EMBRY-RIDDLE Aeronautical University

SCHOLARLY COMMONS

Journal of Aviation/Aerospace Education & Research

Volume 28
Number 1 *JAAER 2018*

Article 4

2018

Scenario Development for Unmanned Aircraft System Simulation-Based Immersive Experiential Learning

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Introduction

Scenario-based training is a time-tested methodology for imparting new skills, knowledge, and behaviors (Lawson, 2015). Over the past decade, training strategies for unmanned aircraft system (UAS) remote pilots and sensor operators have evolved and been refined, but these have generally followed methodologies that were effective for manned pilot training. Scenario-based training is a central practice established by military and commercial aviation for manned and unmanned flight training. UAS remote pilots and sensor operators can train for professional levels of skill through scenario-based training, as evidenced through military applications (U.S. Army Fort Huachuca Training Cadre Unmanned Aircraft Systems Operators, personal communications, February, 15, 2017). The concept of training transfer centers upon learning a task using a surrogate system (e.g., computer-based aircraft simulator) and then subsequently demonstrating an ability to perform the same task in an actual aircraft. The use of computer-based aircraft simulators is a well-established training practice (Macchiarella, Arban, & Dogherty, 2006; Rigby, Macchiarella, & Mirot, 2017). The use of simulation for training has a rich history that is built upon developed educational theory and practice. *Experiential learning theory* (ELT) (Kolb, 1984) is an educational theory that is relevant when considering instructional design for preparing professional UAS remote pilots and sensor operators. Experiential learning is a process through which students develop knowledge, skills, and abilities from direct experiences.

Preparing Professional Remote Pilots

Collegiate UAS degree programs, which require professional-level UAS training, can adapt training methodologies germinated in manned flight (Lerner, 2015). Multiple colleges and universities (e.g., Embry-Riddle Aeronautical University, University of North Dakota, Kansas State University, and Liberty University) have implemented degree programs that lead to academic degrees and professional UAS certifications. The Federal Aviation Administration (FAA) subscribes to the position that remote pilot airmen certification will be integrated throughout the Federal Aviation Regulations (FARs) and be reflective of established manned airmen certification training practice (Duncan, 2016; J. Duncan, personal communication, March 28, 2017). The FAA's issuance of the Small Unmanned Aircraft Systems (sUAS) regulation, 14 C.F.R. § 107 (FAA, 2016), enabled the use of UAS (e.g., systems that weigh less than 55 lbs and have a ground speed less than 100 mph) and prescribed procedures for the commercial use of these systems. The FAA is formalizing flight procedures for all UAS—this includes large, complex, and heavy systems.

The FAA's mission is to ensure the safety of the nation's airspace and aircraft, plus, protect people and property on the ground (FAA, 2017a). Commercial sUAS pilots must now obtain an FAA issued Remote Pilot Certificate (RPC), with the only type rating that is available – Small Unmanned Aircraft System. In the future, as UAS evolves, the FAA will implement higher levels of pilot certification. This certification process will address the complexities of operating large complicated UAS that are performing remote sensing and payload transport missions. Training methodologies for future, and larger, UAS type ratings will be graduated to reflect higher levels of knowledge and skill that are necessary due to increased complexities (i.e., speed, weight, altitude, operational range, etc.) (J. Duncan, personal communication, March 28, 2017). As the complexity of UAS flight operations increase and applications of larger complex UAS proliferate, the need for professional level commercially certificated remote pilots will occur. The FAA will further regulate certification and training through the development of Remote Pilot Airman Certification Standards (FAA, 2017b).

https://commons.erau.edu/jaaer/vol28/iss1/4
DOI: https://doi.org/10.15394/jaaer.2018.1773

The undergraduate UAS Science degree program at Embry-Riddle Aeronautical University, Daytona Beach, Florida, relies extensively upon a generic medium altitude long endurance (MALE) simulator for educational and training purposes. One of the aims of the program is to prepare its students to operate large, heavy, and complicated UAS that are performing remote sensing missions. Various taxonomies of UAS classification help with understanding the wide range of air vehicles and associated levels of skill that are required to perform operations.

The U.S. Department of Defense provides one of the most widely used UAS classification systems (Department of Defense, 2013). At the high end of the range, in terms of UAS size and complexity, are Group 4 and 5 systems; MALE UAS are counted among this group of systems (Department of Defense, 2013). The complexity of these systems and associated operational environments necessitate formalized training and professionalized flight techniques (U.S. Army Fort Huachuca Training Cadre Unmanned Aircraft Systems Operators, personal communications, February 15, 2017). These systems are large, expensive, and typically capable of flying throughout the National Airspace System (NAS) under positive air traffic control (ATC). MALE systems weigh above 1,320 lbs and operate at high altitudes. This simulated MALE UAS has capabilities similar to the General Atomics Aeronautical Systems Inc. *Predator XP* unmanned aircraft (General Atomics, 2015). A heavy and complex UAS was purposefully chosen to expose students with the concepts and performance factors that are uncommon in smaller systems and therefore prepare them for a wider array of careers in the UAS industry.

UAS simulators can provide a realistic virtual representation of the real world, to include flight environment and sensor payloads. Simulator fidelity is a complex topic. Fidelity can be defined as the degree that the simulator represents its referent (Department of Defense, 2018). The university's MALE UAS simulators were built with mathematical, physical, and functional fidelity aimed to match a class appropriate real world referent (i.e., General Atomics *Predator XP*). Mathematical fidelity enables realistic flight dynamics, control loading, displays, and computer-generated imagery. Physical fidelity provides realistic control interactions with the simulator's ground control station (GCS). In total the functional fidelity provides the remote pilot with control and systems experiences nearly matching the real world. Appropriate levels of mathematical, physical, and functional fidelity cannot alone provide exacting levels of real world experience in simulation. Psychological-cognitive fidelity is the extent that psychological and cognitive factors of real world activity can be replicated within the simulation (Kaiser & Schroeder, 2003). Scenarios are integral to the simulation-based training and are tailored to skill task level. This approach is in practice at the university. It provides a practical application that is both motivating and realistic, with the aim of psychologically and cognitively engaging students. Scenario-based training is stratified from basic levels (e.g., UAS flight control and navigation) through intermediate levels (e.g., sensor payload operation) to high-levels (e.g., search/rescue operations, surveillance/reconnaissance operations, etc.). Training in this manner is reflective of methodologies leading to airmen certification for manned commercial flight and military certification approaches presently in use for manned and unmanned military pilots.

Scenario Development

Training Remote Sensing and Operational Mission Methodology

The curriculum supporting the UAS degree program includes three key laboratories in which students learn advanced and mission-oriented techniques and procedures while using the university's MALE UAS simulation (see Figure 1). Students work as a crew to complete collaborative learning experiences. The crew operates from the GCS (see Figure 2) during training while flying and operating sensors. Ultimately, the flight tasks orient on performing remote sensing observation (Embry-Riddle Aeronautical University, 2018).

Figure 1. Visualization of the Generic MALE UAS Simulation.

Figure 2. MALE UAS Simulated Ground Control Station (GCS).

Mission-Planning Lab

The mission-planning lab sets the foundation for UAS control and navigation that enables higher order thinking skills to be developed during scenario-based training. Students enrolled in this lab learn UAS pilotage skills that are required to navigate a UAS from the departure point to an operational working area and then return safely (see Figure 3). The tasks mastered in the lab are reflective of manned primary flight training tasks (e.g., normal take off, climb level off, cruise, systems monitoring, and fuel management). Learning outcomes reflect these skills (see Table 1).

Table 1

Mission-Planning Learning Outcomes

Number	Outcome
1.	Prepare data, charts, and flight logs to assist in the data entry of UAS flight plans.
2.	Select waypoints and flight paths to meet a specified operational need.
3.	Develop original flight plans based on UAS performance data and operational objectives.
4.	Choose a route of flight based on UAS system limitations and capabilities.
5.	Estimate arrival times, energy consumption and signal strength based on student developed flight plans.
6.	Construct contingency plans that address a UAS loss of control link and abnormal conditions.

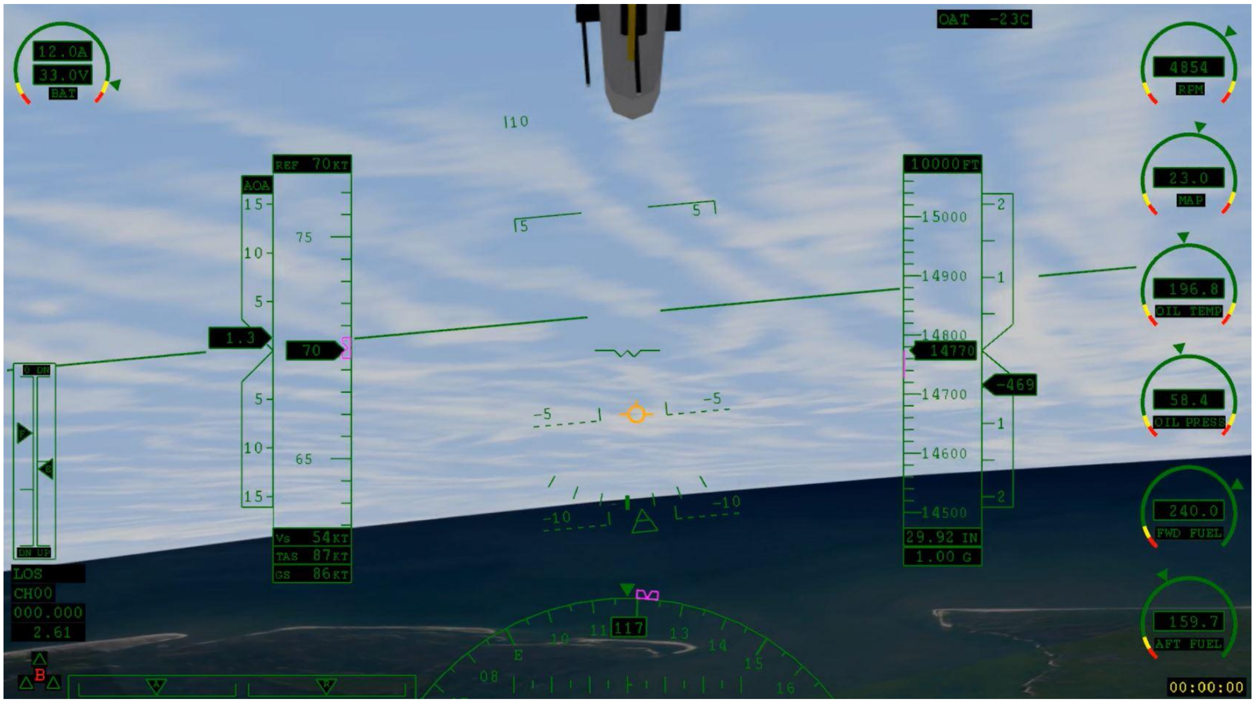

Figure 3. Remote Pilot's Heads Up Display (HUD) as generated by the simulation.

Remote Sensing Lab

The remote sensing lab provides a realistic synthetic environment for employing a sensor payload. Students enrolled in this lab develop mastery of remote piloting and navigation skills. Sensing tasks are designed to teach the art and science necessary to understand planning and conducting operations (see Figures 4 and 5). Remote sensing is at the center of UAS operational art and science. At this time and across domains of use, UAS are flown extensively to conduct remote sensing. Tasks necessary for mastery include selecting appropriate sensors, collecting data, and interpreting the data. Theory and practice includes sensor data that is obtained passively (e.g., infrared [IR], near infrared-low light television [LLTV], and electro-optical [EO]). Learning outcomes reflect these skills (see Table 2).

Table 2

Remote Sensing Learning Outcomes

Number	Outcome
1.	Employ a variety of UAS payload technologies to complete a task as a team.
2.	Interpret imagery captured with a UAS to construct a mental model of condition on the ground.
3.	Synthesize data collected from UAS to make judgments about conditions on the ground.
4.	Utilize search techniques to systematically image an area and point out areas, objects or people of interest.
5.	Choose the appropriate technology to maximize effectiveness of a UAS payload.

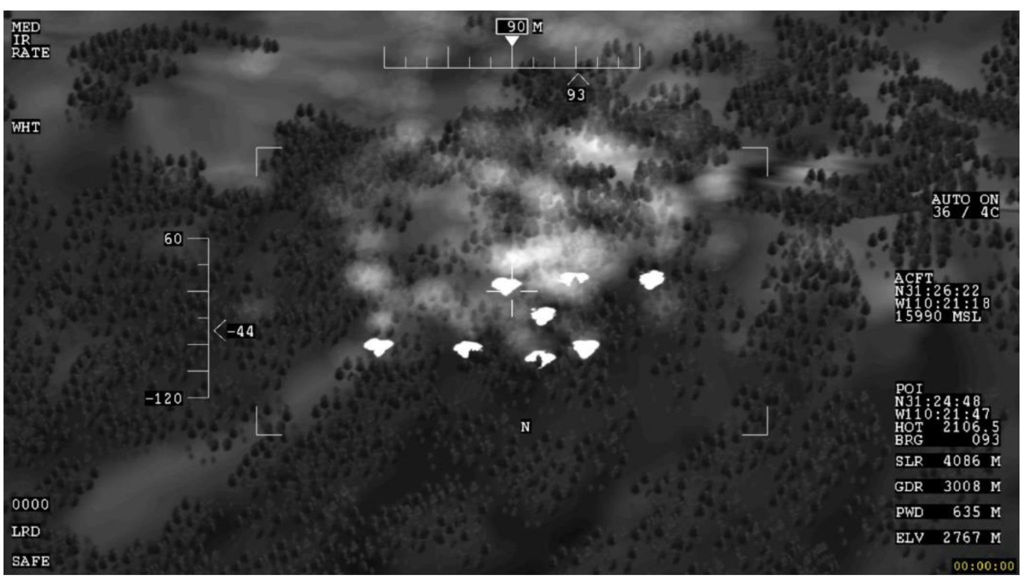

Figure 4. Wildfire as seen through the image generator's infrared (IR) emulator.

DOI: https://doi.org/10.15394/jaaer.2018.1773

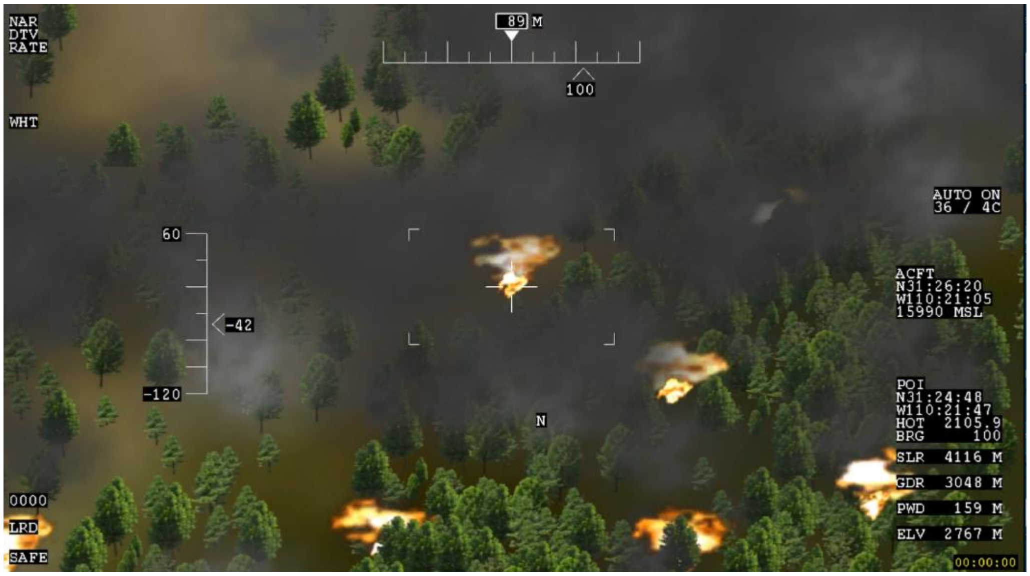

Figure 5. Wildfire as seen through the image generator's electro-optical (EO) emulator.

Operational Mission Lab

As part of a crew, while teamed with simulated collaborative agencies (e.g., ground and sea-based public service organizations), students operate a MALE UAS simulator, to accomplish a mission using a predefined set of parameters. Tasks mastered in this lab are associated with higher-levels of learning that include analysis and evaluation of operational scenarios. Students are challenged to create operational solutions. These solutions are implemented in real-time during simulated mission flights. Flights originate at an operating base and then fly to a mission area where students must make decisions that are necessary to solve problems and achieve mission needs. Learning outcomes reflect these skills (see Table 3).

Table 3

Operational Mission Learning Outcomes

Number	Outcome
1.	Explain the different operational functions of an unmanned aircraft ground control station.
2.	Demonstrate using the unmanned simulator the proper flight operation of an unmanned aircraft.
3.	Demonstrate using the unmanned simulator the proper use of the sensor controls of an unmanned aircraft.
4.	Operate an unmanned aircraft, as part of a team, to accomplish a mission using a predefined set of mission parameters.
5.	Make judgments regarding the future of the UAS flight control systems based upon knowledge of the current state of the technology.

Simulation-Based Experiential Learning

The immersive nature of scenario-based training—a virtual environment replicating real-world conditions and eliciting high degrees of trainee behavioral fidelity (Department of Defense, 2018)—creates a setting where students perform in near real-world-like conditions. This is particularly useful in training UAS remote pilots and sensor operators. The workstation physicality for remote pilots and sensor operators for both simulation-based training and real-world operations is nearly identical; it is a climate-controlled room with no visual sight lines of the aircraft, airfield or area of operation. Scenarios that replicate live missions provide participants with experiences that they can draw upon while mastering principles, techniques, and procedures. These learning processes can be readily described as *experiential learning theory* (ELT) (Kolb, 1984).

Experiential learning is learning derived from experiences or learning by performing. Training based upon ELT principles can occur through simulated or real world equipment.

Experientially oriented education immerses learners in experiences and then facilitates reflection in order to develop new skills, new attitudes or new ways of thinking. Kolb and Kolb (2005) build upon this theory that has its origins in the understandings of human learning and adult development. They identify six propositions that are expressed through ELT. First, learning is a process. Higher order learning occurs in a process that is an engaging environment that includes feedback. Second, learning is a function of relearning. Learning is facilitated when learners draw upon what is known to them and then reconstructed into new levels of knowledge. Third, learning involves weighing and assessing opposing views. Learners consider differences and reflect upon opposing views or possibilities. Fourth, learning is an aggregating process. The process of learning includes more than gaining knowledge; it includes feelings and subsequent behaviors. Fifth, learning involves analytically assimilating new knowledge into what is known. Sixth, higher-level learning is constructive in nature. Knowledge is not transferred directly into the learner but is created by the learner building upon what is known.

ELT Oriented Scenario Design

Scenario-based training is applied as a means for preparing professionals, and aspiring professionals, with the goal of creating performance effectiveness in the real-world to include under conditions of stress (National Research Council, 1998). Properly crafted scenarios, implemented in realistic simulated environments, essentially serve as a surrogate for the real-world, and provide a medium for experiential learning. This occurs with the inherent advantages that simulations and virtual environments afford. Delivering appropriate levels of stressors in a training scenario can serve as an important element for providing a naturalistic environment (Cohen, Brinkman, & Neerincx, 2015). While training in simulation can never fully replicate the stresses and complexities of a real-world operational environment, it can elicit realistic performance and behaviors by UAS sensor operators and remote pilots.

UAS sensor operator training during the remote sensing lab. This laboratory addresses advanced UAS application techniques and procedures in an experiential setting. Students work as a crew to complete operations that focus on sensor payload applications. A typical example of sensor payload application entails the crew using IR, LLTV and EO to search a large area. Students participate in a lecture detailing the types of systematic scan techniques and the interdependency of the aircraft's position with the sensor's gimbal angles. After the material is introduced, students move to the GCS to employ the simulated system.

Students are required to conduct a remote sensing survey of an area that is too large to search with a single sensor's field of view. The purpose of the sensing survey is to find people and items of interest, record locations, and monitor movements throughout. The identified area of interest is in the vicinity of Sierra Vista, Arizona. When students begin the training scenario, the simulator's initial condition places the unmanned aircraft in a holding pattern over the Sierra Vista Municipal Airport. The student crew navigates the unmanned aircraft into an orbit over the area of interest. Once established in holding, the crew works together to find and report the location of all people and items of interest. Students must provide the instructor with a detailed description of each object and the coordinates of each location. In order to accomplish this task, the remote pilot must position the unmanned aircraft to provide an unobstructed view that maximizes the sensor's effectiveness. Meanwhile, the sensor operator employs a variety of systematic scan techniques aimed at the assigned area.

UAS crew operations during the operational mission lab. The Operational Mission lab requires students to apply previously gained knowledge in a collaborative learning environment. Again, the MALE UAS simulator serves as the medium for conducting training. Students are presented with a complex scenario and work to achieve mission objectives by using combinations of new knowledge discovery and problem solving. After the scenario has been completed to a logical end, students evaluate their performance and identify issues that can be extrapolated to future operations. The goal of this lab is to give students an in-depth understanding of UAS flight operations and prepare graduates for future employment developing, supporting, and operating UAS during complex missions in the real world.

Training mission example. One of the key scenarios that is used during crew training missions, requires the employment of the MALE UAS and its sensors in response to a simulated industrial and environmental accident. The scenario is based upon a fictitious oil company that has experienced a catastrophic explosion on one of its oil rigs. The explosion causes the rupture of a main pipeline that spews millions of barrels of oil into the sea (see Figures 6 and 7). An oil platform worker is blown overboard, during the explosion, and is adrift somewhere in the debris field.

Student crews are tasked to survey the aftermath of the catastrophe with the main objective of locating the missing oil platform worker. The scenario has a temporal component that requires the crew to plan for the drift. The drift is caused by wind, tide and currents and must be accounted for in order to successfully find the missing worker. Due to the time delay between mission notification, launch, flight to the operational area, and arrival to the area of operation, the missing worker is no longer adjacent to the oil rig. The scenario covers ten hours of time in total. Successful student crews achieve mission objectives and requirements (Table 4). The knowledge gained by crews is built upon performing in real-world-like conditions, formulating solutions, examining various views, constructing an operational solution, and critically reviewing team performance after completing the scenario. Success enables rescue crews to recover the missing worker.

Table 4

Operational Mission Requirements

Number	Requirement
1.	Develop and fly fully autonomous flight paths.
2.	Flight plans must follow instrument flight rules (IFR).
3.	Locate the missing platform worker and return to base within 6 hours.
4.	Present a plan that complies with all Federal Aviation Regulations.
5.	Make hourly progress reports to the incident commander.
6.	Locate the center of mass for the oil spills and plot the locations of the missing oil platform worker and oil spills on a map using a latitude longitude coordinate system.

Figure 6. Example of an oil rig fire and oil spill as seen through the image generator's electro-optical (EO) emulator.

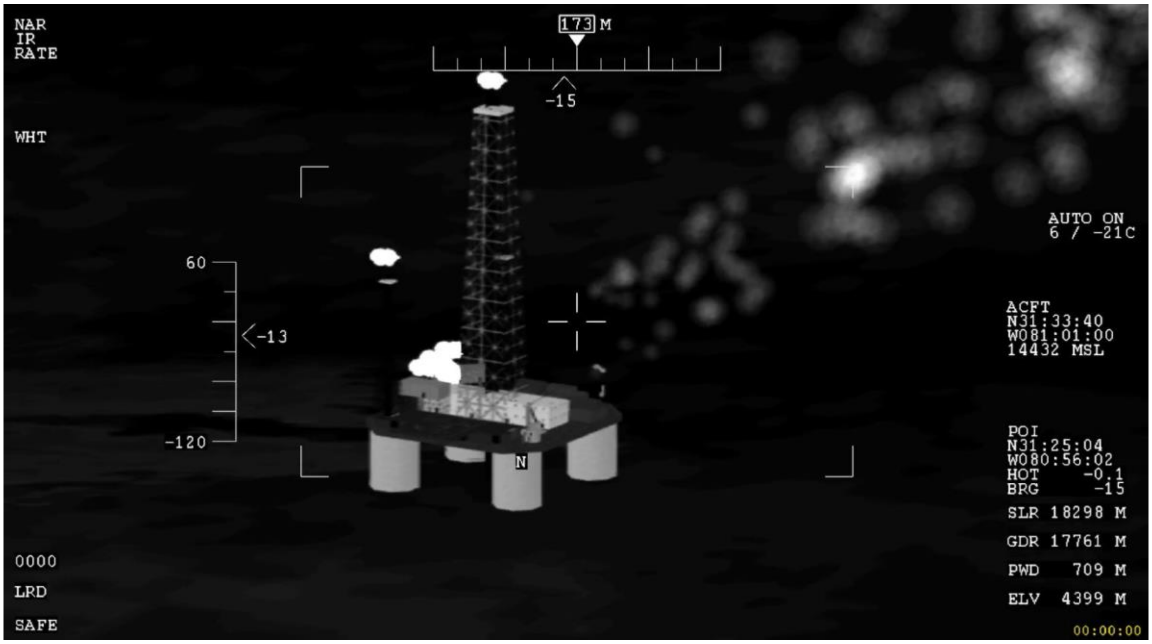

Figure 7. Example of an oil rig fire and oil spill as seen through the image generator's infrared (IR) emulator.

Conclusion

Scenario-based training, implemented in an immersive environment with high degree realism, creates a training medium where aspiring remote pilots and sensor operators can gain experiences that are truly akin to the real world. Applying simulation-based scenarios for developing professional skill levels is well-established practice for the professional preparation of commercial manned pilots and military manned and remote pilots. Experiential learning serves as a means for gaining new knowledge regarding UAS operational missions that are widely applicable in the real world. Student experiences gained during simulated UAS missions facilitate reflection that leads to the construction of new skills, new attitudes, and new ways of thinking.

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