, when combined with the human decision-making process, latency compounds the effect, resulting in significantly lower performance.

Military missions conducted by remotely piloted aircraft (RPA) continue to expand into all facets of operations, including air-to-air combat. While future within-visual-range (WVR) air-to-air combat will be piloted by artificial intelligence, RPAs will likely see combat first. Command-and-control latency could play a significant role during beyond-line-of-sight engagements. The study discussed in this article quantifies the effects of command-and-control latency on 1 v 1 WVR air-to-air combat success during high-speed and low-speed engagements.

The research, pursued in coordination with the Air Force Research Laboratory and the Air Force Warfare Center, employed a repeated-measures experimental design with variable latency to test the various hypotheses associated with beyond line-of-sight latency. Nellis AFB, Nevada, participants experienced in air-to-air operations were subjected to various latency inputs during 1 v 1 simulated combat using a virtual-reality simulator and were scored on the positional geometry of each engagement.

Background

Since the advent of the fighter plane in World War I, every Western-trained fighter pilot has learned the three axioms of air-to-air combat: (1) lose sight, lose fight, (2) maneuver in relation to the bandit, and (3) energy-versus-nose position. These three central themes permeate visual air-to-air combat tactics and describe the importance of analyzing the adversary's current position and state, executing offensive and defensive maneuvers based on the bandit's plane of motion, and making continuous decisions about conserving or exploiting energy.

Dr. David L. Thirtyacre, Colonel, USAF, retired, is the chair of the Department of Flight, Worldwide Campus, Embry-Riddle Aeronautical University, Daytona Beach, Florida.

The common thread in these concepts is time. Losing sight of the adversary momentarily, maneuvering too early or late, or depleting energy at the wrong time all spell defeat in the dogfight. John Boyd codified these ideas in his Observe-Orient-Decide-Act (OODA) Loop theory—completing this faster than the adversary was the key to air-to-air combat success.[1]

Today, military aviation is increasingly expanding the use of remotely piloted aircraft into principal facets of military aviation. The MQ-1 Predator and MQ-9 Reaper have proven the utility of unmanned aircraft systems (UAS) in combat and have amassed millions of flight hours.[2] Since the 1995 introduction of the MQ-1 to the Bosnian theater of operation, the main mission of the medium-altitude, long-endurance RPAs has been intelligence collection and ground attack.[3] In the Department of Defense mission taxonomy, this includes intelligence, surveillance, and reconnaissance and close air support.

Despite not being designed or tasked for air-to-air combat, American RPAs have engaged in air-to-air combat, albeit on a limited scale.[4] The latency of command-and-control transmissions is an inherent drawback of these systems. While latency influences all teleoperations, the extent of the effect during within-visual-range air-to-air combat has not been explored. As the Air Force prepares to use RPA and artificial intelligence (AI) in WVR combat, it must understand the effects of latency, or missing sensor data, during a dogfight.

Requirements

Air-to-air combat typically requires a highly maneuverable fighter aircraft capable of transonic velocities that can sustain high acceleration loads.[5] These attributes are especially important during within-visual-range combat, where two aircraft are entangled in a rapidly changing, highly dynamic fight, each attempting to gain an advantage and employ ordnance. While there are reports of short skirmishes between American remotely piloted aircraft and manned enemy fighters, US RPAs were not well suited for such an engagement and were ultimately defeated.[6]

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[1] Chuck Spinney and Chet Richards, eds., *John Boyd, Patterns of Conflict*, updated slide presentation, (Atlanta, GA: Project White Horse, February 27, 2005), http://www.projectwhitehorse.com/..

[2] "MQ-1 Predator Unmanned Aerial Vehicle," Fact Sheet, Hurlburt Field (website), n.d., accessed October 24, 2022, https://www.hurlburt.af.mil/.

[3] Robert B. Trsek, "The Last Manned Fighter: Replacing Manned Fighters with UCAVS" (master's thesis, Air Command and Staff College, 2007), https://apps.dtic.mil/.

[4] John R. Hoehn, Kelley M. Sayler, and Michael E. DeVine, *Unmanned Aircraft Systems: Roles, Missions, and Future Concepts*, R47188 (Washington, DC: Congressional Research Service, July 18, 2022), https://www.everycrsreport.com/.

[5] Michael Mayer, "The New Killer Drones: Understanding the Strategic Implications of Next-Generation Unmanned Combat Aerial Vehicles," *International Affairs* 91, no. 4 (2015), https://www.jstor.org/.

[6] Hoehn, Sayler, and DeVine, *Unmanned Aircraft Systems*.

Medium-altitude long-endurance UAS such as the MQ-9 lack the attributes required to succeed in this dynamic air combat environment. Still, advances in unmanned aircraft system technology will inevitably yield an aircraft suited for WVR combat. As these fighter-unmanned combat aerial vehicles (F-UCAV) become operational, the opportunity for WVR engagements increases.

The first of these engagements will likely be between an F-UCAV and a traditionally occupied fighter aircraft in an area of responsibility far from the ground control station. Robert B. Trsek identified command-and-control delay as a major hurdle in F-UCAV air-to-air combat and concluded "it is presumptuous to assume that short-range engagements are a thing of the past."[7] But future "short-range engagements" will not look the same as they have in the past.

Future air-to-air engagements will include a mix of autonomous, remotely operated, small hypermaneuverable swarms and manned aircraft. This arsenal and the use of directed-energy and other advanced weapons should make the classic dogfight rare and only a last resort, especially in a conflict with a peer adversary. Still, the effects of latency in such a highly dynamic environment yield key insights into the decrease in human or AI performance with inaccurate or spoofed sensor data. The study isolated latency effects in a highly specific environment and should not be considered a prediction of the overall success of an air-to-air engagement.

Most combat missions employing medium-altitude, long-endurance UAS occur thousands of miles from the ground control station, using terrestrial and satellite communications architecture.[8] During these beyond-line-of-sight operations, the command-and -control signal from the ground control station must travel through terrestrial networks, be uplinked to a satellite constellation, and then downlinked to the UAS. Telemetry data and sensor information travel the same path in reverse before reaching the pilot in the ground control station.

This communication pathway injects latency between the adversary's true position and what is displayed to the pilot. This same latency occurs between the pilot's input and the aircraft receiving the command. Typically, in beyond-line-of-sight operations, the one-way latency can be as low as 0.25 seconds and as high as 1.0 seconds.[9] During completely autonomous AI operations, delayed, inaccurate, and jammed sensors will influence the fight, resembling command-and-control latency.

The latency can be applied to Boyd's OODA Loop as delays in observing, difficulty orienting, latent decisions, and delaying the act phase. The delay between the transmitted

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[7] Trsek, "Last Manned Fighter," 26.

[8] Fubiao Zhang, Tim Fricke, and Florian Holzapfel, "Integrated Control and Display Augmentation for Manual Remote Flight Control in the Presence of Large Latency" (paper presented at the American Institute of Aeronautics and Astronautics Guidance, Navigation, and Control Conference, San Diego, CA: January 4–8, 2016), https://arc.aiaa.org/.

[9] F. C. de Vries, *UAVs and Control Delays*, TNO report DV3 2005 A054 (Soesterberg, NL: TNO Defence, Security and Safety, September 2005), https://apps.dtic.mil/.

video/telemetry of the RPA and when the pilot receives this information corresponds to the observe phase. The delay between the RPA pilot making a flight control input and the aircraft receiving the command corresponds to the act phase (remote manipulation) in the OODA Loop. The sum of these two latencies is the total feedback loop latency induced by command-and-control transmission. But the effect of transmission latency while maneuvering against a changing target location adds another level of complexity, further increasing the error.

The review of relevant literature reveals a distinct gap: the effect of latency during highly dynamic maneuvering while both the vehicle and objective are rapidly changing parameters. This literature gap aligns with Boyd's OODA Loop theory, forms the theoretical construct of this study, and defines the independent variables.

The three research questions focus on the effects of latency while executing the phases of Boyd's OODA Loop theory and compare the results between high-speed and low-speed engagement entry conditions. The study focused on the control loop latency (input to feedback) in order to isolate the effects. The latency input through independent variable (IV) 1 can be seen as the delay from control manipulation to the aircraft movement plus the return delay.

Research question 1: To what extent do different levels of command-and-control latency affect combat success during 1 v 1, WVR, and air-to-air combat?

Research question 2: To what extent does initial engagement geometry/velocity affect combat success during 1 v 1, WVR, and air-to-air combat?

Research question 3: What is the possible interaction between command-and-control latency and initial engagement geometry/velocity during 1 v 1, WVR, and air-to-air combat?

Method

This quantitative research employed a repeated measures experimental design during air-to-air combat simulation. The design allowed multiple, randomized, single-blind treatments of each subject, including a no-treatment control measurement. Each subject experienced all six treatments for each type of engagement (high-speed and low-speed) assigned in the order specified through a balanced Latin square during a one-hour simulation session.

Population/Sample

All fighter pilots are trained in air-to-air combat, but the level of training and proficiency can vary depending on the aircraft and mission. To ensure tactical currency and maintain a homogenous population, participants were current fighter pilots who maintained flight currency in the past five years. All participants completed basic and advanced air-to-air training and achieved a qualification equivalent to four-ship flight lead (Air Force) or division lead (Navy and Marine Corps).

Only manned fighter pilots with air-to-air mission qualifications in aircraft such as the F-15C, F-15E, F-16C, F-18A-G, F-22, and F-35A-C were considered. Pilots who graduated from Navy Top Gun or the Air Force Weapons Instructor Course were preferred due to their advanced knowledge, training, and proficiency. The sampling strategy purposely selected participants from the sampling frame. The principal investigator-initiated selection ensured purposeful sampling was maintained (i.e., ensuring a mix of pilots from different fighter aircraft). (Information on participant prescreening, management, scheduling, and institutional review board authorization can be obtained from the author.)

Simulation

The experiment occurred in a purpose-built, unclassified simulator and induced a system delay. The Windows driver was delay-selectable, allowing an input range from 0.000 to 2.000 seconds in 0.001-second increments. The delay between the pilot controls and the simulation software allowed the investigator to manipulate IV 1.

The IVs, often referred to as the within-subjects factors, were the total round-trip latency (IV1) induced into the simulation system through the delay driver and the engagement type (IV2). The IV1 was operationalized by assigning the given latency to the delay driver. Independent variable 2 was the engagement entry geometry/velocity labeled high-speed or low-speed. The specific engagement type was operationalized by the engagement-starting parameters. The subjects experienced each engagement type six times, with the corresponding treatment of IV1 varying on each test run. Therefore, each subject completed 12 test runs during the simulation.

The dependent variable is the calculated combat score of the engagement. The score was derived from specific angles after the engagement.[10] While the computation of combat score does not directly measure combat success, it codifies the potentially offensive positional advantage. The combat score is, in effect, the normalization of a geometric relationship between the attacker and the target, where 1.0 equates to the optimal offensive position (i.e., the attacker directly behind and pointing at the target). A -1.0 combat score indicates the worst possible defensive position (i.e., the attacker directly in front of the target).

Data Collection Process

The experimental sequence consisted of 12 engagements with an approximate duration of 120 seconds each. Based on the field test results, the high-speed engagement concluded after 105 seconds, while the low-speed engagement concluded in 90 seconds. A 45- to 60-second rest period followed each engagement before the next run. For each engagement, one of the six preset latency categories was assigned through a balanced Latin square design until each subject on each engagement type experienced all latency levels.

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[10] Heemin Shin et al., "An Autonomous Aerial Combat Framework for Two-on-Two Engagements Based on Basic Fighter Maneuvers," *Aerospace Science and Technology* 72 (January 2018), https://www.sciencedirect.com/.

The parameters of each engagement were closely controlled. The data runs for each fight category (i.e., high-speed and low-speed) began from the same starting point, altitude, and range saved in the primary test profile. But each engagement varied the adversary starting velocity vector, introducing slight differences in the engagement geometry; this input decreased predictability. The target and the attacking aircraft remained the same (airframe performance, visual depiction, and avionics) throughout all the test runs.

The high-speed simulation runs began with the attacker (subject) placed 3.5 nautical miles from the target aircraft with both aircraft pointing at each other at 450 knots true airspeed (KTAS), 20,000 feet above sea level. The low-speed engagements started from a 2000-foot line-abreast formation with both aircraft at 250 KTAS, heading in the same direction. These parameters resemble typical high-aspect WVR starting parameters. The adversary (target) flight artificial intelligence profile was set to expert, commanding the target aircraft to attempt to shoot the attacker with the gun throughout the engagement.

Each engagement concluded at a time specified by the field test. Since a combat score changes throughout the fight, angles and scores were assessed multiple times during the engagement. The assessment occurred near the end of the engagement and consisted of three measurements at start + 1:15, 1:30, and 1:45 for the high-speed engagements and start + 1:00, 1:15, and 1:30 for the low-speed engagements. The assessment times were determined during the field test. All engagements were recorded through the simulation system at a parametric update rate greater than 10Hz for post-test analysis and data collection. Researchers collected a sample of 29 participants, which included 348 separate and distinct engagements over the 12 IV combinations.

Results

The mean combat scores for each latency level are plotted in fig. 1.

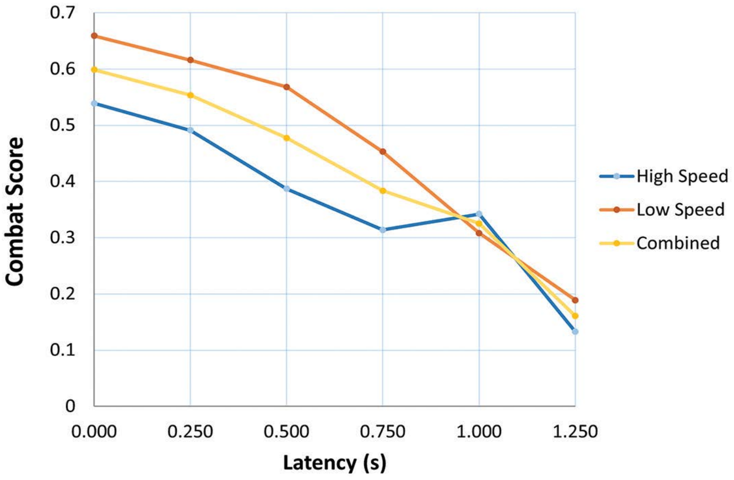

Figure 1. Mean combat scores by latency

The appropriate statistical assumption testing was completed for the two-way repeated measured design, including testing for outliers, sphericity, and normality. In some cases, statistical corrections were required in order to maintain the integrity of the statistical outcome. The two-way repeated measures analysis of variance (ANOVA) indicated a significant two-way interaction between the engagement speed and latency, indicating that the effect of latency on combat scores depends on the amount of latency and the starting velocity or geometry of the engagement. The experimental results were considered as individual functions of the independent variables (simple main effects) as well as combined (main effects).

Discussion

The results of this experiment clearly illustrate the effect of latency and engagement speed on combat success during a within-visual-range fight. But the experiment revealed several areas worthy of further examination, including the performance of the simulated aircraft and the theoretical and practical implications of the research. Before discussing the conclusions of this study, it is important to consider the performance of the simulated aircraft and adversary aircraft.

Performance

While the results of this study indicate pilots can still gain and maintain an offensive position even at the highest-tested latency, the simulated aircraft's superior performance must be considered. During the experimental runs, subjects often max-performed the aircraft, resulting in acceleration loads as high as 11.0 Gz, while the maximum observed adversary load was 7.3 Gz. This was especially true at higher latency levels when the pilots found themselves in poor tactical positions and used superior aircraft performance to outmaneuver the adversary.

A similar observation was present for the aircraft angle of attack. While the maximum observed angle of attack for the adversary was 25.2 degrees, the subjects routinely maneuvered the simulated aircraft to angles of attack greater than 35 degrees (indicated by a warning tone) and sometimes as high as 56 degrees.

Clearly, the simulated aircraft's superior performance influenced the combat outcome of the engagements. Still, this was an intentional aspect of the test plan designed to give pilots a maneuvering advantage resembling what an F-UCAV would provide. While the specific combat score was undoubtedly influenced by aircraft performance, it was apparent that the decrease in performance was present regardless of the F-UCAV's superior performance. Therefore, the conclusions of this study should be taken as combat effectiveness degradation (i.e., the difference between engagements without latency and those with latency) and not a specific value of combat success.

For example, if the combat engagement was between two evenly matched aircraft and pilots of similar skill, experience, and currency, the degradation due to latency would result in a negative combat score. The matched engagement would yield a combat score near zero when latency is not present. When a latency of 1.250 seconds is added to one of the aircraft, a decrease in the combat score of 0.406 should be expected during the high-speed engagement. *This degradation should not be taken lightly since this corresponds to a highly defensive position and would likely result in a combat loss.*

Effects of Latency

The data, observation, and engagement playback led to the conclusion there were several effects of latency with which the pilot must contend, including lift vector control, airspeed control, and general aircraft control. At lower latencies, the main obstacle was lift vector orientation and control. While the pilots may know where the optimal location of their lift vector should be, the latency caused them to either undershoot or overshoot the desired position (i.e., roll past the desired position).

As the latency increased, this issue was compounded, often leading to an orientation in the opposite direction than desired. Latencies of 0.750 seconds and above contributed to large variations in airspeed since the throttle and speed brakes were also delayed as part of the command-and-control link. These large-energy excursions led to a larger-than-desired turn radius or a lack of energy required to complete a maneuver. The airspeed control issues and poor lift vector control often resulted in difficulty controlling the aircraft.

The significant interaction effect indicates the effect of latency on combat scores depends on both latency and engagement speed. Further, it signifies latency does not similarly affect high-speed and low-speed engagements. Fig. 1 illustrates that during the low-speed engagements, the combat score decreased consistently with increased latency, while the high-speed engagements plateaued with latencies of 0.50, 0.75, and 1.00 seconds; there was no significant difference between combat scores at these latencies. The plateau is unique to this research and differs from ground vehicle teleoperations research.[11]

This result could be due to the geometry of the high-speed engagement that allows the pilot to maintain a turn with a constant plane-of-motion. During a turn with the lift vector orientation remaining constant, the latency is only perceptible while increasing or decreasing the turn rate of the aircraft (i.e., changing the acceleration load in Gz). This constant turn also occurred at a higher airspeed than during the low-speed fight, which allowed a higher sustained acceleration load. The higher loading (Gz) resulted in a higher sustained turn rate, allowing the pilot to remain in an offensive position while only adjusting the acceleration load. This conclusion was supported by observation during the engagements and the postflight review.

Overall, the reduction in the combat score was similar between the two engagement speeds. But the high-speed engagement experienced a total degradation of -.406, while the low-speed engagement decreased by -.470, as seen in fig. 1. This result indicates that latency had a larger effect on the low-speed engagement than on the high-speed engage-

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[11] David Gorsich et al., "Evaluating Mobility vs. Latency in Unmanned Ground Vehicles," *Journal of Terramechanics* 80 (2018), https://www.researchgate.net/.

ment. This is supported by the increased slope of the linear regression for the low-speed engagements as compared to the slope of the high-speed engagements. Additionally, while a significant difference existed between the engagement speeds at the lower latencies, the results showed no significant difference at latencies of 1.000 and 1.250 seconds.

Further examination reveals the advantages in combat scores of the low-speed engagements observed at low latencies did not carry over to high latencies. Observations during the simulation indicated early advantage in the low-speed engagements was centered around the superior simulated aircraft's angle-of-attack limit that allowed a higher-energy bleed rate at the start of the fight. This high-bleed rate slowed the simulated aircraft much faster than the adversary aircraft and resulted in a rapid offensive advantage.

This was evident during the engagement review, where pilots were consistently in an offensive position earlier during the low-speed engagements compared to the high-speed engagements. As the engagement continued, the early advantage of the low-speed engagement dissipated and was no longer statistically significant at the higher latencies.

Another point of discussion is the comparative decrease in combat scores between zero latency and 1.000 seconds. While the low-speed engagement score decreased by 0.351 in this region, the high-speed engagement only decreased by 0.197. The decrease in combat scores during the high-speed engagement was 44 percent less than the low-speed engagement. This result further indicates a significant advantage of engaging in a high-speed, two-circle fight when latency is present.

The research results clearly indicate a significant decrease in combat scores with increasing latency regardless of engagement speed. But several areas should be noted. First, there was not a significant difference between 0.000 and 0.250 seconds of latency for either engagement speed, indicating that delays up to 0.250 seconds did not affect the aircraft position after the engagement. This was true through an analysis of both the main effects and simple main effects. Observation also supported that the 0.250-second delay was acceptable and often unnoticed by the subjects. This result is similar to research that found no significant difference between zero latency and 0.2 seconds of latency for trained subjects.[12]

During the high-speed engagements, no significant difference existed between 0.000, 0.250, and 0.500 seconds of latency, although the mean combat score decreased. The standard deviations indicate a larger variance associated with the high-speed engagements than the low-speed engagements that influenced the p-value. The higher combat score deviations could be due to the subject's initial merge gameplan and geometry during the high-speed engagements that allowed more tactical options (variations) than the low-speed fight. Interestingly, the higher variation during the high-speed engagements occurred at lower latencies and resembled low-speed engagements at high latency.

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[12] Gorsich, "Mobility vs Latency," 11–19.

Conclusion

The theoretical foundation of this study was Boyd's OODA Loop. While the original construct of the OODA Loop theory was based on making tactical decisions faster than the adversary, this study indicates technology-based latency influences the engagement outcome geometry similar to a slow decision-making cycle. This is foundational to the understanding of the OODA Loop since, in its original form, it described the human decision-making process where the individual observes an action, orients based on knowledge and previous experience, decides on an action, and executes the action.

This study adds depth to the theory illustrating that technology-induced latency has a similar effect as slow human decision making, resulting in lower performance. Therefore, when combined with the human decision-making process, latency compounds the effect resulting in significantly lower performance.

The current understanding of the OODA Loop process was that command-and-control latency would only affect the observe and act phases of the OODA Loop. But this study indicates latency affects the entire OODA Loop and that the orientdecide-act process was particularly influenced. The pilots' ability to maintain congruency between orientation and action proved more difficult as latency increased. This caused the pilots to spend most of their time in the orient, decide, and act phases while occasionally returning to the observe phase. An analogy would be that the pilots were stuck in a dountil loop between orientation, decision, and action (fig. 2).

The do-until loop was continued until the action determined in the decide phase was satisfactorily completed. Other latency studies identified the move-and-wait strategy to compensate for delays in command and control; the effect seen in this study could be interpreted as a dynamic move-and-wait.[13]

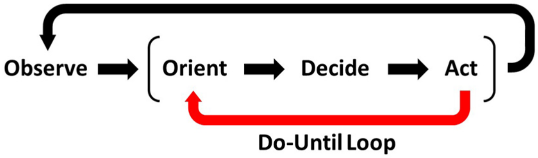

Figure 2. Do-until loop acting internal to OODA Loop process

The study revealed several practical outcomes that are of particular interest. Although the study showed a significant decrease in a combat score with increased latency, pilots could maintain an offensive advantage even at the highest tested latency. As mentioned above, this could be partially attributed to the superior performance of the simulated

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[13] Justin Storms, Kevin Chen, and Dawn Tilbury, "A Shared Control Method for Obstacle Avoidance with Mobile Robots and Its Interaction with Communication Delay," *International Journal of Robotics Research* 36 (2017), https://journals.sagepub.com/.

aircraft but also supports the conclusion that given enough performance advantage, an offensive position is possible even with a 1.250-second latency.

The field test results effectively bounded the upper limit of latency based on manual aircraft control. When latencies of 1.500 seconds and above were tested, severe aircraft control issues emerged, often resulting in ground impact during engagements. Conversely, the experimental results revealed that a latency of 0.250 seconds was not significantly different from the combat scores without latency. These results support the conclusion that command-and-control latencies of 0.250 seconds and below are acceptable and latencies above 1.250 seconds are unacceptable for a manually controlled aircraft. The results also support the conclusion that latencies greater than 0.250 seconds but less than 1.250 seconds may be at least partially offset by superior aircraft performance during high-speed, two-circle engagements and low-speed, one-circle engagements.

The experimental results showed no significant difference in combat scores between zero latency and 0.500 seconds of latency during the high-speed, two-circle fight. Also, the results displayed no significant difference between 0.500 and 1.000 seconds of latency for the high-speed fight. A possible conclusion from these results is that the two-circle fight is less susceptible to degradation due to latency. This conclusion is supported by observation during the experiment that orientation and maneuvering were easier during the two-circle fight versus the one-circle fight, where the lift vector orientation changes rapidly. The practical application of these results is that when latency above 0.250 seconds is present, the two-circle fight is desired over the one-circle fight.

Given that latency-induced control issues with lift vector orientation and airspeed were major obstacles, F-UCAV command-and-control design should consider automating these inputs. The airspeed could be controlled or limited onboard the aircraft by following an optimum maneuvering energy profile to eliminate extreme cases of airspeed mismanagement. The lift vector control issues could be reduced by implementing a predictive algorithm based on current aircraft performance, pilot control input, and measured latency. This would result in a predictive display, allowing the pilot more precise control when orienting the lift vector.

In a few cases, subjects achieved very high combat scores even at the highest tested latency. One subject achieved an average engagement score of .668 with a latency of 1.250 seconds. Results like this indicate that pilot technique may play a larger role than expected in countering the latency effects and should be explored in future studies.

The study's final and ancillary practical contribution demonstrated that a properly configured virtual reality simulator can produce an effective air-to-air training environment. While not the purpose of this experiment, the simulation provided an effective and efficient environment for practicing manual flight skills. Pilot comments, subject matter experts, and other simulation and aviation experts during the experiment support this conclusion. While this study intentionally excluded several variables such as sensors, weapons, weapon cueing, and weapon performance to isolate the pilot's ability to maneuver to and remain in the control zone, the research shows the first step in developing tactics to overcome latency is understanding how latency affects the basic fighter maneuvers.

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