DOT/FAA/AR-11/15

Air Traffic Organization
NextGen & Operations Planning
Office of Research and
Technology Development
Washington, DC 20591

Test and Evaluation of Next Generation 65-Foot, High-Reach Extendable Turret

November 2011

Final Report

U.S. Department of Transportation
Federal Aviation Administration

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/AR-11/15		

4. Title and Subtitle
TEST AND EVALUATION OF NEXT GENERATION 65-FOOT, HIGH-REACH EXTENDABLE TURRET

5. Report Date
November 2011

6. Performing Organization Code

7. Author(s)
Keith Bagot* and John Hawk**

8. Performing Organization Report No.

9. Performing Organization Name and Address
*Federal Aviation Administration
William J. Hughes Technical Center
Airport and Aircraft Safety
Research and Development Group
Airport Technology Research and
Development Team
Atlantic City International Airport, NJ 08405

**Air Force Research Laboratory
Deployed Air Base Systems Fire
Research Group
139 Barnes Drive, Suite 2
Tyndall AFB, FL 32403-5323

10. Work Unit No. (TRAIS)

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
Federal Aviation Administration
Air Traffic Organization NextGen & Operations Planning
Office of Research and Technology Development
Washington, DC 20591

13. Type of Report and Period Covered
Final Report

14. Sponsoring Agency Code
AAS-300

15. Supplementary Notes
The Federal Aviation Administration Airport and Aircraft Safety R&D Group Technical Monitor was Keith Bagot.

16. Abstract
Since the introduction of the High-Reach Extendable Turret (HRET) to the Aircraft Rescue and Firefighting (ARFF) industry, approximately 400 HRET, have been retrofitted into existing ARFF vehicles or purchased with new ARFF vehicles worldwide. Some advantages and benefits of this technology include increased throw range performance, increased range of turret motion, more efficient agent application by applying agent at the seat of the fire, faster extinguishment of two-dimensional pool and three-dimensional flowing fuel fires, and the ability to penetrate inside an aircraft to cool the interior cabin and extinguish the fire. This added capability can increase passenger survivability, protect property, and extinguish fire faster during an aircraft postcrash incident.

The purpose of this research was to document the effects of the installation of the 65-ft HRET on the predelivery inspection test of the Federal Aviation Administration (FAA) Striker ARFF research vehicle (FAA Striker). The second key objective was to evaluate the performance and firefighting effectiveness of the 65-ft HRET in and around new large aircraft, such as the Airbus A380 and the Boeing 747-8. The results of test were as follows:

- The FAA Striker, in both the baseline configuration and with the 65-ft HRET installed, passed all vehicle performance checks, with the exception of the weight distribution and body and chassis flexibility tests. For the weight distribution test, the baseline vehicle exceeded the maximum difference between axles by 1%, and the vehicle with the HRET installed exceeded the maximum difference between axles by 1.6%. For the body and chassis flexibility test, the baseline vehicle failed the tire height requirement by 8 in., and the vehicle with the HRET installed failed the tire height requirement by 4 in.
- From a bedded position, using the HRET, penetration and agent discharge into the lower passenger deck of an A380 mockup occurred in 54 seconds, into the upper passenger deck in 62 seconds, and into the cargo level in 80 seconds.
- The FAA Striker and the HRET were reliable and required only a few repairs throughout the course of the tests, which included hundreds of operations and tests. The only component of that failed repeatedly was the hydraulic gearbox on the HRET.

The findings of this research support the removal of the base turret from the design and increasing the flow rate of the tip nozzle to a selectable low/high flow rate of 500 and 1000 gallons.

17. Key Words
High-Reach Extendable Turret , Turret, Nozzle, Aircraft Rescue and Firefighting

18. Distribution Statement
This document is available to the U.S. public through the National Technical Information Service (NTIS), Springfield, Virginia 22161. This document is also available from the Federal Aviation Administration William J. Hughes Technical Center at actlibrary.tc.faa.gov.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	81	

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

AC	Advisory Circular
AFFF	Aqueous firefighting foam
ARFF	Aircraft Rescue and Firefighting
ECU	Electronic control unit
FAA	Federal Aviation Administration
HRET	High-reach extendable turret
HPRV	High-performance research vehicle
NATO	North Atlantic Treaty Organization
NFPA	National Fire Protection Association
NLA	New large aircraft
OTC	Oshkosh Truck Corporation
PDI	Predelivery inspection
PVC	Polyvinyl chloride

EXECUTIVE SUMMARY

On December 18, 2003, while attempting to land at Memphis International Airport, a wide-body DC-10 cargo aircraft experienced a landing gear failure that caused the aircraft to skid, resulting in one side of the fuselage catching on fire. A high-reach extendable (HRET)-equipped Aircraft Rescue and Firefighting (ARFF) vehicle penetrated the aircraft from the side opposite the fire and was able to minimize burn through of the fuselage. It was determined that 99% of the cargo inside the aircraft was saved from fire damage because of the protective foam barrier discharged from the penetrating nozzle on the HRET.

The Airbus A380 and other new large aircraft (NLA) being currently manufactured present new challenges. Current 50-ft HRET models can only reach the second-level doorway of a Boeing 747 or Airbus A380 if the ARFF vehicle is positioned immediately adjacent to the fuselage, which eliminates visibility of the operator controlling the HRET. In the event of a pool fire below the aircraft, the 50-ft HRET may not be long enough to facilitate penetration without putting the vehicle dangerously close to the fire. Engine pylon location and the complex emergency slide arrangements are other challenges that NLA present. The current HRET performance criteria were established over 15 years ago, and new performance criteria must be evaluated for the next-generation HRET to meet these new challenges.

The purpose of this research was to document the effects of the installation of the 65-ft HRET on the predelivery inspection (PDI) test of the Federal Aviation Administration (FAA) Striker ARFF research vehicle (FAA Striker). Another key objective was to evaluate the performance and firefighting effectiveness of the 65-ft HRET in and around NLA, such as the A380 and B-747-8.

The PDI checks accomplished on the baseline FAA Striker and on the FAA Striker after the 65-ft HRET was installed included maximum acceleration time, weight and weight distribution, top-speed, side-slope stability, brake stopping distance, body and chassis flexibility, dynamic balance, and evasive maneuvering tests. The performance checks done on the 65-ft HRET included base turret pattern and distance, foam concentration and quality, standoff distance measurements, timed deployment and penetration trials, boom oscillation measurement, and timed live fire tests. In this report, references are given for each test for which there is a standard test protocol and performance specifications, each test is briefly described, and the results are summarized. Detailed data from the HRET performance tests are included in the appendices of this report.

The baseline vehicle evaluated was an Oshkosh® Striker 3000 with a Hydro-Chem™ Ranger 1.0 bumper turret. The vehicle was also equipped with a dry chemical system and Halotron I system, both with HRET discharge capability, and an electronic foam proportioning system. At the time the research vehicle design was specified, the final weight of the 65-ft HRET was unknown. To ensure the vehicle weight remained below the vehicle design gross vehicle weight after installation of the prototype HRET, the water tank was modified from the standard 3000 gallon tank to a 2500-gallon tank. The Hydro-Chem nozzle was capable of flowing foam at 500 or 1000 gpm, and dry chemical could be used in combination or separately from the same nozzle at a rate of 20 pps. A Snozzle® model 652 HRET with a 65-ft reach (manufactured and

installed by Crash Rescue Equipment Services, Inc.) was added to the baseline vehicle after an initial round of PDI checks were done. The HRET was equipped with a Hydro-Chem Ranger 1.0 base turret and a Unifire model Force™ 50 tip turret, rated at 500 gpm. The HRET was also fitted with a 250-gpm water/Halotron penetrating nozzle.

HRET performance tests were done on a mockup section of an A380 aircraft built to full scale in a 100-ft-diameter pool. The mockup consisted of a 60-ft-long section of fuselage, part of a wing, an engine nacelle, and three slides that were attached to the fuselage to simulate interference to firefighting. The underbelly of the fuselage was about 9 ft above the surface of the pool. The pool was partially filled with water and then JP-8 was floated on the surface of the water to create a flammable liquid surface of approximately 7000 ft^2.

Test results were as follows:

- The FAA Striker, in both the baseline configuration and with the 65-ft HRET installed, passed all the vehicle performance checks, with the exception of the weight distribution and the body and chassis flexibility tests. For the weight distribution test, the baseline vehicle exceeded the maximum difference between axles by 1%, and the vehicle with the HRET installed exceeded the maximum difference between axles by 1.6%. For the body and chassis flexibility test, the baseline vehicle failed the tire height requirement by 8 in., and the vehicle with the HRET installed failed the tire height requirement by 4 in.

- The electronic foam proportioning system met all requirements throughout the duration of the test.

- The HRET base nozzle exceeded the straight stream turret distance specification.

- Vehicle standoff (with the HRET deployed) ranged from a minimum of 26 ft 7 in. at its maximum height to 38 ft 8 in. at midlevel height.

- From a bedded position, penetration and agent discharge (using the HRET) into the lower passenger deck of the mockup occurred in 54 sec, into the upper passenger deck in 62 sec, and into the cargo level in 80 sec.

- The maximum overshoot was observed in the HRET boom when the joystick was rapidly bumped to fast speed (full travel) and immediately released, for which an overshoot of about 15 ft was observed when the boom was fully extended. It must be noted, however, that experienced operators were able to reposition the boom very quickly while avoiding extreme overshoot by skilled use of the proportional control joystick.

- Fires were controlled (defined as 95% extinguished by area) and extinguished faster when the base turret was used than when the tip turret was used.

- The FAA Striker and the HRET were reliable and required only a few repairs throughout the course of the tests, which included hundreds of operations and tests. The only component that failed repeatedly was the hydraulic gearbox on the HRET.

- The findings of this study support the removal of the base turret from the design and increasing the flow rate of the tip nozzle to a selectable low/high flow rate of 500 and 1000 gallons.

The base turret on the 65-ft HRET met the extendable turret discharge performance parameters of National Fire Protection Association 414. The reliability of the hydraulic gearbox on the HRET must be improved by the manufacturer.

1. INTRODUCTION.

1.1 PURPOSE.

The purpose of this research was to document the predelivery inspection (PDI) testing of the Federal Aviation Administration (FAA) Striker Aircraft Rescue and Firefighting (ARFF) research vehicle (FAA Striker) before and after the installation of the 65-ft High-Reach Extendable Turret (HRET). Another key objective was to evaluate the performance and firefighting effectiveness of the 65-ft HRET for new large aircraft (NLA), such as the Airbus A380 and the Boeing 747-8.

1.2 BACKGROUND.

In 2005, the FAA William J. Hughes Technical Center ARFF Research Program procured a new 6x6 Oshkosh Striker 3000 vehicle to research and evaluate new ARFF technologies. This vehicle replaced the E-ONE Titan high-performance research vehicle (HPRV) as the primary FAA test platform. The FAA Striker is equipped with state-of-the-art technologies, including a high-flow bumper turret, a forward-looking infrared camera, a computer-controlled foam proportioning system, and an independent suspension. The new vehicle allows research and testing on a scale much larger and more complex than the existing HPRV. One of the first technologies evaluated on the new platform was the next generation HRET system. The HRET was a Crash Rescue™ Snozzle® model 652, serial number 30564, with a 65-ft reach.

Previous research conducted by the FAA included studies of the advantages and benefits of ARFF vehicles using HRET with aircraft skin-penetrating nozzles in aviation firefighting. Since the introduction of HRET to the ARFF industry, approximately 400 HRETs have been retrofitted into existing ARFF vehicles or purchased with new ARFF vehicles worldwide. Some advantages and benefits of this technology include increased throw range performance; increased range of turret motion; more efficient agent application by applying the agent at the seat of the fire, faster extinguishment of two-dimensional pool and three-dimensional flowing fuel fires, and the ability to penetrate inside an aircraft to cool the interior cabin and extinguish the fire. This added capability can increase passenger survivability, protect property, and extinguish the fire faster during a postcrash aircraft incident.

On December 18, 2003, an aircraft accident at Memphis International Airport involving a wide-body DC-10 cargo aircraft demonstrated the important role an HRET with a penetrating nozzle can have at an accident scene. While attempting to land, an aircraft landing gear failed, causing the aircraft to skid, consuming one side of the fuselage in fire. Two ARFF vehicles concentrated on the fuel spill fire, while another HRET-equipped ARFF vehicle penetrated the aircraft from the opposite side to minimize fuselage burnthrough. The HRET-equipped ARFF vehicle discharged foam inside the aircraft, flooding the interior with a protective foam barrier. After the fire was extinguished, authorities determined that 99% of the cargo inside the aircraft was not damaged by the fire because of the protective foam barrier. Approximately $25 million in cargo was saved, which exceeded the value of the aircraft itself.

This accident demonstrated the need and ability of an HRET at an aircraft accident and the role it could play in protecting cargo and increasing survivability in passenger aircraft. However, new concerns over the A380 and other NLA being manufactured present new challenges for HRET. Current 50-ft HRET models cannot reach the second-level doorway of a B-747 or an A380 unless the ARFF vehicle is positioned right next to the aircraft fuselage, which reduces the visibility of the HRET operator. Engine pylon location and the complex emergency slide arrangements are other challenges that NLA present. The current HRET performance criteria were established over 15 years, and new performance criteria must be evaluated for the next generation HRET to meet these new challenges.

2. OBJECTIVES.

With the arrival of the A380 aircraft into commercial service in 2006 and future NLA aircraft, the FAA needed to establish the best performance criteria for optimal and safe next generation HRET operations around all aircraft, including second-level aircraft. The next generation HRET is comprised of a 65-ft waterway with three different nozzles. The base turret has a 500/1000 gpm water/foam and dry chemical nozzle. The tip turret has a 500-gpm water/foam nozzle and a 250-gpm water/Halotron penetrating nozzle. The objectives of this project were to

- establish performance-based criteria, including agent discharge distance, foam concentration, foam expansion ratio, and foam drain time.
- determine performance criteria and techniques needed to penetrate second-level aircraft.
- determine maximum standoff distance needed to operate a next generation HRET effectively.
- evaluate discharge reactive forces that affect HRET and optimum discharge pressures.
- evaluate the functionality of the HRET on hydrocarbon fuel fires around obstacles posed by NLA, such as engine nacelles and emergency evacuation slides.

3. METHODS AND RESULTS.

3.1 PREDELIVERY INSPECTION TESTS.

A PDI is performed by the manufacturer on any new ARFF vehicle prior to acceptance by the customer. This series of tests ensures that all systems on the vehicle are functioning correctly and within the specifications outlined by the FAA and the National Fire Protection Association (NFPA). Baseline PDI tests were completed in August 2005 prior to delivery of the FAA Striker in September and prior to the installation of the HRET components. PDI tests are also performed on the FAA Striker after any major modification that potentially changes the weight distribution, stability, or performance characteristics of the vehicle.

In November 2006, the FAA Striker completed a second round of PDI tests after the 65-foot HRET was installed by Crash Rescue Equipment Service, Inc. The second round of tests was necessary to document changes in the performance, handling, and stability of the vehicle with the HRET installed on the top of the vehicle. Figure 1 shows the location of the HRET centered just behind the passenger cab of the vehicle. The turret and base added significant weight to the front of the vehicle, changing the weight distribution and vehicle dynamics. In this report, all tests conducted on the FAA Striker prior to the installation of the HRET will be referred to as the FAA Striker baseline, and all tests completed after the installation will be referred to as the FAA Striker HRET. The tests, with the exception of tilt-table test performed at Oshkosh Truck Corporation (OTC), were performed at Wittman Airport, Oshkosh, Wisconsin.

Figure 1. The FAA Striker With Deployed HRET

All baseline and HRET PDI tests were conducted with the FAA Striker in a fully loaded configuration. According to the FAA, fully loaded is defined as

> "The fully assembled vehicle, complete with a complement of crew, fuel, equipment, and fire fighting agents. The crew allowance shall be 225 pounds (102 kg) per seating position. The equipment allowance for performance tests is a maximum of 1,000 pounds (450 kg) or the actual weight of the equipment provided by the vehicle manufacturer, whichever is higher. [1]"

OTC simulated the fully loaded vehicle with full fuel, water, and foam tanks in addition to 1000 lb of sandbags to simulate the dry chemical and Halotron agents. Three passengers were either stationed in the cab or the appropriate number of sandbags were used to represent the passengers if less than three passengers were stationed in the vehicle during the tests. All requirements and procedures were adopted from FAA Advisory Circular (AC) 150/5220-10C [1].

3.1.1 Acceleration Tests.

The FAA Striker was accelerated from 0 to 50 mph, and the time to reach this speed was recorded [1, section 122]. The maximum time requirement is 35 seconds [1, section 51, table 2]. Figure 2 shows the acceleration performance of the FAA Striker baseline (28.1 sec average) compared with the FAA Striker HRET (31.2 sec average). Both FAA Striker configurations passed the test. The test was run on the taxiway in both the north and south directions to account for any topographical changes in grade.

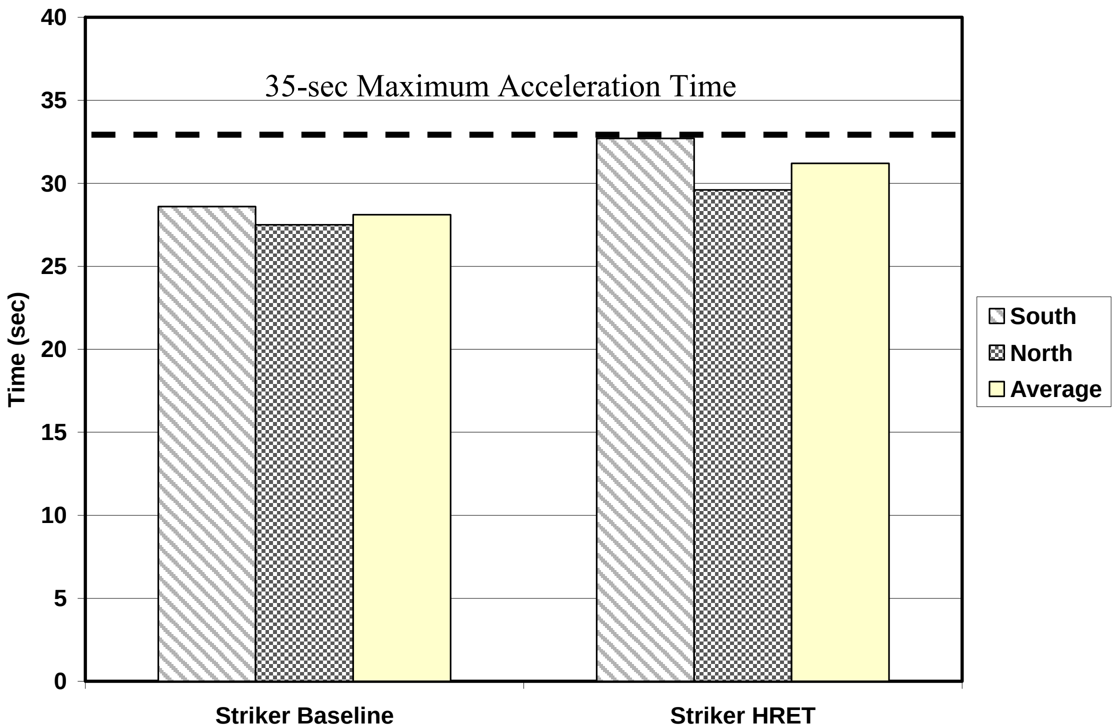


Figure 2. Acceleration Test Results

3.1.2 Weight Configuration and Distribution Tests.

The maximum vehicle weight configuration and distribution were measured on the FAA Striker in both configurations. The maximum gross vehicle weight of a fully loaded vehicle cannot exceed the weight information printed on the data plate by the vehicle manufacturer [1, section 20a]. OTC rated each axle for 29,000 lb. OTC measured the total gross vehicle weight of the FAA Striker baseline at 76,810 lb and the FAA Striker HRET at 82,590 lb, which added 5,780 lb of weight to the vehicle.

The individual wheel weights of the vehicle were recorded using individual scales [1, section 124]. The AC states several different requirements, depending on the location of the heaviest and lightest axle on the vehicle. The difference in weight between tires cannot exceed 5% of the average tire weight for that axle. The difference in weight between any two axles cannot exceed 10% of the weight of the heaviest axle if the heavy axle is a rear axle. The difference in weight between any two axles cannot exceed 5% of the weight of the heaviest axle if the heavy axle is a front axle.

Figure 3 shows the left side of the FAA Striker with axle numbers designated from front to rear. Table 1 shows the weight of each individual wheel on each axle before and after the installation of the HRET. The overall distribution of the weight for each tire did not change after the installation of the HRET; however, the heaviest total axle weight did change (figure 4). Axle 1 increased 4520 lb, axle 2 increased 1650 lb, and axle 3 decreased 380 lb. Axle 3 was the heaviest on the FAA Striker baseline and axle 1 was the heaviest on the FAA Striker HRET. Both configurations of the FAA Striker were within the 29,000-lb vehicle specification weight limit per axle for all three axles. Both FAA Striker configurations failed the axle percent weight difference. The FAA Striker baseline had an 11% difference between the heaviest (3) and lightest (1) axle, while the AC [1] specified a maximum of 10%. The FAA Striker HRET had a 6.6% difference between the heaviest (1) and the lightest (3) axle, while the AC [1] specified a maximum of 5%.

Figure 3. The FAA Striker 6X6 ARFF Vehicle Showing Axle Designations

Table 1. Axle Weight Distribution

Axle	Baseline Configuration (lb)	HRET Configuration (lb)
1 (right)	12,520	14,780
1 (left)	11,660	13,920
2 (right)	12,630	13,390
2 (left)	12,800	13,690
3 (right)	13,250	12,870
3 (left)	13,940	13,940

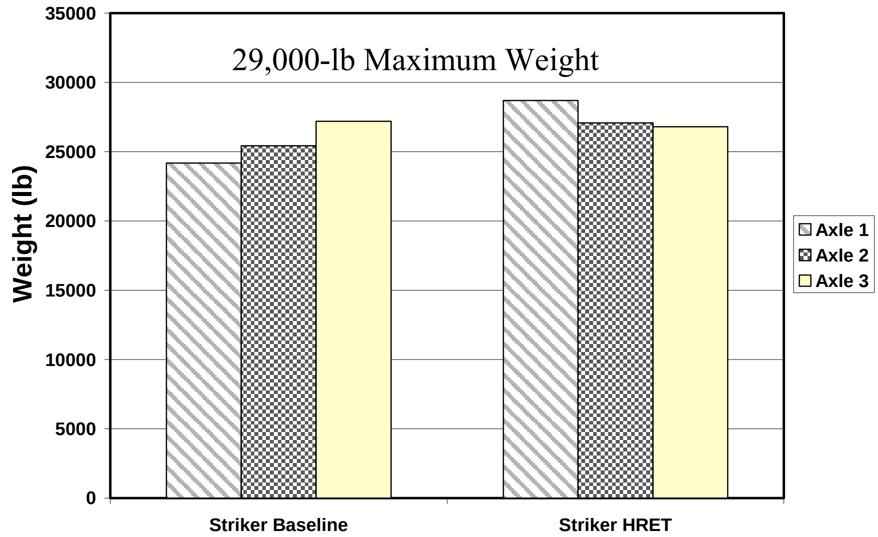


Figure 4. Total Axle Weight

3.1.3 Top-Speed Tests.

The FAA Striker's maximum speed was measured in both the baseline and HRET configurations. The AC [1, section 57] states that the top speed cannot be less than 65 mph. Figure 4 shows that in both the baseline and HRET configurations, the FAA Striker exceeded the minimum top-speed requirement of 65 mph. The FAA Striker baseline and HRET configurations reached an average maximum speed of 71.4 and 69 mph, respectively. The addition of the HRET decreased the top speed by 2.4 mph; however, OTC felt that the FAA Striker did not obtain the maximum speed before reaching the end of the taxiway in either configuration and calculated that the vehicle could reach speeds of 73 mph with adequate distance. Both configurations of the FAA Striker passed the top-speed requirement.

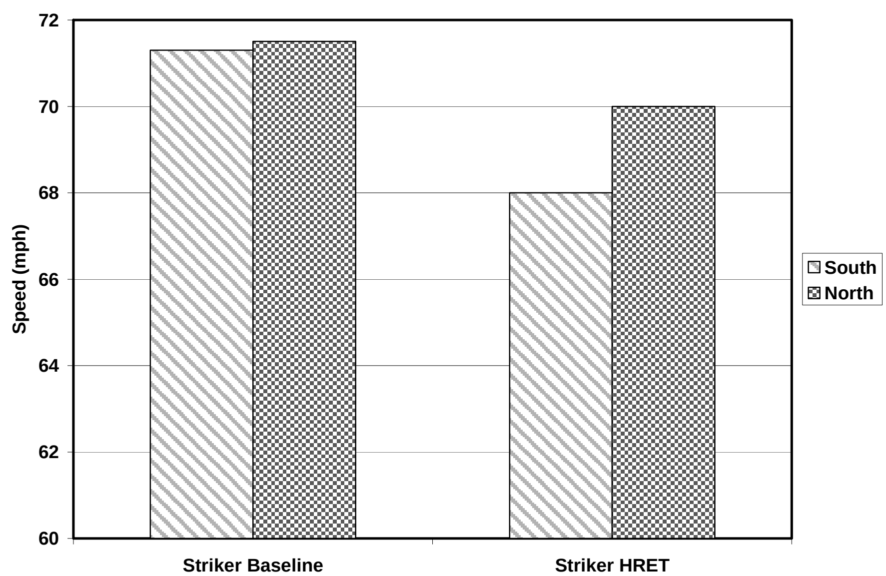


Figure 5. Top-Speed Test Results

3.1.4 Side-Slope Stability Tests.

The static (with HRET bedded) [1, section 20b] and HRET (elevated) [1, section 85] side-slope stabilities were measured. During both tests, the vehicle was placed on the tilt table and tilted with the right side of the vehicle placed uphill until the rollover point was reached. During the HRET side-slope stability test, the turret was fully elevated and the nozzle rotated uphill at maximum horizontal rotation; and water was discharged at the maximum flow rate of 500 gpm. The left side was not tested since the right side presented the worst-case scenario. The static side-slope stability test required a minimum 30° while the HRET side slope required a minimum of 11°. Table 2 shows that the FAA Striker baseline exceeded the minimum 30° static side-slope requirements at 33.5°, and the FAA Striker HRET exceeded the static and HRET side-slope requirements at 31.55° and 11.52°, respectively. The addition of the HRET decreased the static side-slope stability by almost 2°. Figures 6 and 7 show the vehicle on the test platform with and without the HRET, and figure 8 shows the side-slope test with the HRET elevated.

Table 2. Tilt Table Test Results

	Static [1, section 20b]	HRET Elevated [1, section 85]
AC 150/5220-10C Requirement [1]	30°	11°
FAA Striker baseline	33.5°	Not applicable
FAA Striker HRET	31.55°	11.52°

Figure 6. Tilt Table Test Without the HRET

Figure 7. Tilt Table Test With the HRET

Figure 8. Tilt Table Test With the HRET Elevated

3.1.5 Stopping Distance Tests for Service and Emergency Brake Systems.

Stopping distance tests for service and emergency brake systems were completed on the FAA Striker baseline and FAA Striker HRET [1, sections 32b, 32d, table 2]. The AC states that, at 20 mph, the service brakes must be able to stop the fully loaded vehicle within 40 feet, with and without the engine running. The service brakes must be able to stop the fully loaded vehicle travelling 40 mph within 160 feet, with and without the engine running. At 40 mph, the emergency brakes must be able to stop the fully loaded vehicle within 288 feet. A data acquisition system, with a global positioning system, was used to record the stopping distances. Figures 9 through 11 show that the FAA Striker passed all three tests in both the baseline and HRET configurations. At 20 mph, the FAA Striker HRET exceeded the performance of the baseline tests. The service brake stopping distance at 40 mph ranged from 20 to 42.5 feet less than the maximum requirement; the emergency brake stopping distance ranged from 55 to 108 feet less than the maximum requirement.

Figure 9. Service Brake Stopping Distance From 20 mph

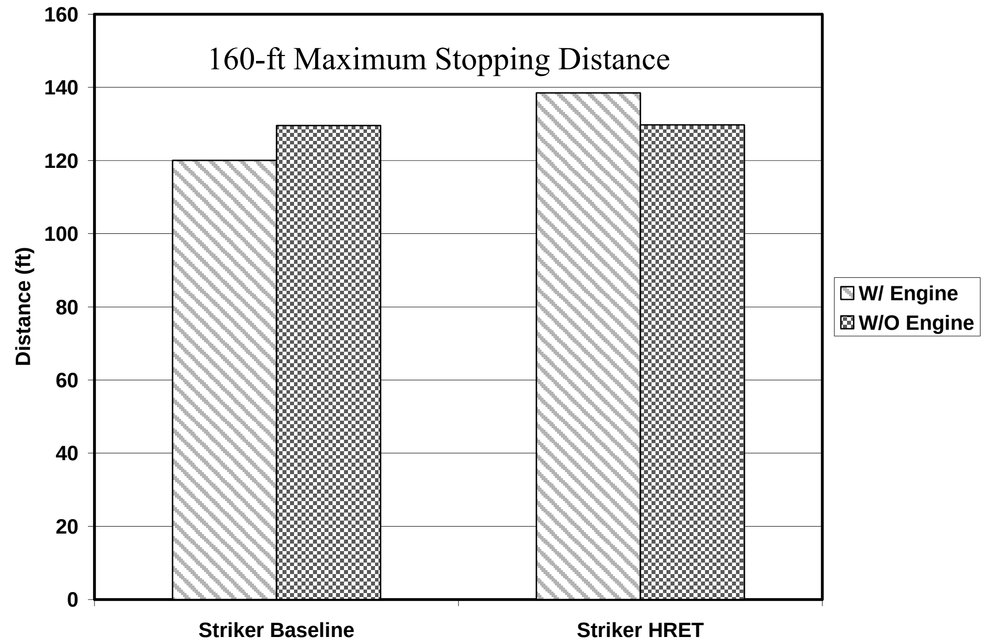


Figure 10. Service Brake Stopping Distance From 40 mph

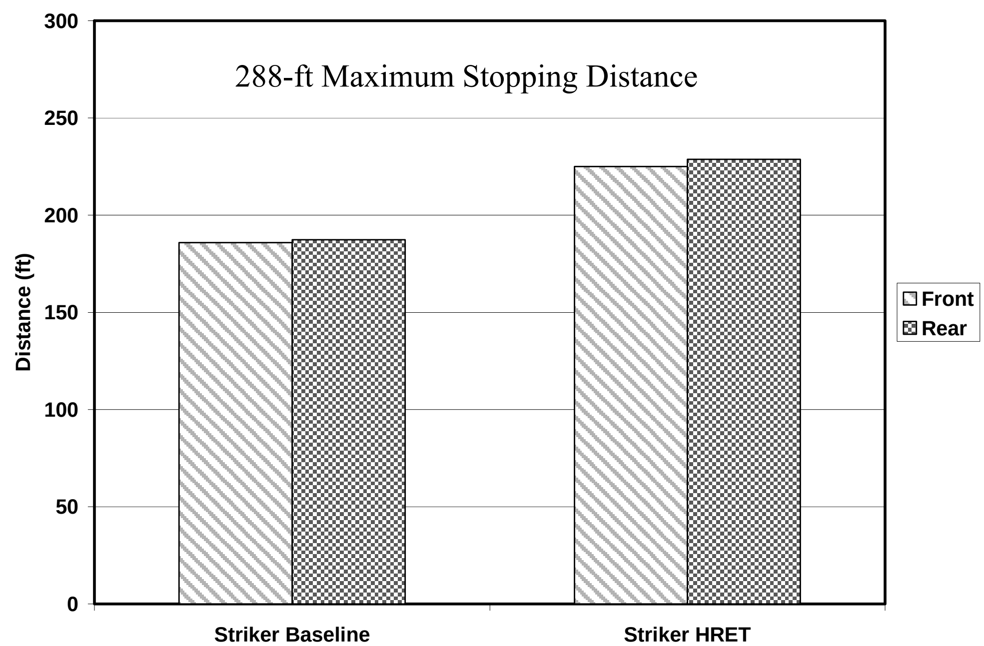


Figure 11. Emergency Brake Stopping Distance From 40 mph

3.1.6 Body and Chassis Flexibility Tests.

Body and chassis flexibility tests were conducted on both the FAA Striker baseline and the FAA Striker HRET [1, section 10]. The tests were conducted according to NFPA 414 6.3.9 [2], and the results were compared to the requirements outlined in AC 150/5220-10C [1]. The AC states that when the vehicle is cross-articulated on 14-inch blocks, no damage to vehicle components, all systems must function properly, and all tires must stay in contact with the ground. Two rear wheels on the same side of the vehicle and one front wheel on the opposing side of the vehicle were placed on 14-inch blocks. All six tires were inspected and any tires not in contact with the ground were measured. After the body and chassis were inspected, the vehicle was cross-articulated with the opposite wheels. Figure 12 shows the FAA Striker baseline cross-articulated with the left-front and right-rear wheels on blocks. Figure 13 shows the FAA Striker HRET cross-articulated with the right-front and left-rear wheels on blocks. Figure 14 shows the distance from the ground of the front tire not on blocks. While results improved with the addition of the HRET, which added weight to the front of the vehicle, the FAA Striker did not pass the flexibility test in either configuration. The FAA Striker baseline test measured a distance of 7 (right) to 8 (left) inches, and the FAA Striker HRET test measured a distance of 4 inches for both the left- and right-front tires.

Figure 12. The FAA Striker Baseline Chassis Flexibility Test

Figure 13. The FAA Striker HRET Chassis Flexibility Test

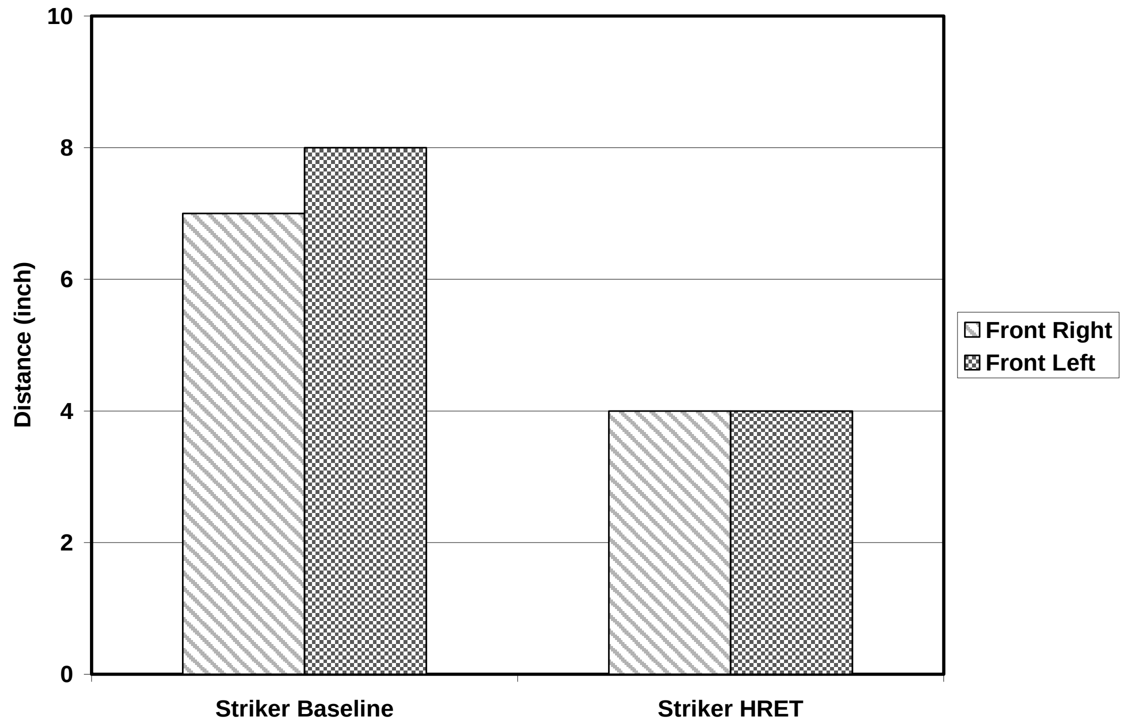


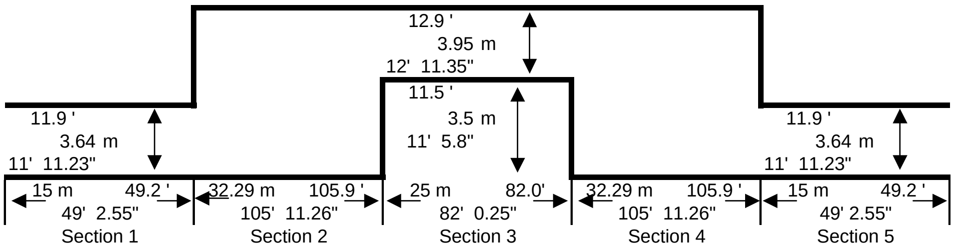
Figure 14. Tire Distance to Ground During Cross-Articulation

3.1.7 Dynamic Turning Control Tests.

Dynamic turning control tests were completed on both configurations of the FAA Striker [1, section 53d, table 2). The AC states that the vehicle must attain a minimum speed of 22 mph while traveling in a 100-foot-radius circle and must not exhibit oversteer characteristics. A 100 foot-radius circle was marked on a flat pavement surface. The vehicle was driven at increasing speeds from 0 to 22 mph around the circle. The FAA Striker passed the test in both configurations. At 22 mph, the FAA Striker baseline showed a 2° understeer with the vehicle traveling left-side out and a 7° understeer with the vehicle traveling right-side out. The FAA Striker HRET showed a 5° and 6° understeer with the vehicle traveling left- and right-side out, respectively, at 22 mph.

3.1.8 The North Atlantic Treaty Organization Lane Change Tests.

The North Atlantic Treaty Organization (NATO) Lane Change Tests were completed on both configurations of the FAA Striker [1, table 2]. The vehicle accelerated to a minimum speed of 35 mph while traveling through the cones without losing control or stability. A double-lane change course (figure 15) was marked per NATO AVTP 03-160W [3]. The vehicle was driven in both configurations through the course at speeds up to 40 mph without losing of control, exceeding the 35-mph minimum requirement. Figures 16 and 17 show the vehicle in each configuration as it was maneuvered through the course.



Enter values in **green** to the right

Vehicle Length: **8.29** m (as measured 0.5m above ground)
Vehicle Width: **3.08** m front tire to rear mudflap

Length was from the front of the front tire to rear mudflap
Width was across the tire sidewalls

Lane change track dimensions

Section 1:	Length:	15 m		
	Width	1.1*Veh. Width + 0.25m	=	3.64 m
Section 2:	Length:	Vehicle Length + 24m	=	32.29 m
Section 3:	Length:	25 m		
	Width:	1.2*Veh. Width + 0.25m	=	3.95 m
Section 4:	Length:	Vehicle Length + 24m	=	32.29 m
Section 5:	Length:	15 m		
	Width:	1.1*Veh. Width + 0.25m	=	3.64 m

Convert feet to meters				**WIDTH**
10.1	ft	=	3.07848	m
0	in	=	0	m
		Total:	3.07848	m

Convert feet to meters				**LENGTH**
27.2	ft	=	8.29056	m
0	in	=	0	m
		Total:	8.29056	m

Figure 15. The NATO Lane Change Course Diagram and Calculations [3]

Figure 16. The FAA Striker Baseline During NATO Lane Change Test

Figure 17. The FAA Striker HRET During NATO Lane Change Test

3.2 THE HRET PERFORMANCE AND FIREFIGHTING EFFECTIVENESS TESTS.

3.2.1 Turret Ground Pattern and Distance Test.

One ground pattern and distance test was done on the base turret in a straight stream. The test was done in accordance with NFPA 412 [4], except the turret was tilted at a 20° angle (not 30°, as specified in NFPA 412), and the test was performed on a gravel surface instead of a paved surface. Historically, this type of FAA equipment test had been conducted at the 20° angle; therefore, this was a deviation from the NFPA 412 protocol. In a straight stream, the effective foam distance from the end of the turret was 235 ft. The NFPA 414 minimum required effective foam distance is 190 ft [2]; therefore, the base turret on the vehicle exceeded the minimum distance by 45 ft.

3.2.2 Foam Solution Concentration, Expansion Ratio, and Drainage Time Tests.

The primary purpose of concentration, expansion ratio, and drainage tests was to evaluate the performance and reliability of the electronic foam proportioning system. A secondary purpose was to ensure a consistent foam quality throughout live fire evaluations. To accomplish these goals, tests were conducted periodically to determine trends in performance. Tests were done in accordance with NFPA 412 [4] on the base turret of the high-reach boom at high flow (1000 gpm) and on the hand line connection on the left side of the truck (125 gpm). The NFPA 412 performance requirements are summarized in table 3. Chemguard 3% concentrate was used for all checks. In addition to the 3% and 6% proportions checked in NFPA 412, checks were done at 1% and 9% proportions to better evaluate the capabilities of the system. NFPA 412 establishes specifications only for foam concentrations of 3% and 6%, the most commonly used foam mixtures. Specifications used to evaluate performance at 1% and 9% concentrations were extrapolated from the NFPA specifications for 3% and 6%. There are also no NFPA requirements for expansion ratio and 25% drainage time at mixture concentrations other than 3% and 6%. Foam concentration greater than 6% would likely meet the NFPA specifications because higher foam content would naturally lead to greater expansion ratio and drain time. At foam concentrations less than 3%, the foam content may not be adequate to meet the NFPA requirements, and so it would be inappropriate to extrapolate the expansion ratio and drainage requirements to a 1% foam concentration. Foam solution concentrations determined were by Test Method A with both a refractometer and conductivity meter; however, the calibration curves for the instruments were established using standard solutions prepared at 1%, 3%, 6%, and 9% aqueous firefighting foam (AFFF) concentration using 3% AFFF concentrate. An Atago® Palette Series model PR32a (±0.1% scale resolution, Brix[1] ±0.1% accuracy) digital refractometer and an Oakton® model CON 200 (±1% full-scale accuracy) conductivity meter were used. Expansion ratio and drainage time were determined using Test Method A.

Table 3. The AFFF Performance Specifications [4]

Discharge Device	Minimum Expansion Ratio	Minimum 25% Drain Time (m) (Method A)	Acceptable Range for Foam Solution Concentration	
			3%	6%
Hand line	3:1	1	2.8-4.0	5.5-8.0
Turret	3:1	1	2.8-3.5	5.5-7.0

The FAA Striker was equipped with a Nordic Systems Corp Foam Boss electronic foam proportioning system. Figure 18 shows a simplified diagram of the system. The desired foam concentration is set using a touch screen on the electronic control unit (ECU). Flow sensors at the foam concentrate suction line and at the foam/water solution discharge from the pump send signals to the ECU. Based on the flow signals, the ECU calculates an actual foam concentration, compares it to the desired concentration, and then sends a control signal to the metering valve in the foam concentrate supply line to adjust the injection rate of concentrate. The foam and water solution is then pumped to the selected turret or hand line.

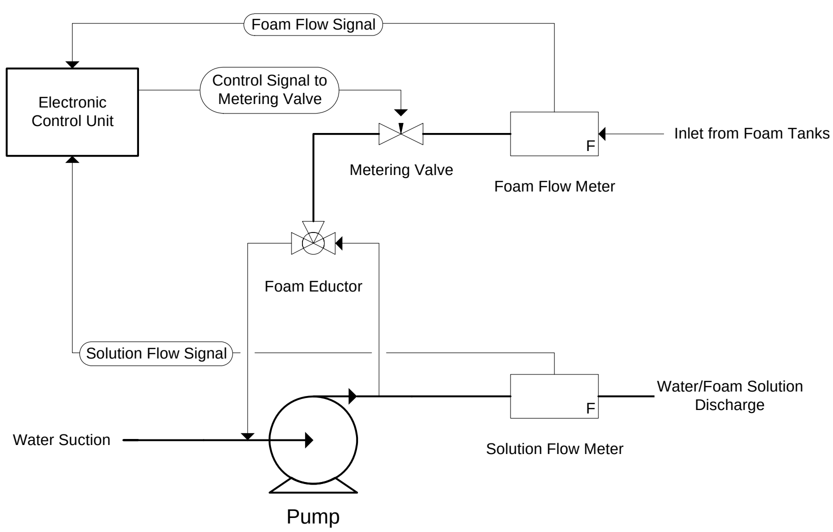


Figure 18. Electronic Foam Proportioning System Diagram

[1]Brix is the sugar content of an aqueous solution.

The flow sensor on the 2-inch line that supplies foam concentrate from the foam tanks is rated by the manufacturer for a recommended flow rate range of 10-300 gpm. The flow sensor on the 6-inch water/foam solution discharge line from the pump is rated for a recommended flow rate range of 90-2650 gpm. Figure 19 shows how the foam concentrate flow rate from the concentrate tank varies with the desired percent foam concentration and with the flow rate of the foam/water solution from the pump to the selected turret or hand line. For example, at a foam concentration of 3% and a foam/water solution flow rate of 60 gpm, the foam concentrate flow rate to the suction side of the pump would be slightly less than 2 gpm (see "Example 1" in figure 19), about 8 gpm below the manufacturer's recommended range. Therefore, there is potential that the system may not accurately meter the concentrate at such a low flow rate. In figure 19, the heavy black line at the 10-gpm foam concentrate flow rate coincides with the minimum recommended flow rate for accurate operation of the 2-inch flow sensor installed on the foam concentrate supply line. Any water/foam solution flow rate combined with a foam concentrate below this line could cause the electronic foam proportioning system to inaccurately meter the foam concentrate. For example, the Nordic Foam Boss may not be able to meter the correct amount of foam concentrate for a 6% foam solution set at the ECU when the water/foam solution flows from the turret or hand line is less than about 167 gpm (see "Example 2" in figure 19).

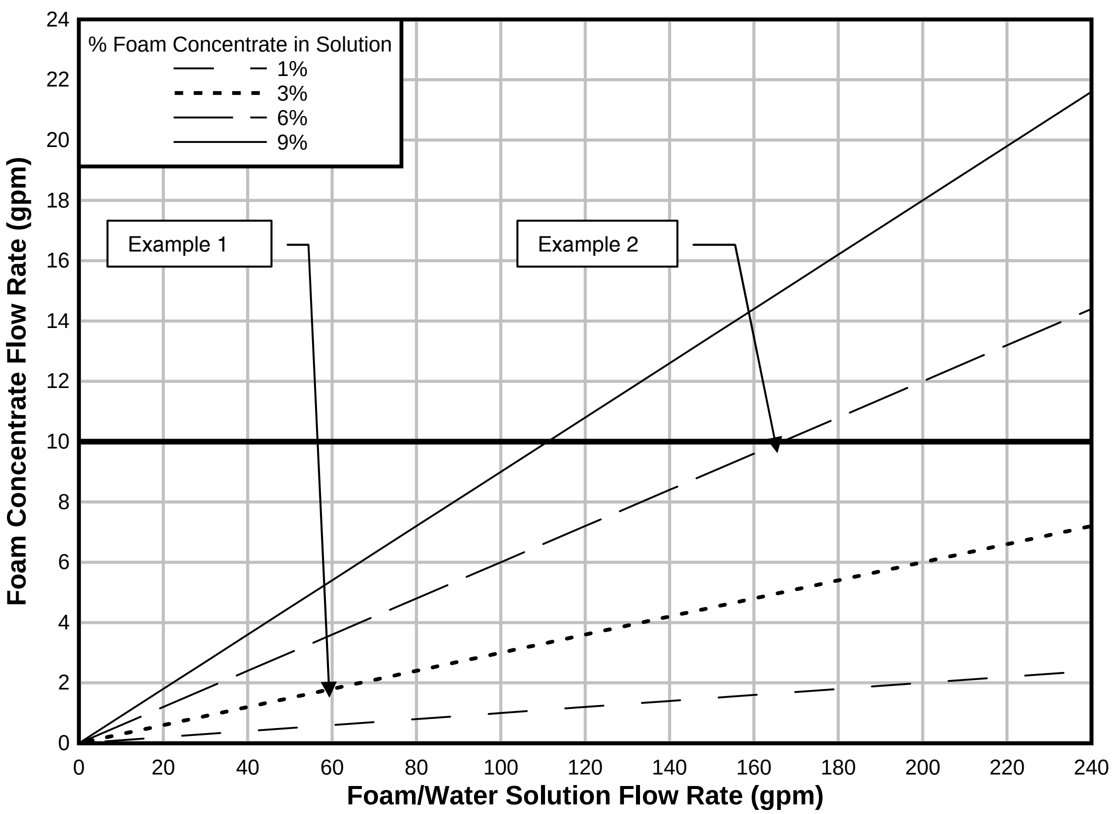


Figure 19. Foam Concentrate Flow Rate Variation

Data for foam concentration, expansion ratio, and drainage times are shown in appendix A. Figure 20 shows the results of the foam concentration checks for the 125-gpm hand line. The results are represented graphically over time for the four test concentrations. The results indicate no significant degradation in performance over time. The results were within specification at 6% and 9% concentrations for every sample. Most results at 3% concentration were within specification. None of the results at 1% were within specification. Poorer performance at the lower concentrations was not surprising with regard to the previous discussion about the design parameters of the flow sensor in the foam concentrate line. At a flow rate of 125 gpm, operational parameters were outside the manufacturer's advertised specifications, even at a 6% foam mixture, but the foam proportioning system satisfactorily maintained the correct foam concentration at 6% and, most of the time, at 3%.

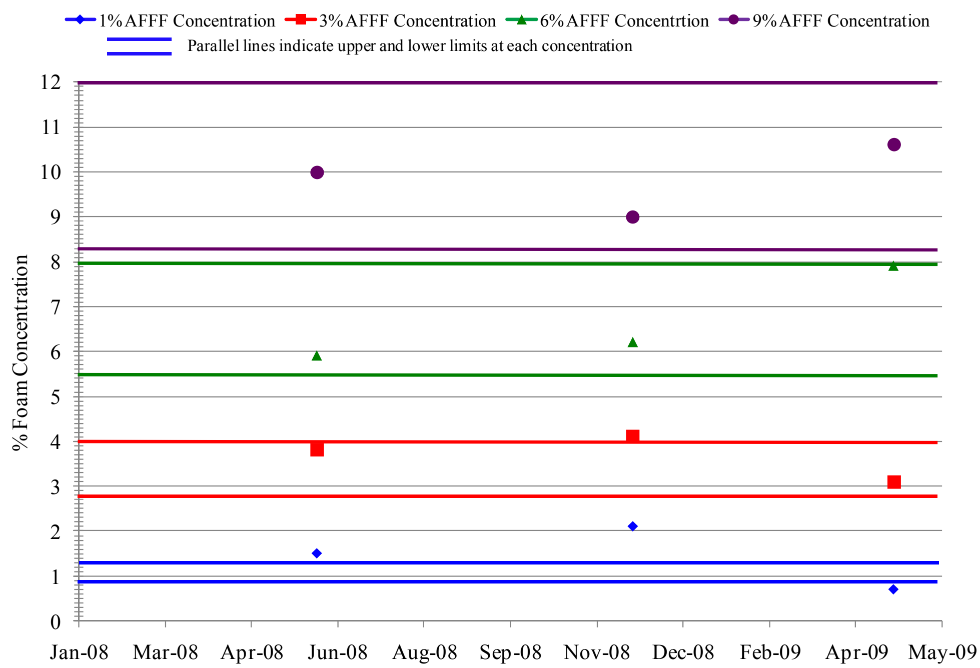


Figure 20. Hand Line Foam Concentration History

Figure 21 shows the results of the foam concentration checks for the 1000-gpm base turret. The results are represented graphically over time for the four test concentrations. The results indicate no significant degradation in performance over time. The results were within specifications at all four concentrations for every sample. The system performed well even at the very low mixture concentration of 1%, for which the extrapolated acceptance band was just 0.9%-1.2%.

Foam/water solution expansion ratios and 25% drainage times are more of an indication of nozzle performance than of foam concentration in solution. However, when expansion ratio and/or 25% drainage time are low (i.e., out of specification), the cause could be a low foam concentration in solution. Drain time data was not measured for 1% foam solutions because it was difficult to perform the test at such a low concentration. At 1% concentration, the mixture was much like an emulsion; the solution remained a continuous mix of tiny bubbles suspended in water for a minute or longer before separating into a two-phase mixture of water and foam. When the solution finally separated into two distinct phases, most of the water had already drained from the foam, and there was no reasonable way to extrapolate backward to determine the 25% drainage time. The data in appendix A show that expansion ratios were within NFPA specifications for every sample except those at 1% foam concentration. To reiterate, this result was expected since expansion ratio decreases in proportion to foam concentration in solution. Drain times met NFPA requirements in all but three samples. A sample at 3% concentration from the base turret taken in June 2008 was low (out of specification) at 24 seconds (1-minute minimum specification). This was the only sample from the base turret that was out of specification, and so it does not point to a systemic deficiency in the base turret nozzle. The other two cases when drain time was out of specification were samples taken in May 2009 from the hand line at 3% and 6%. Although there are no NFPA 412 requirements for 25% drainage time at 9% foam concentration, the measured drain time from the hand line in May 2009 at 9% concentration was also less than 1 minute. Foam concentration measurements from the same samples met NFPA requirements; therefore, low foam concentration was not the cause of the low drain times. The same hand line nozzle was used for all the tests. The nozzle may have developed some problem over time that led to the poor drain times, but there are no implications for performance of the systems on the vehicle.

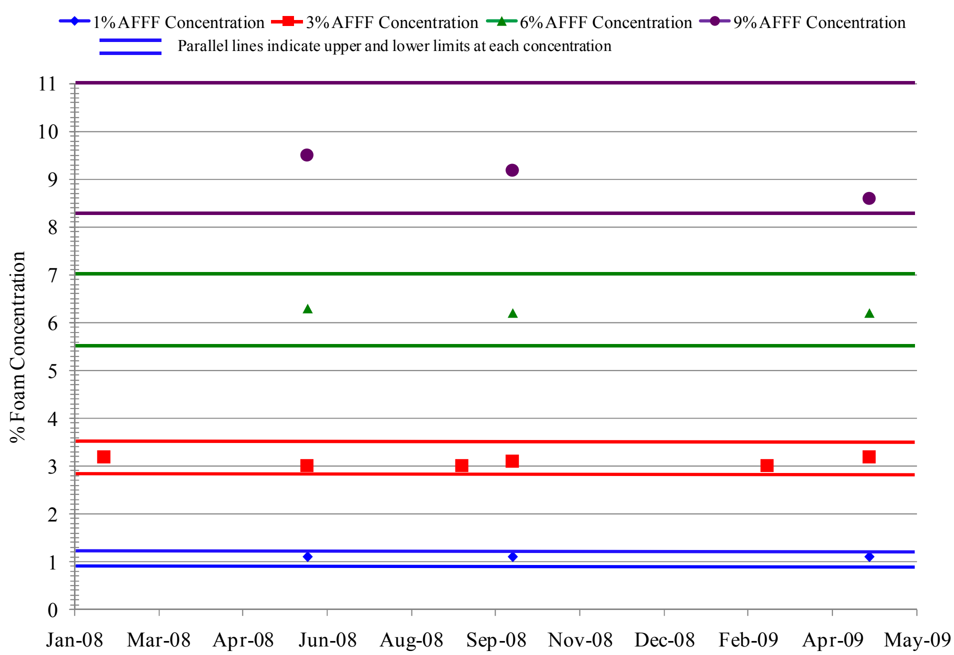


Figure 21. Base Turret Foam Concentration History

In conclusion, the Nordic Foam Boss electronic foam proportioning system performed well over the 16 months it was tested. No repairs were required to the system over the test duration.

3.2.3 The HRET Standoff Distance Measurements.

The purpose of these measurements was to determine the maximum standoff distance of the vehicle when the HRET is deployed in full ground extension, maximum extension, and full-up extension. Refer to figure 22 for a description of the three extension modes and a description of the measured standoff distance for each of the three extension modes. Distances were measured from the front-most part of the truck body (not the front of the bumper) to the tip of the penetrator nozzle. A commercial off-the-shelf tape measure was used to measure distances, and an inclinometer with a magnetic base was used to level the boom for the measurements in maximum extension.

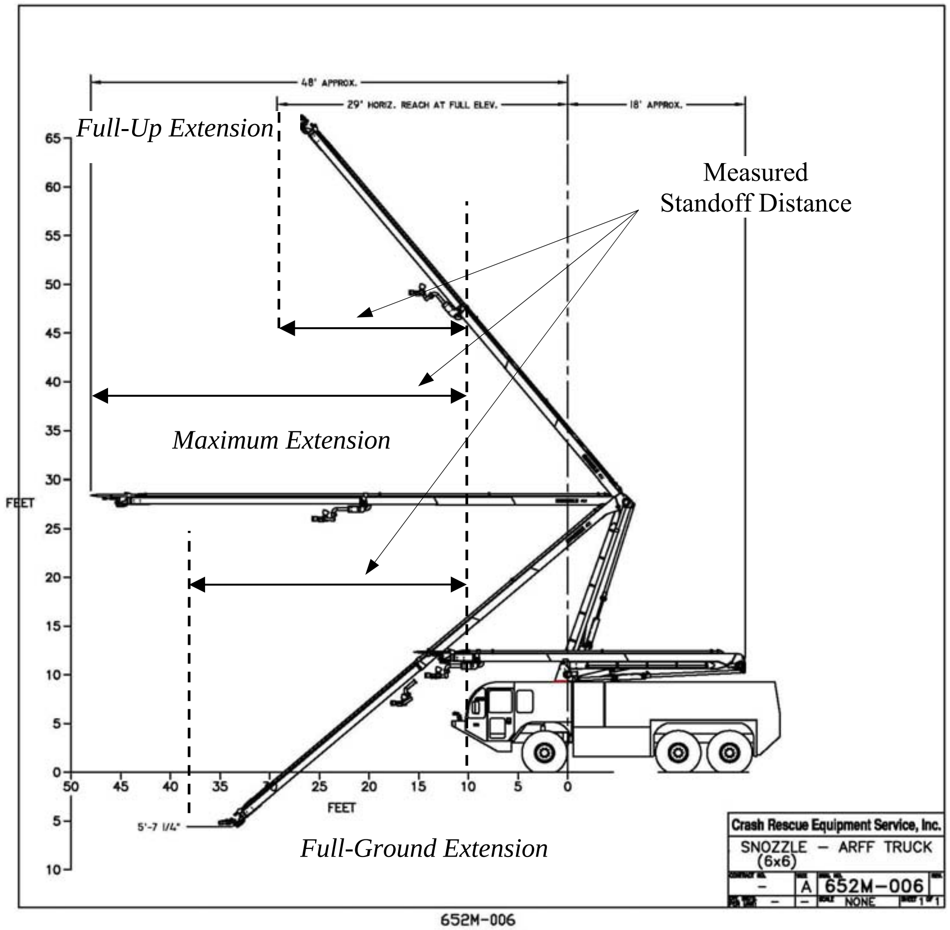


Figure 22. The HRET Extension Modes [5]

Table 4 shows the measured maximum standoff distances and the maximum standoff distances reported by the manufacturer. The front bumper of the vehicle protruded 16.5 in. forward of the front-most part of the truck body. The distance from the front-most part of the boom structure to the tip of the penetrator was 4 ft 10 in. (figure 23), and the distance from the front-most part of the boom structure to the face of the tip turret was 2 ft 6 in. (figure 24). Figure 25 illustrates how the below-grade measurement was made with the HRET in full ground extension.

Table 4. The HRET Standoff Distances

HRET Deployment	Measured Maximum Standoff Distance	Reported Maximum Standoff Distance
Full-ground extension	30 ft 1 in. (1 ft 8 in. below grade)	29 ft (2 ft below grade)
Maximum extension	38 ft 8 in.	39 ft
Full-up extension	26 ft 7 in.	22 ft

Figure 23. Penetrator Length

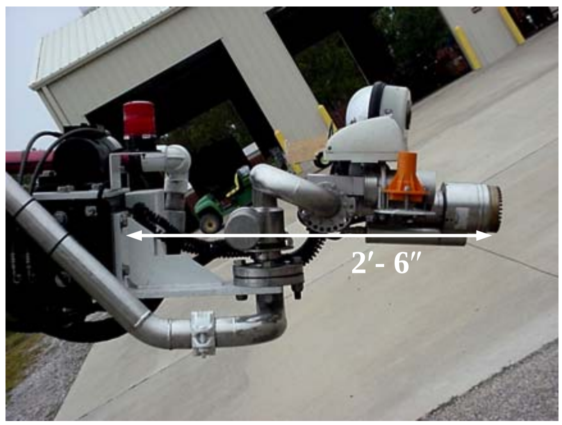


Figure 24. Tip Turret Length

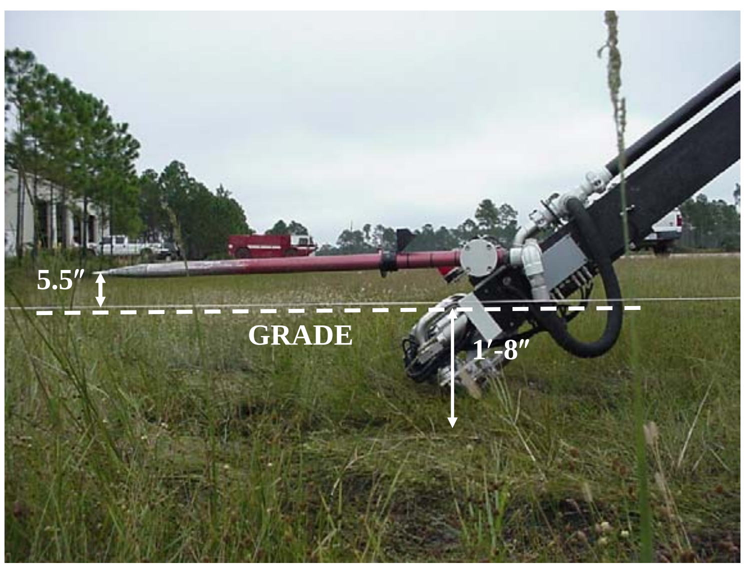


Figure 25. Below Grade Measurement

3.2.4 The HRET Timed Deployment and Penetration Tests.

The purpose of the HRET timed deployment trials was to determine the time to deploy the HRET and penetrate the aircraft mock-up. The penetration targets were 14-gauge (0.075-in.) aluminum plates measuring 24 by 24 in. Deployment tests were conducted at the cargo deck, the lower passenger deck, the upper passenger deck, and in full-up extension (refer to figure 22). The heights measured from the ground surrounding the test pit to the centers of the aluminum penetration windows were approximately 13.5 ft for the cargo deck, 23 ft for the lower passenger deck, and 31 ft for the upper passenger deck. The FAA Striker's position was perpendicular to the fuselage prior to the test, and placement of the truck was marked to repeat the same position for each level and operator. Three operators performed three timed trials for each of the four positions. Tests were randomized by operator and level. Times were recorded from the point at which the HRET left its cradle until full penetration of the aluminum plate was achieved and water was discharged from the penetrator nozzle. No water was discharged during the full-up extension trials and no penetration was performed; this was merely a timed deployment from the bedded position to the full-up extended position. All HRET manipulations were performed using the joystick located in the cab, and all deployment and penetration operations were done with the vehicle engine in high idle.

Data for the timed deployment trials is given in appendix B. Figure 26 shows the average deployment time (marked by an ×) for all operators and the 95% confidence intervals for each of the four levels. The 95% confidence interval is the time period in which 95 of the 100 trials would be expected to fall based on the data taken. Figures 27 through 30 show the averages and 95% confidence intervals for each level by individual fire fighter. The ranges of some data in figures 27 and 28 are less than zero because the sample standard deviation in those data sets was such that the two-sided 95% confidence level range extended to less than zero. It is impossible for the HRET to be deployed in zero seconds or less. The average deployment time was 54 sec for the lower passenger deck and for full-up extension. Data for the full-up extension showed the least variation, which was expected since there was no penetration involved; therefore, it was more of a test of the equipment than operator skill. Average deployment time for the cargo deck was 80 sec, and average deployment time for the upper passenger deck was 62 sec.

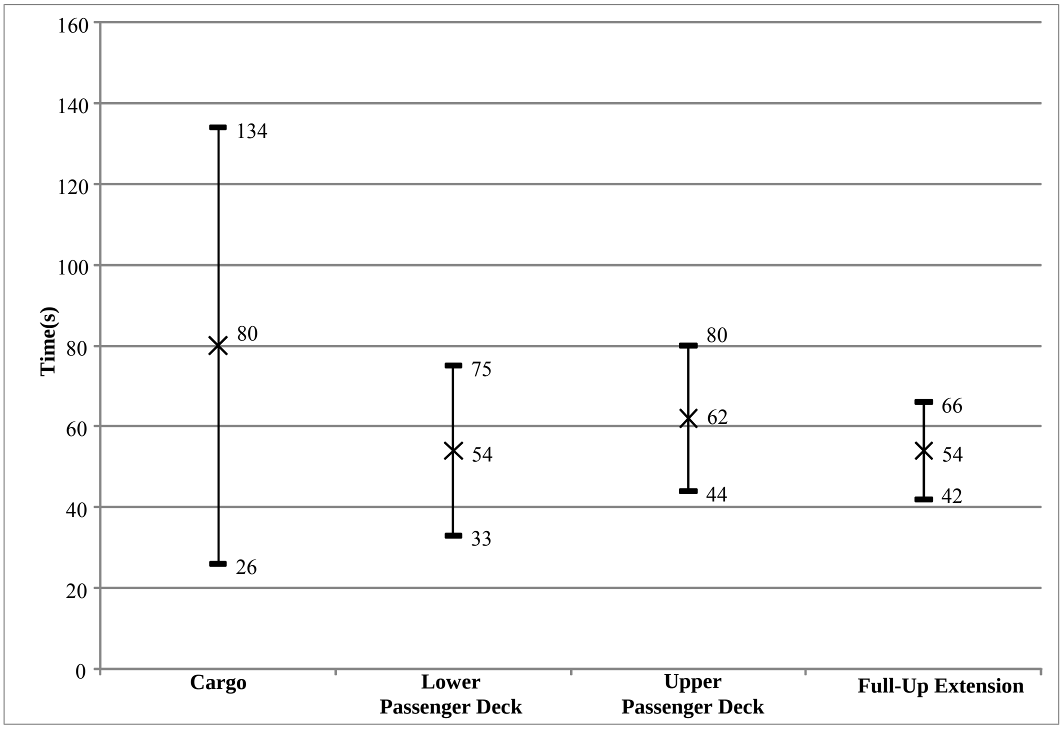


Figure 26. Average Deployment Times for Each Deck

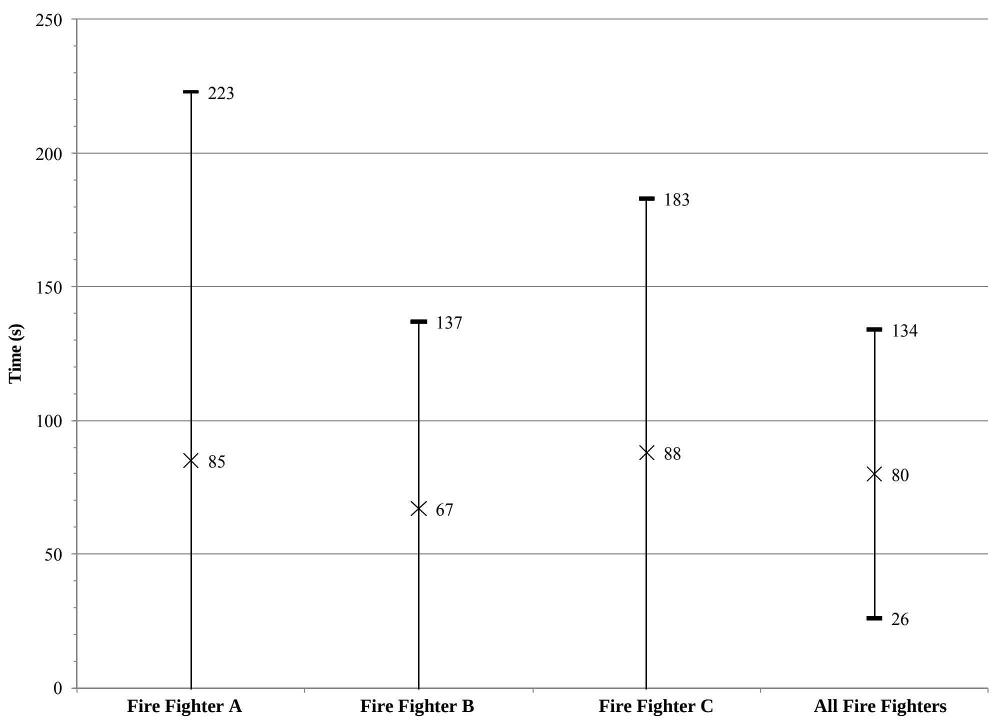


Figure 27. Cargo Deck Average Deployment Times by Fire Fighter

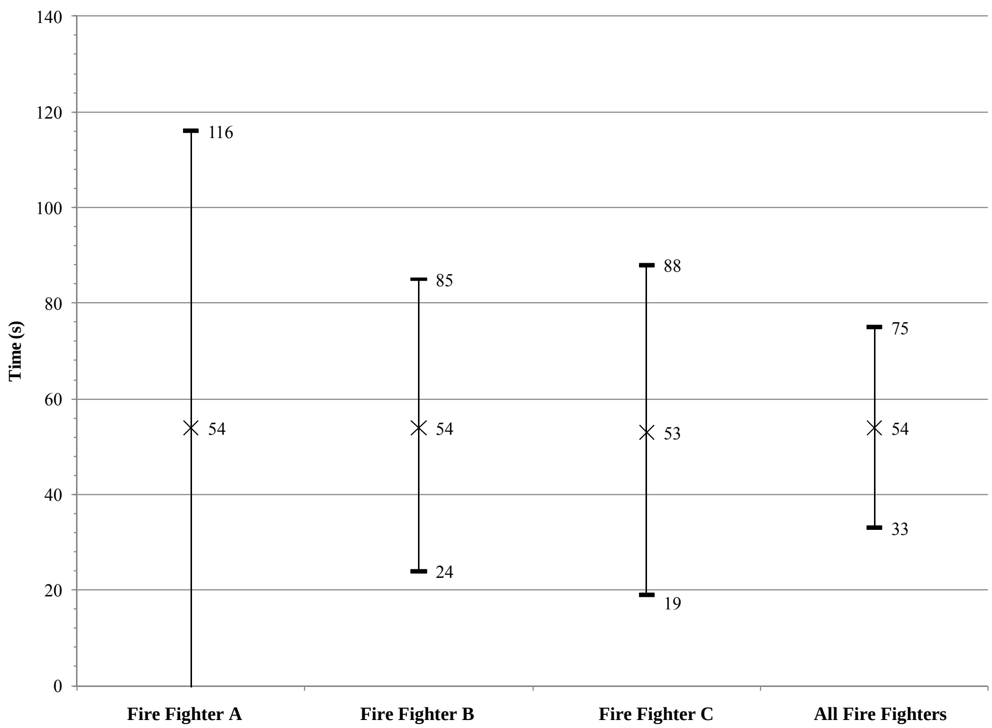


Figure 28. Lower Passenger Deck Average Deployment Times by Fire Fighter

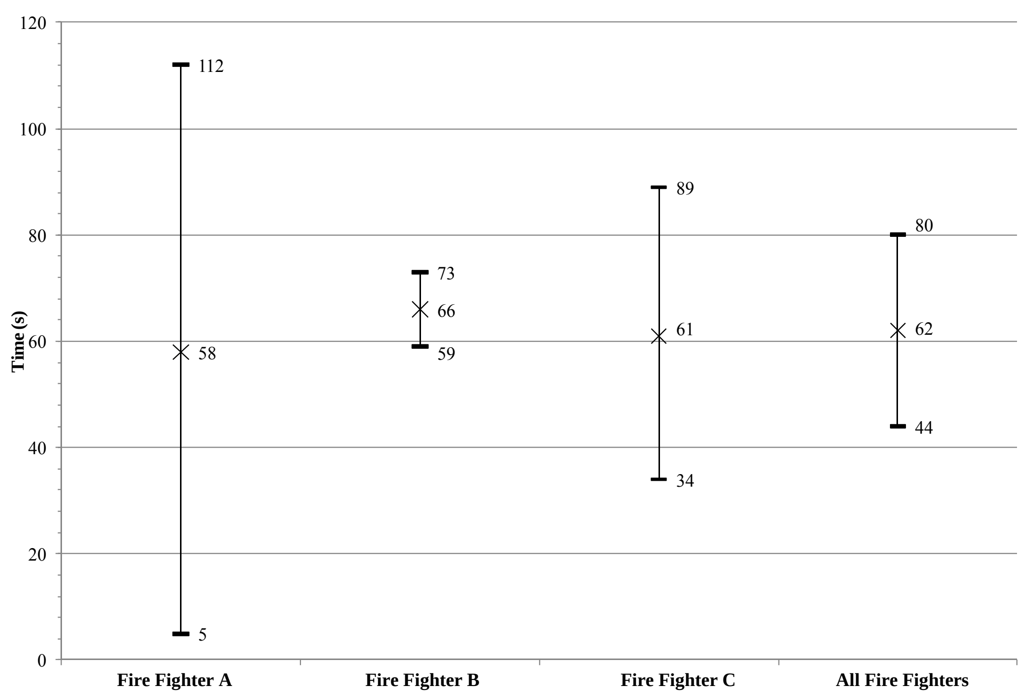


Figure 29. Upper Passenger Deck Average Deployment Times by Fire Fighter

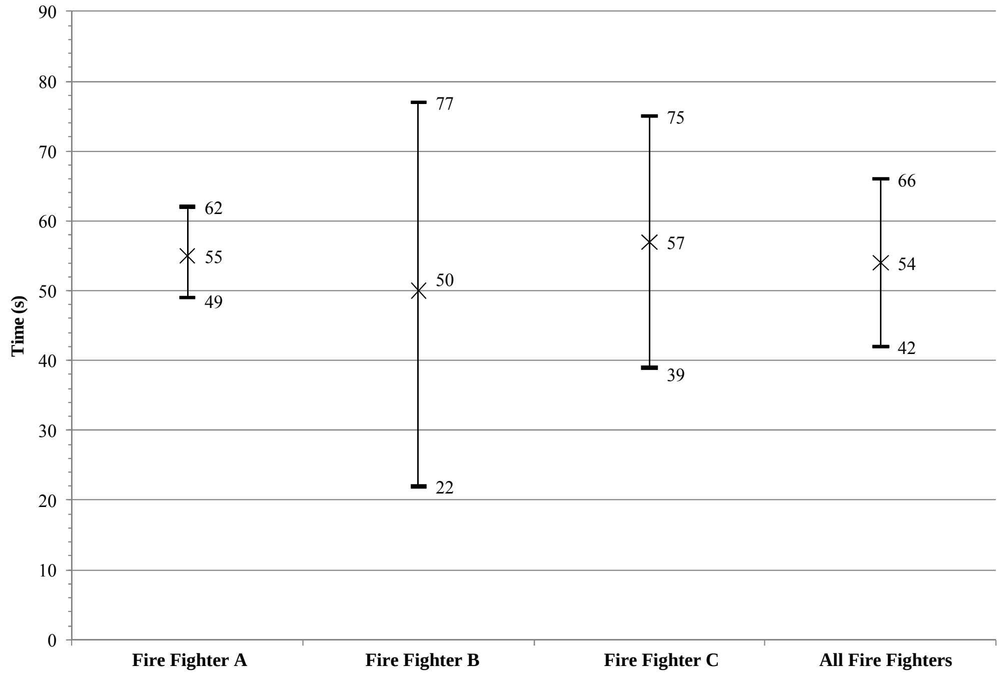


Figure 30. Full-Up Extension Average Deployment Times by Fire Fighter

Penetration times for the cargo deck were longer because more manipulation of the boom was required to line up the penetrator with the target at the cargo deck than for the other two decks. Elevation of the lower boom cannot be controlled independently of the upper boom. To position the boom for penetrating the cargo deck, the joystick was held in the low attack position until the lower boom reached its maximum elevation (figure 31). At the same time, the upper boom was partially extended, but care had to be taken to not extend it so far that it would bump against the fuselage while the boom was still moving into the low attack position. Once the lower boom was fully extended, the upper boom had to be alternately raised and extended in several steps until the penetrator was properly aligned to pierce the target (figure 32). The iterative process of raising and extending was time-consuming and was the direct cause of the excessive time it took to penetrate the cargo deck.

Figure 31. Extending the Lower Boom for low Attack

In contrast, penetrating the lower passenger deck required the least amount of time because it required the least amount of fine adjustments to align the penetrator with the target. To position the boom for penetrating the lower passenger deck, the joystick was held the in the high attack position until the lower boom reached its maximum elevation. There is a programming code in the controls that pauses the boom in the midpoint pierce position when raising the boom. At this pause point, the boom is in close proximity to the lower passenger deck, which is roughly the same as the main cabin height of single passenger deck aircraft. In the high attack mode, while the lower boom is elevating, the upper boom remains approximately level with the ground and does not begin to elevate until the lower boom is fully raised. Releasing the joystick once the lower boom reached full extension, and then extending the inner boom, puts the penetrator almost in the proper position to pierce the target without much additional manipulation of the boom (figure 33). For this reason, the fortuitous height of the lower passenger deck in relation to the boom when the lower boom is fully extended, the average penetration times for the lower passenger deck were less than for the other two decks.

Figure 32. Penetrating the Cargo Deck

Figure 33. Penetrating the Lower Passenger Deck

The boom manipulation to align the penetrator with the target at the upper passenger deck was more than that required for the lower passenger deck but less than required for the cargo deck, and so the average time to penetrate the upper passenger deck fell between the times for the other two decks. First, the lower boom was raised to its fully raised position (figure 34). Then the upper boom was simultaneously raised to near horizontal and extended, taking care to not contact the side of the fuselage with the penetrator. Finally, the boom was alternately raised and extended to position the penetrator to pierce the target (figure 35).

Figure 34. Extending the Boom for High Attack

Figure 35. Penetrating the Upper Passenger Deck

A small video camera was mounted at the base of the penetrator, which fed a live signal to a monitor in the vehicle cab to aid the operators in positioning the penetrator. Because the camera showed only a two-dimensional view, it was difficult for the operators to determine how close the tip of the penetrator was to touching the target. Because of this depth perception problem, the operators used a combination of looking out the windshield to determine position and alignment of the penetrator relative to the target area, then using the camera view once the penetrator tip was positioned to within a few inches of the desired target area.

3.2.5 The HRET Oscillation Tests.

The purpose of the oscillation tests was to determine how the HRET operates in an environment filled with obstacles by measuring the maximum amplitude of boom oscillation or overshoot when it is operated in different configurations. If the boom were to hit an obstacle while it was being positioned for attack on a fire, immediate damage might result that could render the boom inoperable or restrict operation. This could happen when a debris field around the aircraft required careful and precise boom maneuvers to prevent it from colliding with objects in the debris field.

Tests were performed with the boom moving in the up and down directions (vertical), left-to-right and right-to-left (viewed from inside the vehicle cab) (horizontal), and with the inner boom fully retracted and fully extended. Tests were performed at both fast and slow speeds and with the boom in full-up extension, maximum extension, and as near as possible to full-ground position. Additionally, tests were performed at fast and slow speeds in the horizontal directions with the tip turret oriented 90° to the side of the boom and spraying water in the direction opposite to the boom rotation. No tests were done in the vertical directions with water spraying. Trials were replicated three times in each configuration for a total of 168 separate trials. Some additional oscillation measurements were made when the control joystick was "bumped," or quickly moved to the fast speed position and released immediately. Some measurements were also taken to determine boom response due to turning the water on or off to the tip turret while the nozzle was oriented 90° to the side of the boom.

A high-speed camera was used to record boom motion, and then analysis software was used to determine the amplitude of boom displacement and the average speed of the boom during the initial oscillation. Video was recorded using a Phantom® v7 color high-speed camera set to record at 100 frames/sec, with a frame exposure interval of 1 ms and a resolution of 800 by 600. Video footage was downloaded to a Dell™ Latitude™ D630 laptop and analyzed using the Phantom Camera Control version 9.2 software package. The camera and data acquisition computer are shown in figure 36.

Figure 36. High-Speed Camera and Data Computer

The displacement analysis software required an object of known length in the recorded video for calibration. A 6-ft length of small diameter polyvinyl chloride (PVC) pipe was used to give the known length. Figure 37 shows the PVC pipe attached to the end of the boom. The mass of the PVC pipe was insignificant in comparison to the mass of the boom and therefore had a negligible effect on the boom response.

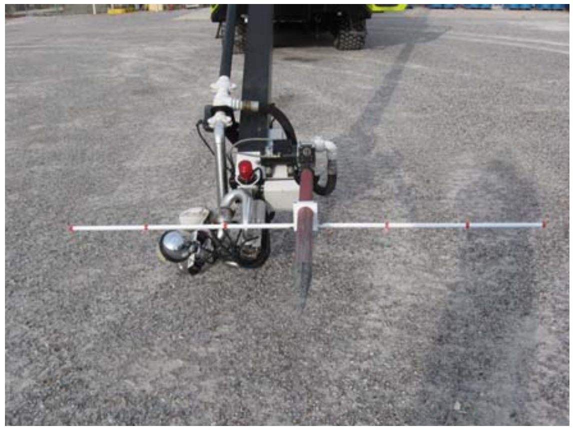


Figure 37. Distance Reference for Measuring Oscillation Magnitude

Oscillation measurements in the vertical directions were performed with the lower boom in the fully extended (raised) position. For tests in the downward direction, the boom was initially positioned above the horizontal then rotated until the boom reached horizontal (parallel to the ground). For tests in the upward direction, the boom was initially positioned below the horizontal then rotated until the boom reached horizontal. Oscillation measurements in the horizontal directions were done in a similar manner, but in addition to measuring the displacement of the first oscillation after releasing the joystick, the displacement of the second oscillation was also measured. The high-speed camera recorded motion from the start of each test until oscillatory motion almost completely stopped. A stopwatch was used to measure the time from when the operator released the joystick until the boom finished oscillating or reached a steady state of very small oscillations. It must be emphasized here that the HRET, especially in the fully extended configuration, was very sensitive to wind, ground vibration due to vehicle traffic, and even to movement of the operator inside the vehicle. Therefore, boom oscillation rarely ceased completely, but it did reach a point where the amplitude of the oscillations was very small and due to random external disturbances. At this point in the tests, video recording was stopped and the total duration of oscillation was measured. Each video was first scaled by marking both ends of the 6-ft PVC pipe. Next, the final resting point (center) and the location of the maximum displacement from the center for the first oscillation after releasing the joystick were marked. With this information, the analysis software then measured the magnitude of the oscillation displacement and the corresponding average speed of the first oscillation. Measuring displacement by this method was accurate to ±0.25 ft (3 in.), and measuring time duration was accurate to ±0.01 sec. Measuring total duration of oscillation by stopwatch was accurate to ±3 sec, primarily due to the subjectivity of deciding when the oscillations reached a steady state.

When rotated in a horizontal plane, the boom did not quickly accelerate to a constant velocity and then continue rotating at that constant velocity until the joystick was released. Instead, the boom accelerated to some maximum velocity, then slowed, then accelerated again, and then slowed. This pattern of accelerating and decelerating continued until the joystick was released. This was noted in both fast and slow speeds, but was much more pronounced at fast speed. This was not observed in motion in the vertical plane. It was also noted that the acceleration-deceleration was more evident when the hydraulic gearbox for the boom was new, and grew less evident as the boom was exercised in the clockwise and counter-clockwise directions. For horizontal tests, the boom was initially positioned left or right of the longitudinal centerline of the vehicle so that it would reach maximum velocity as it passed through the centerline. For tests in the up and down directions in fast speed, the boom was initially positioned as close as possible to the ground or in full-up extension, and displacement was measured when the boom reached the horizontal position. Slow-speed tests in the up and down directions were started with the boom oriented about 25° above or below the horizontal position. Displacement was also measured when the joystick was very quickly bumped to its maximum position (up, down, left, or right) and immediately released to create a whip-like motion of the boom. Boom movement due to starting and stopping water flow to the tip turret was measured as well. These different combinations were done so that the worst-case conditions for displacement of the boom could be indentified and quantified.

Figure 38 shows a typical test setup. Figure 39 shows the boom during the test while water was sprayed from the tip turret (note the curve in the boom due to the water flow).

Figure 38. Typical Test Setting for Boom Oscillation Tests

Figure 39. Oscillation Tests With Water Spray

Data for the oscillation displacement tests are presented in table C-1 and C-2 in appendix C. In the tables, amplitude is the maximum overshoot, measured in feet, relative to the final resting position of the boom, which is assumed to be the same position the boom was in when the operator released the joystick. Duration is the time, in seconds, measured for the boom to travel from the point where the joystick was released to its maximum amplitude and back to the point of release (for the horizontal tests in which the first two oscillation amplitudes were measured, the duration is the corresponding time to complete both oscillations). The average speed was calculated (using analysis software associated with the camera) by dividing the amplitude by its corresponding duration based on the frame speed of the camera. The total oscillation time was the duration, measured in seconds, from releasing the joystick until the oscillating motion stopped or reached a steady-state condition of very small oscillation amplitude.

Displacement data for oscillatory motion of the boom, when operated in the up and down directions, are shown graphically in figure 40. Data for the total time duration of oscillation of the boom, when operated in the up and down directions, are shown graphically in figure 41. The averages for each data set are shown in the figures for each boom configuration. The complete data sets are given in tables C-1 and C-2 in appendix C. In the tables, the terms "extended" and "retracted" refer to the position of the inner boom. "Upward" and "downward" refer to the direction the boom was rotated for the test. "Fast" and "slow" refer to the speed at which the boom was rotated. It should be re-emphasized at this point that the joystick for the boom provides for proportional control; the speed of rotation is proportional to how far the joystick is moved from its normal position. Fast-speed operation can be attained by moving the joystick to its maximum extent. Slow operation, on the other hand, is not as straightforward because it requires the operator to very slowly move the joystick until it reaches a position to cause the boom to rotate. There is some play in the joystick, and there is some threshold position that must be passed before motion begins. Therefore, a precise slow-speed operation is difficult to duplicate. Appendix C shows that the data for most of the test conditions were tightly grouped, except the trials when the extended boom was rotated upward slowly and when a sudden upward jerk was applied. The relatively wider range of data in the case of the boom being rotated upward slowly is most likely attributable to the difficulty in precisely replicating slow-speed operation. In the case when a sudden upward jerk was applied, it is likely that the operator did not position the joystick at the same speed and to the same extent in both trials. This sudden bump check was not part of the test plan, it was done simply to provide additional information concerning boom operation; therefore, only two runs were done. Generally, the data showed that oscillations were larger when operated in fast speed than when operated in slow speed and when operated with the inner boom extended rather than retracted. The data also indicated that applying a quick bump to the joystick caused about the same magnitude of oscillation as when operated in fast speed.

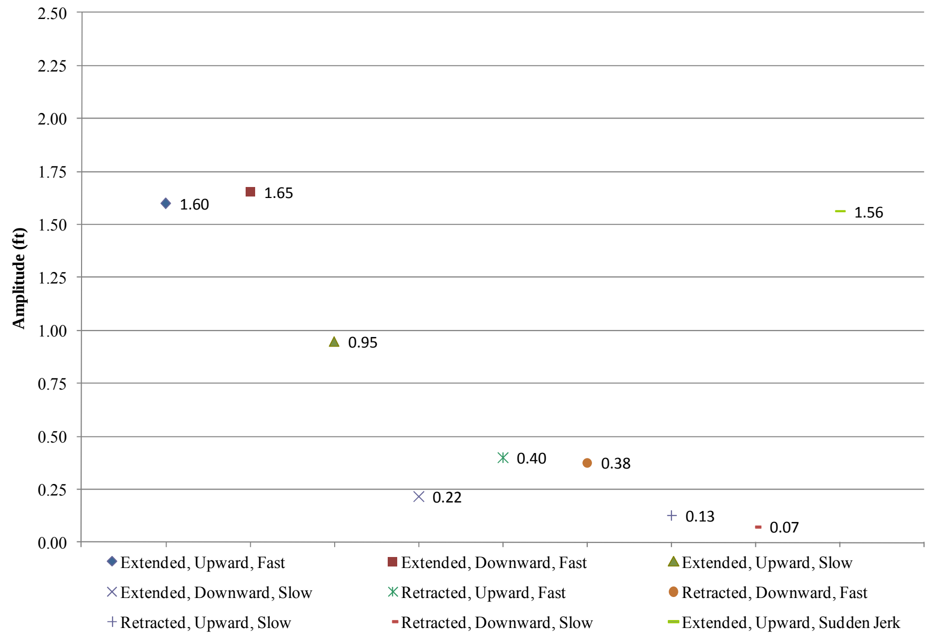


Figure 40. Amplitude Data for Up and Down Oscillation

Figure 41. Total Oscillation Time for Up and Down Motion

Figures 42 through 47 are grouped in pairs, respectively, to show (1) the displacement data for side-to-side motion and (2) the corresponding data for total oscillation time durations for the various HRET conditions, i.e., the inner boom retracted, the inner boom extended, and for transient operations. Transient operations included tests for which a sudden bump was applied to the joystick (in the right-to-left direction) and tests for which water was turned on or off to the tip turret while the turret was oriented 90° to the side of the boom. For all transient operations tests, the inner boom was extended and the HRET was in the maximum extension posture (refer to figure 22). Overshoot, when the boom was rotated in the horizontal plane, was generally worse in the mid-attack posture than in the low- or high-attack posture; having the inner boom extended was worse than when it was retracted; fast-speed rotation was worse than slow-speed operation; and without water discharging was worse than with water discharging. Notably, total time for oscillations to diminish were worse when water was flowing to the tip turret, with the inner boom retracted or extended, even though the amplitude of the oscillations tended to be smaller than for corresponding tests where water was not flowing. There was no significant difference in the direction of rotation, right-to-left or left-to-right. The maximum overshoot occurred with the HRET in mid-attack with the inner boom extended, rotating at fast speed without water discharging; moving left-to-right, the overshoot was 5.5 ft, and moving right-to-left, the overshoot was 4.7 ft. Minimum overshoot occurred when the inner boom was in the retracted position rotating at slow speed with water streaming from the tip turret, for which the maximum overshoot was about 0.1 ft in the low-, mid-, and high-attack positions.

The maximum overshoot observed in all tests was 15.1 ft. This occurred during transient operations tests when the joystick was given a fast bump to the high-speed position while no water was flowing from the tip turret. This type of operation might be used by an operator attempting to apply fine corrections to the boom position in preparation for penetrating the aircraft or for manipulating the boom between obstacles in a debris field to better position the tip turret to reach hidden fires. For the same conditions but with water spraying from the tip turret, the maximum overshoot observed was 9.7 ft.

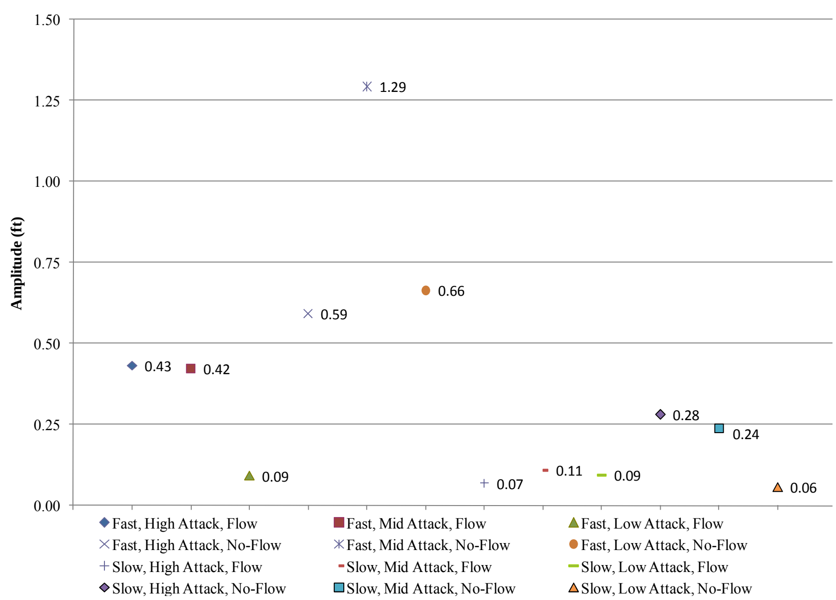


Figure 42. Oscillation Amplitude With Inner Boom Retracted, Horizontal Motion

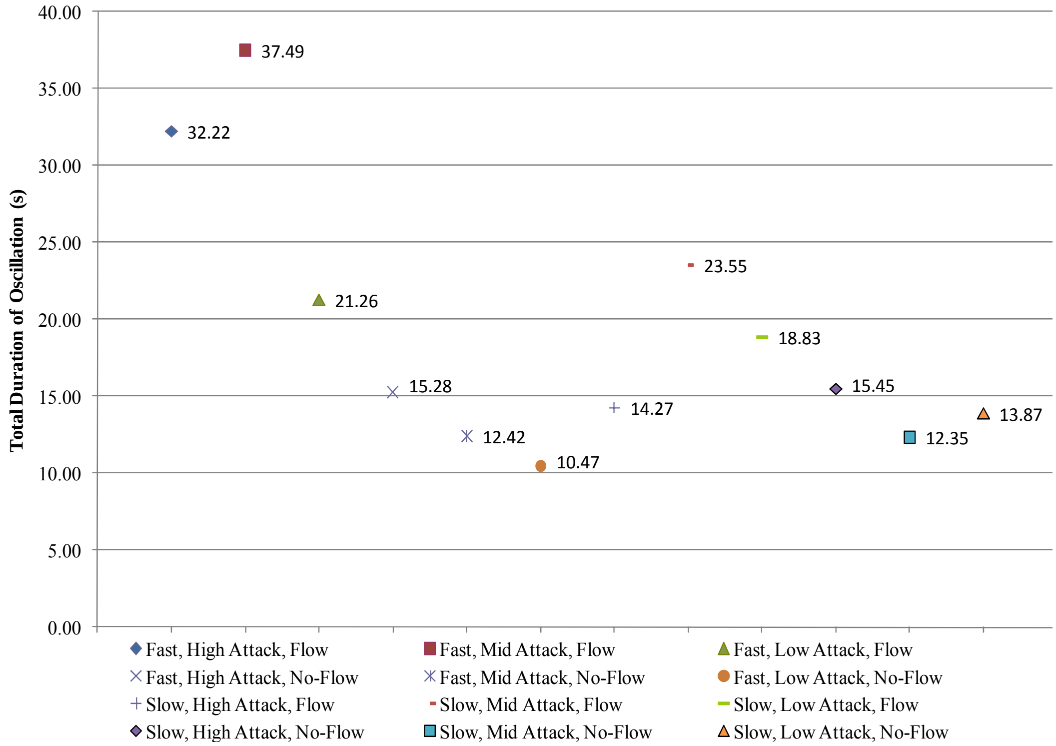


Figure 43. Total Oscillation Time With Inner Boom Retracted, Horizontal Motion

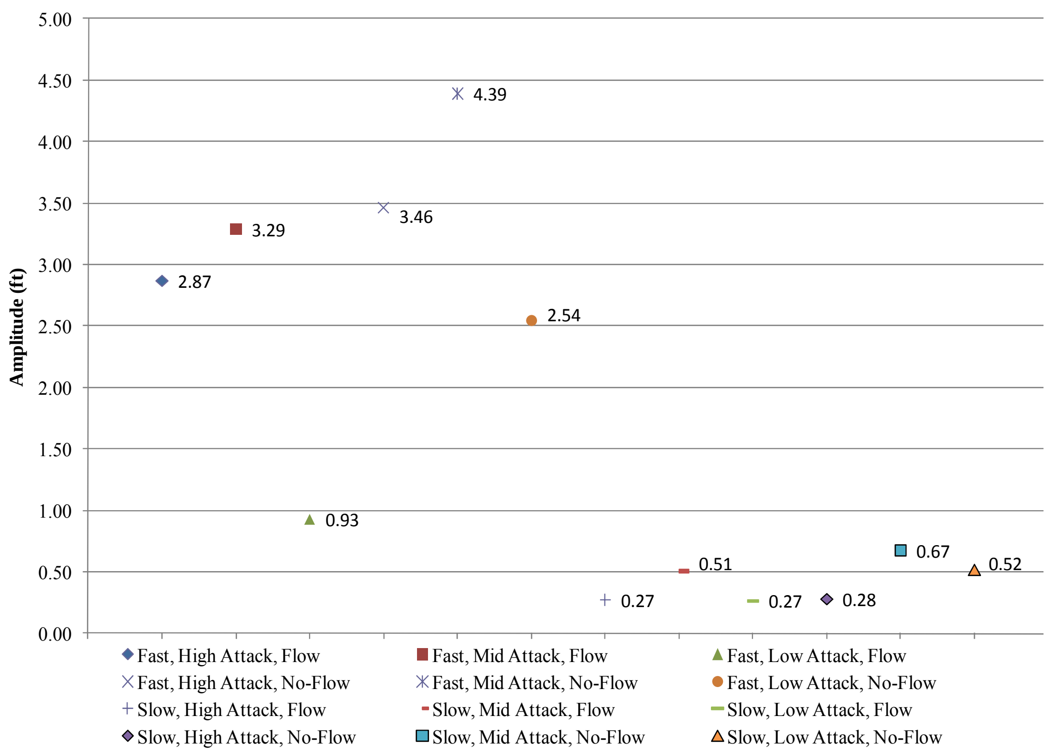


Figure 44. Oscillation Amplitude With Inner Boom Extended, Horizontal Motion

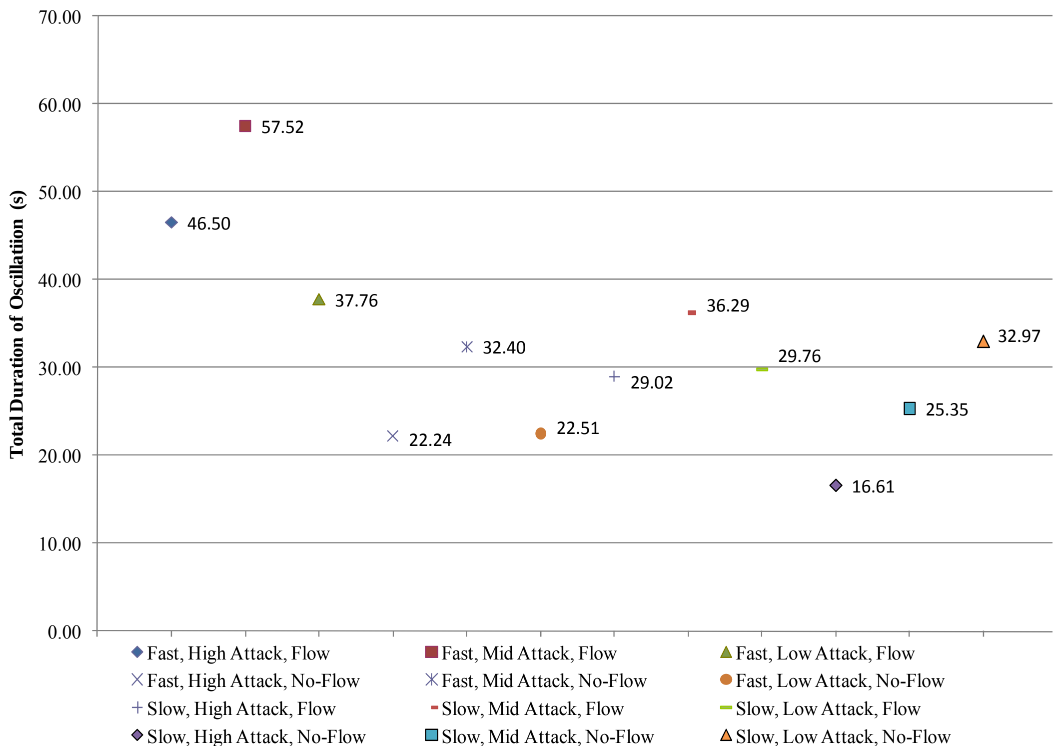


Figure 45. Total Oscillation Time With Inner Boom Extended, Horizontal Motion

Figure 46. Oscillation Amplitude for Transient Operations, Horizontal Motion

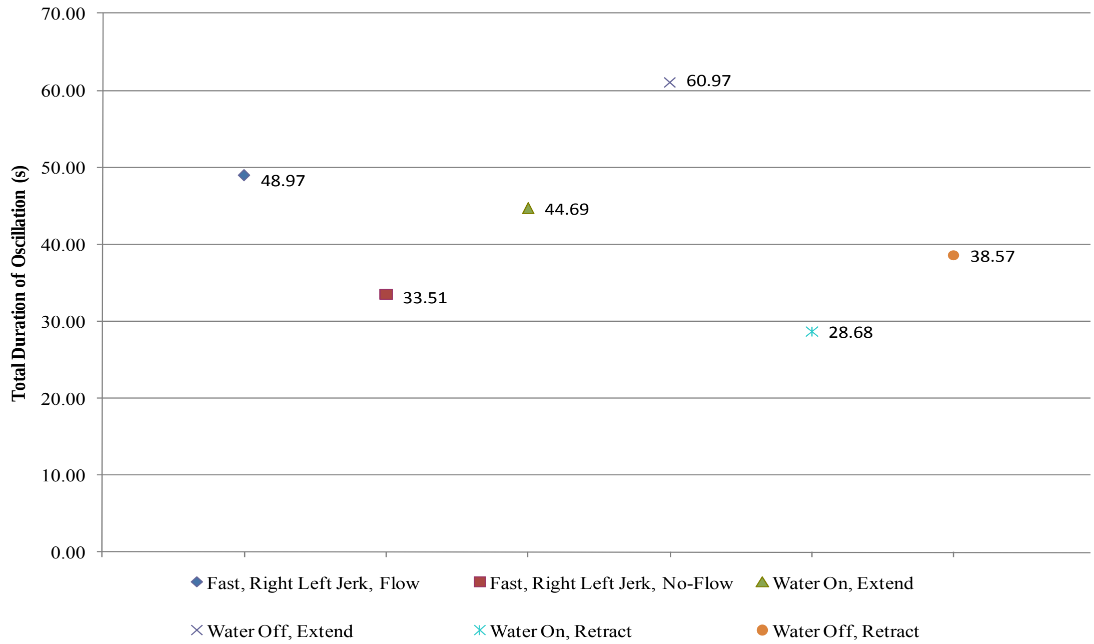


Figure 47. Total Oscillation Time for Transient Operations, Horizontal Motion

In summary, in normal operations with the inner boom extended, operating at fast speed and with no water flowing from the tip turret, overshoot of about 2 ft was observed in up-and-down operation and about 5 ft in side-to-side operation. With water flowing from the tip turret oriented 90° to the boom in side-to-side operation, overshoot dropped to about 3 1/2 ft. For normal operations with the inner boom retracted, operating at fast speed and with no water flowing from the tip turret, overshoot of about 1/2 ft was observed in up-and-down operation and about 1 1/2 ft in side-to-side operation. With water flowing from the tip turret oriented 90° to the boom in side-to-side operation with the inner boom retracted, overshoot decreased to about 1/2 ft. For all operations in slow speed, overshoot was 1 ft or less with the inner boom retracted or extended, water off or water on, and in up-down or side-to-side operations. The worst situation observed occurred when the joystick was rapidly bumped to fast speed (full travel) and immediately released, for which an overshoot of about 15 ft was observed when water was not flowing from the tip turret.

It must be noted, however, that in spite of the fact that overshoots of 5 and 15 ft seem large and potentially dangerous, an experienced operator can reposition the boom very quickly while avoiding extreme overshoot by skilled use of the proportional control joystick. With just a few hours of training and practice, fire fighters at the Air Force Research Laboratory (AFRL) Fire Research Facility were able to deploy the HRET from the stowed position and penetrate a 2- by 2-ft target on the full-scale A380 mockup in about a minute without hitting any part of the HRET against the aircraft.

3.2.6 The HRET Live Fire Evaluations.

The purpose of live fire evaluations was to learn how the base and tip turrets on the 65-ft HRET might best be used in fighting flammable liquid pool fires, like those that commonly occur in survivable aircraft ground accidents, and to quantify the performance of each. To accomplish this goal, live JP-8 pool fire evaluations were conducted using the HRET base turret and tip turret. For all fires, the measures of effectiveness were the elapsed times from the start of applying agent until the fire was controlled (defined as 95% extinguished by area) and 100% extinguished. The data for all live fire evaluations are shown in appendix D.

The live fire assessments were performed on a mockup section of an A380 aircraft built to full scale in a 100-ft-diameter pool. Photographs of the mockup are shown in figures 48 through 51. The directional orientation of the mockup is shown in figure 52. The mockup consisted of a 60-ft-long section of fuselage, the leading-edge section of a wing, an engine nacelle, and three slides that were attached to the fuselage to simulate interference to firefighting. The underbelly of the fuselage was about 9 ft above the surface of the pool. The pool was partially filled with water and then JP-8 was floated on the surface of the water to create a flammable liquid surface of approximately 7000 ft^2.

The base turret was a Hydro-Chem™ Ranger 1.0 model turret. The tip turret was a Unifire model Force 50. Williams PKW™, an AFFF-compatible dry chemical, was used in combination with Chemguard 3% Mil Spec AFFF in all live fire tests.

Figure 48. Front View of Mockup, Facing Southwest

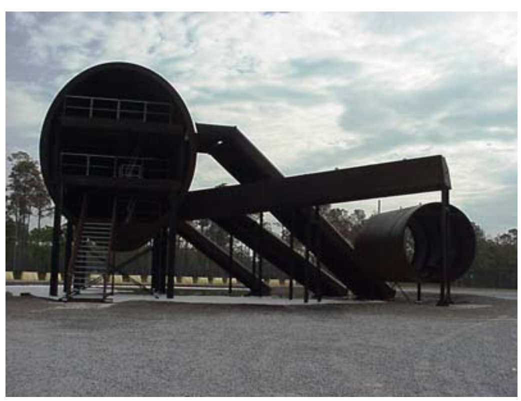


Figure 49. Back View of Mockup, Facing Northeast

Figure 50. View of Right Side, Facing Northwest

Figure 51. View of Left Side, Facing Southeast

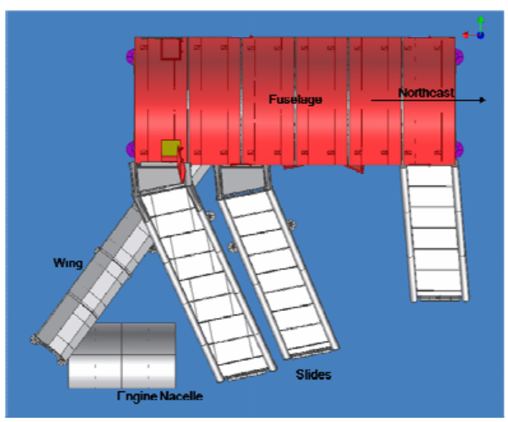


Figure 52. Mockup Orientation

Up to 1000 gallons of JP-8 was used to create each 7000 ft^2 test fire. The test fires were only conducted when sustained wind speed was below 10 mph. When sustained wind speeds were 5 mph or greater, moveable weirs were used to ensure the fire covered at least 90% of the pool area. Once the fuel was distributed over the test area, the fires were lit by a fire fighter using a propane brush igniter around the perimeter of the pool. After the fire was fully involved over at least 90% of the pool area and the fire fighters had left the vicinity of the fire, a preburn time of 10 ±1 sec elapsed before extinguishment commenced.

Before the live fire tests began, all FAA Striker operators were trained and were required to practice approaching and fighting a simulated fire using just water. Operators were also allowed some practice fires to become accustomed to using the vehicle in an actual fire environment. For each combination of agent, apparatus, and flow rate, a minimum of five test fires were done, and the elapsed times from the start of applying agent until the fires were controlled and extinguished were measured and recorded. If the five data points for extinguishment time fell within two standard deviations of their average times and their quotients of standard deviation divided by the average (called the coefficient of variation) were within ±20%, then the tests for that particular combination were considered complete. This method of data selection was used as a way to capture data only after the fire fighters had achieved proficiency at operating the equipment and fighting the fires, which would be reflected in the consistency of the data over successive trials. If after five tests, the data did not meet both criteria, up to three additional tests were done in an attempt to achieve five consecutive data points that met both criteria. Table 5 summarizes the live fire test combinations.

Table 5. Turret, Flow Rate, and Agent Combinations

Apparatus/Flow Rate	Foam	Foam + Dry Chemical
Base turret		
High flow	1000 gpm	1000 gpm + 20 pps
Low flow	500 gpm	500 gpm + 20 pps
Tip turret		
Low flow	500 gpm	Not applicable

The approach for the fires extinguished using the base and the tip turrets were from the east, on a line of approach toward the front starboard quarter of the mockup. Figure 53 shows the mockup from this line of approach. From this direction, the slides and engine nacelle presented challenging impediments to targeting the agent onto the fire. For the base turret fire tests, after the fire fighter had extinguished all the fire that could be reached from the direction of the initial approach (figure 54), he was instructed to maneuver the truck and manipulate the base turret as necessary to aggressively extinguish the fires as quickly as possible behind obstacles. In those cases when 100% of the fire was not extinguished on the initial approach, the fire fighter drove the truck counter-clockwise (looking down from above) around the edge of the pool while rotating and elevating the turret as necessary to reach the remnants of the fires (figure 55). For the base turret live fires, the HRET was in the extended position, as shown in figures 54 and 55.

Figure 53. Approach for Base and Tip Turret Live Fires

Figure 54. Base Turret Initial Approach

Figure 55. Base Turret Follow-Up Attack

For the tip turret fire tests, the approach to the fire was the same as the base turret fires, but the fire fighter was not permitted to maneuver the truck around the perimeter of the pool fire. Instead, the fire was approached with the HRET in the extended position and with the extendable boom partially extended so that the tip turret was 2 to 3 feet above the ground (figure 56). The fire fighter was permitted to use only the tip turret during the approach and attack of the fire. After the fire fighter had extinguished all the fire that could be reached from the direction of the initial approach with the extendable boom only partially extended, he was instructed to fully extend the boom to place the tip turret between the two forward-most slides and rotate and elevate the tip turret as necessary to aggressively extinguish the fires behind the obstacles as quickly as possible (figure 57).

Figure 56. Tip Turret Initial Attack

Figure 57. Tip Turret Follow-Up Attack

A consequence of the HRET design is that changing from tip turret operation to base turret operation and vice versa cannot be accomplished with a simple flip of a switch. Due to clash points and operational angles, the operator has to perform a time-consuming series of steps to switch from tip turret firefighting operation to base turret operation. For example, when the HRET is in a low-attack position, the angle of the upper boom section will prevent the base turret from being raised to a horizontal position. To accomplish this, the entire upper boom section must be elevated to raise the discharge angle of the base turret. Figure 1 shows how the inner boom, if extended, prevents the base nozzle from having full range of motion. To switch from the tip turret to the base turret and maintain a lower-attack position, an operator would have to shut down the tip turret, select the base turret, retract the inner boom, wait for the tip turret to move to its bedded position, raise the upper arm of the HRET then discharge from the base turret. Figures 54 through 57 clearly identify the change in the angle of attack of the HRET necessary when using the tip and base turrets.

The data are summarized graphically in figure 58 for 95% extinguishment times and in figure 59 for 100% extinguishment times, which show the average extinguishment times (✻) and the range of times for each method. Detailed data are given in appendix D. Figures 60 and 61 show the average 95% and 100% extinguishment times and the 95% confidence intervals for each method. A confidence interval is a statistical range that depends on the number of data points (extinguishment times) and the variation in the data points. More data grouped more closely together yields a smaller confidence interval. For example, figure 58 shows five closely spaced data points for the base turret, low-flow AFFF and five data points spaced more widely for the base turret, high-flow AFFF. Correspondingly, figure 60 shows that the 95% confidence interval for the base turret, low-flow AFFF is 24 sec compared to 34 sec for the base turret, high-flow AFFF. In 95 of 100 test fires, extinguishment times would be expected to fall within these 95% confidence time intervals.

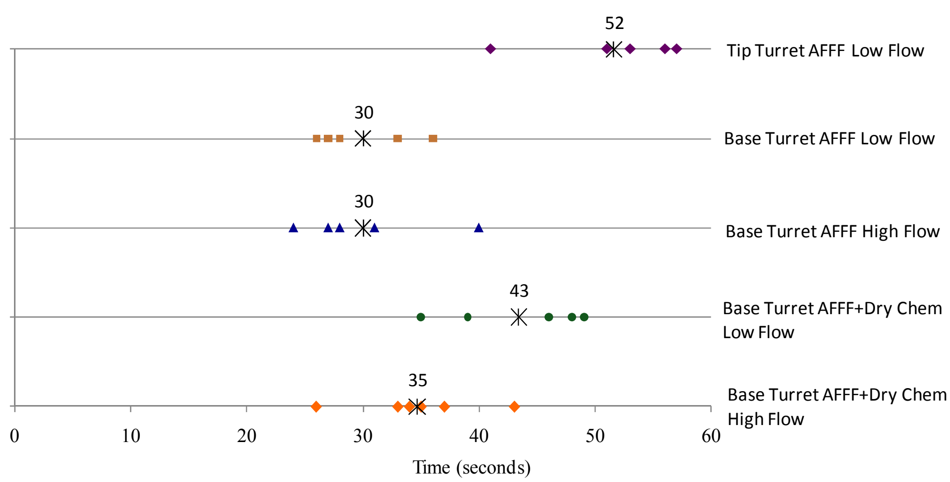


Figure 58. The 95% Extinguishment Times—Averages and Ranges

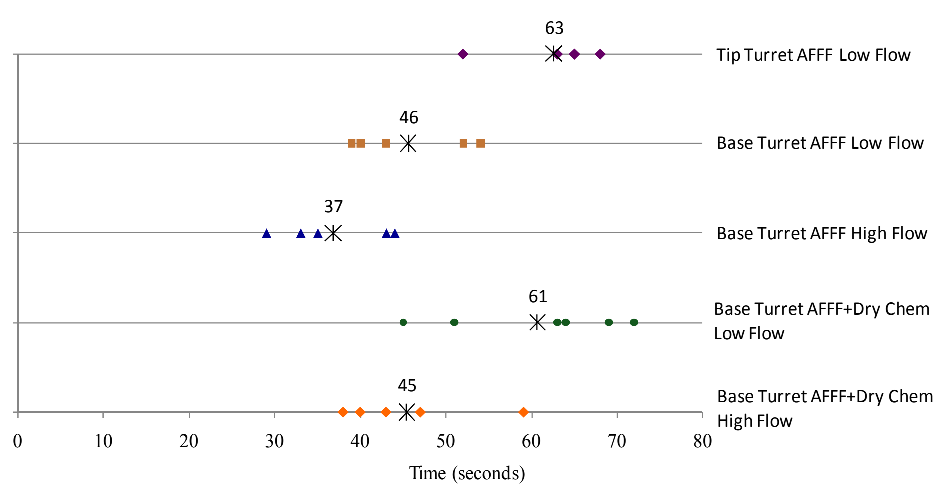


Figure 59. The 100% Extinguishment Times—Averages and Ranges

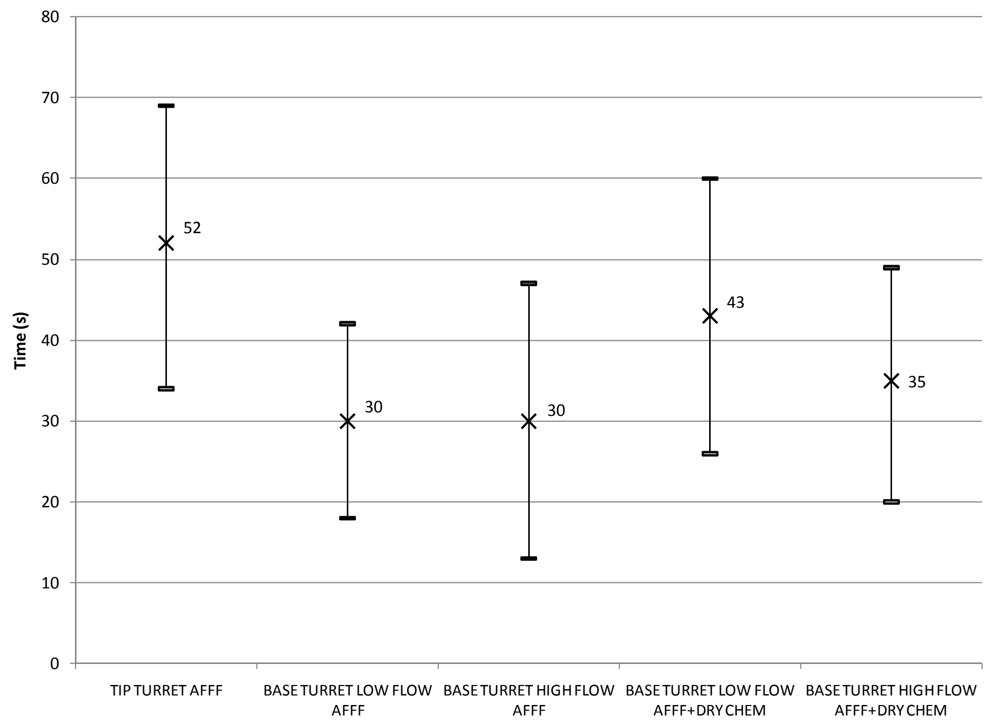


Figure 60. The 95% Extinguishment Times—Average and 95% Confidence Interval

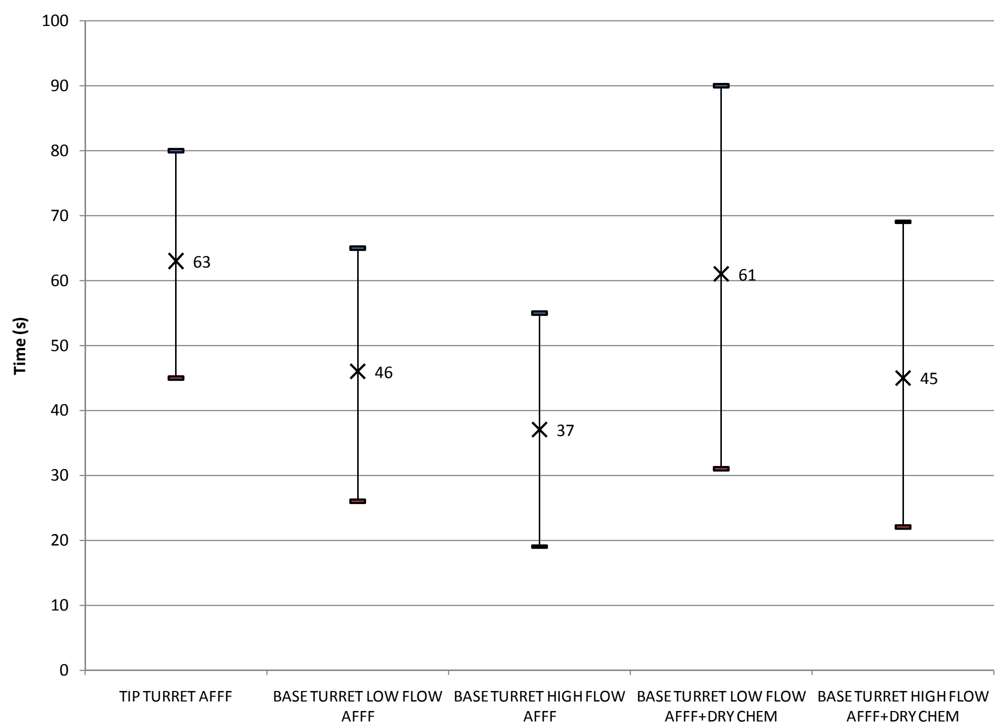


Figure 61. The 100% Extinguishment Times—Average and 95% Confidence Interval

The data indicated that the base turret was superior to the tip turret for fighting pool fires with obstructions; fires were controlled and extinguished faster when the base turret was used and the vehicle was maneuvered around obstacles than when the HRET was fully extended to position the tip turret between obstacles while the vehicle remained in place. The data also showed that an agent applied at 1000 gpm controlled and extinguished fires more quickly than an agent applied at 500 gpm. This was observed in the data for both AFFF and AFFF used in combination with dry chemicals.

The base turret flowing AFFF at the high-flow setting of 1000 gpm was the quickest method to extinguish pool fires, and even at the low-flow rate of 500 gpm, fires were extinguished faster using a combination of maneuvering the vehicle and repositioning the base turret than using the tip turret alone without maneuvering the vehicle. It is not a surprising result that fires were extinguished faster at 1000 gpm than at 500 gpm; however, considering the drawbacks of having both a base and a tip turret, the findings of this research justify removal of the base turret from the HRET and replacing the tip nozzle with a selectable 500/1000-gpm flow rate nozzle.

The vehicle, as-tested, was also equipped with a 500/1000-gpm bumper turret, and it is likely that the bumper turret would have been as effective on pool fires as the base turret; therefore, the overall firefighting capability of the vehicle was probably not improved by adding the base turret. However, for the water capacity on this vehicle, the NFPA 414 requirement for individual flow rate of an extendable turret used in combination with a bumper turret is ≥1000 gpm, and the vehicle, as-tested, would not have met the NFPA requirement without the 1000-gpm base turret. But, the addition of a base turret comes at the cost of additional piping for firefighting water and for hydraulics, and additional electrical power and control wiring. This adds weight and increases the opportunity for failures in cabling, instrumentation, and mechanical components. With a second turret, there is also an increase in complexity for the operator in selecting and directing a nozzle for firefighting operations while having to anticipate potential interference posed by the boom structure, as well as the delay in fire attack and potential for mistakes in executing the series of steps necessary to switch from one turret to the other. With the HRET retracted, the tip turret could perform the same function as the base turret. With the HRET extended, the tip turret is able to reach engine nacelles and passenger decks on large aircraft that the base turret or a shorter HRET cannot reach, and the tip turret is able to direct water onto fire behind obstacles in a debris field that a bumper or base turret might not be able to reach without repositioning the vehicle. Removing the base turret and replacing the tip turret with a higher flow rate nozzle would combine the advantages of the dexterity and reach of the extendable turret with increased flow rate, while meeting the NFPA 414 requirements for individual flow from an extendable turret.

Doubling the flow rate at the tip with the 65-ft HRET fully extended would impose more mechanical stress on the HRET and on the vehicle; however, restricting operation to 500 gpm when the inner boom was not in the fully retracted position would put no additional stress on the HRET or vehicle than in its current configuration. The 65-ft HRET with a single selectable 500/1000-gpm tip turret could provide the same firefighting capability as the current design of separate tip and base turrets, but with less complexity and more reliability.

3.3 MAINTENANCE AND REPAIR ISSUES FOR HRET.

3.3.1 Hydraulic Gearbox Failures.

Boom oscillation tests began in November 2007. No more than 20 preliminary boom oscillations were performed to verify instrumentation and data acquisition equipment, followed by 38 actual tests. In December 2007, after the 38th test, it was noted that when the boom was rotated at fast speed while in maximum extension, rotation continued until the boom reached the mechanical stops even when the joystick was released. Because of the problem with the boom, the 38 oscillation tests were judged invalid. In February 2008, the HRET was overhauled by Crash Rescue at their facility in Dallas, TX, and the hydraulic gearbox for the boom was included in the overhaul.

Between May 2008 and July 2009, 42 live fire tests (plus practice) involving the HRET were performed, and 36 boom deployment tests (plus practice) were performed before oscillation tests were started again. When oscillation tests resumed in July 2009, the HRET showed the same symptoms of gearbox failure as it did in December 2007; once rotation was started at fast speed in a direction, the boom did not stop rotating when the joystick was released, and rotation continued until the boom reached the mechanical stop. The hydraulic gearbox was replaced again in September 2009, and the boom operated normally through 129 side-to-side rotation oscillation tests before it began to again exhibit the symptoms of gearbox failure. The hydraulic gearbox was replaced a third time in October 2009, and the remaining 15 oscillation tests were completed.

3.3.2 Loss of Remote Control of Base and Tip Turrets.

Starting in September 2007, the base and tip turrets on the HRET occasionally would not respond to commands from the joystick. Sometimes, this was accompanied by a red flashing light on the tip selector button at the console. The turrets would not rotate through their full ranges of motion, or they would not respond at all. The fire fighters discovered that turning off the vehicle and restarting it restored full control. Crash Rescue made some modifications to the joystick hardware and did some software upgrades to the control system in October 2007, which reduced the frequency of turret control problems. Crash Rescue also recommended doing a recalibration of the turrets whenever the problem recurred. Subsequent to October 2007, when the turrets would not respond to joystick commands, fire fighters found that the recalibration procedure did not always correct the problem, and so they reverted to turning the vehicle off and on to restore control. In January 2009, in conversation with Crash Rescue, research personnel realized that they were not performing the recalibration procedure correctly. When the recalibration procedure was done correctly, the turrets worked correctly through the final 10 months of tests, including many live fires and practice sessions that required repeated operation of the base and tip turrets. Shutting down and restarting the vehicle however is not an option when a vehicle is in operation at an aircraft emergency.

3.3.3 Nonresponsive Upper and Lower Booms.

In September 2007, it was observed that the upper and lower booms would occasionally stop responding to joystick control, or that only the lower boom would stop responding in the vertical (up and down) direction while control of boom rotation was unaffected. In some cases, the boom would not properly respond to signals from the joystick for as long as 30 minutes. Cycling the vehicle's engine, sometimes repeatedly, was found to re-establish communications with the upper portion of the boom, and attempting to maneuver the boom side-to-side, typically multiple times, re-established communications with the lower boom. Once again, shutting down and restarting the vehicle is not an acceptable solution to this fault. This problem was not observed again after the boom was overhauled by Crash Rescue in March 2008.

3.3.4 Bedding and Alignment Problems.

On three occasions between December 2007 and July 2009, the boom developed problems aligning and bedding. When using the auto-bed function, the boom would not self-align to correctly bed over the boom anchor on the roof of the vehicle. This was caused by a failed or misaligned potentiometer in the boom control system. The potentiometer is driven by the gear at the base of the boom, which is used to rotate the boom. The potentiometer sends a signal to the control system that tells the system the rotational position of the boom, and then the position information is used by the control system to correctly align and bed the boom. If the potentiometer fails or gets out of proper alignment relative to the boom drive gear, then erroneous position information is sent to the control system and the system is incapable of properly bedding the boom. The potentiometer was realigned twice and replaced once (July 2009) between December 2007 and July 2009.

4. CONCLUSIONS.

The purpose of this research was to document the performance characteristics of the Federal Aviation Administration (FAA) Striker Aircraft Rescue and Firefighting (ARFF) vehicle and the 65-ft, high-reach extendable turret (HRET) waterway system. The performance parameters of the FAA Striker vehicle and the HRET follow.

- The FAA Striker passed acceleration tests in both its baseline configuration (no HRET) and with the HRET installed.

- Vehicle weight, with and without the HRET, met the maximum allowable weight criteria; however, in both configurations, the FAA Striker failed to meet the criteria for weight distribution on individual axles.

- The FAA Striker exceeded the specification for minimum top speed, both with and without the HRET installed.

- Requirements for side-slope stability were met in the baseline configuration and with the HRET installed.

- The vehicle met the maximum stopping distance specifications, both with and without the HRET installed.

- The FAA Striker failed to pass the body and chassis flexibility test in either configuration.

- The criteria for dynamic turning control were met, both with and without the HRET installed.

- The FAA Striker, with and without the HRET, exceeded the minimum specification for the North Atlantic Treaty Organization (NATO) double-lane change test.

- In straight stream, the bumper turret on the vehicle exceeded the minimum throw distance requirement by 45 ft. Only one test was done in a straight stream, and no tests were done in a dispersed stream pattern.

- The electronic foam proportioning system met the foam proportioning requirements of National Fire Protection Association (NFPA) 412 over the 16 months that it was evaluated. In addition to 3% and 6% foam concentrations, the system accurately proportioned foam at 1% and 9% foam concentration for the 1000-gpm bumper turret, and at 9% for the 125-gpm hand line. The system did not proportion accurately at 1% concentration for the 125-gpm hand line; however, there is no specification in NFPA 412 for 1% concentration, and 1% foam concentration at 125-gpm flow rate is far below the designed system capabilities stated by the manufacturer.

- The standoff distances for the HRET were 30 ft 1 in. at full ground extension (low attack), 38 ft 8 in. at maximum extension (mid-attack), and 26 ft 7 in. at full-up extension (high attack).

- The average deployment times for the HRET, from the fully bedded position to completion of penetration were 80 sec for the cargo deck, 54 sec for the lower passenger deck, and 62 sec for the upper passenger deck of a full-scale mockup of a section of an Airbus A380 aircraft. The average deployment time from the fully bedded position to full-up extension was 54 sec.

- Operating the HRET with the inner boom extended, at fast speed, and with no water flowing from the tip turret, overshoot averaged 2 ft in up-and-down operation and about 5 ft in side-to-side operation. With water flowing from the tip turret oriented 90° to the boom in side-to-side operation, overshoot averaged 3 1/2 ft.

- Operating with the inner boom retracted, at fast speed, and with no water flowing from the tip turret, overshoot averaged 1/2 ft in up-and-down operation and 1 1/2 ft in side-to-side operation. With water flowing from the tip turret oriented 90° to the boom in side-to-side operation, overshoot averaged 1/2 ft.

- Operating in slow speed, overshoot was 1 ft or less with the inner boom retracted or extended, with water on or off, for up-down or side-to-side operations. With water flowing from the tip turret oriented 90° to the boom in side-to-side operation with the inner boom retracted, overshoot decreased to about 1/2 ft.

- The maximum boom overshoot occurred when the joystick was rapidly bumped to fast speed (full travel) and immediately released, for which an overshoot of about 15 ft was observed when water was not flowing from the tip turret.

- An experienced operator can reposition the boom very quickly while avoiding extreme overshoot by skilled use of the proportional control joystick.

- 7000 ft^2 JP-8 pool fires were controlled and extinguished faster when the base turret was operated at 1000 gpm than when it was operated at 500 gpm.

- 7000 ft^2 JP-8 pool fires were controlled and extinguished faster using the base turret operating at 500 gpm than using the HRET tip turret (at 500 gpm).

- The Snozzle® HRET was reliable and required few repairs throughout the course of the testing, which included hundreds of operations during deployment, live fire, and boom oscillation tests. The only component of that failed repeatedly was the hydraulic gearbox. One of the failed gearboxes was returned to Crash Rescue for further inspection.

- The findings of this research support the removal of the base turret from the design and increasing the flow rate of the tip nozzle to a selectable low/high flow rate of 500 and 1000 gpm, respectively.

5. REFERENCES.

1. FAA Advisory Circular (AC) 150/5220-10C, "Guide Specification for Water/Foam Aircraft Rescue and Firefighting Vehicles."

2. NFPA Code 414, "Standard for Aircraft Rescue and Fire-Fighting Vehicles," 2001 edition.

3. NATO Document, "Dynamic Stability Report—Allied Vehicle Testing Publication (AVTP)," 03-160W.

4. NFPA Code 412, Standard for Evaluating Aircraft Rescue and Fire-Fighting Foam Equipment, 2003 edition.

5. Snozzle® Model 652 Operations Manual, Crash Rescue Service, Inc., http://www.crashrescue.com/imageuploads/Media-536.pdf (last visited May 24, 2011).

APPENDIX A—FOAM SOLUTION CONCENTRATION, EXPANSION, AND DRAINAGE TIME DATA

In the following percent foam concentration data tables, the data shaded in light gray corresponds to combinations of water flow rates (125 gpm) and selected foam concentrations (1%, 3%, and 6%), which fall below the manufacturer's recommended range of operation (refer to section 3.1.10 for a detailed explanation).

Table A-1. Foam Concentration Check Results

Sample Point	% Foam Concentrate Selected at Electronic Control Unit	NFPA Allowable Limits	Measured % Foam Concentrate in Solution by Refraction (ref) and Conductivity (cond)							
			2/2008		6/2008		9/2008		10/2008	
			ref	cond	ref	cond	ref	cond	ref	cond
Hand line (125 gpm)	1	0.9-1.3[1]			1.5	1.5				
	3	2.8-4.0			3.8	3.8				
	6	5.5-8.0			5.5	6.3				
	9	8.3-12[1]			9.7	10.2				
Base turret (1000 gpm)	1	0.9-1.2[1]			1.0	1.1			1.0	1.2
	3	2.8-3.5	3.2		3.1	2.9	3.0		3.0	3.1
	6	5.5-7.0			6.2	6.3			5.9	6.5
	9	8.3-11[1]			9.5	9.5			8.9	9.4
			12/2008		3/2009		5/2009			
Hand Line (125 gpm)	1	0.9-1.3[1]	2.0	2.1			0.6	0.7		
	3	2.8-4.0	4.2[3]	3.9			2.9	3.3		
	6	5.5-8.0	6.2	6.2			7.7	8.1[3]		
	9	8.3-12[1]	8.9	9.0			10.3	10.8		
Base Turret (1000 gpm)	1	0.9-1.2[1]					1.1	[2]		
	3	2.8-3.5			2.8	3.1	3.2	[2]		
	6	5.5-7.0					6.2	[2]		
	9	8.3-11[1]					8.6	[2]		

[1] There are no National Fire Protection Association (NFPA) specifications for 1% and 9% mixtures; however, if the NFPA limits for 3% and 6% are extrapolated to 1% and 9%, foam concentration should fall within the range given.
[2] It was discovered after completing the tests that the conductivity instrument had been used incorrectly, causing erroneous out-of-specification values. Results by refractometer were consistent with past tests, and the cause of the out-of-specification values was known, so the decision was made to not repeat the tests.
[3] Out of specification data.

Table A-2. Foam Expansion Ratio Results

Sample Point	% Foam Concentrate Selected at Electronic Control Unit	NFPA Minimum Allowable Expansion Ratio	Measured Expansion Ratio				
			6/2008	10/2008	12/2008	3/2009	5/2009
Hand line (125 gpm)	1	*	2.1:1		2.3:1		1.8:1
	3	≥ 3:1	5.9:1		3.1:1		3.2:1
	6	≥ 3:1	8.1:1		5.1:1		4.8:1
	9	[1]	13:1		8.0:1		5.4:1
Base turret (1000 gpm)	1	[1]	2.2:1	3.7:1			2.4:1
	3	≥ 3:1	3.2:1	5.3:1		7.0:1	6.9:1
	6	≥ 3:1	8.5:1	20:1			15:1
	9	*	13:1	25:1			17:1

*There are no NFPA specifications for 1% and 9% mixtures.

Table A-3. Foam 25% Drain Time Results

Sample Point	% Foam Concentrate Selected at Electronic Control Unit	NFPA Minimum Allowable Drainage Time (m)	Measured Drainage Time (m)					
			12/2007	6/2008	10/2008	12/2008	3/2009	5/2009
Hand line (125 gpm)	1	[1]						
	3	≥1		1		1.4		0.4[2]
	6	≥1		1.3		3.5		0.8[2]
	9	[1]		2.3		2.3		0.9
Base turret (1000 gpm)	1	[1]						
	3	≥1	1.1	0.4[2]	1.1		3.1	1.0
	6	≥1		1.8	1.2			2.2
	9	[1]		1.6	2.5			3.2

[1]There are no NFPA specifications for 1% and 9% mixtures.
[2]Out of specification data.
.

APPENDIX B—TIMED DEPLOYMENT DATA FOR HIGH-REACH EXTENDABLE TURRET

Table B-1. Timed Deployment Test Results

Test Order	Date of Test	Penetration Location	Fire Fighter	Time (sec)
17	8/5/2008	Level 1	A	118
28	8/5/2008	Level 1	A	84
34	8/5/2008	Level 1	A	54
3	8/5/2008	Level 1	B	70
11	8/5/2008	Level 1	B	49
35	8/5/2008	Level 1	B	81
7	8/5/2008	Level 1	C	113
10	8/5/2008	Level 1	C	72
16	8/5/2008	Level 1	C	78
5	8/5/2008	Level 2	A	70
18	8/5/2008	Level 2	A	49
26	8/5/2008	Level 2	A	42
8	8/5/2008	Level 2	B	48
23	8/5/2008	Level 2	B	53
30	8/5/2008	Level 2	B	62
6	8/5/2008	Level 2	C	58
9	8/5/2008	Level 2	C	58
25	8/5/2008	Level 2	C	44
22	8/5/2008	Level 3	A	71
24	8/5/2008	Level 3	A	58
33	8/5/2008	Level 3	A	46
13	8/5/2008	Level 3	B	65
31	8/5/2008	Level 3	B	65
36	8/5/2008	Level 3	B	68
4	8/5/2008	Level 3	C	66
14	8/5/2008	Level 3	C	54
29	8/5/2008	Level 3	C	64
12	8/5/2008	Full-up extension	A	57
19	8/5/2008	Full-up extension	A	55
20	8/5/2008	Full-up extension	A	54
2	8/5/2008	Full-up extension	B	57
27	8/5/2008	Full-up extension	B	46
32	8/5/2008	Full-up extension	B	46
1	8/5/2008	Full-up extension	C	56
15	8/5/2008	Full-up extension	C	62
21	8/5/2008	Full-up extension	C	54

Table B-2. Level 1 Timed Deployment Data

Test Order	Test Date	Penetration Location	Fire Fighter	Time (sec)		Time (sec)
17	8/5/08	Level 1	A	118	Mean	85
28	8/5/08	Level 1	A	84	Sample standard deviation	32
34	8/5/08	Level 1	A	54	95% confidence interval	±138
3	8/5/08	Level 1	B	70	Mean	67
11	8/5/08	Level 1	B	49	Sample standard deviation	16
35	8/5/08	Level 1	B	81	95% confidence interval	±70
7	8/5/08	Level 1	C	113	Mean	88
10	8/5/08	Level 1	C	72	Sample standard deviation	22
16	8/5/08	Level 1	C	78	95% confidence interval	±96
			Mean	80		
			Sample standard deviation	23		
			95% confidence interval	±54		

Table B-3. Level 2 Timed Deployment Data

Test Order	Test Date	Penetration Location	Fire Fighter	Time (sec)		Time (sec)
5	8/5/08	Level 2	A	70	Mean	54
18	8/5/08	Level 2	A	49	Sample standard deviation	15
26	8/5/08	Level 2	A	42	95% confidence interval	±63
8	8/5/08	Level 2	B	48	Mean	54
23	8/5/08	Level 2	B	53	Sample standard deviation	7
30	8/5/08	Level 2	B	62	95% confidence interval	±31
6	8/5/08	Level 2	C	58	Mean	53
9	8/5/08	Level 2	C	58	Sample standard deviation	8
25	8/5/08	Level 2	C	44	95% confidence interval	±35
			Mean	54		
			Sample standard deviation	9		
			95% confidence interval	±21		

Table B-4. Level 3 Timed Deployment Data

Test Order	Test Date	Penetration Location	Fire Fighter	Time (sec)		Time (sec)
22	8/5/08	Level 3	A	71	Mean	58
24	8/5/08	Level 3	A	58	Sample standard deviation	13
33	8/5/08	Level 3	A	46	95% confidence interval	±54
13	8/5/08	Level 3	B	65	Mean	66
31	8/5/08	Level 3	B	65	Sample standard deviation	2
36	8/5/08	Level 3	B	68	95% confidence interval	±7
4	8/5/08	Level 3	C	66	Mean	61
14	8/5/08	Level 3	C	54	Sample standard deviation	6
29	8/5/08	Level 3	C	64	95% confidence interval	±28
				Mean	62	
				Sample standard deviation	8	
				95% confidence interval	±18	

Table B-5. Full-Up Extension Timed Deployment Data

Test Order	Test Date	Penetration Location	Fire Fighter	Time (sec)		Time (sec)
12	8/5/08	Full Up	A	57	Mean	55
19	8/5/08	Full Up	A	55	Sample standard deviation	2
20	8/5/08	Full Up	A	54	95% confidence interval	±7
2	8/5/08	Full Up	B	57	Mean	50
27	8/5/08	Full Up	B	46	Sample standard deviation	6
32	8/5/08	Full Up	B	46	95% confidence interval	±28
1	8/5/08	Full Up	C	56	Mean	57
15	8/5/08	Full Up	C	62	Sample standard deviation	4
21	8/5/08	Full Up	C	54	95% confidence interval	±18
				Mean	54	
				Sample standard deviation	5	
				95% confidence interval	±12	

APPENDIX C—OSCILLATION DATA FOR HIGH-REACH EXTENDABLE TURRET

Table C-1. Data for Vertical Rotation (Up-Down) Boom Oscillation

Boom Elevation	Boom Extension	Movement	Speed	Amplitude (ft)	Duration (sec)	Average Speed (ft/sec)	Total Oscillation Time (sec)
Center	Retract	Up to center	Fast	0.43	1.06	0.40	8.93
Center	Retract	Up to center	Fast	0.40	1.04	0.38	12.43
Center	Retract	Up to center	Fast	0.38	1.05	0.36	8.92
Center	Retract	Up to center	Slow	0.16	0.44	0.35	8.05
Center	Retract	Up to center	Slow	0.11	0.35	0.32	6.84
Center	Retract	Up to center	Slow	0.11	0.35	0.32	7.95
Center	Retract	Down to center	Fast	0.35	1.01	0.35	10.46
Center	Retract	Down to center	Fast	0.40	1.05	0.38	8.74
Center	Retract	Down to center	Fast	0.37	1.04	0.36	11.43
Center	Retract	Down to center	Slow	0.09	0.26	0.34	7.05
Center	Retract	Down to center	Slow	0.07	0.20	0.33	5.77
Center	Retract	Down to center	Slow	0.07	0.19	0.34	7.06
Center	Extended	Up to center	Fast	1.75	2.65	0.66	21.97
Center	Extended	Up to center	Fast	1.48	2.00	0.74	18.56
Center	Extended	Up to center	Fast	1.57	2.21	0.71	21.07
Center	Extended	Up to center	Slow	1.77	2.69	0.66	22.73
Center	Extended	Up to center	Slow		Poor camera footage		22.57
Center	Extended	Up to center	Slow	0.18	0.29	0.61	21.27
Center	Extended	Up to center	Slow	0.89	1.33	0.67	19.66
Center	Extended	Down to center	Fast	1.60	2.39	0.67	25.96
Center	Extended	Down to center	Fast	1.73	2.41	0.72	25.68
Center	Extended	Down to center	Fast	1.63	2.32	0.70	25.95
Center	Extended	Down to center	Slow	0.28	0.44	0.65	21.74
Center	Extended	Down to center	Slow	0.25	0.36	0.70	25.24
Center	Extended	Down to center	Slow	0.11	0.18	0.60	18.64
Center	Extended	Up to center	Sudden jerk	2.46	3.73	0.66	19.75
Center	Extended	Up to center	Sudden jerk	0.67	0.97	0.69	16.09

Table C- 2. Data for Horizontal Rotation (Left-Right) Boom Oscillation

Boom Elevation	Boom Extension	Movement	Speed	Discharge	Trial	Amplitude A (ft)	Amplitude B (ft)	Duration (sec)	Average Speed (ft/sec)	Total Oscillation Time (sec)
High attack	Retract	Right to center	Fast	Without	1	0.79	0.57	1.64	0.83	10.41
High attack	Retract	Right to center	Fast	Without	2	0.62	0.23	1.86	0.46	13.06
High attack	Retract	Right to center	Fast	Without	3	0.72	0.51	1.71	0.72	14.69
High attack	Retract	Right to center	Fast	With	1	0.40	0.35	1.29	0.58	30.06
High attack	Retract	Right to center	Fast	With	2	0.33	0.36	1.23	0.55	29.09
High attack	Retract	Right to center	Fast	With	3	0.50	0.39	1.26	0.70	30.41
High attack	Retract	Right to center	Slow	Without	1	0.11	0.04	1.38	0.11	13.15
High attack	Retract	Right to center	Slow	Without	2	0.13	0.03	1.17	0.14	12.84
High attack	Retract	Right to center	Slow	Without	3	0.15	0.03	1.67	0.10	13.88
High attack	Retract	Right to center	Slow	With	1	0.03	0.04	1.31	0.06	13.16
High attack	Retract	Right to center	Slow	With	2	0.04	0.05	1.23	0.08	14.34
High attack	Retract	Right to center	Slow	With	3	0.01	0.06	0.94	0.07	12.00
High attack	Retract	Left to center	Fast	Without	1	0.37	0.13	1.86	0.27	19.04
High attack	Retract	Left to center	Fast	Without	2	0.69	0.35	1.65	0.63	20.88
High attack	Retract	Left to center	Fast	Without	3	0.36	0.17	1.76	0.30	13.62
High attack	Retract	Left to center	Fast	With	1	0.41	0.31	1.32	0.54	30.56
High attack	Retract	Left to center	Fast	With	2	0.50	0.38	1.25	0.70	36.15
High attack	Retract	Left to center	Fast	With	3	0.46	0.45	1.23	0.73	37.03
High attack	Retract	Left to center	Slow	Without	1	0.11	0.04	1.45	0.10	16.97
High attack	Retract	Left to center	Slow	Without	2	0.12	0.07	1.32	0.14	18.78
High attack	Retract	Left to center	Slow	Without	3	1.07	0.12	1.64	0.73	17.09
High attack	Retract	Left to center	Slow	With	1	0.04	0.08	1.14	0.11	15.16
High attack	Retract	Left to center	Slow	With	2	0.04	0.08	1.03	0.12	15.69
High attack	Retract	Left to center	Slow	With	3	0.02	0.10	1.03	0.11	15.28
High attack	Extend	Right to center	Fast	Without	1	3.70	2.16	2.12	2.76	20.97

Table C- 2. Data for Horizontal Rotation (Left-Right) Boom Oscillation (Continued)

Boom Elevation	Boom Extension	Movement	Speed	Discharge	Trial	Amplitude A (ft)	Amplitude B (ft)	Duration (sec)	Average Speed (ft/sec)	Total Oscillation Time (sec)
High attack	Extend	Right to center	Fast	Without	2	3.87	2.23	2.01	3.03	22.25
High attack	Extend	Right to center	Fast	Without	3	3.82	2.23	2.09	2.90	24.65
High attack	Extend	Right to center	Fast	With	1	2.46	1.75	1.87	2.25	43.47
High attack	Extend	Right to center	Fast	With	2	2.32	1.57	1.98	1.96	47.87
High attack	Extend	Right to center	Fast	With	3	2.22	1.55	1.87	2.01	35.35
High attack	Extend	Right to center	Slow	Without	1	0.23	0.15	2.03	0.19	17.75
High attack	Extend	Right to center	Slow	Without	2	0.12	0.15	1.86	0.14	14.10
High attack	Extend	Right to center	Slow	Without	3	0.24	0.17	2.18	0.19	14.57
High attack	Extend	Right to center	Slow	With	1	0.09	0.26	1.41	0.25	22.25
High attack	Extend	Right to center	Slow	With	2	0.11	0.23	1.82	0.19	18.91
High attack	Extend	Right to center	Slow	With	3	0.14	0.17	1.78	0.18	19.78
High attack	Extend	Left to center	Fast	Without	1	2.98	3.26	1.99	3.14	24.69
High attack	Extend	Left to center	Fast	Without	2	3.10	3.09	2.11	2.94	21.94
High attack	Extend	Left to center	Fast	Without	3	3.30	3.26	2.06	3.19	18.94
High attack	Extend	Left to center	Fast	With	1	2.95	2.15	1.88	2.71	45.31
High attack	Extend	Left to center	Fast	With	2	3.79	2.85	1.87	3.55	56.21
High attack	Extend	Left to center	Fast	With	3	3.46	2.62	1.91	3.18	50.79
High attack	Extend	Left to center	Slow	Without	1	0.33	0.09	2.12	0.20	20.66
High attack	Extend	Left to center	Slow	Without	2	0.40	0.16	1.89	0.30	16.92
High attack	Extend	Left to center	Slow	Without	3	0.33	0.16	2.07	0.24	15.63
High attack	Extend	Left to center	Slow	With	1	0.40	0.25	1.77	0.37	43.66
High attack	Extend	Left to center	Slow	With	2	0.37	0.43	1.56	0.51	39.00
High attack	Extend	Left to center	Slow	With	3	0.26	0.29	1.70	0.32	30.50
Mid attack	Retract	Right to center	Fast	Without	1	1.31	0.26	1.59	0.99	10.03
Mid attack	Retract	Right to center	Fast	Without	2	1.20	0.35	1.44	1.08	10.32
Mid attack	Retract	Right to center	Fast	Without	3	1.21	0.34	1.37	1.13	10.65

Table C-2. Data for Horizontal Rotation (Left-Right) Boom Oscillation (Continued)

Boom Elevation	Boom Extension	Movement	Speed	Discharge	Trial	Amplitude A (ft)	Amplitude B (ft)	Duration (sec)	Average Speed (ft/sec)	Total Oscillation Time (sec)
Mid attack	Retract	Right to center	Fast	With	1	0.27	0.34	0.98	0.62	37.68
Mid attack	Retract	Right to center	Fast	With	2	1.08	0.78	1.16	1.61	45.41
Mid attack	Retract	Right to center	Fast	With	3	0.14	0.16	1.30	0.23	27.75
Mid attack	Retract	Right to center	Slow	Without	1	0.12	0.05	1.23	0.14	9.56
Mid attack	Retract	Right to center	Slow	Without	2	0.10	0.06	1.18	0.13	12.40
Mid attack	Retract	Right to center	Slow	Without	3	0.13	0.11	1.25	0.19	11.15
Mid attack	Retract	Right to center	Slow	With	1	0.08	0.12	1.08	0.19	23.16
Mid attack	Retract	Right to center	Slow	With	2	0.08	0.09	1.12	0.16	21.94
Mid attack	Retract	Right to center	Slow	With	3	0.13	0.07	1.05	0.19	25.16
Mid attack	Retract	Left to center	Fast	Without	1	0.88	0.95	1.47	1.25	12.19
Mid attack	Retract	Left to center	Fast	Without	2	1.11	1.22	1.55	1.50	13.50
Mid attack	Retract	Left to center	Fast	Without	3	2.06	1.02	1.47	2.09	17.84
Mid attack	Retract	Left to center	Fast	With	1	0.25	0.16	1.03	0.40	34.62
Mid attack	Retract	Left to center	Fast	With	2	0.34	0.33	0.91	0.74	38.40
Mid attack	Retract	Left to center	Fast	With	3	0.45	0.52	1.10	0.88	41.07
Mid attack	Retract	Left to center	Slow	Without	1	0.28	0.09	1.34	0.27	14.81
Mid attack	Retract	Left to center	Slow	Without	2	0.45	0.12	2.04	0.28	13.90
Mid attack	Retract	Left to center	Slow	Without	3	0.35	0.05	1.65	0.24	12.25
Mid attack	Retract	Left to center	Slow	With	1	0.13	0.07	1.32	0.15	19.22
Mid attack	Retract	Left to center	Slow	With	2	0.12	0.11	0.99	0.23	27.75
Mid attack	Retract	Left to center	Slow	With	3	0.11	0.12	1.27	0.18	24.06
Mid attack	Extend	Right to center	Fast	Without	1	3.07	3.93	1.84	3.80	33.10
Mid attack	Extend	Right to center	Fast	Without	2	4.11	4.68	1.70	5.17	28.78
Mid attack	Extend	Right to center	Fast	Without	3	3.90	4.57	1.70	4.98	31.85
Mid attack	Extend	Right to center	Fast	With	1	4.08	3.32	1.64	4.51	58.81
Mid attack	Extend	Right to center	Fast	With	2	3.27	2.83	1.54	3.96	55.41

Table C-2. Data for Horizontal Rotation (Left-Right) Boom Oscillation (Continued)

Boom Elevation	Boom Extension	Movement	Speed	Discharge	Trial	Amplitude A (ft)	Amplitude B (ft)	Duration (sec)	Average Speed (ft/sec)	Total Oscillation Time (sec)
Mid attack	Extend	Right to center	Fast	With	3	3.26	2.68	1.59	3.74	56.22
Mid attack	Extend	Right to center	Slow	Without	1	0.16	0.27	1.35	0.32	32.68
Mid attack	Extend	Right to center	Slow	Without	2	0.21	0.27	1.72	0.28	32.25
Mid attack	Extend	Right to center	Slow	Without	3	Odd boom motion*				20.68
Mid attack	Extend	Right to center	Slow	Without	4	0.80	0.25	2.88	0.36	17.44
Mid attack	Extend	Right to center	Slow	With	1	0.14	0.11	1.55	0.16	30.65
Mid attack	Extend	Right to center	Slow	With	2	0.39	0.44	1.49	0.56	34.25
Mid attack	Extend	Right to center	Slow	With	3	0.63	0.56	1.53	0.78	41.97
Mid attack	Extend	Left to center	Fast	Without	1	5.50	3.44	1.87	4.78	29.50
Mid attack	Extend	Left to center	Fast	Without	2	5.20	3.09	1.85	4.48	32.68
Mid attack	Extend	Left to center	Fast	Without	3	4.57	2.79	1.78	4.13	38.50
Mid attack	Extend	Left to center	Fast	With	1	3.22	2.46	1.59	3.57	61.22
Mid attack	Extend	Left to center	Fast	With	2	2.32	1.44	1.66	2.26	60.37
Mid attack	Extend	Left to center	Fast	With	3	3.58	2.69	1.61	3.90	53.11
Mid attack	Extend	Left to center	Slow	Without	1	0.44	0.75	2.04	0.58	20.22
Mid attack	Extend	Left to center	Slow	Without	2	0.64	1.26	2.55	0.75	18.34
Mid attack	Extend	Left to center	Slow	Without	3	0.62	1.25	2.53	0.74	31.14
Mid attack	Extend	Left to center	Slow	With	1	Odd boom motion*				39.09
Mid attack	Extend	Left to center	Slow	With	2	Odd boom motion*				47.75
Mid attack	Extend	Left to center	Slow	With	3	Odd boom motion*				39.63
Mid attack	Extend	Left to center	Slow	With	4	0.63	0.40	1.51	0.69	34.87
Mid attack	Extend	Left to center	Slow	With	5	0.52	0.48	1.55	0.65	33.07
Mid attack	Extend	Left to center	Slow	With	6	0.71	0.47	1.56	0.76	42.94
Low attack	Retract	Right to center	Fast	Without	1	0.30	0.53	1.23	0.67	7.94
Low attack	Retract	Right to center	Fast	Without	2	0.38	0.60	1.26	0.78	10.25
Low attack	Retract	Right to center	Fast	Without	3	0.30	0.57	1.30	0.66	12.34

Table C-2. Data for Horizontal Rotation (Left-Right) Boom Oscillation (Continued)

Boom Elevation	Boom Extension	Movement	Speed	Discharge	Trial	Amplitude A (ft)	Amplitude B (ft)	Duration (sec)	Average Speed (ft/sec)	Total Oscillation Time (sec)
Low attack	Retract	Right to center	Fast	With	1	0.07	0.04	0.67	0.17	20.06
Low attack	Retract	Right to center	Fast	With	2	0.08	0.05	0.76	0.16	15.65
Low attack	Retract	Right to center	Fast	With	3	0.12	0.07	0.73	0.26	32.09
Low attack	Retract	Right to center	Slow	Without	1	0.07	0.05	0.86	0.13	20.68
Low attack	Retract	Right to center	Slow	Without	2	0.10	0.06	0.84	0.18	18.84
Low attack	Retract	Right to center	Slow	Without	3	0.08	0.06	0.77	0.17	24.05
Low attack	Retract	Right to center	Slow	With	1	0.07	0.04	0.63	0.18	21.79
Low attack	Retract	Right to center	Slow	With	2	0.11	0.04	0.72	0.21	13.50
Low attack	Retract	Right to center	Slow	With	3	0.12	0.02	0.64	0.22	16.72
Low attack	Retract	Left to center	Fast	Without	1	0.89	0.92	0.97	1.87	11.44
Low attack	Retract	Left to center	Fast	Without	2	1.01	0.69	0.97	1.75	10.82
Low attack	Retract	Left to center	Fast	Without	3	1.04	0.68	0.95	1.81	10.00
Low attack	Retract	Left to center	Fast	With	1	0.19	0.20	0.65	0.59	23.19
Low attack	Retract	Left to center	Fast	With	2	0.05	0.01	0.65	0.09	17.59
Low attack	Retract	Left to center	Fast	With	3	0.05	0.04	0.62	0.14	18.97
Low attack	Retract	Left to center	Slow	Without	1	0.05	0.03	1.02	0.07	5.82
Low attack	Retract	Left to center	Slow	Without	2	0.03	0.01	0.68	0.05	7.34
Low attack	Retract	Left to center	Slow	Without	3	0.03	0.05	0.85	0.09	6.50
Low attack	Retract	Left to center	Slow	With	1	0.08	0.05	0.66	0.20	19.13
Low attack	Retract	Left to center	Slow	With	2	0.10	0.09	0.64	0.31	21.91
Low attack	Retract	Left to center	Slow	With	3	0.07	0.08	0.56	0.28	19.90
Low attack	Extend	Right to center	Fast	Without	1	3.34	2.04	1.35	3.98	25.69
Low attack	Extend	Right to center	Fast	Without	2	Bad camera view				
Low attack	Extend	Right to center	Fast	Without	3	2.90	1.68	1.44	3.18	19.47
Low attack	Extend	Right to center	Fast	Without	4	2.34	1.13	1.51	2.30	19.87
Low attack	Extend	Right to center	Fast	Without	5	3.46	2.30	1.38	4.17	31.72

Table C-2. Data for Horizontal Rotation (Left-Right) Boom Oscillation (Continued)

Boom Elevation	Boom Extension	Movement	Speed	Discharge	Trial	Amplitude A (ft)	Amplitude B (ft)	Duration (sec)	Average Speed (ft/sec)	Total Oscillation Time (sec)
Low attack	Extend	Right to center	Fast	With	1	0.52	0.35	1.01	0.86	28.42
Low attack	Extend	Right to center	Fast	With	2	0.48	0.33	1.03	0.78	48.74
Low attack	Extend	Right to center	Fast	With	3	0.33	0.21	1.06	0.51	26.44
Low attack	Extend	Right to center	Fast	With	4	0.67	0.40	1.07	1.00	28.38
Low attack	Extend	Right to center	Slow	Without	1	0.09	0.11	1.14	0.18	30.91
Low attack	Extend	Right to center	Slow	Without	2	0.53	0.17	2.07	0.34	36.84
Low attack	Extend	Right to center	Slow	Without	3	0.30	0.15	1.43	0.31	31.03
Low attack	Extend	Right to center	Slow	With	1	0.16	0.17	1.01	0.33	30.44
Low attack	Extend	Right to center	Slow	With	2	0.17	0.13	1.01	0.30	26.53
Low attack	Extend	Right to center	Slow	With	3	0.22	0.13	1.00	0.34	31.55
Low attack	Extend	Left to center	Fast	Without	1	1.53	2.13	1.42	2.58	21.38
Low attack	Extend	Left to center	Fast	Without	2	2.09	2.66	1.50	3.17	21.53
Low attack	Extend	Left to center	Fast	Without	3	Odd boom motion*				16.44
Low attack	Extend	Left to center	Fast	Without	4	2.12	2.51	1.45	3.19	17.92
Low attack	Extend	Left to center	Fast	With	1	1.37	1.14	1.11	2.27	38.99
Low attack	Extend	Left to center	Fast	With	2	1.29	0.96	1.15	1.95	42.41
Low attack	Extend	Left to center	Fast	With	3	0.94	0.83	1.12	1.58	43.50
Low attack	Extend	Left to center	Fast	With	4	1.82	1.52	1.19	2.81	45.18
Low attack	Extend	Left to center	Slow	Without	1	0.61	0.18	1.98	0.40	34.84
Low attack	Extend	Left to center	Slow	Without	2	0.78	0.30	2.09	0.52	26.22
Low attack	Extend	Left to center	Slow	Without	3	0.78	0.24	2.16	0.48	38.00
Low attack	Extend	Left to center	Slow	With	1	0.61	0.69	1.32	0.99	33.00
Low attack	Extend	Left to center	Slow	With	2	0.24	0.18	1.02	0.42	25.87
Low attack	Extend	Left to center	Slow	With	3	0.20	0.17	1.06	0.35	31.15

*Odd boom motion required test to be repeated.

APPENDIX D—LIVE FIRE EVALUATION DATA FOR HIGH-REACH EXTENDABLE TURRET

Table D-1. Bumper Turret Low-Flow Aqueous Firefighting Foam Baseline Tests

Apparatus	Agent	Flow	Test Date	Fire Fighter	Time of Day	Temperature (°F)	Relative Humidity (%)	Wind Direction	Wind Speed (mph)	95% Extinguish Time (sec)	100% Extinguish Time (sec)
Bumper turret*	AFFF	Low	5/28/2008	Brill	9:00	91.3	26.9	NE	2.3	67	87
Bumper turret[1]	AFFF	Low	5/29/2008	Brill	6:53	75.5	85.7	NE	2.2	60	79
Bumper turret	AFFF	Low	5/29/2008	Brill	9:00	82.4	62	NW	4	34	50
Bumper turret	AFFF	Low	5/29/2008	Brill	10:15	90.8	46.6	NE	5.3	25	35
Bumper turret	AFFF	Low	5/29/2008	Brill	11:10	91	46.6	N	5.3	43	59
Bumper turret	AFFF	Low	3/20/2009	Brill	9:30	66	37	NE	8	27	36
Bumper turret	AFFF	Low	3/20/2009	Brill	13:30	86	16	N	5	22	38
Bumper turret	AFFF	Low	3/24/2009	Brill	8:00	63	64	E	6	27	36
Bumper turret	AFFF	Low	3/24/2009	Brill	8:45	67	51	SE	6	32	38
									Mean	30	42
									Sample standard deviation	7	9
									95% upper bound	47	64
									95% lower bound	13	19
									Coefficient of variation	23%	22%

*Live fires done for fire fighter familiarization. Not included in data for analysis.
AFFF = Aqueous firefighting foam

Table D-2. Bumper Turret High-Flow AFFF Baseline Tests

Apparatus	Agent	Flow	Test Date	Fire Fighter	Time of Day	Temperature (°F)	Relative Humidity (%)	Wind Direction	Wind Speed (mph)	95% Extinguish Time (sec)	100% Extinguish Time (sec)
Bumper turret	AFFF	High	6/10/2008	Brill	9:10	81.6	72.3	NE	2.2	15	30
Bumper turret	AFFF	High	6/11/2008	Brill	8:45	88.9	57.3		2.2	21	41
Bumper turret	AFFF	High	6/27/2008	Brill	8:40	98.9	50.3	SW	3.5	19	24
Bumper turret	AFFF	High	7/1/2008	Brill	7:20	76.8	75.5	N	1.5	23	26
Bumper turret	AFFF	High	7/1/2008	Brill	9:45	86.4	46.9	NE	4	24	30
Bumper turret	AFFF	High	7/17/2008	Brill	9:45	86.4	46.9	E	3.5	17	26
Bumper turret	AFFF	High	7/18/2008	Brill	9:45	91.5	30.8	N	1.2	13	26
Bumper turret	AFFF	High	9/23/2008	Brill	10:15	82	59	NE	7.5	22	27
									Mean	20	27
									Sample standard deviation	4	2
									95% upper bound	29	32
									95% lower bound	10	21
									Coefficient of variation	19%	7%

Table D-3. Bumper Turret Low-Flow Hydro-Chem™ Baseline Tests

Apparatus	Agent	Flow	Test Date	Fire Fighter	Time of Day	Temperature (°F)	Relative Humidity (%)	Wind Direction	Wind Speed (mph)	95% Extinguish Time (sec)	100% Extinguish Time (sec)
Bumper turret	Hydro-Chem	Low	6/4/2008	Brill	6:45	81	74	SW	3.5	49	92*
Bumper turret	Hydro-Chem	Low	6/10/2008	Brill	7:00	79.9	77.8	SW	1.5	43	63
Bumper turret	Hydro-Chem	Low	6/11/2008	Brill	6:45	80	84.1	Calm	0	52	70
Bumper turret	Hydro-Chem	Low	6/27/2008	Brill	7:30	86.8	66.5	W	3.7	55	63
Bumper turret	Hydro-Chem	Low	7/18/2008	Brill	7:30	79.4	71.7	E	1.5	47	74
Bumper turret	Hydro-Chem	Low	9/23/2008	Brill	8:25	75	70	N	6	54	62
									Mean	50	66
									Sample standard deviation	5	5
									95% upper bound	62	81
									95% lower bound	38	52
									Coefficient of variation	9%	8%

*The 92-second extinguish time fell outside the 95% confidence band and was excluded from data analysis.

Table D-4. Bumper Turret High-Flow Hydro-Chem Baseline Tests

Apparatus	Agent	Flow	Test Date	Fire Fighter	Time of Day	Temperature (°F)	Relative Humidity (%)	Wind Direction	Wind Speed (mph)	95% Extinguish Time (sec)	100% Extinguish Time (sec)
Bumper turret	Hydro-Chem	High	9/24/2008	Brill	8:10	70	61	N	6	30*	35
Bumper turret	Hydro-Chem	High	9/25/2008	Brill	8:20	66	51	N	6	21	33
Bumper turret	Hydro-Chem	High	9/25/2008	Brill	9:32	71	51	NE	8	18	27
Bumper turret	Hydro-Chem	High	9/26/2008	Brill		74	42	Calm	0	22	40
Bumper turret	Hydro-Chem	High	9/26/2008	Brill		74	65	N	3	18	29
Bumper turret	Hydro-Chem	High	3/20/2009	Brill	11:00	77	26	NE	4	19	25
									Mean	20	32
									Sample standard deviation	2	6
									95% upper bound	25	46
									95% lower bound	15	17
									Coefficient of variation	9%	18%

*The 30-second extinguish time fell outside the 95% confidence band and was excluded from data analysis.

Table D-5. Tip Turret AFFF Tests

Apparatus	Agent	Flow	Test Date	Fire Fighter	Time of Day	Temperature (°F)	Relative Humidity (%)	Wind Direction	Wind Speed (mph)	95% Extinguish Time (sec)	100% Extinguish Time (sec)
Tip Turret[1]	AFFF	Low	7/7/2008	Brill	10:45	91.5	54.2	SW	2.3	30	35
Tip Turret[1]	AFFF	Low	7/7/2008	Brill	12:30	85.8	66.5	SE	5.5		
Tip Turret[1]	AFFF	Low	7/8/2008	Brill	7:05	76.7	83.8	E	3	41	44
Tip Turret[1]	AFFF	Low	7/9/2008	Brill	6:50	80.9	85.1	E	1		
Tip Turret[1]	AFFF	Low	7/10/2008	Brill	7:30	80.9	85.1	Calm	0	35	44
Tip Turret	AFFF	Low	11/13/2008	Brill	9:40	75	87	S	3.5	53	65
Tip Turret	AFFF	Low	11/13/2008	Brill	11:00	78	76	S	4	51	65
Tip Turret	AFFF	Low	2/3/2009	Brill	8:15	45.3	37	N	6	57	68
Tip Turret	AFFF	Low	2/3/2009	Brill	9:35	53.4	18	NE	5	41	52
Tip Turret[2]	AFFF	Low	2/5/2009	Brill	2:40	53.1	13	W	5	110	127
Tip Turret[3]	AFFF	Low	2/25/2009	Brill	8:50	54.5	50	E	8		
Tip Turret	AFFF	Low	3/6/2009	Brill	12:05	70	36	S	8.7	56	63
									Mean	52	63
									Sample standard deviation	6	6
									95% upper bound	69	80
									95% lower bound	34	45
									Coefficient of variation	12%	10%

[1]Live fires done for fire fighter familiarization. Not included in data for analysis.
[2]Wind direction for this test blew directly toward the truck. Not included in data for analysis.
[3]Equipment malfunction. Tip turret would not rotate through full range of motion.

Table D-6. Base Turret Low-Flow AFFF Tests

Apparatus	Agent	Flow	Test Date	Fire Fighter	Time of Day	Temperature (°F)	Relative Humidity (%)	Wind Direction	Wind Speed (mph)	95% Extinguish Time (sec)	100% Extinguish Time (sec)
Base turret*	AFFF	Low	2/12/2009	Pierce	10:56	73.5	21	NE	6.3	55	64
Base turret*	AFFF	Low	2/26/2009	Pierce	8:45	68.5	40	SE	6	38	80
Base turret*	AFFF	Low	3/25/2009	Pierce	8:00	64	64	SE	4	51	62
Base turret	AFFF	Low	4/29/2009	Pierce	9:30	77.7	41	SE	5	36	54
Base turret	AFFF	Low	4/29/2009	Pierce	10:00	79.7	36	SE	6	26	39
Base turret	AFFF	Low	4/29/2009	Pierce	10:30	79	40	SE	6	27	52
Base turret	AFFF	Low	4/30/2009	Pierce	9:00	77.7	42	E	5	28	43
Base turret	AFFF	Low	4/30/2009	Pierce	9:45	82	33	E	5	33	40
									Mean	30	46
									Sample standard deviation	4	7
									95% upper bound	42	65
									95% lower bound	18	26
									Coefficient of variation	14%	15%

*Live fires done for fire fighter familiarization. Not included in data for analysis.

Table D-7. Base Turret High-Flow AFFF Tests

Apparatus	Agent	Flow	Test Date	Fire Fighter	Time of Day	Temperature (°F)	Relative Humidity (%)	Wind Direction	Wind Speed (mph)	95% Extinguish Time (sec)	100% Extinguish Time (sec)
Base turret	AFFF	High	3/2/2009	Fischer	9:00	46.4	30	N	7	40	44
Base turret	AFFF	High	3/2/2009	Fischer	10:30	52.9	21	N	6	31	35
Base turret*	AFFF	High	3/4/2009	Fischer	13:00	60.3	27	W	8		
Base turret	AFFF	High	3/4/2009	Fischer	14:30	55.4	29	W	9	27	43
Base turret	AFFF	High	3/5/2009	Fischer	8:00	50.2	56	E	5	28	33
Base turret	AFFF	High	3/5/2009	Fischer	9:15	62.1	42	E	6	24	29
									Mean	30	37
									Sample standard deviation	6	6
									95% upper bound	47	55
									95% lower bound	13	19
									Coefficient of variation	20%	18%

*Operator error. Only water selected, not foam.

Table D-8. Base Turret Low-Flow Hydro-Chem Tests

Apparatus	Agent	Flow	Test Date	Fire Fighter	Time of Day	Temperature (°F)	Relative Humidity (%)	Wind Direction	Wind Speed (mph)	95% Extinguish Time (sec)	100% Extinguish Time (sec)
Base turret[1]	Hydro-Chem	Low	2/12/2009	Pierce	8:40	64	54	N	3.6	55	115
Base turret[1]	Hydro-Chem	Low	2/12/2009	Pierce	9:50	70	25	N	6.3	55	160
Base turret	Hydro-Chem	Low	3/25/2009	Pierce	9:15	69	50	SE	7.6	35	63
Base turret[2]	Hydro-Chem	Low	4/29/2009	Pierce	7:45	73.9	47	N	3	27	51
Base turret	Hydro-Chem	Low	4/30/2009	Pierce	8:15	68.7	66	SE	6	48	72
Base turret	Hydro-Chem	Low	5/1/2009	Pierce	6:45	65.7	97	E	3	35	45
Base turret	Hydro-Chem	Low	5/1/2009	Pierce	8:00	73.6	55	SE	5	39	69
Base turret[3]	Hydro-Chem	Low	5/1/2009	Pierce	9:30	81	35	SE	6	49	
Base turret	Hydro-Chem	Low	5/1/2009	Pierce	11:00	84.2	23	SE	7	46	64
									Mean	43	61
									Sample standard deviation	6	11
									95% upper bound	60	90
									95% lower bound	26	31
									Coefficient of variation	14%	17%

[1]Live fires done for fire fighter familiarization. Not included in data for analysis.
[2]The 95% extinguishment times for this trial and earlier were excluded from data analysis. The 27-second time fell outside 95% confidence band, and this broke the string of consistent times within the ±95% range for data inclusion.
[3]Operator error. Insufficient AFFF for duration of test.

Table D-9. Base Turret High-Flow Hydro-Chem Tests

Apparatus	Agent	Flow	Test Date	Fire Fighter	Time of Day	Temperature (°F)	Relative Humidity (%)	Wind Direction	Wind Speed (mph)	95% Extinguish Time (sec)	100% Extinguish Time (sec)
Base turret	Hydro-Chem	High	3/5/2009	Fischer	13:30	71.6	41	W	6	43	59
Base turret[1]	Hydro-Chem	High	3/10/2009	Fischer	8:00	61	97	E	3.1	37	140
Base turret[2]	Hydro-Chem	High	3/10/2009	Fischer	9:25	63.9	89	E	3.1	49	67
Base turret	Hydro-Chem	High	3/11/2009	Fischer	9:30	71.2	50	S	3	35	47
Base turret	Hydro-Chem	High	3/12/2009	Fischer	8:15	60.4	98	N	2	33	40
Base turret	Hydro-Chem	High	3/12/2009	Fischer	9:45	75.4	56	N	3	34	43
Base turret	Hydro-Chem	High	3/20/2009	Fischer	8:30	63	46	N	6	26	38
									Mean	35	45
									Sample standard deviation	6	8
									95% upper bound	49	69
									95% lower bound	20	22
									Coefficient of variation	16%	18%

[1]Operator error. Fire fighter misunderstood instructions for attack strategy. The 140-second extinguish time was not included in data for analysis.
[2]Equipment malfunction. Base turret would not rotate through full range of motion. Not included in data for analysis.