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High-Reach Extendable Turrets With Skin-Penetrating Nozzle

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16. Abstract

New equipment for aircraft rescue firefighting vehicles can help improve firefighting after an aircraft crash. New equipment such as a high-reach extendable turret (HRET) with skin-penetrating nozzle mounted on an airport firefighting vehicle could extinguish fires faster, apply firefighting agent more accurately on fires, and possibly save passengers lives as a result. The evaluation in this report will determine the extinguishment abilities of an HRET with skin-penetrating nozzle on simulated real fire aircraft crashes and during a full-scale fire field test.

One objective of this research was to compare the abilities of an airport firefighting vehicle using an HRET to that of another vehicle using traditional airport firefighting methods of extinguishment on several real fire aircraft crash simulations. Another objective was to evaluate and determine if an airport firefighting vehicle using an HRET with skin-penetrating nozzle can control and extinguish an aircraft interior fire and reduce interior temperatures. Two different research efforts were undertaken for the described objectives. One was completed by the Air Force Research Laboratory using its fire test facility, and the second was completed at the San Antonio Airport using a training aircraft.

The HRET with skin-penetrating nozzle outperformed the traditional firefighting methods during many simulated real fire aircraft crashes at the fire test facility with its ability to extinguish several fires faster, increased accuracy of firefighting agent application by positioning the HRET close to the source of the fires, and using less firefighting agent on several fires. The skin-penetrating nozzle used on the full-scale fire field test showed the ability to control and contain the fire from spreading beyond the tail section, reduce high cabin temperatures from over 1500° to approximately 250°, provide rapid smoke ventilation, and the ability to extinguish the fire.

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LIST OF ACRONYMS AND SYMBOLS

2-D	Two-dimensional
3-D	Three-dimensional
AFB	Air Force Base
AFFF	Aqueous film forming foam
AFRL	Air Force Research Laboratory
ARFF	Aircraft rescue and firefighting
DNE	Did not extinguish
FAA	Federal Aviation Administration
gpm	Gallons per minute
HRET	High-reach extendable turret
HPRV	High-performance research vehicle
LFA	Large frame aircraft
PKP	Potassium bicarbonate
psi	Pounds per square inch
sq. ft.	Square feet
USAF	United States Air Force

EXECUTIVE SUMMARY

New equipment for aircraft rescue firefighting vehicles can help improve firefighting after an aircraft crash. New equipment such as a high-reach extendable turret (HRET) with skin-penetrating nozzle mounted on an airport firefighting vehicle could extinguish fires faster, apply firefighting agent more accurately on fires, and possibly save passengers lives as a result. The evaluation in this report will determine the extinguishment abilities of a HRET with skin-penetrating nozzle on simulated real fire aircraft crashes and during a full-scale fire field test.

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INTRODUCTION

PURPOSE.

The purpose of this research test series was to determine the abilities and capabilities of a high-reach extendable turret (HRET) (National Fire Protection Association 402 defines turret as a vehicle-mounted master stream appliance) with a skin-penetrating nozzle mounted on an airport firefighting vehicle and compare it to another firefighting vehicle using a roof-mounted turret on simulated real fire aircraft crashes. This research also examined the complexities of aircraft interior fire suppression and extinguishment using a HRET with a skin-penetrating nozzle on a full-scale fire field test using an aircraft and the role it might play in combating a postcrash aircraft interior fire to existing firefighting strategies. This analysis specifically examines the firefighting problems created by today's large frame aircraft (LFA) and to validate the skin-penetrating nozzle as a new piece of equipment that could affect the outcome of aircraft interior fire situations prior to fire fighters being deployed to perform an aircraft interior fire extinguishment. The approach, methods, and techniques to combat LFA fires and aircraft interior fires are an important research issue.

OBJECTIVES.

The intent of this research test series was to advance aircraft postcrash fire protection. Test objectives and test criteria during the real fire simulations research effort and the full-scale fire field test research effort included:

- Evaluate and compare the abilities and capabilities of airport firefighting vehicles using a roof-mounted turret and an HRET with a skin-penetrating nozzle to extinguish several different simulated real fire aircraft crashes.

- Evaluate and determine if an airport firefighting vehicle with an HRET with skin-penetrating nozzle can control and extinguish an aircraft interior fire and reduce interior temperatures.

BACKGROUND.

The FAA has a need to understand the impact new technologies will have on civil aviation's firefighting fleet. The HPRV is a test platform for the examination and exploration of innovative technologies of interest to both civil and military aviation. Within the framework of an Interagency Agreement, the FAA William J. Hughes Technical Center tasked the Air Force Research Laboratory's (AFRL) Fire Research Group at Tyndall AFB, FL, to evaluate the performance of the HPRV with HRET compared to the USAF P-19 Crash Vehicle.

The AFRL 100′ diameter, open-air burn facility located at Tyndall AFB, with an LFA mockup including high and low engine nacelle test stands, were used exclusively during the test series. This facility's design and test apparatus are effective in the instrumentation, collection, and validation of aircraft crash parameters to include the documentation of the actual firefighting performance of an HRET and similar systems of interest to the FAA. An HRET system is currently manufactured and sold as an accessory piece of equipment for aircraft rescue and firefighting (ARFF) vehicles under the trade name Snozzle™.

A Cooperative Research and Development Agreement was also made between the FAA, San Antonio Airport Authority, and the San Antonio City Fire Department to conduct a fire suppression test and demonstration on one of San Antonio's training aircraft. The analysis of aircraft accidents involving external fuel fires has shown that although external fires are effectively extinguished, secondary fires within the aircraft fuselage are difficult to control with existing equipment and procedures. Large amounts of smoke-laden toxic gases and high temperature levels in the passenger cabin can cause delays in evacuation and pose a severe safety hazard to fleeing passengers. Fire fighters put themselves at great personal risk when attempting any aircraft interior fire with hand-held attack lines.

Upon arrival to any accident site in which a postcrash fuel fire exists, ARFF services immediately start to apply foam. In the United States, aqueous film forming foams (AFFF) are applied rapidly to the fuselage and adjacent fire areas. The fire fighters objective is to suppress the outside fires as quickly as possible, thus providing an escape path from the aircraft and then aid in the evacuation of passengers as necessary. These requirements often prevent a timely, early aircraft interior fire suppression attempt. In many cases, the cabin fire has already reached high flashover temperatures, and is destroying the aircraft interior seats and furnishing materials before the fire fighters are able to enter the aircraft. Flammable materials inside the cabin, such as fabrics, seat cushions, aircraft panels, and carry-on baggage, usually sustain aircraft cabin fires. The presence of super-heated Class A combustible materials can cause the release of large volumes of flammable vapors and can result in flashover with rapid flame propagation in the cabin interior. Ventilation or air drafts of toxic burning combustible vapors play an important role in the ultimate fire growth and damage in an aircraft interior cabin fire.

Aircraft crash fires are almost always initiated and sustained by spilled aircraft fuel, thus creating a Class B fire. The integrity of the fuselage determines how quickly the fire can enter the aircraft, and whether or not an aircraft interior fire will develop. Upon entry, the fire can soon become both a Class A fire as well as an on-going Class B fire. When researchers try to simulate an aircraft fire, it is difficult to develop fire tests that are both realistic to the real accident events and yet controllable for the important measurements of radiant heat profiles.

METHODS AND PROCEDURES—TYNDALL RESEARCH

TEST VEHICLES.

THE HPRV. The HPRV, as shown in figure 1, is designed for ARFF operations with tri-extinguishing agent capabilities. The HPRV carries 850 gallons of water and 120 gallons of AFFF concentrate. The HRET can deliver 250 or 500 gallons per minute (gpm) from its turret. It also carries two secondary extinguishing agents: 460 pounds of Halotron I clean agent and 500 pounds of potassium bicarbonate (PKP), dry chemical powder. The dry chemical agent was delivered at 12-14 pounds per second at 225 pounds per square inch (psi) during testing. The secondary agents are used for combating three-dimensional (3-D), running fuel fires. The HRET and skin-penetrating nozzle with an internal computer and a joystick control for driver operations was purchased for the HPRV. Agent delivery methods used during testing were the HRET and the skin-penetrating nozzle.

FIGURE 1. THE HPRV WITH HRET IN A CRADLED POSITION

THE P-19. The P-19, as shown in figure 2, was used in the comparison tests with the HPRV. The P-19 carries 1000 gallons of water, 100 gallons of AFFF concentrate, and 450 pounds of secondary extinguishing agent PKP, dry chemical. Agent delivery methods used during testing were a dual agent roof-mounted turret and side compartment hand line nozzle. The roof-mounted turret delivered 500 gpm, and the hand line delivered 100 gpm. Dry chemical agent was delivered at 16 pounds per second at 220 psi. The P-19 was chosen for comparison to the HPRV due to near equivalent agent delivery rates, horsepower, and the P-19's proven standard in the ARFF world.

FIGURE 2. THE P-19 WITH ROOF-MOUNTED TURRET

TEST DEVICES.

LARGE-SCALE, 100′ DIAMETER FIRE BURN AREA. The large-scale, ARFF vehicle evaluations and agent performance extinguishment tests were conducted inside a 100′ diameter test facility. All test fires were conducted on a full concrete pad surface covered with a slight film of water to prevent spalling of the concrete. A large-scale aircraft mockup was located in the center of the burn area. All fuel, foam, and water were removed from the burn area through an intricate drain and storage system to facilitate the subsequent tests. Figure 3 shows the fire burn area, and the large-scale aircraft mockup that were used throughout the tests.

FIGURE 3. THE AFRL LARGE-SCALE, 100′ DIAMETER TEST FACILITY WITH AIRCRAFT MOCKUP

LARGE-SCALE AIRCRAFT MOCKUP. Figure 4 shows the dimensions and the arrangement of the cabin during preparations of the large-scale aircraft mockup interior fire tests. Class A combustibles were used to simulate interior LFA fire conditions. Approximately 374 cubic feet of materials were burned in each test replication. Class A combustibles included aircraft seats, wood pallets, rags, rugs, plastics, and electrical wires. Five gallons of JP-8 aircraft fuel were used as an accelerant to ignite and sustain the fire during the early stages of its propagation. The large-scale aircraft mockup also allowed testing of both a high wing and a high engine nacelle to facilitate fires in both of those locations.

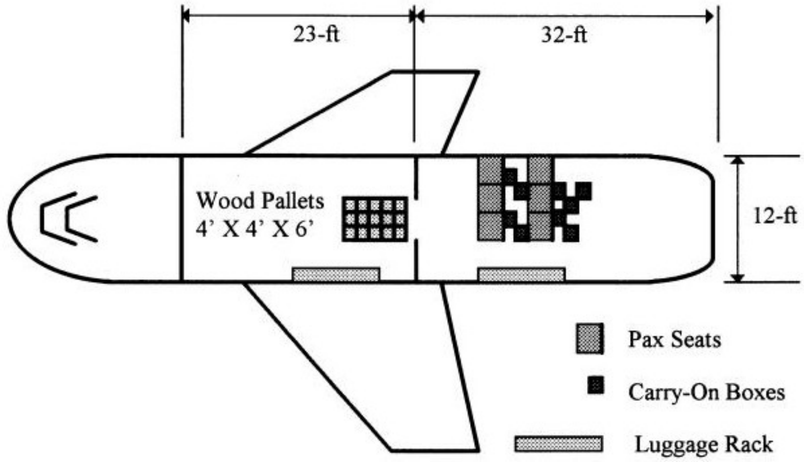

FIGURE 4. LARGE-SCALE AIRCRAFT MOCKUP AND CLASS A COMBUSTIBLES FIRE LOCATIONS

HIGH ENGINE NACELLE. The high engine nacelle, as shown in figure 5, affixed to the rear of the large-scale aircraft mockup is approximately 25 feet above ground at its highest point. JP-8 aircraft fuel was piped to the engine in two locations, creating two internal engine fire sources. Ignited fuel spills from the elevated engine nacelle and out onto the surrounding surface areas and ground created both a 2-D surface pool fire and 3-D running fuel fire.

FIGURE 5. HIGH ENGINE NACELLE

TEST DESCRIPTIONS.

The test matrix in table 1 shows the HRET live fire testing series in the test plan. Three replications of each test configuration were conducted.

TABLE 1. THE HRET LIVE FIRE TEST SERIES

Test Event Description	Total Number JP-8 Fires
P-19 (Water and AFFF)	
High wing	3
High engine nacelle	3
Pool	3
Interior cabin	3
P-19 Combination Agent (AFFF and PKP)	
High wing	3
High engine nacelle	3
High engine nacelle with hand line	3
HPRV Skin-Penetrating Nozzle (Water)	
Extendable penetrating nozzle	1
Standard penetrating nozzle	3
HPRV HRET (Water and AFFF)	
High wing	3
High engine nacelle	3
Pool	3
Interior cabin	3
HPRV HRET (Water, AFFF, and PKP)	
High wing	3
High engine nacelle	3

During the HRET live fire tests, a 60-second preburn fire of JP-8 aircraft fuel was ignited to ensure the fire had reached a steady state and was burning at its maximum intensity prior to the initiation of suppression operations. During the high engine nacelle fire tests, the nacelle was preheated using a small internal fire prior to the start of the test. The small internal fire was allowed to burn out prior to starting the 60-second preburn period. Agent was applied to pool fires first and then to the source of the flowing fuel fire. Fires involving Class A combustible materials inside the fuselage were allowed to burn for several minutes to ensure all the materials were engulfed in flame and the fire could not be easily extinguished.

The following HRET attack modes were evaluated during the test series.

Figure 6 shows the down-in-front attack mode of the HRET. The boom waterway is positioned approximately 3 to 4 feet above ground level in front of the HPRV. The waterway nozzle applies agent directly to the fire by oscillating the waterway boom or nozzle left and right.

FIGURE 6. THE HPRV WITH HRET IN A DOWN-IN-FRONT ATTACK MODE

Figure 7 shows the full forward extended attack mode of the HRET. The boom is cradled and fully extended horizontally from the top of the cab. The waterway nozzle remains at roof-mounted turret height above the cab. Agent is applied directly to the fire by oscillating the waterway nozzle left and right.

FIGURE 7. THE HPRV WITH HRET IN FULL FORWARD EXTENDED ATTACK MODE

Figure 8 shows the fully elevated, extended attack mode of the HRET. The boom is raised to a 50′ maximum height above the fire area. The waterway nozzle applies agent directly to the fire by oscillating the waterway boom or nozzle left and right. This is referred to as the raindrop agent delivery method.

FIGURE 8. THE HPRV WITH HRET IN A FULLY ELEVATED, EXTENDED ATTACK MODE

Figure 9 shows the HRET in a skin-penetrating position. Water is then pumped through the skin-penetrating nozzle and out holes to be used for extinguishment.

FIGURE 9. THE HRET IN A PENETRATING POSITION

TEST RESULTS AND DISCUSSION

THE HPRV ATTACK MODE COMPARISON TEST RESULTS.

The HRET was evaluated to determine the optimum agent delivery method for 2-D or pool fire extinguishment. The fire tests and comparisons included the down-in-front, full forward extended, and fully elevated extended attack modes on the large-scale, 100′ diameter burn area of 7854 square feet (sq. ft). The burn area was filled with 1000 gallons of JP-8 aircraft fuel overtop a thin water surface. A frontal attack method was used on the burn area as the HPRV approached the nose of the large-scale aircraft mockup head on and applied agent to the left and right of the aircraft fuselage mockup in calm or 0, 1-5, and +5 knot wind conditions. Extinguishment times were stopped once 90% of the burn area was extinguished. Ninety percent extinguishment was defined as when the main burn area was extinguished, but residual fuel and fire would burn at the rocky perimeter of the burn area. This residual fire on the outside of the burn area was not considered. One hundred percent extinguishment was defined as the complete extinguishment of all fire during the tests. The HRET attack mode comparison test results are shown in table 2. The down-in-front attack mode was the optimum mode for extinguishing a large-scale pool fire and was 58% faster than the next closest attack mode. Wind velocities did not significantly impact the agent delivery and extinguishment performance of the HRET.

TABLE 2. THE HRET ATTACK MODE COMPARISON TESTS

90% Fire Extinguishment Times Fire Surface Area – 7854 sq. ft			
Wind Speed (kts)	Down-In-Front (sec)	Fully Extended (sec)	Fully Elevated (sec)
0	22		
1-5	24		
+5	19		
Average	22		
0		39	
1-5		35	
+5		41	
Average		38	
0			60
1-5			61
+5			62
Average			61

THE HRET AND P-19 ROOF-MOUNTED TURRET POOL FIRE EXTINGUISHMENT COMPARISON TEST RESULTS.

The HRET in its optimum attack mode, the down-in-front configuration, was compared to the P-19 roof-mounted turret agent delivery system. Both vehicles were tested in the same conditions as the HPRV attack mode comparison tests. The results of the HRET and P-19 roof-mounted turret fire extinguishment comparison test are shown in table 3. The HRET in the down-in-front attack mode extinguished the burn area an average of 53% faster than the P-19 roof-mounted turret. Both vehicles used a frontal attack method on the large-scale burn area. The HRET in the down-in-front position was able to extinguish the burn area by oscillating the HRET from right to left without repositioning the HPRV. The P-19, however, had to make slight vehicle adjustments to the right and left of the burn area in order for its roof-mounted turret to reach the sides of the large-scale aircraft mockup.

TABLE 3. THE HRET AND P-19 ROOF-MOUNTED TURRET POOL FIRE COMPARISON RESULTS

Average 90% Fire Extinguishment Times Fire Surface Area – 7854 sq. ft	
HRET Down-In-Front Attack Mode	P-19 Roof-Mounted Turret
27 seconds	51 seconds

THE HRET AND THE P-19-ROOF-MOUNTED TURRET HIGH WING FIRE EXTINGUISHMENT COMPARISON TEST RESULTS.

For the high wing fire tests, C-130 Hercules wing sections were placed on top of the large-scale aircraft mockup inside the large-scale burn area, as shown in figure 10. Piping was plumbed up to the C-130 wing section engine nacelles to create a flowing fuel fire. Fuel flowing from the engine nacelles was regulated at 10 gpm with a 30-second preburn. The fire area consisted of two 3927 sq. ft sides of the large-scale aircraft mockup. Both the HPRV and P-19 used a straight in frontal attack mode from the nose of the aircraft mockup to extinguish the pool fire under the wings, which was created by the flowing fuel fire, and then the engine nacelle fire. Three test replications using AFFF and a combination agent of AFFF, and dry chemical were used for extinguishing high wing fires at 90% and 100% extinguishment.

There was a significant reduction in windshield obstruction and driver/operator visibility, which was caused by the extinguishing agent blowing back onto the windshield of the vehicles, with the HRET compared to the P-19 roof-mounted turret.

FIGURE 10. LARGE-SCALE AIRCRAFT MOCKUP WITH C-130 WING SECTIONS

The average results using AFFF and combination agents on a high wing flowing fuel fire are shown in table 4. Using AFFF only, with 90% extinguishment, the HRET averaged 38 seconds, while the P-19 roof-mounted turret averaged 51 seconds. The HRET had a 25% faster extinguishment rate using AFFF alone at 90% extinguishment than the P-19 roof-mounted turret. Using AFFF only, with 100% extinguishment, the HRET extinguished all three fires in an average of 65 seconds using 541 gallons of AFFF. The P-19 roof-mounted turret using AFFF only with 100% extinguishment could only extinguish one of the three test fires. Two of the fires did not extinguish before all of 1000 gallons onboard of AFFF was used. The one fire that the P-19 roof-mounted turret did extinguish 100% required 915 gallons of AFFF, thus making the average of the three test fires greater than 120 seconds. Using a combination of agents, AFFF and dry chemical, both the HRET and the P-19 roof-mounted turret extinguished all the test fires. At 90% extinguishment, the HRET averaged 23 seconds, while the P-19 roof-mounted turret using dual agent for dry chemical application averaged 25 seconds. At 100% extinguishment, using the combination of agents, the HRET extinguished the fire in 30 seconds, while the P-19 roof-mounted turret extinguished the fire in 34 seconds. On average, the combination of agents from the HRET and the P-19 roof-mounted turret resulted in a 46% faster extinguishment rate than the AFFF alone in the 90% fire extinguishment tests. The key extinguishment performance advantage of the HRET was the accuracy of the agent application and the ability to apply very close-in applications of AFFF and dry chemical agents.

TABLE 4. THE HPRV AND P-19 HIGH WING FIRE COMPARISON RESULTS

Average 90% Fire Extinguishment		
ARFF Vehicle	Combination Agent (sec)	AFFF (sec)
HPRV	23	38
P-19	25	51
Average 100% Fire Extinguishment		
ARFF Vehicle	Combination Agent (sec)	AFFF (sec)
HPRV	30	65
P-19	34	DNE

DNE = Did not extinguish

COMPARISON TEST RESULTS OF THE HPRV AND P-19 HIGH ENGINE NACELLE.

For the high engine nacelle fire tests, the high engine nacelle on the rear of the large-scale aircraft mockup was used. Figure 11 shows of the high engine nacelle on the rear of the large-scale aircraft mockup. Three test replications using AFFF, a combination of AFFF and dry chemical agents, and the P-19 roof-mounted turret using AFFF in combination with its dry chemical hand line were done during testing. Fuel flowing from the high engine nacelle was regulated at 10 gpm with a 30-second preburn. The fire consisted of a pool fire under the high engine nacelle and a flowing fuel fire in the high engine nacelle. Both the HPRV and P-19 used a straight in rear attack mode from the rear of the aircraft mockup to extinguish the pool fire under the high engine nacelle first, then the high engine nacelle fire. Times were recorded for the pool fire at 90% extinguishment, and then total time for the high engine nacelle fire at 90% extinguishment.

FIGURE 11. HIGH ENGINE NACELLE ON THE LARGE-SCALE
AIRCRAFT MOCKUP

The average results of the HRET and P-19 roof-mounted turret high engine nacelle fire tests are shown in table 5. Using AFFF only for the initial pool fires, the HRET extinguished the pool fire in 6 seconds, and the P-19 roof-mounted turret extinguished the pool fire in 9 seconds. Using the combination of agents on the initial pool fires, the HRET extinguished the pool fires in 4 seconds, and the P-19 roof-mounted turret extinguished the pool fire in 5 seconds. The HRET using AFFF only on the initial pool fire and then on the high engine nacelle was able to extinguish the fire in 97 seconds. An average of 808 gallons of AFFF was used to extinguish the fires. The P-19 roof-mounted turret using its full complement of 1000 gallons of AFFF only on the initial pool fire and then on the high engine nacelle was unable to extinguish the high engine nacelle fire. Using the combination agents on the initial pool fire and then on the high engine nacelle, the HRET extinguished the fire in 36 seconds. The P-19 in the same test using its dual agent roof-mounted turret was able to extinguish the fire in 53 seconds. The HRET using the combination of agents had a 32% faster extinguishment rate than the P-19 with its dual agent roof-mounted turret. The final test series was the P-19 using its roof-mounted turret on the initial pool fire and then on the high engine nacelle along with a fire fighter using a dry chemical hand line extinguished the fire in 65 seconds. The HRET using the combination of agents is once again faster in extinguishment by 45% compared to the P-19 roof-mounted turret and dry chemical hand line. Overall, the HRET extinguished the high engine nacelle fires faster by 63% using the combination of agents compared to AFFF alone.

TABLE 5. THE HPRV AND P-19 HIGH ENGINE NACELLE FIRE COMPARISON RESULTS

90% Fire Extinguishment				
Fire Type	ARFF Vehicle	Method	AFFF (sec)	Combination Agent (sec)
Pool	HPRV	HRET	6	4
Pool	P-19	Dual agent turret	9	5
High Engine Nacelle	HPRV	HRET	97	36
High Engine Nacelle	P-19	Dual agent turret	DNE	53
High Engine Nacelle	P-19	Roof-mounted turret and dry chemical hand line	-	65

DNE = Did not extinguish

RESULTS OF THE HPRV AND P-19 INTERIOR CABIN FIRE TESTS.

The HPRV and P-19 interior cabin fire extinguishment test results are shown in table 6. During the test series, the HPRV delivered its water stream through the HRET skin-penetrating nozzle and two different types of penetrating nozzles. The P-19 firefighting crew had to advance a hand line nozzle into the cabin for an effective extinguishment of the interior cabin fire.

TABLE 6. INTERIOR CABIN FIRE EXTINGUISHMENT RESULTS

ARFF Vehicle	Water Delivery System	Cabin Penetration Location	Average Extinguishment Time (sec)	Water Quantity (gal)	gpm
HPRV	Extended waterway	Rear Passenger Door	52	212	250
P-19	Hand line nozzle	Rear Passenger Door	90	160	100
HPRV	Extendable penetrating nozzle	Top of Fuselage	DNE	850	250
HPRV	Standard penetrating nozzle	Top of Fuselage	120	498	250
HPRV	Standard penetrating nozzle	Side of Fuselage	90	370	250

DNE = Did not extinguish

THE HRET AND HAND LINE NOZZLE. Both the HPRV and the P-19 firefighting crews used the rear passenger cabin door on the left side of the fuselage as the entry point. The HRET firefighting crew positioned the HRET skin-penetrating nozzle at 90° following entry into the fuselage cavity and delivered water to the fire area. The cabin fire, involving the cargo and passenger compartments, was extinguished by one total flood suppression boom operation with the HRET. The HRET was first directed to extinguish the passenger compartment fire area. Once the passenger compartment fire was extinguished, water was then delivered through a bulkhead opening to the cargo compartment fire. The P-19 firefighting crew had to make a ground approach using a hand line nozzle. The fire fighters had to visually determine the fire area targets before beginning the extinguishment. A variable-stream flow nozzle was used to deliver the water. The HRET extinguished the fire in 52 seconds using 212 gallons of water. The P-19 firefighting crew extinguished the same fire in 90 seconds using 160 gallons of water. The time it took to setup and arrange the vehicles, deploy the HRET, and remove the P-19 hand line was not included in the actual extinguishment time. Figure 12 shows the ground approach used by the P-19 firefighting crew to gain entry into the aircraft. All fire fighters are required to use a self-contained breathing apparatus while using hand lines and during entry into the fuselage.

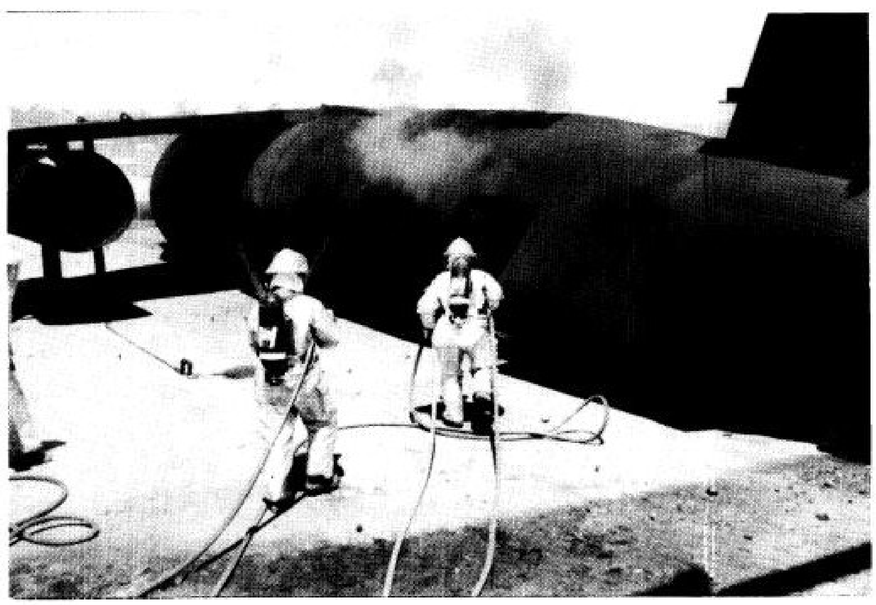

FIGURE 12. INTERIOR P-19 HAND LINE EXTINGUISHMENT APPROACH

SKIN-PENETRATING NOZZLES. Two types of skin-penetrating nozzles were used for the tests, an extendable skin-penetrating nozzle, developed by the USAF, and a standard skin-penetrating nozzle. The extendable skin-penetrating nozzle dispenses water streams from several holes 90° from the axis of penetration. The standard skin-penetrating nozzle dispenses a fine mist water spray 90° from the axis of penetration and as well as in the direction of the penetration. Figure 13 shows the skin-penetrating nozzle water patterns. The skin-penetrating nozzles required an initial penetration of both the passenger compartment and the cargo compartment. The extendable skin-penetrating nozzle was unsuccessful in extinguishing an interior cabin test fire via a fuselage top penetration. Because no water was dispensed from the tip of the extendable skin-penetrating nozzle as shown in figure 13, it ineffectively directed the water streams on the fire. Therefore, further testing of the extendable skin-penetrating nozzle was not attempted.

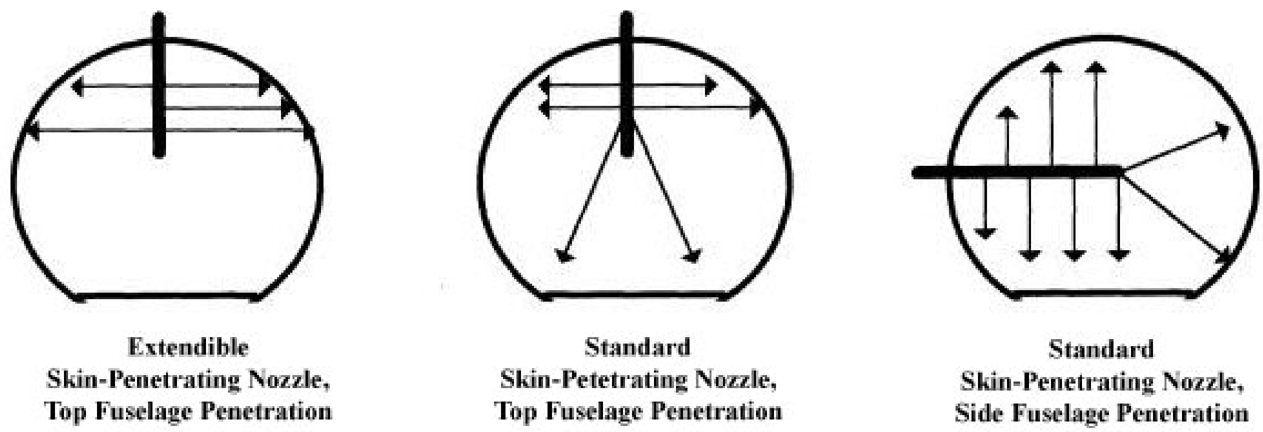

FIGURE 13. SKIN-PENETRATING NOZZLE WATER PATTERNS

The standard skin-penetrating nozzle successfully extinguished an interior cabin test fire via a top and side fuselage penetration. The standard skin-penetrating nozzle in figure 14 is making a top fuselage penetration that extinguished the fire with 498 gallons of water in 120 seconds. The standard skin-penetrating nozzle, with side fuselage penetration, extinguished the fire with 370 gallons of water in 90 seconds.

FIGURE 14. THE HPRV APPROACH WITH STANDARD SKIN-PENETRATING NOZZLE

In evaluating the performance of the HPRV and P-19 during large frame aircraft interior cabin fires, several methods were used and compared. The HRET and P-19 hand line interior fire extinguishment demonstrated to be effective. The HRET produced the fastest extinguishment time, while the hand line application required the least amount of water. However, hand line operations required the fire fighters to enter the fuselage, which adds an extreme element of risk. Also, individual boom placements and penetrations of the HRET or skin-penetrating nozzle are required for each discrete cabin area where extinguishment is required. The HRET must use a breach in the fuselage to gain access to the fire area. It is most effective when an open side door or breach is available in the immediate vicinity of the fire area. If a rear fuselage cargo door entry can be used, the boom can be extended along the interior cabin length. The primary strength of the HRET and the skin-penetrating nozzle is the rapid delivery of agent to an interior fire. Significant amounts of water or AFFF can be delivered inside the cabin without ventilation, without forced entry into the fuselage, without the use of ladders for fire fighter ingress, and without the need of a rescue corridor. The elevated boom and cabin skin penetration devices can substantially lower the risk for fire fighters when interior firefighting is necessary. Early intervention of fine mist water spray into the cabin interior can extend the valuable survivability time for passengers in the cabin. As demonstrated, hand line attacks are time-consuming and have not shown positive results because of delays in getting this strategy in place early enough in an event to greatly affect an outcome. Interior intervention requires teamwork and extensive manpower. Before fire fighters make entry into the aircraft, fine mist water spray can be injected into the cabin. The HRET with skin-penetrating device can broaden the range of firefighting strategies and proved increase passenger survival. Interior firefighting tactics should be developed and demonstrated to ensure maximum effectiveness in rescue operations using HRET and skin-penetrating device.

METHODS AND PROCEDURES—SAN ANTONIO RESEARCH

TEST ARTICLES.

TEST AIRCRAFT. A Boeing Model 707-321B large commercial aircraft served as the test aircraft during the live aircraft interior fire suppression tests. The San Antonio International Airport used the B707-321B for training its ARFF department. The aircraft was positioned in a secure, approved area for burning, and the area was sufficient to allow the full circumference travel and approach of any rescue vehicles. The aircraft wings were removed prior to testing, but were not a factor in the test. However, to simulate the wing positions, the area was marked with emergency barrier tape so that the driver/operator was required to consider the vehicle's location relative to the location of the dismantled wings. The landing gear was removed, but the aircraft was raised to the correct height as if the aircraft was sitting with the landing gear in the down and locked position. All the passenger doors and overwing exits were opened, except for the right rear galley service door.

TEST ARFF VEHICLE. The San Antonio Airport Rescue Fire Service provided one of their ARFF vehicles for testing. The vehicle was an Oshkosh T-1500, with an HRET and skin-penetrating nozzle.

SKIN-PENETRATING NOZZLE. A standard skin-penetrating nozzle was used for the aircraft cabin penetrations with water injected in a spray pattern. The design uses several converging steams of water from multiple holes on the skin-penetrating nozzle that create a fine mist spray pattern with flow rates of 375 gpm, as shown in figure 15.

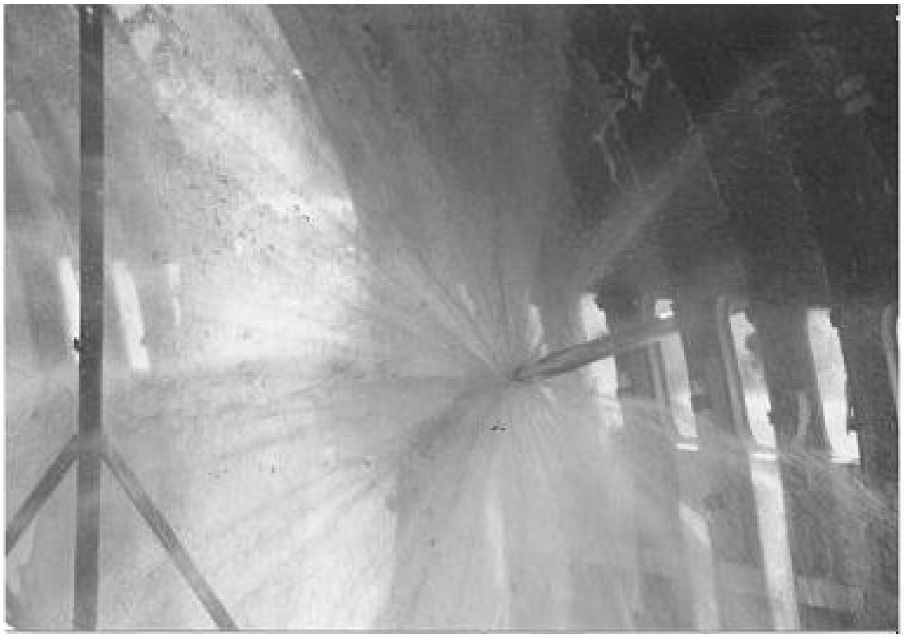

FIGURE 15. FINE MIST WATER SPRAY FROM SKIN-PENETRATING NOZZLE

INSTRUMENTATION AND DATA ACQUISITION.

The thermal effects of the fire in the aircraft interior were measured with thermocouples located strategically in the aircraft aisles along the aircraft interior. These cabin interior temperatures were collected and monitored throughout the test sequence. Five thermocouple trees were positioned from the front of the aircraft cabin to the last row of cabin passenger seating. The aircraft was fitted with two bulkheads located between the forward galley area and the last row of passenger seating. Eight Thermal Electric Type "K" chrome-alamol thermocouples were fitted to each tree. Four additional thermocouple trees were hooked to separate IBM AT-based computer collection systems spaced approximately 22 feet apart going towards the front of the aircraft. Temperature data was collected at 1-second intervals with a Burr Brown Data Acquisition hardware system, which uses Labtech Notebook Software for data collection. The thermocouples were positioned at 24 inches (armrest height), 42 inches (nose height when passengers are seated), 68 inches (mid height 12 inches from the cabin ceiling), and 80 inches (top of the ceiling height).

The thermocouple trees were placed from the rear bulkhead forward of the opened aft doorway at the following positions:

- Tree 1 was located 6 feet forward, at the center of the aisle, at the opened left aft rear door centerline. This position coincided with the last cabin seat row location and just forward of the rear cabin bulkheads. The fire growth was expected to first pass into the cabin from this area.

- Tree 2 was positioned at 22 feet from the rear aft bulkhead position. This location coincided with the position in which the aircraft skin-penetrating nozzle entered the aircraft on the left side above the cabin window, or located at row seven of the aircraft.

- Tree 3 was positioned at the opened aft overwing exit doorway area 44 feet forward of the aft bulkhead location.

- Tree 4 was positioned at 66 feet forward of the aft doorway and forward of all overwing exit doorways.

- Tree 5 was positioned between the first and second rows of the forward cabin seats. Tree 5 was located a total of 94 feet from the centerline of the opened left aft doorway and fire source area.

Additional instrumentation included an internal video camera viewing aft from the overwing exit area and two water-cooled radiometers located in the aft section of the aircraft for viewing fire growth in the cabin area.

TEST DESCRIPTION.

Aircraft crash fires are almost always initiated by the ignition of spilled aircraft fuel. The size of the pool fire, wind direction, and flame impingement on the fuselage as well as the structural integrity of the affected aircraft play a major role in the determination of whether an aircraft interior fire will develop. Fuselage integrity determines how quickly the fire can enter the aircraft.

All passenger doors and overwing emergency exits on the Boeing 707 were opened, except for the right aft galley service door. Several steel pans were positioned together at the centerline of the left open aft doorway, measuring a combined 18 feet long by 6 feet wide. The pans were positioned on top of metal drums, 48 inches off the ground that would ensure flame penetration into the aft cabin area through the left aft doorway or along the bottom fuselage skin area. Two inches of water was placed inside the pans to provide cooling, and a total of 200 gallons of Jet A aircraft fuel was floated on top of the water. The wind velocity at the time of the test was 6 knots, blowing in the direction towards the open left aft doorway.

The Jet A aircraft fuel was then ignited to simulate a spilled pool fire under the aircraft with the flame growth and penetration entering the open left aft doorway. The intent of this test was not to completely burn the interior furnishings, but to provide a small fire adjacent to an opened doorway that would provide a fire source to generate a full-scale aircraft interior fire. Once the aircraft interior fire was established, the San Antonio Airport Rescue Fire Service would attempt a fire stop or blocking attack with its ARFF vehicle using its HRET with the cabin skin-penetrating nozzle using fine mist water spray to prevent full growth of the aircraft interior fire along the length of the cabin fuselage.

TEST RESULTS.

After the fire was ignited during the early portion of the test, the wind velocity increased to 10 to 12 knots. This increase in wind speed became an important factor in the fire growth into the aircraft. The higher wind velocity prevented the fire from entering the open left aft doorway as planned. Instead, the flames were carried under the aircraft and up the right side of the aircraft. The change in wind resulted in a major burn-through of the lower aft cabin galley floor area and delayed aircraft interior fire buildup. Because the aircraft was instrumented for thermocouple profiles, the aircraft interior fire growth was monitored, and the test was continued even though there was a delay of several minutes in the interior cabin involvement during the actual fire.

A hole, approximately 15 feet, was burned through the lower floor area at the aft cabin bulkhead. The galley and aft seating sections fell to the ground during the fuselage burn-through process, as shown in figures 16 and 17.

This large hole continued to expand up the right side of the aircraft and spread to an open area of approximately 22 feet that completely opened up the right side cabin skin area around the galley service entrance. The result of this burn-through was a full interior flashover fire that started at approximately 280 seconds into the test.

The positioning of the ARFF vehicle and boom placement took 37 seconds. The injection of fine mist water spray by the skin-penetrating nozzle was started approximately 361 seconds into the test. The penetrating point was made above the fourteenth window from the left aft doorway, or approximately the seventh row of seats from the aft galley. Figure 18 shows the location of the penetration point by the skin-penetrating nozzle. Water was allowed to flow for 1 minute and 50 seconds.

FIGURE 16. BURN-THROUGH AREA ON RIGHT SIDE OF AFT GALLEY AREA

FIGURE 17. CLOSE-UP VIEW OF AFT GALLEY AREA AND AFT SEATING SECTIONS

FIGURE 18. PENETRATION POINT ON LEFT SIDE OF FUSELAGE

At the time of penetration, the last seven rows of seats were involved in the fire. The fire rapidly progressed along the cabin overhead ceiling and baggage stowage areas traveling forward quickly in the aircraft. Interior aft cabin temperatures had risen to over 1800°F. Fine mist water spray from the skin-penetrating nozzle was started even though the ceiling fire had already moved beyond the penetration point. Thermocouple data showed that the water mist rapidly brought the interior temperatures down. Within 30 seconds of fine mist water spray injection, the fire was reduced and was under control in less than 1 minute. An investigation after the test showed that ten full rows of seats were involved and destroyed in the fire. The aircraft internal areas were severely damaged aft of the cabin penetration point. Figure 19 shows the internal damage caused by the fire.

FIGURE 19. INTERIOR CONDITIONS AFTER FIRE

INTERIOR ENVIRONMENTAL CONDITIONS.

The interior conditions after the fire test showed little seat involvement forward of the overwing exit area. The cabin skin penetration point was approximately 22 feet forward of the aft galley bulkhead area, which provided a successful fire-blocking strategy. The overhead ceiling fire had progressed forward quickly past the overwing areas causing elevated temperatures in the forward cabin section. Because of the cooling effect of the fine mist spray into the interior area, the injected water quickly took control of the ceiling fire as well as the seats that were involved. The interior cabin temperatures were immediately and dramatically reduced forward of the cabin skin penetration point. Figure 20 shows the thermocouple temperature profile taken at the overwing exit.

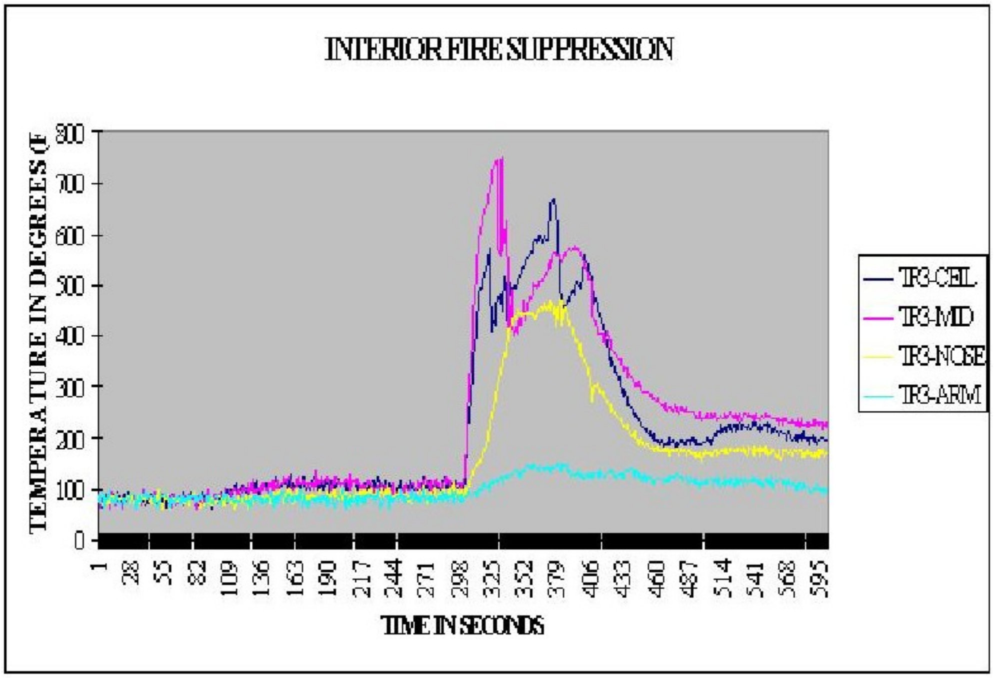

FIGURE 20. TEMPERATURE PROFILE OF OVERWING EXIT

It was observed that the fine mist water spray from the skin-penetrating nozzle was rapidly changing the smoke from a deep black to a light gray color. The smoke was pushed or positively pressurized from the spray pattern and pushed out of all available openings. The temperature profile data showed that there was no recognizable steam buildup. The thermocouple data showed that the fine mist water spray immediately cooled the cabin area and, at the same time, provided a noticeably positive push of smoke out of all the open doorways and exit areas. This pushing or venting of smoke resulted in a great deal of smoke being pushed from the estimated 22-foot burn-through hole at the aft right side of the aircraft. At the same time, a lot of smoke could also be seen venting at the aft left doorway area. All doorways and exits had an increase in smoke output from the upper half of the doorways. This demonstrated that the ventilation process did not take the easiest route and far more ventilating was occurring than just from the aft area.

CONCLUSIONS

The high-reach extendable turret (HRET) and skin-penetrating nozzle evaluated at the fire test facility outperformed the standard roof-mounted turret and hand line. In all aspects of the evaluation, the data gathered from simulated real fire aircraft crashes involving the HRET with skin-penetrating nozzle demonstrated the ability to extinguish fire faster, increase the accuracy of firefighting agent application by positioning the HRET close to the source of the fires, and using less firefighting agent on several fires. Other fire extinguishment performance advantages included the extendable reach of the HRETs nozzle, increase in firefighting agent throw range because of its extendibility, and its ability to reposition the HRET in all directions without moving the airport firefighting vehicle.

The HRET with skin-penetrating nozzle, when used on the full-scale fire field test using a training aircraft, showed the ability to control and contain the fire from spreading beyond the tail section, reduce high cabin temperatures from over 1500° to approximately 250°, provide rapid smoke ventilation, and the ability to extinguish fire. The injection of fine mist water spray showed immediate results providing a fire-block and lowering cabin temperatures. The ability to ventilate using the skin-penetrating nozzle is a less manpower-intensive and time-consuming process compared to using traditional ventilation fans. The cabin conditions after discharging the fine mist water spray allowed fire fighters to enter the aircraft.