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Evaluation of Quad-Agent Small Firefighting System

Keith Bagot
Nicholas Subbotin

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16. Abstract

Technological advances and firefighting research have helped improve new firefighting systems on large and small aircraft rescue and firefighting vehicles at airports. One such technology is a quad-agent firefighting system that has the capability to discharge four firefighting agents, i.e., water, foam, dry chemical (potassium bicarbonate (PK)), and clean agent (Halotron), individually or simultaneously. Water by itself is typically not used for aviation fuel firefighting. The water in the quad-agent system is used to mix with foam concentrate solution to create firefighting foam. The quad-agent firefighting system attempts to advance the concept of multiple agents simultaneously applied to the fire to affect a more rapid extinguishment of pool and flowing fuel fires, and maximize fire fighter safety by extending the distance needed to properly apply agent to the fire using its pulse delivery technology.

This research evaluated the capabilities and effectiveness of a quad-agent firefighting system. The research was done in terms of using different combinations of firefighting agents from the same discharge point during an agent flow duration test, agent discharge distance test, engine nacelle flowing fuel fires, and large-scale pool fires.

The results showed that during the agent flow duration tests, using aqueous film forming foam (AFFF) only, the quad-agent system produced an average flow duration of 155 seconds in compressed air foam (CAF) mode. Agent discharge distance results, using AFFF only, showed that the system produced its greatest average distance at a 20° discharge angle. The results from the engine nacelle with 30-ft-diameter ring and concrete pad flowing fuel fires showed the quad-agent system was capable of extinguishing the fires using AFFF only and its agent combinations with AFFF. Individual test results and agent combination averages differed throughout testing. Discharging AFFF, PK, and Halotron agents simultaneously did not significantly decrease the extinguishment time compared to the AFFF and PK combination. The results from the large-scale pool fires showed that the quad-agent system was capable of extinguishing the fire using AFFF only and its agent combinations with AFFF. Individual test results and agent combination averages differed throughout testing. Discharging AFFF, PK, and Halotron agents simultaneously did not significantly decrease the total extinguishment time or total agent discharge times compared to other agent combinations. During the engine nacelle flowing fuel fires and large-scale pool fires, discharging, AFFF, PK, and Halotron agents simultaneously was a less efficient use of available firefighting agent based on average test results. However, the quad-agent system's ability to discharge its agents at the same discharge point will allow a fire fighter to adapt a fire attack as to what agent or agents they could use when extinguishing a fire.

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LIST OF ACRONYMS

2D	Two-dimensional
3D	Three-dimensional
AC	Advisory Circular
AFFF	Aqueous film forming foam
AFRL	Air Force Research Laboratory
ARFF	Aircraft rescue and firefighting
CAF	Compressed air foam
FAA	Federal Aviation Administration
gpm	Gallons per minute
NFPA	National Fire Protection Association
PCA	Practical Critical Area
PK	Potassium bicarbonate
pps	Pounds per second

EXECUTIVE SUMMARY

Technological advances and firefighting research have helped improve new firefighting systems on large and small aircraft rescue and firefighting vehicles at airports. One such technology is a quad-agent firefighting system that has the capability to discharge four firefighting agents, i.e., water, foam, dry chemical (potassium bicarbonate (PK)), and clean agent (Halotron), individually or simultaneously. Water by its self is typically not used for aviation fuel firefighting. The water in the quad-agent system is used to mix with foam concentrate solution to create firefighting foam. The quad-agent firefighting system attempts to advance the concept of multiple agents simultaneously applied to the fire to affect a more rapid extinguishment of pool and flowing fuel fires and maximize fire fighter safety by extending the distance needed to properly apply agent to the fire using its pulse delivery technology.

This research evaluated the capabilities and effectiveness of a quad-agent firefighting system. The research was done in terms of using different combinations of firefighting agents from the same discharge point during an agent flow duration test, agent discharge distance test, engine nacelle flowing fuel fires, and large-scale pool fires.

The results showed that during the agent flow duration tests, using aqueous film forming foam (AFFF) only, the quad-agent system produced an average flow duration of 155 seconds in compressed air foam (CAF) mode. Agent discharge distance results, using AFFF only, showed that the system produced its greatest average distance at a 20° discharge angle.

The results from the engine nacelle with 30-ft-diameter ring flowing fuel fires showed that the quad-agent system was capable of extinguishing the fire using AFFF only and its agent combinations with AFFF. The fastest three-test average extinguishment time was with AFFF and PK (AFFF/PK) simultaneously, slightly faster than the next closest average using AFFF, PK, and Halotron (AFFF/PK/Halotron) simultaneously. The single fastest extinguishment time during one test was using AFFF/PK/Halotron simultaneously. Discharging AFFF/PK/Halotron agents simultaneously did not significantly decrease the extinguishment time and was determined to be a less efficient use of available firefighting agent based on the average test results. The results from the engine nacelle with concrete pad flowing fuel fires showed that the system was capable of extinguishing the fire using the two test combinations tested, AFFF/PK and AFFF and Halotron. The fastest three-test average and single extinguishment time was with AFFF/PK simultaneously.

The results from the large-scale pool fires showed that the quad-agent system was capable of extinguishing the fire using AFFF only and its agent combinations with AFFF. For the large-scale pool fire test, total discharge time was a more accurate indicator of the agent combination and firefighting system’s performance compared to total extinguishment time. Total discharge time is a segment of the total extinguishment time, and is the actual time the agent was being discharged from the hand line nozzle onto the fire by eliminating when the agent stream was turned off, fire fighter repositioning, or any other delay where the fire fighter was not attempting to extinguish fire. The fastest three-test average total discharge time was with AFFF/PK simultaneously; however, all the agent combinations were within seconds of each other. The single fastest total discharge time during one test was recorded with AFFF/PK/Halotron simultaneously, which was slightly faster than AFFF/PK simultaneously. Discharging AFFF/PK/Halotron agents simultaneously did not significantly decrease the total discharge time, and was determined to be a less efficient use of available firefighting agent based on average test results.

The quad-agent system's ability to discharge its agents at the same discharge point will allow a fire fighter to adapt a fire attack as to what agent or agents they could use when extinguishing a fire.

INTRODUCTION

PURPOSE.

The capabilities and effectiveness of a quad-agent firefighting system were evaluated using different combinations of agents from the same discharge point in fire test scenarios.

OBJECTIVES.

The objectives of this research were to evaluate the capabilities and effectiveness of a quad-agent firefighting system using different combinations of agents from the same discharge point during the following fire test scenarios:

- Agent flow durations
- Agent discharge distance performance
- Engine nacelle flowing fuel fires
- Large-scale pool fires

BACKGROUND.

The Federal Aviation Administration (FAA) is interested in new firefighting technologies that can be applied to small airport firefighting to effectively extinguish fires faster, save lives, and increase fire fighter safety. Most small airports have an FAA Advisory Circular (AC) 150/5220-19 compliant dual-agent firefighting system. A dual-agent firefighting system is a common small airport firefighting system with proven capabilities and history in successfully extinguishing fuel fires.

The Phoenix® Pulse Delivery® QuadAgent® firefighting system, hereinafter referred to as the quad-agent system, represents a new generation and technology of small airport firefighting systems. The quad-agent firefighting system attempts to advance the concept of multiple agents simultaneously applied to the fire to effect a more rapid extinguishment of pool and flowing fuel fires and maximize fire fighter safety by extending the distance needed to properly apply agent to the fire using its pulse delivery technology. The quad-agent firefighting system also gives the fire fighter a choice of which agents to use on the nozzle.

Within the framework of an Interagency Agreement, the FAA tasked the Air Force Research Laboratory (AFRL) Fire Research Group at Tyndall Air Force Base, Florida, to evaluate the capabilities and performance of the quad-agent firefighting system. The AFRL's 100-ft-diameter, open-air burn facility, with a large frame aircraft mockup, was used during the testing. This facility's design and test apparatus are effective in the instrumentation, collection, and validation of aircraft crash parameters, which include the documentation of the actual firefighting performance of a quad-agent firefighting system and similar systems of interest to the FAA.

METHODS AND PROCEDURES

TEST VEHICLE.

QUAD-AGENT FIRE SYSTEM. Figure 1 shows the Phoenix® Pulse Delivery® QuadAgent® firefighting system integrated into its test vehicle. The system contains a 100-gallon water tank, two 5-gallon foam concentrate tanks, 500 lb capacity of dry chemical, and 120 lb capacity of clean agent. The quad-agent system is capable of discharging foam, dry chemical, clean agent, or a combination of those agents simultaneously. The fourth agent in the quad-agent system, water only, is typically not used for aviation fuel firefighting, and was not used in combination with other agents during the tests, except for mixing with the foam concentrate solution to create firefighting foam. The quad-agent system can operate in nonaspirated or aspirated compressed air foam (CAF) modes. The hose line consists of three separate 100-ft hoses of water and foam, dry chemical, and clean agent that is bundled and wrapped to make one woven jacket hose. The nozzle shown in figure 2 is unique to the quad-agent system, which has three adjacent discharge points for each agent. The system was setup to discharge 40 gallons per minute (gpm) in CAF mode, 8 pounds per second (pps) of dry chemical, and 1 pps of clean agent. When all three agents are discharged simultaneous, the discharges were 40 gpm in CAF, 6 pps of dry chemical, and 1/3 pps of clean agent. The system is charged, and the agent is delivered using a pressurized cylinder system. The firefighting system can be charged by the driver prior to departing the vehicle to fight a fire. Having all the agents ready on the same hand line nozzle allows a fire fighter to be ready for any situation they may encounter without going back to the truck to change the system's settings. The unique technology of this system has also been built-in to a bumper turret, but was not tested in this evaluation. The agents are reserviced using vacuum and electric pumps, pressure transfer, and water hose fill.

Figure 1. Quad-Agent Fire System

Figure 2. Quad-Agent System Nozzle

EXTINGUISHING AGENTS.

Most aircraft incidents and accidents involve some type of three-dimensional (3D) flowing fuel fires and two-dimensional (2D) pool fires. The potential for ignition of flowing fuel in contact with hot metal surfaces is present in virtually every aircraft fire situation. 3D fires occur when fuel or hydraulic fluid from damaged lines and equipment on the aircraft continuously drain into normally dry bay compartments or external openings. The 2D pool fire is constantly resupplied by a 3D flowing fuel column and generally will require constant aggressive agent application for control. These factors make control and extinguishment of the combination 2D and 3D fires difficult when only a foam agent is applied. 3D agents are highly effective knockdown agents but do not possess adequate cooling and burn-back resistance to prevent reignition. They are limited in their ability to be thrown over long distances.

AQUEOUS FILM FORMING FOAM. A Mil Spec 3% aqueous film forming foam (AFFF) concentrate used during the tests is the most widely used foam agent in the world for extinguishing 2D ground or surface pool class B fires. Military and civil aviation fire trucks are equipped with foam and water firefighting systems designed specifically for discharging AFFF. AFFF provides cooling and has superior burn-back resistance to impinging fire by creating a film that quickly spreads across the surface of burning fuel and sealing flammable vapors.

DRY CHEMICAL. The dry chemical chosen for the tests was Purple K, potassium bicarbonate (PK). PK is an effective fire knockdown agent and is very effective against hydrocarbon fires, which occur in aviation. When discharged by itself, a slight breeze can easily influence the direction of the dry chemical, and a gust of wind could diffuse the agent, rendering it ineffective. A downwind approach was necessary to prevent the agent from being carried away in the wind. Purple dye is added to the dry chemical to visually aide fire fighters as they discharge the agent into the fire. Similarly, the purple dye aided laboratory personnel in determining how the agent interacted with AFFF when it was released with the combination agent stream.

CLEAN AGENT. The clean agent selected for the tests was Halotron I, an Environmental Protection Agency and Occupational Safety & Health Administration-approved Halon 1211 replacement alternative. Halotron I is effective against class B and C fires. The agent is stored under pressure and is discharged as a stream. Since evaporation occurs quickly after discharge, there is little or no residue. Because Halotron I leaves little or no residue, it is the preferred secondary agent when extinguishing engine fires because it does not damage the internal components like dry chemical. Halotron I is less easily influenced by windy conditions as is dry chemical. Halotron I is currently the only FAA-approved clean extinguishing agent used for ARFF use.

TEST PROCEDURES.

AGENT FLOW DURATION TESTS. Three agent flow duration tests were conducted to measure the total discharge time of the quad-agent firefighting system's capacity. The agent flow duration tests were conducted using AFFF only. When using the hand line nozzle, the full length of the firefighting system's hose was extended. The firefighting system was set in CAF mode, with its normal operating pressures, and discharged. Timing began when the AFFF agent started to discharge from the nozzle and was stopped when the AFFF agent flow stopped as determined by the test coordinator. Average agent flow duration was calculated from the three tests. The gpm discharge was then calculated using the average agent flow duration and used during other tests to determine the approximate amount of agent discharged.

AGENT DISCHARGE DISTANCE TESTS. Discharge distance tests were conducted to measure the agent discharge distance and performance produced by the quad-agent firefighting system using its hand line nozzle. The full length of the firefighting system's hose was extended while using the hand line nozzle. The firefighting system was set in CAF mode with normal operating pressures for all agents. The hand line nozzle was mounted on a stationary workbench and preset to a 0°, 10°, 20°, and 30° discharge angle, see figure 3. The agent was discharged with wind conditions under 5 miles-per-hour downwind for approximately 5 seconds at each test elevation. PK and Halotron agents were discharged inside a building to eliminate blowing wind conditions for a more repeatable agent discharge. Distance was measured from nozzle tip to the farthest point the agent stream reached on the ground, excluding overspray as determined by the test coordinator. The agent pattern width was also recorded by measuring the widest pattern point on the ground as determined by the test coordinator. All discharge distance tests were averaged for each agent discharge angle to get an overall agent discharge distance performance.

Figure 3. Hand Line Nozzle Mounted on Table for the Agent Discharge Distance Test

F-100 ENGINE NACELLE WITH 30-ft-DIAMETER RING TEST. The F-100 engine nacelle with 30-ft-diameter (707-ft^2) ring, shown in figure 4, is used to demonstrate the ability of small firefighting systems, using hand line nozzles, to extinguish flowing fuel fires that might occur from under wing-mounted engines. The F-100 engine nacelle provides a standardized device for the experimental testing of firefighting systems and firefighting agents on a medium-scale 2D surface pool fire and a 3D running fuel fire. JP-8 jet fuel is piped into the engine nacelle at 5 gpm, creating an internal engine fire source. The ignited fuel from inside the nacelle then flows out into the 30-ft containment ring around the engine nacelle. The water inside the containment ring was to prevent spalling of the concrete surface while the fuel was burning. The hot metal surfaces inside the F-100 engine nacelle vaporize the JP-8 jet fuel, making extinguishment difficult until the hot metal surfaces cooled down. In figure 5, metal baffling strips inside the nacelle obstruct the flow of agent, simulating the difficulty of extinguishing the internal engine components and hidden fires that may be present.

Figure 4. F-100 Engine Nacelle With 30-ft-Diameter Ring

Figure 5. F-100 Engine Nacelle Metal Baffling Inside Nacelle

The procedures for the F-100 engine nacelle tests were as follows:

1. Pre-position the firefighting vehicle on the upwind side with the firefighting system's hand line fully extended and fully charged.

2. The F-100 engine nacelle was heated and then cooled to just below the JP-8 jet fuel's autoignition temperature of approximately 400°F.

3. One hundred gallons of fuel were poured into the 30-ft containment ring.

4. The fuel inside the F-100 engine nacelle was ignited and allowed to flow continuously into the containment ring.

5. Once the F-100 engine nacelle was totally engulfed in fire, a 30-second preburn was allowed to ensure that the fire had reached a steady state and was burning at its maximum intensity prior to the initiation of suppression operations.

6. Agent was applied to the pool fire first, and then the source of the flowing fuel fire.

7. Extinguishment time was recorded when all the fire inside the ring and inside the F-100 engine nacelle was completely extinguished. Extinguishment time was derived from when the agent was first applied to the fire until all the fire was extinguished as determined by the test coordinator and using video documentation.

The 30-ft-diameter fire area in this test corresponds to the Practical Critical Area (PCA) of a Category 1 airport based on the National Fire Protection Association (NFPA) standard for Aircraft Rescue and Firefighting Services at Airports (NFPA 403). A Cessna 206 or Beech Bonanza 35 would be the type of aircraft using a Category 1 airport.

<u>THE F-100 ENGINE NACELLE WITH CONCRETE PAD TEST</u>. The F-100 engine nacelle and concrete pad, shown in figure 6, are normally used for flight line fire extinguisher tests. This test provides a small-scale, 25 gallon 2D surface pool fire on a concrete pad and a 3D running fuel fire from the F-100 engine nacelle. JP-8 jet fuel is piped into the engine nacelle at 5 gpm, creating the same internal engine fire source as described during the F-100 engine nacelle with 30-ft-diameter ring test. The procedure for the F-100 engine nacelle with concrete pad test is the same as the F-100 engine nacelle with 30-ft-diameter ring.

Figure 6. F-100 Engine Nacelle With Concrete pad

LARGE-SCALE, 100-ft-DIAMETER FIRE BURN AREA TEST. The 100-ft-diameter (7854-ft^2) fire burn area with large-scale mockup shown in figure 7 was used to evaluate the firefighting performance of the system using its hand line nozzle in a large-scale pool fire test environment. The large-scale burn area is primarily used for testing and extinguishing large-scale 2D surface pool fires, which might occur from fuel that had spilled on the ground or tarmac. Approximately 1000 gallons of JP-8 jet fuel is pumped into the large-scale burn area for testing. All test fires were conducted on a concrete pad surface covered with approximately 3 inches of water to prevent spalling of the concrete while the fuel burned inside the large-scale burn area. The large-scale aircraft mockup located in the center of the burn area simulates a downed aircraft and obstacles a fire fighter may encounter during a postcrash fire scenario.

Figure 7. Large-Scale, 100-ft-Diameter Fire Burn Area With Aircraft Mockup

The procedures for the large-scale burn area tests were as follows:

1. Pre-position the firefighting vehicle on the upwind side with the firefighting system's hand line completely extended and fully charged.

2. One thousand gallons of JP-8 jet fuel were pumped into the large-scale burn area, covering over 90% of the burn area's surface.

3. The fuel was ignited, and the fire was allowed to grow until the entire large-scale burn area was engulfed.

4. The fire was allowed to preburn for 30 seconds to ensure the fire had reached a steady state and was burning at its maximum intensity prior to the initiation of suppression operations.

5. The fire fighters were instructed to approach the fire from the upwind side and apply the agent or combination of agents uniformly to the fire surface. They were also instructed to extinguish the fire as rapidly and as safely as firefighting practices would permit.

6. Total extinguishment time during this test was recorded when the agent was first applied to the fire until all the fire was extinguished inside the large-scale 100-ft-diameter burn area as determined by the test coordinator and using video documentation. Total extinguishment time may vary during each test due to different fire fighter techniques, experience, repositioning time or speed, slips, falls, trips, or any other condition that may impact the total extinguishment time until the fire was extinguished.

7. Total discharge time is a segment of the total extinguishment time, and was recorded as the actual time the agent was being discharged from the hand line nozzle onto the fire inside the burn area by eliminating when the agent stream was turned off, fire fighter repositioning, or any other delay where the fire fighter was not attempting to extinguish the fire. The total discharge time was derived and verified using video documentation. The total discharge time is a more accurate indicator of the firefighting agent/firefighting system performance during the large scale 100-ft-diameter burn area test.

The fire area in this test corresponds to the PCA of a Category 6 airport based on NFPA 403. This is equivalent to the FAA Index B airport under Title 14 Code of Federal Regulations Part 139. An Airbus A320 300 or Boeing 737-300 is a representative aircraft that would use a Category 6 airport.

TEST RESULTS AND DISCUSSION

AGENT FLOW DURATION TEST RESULTS.

The quad-agent firefighting system was tested to validate and record total flow duration for discharging AFFF through its nozzle in the CAF mode. Figure 8 shows an agent flow duration test. Table 1 shows the average flow duration results of the quad-agent system. From the average agent flow duration numbers, a gpm average was calculated. The quad-agent system had an average flow duration of 155 seconds at 39 gpm. The flow duration of the quad-agent system discharging AFFF in non-CAF mode was also recorded; however, this flow setting was not used during the other tests. The average flow duration in non-CAF mode was 115 seconds at 52 gpm.

Figure 8. Flow Duration Test

Table 1. Agent Flow Duration Test Results

Firefighting System	Agent	Device	Average Flow Duration (sec)	Calculated gpm
Quad-Agent	AFFF (CAF)	Hand line nozzle	155	39
Quad-Agent	AFFF (non-CAF)	Hand line nozzle	115	52

AGENT DISCHARGE DISTANCE TEST RESULTS.

The quad-agent firefighting system was tested to validate and record discharge distance performance for discharging different agents through its hand line nozzle, see figure 9. The system was set in CAF mode and normal operating pressures. Table 2 shows the average agent discharge distance and pattern width test results for the quad-agent system.

The quad-agent system's longest AFFF discharge distance average was at 20° at a distance of 85 ft 6 in. During the dry chemical discharge distance tests at a 20° elevation, PK was too diffused and could not be measured accurately. The test was repeated at a 10° elevation for a more accurate measurement.

Figure 9. Discharge Distance AFFF Test

Table 2. Quad-Agent System Average Discharge Distance Test Results

Agent	Elevation	Length (ft-in.)	Width (ft-in.)
AFFF	0°	60-4	3-2
AFFF	10°	69-8	3-11
AFFF	20°	85-6	3-7
AFFF	30°	68-5	5-1
AFFF/PK	20°	82-5	4-5
PK	10°	91-2	18-1
Halotron	20°	42-9	8-5

THE F-100 ENGINE NACELLE WITH 30-ft-DIAMETER RING TEST RESULTS.

The quad-agent firefighting system was evaluated on the F-100 engine nacelle and 30-ft-diameter ring test with a single agent attack using AFFF and combination agent attacks. The quad-agent system was set in CAF mode during these tests. Three fire tests were conducted using each agent combination. Figure 10 shows a fire fighter extinguishing the F-100 engine nacelle and 30-ft-diameter ring test.

AFFF only tests were conducted on a different date then the other agent combination tests. It was later learned after the AFFF only tests were completed that the F-100 engine nacelle had been modified between testing dates. AFRL had modified the F-100 engine nacelle prior to conducting AFFF only tests with the quad-agent system. The FAA and test coordinator were not aware of these changes until after viewing the video documentation. The modified F-100 engine nacelle presented a more difficult fire to extinguish due to extra baffling in the front of the engine nacelle. The AFFF only tests during the F-100 engine nacelle and 30-ft-diameter ring test were the only tests that used the modified F-100 engine nacelle.

Figure 10. Fire Fighter Extinguishing F-100 Engine Nacelle Fire

The individual test results and agent combination test averages from the quad-agent firefighting system are shown in figure 11. AFFF only tests produced the longest extinguishment time due to the modified test device. Test results showed that using AFFF and PK simultaneously averaged the fastest extinguishment time on the F-100 engine nacelle with 30-ft-diameter ring fire. The FAA has only tested Halotron in a single-agent discharge application at greater than or equal to 5 pps and less than or equal to 7 pps using a handline. The quad-agent system's ability to discharge 1 pps individually was not tested and could not be verified if it could extinguish the fire in these tests. Using the quad-agent system's unique ability to discharge all three agents (AFFF, PK, and Halotron) at one time resulted in the fastest extinguishment during a single test. However, it was determined that discharging all three agents did not significantly decrease the extinguishment time and was a less efficient use of available firefighting agent based on the average test results.

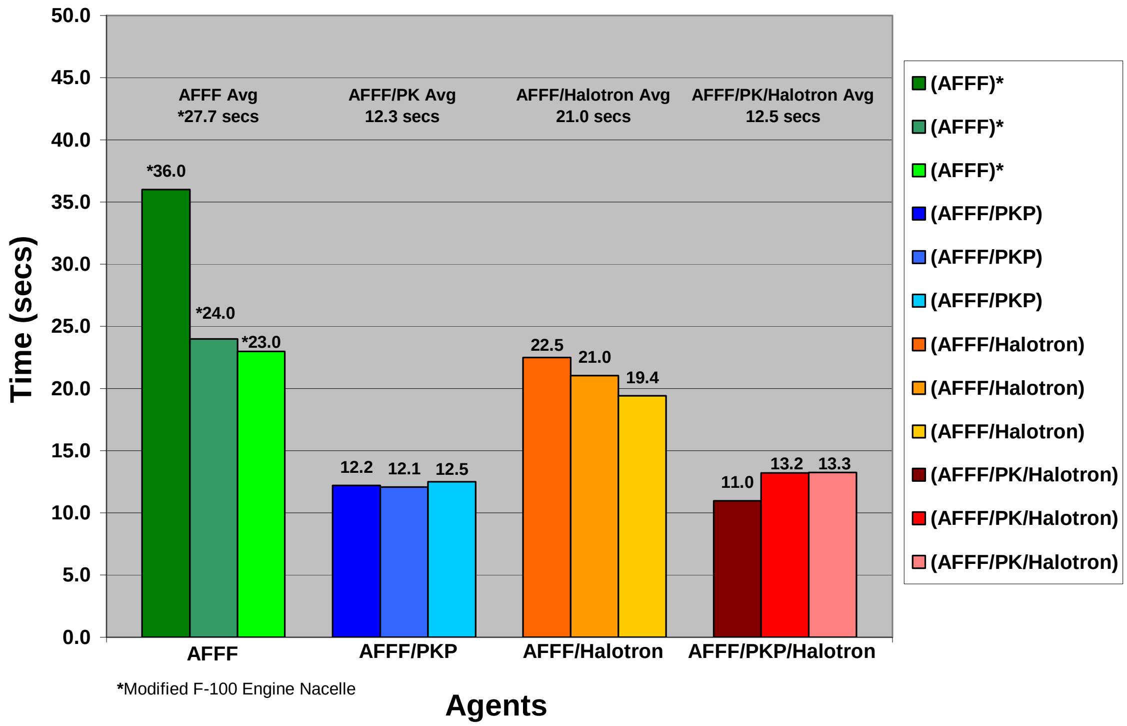

Figure 11. Quad-Agent System F-100 Engine Nacelle Test Results

THE F-100 ENGINE NACELLE WITH CONCRETE PAD TEST RESULTS.

The quad-agent firefighting system was evaluated on the F-100 engine nacelle with concrete pad test with combination agent attacks (AFFF/PK and AFFF/Halotron). The quad-agent system was set in CAF mode during these tests. Fire fighters extinguished the 2D fire on the concrete pad using only AFFF and then added the additional agent once the agent stream was concentrated on the F-100 engine nacelle. Three fire tests were conducted using each agent combination. Figure 12 shows a fire fighter extinguishing the F-100 engine nacelle with concrete pad test.

Figure 12. Fire Fighter Extinguishing F-100 Engine Nacelle With Concrete pad

The individual test results and agent combination test averages from the quad-agent firefighting system are shown in figure 13. The test results showed that using the AFFF and PK combination averaged the fastest extinguishment time on the F-100 engine nacelle with concrete pad fire. AFFF and PK also resulted in the fastest extinguishment during a single test.

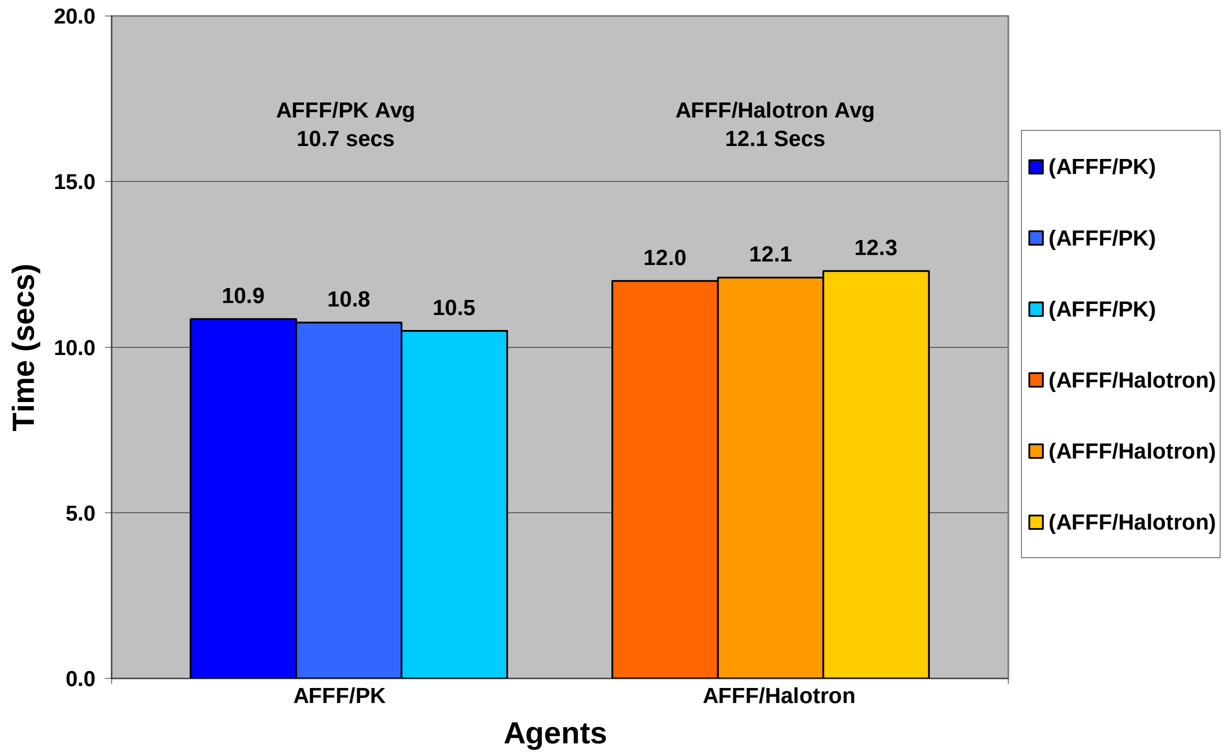

Figure 13. F-100 Engine Nacelle With Concrete pad Test Results

LARGE-SCALE, 100-ft-DIAMETER FIRE BURN AREA TEST RESULTS.

The quad-agent firefighting system was evaluated on the large-scale fire burn area with a single agent attack using AFFF only and combination agent attacks on large-scale pool fires. Three test fires were conducted using each agent combination. The firefighting system was set in CAF mode during these tests. Each test was timed for total extinguishment and total agent discharge time. Total discharge time is a segment of the total extinguishment time, which is a more accurate indicator of the firefighting agent/firefighting system performance during large-scale burn area tests as stated in the procedures. The times for each agent combination attack were averaged for an overall total extinguishment time and overall total discharge time. Figure 14 shows the large-scale fire burn area fully involved with fire.

Figure 14. Large-Scale Burn Area Fully Involved With Fire

The quad-agent firefighting system individual total extinguishment time results and average total extinguishment time results are shown in figure 15. Total extinguishment time during this test was recorded when the agent was first applied to the fire until all the fire was extinguished inside the large-scale 100-ft-diameter burn area as determined by the test coordinator and using video documentation. Total extinguishment time may vary during each test due to different fire fighter techniques, experience, repositioning time or speed, slips, falls, trips, or any other condition that may impact the total extinguishment time until the fire was extinguished. During one of the AFFF and PK tests, the fire fighter turned the PK on and off during a portion of the test. During another AFFF and PK test, approximately one quarter of the fire burn area was not involved with fire.

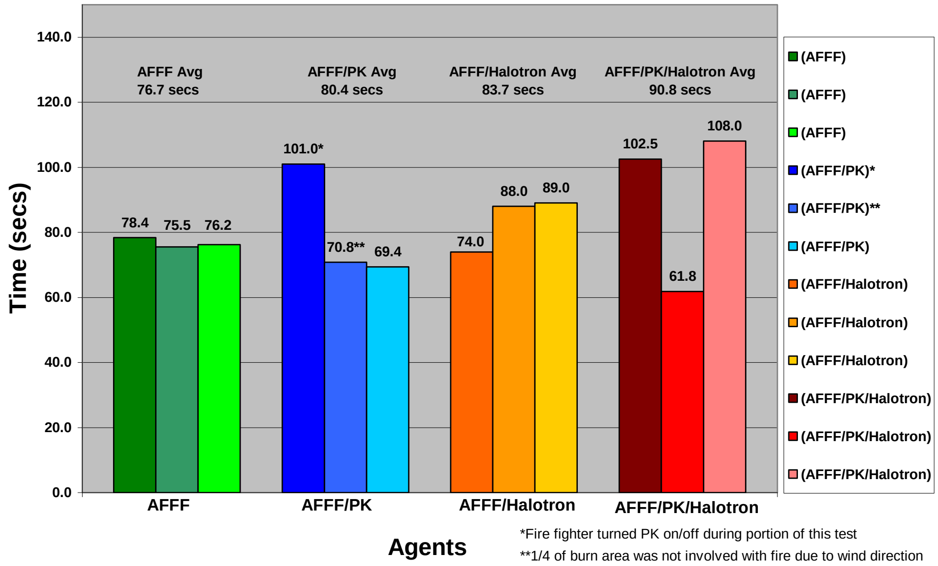

Figure 15. Quad-Agent System Large-Scale Fire Total Extinguishment Test Results

The quad-agent firefighting system individual total discharge time results and average total discharge time results are shown in figure 16. Total discharge time is a segment of the total extinguishment time and was recorded as the actual time the agent was being discharged from the hand line nozzle onto the fire inside the burn area by eliminating when the agent stream was turned off, fire fighter repositioning, or any other delay where the fire fighter was not attempting to extinguish the fire. The total discharge time was derived and verified using video documentation. The total discharge time is a more accurate indicator of the firefighting agent/firefighting system performance during the large-scale, 100-ft-diameter burn area test.

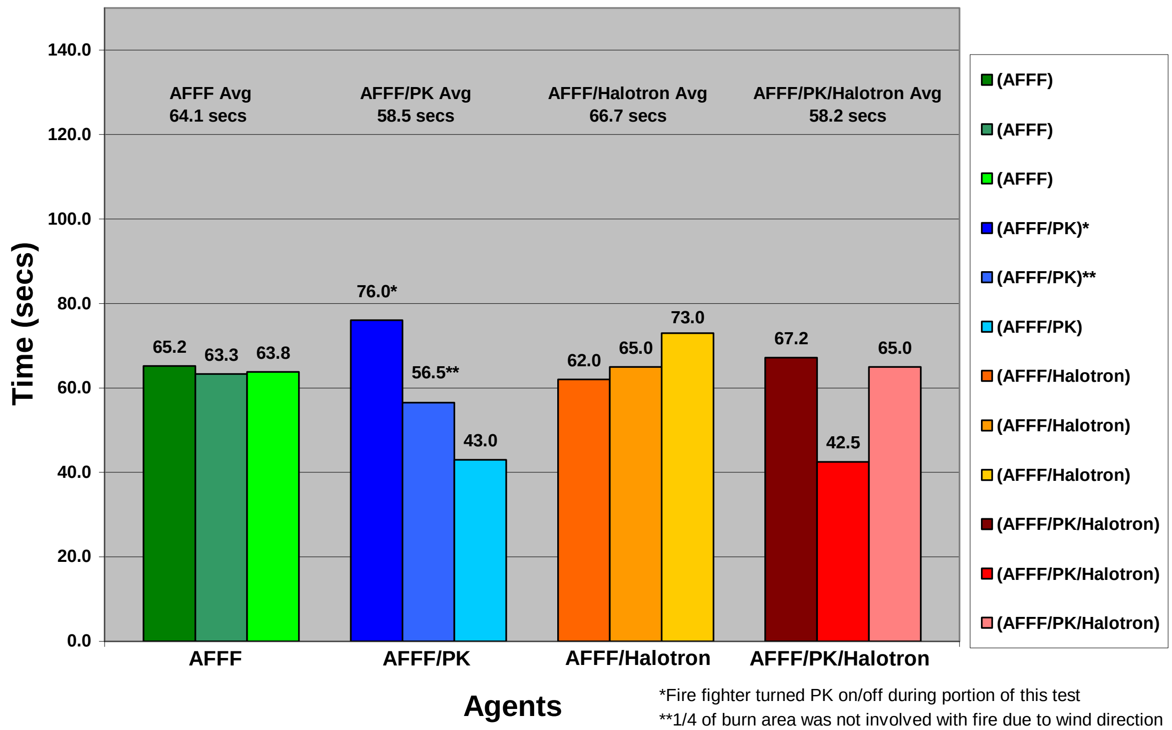

Figure 16. Quad-Agent System Large-Scale Fire Total Discharge Test Results

The amount of agent usage during the fire tests is derived from the total discharge time, the agent discharge settings on the firefighting system, and the calculated gpm of CAF from the agent flow duration tests. Table 3 shows the approximate calculated agent usage for the high and low total agent discharge times for each agent combination tested. (Only one AFFF/PK was used to calculated agent usage due to test dissimilarities.)

Table 3. Agent Usage on Large-Scale Fire Test Results

Time	AFFF	AFFF/PK	AFFF/Halotron	AFFF/PK/Halotron
Low	41 gal	28 gal/344 lb	40 gal/62 lb	28 gal/255 lb/14 lb
High	42 gal	n/a	47.5 gal/73 lb	44 gal/403 lb/22 lb

SUMMARY

When evaluating the agent flow duration, the quad-agent firefighting system had three similar aqueous film forming foam (AFFF) discharge times averaging 155 seconds through the system's hand line nozzle in compressed air foam (CAF) mode. Longer agent discharge duration with equivalent fire extinguishment gives a fire fighter the ability to attack a fire longer with necessary extinguishing agent and to keep available extinguishing agent in reserve after a fire is extinguished.

When evaluating the agent discharge distance performance, the quad-agent firefighting system produced its greatest distance results discharging AFFF through the system's hand line nozzle at 20° discharge angle in CAF mode. The 20° discharge angle was 15 ft 10 in. farther than the next closest discharge angle at 10°. The system produced its widest agent pattern at 30° in CAF mode. The 30° discharge angle had a 1 ft 10 in. wider pattern than the next closest discharge angle at 10°.

The quad-agent firefighting system was evaluated on two different engine nacelle flowing fire tests. During the engine nacelle with 30-ft-diameter ring test, the quad-agent system was able to extinguish all the fire using the following combinations of agents: AFFF only, AFFF and potassium bicarbonate (PK), AFFF and Halotron, and AFFF, PK, Halotron simultaneously. The fastest three-test average extinguishment time was when using AFFF and PK (AFFF/PK) simultaneously. The fastest extinguishment time during a single test was recorded using AFFF, PK, and Halotron (AFFF/PK/Halotron) simultaneously. However, the quad-agent system's unique ability of discharging AFFF/PK/Halotron at one time produced similar results to using AFFF/PK simultaneously. Based on average test results, discharging AFFF/PK/Halotron simultaneously did not significantly decrease extinguishment time and was a less efficient use of available firefighting agent. During the engine nacelle with concrete pad test, the quad-agent system was able to extinguish all the fire using the combinations of AFFF/PK and AFFF and Halotron simultaneously. The fastest three-test average and single-test extinguishment time was when using AFFF/PK simultaneously. The quad-agent system's ability to discharge 1 pound per second (pps) individually was not tested and could not be verified if it could extinguish the fire in these tests. The FAA has only tested Halotron in a single-agent discharge application at greater than or equal to 5 pps and less than or equal to 7 pps using a hand line.

When evaluating the quad-agent firefighting system on large-scale pool fires, the quad-agent system was able to extinguish all fire using of the following combinations of agents: AFFF only, AFFF/PK, AFFF and Halotron, and AFFF/PK/Halotron simultaneously in the large-scale 100-ft-diameter burn area. Total extinguishment times varied throughout the tests as described in the results. For large-scale pool fires, total discharge time is a more accurate indicator of the firefighting agent combination and firefighting system's performance compared to total extinguishment time. Total discharge time is a segment of the total extinguishment time, and is the actual time the agent combination was being discharged from the hand line nozzle onto the fire by eliminating when the agent combination stream was turned off, fire fighter repositioning, or any other delay where the fire fighter was not attempting to extinguish the fire. The fastest three-test average total discharge time during this test was using AFFF/PK simultaneously; however, all the agent combinations were within seconds of each other. The single fastest total discharge time during one test was recorded with AFFF/PK/Halotron simultaneously, slightly faster than AFFF/PK simultaneously. The quad-agent system's unique ability to discharge AFFF/PK/Halotron at one time did not significantly decrease the average total discharge time compared to the other agent combinations, and was a less efficient use of available firefighting agent based on the average test results.

CONCLUDING REMARKS

The quad-agent system provides more extinguishing agent options to a fire fighter as to what agent or agents they could use when extinguishing fires. By activating all the agents on the quad-agent system prior to a fire fighter departing the vehicle, the fire fighter has the ability to select the desired agent or agents to discharge at the nozzle. This allows a fire fighter to more efficiently and effectively adapt a fire attack at a fire scenario.