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Full-Scale Evaluation of ARFF Tactics for Cargo Fires on Freighter Aircraft

August 2013

Final Report

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16. Abstract

On February 7, 2006, the United Parcel Service Flight 1307 was involved in a cargo fire incident at the Philadelphia International Airport. The official investigation of the incident identified deficiencies in training that Aircraft Rescue and Firefighting (ARFF) personnel had in fighting cargo fires inside freighter aircraft. The National Transportation Safety Board made several recommendations to the Federal Aviation Administration (FAA) related to ARFF training, tactics, strategy, and performance, to provide cargo firefighting training methods to ARFF personnel. As part of a response to these recommendations, the FAA launched a series of full-scale research tests to evaluate different tactics to combat cargo fires.

A series of 11 test scenarios evaluated the effectiveness of certain firefighting tactics on specific cargo scenarios with various types of unit load devices (ULD), also referred to as cargo containers. The tests were performed at the Southern California Logistics Airport inside an Airbus A310. An oxygen deprivation tactic was used to seal all ventilation in the aircraft to determine if it could create an oxygen-deprived environment (i.e., oxygen levels drop below 12%) that would cause the fire to self-extinguish. Two high-reach extendable turrets with aircraft skin-penetrating nozzle (ASPN) technologies were used to evaluate penetration tactics on different-sized containers placed right next to the interior walls of the fuselage and their effectiveness in extinguishing or controlling a container fire. These penetrations were known as direct attacks. Two Snozzle® ASPN configurations and one Stinger® ASPN configuration were evaluated for this part of the research. For the next test scenarios, a Snozzle® ASPN, a Stinger® ASPN, and one prototype ASPN were used to evaluate tactics that involved indirectly attacking containers that were placed at an unreachable distance away from the interior wall of the fuselage. This meant water was discharged into the container from a distance and not from penetrating the container. In addition to container fires, pallet fires were produced to test the indirect attack tactic effectiveness using the standard Snozzle® ASPN.

Data from the oxygen deprivation tests were inconclusive in determining the effectiveness of the tactic. Results from the direct attack tactics indicated that successful control and/or extinguishment of the fire can be achieved if the ASPN is able to penetrate into the container. Longer penetration into the fuselage proved to be more effective in controlling the fire. Data indicated that the prototype ASPN proved to be more effective than the current designs when indirectly attacking a burning ULD container. The data also showed the current standard ASPN design effectively controlled the open pallet fire in the tests.

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LIST OF ACRONYMS

AC	Advisory Circular
ARFF	Aircraft Rescue and Firefighting
ASPN	Aircraft Skin-Penetrating Nozzle
CFR	Code of Federal Regulations
FAA	Federal Aviation Administration
FedEx	Federal Express
FLIR	Forward-looking infrared
GPM	Gallons per minute
HD	High definition
HRET	High-reach extendable turret
NFPA	National Fire Protection Association
NTSB	National Transportation Safety Board
psi	Pounds per square inch
SCLA	Southern California Logistics Airport
TIC	Thermal imaging camera
ULD	Unit load device
UPS	United Parcel Service, Inc.

DEFINITIONS

Accessible Freight	Freight loaded on a freighter aircraft in a location that is accessible to a crewmember during flight.
Agent	Media or a combination of media, used to extinguish a fire. Typically, water or water mixed with foam. Other agents include dry chemical powders and inert gases, such as Halon® or Halotron®.
Aircraft Skin-Penetrating Nozzle	Abbreviated as ASPN, a device mounted on the end of a high-reach extendable turret that penetrates through the fuselage to apply agent to the interior of an aircraft.
Cargo Liner Material	*(Brand names: Gill Liner or Conolite)* A protective liner material fixed to the fuselage that serves to protect the aircraft components and structure from damage during fires and loading and unloading of cargo. The liner is comprised of a cured polyester or phenolic resin binder with woven glass fiber reinforcement, which typically ranges in thickness from 0.013 to 0.070 inch. The glass fibers can be either e-glass or s-glass.
Cheek Area	The void between the skin of the aircraft and the lower cargo compartment created by the vertical members that comprise the vertical sides of the cargo compartment.
Class A Fire Load	Ordinary combustibles (e.g., paper, cardboard).
Dzus Fasteners	A proprietary name for a quarter-turn fastener used to secure cargo liner in freighter cargo compartments.
Fire Control	The point at which the fire intensity is reduced by 90%.
Fire Extinguishment	The point at which the fire is completely extinguished.
High-Reach Extendable Turret	Abbreviated as HRET, an articulated device mounted on the top of an extendable turret of a firefighting vehicle; the HRET is comprised of an upper and lower section that allows for application of agent from nozzles at various heights. It can be equipped with a skin-penetrating nozzle for remotely applying agent inside of an aircraft.
Inaccessible Freight	Freight loaded on a cargo aircraft in a location that is not accessible to a crewmember during flight.

Oshkosh Striker®	ARFF vehicle brand manufactured by the Oshkosh Corporation.
Positions	A combination of letters and numbers identifying specific locations for unit load devices (ULD) in an aircraft cargo compartment. · Main cargo compartment positions are numbered from the front of the aircraft starting with 1, ascending to the rear. A suffix letter indicates if the ULD is in that location on the left side, center, or right side. A full-width ULD that encompasses all the locations of Position 1 would simply be identified as Position 1. · Lower cargo compartment or "belly" positions are identified using the same system of numbers and letters, but a prefix is added to identify the specific lower cargo compartment, either forward or aft.
Preburn	The period after ignition that the fire is allowed to burn before attempting any suppression strategy associated with the test.
Rosenbauer Panther®	An ARFF vehicle brand manufactured by Rosenbauer America.
Snozzle® 652	An HRET design manufactured by Crash Rescue that has a vertical reach of 65 feet and is mounted on the FAA Oshkosh Striker®. It has an ASPN that penetrates by slowly extending the upper section of the HRET.
Stinger®	An HRET mounted on the Rosenbauer Panther® manufactured by Rosenbauer America. It has an ASPN that uses hydraulic actuators to rapidly punch the nozzle through the fuselage.
Unit Load Device	Abbreviated as ULD, a device used for grouping, transferring, and restraining cargo for transit. This could be a cargo container or a pallet.
Ventilation	The exchange of the interior atmosphere of a structure with the outside.

EXECUTIVE SUMMARY

A cargo fire incident involving United Parcel Service Flight 1307 at the Philadelphia International Airport highlighted deficiencies in training that Aircraft Rescue and Firefighting (ARFF) personnel have when fighting cargo fires inside freighter aircraft. After this incident, the National Transportation Safety Board made recommendations to the Federal Aviation Administration (FAA) to provide cargo firefighting training methods to ARFF personnel. As part of the response to the recommendations, the FAA launched a series of full-scale research tests to evaluate different tactics to combat cargo fires.

A series of 11 test scenarios were performed to evaluate the effectiveness of certain firefighting tactics on specific cargo scenarios with various types of unit load devices, also referred to as cargo containers. A freighter-modified Airbus A310 was used as the article for full-scale container fire tests at the Southern California Logistics Airport.

An oxygen deprivation tactic was evaluated to determine if sealing all the ventilation in the aircraft would create an oxygen-deprived environment (i.e., in which oxygen levels drop below 12%) that would cause the fire to self-extinguish. Tests showed that although oxygen levels decreased as the test was running, the levels were not low enough to create an oxygen-deprived environment with the amount of fire load used for the tests. Oxygen levels decreased only 4%-5% from the original oxygen levels before ARFF personnel introduced ventilation to the aircraft again. The results were inconclusive as to whether this tactic was effective in extinguishing a cargo fire.

The efficiency of penetration tactics to extinguish or control a container fire were evaluated using two high-reach extendable turrets with aircraft skin-penetrating nozzle (ASPN) technologies on different-sized containers placed against the interior walls of the fuselage. Two Snozzle® ASPN configurations and one Stinger® ASPN configuration were evaluated for this part of the research. All ASPNs penetrated the test containers in the main cargo compartment successfully and controlled the container fires efficiently. However, for the half-width containers, some of the Stinger® ASPN discharge holes failed to completely enter the container, and some sprayed outside the container. ASPNs with longer penetration depths controlled container fires more efficiently, and in some cases extinguished fires, compared to ASPNs with shorter penetration depths. Snozzle® ASPNs equipped with an extension successfully extinguished container fires, while other ASPN modifications only controlled the container fire. It was more difficult to control the container fires in the lower cargo compartment because the penetration angle forced the ASPN to enter the lower portion of the container; the discharge was blocked by the burning contents.

Tactics that involved indirectly attacking test containers, i.e., containers that were placed in an unreachable distance away from the fuselage and could not be penetrated, were evaluated using two ASPN configurations and one prototype ASPN. These ASPNs would attempt to discharge water into the container without penetrating the containers. Although water reached the test containers, both the Stinger® and Snozzle® ASPNs could not efficiently control the container fires. After the water discharge was stopped, the fire rekindled and container temperatures increased again. In comparison, the prototype ASPN, developed at the FAA William J. Hughes Technical Center, controlled the container fire more efficiently than current ASPNs, yet no ASPN could completely extinguish a container fire in an indirect attack. In addition to container fires, pallet fires were staged using the standard Snozzle® ASPN to test the indirect attack tactic effectiveness. The indirect attack tactic efficiently controlled the pallet fires.

The findings from these tests will be used to create training material for ARFF personnel.

1. INTRODUCTION.

On February 17, 2006, the United Parcel Service (UPS) Flight 1307 was involved in a cargo fire incident. The McDonnell Douglas DC-8-71F aircraft made an emergency landing at the Philadelphia International Airport due to a possible fire inside the aircraft. The National Transportation Safety Board (NTSB) Accident Report states that the first officer of Flight 1307 reported that he smelled an odor that he compared to wood burning 25 minutes before landing [1]. After 20 minutes from reporting the order, smoke was confirmed inside the aircraft. Once the aircraft landed, it took approximately 4 hours to declare the fire under control. The NTSB found that the Aircraft Rescue and Firefighting (ARFF) personnel who responded to this incident were not adequately trained with regard to freighter aircraft.

In the 2009, Federal Aviation Administration (FAA) Advisory Circular (AC) 150/5210-17B, "Program for Training of Aircraft Rescue and Firefighting Personnel," the FAA added freighter aircraft familiarization as a requirement for ARFF training [2]. To assist the ARFF community improve training and determine the best tactics when fighting cargo fires on freighter aircraft, the FAA tasked the Airport Technology Research and Development Branch's ARFF Research Program to conduct research on freighter aircraft firefighting.

Part of the research effort entailed conducting full-scale interior fire tests inside a freighter aircraft. A series of 11 test scenarios evaluated the effectiveness of certain firefighting tactics and strategies on specific cargo scenarios with various types of unit load devices (ULD), also referred to as cargo containers.

2. PURPOSE.

Most of the tactics and strategies for fighting cargo fires on freighter aircraft currently in use at airports are theoretical and not based on any real-time experience. The purpose of this project was to evaluate some of these theories, develop best practices, and apply science to validate old theories and new concepts. The case studies presented in this report identify a number of NTSB recommendations and findings relative to ARFF training, tactics, strategy, and performance of ARFF at freighter aircraft accidents/incidents. The test results provide data to support recommendations on best methods, tactics, and strategies for ARFF fire departments fighting freighter aircraft fires.

3. OBJECTIVES.

The objectives of this research project were to

- assess the effectiveness of depriving oxygen from a cargo fire inside an intact aircraft on fire control or extinguishment.
- evaluate aircraft skin-penetrating nozzles (ASPN) with different lengths and spray patterns to determine which is most effective in controlling or extinguishing a cargo fire when penetrating a ULD container.

- evaluate the effectiveness of different ASPNs when indirectly attacking a burning ULD container.

4. BACKGROUND.

ARFF personnel have the most experience with incidents that begin with a pooled fuel fire. ARFF apparatus are designed for mass foam application to pooled fuel fires through primary and secondary turrets, as well as hand lines. ARFF apparatus are self-contained vehicles that carry water and aqueous film forming foam concentrate. They can apply foam while driving to control and extinguish flammable liquid fires. All ARFF personnel at Title 14 Code of Federal Regulations (CFR) Part 139 certificated airports are required to train every 12 consecutive calendar months as part of their recurrent training on pooled fuel fires of a size scaled to the aircraft applicable to the airport index [3].

Each certificated airport receives a letter designator, known as the airport index, to describe the type of aircraft and level of activity. The index determines how many ARFF vehicles and what type and how much agent are required at the airport. Cargo aircraft operating into and out of airports certificated under 14 CFR Part 139 are not included in index determination. Therefore, cargo aircraft operating at a given airport may be larger than air carrier aircraft operating at that airport. The airport's index would not reflect the larger cargo aircraft operations, meaning ARFF vehicles may not provide an adequate quantity of agent to control and extinguish a pooled fuel fire. Additionally, the ARFF personnel may have never trained on or experienced a pooled fuel fire of that magnitude.

Fires that begin in the cargo compartment of an aircraft present a very different fire scenario than pooled fuel fires. A cargo fire in an aircraft is an interior fire, but it is quite different from that of an interior structural fire. Each cargo fire is a unique event, and the methods required to control and extinguish these fires must be carefully selected to address the specifics of the fire. Presently, no single tactical approach will work in every situation. An understanding of aircraft construction and configuration, as well as fire behavior, is necessary when selecting the best tactics, strategies, and methods available.

In general, ARFF personnel strive to launch an aggressive fire attack targeting the base of the fire. The majority of locations that a cargo fire can occur on freighter aircraft are inaccessible to ARFF personnel; therefore, attacking the fire at the base may not be possible. Finding the fire and gaining access to the fire location are among the first tactical challenges facing the ARFF department. Knowledge of what exactly is on fire is also crucial in determining what type of agent will be used. Most cargo fires begin as smoldering, smoky fires enclosed in a ULD. The entire cargo compartment eventually fills with smoke, and the origin of the fire is often not evident. The smoldering fire is in search of additional fuel and oxygen source. Once fuel and oxygen sources are found, the fire grows and consumes the fuel. If the fire breaches the ULD, it will grow rapidly in both size and magnitude. Unless the fire is visible through an open door, or the aircraft crew is able to provide a specific fire location, it is unlikely that fire fighters will be able to determine its exact fire location. In fact, rarely have ARFF personnel been able to access burning cargo on a loaded freighter. The spaces in the cargo compartments of a freighter are revenue spaces. The most efficient use of the aircraft is to fill the entire space with freight. As shown in figures 1 and 2, gaining access to a cargo compartment does not usually provide ARFF personnel with the ability to access the location of the fire. Each aircraft and each carrier may use slightly different load configurations. However, in nearly all configurations, fire fighters do not have access to the majority of the cargo on a freighter aircraft. Using the large cargo loading door/hatch does not necessarily provide access for the fire fighters, but does provide a huge influx of oxygen, thereby feeding the fire and increasing the fire intensity, making conditions more dangerous.

Figure 1. Wide-Body ULD Load

Figure 2. Loaded Cargo ULD in Narrow-Body Aircraft

Among the steps for a safe interior fire attack in a structure, fire fighters gain access to the space containing the fire and attack the fire with sufficient water flow to overcome the intensity of the fire with coordinated ventilation efforts. Cargo aircraft are loaded in such a way that gaining access to the cargo compartment does not necessarily provide any access or even a view of the cargo fire. Typically, only the "accessible freight," i.e., the ULDs located immediately aft of the forward bulkhead or the 9G net (the safety net that prevents freight from moving into the cockpit), is accessible to ARFF personnel entering through the main cargo compartment. Therefore, in an intact or largely intact aircraft, the vast majority of the freight is not usually accessible for a typical interior fire attack method. In addition, many ARFF departments lack adequate staffing to launch an interior attack while continuing to protect the exterior exposure. In this case, a traditional interior attack is likely to depend upon mutual aid response. Mutual aid responders are far less likely to be as familiar with aircraft construction, weight and balance, configuration, and aircraft forcible entry techniques as are ARFF personnel.

The following sections discuss three areas of technological improvements that greatly affect the way that cargo fires are fought, ranging from aircraft advancements to new firefighting technologies.

4.1 AIR CARGO AIRCRAFT.

In 1977, the air cargo industry was deregulated, and airfreight companies became eligible to operate their own aircraft. From 1977 through the early 1980s, a transformation in air cargo transportation occurred. Freight forwarding companies moved into the direct air carrier business marketplace, and an entirely new industry evolved to satisfy the needs of the business that they were competing to serve. The overnight express business was born. Federal Express (FedEx) led the way in the 1970s. This new model for freight transportation exploded onto the world market in the 1980s. Today, there are dozens of all-cargo airlines, as well as a number of air carrier airlines that also operate all-cargo aircraft through their cargo subsidiaries.

Air cargo operations are conducted in a variety of different aircraft types. The major carriers maintain a fleet mix, which satisfies the needs of their time-sensitive distribution system. UPS Airlines operates approximately 230 of their own aircraft. The UPS fleet consists of Airbus A300-600, Boeing B-747-400, B-757-200, B-767-300, and McDonnell-Douglas MD-11F aircraft. In addition, UPS charters over 200 aircraft.

FedEx has the largest fleet of aircraft in the world. They own approximately 650 aircraft. The FedEx fleet consists of the following aircraft: Airbus A300-600, A310-200/300, (Aerei da Trasporto Regionale or Avions de Transport Regional) ATR 72, ATR 42, B-727-200, DC-10-10, DC-10-30, MD-10-10, MD-10-30, MD-11, Cessna 208A, Cessna 208B, and B-757-200.

These two carriers move 95% of the freight in the United States and 90% of the freight in the world. A number of other carriers have a smaller market share but still maintain a place in the cargo transportation industry. These carriers use many of the same type of aircraft, as well as B-707, DC-8, Ilyshin II-76, C-130 (Hercules), Fokker, and Antonov 124 and 225 aircraft.

It is clear that the air cargo industry has a significant presence in the aviation system and conducts daily flight operations at many certificated airports in the United States and its territories. Having an increased presence has also led to a number of incidents occurring in airports. Appendix A provides a summary of the NTSB reports for these incidents. These incidents range from a collapsed landing gear to an interior cargo fire. These incidents initiated many NTSB recommendations, such as increasing the efficiency of relaying information regarding hazardous onboard cargo to emergency responders, and requiring Part 139 airports with cargo operations to include cargo aircraft as part of their ARFF training.

4.2 HIGH-REACH EXTENDABLE TURRETS.

High-reach extendable turrets (HRET) provide an opportunity to discharge agent into a fuselage without introducing additional oxygen, as occurs when doors are opened. An additional benefit is the fact that agent can be introduced on the interior of the aircraft in areas that are not accessible for ARFF personnel without putting ARFF personnel inside the burning aircraft. The HRET allows the fire apparatus operator to extend nozzles, cameras, and other equipment out to and above different parts of the aircraft.

Current HRET designs include an ASPN that meets the flow requirements of National Fire Protection Association (NFPA) 414, "Standard for Aircraft Rescue and Fire-Fighting Vehicles," [4], Table 4.1.1 (d). The ASPN is a firefighting nozzle (which is mounted on the HRET of a fire apparatus) that penetrates the aircraft skin to deliver firefighting agent to the aircraft interior. NFPA 414, 4.18.6.7 describes a "nozzle system designed and constructed to direct or spray agent on both sides of the aircraft at the same time after the penetration is made. (Concept—delivery shall be multiple holes causing a spray to cover 25 to 30 feet on each side of the aircraft interior and in the aircraft aisle way)" [4]. The piercing nozzle flow rate must be ≥ 250 gallons per minute (GPM). A flow rate of 250 GPM is a significant increase over the flow rate of the hand-held devices, which flow 95 to 125 GPM. A higher flow rate can overcome higher British thermal units. There are currently two manufacturers of HRETs with ASPNs. ARFF personnel have used HRETs and ASPNs on cargo aircraft fires, but not enough practical experience has been documented to date to identify best tactical practices.

Knowledge of the piercing depth required to pierce into a ULD is an important consideration. Most narrow-body aircraft have approximately 12 inches between the outside of the fuselage and the wall of the ULD. Most ASPNs pierce the container and extend several inches inside, allowing direct attack with agent from the piercing tip. Wide-body aircraft piercing depths vary. B-777, MD-10, MD-11, and B-747 aircraft have distances of 30 to 33 inches between the outside of the fuselage and the wall of the ULD on the main cargo compartment. This is near or exceeds the capabilities of most ASPNs. Some HRET manufacturers may offer an ASPN extension to increase the piercing length of the tool. The aftmost cargo positions of wide-body aircraft are loaded differently than the main portion of the cargo compartment. As the aircraft narrows toward the tail, a single cargo container is mounted on the centerline, which creates a greater void between the outside skin of the fuselage and the ULD. In those aftmost positions, distances of 43 to 57 inches are beyond the effective piercing range of existing HRET-mounted ASPNs.

4.3 FORWARD-LOOKING INFRARED CAMERAS/THERMAL IMAGING CAMERAS.

Forward-looking infrared (FLIR) cameras are installed on many ARFF vehicles and are required on ARFF vehicles purchased with funds from the FAA Airport Improvement Program. Originally, FLIR cameras were installed on ARFF vehicles to aide in responses during low-visibility conditions. Additionally, FLIR cameras have shown value in evaluating the heat signature of aircraft components during emergency operations. The FLIR is most effective when there are extreme temperature differences between the viewed component and ambient temperatures. The effectiveness of detecting interior heat signatures diminishes when aircraft skin, insulation, interior finishes, and cargo liners shield the interior heat source.

In addition to FLIR cameras, many fire departments carry thermal imaging cameras (TIC). These hand-held cameras are capable of reading temperatures at a lower range than the FLIR cameras, but are less effective than FLIRs when positioned a distance from the heat source.

5. UNDERSTANDING FREIGHTER AIRCRAFT.

An understanding of basic aircraft construction is an important baseline for developing tactical plans for aircraft forcible entry or piercing with an HRET and an ASPN. The load-bearing structure of a large passenger or cargo aircraft is composed of strong beams, known as stringers or formers that run the length of the aircraft, as well as frames that circle those beams. A bay, known as an open area between stringers and frames, typically are 18 to 20 inches long and 8 to 10 inches wide. Figure 3 provides a generic view of how the stringers and frames make up the structure of the aircraft. The bays can be identified from outside an aircraft by noting the lack of fasteners on the skin.

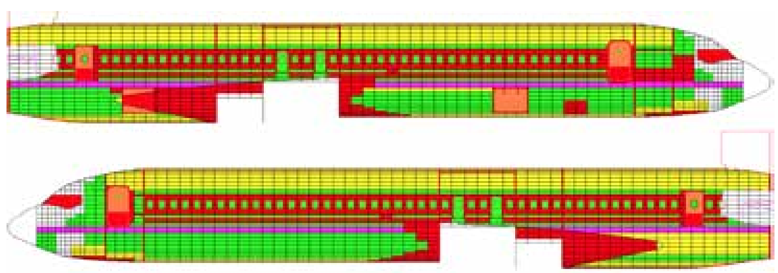


Figure 3. Generic Aircraft Structure Penetration Chart (The green areas represent optimal piercing locations, the yellow areas represent sufficient piercing locations, and the red areas represent the least efficient piercing locations.)

Piercing operations have the least amount of resistance in the bay areas. Therefore, the ASPNs should target the bays for piercing to apply agent or for creating a drain to release water trapped in the bilge from firefighting operations.

5.1 CONVERTED FREIGHTER AIRCRAFT.

There are two types of freighter aircraft in operation: the first type was originally built as freighter aircraft; the second type includes aircraft that was originally built for passenger operations and then converted to freighter aircraft. Converted freighter aircraft are easy to identify, as the window lines are still visible on the aircraft. In most cases, the original windows are replaced with window blanks. Typically, these blanks are clipped in position using similar mounting hardware that was used to mount the windows, as shown in figure 4. Figure 5 shows the appearance of the window blanks from the outside of the aircraft.

Figure 4. Window Blanks in Converted Freighter Aircraft

Figure 5. Exterior View of Window Blanks in Converted Freighter Aircraft

In the interior of the aircraft, insulation and a cargo liner cover the walls, including the window blanks. A cargo liner is a flexible laminate composite used to shield aircraft walls from potential moving containers and to provide fire resistance to the aircraft cargo compartments. Installation of a cargo liner consists of a combination of retaining clips, screws, and Dzus® Fasteners. Some windows remain in place to serve as observation points. A removable piece of cargo liner covers these windows so maintenance personnel can gain access. As shown in figure 6, from the interior of the cargo compartment, the unused doors and windows are not visible, and cargo liners cover the walls, leaving clean, smooth surfaces.

Figure 6. Main Cargo Compartment Interior Finish

Converted freighter aircraft also have doors not typically installed in freighter aircraft but were necessary when the aircraft was configured for passengers. Modified aircraft for some carriers have the rear doors disabled and secured to prevent opening; therefore, attempts to gain access through rear doors on these carrier-converted freighter aircraft will not be successful. The L1 door remains operational and serves as the boarding point for the crew. The L1 door is also the door that the crew uses for emergency evacuation, if possible. This door is located in the forward left side of the aircraft. Using this door is preferable to using cockpit windows for escape, if fire conditions allow, because they provide an easy escape from the aircraft in case of an emergency. The R1 door, entry door located in the forward right side of the aircraft, may or may not be operational on a converted freighter aircraft.

5.2 UNIT LOAD DEVICES.

Cargo is transported in ULDs, which most often include pallets or containers. There are also specialized ULDs used to transport livestock, racehorses, and wild animals. The ULD containers are manufactured in a variety of sizes and shapes, designed specifically for particular aircraft and carriers. A single aircraft's load can consist of cans, pallets, or other types of ULDs. Cargo ULDs can range in storage capacity from 153 cubic ft to 775 cubic ft. Pallets can be as large as 8 ft wide and 20 ft long, carrying as much as 25,000 lb. Figures 7 through 12 show a sampling of typical ULD construction. Each ULD is identified by a three-letter classification designated by the International Air Transport Association. The first letter describes the ULD category; the second letter describes the base dimension of the device; and the third letter describes the contour or shape of the ULD, such as curved ceiling or trapezoidal-shaped container. ULDs are constructed with aluminum floors and frames. The skins vary and may be made of aluminum sheets, Lexan™, or a combination of the two. The doors may be aluminum or canvas. Currently, the use of composite materials for skins is in the research stages. The materials used for construction have a significant effect on the amount of time during which the ULD can contain heat and fire.

Figure 7. A ULD Pallet Built up With Freight and Cargo Net

Figure 8. Lexan ULD

Figure 9. Cargo Pallet With no Freight

Figure 10. Livestock ULD

Figure 11. All Aluminum ULD With Aluminum Door

Figure 12. Aluminum and Lexan ULD With Canvas Door

Each ULD is loaded with freight and placed into designated positions in the aircraft to maintain the correct weight and balance for flight. The ULDs are locked into the floor system in the cargo compartments of the aircraft. As shown in figure 13, the aircraft cargo compartment floor is equipped with floor rollers and locks to allow the ULDs to be moved in and out. The locks pop up from the floor system to secure the ULDs and keep the load from shifting in flight.

Figure 13. Cargo Compartment Floor With Rollers and Locks

The area between the flight deck and the main cargo compartment will be equipped with either a bulkhead or a 9G net. Both are designed to prevent any load shift in flight from affecting the flight deck. There will also be a smoke curtain meant to isolate smoke in the cargo compartment and prevent travel into the flight deck. All of these points are important to ARFF personnel, as access into the cargo compartment from the L1 door may be necessary. The bulkheads have access doors, and the smoke curtains have zippered or Velcro flaps that need to be opened to gain access. The area directly aft of the bulkhead or 9G net is where the "accessible freight" is located. This often includes hazmat shipments or live animals. Figure 14 depicts a 9G net in the forward portion of a cargo compartment.

Figure 14. A 9G Net

Each aircraft type, and, in some cases each carrier, has a plan for how the ULDs are loaded and positioned in the aircraft. This is important information for ARFF, because the distance between the ULD and the interior wall of the fuselage determines whether a direct attack into a ULD using an ASPN on a HRET is possible. Main cargo compartments on 14 CFR Part 121 certificated U.S. carrier aircraft using large category transport aircraft are considered Class E cargo compartments. Appendix A provides detailed information on the classes of cargo compartments. Class E compartments are equipped with smoke detection reporting to the cockpit. The aircraft is not fitted with automatic fire suppression, but is equipped with portable fire extinguishers in the event that the fire is in an area accessible to the crew. The majority of the freight is not accessible to the crew.

Although there is currently no requirement to do so, it would be helpful for ARFF crews to meet with the cargo carriers at the airport to determine what types of protection and suppression are installed on aircraft with service at the airport. This type of knowledge would better prepare ARFF personnel when dealing with freighter aircraft incidents. On certain FedEx aircraft, the first few ULD positions are for ULDs referred to as haz cans, for hazardous material or other dangerous goods carried in them. A red stripe identifies these types of ULDs. They have an inlet that ties into hoses connected to manually operated fire extinguishers, which can be activated by the crew. FedEx has also equipped certain wide-body aircraft dedicated to trans-Atlantic routes with a fire suppression system (FSS). The FSS includes a detection and suppression system. When a fire is detected in a ULD, an overhead piercing nozzle moves into position above the burning ULD. It drops the piercing tip to puncture the ULD and fill the container with special foam aerated with argon gas.

5.3 STRATEGIES AND THEORIES.

5.3.1 Main Cargo Compartment Piercing Locations.

On freighter aircraft, the piercing locations are identified differently than on passenger aircraft. On passenger aircraft, the windows are used as a visible landmark. A piercing position 10 to 12 inches above the top of the window will pass into the space between the top of the seat backs and the bottom of the overhead storage bin. In the passenger aircraft operation, it is important to keep the angle of the ASPN level, parallel with the horizon. This will provide clearance for the full pattern of the water stream to cover the fuselage interior without being blocked by the seat backs.

However, because the majority of cargo carried on freighter aircraft is packed into ULD containers, it is highly likely that a fire onboard a freighter aircraft has started within a ULD container. The position and height of the ULD is not visible from outside the aircraft. Therefore, knowledge of the aircraft type, typical load configurations, and planning with the cargo carriers are essential to developing prefire plans for the most effective fire attack for a cargo fire on a freighter aircraft.

The optimum piercing location on a freighter aircraft is at the location where the ULD is closest to the fuselage skin. When planning to pierce a freighter aircraft fuselage, the general rule for a fire on the main cargo compartment is at the 10 o'clock or 2 o'clock position of the fuselage, as viewed from the nose or tail. This position is higher than the typical piercing location on a passenger aircraft. The angle of the ASPN ideally will not be level, but rather angled slightly downward, and perpendicular with the fuselage. This is an easier piercing angle to achieve, as it is on the steeper angle of the curve of the fuselage. This position is desirable for a number of reasons:

- As shown in figure 15, there is a higher likelihood of piercing into the ULD even in wide-body aircraft and offset loads.

- The top portion of the ULD container is the most likely place where there is a void or air space. If the ASPN pierces into a void, the rated flow, pattern, and capacity of the nozzle will have greater effectiveness than if pierced into densely packed material.

- The slight downward angle of the ASPN tends to better direct the pattern for coverage within the container. Flow through the slightly angled tip provides greater coverage of the ULD.

- Piercing at lower positions is likely to enter only the void between the cargo and the fuselage wall. This is particularly true in wide-body aircraft and aircraft with offset loads.

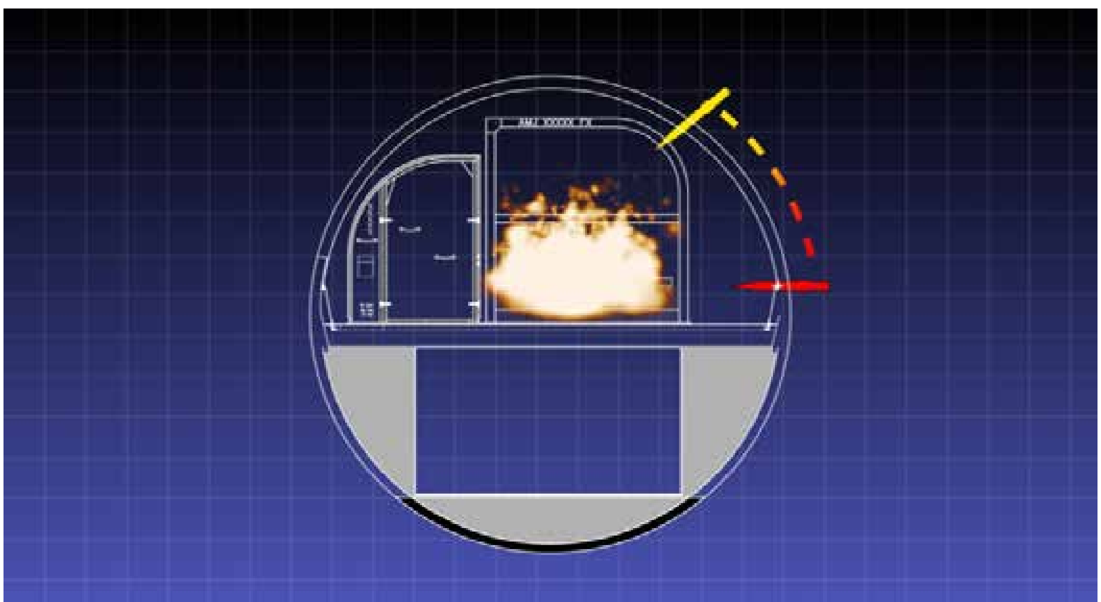


Figure 15. Main Cargo Compartment Piercing Location Examples

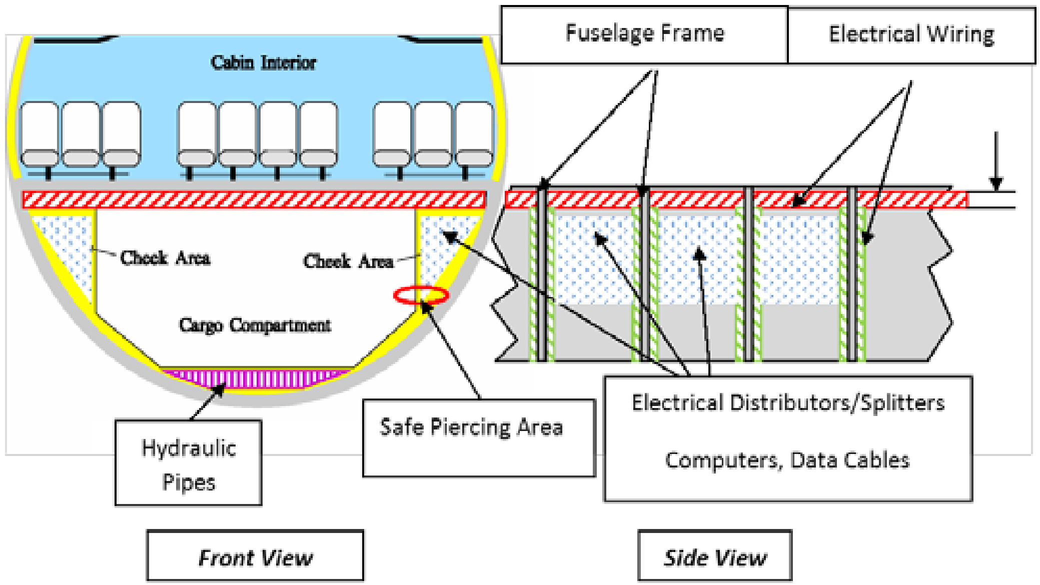
<u>5.3.2 Lower Cargo Compartments</u>.

The lower cargo compartments are located below the main cargo compartment of the aircraft. These cargo compartments have a lower overhead clearance and are shorter and narrower than the main cargo compartment. The lower cargo compartments do not run the full length of the aircraft, as the landing gear compartments and wing box separate them. They are equipped with the same floor roller systems as in the main cargo compartment to assist in the loading and offloading of ULDs.

The cheek areas are the voids created in the lower cargo compartment after the vertical bulkheads (walls) are installed to create the cargo compartment. As shown in figure 16, from the inside, the bulkheads and overhead are covered in cargo liner material with tape sealing all the joints.

Figure 16. Forward, Lower Cargo Compartment of A310

The cheek areas in the lower cargo compartments are not suitable for piercing. As shown in figure 17, a number of obstructions in the cheek areas may interfere with piercing operations. Further, the depth of the cheek area prevents any of the ASPNs currently available from reaching a fire in the ULD. Figure 18 shows the general configuration of a lower cargo compartment with a few representative distances required to pierce through the cheek area.



Legend for Cheek Area Diagram:

Electrical wiring is normally placed in and below the cabin floor, the height h shown in the above picture will be small for older aircraft as A300 and A310 and for the single aisle aircraft in the A320 family, but will increase for more sophisticated aircraft as A380 and A350. In this area you also can find air conditioning pipes, which probably will not be a hazard for firefighting activities.

The area directly beside the frames is another area used for electrical wiring and air conditioning pipes.

The area below the cargo floor is normally reserved for hydraulic and water piping, although additional electrical wires for antennas, valves and other systems can be found.

The area between the frames normally should be free of all system installation. However, due to limited space some system components as electrical distributors, splitters, computers, data cables can be found.

In this area at the lower end of the cheek area the probability to find system components is relatively low since the volume is too limited for installing voluminous parts.

Figure 17. Diagram of Lower Cargo Compartment (Courtesy of Herbert Gielen, Airbus)

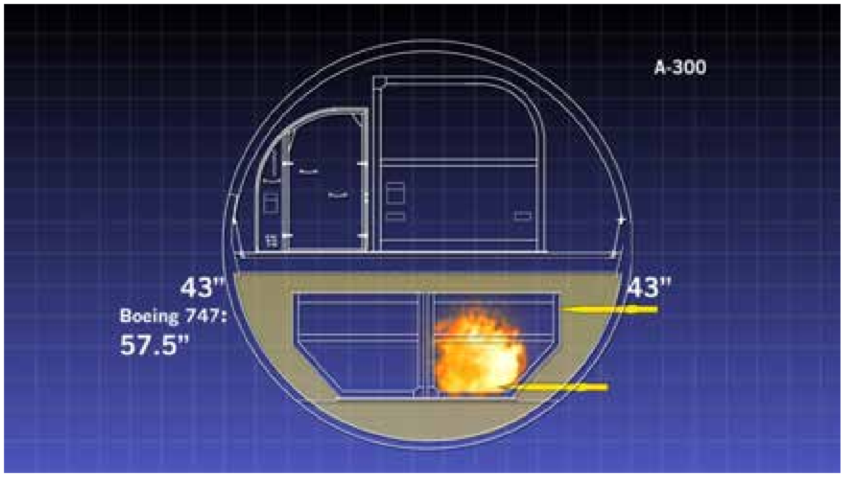


Figure 18. General Configuration of Lower Cargo Compartment

If indications and conditions suggest that the fire is out, the door can be opened with the protection of a charged hose line, full personal protection equipment, and an ARFF vehicle protecting the opening. Strategies have been identified to provide an opportunity to get agent into the lower cargo compartment without opening the door if it is determined that the fire was not extinguished with the onboard suppression system.

If piercing the compartment is necessary, there are two primary tactics.

- If piercing with the intention of discharging clean agent, piercing through the cargo door is the most direct route. There is no cheek area behind the cargo door, so the piercing tip and the discharge holes on the ASPN will be fully inside the lower cargo compartment. Choose an area away from the edges of the door, as well as the door controls and operating controls. Choose an area without rivet lines and pierce straight in. Discharge the entire volume of the clean agent system, as a great deal is consumed just filling the plumbing, and the agent may leak back if the flow stops before the full volume has been discharged. Leave the ASPN in place after discharging. This will serve to "plug the hole" made by the ASPN. Do not open the door for several minutes after discharging. If the vents have been closed, the re-introduction of agent should be able to maintain the atmosphere for an extended period. Opening the door and introducing air prematurely will defeat the intention of maintaining the atmosphere.

- If piercing with the intention of discharging water or foam into the container with a fire inside, choose a piercing location at approximately the 4 o' clock or 8 o'clock position (depending on the side of the aircraft involved). This will provide the shortest distance for the ASPN and avoid the cheek areas as much as possible. Piercing at this angle gives ARFF personnel a higher possibility of piercing into the container; if successful, it pierces through the lower portion of the container. When the agent is discharged into the container, it will have to flow through debris and packages before reaching the fire.

5.4 PREVIOUS RESEARCH: CARGO LINER.

After the UPS Flight 1307 incident, UPS fire investigators developed a theory to explain why the firefighting streams from the HRET ASPN that had pierced the fuselage had little to no effect on the burning cargo. They theorized that the cargo liner material, which lines the interior walls of the cargo compartment, became pliable due to the heat from the fire. The speculation was that, as the piercing tip passed through the aircraft skin and contacted the backside of the cargo liner, it stretched and tented inward from the force of the piercing tip. The HRET operator would expect that the ASPN would pass through the cargo liner and discharge would then be into the main cargo compartment, or ideally into the cargo ULD.

The FAA conducted two tests to evaluate the ability of an ASPN to penetrate through an aircraft cargo compartment liner while a flame is impinging on it [5]. The first was a small-scale test that used a high-intensity open flame to heat a piece of cargo liner and then penetrated the cargo liner with a mock HRET ASPN. During this test, the ASPN was able to penetrate the cargo liner, but the cargo liner was stretched. Because of the stretching, a number of holes from the ASPN were blocked, giving some initial validity to the UPS investigators' theory.

The second test used a C133 as a mock freighter aircraft with a cargo liner installed the same way it would be installed in a regular freighter aircraft. A series of radiant heater and pool fires was used as a heating source. The heaters represented radiated heat from a fire, while the pool fire represented an actual fire inside the aircraft. Tests determined that the ASPN could penetrate a cargo liner completely when heated so long as the mounting hardware did not fail.

6. FULL-SCALE, LIVE FIRE TESTS.

The freighter aircraft business is establishing an increasing presence at airports. Past freighter aircraft incidents indicate a need for new and validated tactics for the ARFF community. The FAA ARFF Research Team conducted full-scale, live fire tests to evaluate these tactics and to provide guidance to fire fighters for cargo fire incidents.

6.1 TEST AIRCRAFT.

The test aircraft, shown in figure 19, used in all the tests was an Airbus A310-203F donated by FedEx. This aircraft is frame number 254, delivered June 1, 1983, and was originally operated by Lufthansa Airlines as a passenger aircraft. FedEx acquired the aircraft on July 18, 1994, and converted it to a freighter aircraft with tail number N407FE. At the end of the aircraft's flight life, FedEx decommissioned the aircraft and donated it to the FAA for these full-scale fire tests. Due to the salvage operations associated with decommissioning the aircraft, many essential airplane parts, such as aircraft engines and electronics, were absent from the aircraft, but most of the interior of the aircraft remained intact. Because the interior was mainly intact, it was possible to run the fire tests in conditions that were as close to a normal interior environment as possible. The aircraft interior still contained the normal combination of aircraft-grade insulation and cargo liner.

Figure 19. The FAA A310 Aircraft

The aircraft's main cargo compartment remained equipped with floor rollers, container locks, and edge rails, which help move and secure containerized cargo that comes as an open pallet and cargo net or a standardized closed container. The lock system also configures the layout or placement of the containers within the aircraft. Because the aircraft was a wide-body aircraft, two or more containers could be loaded per row when loading the aircraft. In addition, container placement could vary and provide different container standoff distances away from the wall. Figure 20 shows an example of an asymmetric FedEx loading configuration in the main cargo compartment of A310 aircraft. This causes a greater distance between the fuselage and the cargo containers on the port (left) side compared to the starboard (right) side. The containers located on the port side of the aircraft stand 46 inches from the wall of the fuselage. The containers located on the starboard side stand 17 inches from the fuselage wall. The final four aft cargo positions use narrower containers or pallets to accommodate the narrowing of the fuselage. In this area, the distance from the fuselage to the container is 46 inches on both sides. Several tests examined whether the distance between the cargo container and fuselage plays an important role in the use of an HRET-mounted ASPN for firefighting operations.

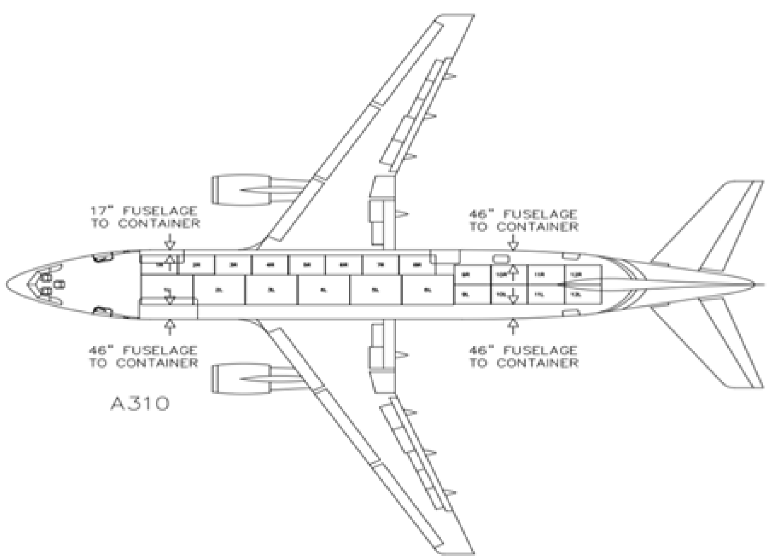


Figure 20. Standard ULD Loading Pattern for a FedEx A310 (Courtesy of FedEx)

Tactics were tested with containers at different locations, designated as three different test zones, shown in figure 21. The first test zone, where oxygen deprivation tests and penetration tests were conducted, was located in the forward part of the aircraft, 9 ft aft of the main cargo door. The second test zone, where indirect attacks were tested, was located aft of the aircraft wing, 28 ft forward of the L2 door. Finally, the third zone, where tests pertaining to cheek area penetrations occurred, was located in the forward, lower cargo compartment of the aircraft. Each test zone contained a set of sprinklers to ensure control of the fires and to prevent premature breach of the aircraft. Each sprinkler set created a water spray that would cover the whole test container and prevent the fire from spreading throughout the aircraft. The aft, lower cargo compartment served as the area where instrumentation and a data collection system were stored during the test.

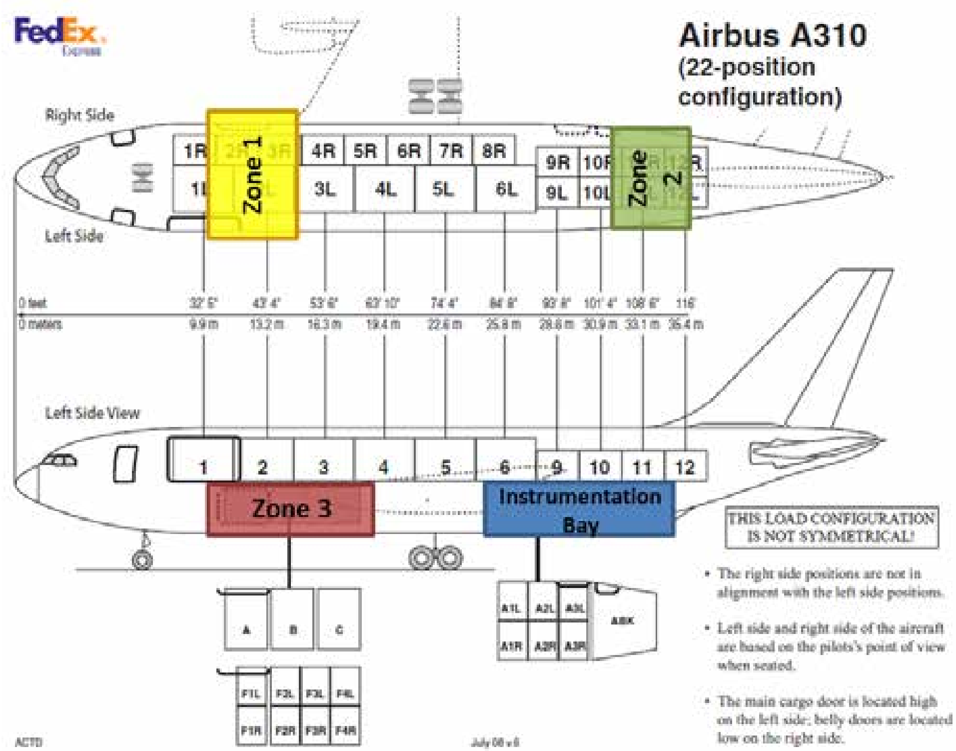


Figure 21. Locations of Test Zones

6.2 TEST SITE.

The freighter fire tests took place at the Southern California Logistics Airport (SCLA) in Victorville, CA. This airport covers approximately 2300 acres, and several aviation companies, such as the aircraft storage companies shown in figure 22, are located on the airport. The test aircraft was also decommissioned at this airport. The tests occurred on a 100- by 100-ft demolition pad owned by ARC Aerospace Industries, which consists of 20-inch-thick, 50,000 pounds per square inch (psi) concrete. The pad, designed for aircraft recycling, is equipped with spill reservoirs that can hold approximately 50,000 gallons of fuel or other liquid spilled from the aircraft. During testing, these reservoirs collected runoff water from each test run. The ARC

Aerospace demolition pad is the only place in the region where the test fires can be conducted in compliance with the Superfund Site Ground Water Monitoring Division of the San Bernardino County Fire Department. Figure 23 depicts the test aircraft on the demolition pad.

Figure 22. Aircraft Storage at SCLA

Figure 23. The ARC Aerospace Demolition Pad at SCLA

Planning meetings were conducted in October 2011 to obtain approvals from the City of Victorville, the San Bernardino County Fire Department, the Mojave Desert Air Quality Monitoring District, ARC Aerospace, Global Access (the Airport Operator), and Victorville Airport Air Traffic Control.

Instrumentation and configuration of the aircraft for the full-scale tests occurred during five set-up visits conducted in the first quarter of 2012. The first week of full-scale fire tests was conducted in late March 2012. A total of 8 weeks of fire testing was completed on November 9, 2012.

6.3 THE ULD CONTAINERS.

The tests used four different types of ULDs, as shown in figure 24. A modified half section of an AAY* container simulated a half-width container (figure 24(a)). An intact AAY container represented a full-width container (figure 24(b)). Lower cargo compartment tests used an LD3 container (figure 24(c)). The base of an AAY container represented a pallet ULD (figure 24(d)). Lexan containers with canvas doors have a tendency to breach easily, as shown in figure 25, meaning the container wall damage from the fire test is irreparable (figure 26) and can only be used once. Because it was necessary to use the containers for more than one test, the Lexan walls of the containers were replaced with aluminum sheets. Ventilation holes in the ULDs prevented self-extinguishment and allowed the fire to grow at a controlled rate.

Figure 24. Containers and Pallets Used for the Full-Scale Live Fire Tests (a) Half-Width ULD Container, (b) Full-Width ULD Container, (c) LD3 Container, and (d) Pallet

* AAY: LD7 container (88" x 125"), 81" tall, contoured for main deck wide-body and narrow-body (aka A2).

Figure 25. Fire Breaching Lexan Full-Width Container

Figure 26. Breached Lexan Container Damage

6.4 LOCKING MECHANISM.

The test aircraft contained an intact cargo floor system of rollers and container lock-down devices commonly found in freighter aircraft. The locking devices pop up to hold the containers or pallets in place, or fold down to allow them to roll unimpeded. This allowed for quick removal of the cargo container, the ability to run tests multiple times in the same location, and for restriction of cargo container movement when penetrated by an ASPN. The locations of the lock-down devices varied in each test zone because of the type of cargo container positioned in that section.

6.5 VIDEO RECORDING SYSTEM.

Several video cameras collected the visual data that provided information about the status of the aircraft interior and test container. The exterior cameras used consisted of a FLIR camera, a TIC typical of the fire service, a standard definition color camera with a narrow angle lens, and both standard- and high-definition (HD) color cameras with a wide-angle lens. Exterior camera placement depended on the test zone used. For test Zones 1 and 2, the cameras were located on top of the aircraft wing on the side of the fire apparatus. For test Zone 3, cameras were located on ground level underneath the wing adjacent to the fire apparatus. The HD camera was located some distance away from the aircraft to capture a full shot of the aircraft. The TIC was also located at a distance away from the aircraft with the purpose of capturing the thermal signatures that would be familiar to fire fighters. Inside the aircraft, a second set of video cameras used two color cameras and two FLIR cameras that were in environmentally protected housings. For test Zones 1 and 2, the cameras covered both the forward and aft sides of the test container. Figure 27 shows the positions of the cameras around the test container. The aft cameras pointed towards the door of the test container, and the forward cameras pointed towards the gap between the aircraft and the test container wall. Figure 28 shows the placement of the cameras in test Zone 3. Because of the lack of sufficient space between the aircraft wall and the right side of the test container, only one color camera and one FLIR camera were used in the left side of the test container.

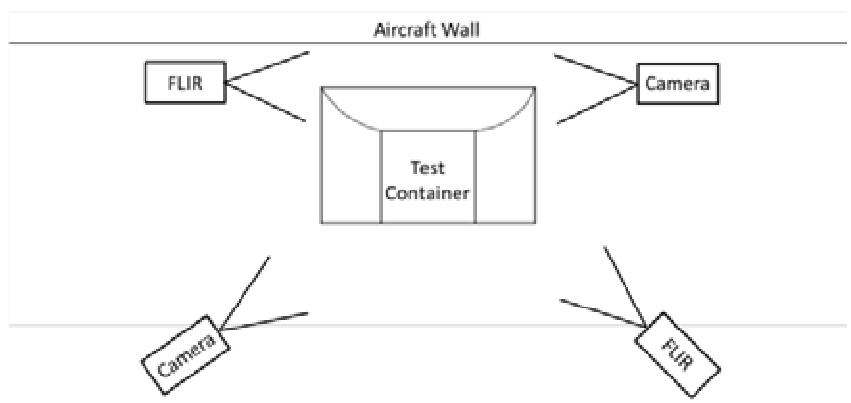


Figure 27. Camera Locations Around the Test Container in Test Zones 1 and 2

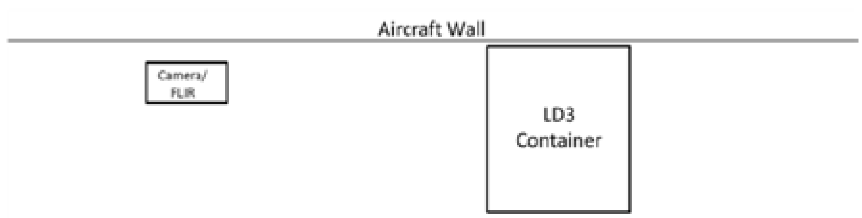


Figure 28. Camera Location Around the Test Container in Test Zone 3

6.6 OXYGEN-MONITORING SYSTEM.

One test scenario called for the monitoring of oxygen levels while tests were running. For this reason, an oxygen-sensing system was fabricated. The system, shown in figure 29, would take continuous air samples and was equipped with a set of air filters, a flow regulator, an air pump, and a Teledyne Analytical Instruments R-17A electro-galvanic fuel cell-type oxygen sensor. The air samples entered the initial pre-filter/filter in the main cargo compartment. They then would flow through tubing and would pass through an ice bath heat exchanger in order to cool the sample to a temperature that was compatible with the sensor. The samples then would pass through a desiccant filter and a 5-micron filter before passing across the oxygen sensor. Four of these sensing systems monitored the oxygen level, each in a different aircraft section. This provided an indicator of oxygen levels through the aircraft when there is a fire present. The first sensor was located 9 ft aft from the main cargo door, and the other sensors were spaced 20 ft apart from each other.

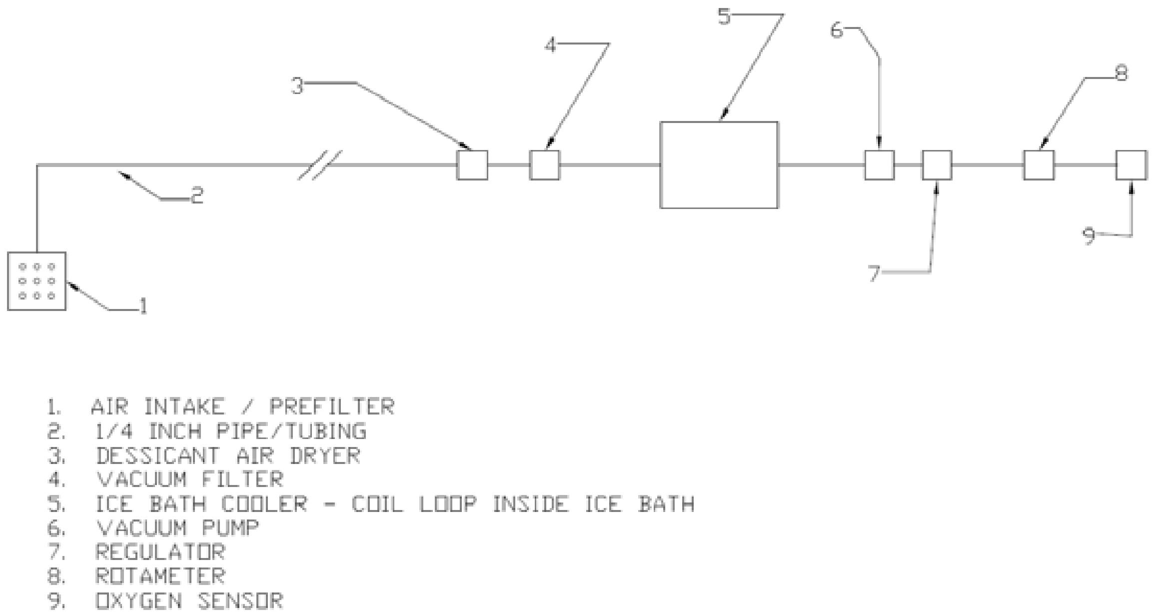


Figure 29. Oxygen-Sensing System

6.7 FIRE APPARATUS.

Two different HRET/ASPN technologies were tested and evaluated. The first was the Oshkosh Snozzle® 652 HRET system (figure 30). This HRET was on an Oshkosh Striker® 3000 ARFF vehicle, shown in figure 30. The Striker® has the ability to hold up to 2500 gallons of water and 420 gallons of extinguishing foam. This vehicle also has a fire pump with the ability to pump up to 1950 GPM at 240 psi. The Snozzle® HRET consists of a 65-ft boom with two high-flow turrets, a 45-ft horizontal reach, and an ASPN. The ASPN can apply agent at a flow rate of 345 GPM. The standard Snozzle® with no extension, as shown in figure 31, has a penetrating depth of 34 inches. With the addition of an extension, it has a penetrating depth of 46 inches.

Figure 30. The FAA Striker® 3000

Figure 31. The Snozzle® 652 HRET

The second was the Stinger® HRET system that sits on top of the Rosenbauer Panther® 6X6 ARFF vehicle, as shown in figure 32. This vehicle is capable of holding up to 3000 gallons of water and 400 gallons of foam concentrate. The Panther water pump can flow water at rates of up to 1850 GPM. The Stinger® HRET is 54-ft boom with a horizontal reach of 37.5 ft. It also has an ASPN attached to a piercing lance. According to the manufacturer, the piercing lance works as follows:

> "The piercing lance shall be retracted inside a tube when not in use to protect the piercing tip. The lance shall be hydraulically fired with amplified hydraulic flow from the three 3,000 PSI (210 bar) hydraulic accumulators for maximum piercing velocity and impacts" [6].

Figure 32. Rosenbauer Panther® 6X6

The Stinger® ASPN creates a 250-GPM, fan-shaped spray pattern. Figure 33 show how the Stinger® ASPN penetrates an aircraft.

Figure 33. Rosenbauer Stinger® HRET

6.8 FIRE LOAD.

Different types or classes of fire loads are present in airfreight, but to have consistency during each burn, the tests used Class A combustibles for the fire load. The fire load used for these tests was consistent with the Class A fire load established by the FAA Cabin Fire Safety Group for cargo fire tests [7]. The fire load consisted of 2.5 ±0.2 lb of single-cut, shredded paper placed inside a cardboard box with dimensions of 18 inches wide, 18 inches long, and 18 inches tall. In total, the box with paper should weigh approximately 4.5 lb. The exact number of boxes used per container depended on the type of container used for the test scenario. The AAY containers had 70 boxes of fire load. The modified half-width containers had 35 boxes of fire load, while the LD3 containers had 32 boxes of fire load. The pallets carried 48 boxes of fire load.

6.9 IGNITION SOURCE.

The ignition source used in these tests, like the fire load, was a 7-ft-long nichrome wire wrapped around four sheets of generic white c-fold paper towels, which was the same fire source used by the Fire Safety Group. The nichrome wire bundle was placed inside a box, identified as the ignition box, with shredded paper. A series of ventilation holes were cut into one side of the ignition box to prevent self-extinguishment and promote fire growth. The nichrome wire was connected to a 115-volt alternating current source through an insulated wire extension and was triggered remotely. When current passed through the nichrome wire, the wire heated and ignited the paper in the ignition box.

6.10 TEMPERATURE MEASUREMENTS.

To collect temperature data from each test, the containers were instrumented with thermocouples. The thermocouples used were 20-gauge K-type thermocouples with fiberglass insulation. Container-type ULDs had the thermocouples attached evenly onto the walls of the container with the intention of tracking the fire inside the container. The locations of the thermocouples varied due to the different types of containers. Appendix B provides the exact location of the thermocouples for each type of container. Figure 34 shows a thermocouple tree fabricated to map the intensity and behavior of pallet fires. The thermocouple tree consisted of a steel frame hung from the ceiling with multiple sash chains hanging from the frame. The sash chains located thermocouples at specified heights around the pallet. Appendix C provides a map of the thermocouple locations on the thermocouple tree. The graphing software Tecplot® 10 created surface temperature contour graphs of the containers from the thermocouple data.

Figure 34. Thermocouple Tree for Pallet Fires

6.11 FIRE BARRIER.

The ceilings of wide-body aircraft like the A310 are not always completely protected by a cargo liner. In the test aircraft, only a layer of thermo-acoustic insulation covered the ceiling. Part of the indirect attack test called for the use of breached containers, increasing the potential of direct fire impingement on the aircraft's ceiling and increasing the chance of a fuselage breach. Since maintaining structural integrity was a main priority, a fire barrier using a combination of high-temperature ceramic insulation and a cargo liner, as shown in figure 35, covered the ceiling of test Zone 2. This was effective in preventing fire from prematurely breaching the fuselage.

Figure 35. Fire Barrier in Test Zone 2

6.12 WEIGHT AND BALANCE.

Weight and balance were monitored during each test fire. It is clear that with too much weight on the tail, an aircraft could tail tip, which would be extremely dangerous to emergency personnel working on and around the aircraft. To monitor the weight and balance, basic measuring devices were installed at forward, aft, port, and starboard monitoring points on the test aircraft. Readings were taken before and after each test run. The amount of water discharged into the aircraft was calculated to determine the effect the water had on overall weight and balance.

The A310 is a tail-heavy aircraft, and the removal or loss of the aircraft engines increases the chances of altering the aircraft's balance. For this reason, four sets of chains and ruled pipes, as shown in figure 36, were hung from the aircraft to measure the vertical displacement of the aircraft as the weight changed. The chains were connected from each wing, the tail, and the nose below the lower part of the cockpit. The bottom of the chain was fitted with a pipe labeled with a measuring tape that fit into a larger pipe, creating a gauge. As the level of the aircraft changed, the readings from each pipe would change.

Figure 36. Weight and Balance Measuring Chains

To control the water, all existing bilge drains were sealed. It is likely that during a fire these drains could be clogged very quickly. Remotely operated bilge drains were installed. Three bilge drains, as shown in figure 37, were installed in the bottom of the aircraft to control the water remaining inside the fuselage bilge, which assisted in accurately measuring the vertical displacement of the aircraft. These drains maintained the water inside while the test ran and opened upon completion of each test. At the end of each fire test, the weight and balance readings were recorded. The final step was to ensure the area was clear of personnel and then open the drains. For each test, there was an interest in seeing how the amount of water applied to an aircraft would affect its balance. The concern was that if too much water was added to the aircraft, there would be the possibility of instability or tipping the aircraft.

Figure 37. Bilge Drain

6.13 STANDOFF DISTANCE.

For successful penetration, the ARFF vehicles needed to be at a specific distance away from the aircraft. This distance, known as the standoff distance, represents the distance that the ARFF vehicle sits away from the aircraft. If the standoff distance is too close or too near the aircraft, the HRET will not be able to position itself correctly, and penetration of the aircraft will not be successful. To measure the standoff distance, a hand-held distance meter (Leica DISTO™ D330i) was placed inside the cab at the ceiling and pointed horizontally toward the fuselage of the aircraft.

6.14 TEST SCENARIOS.

Eleven scenarios were completed, each consisting of a minimum of three tests for repeatability and to detect unusual test outliers. Table 1 provides a matrix of the test scenarios for the full-scale tests.

Table 1. Full-Scale Test Scenarios

Test Scenario	Type of Test	ULD Type	Nozzle/HRET Used	Test Zone
1	Oxygen limitation	Full-width	N/A	1
2	Penetration	Half-width	Snozzle®	1
3	Penetration	Half-width	Extended Snozzle®	1
4	Penetration	Half-width	Stinger®	1
5	Penetration	Full-width	Stinger®	1
6	Penetration	Full-width	Extended Snozzle®	1
7	Penetration—Cheek area	LD3	Stinger®	2
8	Indirect	Full-width	Stinger®	3
9	Indirect	Full-width	Snozzle®	2
10	Indirect	Full-width	Prototype nozzle	2
11	Pallet—Indirect	Pallet	Snozzle®	2

Due to the availability of the aircraft, a series of tests consisting of additional tactics were tested inside the aircraft after all the test scenarios in table 1 were completed. The results of these test scenarios are discussed in section 7.

7. RESULTS AND DISCUSSIONS.

Table 2 gives a summary of all the tests completed for this study. This table shows the configurations for the type of ULD device and the ASPN used for each specific test scenario. The table also shows how long each test continued before ARFF personnel entered the aircraft and the approximate amount of water discharged by the ASPN. The table also shows the maximum temperature of the container at different points in the test. Additional information of each test is in each of the respective test sections.

Table 2. Overview of All Tests

Test No.	ULD Type	Extinguishment Tactic	HRET	Test Duration	Water Used (gallons)	Maximum Temperature at Time of Discharge (°F)	Maximum Temperature at End of Discharge (°F)	Maximum Temperature 2 Minutes After Discharge (°F)
1.1	Full-width	Oxygen limitation	N/A	62 m 40 s	0	N/A	N/A	N/A
1.2	Full-width	Oxygen limitation	N/A	50 m 17 s	0	N/A	N/A	N/A
1.3	Full-width	Oxygen limitation	N/A	45 m 30 s	0	N/A	N/A	N/A
2.1	Half-width	Penetration	Snozzle®	22 m 48 s	575.0	756	119	100
2.2	Half-width	Penetration	Snozzle®	19 m 30 s	718.8	738	97	106
2.3	Half-width	Penetration	Snozzle®	18 m 58 s	517.5	987	252	226
3.1	Half-width	Penetration	Extended Snozzle®	18 m 29 s	345.0	634	160	112
3.2	Half-width	Penetration	Extended Snozzle®	18 m 38 s	345.0	951	105	100
3.3	Half-width	Penetration	Extended Snozzle®	25 m 47 s	373.8	989	191	128
4.1	Half-width	Penetration	Stinger®	18 m 46 s	375.0	595	101	126
4.2	Half-width	Penetration	Stinger®	18 m 52 s	375.0	874	209	235
4.3	Half-width	Penetration	Stinger®	23 m 59 s	375.0	891	258	334
5.1	Full-width	Penetration	Stinger®	23 m 44 s	375.0	499	352	320
5.2	Full-width	Penetration	Stinger®	23 m 58 s	375.0	800	580	465
5.3	Full-width	Penetration	Stinger®	23 m 56 s	375.0	1060	341	278
6.1	Full-width	Penetration	Extended Snozzle®	19 m	517.5	455	165	138

Table 2. Overview of All Tests (Continued)

Test No.	ULD Type	Extinguishment Tactic	HRET	Test Duration	Water Used (gallons)	Maximum Temperature at Time of Discharge (°F)	Maximum Temperature at End of Discharge (°F)	Maximum Temperature 2 Minutes After Discharge (°F)
6.2	Full-width	Penetration	Extended Snozzle®	24 m	517.5	572	109	109
6.3	Full-width	Penetration	Extended Snozzle®	19 m 21 s	517.5	1155	640	532
7.1	LD3	Penetration—Cheek area	Stinger®	29 m 2 s	387.5	546	424	382
7.2	LD3	Penetration—Cheek area	Stinger®	29 m 30 s	500.0	875	850	636
7.3	LD3	Penetration—Cheek area	Stinger®	19 m 21 s	750.0	922	737	590
8.1	Full-width	Indirect	Stinger®	6 m 9 s	395.8	1767	689	512
8.2	Full-width	Indirect	Stinger®	10 m 27 s	625.0	912	468	487
8.3	Full-width	Indirect	Stinger®	11 m 20 s	625.0	926	339	390
9.1	Full-width	Indirect	Snozzle®	6 m 30 s	609.5	688	536	569
9.2	Full-width	Indirect	Snozzle®	6 m 17 s	690.0	1013	833	830
9.3	Full-width	Indirect	Snozzle®	7 m 57 s	690.0	911	695	649
10.1	Full-width	Indirect	Prototype	6 m	517.5	1046	155	269
10.2	Full-width	Indirect	Prototype	6 m 6 s	690.0	1070	182	482
10.3	Full-width	Indirect	Prototype	7 m 17 s	724.5	1697	443	398
11.1	Pallet	Indirect	Snozzle®	30 m 7 s	753.3	1418	191	170
11.2	Pallet	Indirect	Snozzle®	7 m 36 s	730.3	1753	142	143
11.3	Pallet	Indirect	Snozzle®	6 m 41 s	690.0	1656	225	126

7.1 OXYGEN DEPRIVATION.

The first test scenario examined the tactic of oxygen deprivation (see test numbers 1.1 through 1.3 in table 2), which prevents the fire from getting an adequate amount of oxygen by limiting the amount of fresh air in the main cargo compartment. By doing this, the growth or spread of the fire can be reduced to give ARFF personnel time to stage and prepare to extinguish the fire using hand line techniques. It may also prevent the need for immediate aircraft entry by reducing the fire to a smoldering state. To accomplish this normally, ARFF personnel would close the aircraft doors and windows. For this test scenario, the excess holes from part removal during decommissioning were also sealed. Nine AAY containers, each filled with 70 boxes of fire load, were loaded into the A310 with the intention of reducing airspace and simulating a fully loaded aircraft. The test container was located in Zone 1, directly under an oxygen sensor. The fire was allowed to burn for a period of 45 minutes or more.

For the first test run (see test number 1.1 in table 2), the fire burned for 62 minutes and 40 seconds before ARFF personnel entered the aircraft. Thirty minutes into the first test, all the test container ceiling thermocouples showed readings above 500°F. The highest temperature reading of the thermocouples at the 30-minute mark was 648°F and was near the test container door. Forty-five minutes after ignition, the temperatures of the ceiling thermocouples ranged between 550° and 600°F. The maximum ceiling temperature of the test container at that time was 836°F. Fifty minutes after ignition, the AAY container had a maximum ceiling temperature of 540°F on the right side of the test container. In addition, the overall wall temperatures of the test container continued to rise. Although the maximum ceiling temperature dropped to 724°F, temperatures around the test container as a whole kept going up. When fire fighters opened the test container, they found that a robust fire remained inside the test container. The fire consumed almost the entire fire load in the test container.

The second test run for this scenario (see test number 1.2 in table 2) ran for 50 minutes and 17 seconds before ARFF personnel entered the aircraft. The temperature readings from this test indicate that the results were similar to the first test. Figure 38 shows the temperature contours of the container during test 2. Fifteen minutes after ignition, ceiling temperatures ranged from 409° to 617°F (figure 38(a)). The top right side of the container indicated the highest heat concentration. Thirty minutes after ignition, ceiling temperatures continued to rise with temperature ranges of 558° to 711°F (figure 38(b)). The highest temperature around the container was 916°F, located in the right side of the container door. The container temperatures also rose, with some wall thermocouples reaching temperatures of over 500°F. Figure 38(c) shows the maximum ceiling temperature dropped from 916° to 821°F 45 minutes into the test. Meanwhile, the hotspot around the container door dropped to 771°F. Inspecting the thermocouple readings suggested that most of the fire was concentrated around the right side of the container. After ARFF personnel entered the aircraft and extinguished the fire, inspection determined that the fire had consumed most of the fire load.

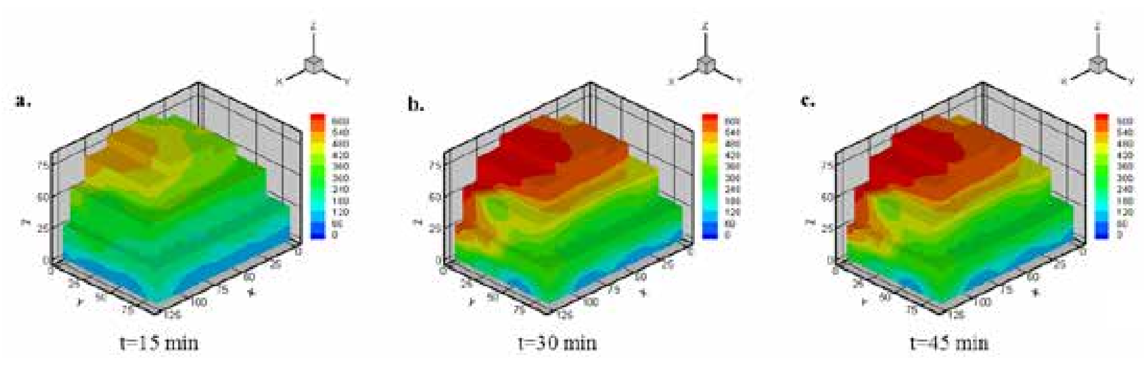


Figure 38. Oxygen Deprivation Inside an AAY Container

The third test run for this scenario (see test number 1.3 in table 2) ran for 45 minutes and 30 seconds before ARFF personnel entered the aircraft. Fifteen minutes after ignition, the ceiling temperatures of the container ranged from 415° to 646°F. After burning for 30 minutes, the ceiling temperatures rose to the range of 519° and 664°F. The highest temperature reading was 735°F, which was located close to the right side of the container door. After 45 minutes of burning, temperatures continued to rise, which was similar to the first two tests. Approximately half of the container temperatures read above 400°F. Ceiling temperatures ranged from 588° to 645°F. The hottest spot in the container remained to the right side of the container door, but its temperature dropped to from 735° to 703°F. Like the previous tests, only a small amount of the fire load remained inside the container.

Figure 39 shows the oxygen levels for all three tests for this scenario. These graphs start from the time of ignition and conclude 5 minutes after ARFF personnel opened the L1 door. Each line represents a 10-point moving average with data collected at a rate of one sample taken every 10 seconds. Figure 39(a) represents the oxygen level of test 1.1. Note that the oxygen levels by each sensor seem to drop at a similar rate. The oxygen levels continue to decrease until approximately 4 minutes after opening the L1 door. This could be because of the large size of the main cargo compartment compared to the size of the L1 door; it will take some time for the L1 door to influence ventilation inside the aircraft. Sensors 1 and 3 recorded the lowest oxygen readings. Sensor 1 was located right above the test container and the local consumption of oxygen from the fire, which may have caused the low reading. The overall oxygen levels dropped between 4% and 5%. The oxygen levels of all sensors from test 1.2 dropped at a similar rate. Again, the oxygen levels continued to drop after opening the L1 door. For this test, sensors 1 and 4 recorded the lowest oxygen levels, as shown in figure 39(b). Like the first test run, oxygen levels dropped by 4% to 5% after a burn time of approximately 50 minutes. The oxygen levels for test 1.3 dropped at a similar rate throughout the aircraft, as shown in figure 39(c). Sensor 4 registered the lowest oxygen levels of all the sensors. The oxygen levels in test 1.3 dropped by 4% and 5%.

The temperature data showed that container temperatures continued to rise throughout the test instead of indicating any decrease. The oxygen concentration levels decreased at a slower rate than expected. To declare an environment to be oxygen deprived, oxygen levels need to be below 12%, which was not observed in these tests. Overall, although oxygen levels inside the aircraft did drop, they did not drop low enough to declare the tactic effective.

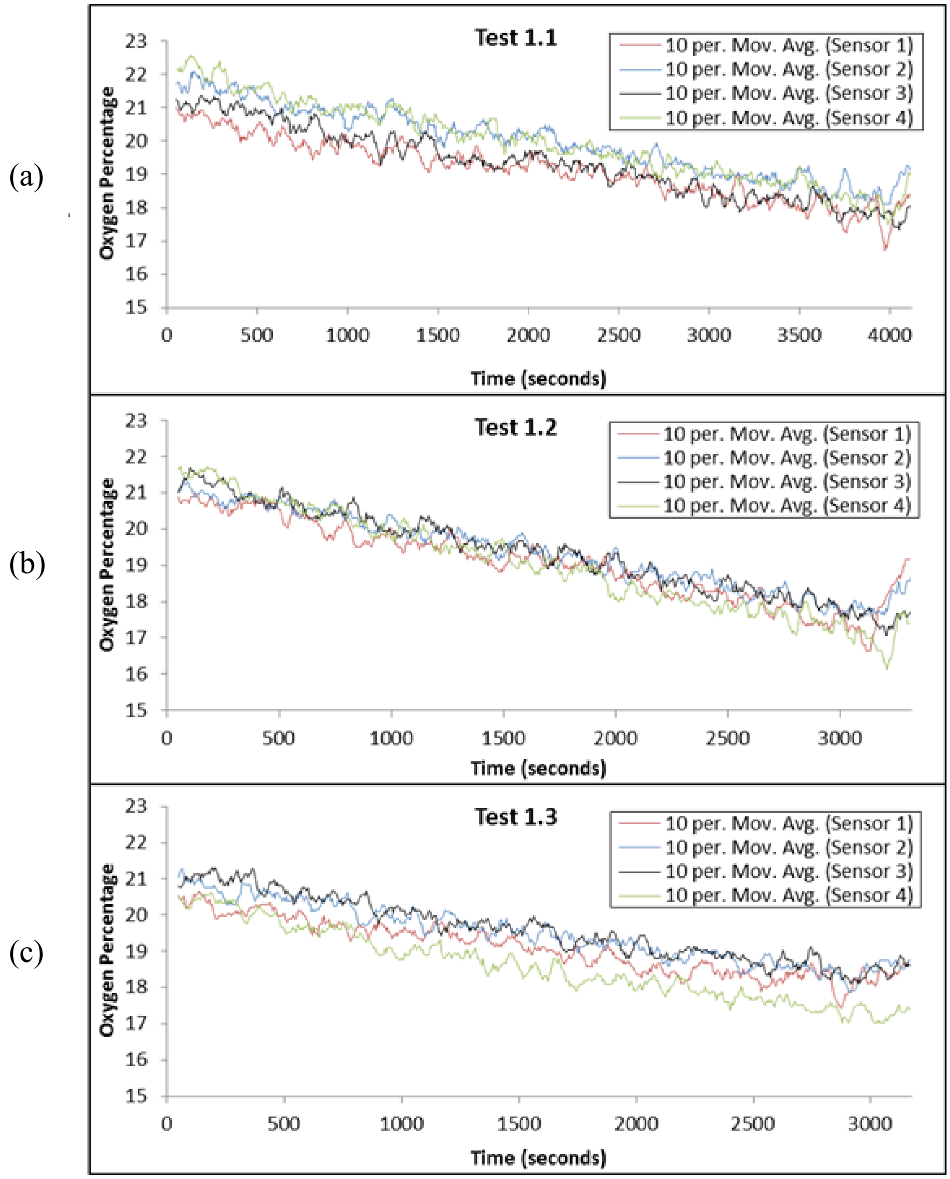


Figure 39. Oxygen Levels From Oxygen Deprivation (a) Test 1.1, (b) Test 1.2, and (c) Test 1.3

7.2 HALF-WIDTH CONTAINER PENETRATION.

The next series of test scenarios examined tactics using an HRET equipped with an ASPN to penetrate through the aircraft and into a half-width container. These scenarios determined the ability of the ASPN to penetrate the container and control the fire, and documented other notable observations that could affect this tactic. Since the container was in the main cargo compartment, the various ASPNs pierced the fuselage at a 2 o'clock position. All the test scenarios were conducted in Zone 1.

7.2.1 Half-Width Container Snozzle® Penetration.

The first penetration test scenario consisted of piercing the modified half-width container with a standard Snozzle® ASPN. Each container was filled with a fire load of 35 boxes and burned for a period of time until the fire had grown to a considerable size. Once the container was penetrated, agent discharge continued until it was determined that most of the fire had been extinguished. The Snozzle® ASPN successfully pierced through the container, and all the ASPN holes were inside the container by 2 or more inches. Figure 40 shows the extent of penetration into the container. Because the ASPN's holes remained near the back wall, most of the water spray wrapped around the container walls and did not directly contact the fire.

Figure 40. Snozzle® ASPN Penetrating the Half-Width Container

The first test run for this scenario (see test number 2.1 in table 2) ran for 22 minutes and 42 seconds before ARFF personnel entered the aircraft. After ignition, the fire grew for 12 minutes and 40 seconds before discharging agent (water) into the container. A small breach appeared in the lower right corner of the container wall at 11 minutes and 30 seconds after ignition. The TIC did not detect any hotspots while the container fire grew. Once discharge began, the container ceiling temperatures reached as high as 712°F, while the container door temperatures reached as high as 756°F. A small wall breach, which allowed more air into the container, may have been the cause for the high container door temperature. Figure 41 shows the temperature variations of the entire aircraft from the TIC at the moment the first water discharge began. Once the water discharge began, the container temperatures started dropping. Two water discharges were used for this test. The first discharge continued for 1 minute and 8 seconds. After which, temperatures were monitored for 4 minutes and 30 seconds before beginning the second discharge. The interior FLIR imagery did show the presence of heat signatures. Just before the second discharge began, the maximum container temperature was 118°F. The second discharge continued for 32 seconds, and the maximum temperature at the end of the second discharge was 119°F. Essentially, there was no change in the temperatures around the container. Two minutes after the second discharge ended, the container's temperatures dropped to a maximum of 100°F. When ARFF personnel reached the container and opened the door, they only found a small fire in one of the corners of the container, even though 575 gallons of water were discharged into the container. Upon inspection, less than 50% of the fire load remained unburned.

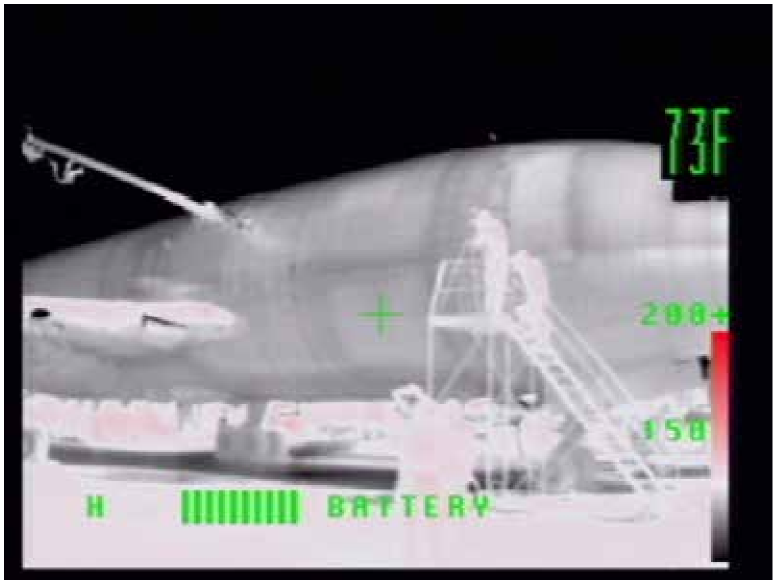


Figure 41. The TIC Temperature Reading of the Entire Aircraft at the Moment Discharge Began

The second test run for this scenario (see test number 2.2 in table 2) only ran for 29 minutes and 30 seconds before ARFF personnel entered the aircraft. The fire matured for 20 minutes and 40 seconds before water discharge began. Figure 42 shows the temperature readings for the second test run. At this point, as shown in figure 42(a), the highest temperature read by the container thermocouples was 738°F and was located in the left lower corner of the container door. The maximum container ceiling temperature at the time was 649°F. For this test, two water discharges were attempted. For the first discharge, the ASPN sprayed water into the container for 1 minute and 4 seconds. When the second discharge began at 1 minute and 32 seconds after the end of the first discharge, container temperatures were just below 300°F. Figure 42(b) shows the temperature contours of the container at that time. The second discharge continued for 1 minute and 1 second. The subsequent maximum container temperature at the end of the second discharge was 97°F, as shown in figure 42(c). By the time the second discharge ended, approximately 719 gallons of water had been discharged into the container. Two minutes after the second discharge ended (figure 42(d)), the highest temperature read by the container thermocouples was 106°F. The only residual fire was a small fire found in the corner upon opening the container door. Approximately 20% to 25% of the fire load remained, and a breach hole was present in the lower section of the container door. When evaluating the test container, the breach on the container door appeared to be from the water spray itself. This type of hole can be created from quenching and contraction when the cold spray makes contact with the high temperature wall.

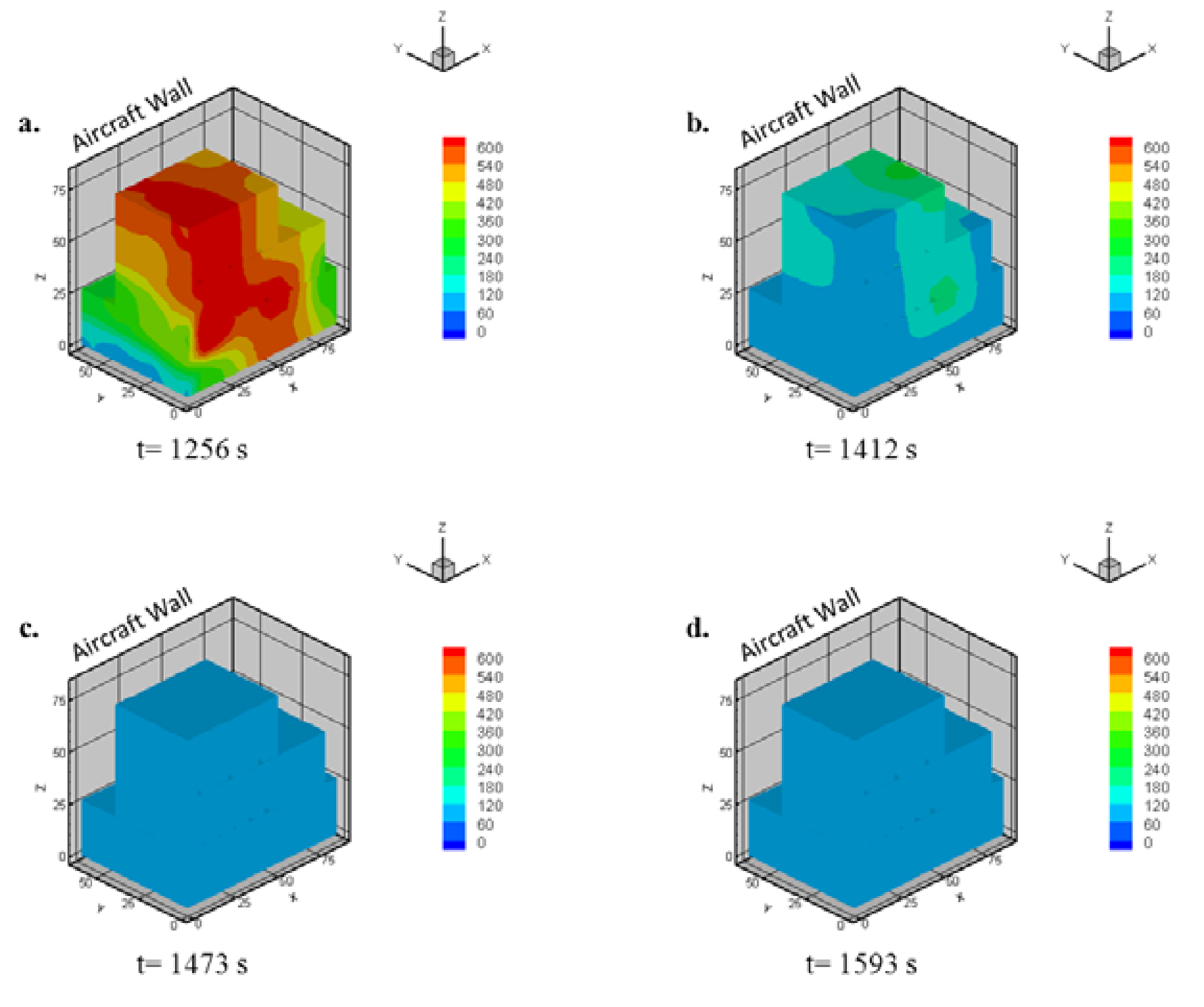


Figure 42. Temperature Readings During Half-Width Container Penetration Using a Snozzle® ASPN

The third test run for this scenario (see test number 2.3 in table 2) ran for 18 minutes and 58 seconds before ARFF personnel entered the aircraft. After ignition, the fire grew for 15 minutes and 16 seconds before discharge began. When the discharge began, container ceiling temperatures were above 400°F, with a maximum reading of 931°F. Door temperatures reached as high as 987°F. After penetrating the container, the ASPN sprayed water into the container for 1 minute and 30 seconds—meaning approximately 518 gallons of water entered the container. As discharge occurred, the container door opened and some of the water sprayed out of the container. Ten seconds into the discharge, the highest ceiling temperature was 789°F. When discharge ended, the container ceiling temperatures ranged from 93° to 252°F. Two minutes after the discharge ended, the highest ceiling temperature dropped from 252° to 226°F. When ARFF personnel inspected the container, they found that only smoldering boxes remained inside the container. A breach was present in the right side of the container, as shown in figure 43. The high-pressure spray from the ASPN may have caused the breach. It is likely that the spray blew through the aluminum, which softened from the heat of the fire. The test consumed approximately 75% of the fire load.

Figure 43. Breached Wall After Penetration Test

Overall, a standard Snozzle® ASPN displayed the ability to penetrate through the aircraft wall, cargo liner, and container wall with relative ease. Once it penetrated the container, the ASPN successfully extinguished and/or controlled most of the fire. It should be noted that the ASPN's water had enough strength to create holes in the heat-softened container walls.

7.2.2 Half-Width Container Extended Snozzle® Penetration.

The second penetration test scenario consisted of piercing a modified half-width container with a Snozzle® ASPN fitted with an extension tube. As in the first scenario (see section 7.2.1), the container was filled with a fire load of 35 boxes and burned until a robust fire was present inside the container. Figure 44 shows the Snozzle® ASPN (fitted with extension) piercing through a half-width container that was located next to the fuselage wall. When using the Snozzle® ASPN with an extension, the ASPN tip penetrated further into the container; with the extension, the ASPN can penetrate 14 inches inside the container versus an approximate 2 inches without it. This promoted effective container fire extinguishment.

Figure 44. Snozzle® ASPN With Extension Penetrating the Half-Width Container

The first test run for this scenario (see test number 3.1 in table 2) ran for 18 minutes and 29 seconds before ARFF personnel entered the aircraft. After ignition, the fire grew for 15 minutes and 15 seconds before discharge occurred. When the extended ASPN penetrated the container and discharge was about to begin, the maximum container ceiling temperature was 589°F. Most of the heat concentration was around the container door where temperatures ranged from 131° to 634°F. The ASPN sprayed water into the container for 1 minute (345 gallons). Observing temperature readings 10 seconds into water discharge showed no significant change in the container temperatures. When discharge was complete, the highest temperature was 160°F, and this reduced to 112°F after 2 minutes. When ARFF personnel inspected the container, they found no fire inside the container, only smoldering boxes. The fire consumed approximately 75% of the fuel during the test and did not appear to damage the container.

The second test run for this scenario (see test number 3.2 in table 2) ran for 18 minutes and 38 seconds before ARFF personnel entered the aircraft. After ignition, the fire grew for 15 minutes and 23 seconds before discharge began. Once the ASPN penetrated the container, discharge continued 1 minute. When the discharge began, the container ceiling temperatures ranged from 580° to 951°F. When observing the temperature readings, most of the heat concentration was located in the right side of the container. Ten seconds into discharge, the container ceiling temperatures significantly dropped, with the maximum ceiling temperature being 596°F. When the discharge ended, the container temperatures ranged from 76° to 105°F. After 2 minutes, thermocouple data showed a 5°F reduction to the maximum temperature. When ARFF personnel entered the aircraft and inspected the container, they found no fire inside the container. Smoldering boxes (approximately 10% of the fire load) were the only things present inside the container.

The third test run for this scenario (see test number 3.3 in table 2) ran for 25 minutes and 47 before ARFF personnel entered the aircraft. Figure 45 shows the temperature contours from the time the discharge began until 2 minutes after discharge ended. For this test, the fire grew for 21 minutes and 20 seconds before attempting to extinguish the fire. When the ASPN pierced the container, it sprayed water into the container for 1 minute and 5 seconds, applying approximately 374 gallons of water. From the thermocouple data recorded at the time discharge began (figure 45(a)), the container ceiling temperatures ranged from 600° to 864°F. The highest temperature readings were located close to the container door, where temperatures ranged up to 989°F. Figure 45(b) shows that 10 seconds after discharge began, most of the container ceiling temperatures had already dropped below 200°F, except for a ceiling thermocouple near the container door that read 486°F. At the same time, the container door still had a hotspot of 952°F present. Most of the heat was concentrated in the front of the container and not the back. When discharge was complete, all ceiling temperatures had dropped below 90°F (figure 45(c)). The hotspot at the container door was still present at the end of discharge, but its temperature dropped from 952° to 191°F. After 2 minutes, the hotspot dropped to 128°F. The remaining container temperatures evened out but were no higher than 120°F. When ARFF personnel inspected the container, they only found approximately 15% of unburned fire load. Inspecting the container showed that cracks in the front of the container and a large breach hole were present, as shown in figure 46. Again, the cracks were likely from quenching and contraction of the aluminum wall.

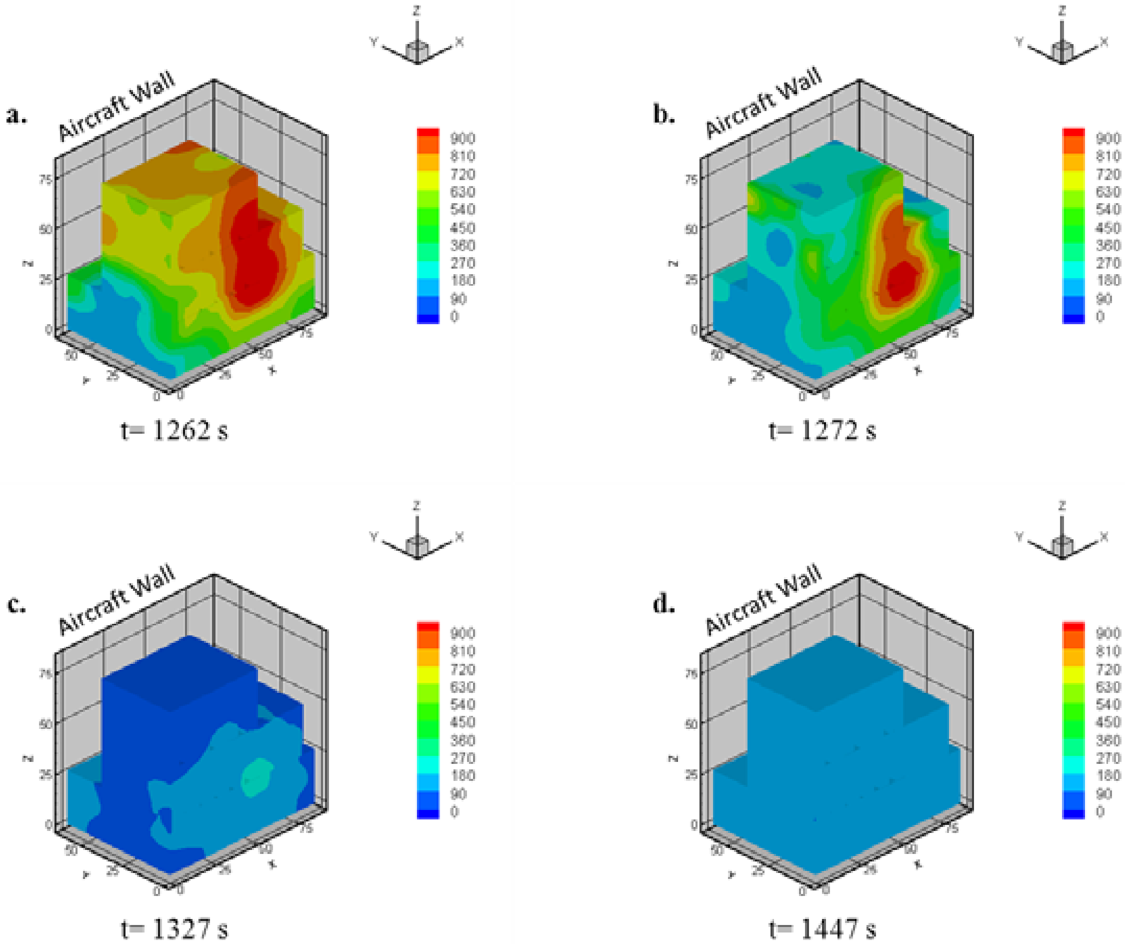


Figure 45. Temperature Readings During Half-Width Container Penetration Using an Extended Snozzle® ASPN

Figure 46. Breached Door of Half-Width Container After Penetration Test

These test results provide evidence that the Snozzle® ASPN with the extension provided better control of the fire inside the container, while using less water, compared to the standard Snozzle® ASPN. This could be because the extension allowed the ASPN to be closer to the fire source. This increased the effectiveness of potential extinguishment. In addition, the tests showed the interaction of hot metal and cold-water spray caused cracks in the container.

7.2.3 Half-Width Container Stinger® Penetration.

The third penetration test scenario consisted of using the Stinger® ASPN as the penetrating device. As in the previous two scenarios (see section 7.2.1 and 7.2.2), the test articles were modified half-width containers and filled with 35 boxes of fire load. Once a robust fire was present, the ASPN pierced the container, and water discharge was attempted. The ASPN penetrated the container but only three of the four rows of holes in the ASPN made it through the container wall, as shown in figure 47. This indicated that when attempting to extinguish the fire, not all of the water would make it into the container, meaning longer discharges would be needed to extinguish the fire.

Figure 47. Stinger® ASPN Penetrating the Half-Width Container

The first test run for this scenario (see test number 4.1 in table 2) ran for 18 minutes and 46 seconds before ARFF personnel entered the aircraft. The time between ignition and water discharge was 15 minutes and 18 seconds. Figure 48 shows the temperature contours of the container from the beginning of water discharge until 2 minutes after discharge ended. Discharge into the container took 1 minute and 30 seconds. Before the Stinger® ASPN commenced discharge (figure 48(a)), the container ceiling temperatures ranged from 192° to 595°F. A hotspot was also present at the top right corner of the container door with temperatures that ranged up to 590°F. Ten seconds into discharge, container ceiling temperatures dropped as low as 116°F while still having a ceiling hotspot of 418°F present in the top left corner, as shown in figure 48(b). Meanwhile, the door hotspot dropped from 590° to 474°F. At the end of discharge, the highest temperature read by any of the container thermocouples was 101°F, and most thermocouples read between 80° and 90°F, as shown in figure 48(c). Two minutes after the discharge ended, most of the thermocouples around the container recorded temperatures between 95° and 126°F, as shown in figure 48(d). Most of the higher temperatures were located toward the back of the container. When ARFF personnel inspected the container, they found a small fire still present inside the container. After extinguishing this small fire, approximately 15% of the fire load remained unburned.

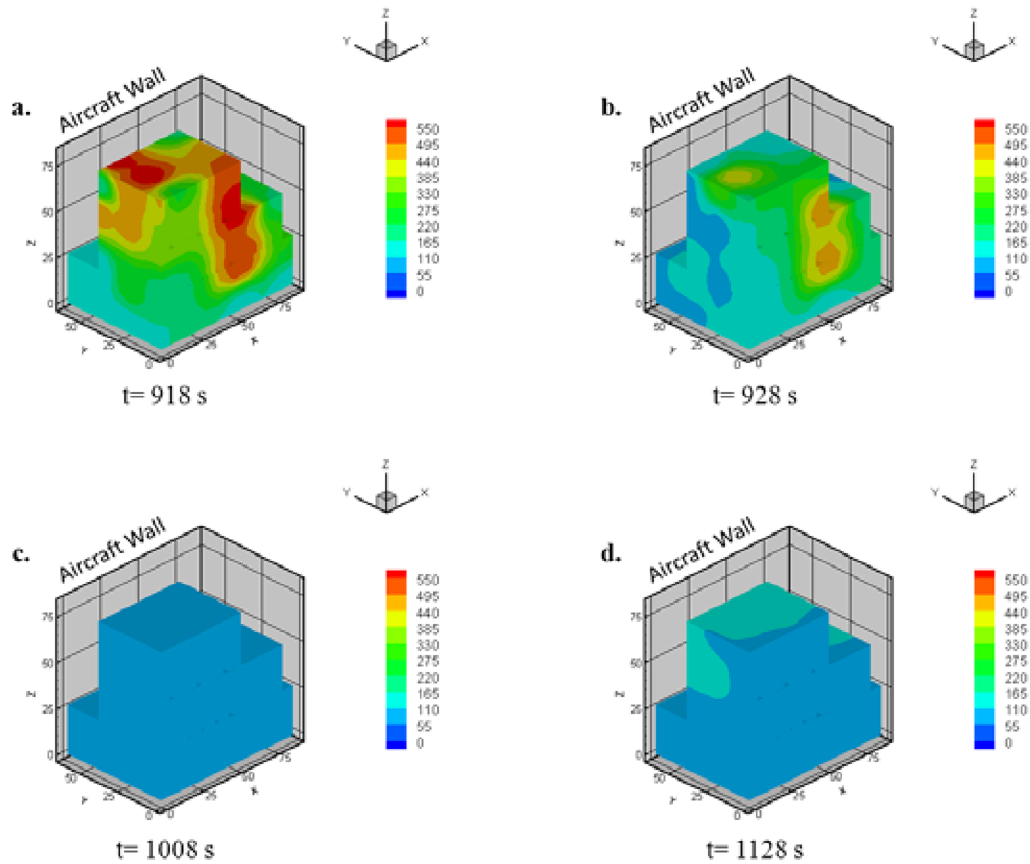


Figure 48. Temperature Readings During Half-Width Container Penetration Using a Stinger® ASPN

The second test run for this scenario (see test number 4.2 in table 2) ran for 18 minutes and 52 before ARFF personnel entered the aircraft. Before discharge began, the fire burned inside the container for 15 minutes and 8 seconds. Water discharge into the container took 1 minute and 34 seconds. When discharge began, the container ceiling temperatures ranged from 478° to 803°F. The forward right side of the container contained a hotspot of 874°F. The highest temperature read by the thermocouples in the left side of the container was 502°F. Ten seconds into the water discharge, most of the container ceiling temperatures dropped below 300°F, with the exception of the top left side of the container, where temperatures were 511°F. The hotspot in the right side of the container remained, but its maximum temperature reduced from 874° to 820°F. At the end of discharge, most of the thermocouples read approximately 95°F. The hotspot in the right side of the container disappeared; and the only noticeable hotspot in the container was located in the top right corner of the container door, which recorded a temperature of 209°F. Two minutes after the discharge ended, this temperature rose to 235°F. When ARFF personnel opened the container, they found and extinguished a small fire still present. Overall, the fire consumed approximately 85% of the fuel during the test.

The third test run for this scenario (see test number 4.3 in table 2) ran for 23 minutes and 59 seconds before ARFF personnel entered the aircraft. The fire inside the container burned for 20 minutes and 10 seconds before discharge began. This test was performed for an additional 5 minutes compared to the previous two tests because the fire growth was much slower than the past two tests. Just before discharge began, the container temperatures ranged from 89° to 891°F, with a hotspot located in the lower right side of the container door. Discharge into the container continued 1 minute and 36 seconds. Ten seconds into discharge, the hotspot was still present at the container door, and the highest temperature dropped from 891° to 844°F. When discharge into the container had finished, this hotspot dropped down to 258°F; and 2 minutes later, the hotspot increased to 334°F. When ARFF personnel inspected the container, there was a small fire still present in the location of the hotspot. During the test, fuel consumption was approximately 90%.

Although the Stinger® ASPN did not penetrate the container wall completely, test results showed that it had the ability to control the fire inside the container. Unlike the Snozzle® ASPNs, the Stinger® ASPN spray did not appear to cause any damage to the container.

7.3 FULL-WIDTH CONTAINER PENETRATION.

The next test scenario examined the tactic of using an ASPN on a full-width container. Additionally, there was an interest as to whether the depth of ASPN penetrating into the cargo container could have an effect on fire extinguishment. The Stinger® ASPN, with the shortest length, and the Snozzle® extended ASPN, with the longest length, were used in this test scenario. Each ASPN penetrated the aircraft fuselage at a 3 o'clock attack position.

7.3.1 Full-Width Container Stinger® Penetration.

The first full-width container penetration test scenario consisted of penetrating the AAY container with the Stinger® ASPN. The test used full-width containers, filled with 70 boxes of fire load. When the Stinger® ASPN pierced the full-width container, the holes of the ASPN barely passed through the container wall, as shown in figure 49. Compared to the half-width container tests, this penetration was more successful because all the ASPN holes made it through the container.

Figure 49. Stinger® ASPN Penetrating the Full-Width Container

The first test run for this scenario (see test number 5.1 in table 2) ran for 23 minutes and 44 seconds before ARFF personnel entered the aircraft. Between ignition and the beginning of discharge, the fire grew inside the container for 20 minutes and 12 seconds. Figure 50 shows the temperature readings of the container from one of the interior FLIR cameras from beginning of discharge to 2 minutes after discharge ended. From what was observed, the FLIR temperature readings did not agree with thermocouple readings. The emissivity settings on the FLIR camera and the reflective surface of the container were some of the factors contributing to this discrepancy. The FLIR images were used for visual observation of the interior conditions and not for temperature data. By the time the Stinger® ASPN penetrated the container and was about to begin discharge, the container's ceiling temperatures (as recorded by the thermocouples) ranged from 92° to 499°F. The higher temperature readings were located near the top right corner of the container door. Meanwhile, a majority of the other container thermocouples had readings of approximately 95°F. Once discharge began, the ASPN sprayed water for 1 minute and 30 seconds at 375 GPM. When reviewing the data collected, the hotspot in the top right corner of the container door increased to 509°F after 10 seconds into discharge. Meanwhile, almost all the other container thermocouples remained unchanged. When the discharge ended, the hotspot temperature decreased from 509° to 352°F. After 2 minutes, the hotspot decreased to 320°F. When the ARFF personnel inspected the container, they found a small fire inside the container. Upon inspection of the container, approximately 50% of the boxes were consumed and a small breach hole was present in the container door.

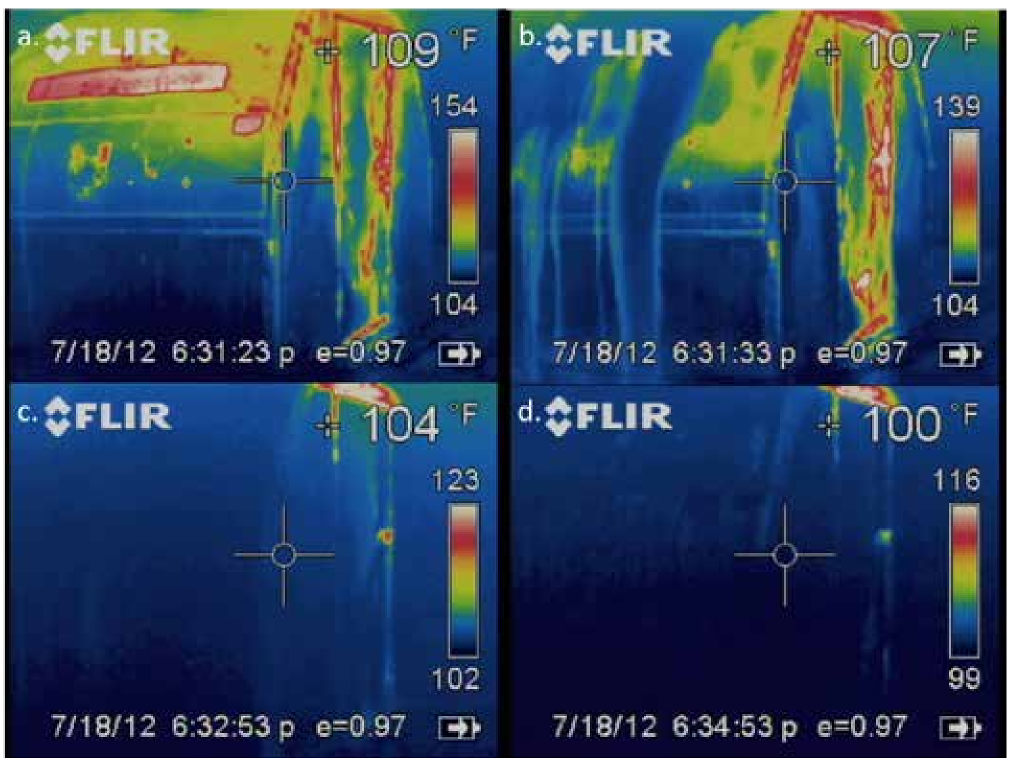


Figure 50. Heat Signature and Temperatures of Burning Container at (a) t = 1212 s, (b) t = 1222 s, (c) t =1302 s, and (d) t =1422 s

The second run for this test scenario (see test number 5.2 in table 2) ran for 23 minutes and 58 seconds before ARFF personnel entered the aircraft. After ignition, the fire grew for 20 minutes and 16 seconds before discharge began. Once the container was penetrated, discharge continued for 1 minute and 30 seconds. Figure 51 shows the temperature contours of the container from the beginning of discharge to 2 minutes after discharge ended. Observing the start of the discharge, as shown in figure 51(a), the container had a hotspot that covered the entire right side of the container door. The hotspot at this location had temperatures that ranged from 219° to 800°F. Figure 51(b) shows the temperature contour at 10 seconds into discharge; the temperatures of the hotspot dropped, ranging from 209° to 724°F. At the end of discharge, two small areas in the ceiling of the container had temperatures of 415° and 580°F, as shown in figure 51(c). After 2 minutes, the temperature of these two hotspots dropped to 368° and 465°F, as shown in figure 51(d). After opening the container door, ARFF personnel once again found a small fire still present in the container. The fire was extinguished and approximately 30% of the fire load remained untouched. The lower right corner of the container door contained a small breach hole.

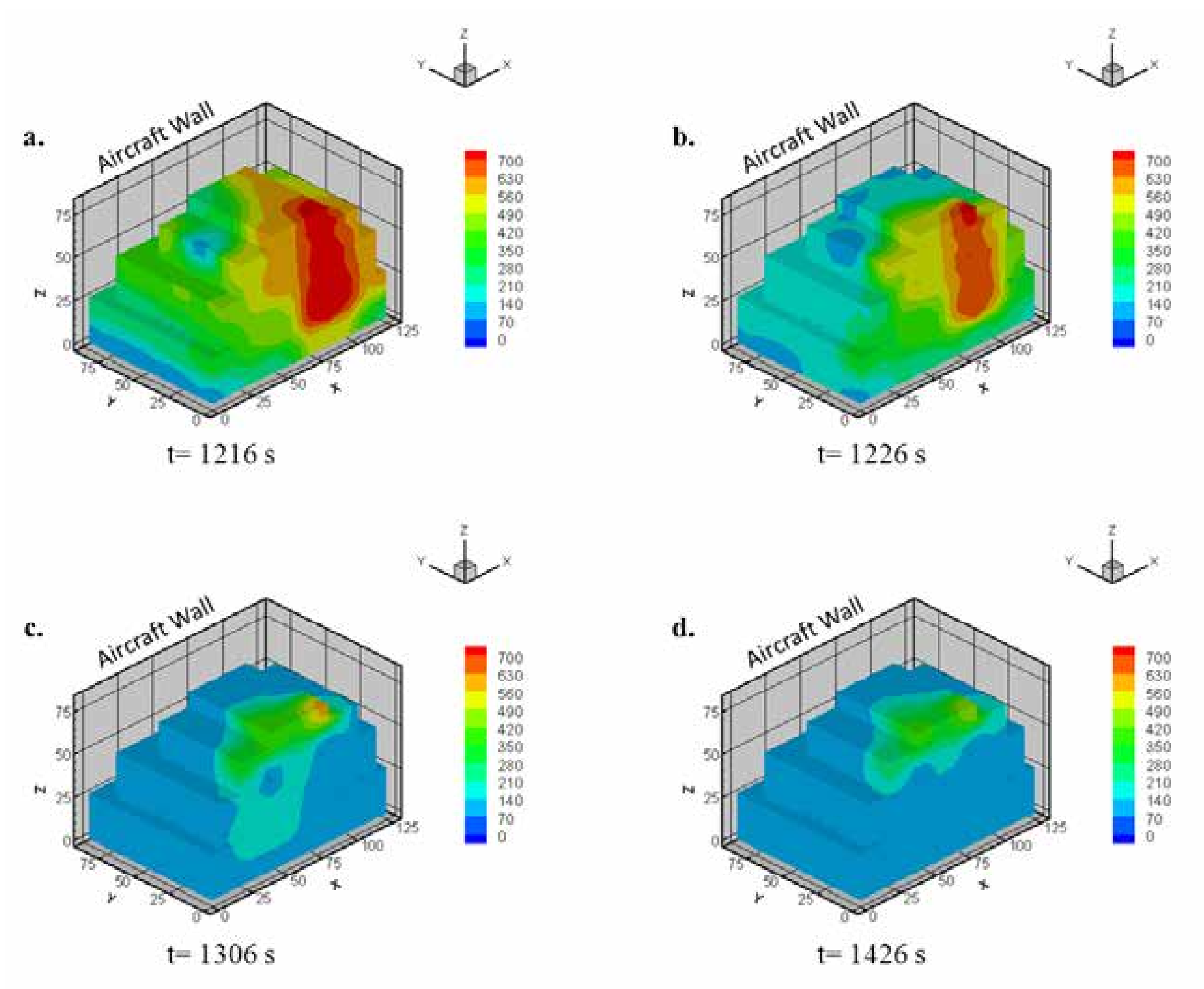


Figure 51. Temperature Readings During Full-Width Container Penetration Using a Stinger® ASPN

The third test run for this scenario (see test number 5.3 in table 2) ran for 20 minutes and 11 seconds before ARFF personnel entered the aircraft. The fire inside the container grew for 20 minutes and 11 seconds before water discharge began. Water discharge for this test run continued for the same amount of time as the other test runs: 1 minute and 30 seconds. At the beginning of discharge, ceiling temperatures for the container ranged from 469° to 670°F. The container had a hotspot on its right portion with temperatures that reached 1060°F. Ten seconds into discharge, the back ceiling temperatures dropped to approximately 120° to 130°F, while most of the front ceiling temperatures still remained above 500°F. In addition, the hotspot in the mid-section of the door remained present, and its temperatures were still above 1000°F. When the discharge ended, the maximum temperature was 341°F. Two minutes after the discharge ended, the front ceiling thermocouples recorded temperatures of 181° and 278°F. When ARFF personnel inspected the container, only a small fire remained inside. For this test run, approximately 60% of the boxes were consumed, and a small breach was present in the right front side of the container.

Overall, the Stinger® ASPN successfully penetrated the full-width container and was able to control the fire inside the container. After inspecting the test containers, the breach holes were thought to be caused by thermal shock and force from the water spray's high-pressure flow. It was noted that a hotspot was always present in the top right corner of the container, which led to the assumption that the water spray did not reach this corner of the container.

7.3.2 Full-Width Container Snozzle® Penetration.

The second full-width container penetration test scenario used a Snozzle® ASPN with an extension attachment. The full-width container had a fire load of 70 boxes. The extended Snozzle® ASPN successfully penetrated the container, as shown in figure 52. Because the Snozzle® ASPN had an extension attached to it, the Snozzle® ASPN was able to penetrate nearly to the center of the container. This meant that if the seat of the fire was in the center of the container, the water spray would travel through less debris.

Figure 52. Snozzle® ASPN With Extension Penetrating the Full-Width Container

The first test run for this scenario (see test number 6.1 in table 2) ran for 21 minutes before ARFF personnel entered the aircraft. After the fire burned for 15 minutes and 16 seconds, a 455°F hotspot was present at the top of the container door. There was also a hotspot on the right side of the container door that had a temperature of 430°F. At this time, most of the remaining container thermocouples recorded temperatures above 110°F. After the Snozzle® ASPN penetrated the container, a water discharge continued for 1 minute and 30 seconds. When the discharge ended, the hotspot on top of the container door reduced to 165°F, while most of the other container thermocouples recorded temperatures near 80°F. Two minutes after the discharge ended, the maximum temperature reduced to 138°F. When ARFF personnel inspected the container, they only found smoldering boxes inside the container. Approximately 50% of the fire load was consumed during the test.

The second test run for this scenario (see test number 6.2 in table 2) ran for 24 minutes before ARFF personnel entered the aircraft. After ignition, the fire grew for 20 minutes and 14 seconds before discharge began. The ceiling temperatures ranged from 460° to 572°F. The container door had temperatures that ranged from 210° to 536°F. The combination of readings from the container ceiling and the door demonstrated that a large hotspot was located on the top half section of the container door. Discharge into the container continued for 1 minute and 30 seconds. Ten seconds into discharge, the highest temperature around the container was 552°F. When the discharge ended, the highest temperatures reached 109°F, while most ceiling temperatures reached approximately 80°F. After 2 minutes, these readings increased to between 100° and 108°F, but the maximum temperatures remained the same. When ARFF personnel inspected the container, no fire was present—only smoldering boxes. During the test, the fire consumed approximately 60% to 65% of the boxes.

The third test run for this scenario (see test number 6.3 in table 2) ran for 19 minutes and 21 seconds before ARFF personnel entered the aircraft. Before discharge began, the fire grew for 15 minutes and 14 seconds. Figure 53 shows the temperature contours on the container from the time of discharge until 2 minutes after discharge ended. When discharge began, the ceiling temperatures ranged from 803° to 972°F. Temperatures indicated a large hotspot located at the container door. The door temperatures ranged from 200° to 1107°F. Discharge into the container continued for 1 minute and 30 seconds after Snozzle® ASPN penetration. Ten seconds into discharge, ceiling temperatures dropped from 972° to 957°F. The hotspot at the container door remained, with temperatures above 1100°F. When the discharge ended, the only hotspot remaining was located on the top edge of the door where temperatures were up to 640°F. The hotspot remained in the container 2 minutes after discharged ended, but the maximum temperature dropped to 532°F. When ARFF personnel inspected the container, they found a small fire still present inside the container. Approximately 50% of the fire load remained untouched inside the container.

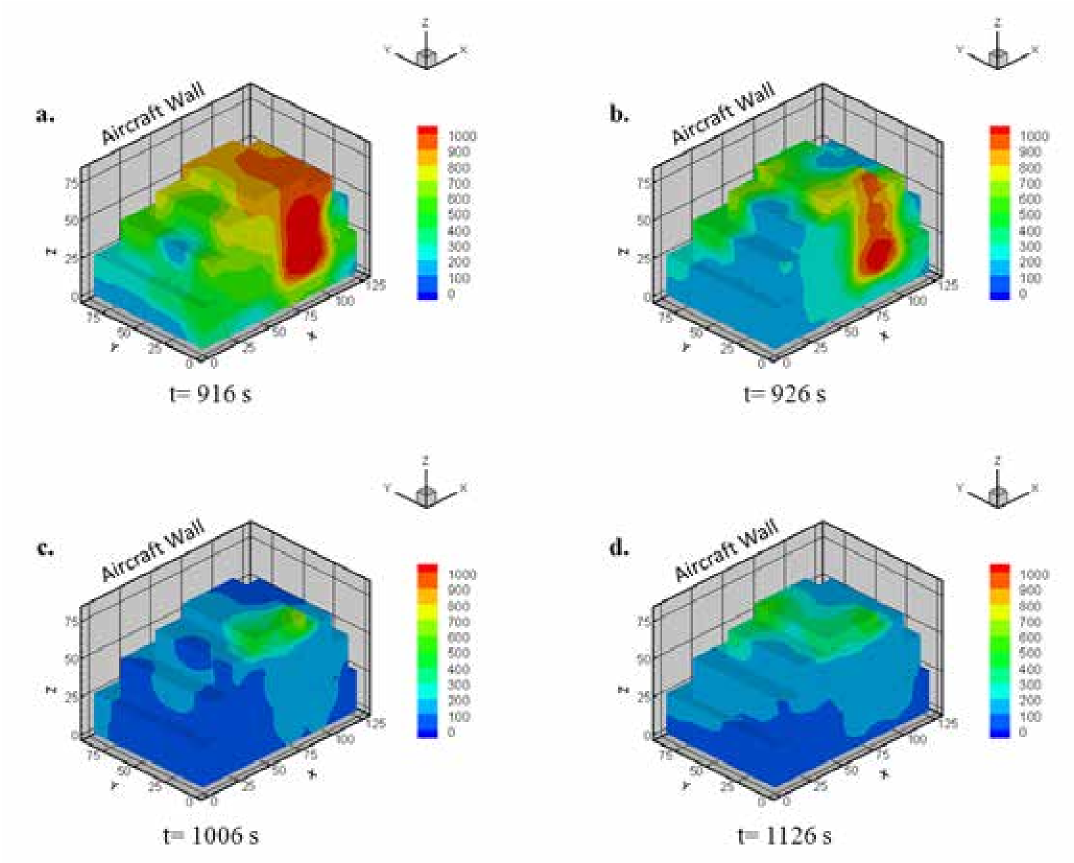


Figure 53. Temperature Readings of Full-Width Container Penetration Using the Extended Snozzle® ASPN

The extension attached to the Snozzle® ASPN proved effective in controlling the fire inside a full-width container compared to the Stinger® ASPN. With the Snozzle® ASPN in the center of the container, the water spray could attack the fire directly, since the ignition box was placed in the center floor of the container. With the exception of the last test, the container temperatures, after water discharge, were much lower than those that used the Stinger® ASPN. Compared to a similar operation by the Stinger® ASPN, the Snozzle® ASPN sprayed approximately 145 more gallons of water into the container, meaning more agent was used in these tests than in the tests that used the Stinger® ASPN.

7.4 THE LD3 STINGER® PENETRATION.

This test scenario examined the tactic of using a Stinger® ASPN to penetrate an LD3 container located in the lower cargo compartment. To properly position the Stinger® ASPN to pierce this container, the Stinger® ASPN was at a 7 o'clock position to the aircraft fuselage. Piercing the fuselage at that angle avoided the cheek area in the lower cargo compartment and improved the chances of penetrating the container. After positioning the HRET to the specified angle, the Stinger® ASPN penetrated the LD3 container through the slanted side of the container. Figure 54 shows the Stinger® ASPN penetrating an LD3 container. When the Stinger® ASPN pierced the container, all the holes from the Stinger® ASPN were able to pass through the container wall and the last row of the Stinger® ASPN holes were 2.5 inches away from the wall.

Figure 54. An LD3 Container Penetration Using the Stinger® ASPN

The first test run for this scenario (see test number 7.1 in table 2) ran for 35 minutes and 30 seconds before ARFF personnel entered the aircraft. After ignition occurred, it took over 25 minutes for the fire in the container to grow into a robust fire. This was due to the ventilation of the container. Figure 55 shows the temperature contours of the LD3 container from the beginning of water discharge to 2 minutes after discharge ended. After container penetration, water discharge continued for 1 minute and 33 seconds. This meant that the Stinger® ASPN introduced 387 gallons of water into the test container. The maximum temperature read in the container at the beginning of discharge was a container ceiling temperature of 546°F. Video from the FLIR cameras showed some of the water spray was present outside the container, meaning that not all the agent reached the fire. Two minutes after the discharge ended, readings of over 300°F still existed around the container with the maximum temperature being 382°F. When ARFF personnel inspected the container, fire was still present inside the container near the door of the container.

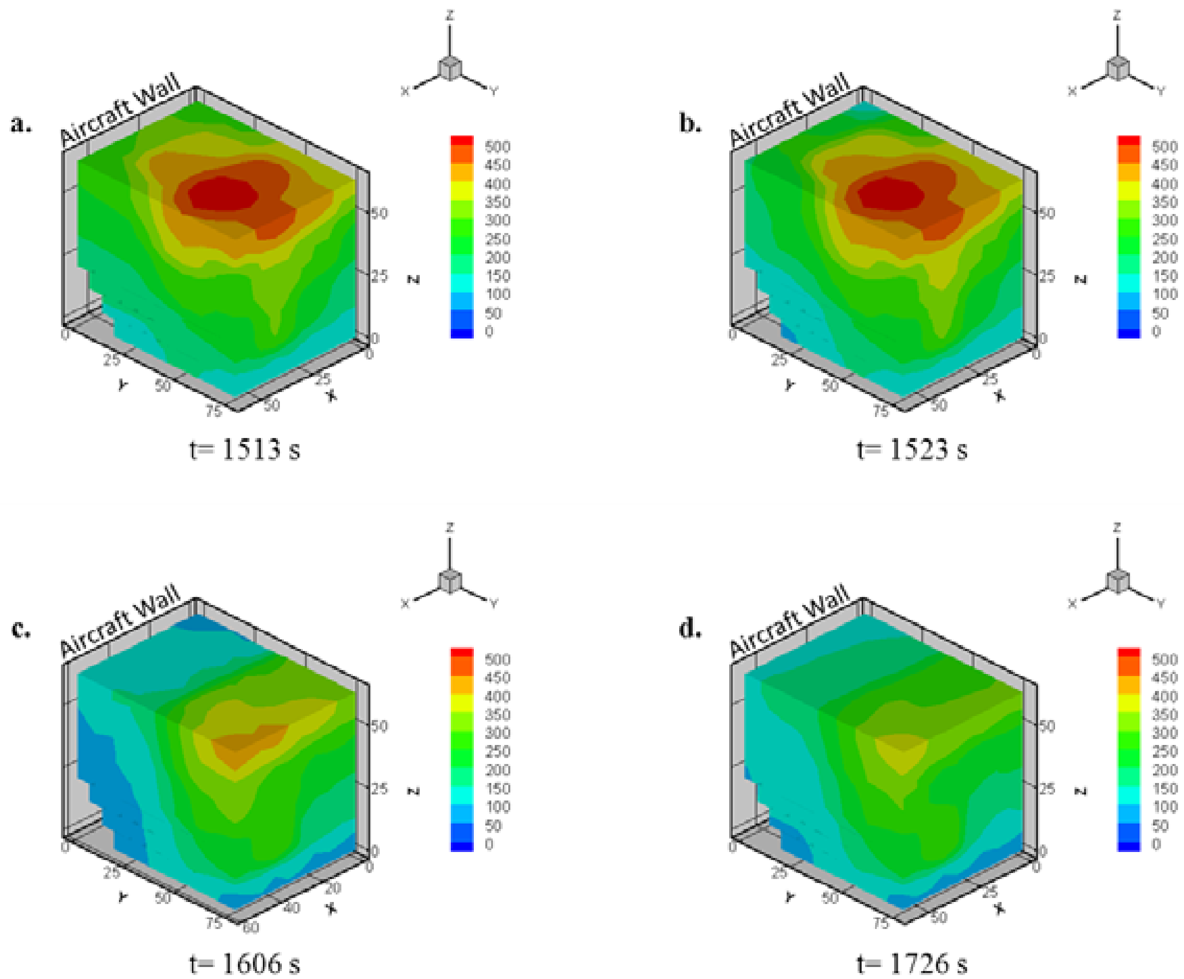


Figure 55. Temperature Readings of the LD3 During Penetration Using the Stinger® ASPN

The second test run for this scenario (see test number 7.2 in table 2) ran for 35 minutes and 56 seconds before ARFF personnel entered the aircraft. After ignition, over 27 minutes passed before a fire of sufficient size was present inside the container. Similar to the previous test run, the length of time to obtain a good robust fire depended greatly on the ventilation of the container. When the Stinger® ASPN penetrated the container, it introduced water for 2 minutes (500 gallons). Some of the water from the Stinger® ASPN sprayed outside the container. When discharge began, temperatures were over 800°F on the ceiling of the container and the right corner of the container wall. The maximum temperature was 875°F. When the discharge ended, a hotspot located in the lower right corner of the container was 850°F. After 2 minutes of discharge, the hotspot was 636°F. Temperatures around the container door and ceiling were above 300°F. When ARFF personnel opened the container, fire was still present near the container door. When inspecting the surroundings, the ceiling above the container was charred even though there was no breach in the container. Figure 56 shows the extent of the damage in the lower cargo compartment.

Figure 56. Ceiling Damage After LD3 Penetration Test

The third test run for this scenario (see test number 7.3 in table 2) ran for 25 minutes and 36 seconds before ARFF personnel entered the aircraft. It took 15 minutes and 39 seconds to have a robust fire inside the container. The fire grew faster in this test than the previous two tests because of the additional ventilation holes to the container. Figure 57 shows TIC temperature variations for this test run at the time of ignition and the time of water discharge. The container was located in the area of the ASPN in this figure; however, the hotspot is visible at the lower compartment door (right side of figure 57(b), below temperature reading). This was due to the cargo door not having insulation, which caused it to heat up faster. After the Stinger® ASPN penetrated the container, it released 750 gallons of water during a 3-minute spray into the container. The container exhibited temperatures of over 600°F throughout the center and right side of the ceiling when water discharge was about to begin. A 922°F hotspot was present in the top right side of the container door. Ten seconds into discharge, the water spray did not strongly affect the temperature contours of the container. Like the previous tests, not all the water made it inside the container. When the discharge ended, the container still had a hotspot in the top right corner of the door with a temperature of 737°F. Near the container door, temperatures ranged from 90° to over 600°F. Two minutes after the discharge ended, the temperature of the hotspot reduced to 590°F. Another hotspot of 586°F appeared in the lower right corner of the door, meaning that a small fire developed in that area. A large portion of the container still had temperatures over 300°F. When ARFF personnel inspected the container, they found a significant-sized fire still present in the container toward the right side of the door.

Figure 57. The TIC Temperature Measurements at (a) Ignition t = 0 s and (b) Water Discharge t = 909 s

Penetrating at this position posed a challenge, because extinguishing the fire from below the boxes obstructed the Stinger® ASPN stream. Like the previous two penetrations, the Stinger® ASPN was close to the container wall and the water wrapped around the container. Even with 750 gallons of water, the fire continued inside the container.

7.5 INDIRECT ATTACK.

The next test scenario examined having containers or pallets at such a distance away from the aircraft wall that the ASPNs could not perform penetrations. Since the target container is out of reach for the ASPNs in this scenario, breaches in the container are more likely. Test runs examined the tactics used to extinguish these types of fires by discharging agent into those breaches indirectly. Because container fires can burn and create through-wall breaches, and because a pallet fire is essentially an open fire, these tests were run in Zone 2 where a ceiling fire barrier was installed. The fire barrier ensured that the aircraft retained its structural integrity throughout the tests.

7.5.1 Full-Width Container Indirect Attack.

Since a breached container was desirable for the indirect attacks, an elliptical-shaped hole was cut out of the back wall of some of the AAY containers. This ensured that a predictable breach in the container was always present and would allow the fire to grow faster. Figure 58 shows that the fire inside the container impinged against the aircraft wall. Monitoring the ceiling temperature of the aircraft during each test helped ensure that no potential fuselage breach conditions were present.

Figure 58. Fire Growing Through Breached Hole of an AAY Container

7.5.1.1 Full-Width Container Stinger® Indirect Attack.

The first indirect attack test scenario used a Stinger® ASPN to extinguish a container fire inside an AAY container from a distance. For this test scenario, prebreached containers were used. In addition, as in the previous scenario, the fire load for each test consisted of 70 boxes of fire load. When the Stinger® ASPN penetrated the aircraft wall, the tip of the Stinger® ASPN was 12 inches away from the aircraft wall (figure 59), leaving a gap of 15 inches between the Stinger® ASPN and the test container.

Figure 59. Penetration Depth of Stinger® ASPN

The first test run for this scenario (see test number 8.1 in table 2) ran for 6 minutes and 9 seconds before ARFF personnel entered the aircraft. Between the time of ignition and the beginning of discharge, the fire grew for 3 minutes and 54 seconds. During the fire growth, the fire breached the ceiling of the container, which caused aircraft ceiling temperatures to reach as high as 1620°F. When the Stinger® ASPN penetrated the aircraft, water flowed into the aircraft for 1 minute and 35 seconds. When discharge began, the container ceiling temperatures ranged from 911° to 1767°F. By the time discharge began, the container ceiling had already melted away, and most of the fire was concentrated to the right side of the container. Ten seconds into discharge, the ceiling temperature dropped to between 838° and 1036°F, while other temperatures throughout the container remained relatively unchanged. When the discharge ended, the ceiling temperatures dropped to between 115° and 661°F. Most of the container had cooled, but a small hotspot of 689°F was present in the right top corner of the container. Two minutes after the discharge ended, the hotspot remained but dropped to 485°F. Additionally, the ceiling temperatures above the container door remained at 490° and 512°F. When ARFF personnel inspected the container, they found only smoldering boxes inside the container. Figure 60 shows the damage to the container.

Figure 60. Container Breach During Indirect Attacks

The second test run for this scenario (see test number 8.2 in table 2) ran for 10 minutes and 27 seconds before ARFF personnel entered the aircraft. After ignition, the fire grew for 5 minutes and 52 seconds before discharge began. For this test, two discharges were attempted. The first discharge continued for 1 minute and 30 seconds, and the second discharge continued for 1 minute. Although the aircraft ceiling temperatures only reached temperatures as high as 608°F before discharge, the container ceiling temperatures ranged from 783° to 912°F by the time the first discharge began. A hotspot was also present on the right side of the container, where the highest temperature was 876°F. Prior to discharge, the container ceiling temperatures ranged from 192° to 712°F. When examining the temperature data from the container, the highest temperatures were located at the front of the container, which had a reading of 897°F. When discharge ended, ceiling temperatures ranged from 97° to 456°F. Two minutes after the second discharge ended the container temperature ranges remained approximately the same, and the maximum container temperature was 487°F. When ARFF personnel inspected the container, they found the fire was still present inside the container. Approximately 20% of the fire load remained inside the container; a breach formed in the lower section of the container door.

The third test run (see test number 8.3 in table 2) ran for 9 minutes and 29 seconds before ARFF personnel entered the aircraft. After ignition, the fire grew for 7 minutes and 6 seconds before discharge began. For this test run, discharge was attempted twice. The first discharge continued for 1 minute and 30 seconds, and the second discharge continued for 1 minute. Figure 61 shows the temperature of the container from the beginning of the first discharge until 2 minutes after the end of the second discharge. When the first discharge began, the container ceiling temperatures ranged from 692° to 926°F. Additionally, from observing the temperature readings, the fire appeared to be concentrated in the left side of the container. After the first discharge ended and the second one was about to begin, the container ceiling temperatures ranged from 178° to 546°F. At this time, most of the heat was concentrated around the container door. Once the second discharge ended, the container ceiling temperatures had dropped and the highest ceiling temperature reading was 245°F, while the highest container temperature was 339°F. Two minutes after the second discharge ended, temperatures across the container rose, with 390°F as the highest container temperature. When ARFF personnel inspected the container, they found that a fire still existed inside the container.

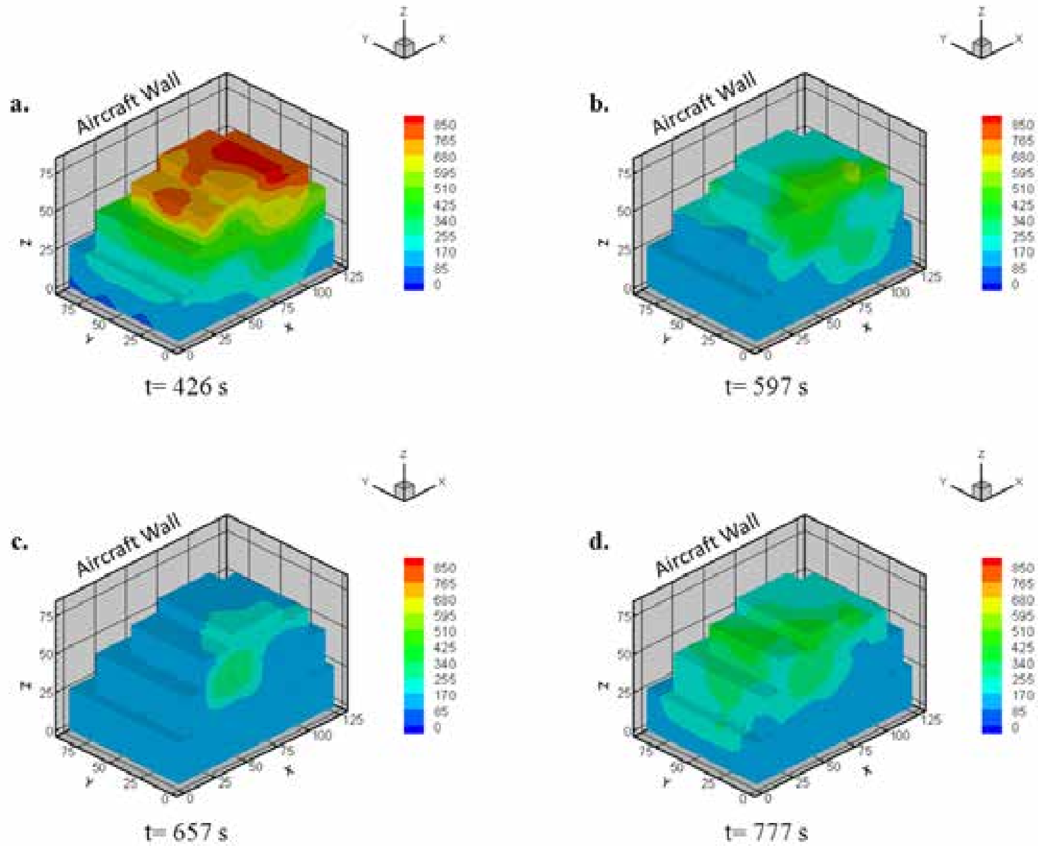


Figure 61. Temperature Readings During an Indirect Attack on an AAY ULD Using the Stinger® ASPN

Indirect attacks pose a different challenge to the fire fighter because unlike direct attacks, the ASPN does not penetrate into the container. While water sprayed into the container, most of the water was not concentrated towards the fire itself. Fire remained inside the container and had a potential of growing again in size. Furthermore, a large breach caused a greater amount of fire exposure to the ASPN spray, causing the spray to be more effective.

7.5.1.2 Full-Width Container Snozzle® Indirect Attack.

This test scenario examined an indirect discharge tactic using an AAY container as the test article and using a standard Snozzle® ASPN with no extension to extinguish the container fire. When the Snozzle® ASPN penetrated the aircraft wall, the tip reached 18 inches away from the wall. The container was 38 inches away from the base of the aircraft wall, and the container top was 9 inches away from the tip of the Snozzle® ASPN, as shown in figure 62. Similar to the full-width container penetration test scenarios, the container consisted of 70 boxes of fire load.

Figure 62. Measuring the Distance Between the Container and the Aircraft Wall

The first test run for this scenario (see test number 9.1 in table 2) ran for 6 minutes and 30 seconds before ARFF personnel entered the aircraft. The fire burned for 3 minutes and 9 seconds before discharge began. Throughout the test, the highest temperature reached at the aircraft ceiling was 1450°F. Two discharges were performed during this test. The first discharge continued for 1 minute while the second discharge continued for 44 seconds. Figure 63 shows the temperature contour of the container from the beginning of the first discharge to 2 minutes after the second discharge ended. At the beginning of the first discharge, the highest temperature was read by the left back ceiling thermocouple, which had a reading of 688°F. The reason for this area's high temperature was that the fire breach hole was near the thermocouple. At the time the second discharge began, the ceiling temperature dropped to 189°F, yet two hotspots appeared in the two top corners of the container door. These hotspots had temperatures of 502° and 541°F. At the end of the second discharge, the hotspots were still present with the highest temperature being 536°F. Two minutes after the discharge ended, these two hotspots had temperatures of 569°F. When ARFF personnel inspected the container, they found that a moderately sized fire existed inside the container. Approximately 50% of the fire load remained untouched, and the top section of the container door had a breach hole.

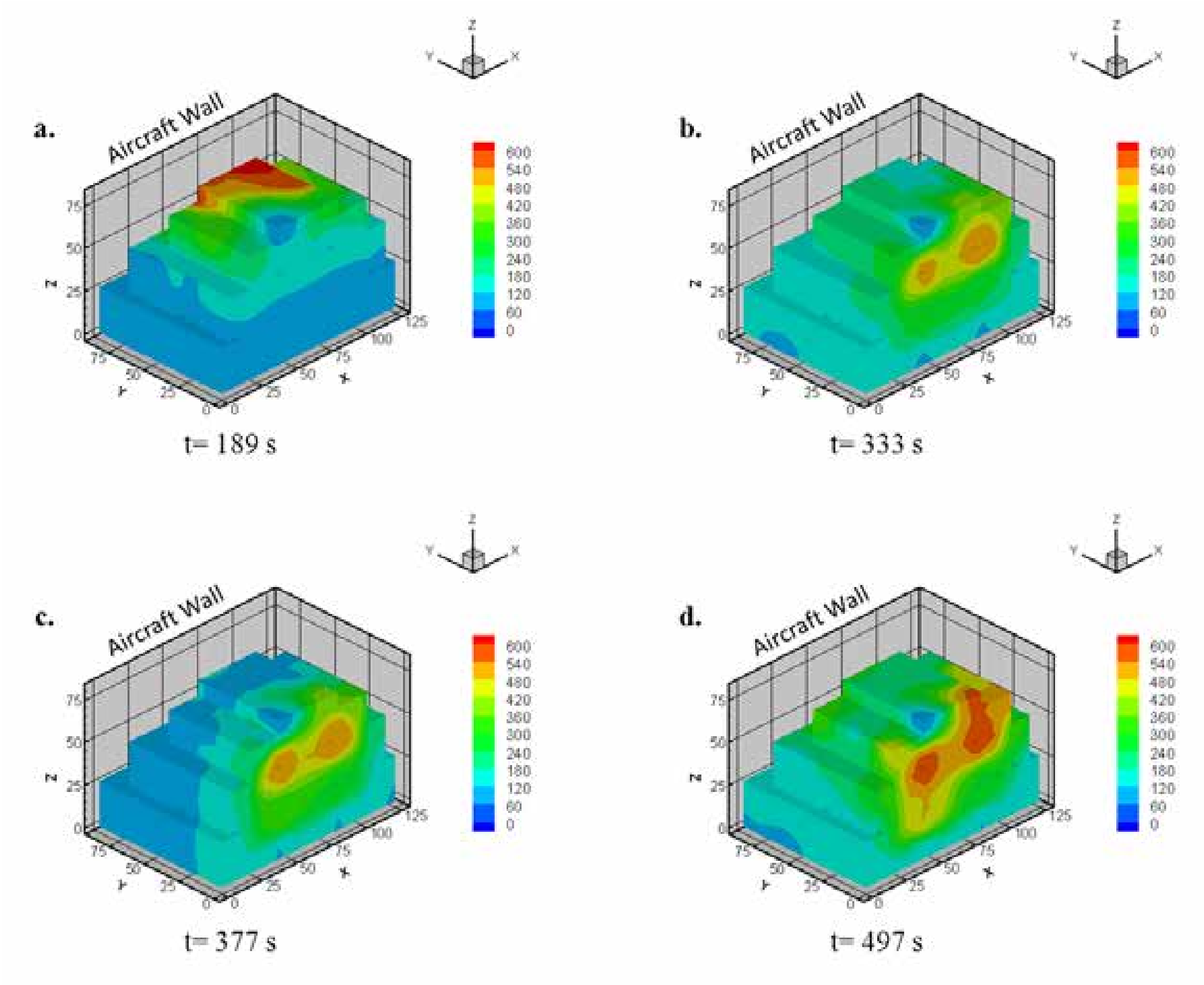


Figure 63. Temperature Readings During an Indirect Attack on an AAY ULD Using the Snozzle® ASPN

The second test run for this test scenario (see test number 9.2 in table 2) ran for 6 minutes and 17 seconds before ARFF personnel entered the aircraft. After ignition, the fire grew for 3 minutes and 43 minutes before discharge began. For this test, only one discharge was performed. This attack continued for 2 minutes, causing approximately 690 gallons of water to enter the main cargo compartment of the aircraft. By the time discharge into the container began, temperatures at the aircraft ceiling were as high as 1485°F. The container ceiling temperatures ranged from 346° to 1013°F. Ten seconds into discharge, the temperature of the container ceiling ranged from 131° to 484°F. When discharge into the container ended, the container ceiling temperatures dropped to between 109° and 459°F. Although the container ceiling temperatures dropped, a hotspot of 833°F appeared in the container. Two minutes after the discharge ended, the container ceiling temperatures rose to between 586° and 830°F. This meant that a fire still existed inside the container. ARFF personnel confirmed this when they inspected the test container. Approximately 70% of the fire load was consumed during the test and, again, a breach was found in the top section of the container door, as shown in figure 64.

Figure 64. Breach on the Top of the AAY Container Door

The third test run for this test scenario (see test number 9.3 in table 2) ran for 7 minutes and 57 seconds before ARFF personnel entered the aircraft. Before discharge, it took 5 minutes and 22 seconds for the fire to become robust. As the fire grew, the aircraft ceiling temperature rose to as high as 1153°F. As in the previous test run, discharge into the container continued for 2 minutes (690 gallons of water). Figures 65 and 66 show FLIR images of the aircraft and container, respectively, at the beginning of discharge. When discharge began, the ceiling temperatures of the container ranged from 364° to 911°F, while the bottom of the container had temperatures that ranged from 83° to 160°F. Ten seconds into discharge, the container ceiling temperatures ranged from 160° to 398°F. When discharge ended, the temperature ranged from 135° to 695°F. After 2 minutes, the ceiling temperature increased to a range of 192° and 484°F, while the maximum temperature was 649°F. After ARFF personnel inspected the container, a fire still existed inside the container. The fire consumed approximately 70% of the fire load, and only a small crack was present in the container door.

Overall, while the Snozzle® ASPN was effectively able to spray water into the container, most of the spray was not concentrated towards the fire itself. This posed a problem because of the possibility that a fire could rekindle inside the container and spread. The Snozzle® ASPN spray pattern provided a barrier around the container, which prevented the fire from spreading during water discharge.

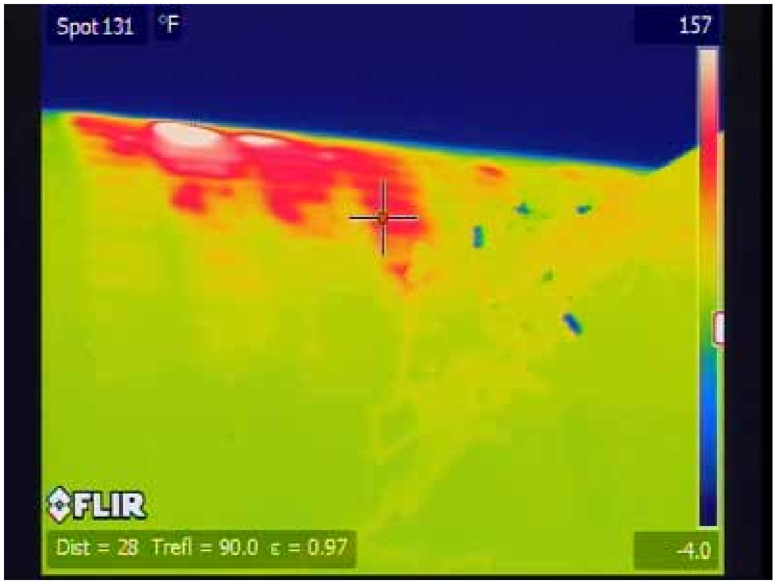


Figure 65. Exterior FLIR Image of the Aircraft When Discharge Began

Figure 66. Interior FLIR Image of the Test Container When Discharge Began

7.5.1.3 Full-Width Container Prototype Indirect Attack.

The third test scenario for the indirect attack of cargo containers examined using the Snozzle® HRET with a prototype ASPN fabricated at the FAA William J. Hughes Technical Center at the Atlantic City International Airport, NJ. The prototype ASPN (Version 3, shown in figure 67) was designed specifically to combat container fires indirectly. More information regarding the prototype ASPN is contained in the FAA Technical Note "Development of Prototype Nozzles for Freighter Aircraft Fire Applications" [8]. The container was at the same distance from the wall as the previous test scenarios. Because of the size of the prototype ASPN, a gap of 12 inches existed between the ASPN and the container.

Figure 67. Prototype ASPN

The first test run for this test scenario (see test number 10.1 in table 2) ran for 6 minutes before ARFF personnel entered the aircraft. After ignition, the fire grew for 3 minutes and 5 seconds before discharge began. Before discharge, the aircraft ceiling temperatures reached as high as 1503°F. When the prototype ASPN penetrated the aircraft, it sprayed water for 1 minute and 30 seconds. Figure 68 shows the temperature contours of the container. When discharge into the container was about to begin, the container ceiling temperatures ranged from 401° to 1046°F. The temperature readings indicated that the fire was concentrated toward the back of the container. When discharge ended, the container ceiling temperatures dropped to between 109° and 155°F. Two minutes after the discharge ended, the container temperatures rose to 269°F. When ARFF personnel inspected the container, a small fire was still present inside the container. Approximately 50% of the boxes remained unburned.

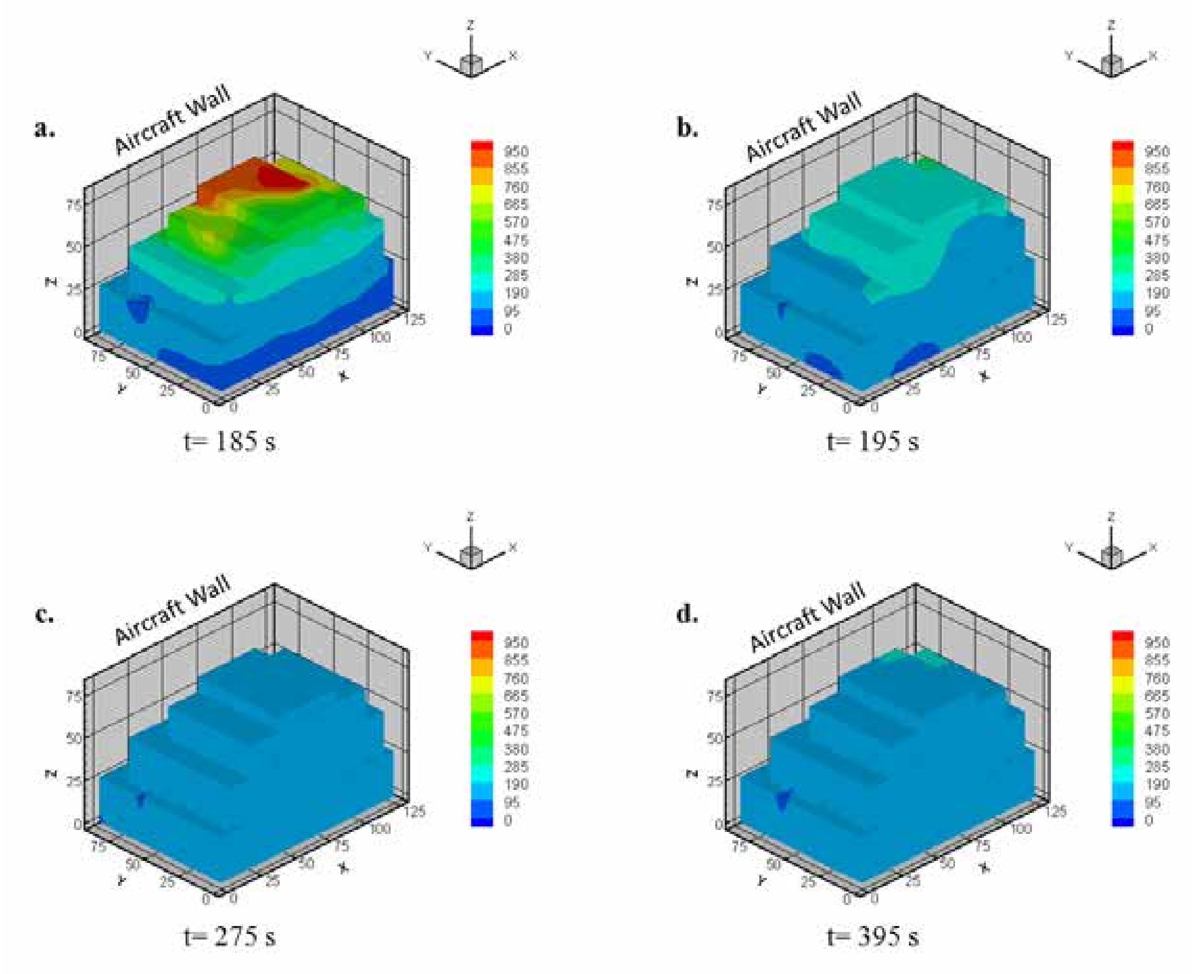


Figure 68. Temperature Readings During an Indirect Attack on an AAY ULD Using the Prototype ASPN

The second test run for this scenario (see test number 10.2 in table 2) ran for 6 minutes and 6 seconds before ARFF personnel entered the aircraft. After ignition, the fire grew for 3 minutes and 9 seconds before discharge began. When the prototype ASPN penetrated the aircraft, aircraft ceiling temperatures were as high as 1512°F. Immediately before discharge, the highest reading recorded from the container thermocouples was 1070°F. Similar to the previous test run, the fire was mostly concentrated at the back of the container. Ten seconds into discharge, the container ceiling temperatures ranged from 197° to 266°F. At that time, a small hotspot of 599°F was present in the top right side of the container. When the discharge ended, the temperatures around the container ranged from 95° to 182°F. Two minutes after the discharge ended, the container temperatures rose, and the highest temperature was 482°F. When ARFF personnel inspected the container, a small fire still existed inside the container. Approximately 40% of the fire load remained inside the container, and a breach existed in the container ceiling, as shown in figure 69.

Figure 69. Ceiling Breach in the AAY Container After Indirect Attack

The third test run for this scenario (see test number 10.3 in table 2) ran for 7 minutes and 12 seconds before ARFF personnel entered the aircraft. After ignition, the fire grew for 3 minutes and 39 seconds before discharge began. Only one water discharge was performed and continued for 1 minute and 30 seconds. During this time, aircraft ceiling temperatures reached a maximum of 1729°F. Immediately before discharge began, the container ceiling temperatures ranged from 725° to 1697°F. Meanwhile, the temperatures near the container door ranged from 91° to 988°F. Ten seconds into discharge, the container ceiling temperatures dropped to between 658° and 1138°F. When the discharge ended, temperatures across the container ranged from 91° to 443°F. Two minutes after the discharge ended, the maximum temperature dropped to 398°F. When ARFF personnel inspected the container, a small fire was still present inside the container. The fire consumed approximately 85% of the fire load.

Similar to the Snozzle® and Striker® ASPNs , the prototype ASPN tests ended with a fire still present inside the container, but the remaining fires were much smaller. When examining the container temperatures after discharge, the tests using the prototype ASPN registered lower temperatures than the Snozzle® and Striker® ASPNs. Observations from these tests suggested that unlike the Snozzle® and Striker® ASPNs, the forward streams from the prototype ASPN prevented the fire from moving towards the front of the container. Overall, the prototype ASPN proved to be more effective for freighter aircraft applications.

7.5.2 Pallet Indirect Attack.

For pallet fires, a ULD base was used as a modified pallet and was placed in Zone 2, which is in the rear of the aircraft. Each pallet carried 48 boxes secured to the pallet with a cargo net. Small gaps existed around the boxes to allow the fire to breathe and grow at a rapid rate. The fire inside the pallet continued to grow until approximately 80% to 85% of the boxes were involved, as shown in figure 70. The aircraft ceiling temperatures were monitored during the fire growth stage to ensure that the fuselage interior conditions reach a temperature that could cause a fuselage breach. For this test, a Snozzle® ASPN was used to extinguish the fire.

Figure 70. Pallet Fire Inside the A310

The first test run for this scenario (see test number 11.1 in table 2) ran for 32 minutes and 4 seconds before ARFF personnel entered the aircraft. After ignition, the fire grew for 26 minutes and 53 seconds before discharge began. The boxes on the pallet were packed so tightly that the lack of ventilation through the boxes became an issue. When the fire reached the top of the boxes, the fire spread quickly through the pallet. Once the Snozzle® ASPN penetrated the aircraft, thermocouples around the pallet had readings as high as 1418°F, and the aircraft ceiling had reached temperatures as high as 1626°F. Figure 71 shows the hotspot, as observed through the FLIR camera, of a fire impinging on the aircraft wall before water discharge began. Before the fire impinged on the aircraft, no hotspots were visible through the FLIR cameras. When discharge began, the Snozzle® ASPN sprayed water into the pallet for 2 minutes and 11 seconds. Ten seconds into discharge, the temperatures dropped drastically, and the maximum temperature around the pallet was 855°F. When the discharge ended, the highest temperature recorded around the pallet was 191°F. Two minutes after the discharge ended, all pallet temperatures dropped below 170°F. When ARFF personnel inspected the pallet, they only found smoldering boxes. The fire consumed approximately 60% of the boxes; the remaining 40% were unburned.

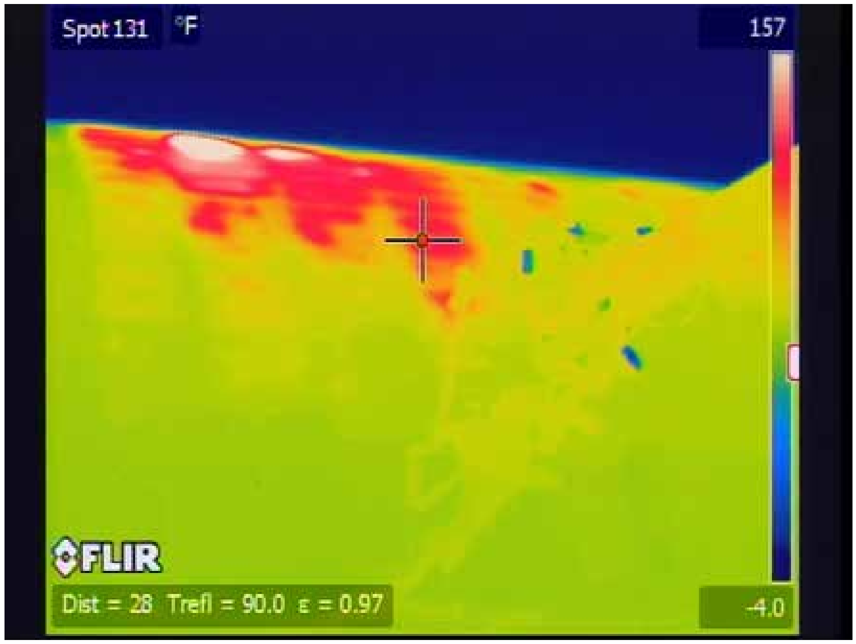


Figure 71. A FLIR Temperature Reading of the Aircraft at the Beginning of Discharge

The second test run for this scenario (see test number 11.2 in table 2) ran for 7 minutes and 36 seconds before ARFF personnel entered the aircraft. Unlike the first test run, it only took 4 minutes and 18 seconds to develop a robust fire. The drop in time was due to the added space between the boxes. Figure 72 shows the temperature contours for various times during this test. At 258 seconds, the maximum temperature read by one of the pallet thermocouples was 1753°F, as shown in figure 72(a), and aircraft ceiling temperatures had already reached temperatures over 1700°F. Discharge for this test only continued 2 minutes and 7 seconds. The Snozzle® ASPN spray was effective as temperatures dropped to 814°F and below (almost a 900°F drop from the original maximum temperature), as shown in figure 72(b). In addition, also shown in figure 72, most of the fire moved away from the aircraft wall. At the end of discharge (figure 72(c)), the highest temperature recorded by the pallet thermocouples was 142°F. Two minutes after the discharge ended, the maximum temperature had only increased by 1°F, as shown in figure 72(d). When ARFF personnel inspected the pallet, they only found some minor smoldering. The fire consumed approximately 60% of the boxes.

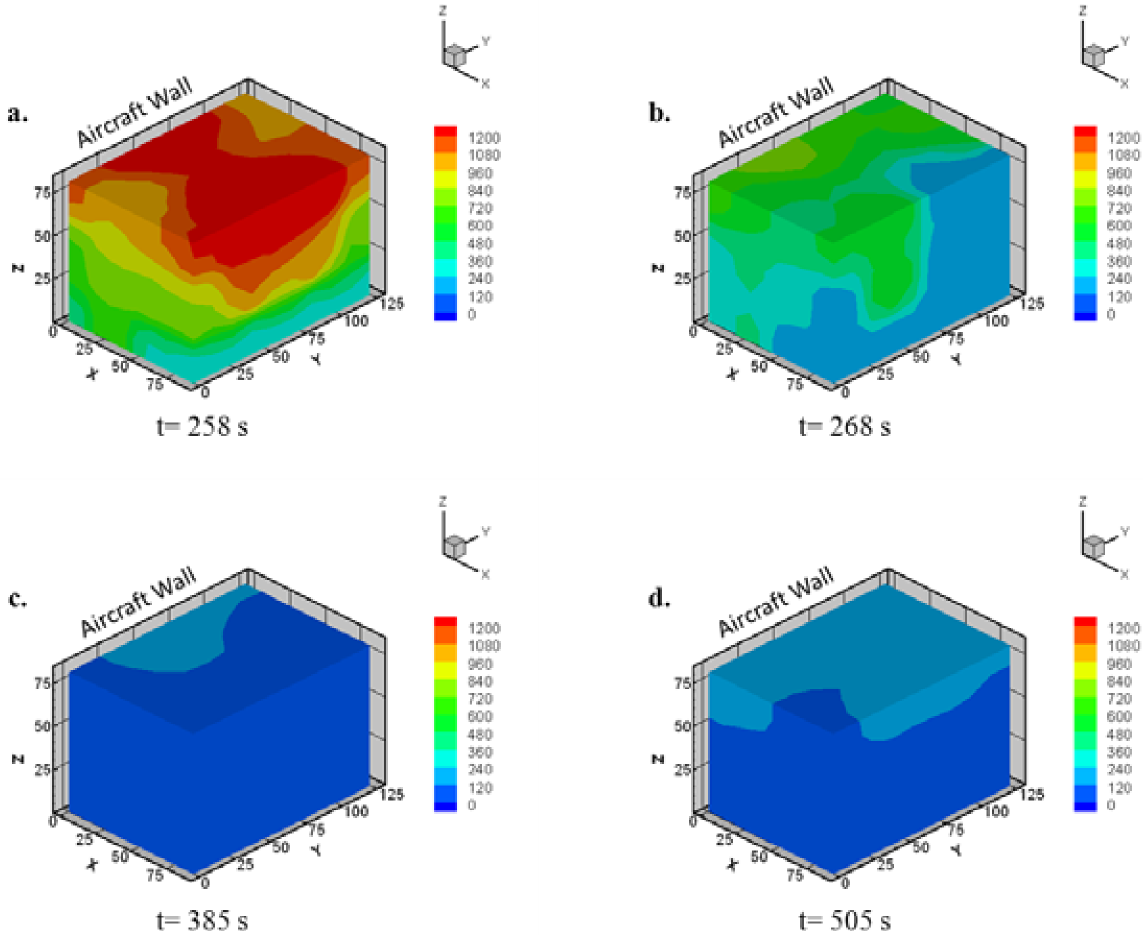


Figure 72. Temperatures Readings During an Indirect Attack on a Pallet Using a Snozzle® ASPN

The third test run for this test scenario (see test number 11.3 in table 2) ran for 6 minutes and 41 seconds before ARFF personnel entered the aircraft. It only took 3 minutes and 24 seconds to have a robust fire on the pallet. After the Snozzle® ASPN penetrated the aircraft, the Snozzle® ASPN sprayed water into the pallet for 2 minutes. When the water discharge started, aircraft ceiling temperatures were already near 1700°F, and the pallet thermocouples had recorded temperatures as high as 1655°F. Ten seconds into discharge, maximum temperatures dropped to below 770°F. At the end of discharge, the pallet thermocouples read temperatures below 225°F. A total of 690 gallons of water was discharged into the aircraft. Two minutes after the discharge ended, the maximum pallet temperature dropped to 126°F. When ARFF personnel inspected the pallet, they found a small fire in one of the corners of the pallet but everything else was extinguished. The fire consumed approximately 50% of the boxes.

The attempt to extinguish the fire on a pallet proved to be effective when using a Snozzle® ASPN with no extension. The lack of a container wall allowed for more water to reach the seed of the fire. Overall, it was determined that pallet fires can be controlled using an indirect attack.

7.6 ADDITIONAL TESTS.

7.6.1 Weight and Balance.

Weight and balance readings were taking before and after each test. Before taking each reading, ARFF personnel had to clear the aircraft and make sure that no other apparatus were making contact with the aircraft. For the readings before each test, ARFF personnel ensured that all the bilge drains were closed. After taking the readings, the bilge drains were opened to drain the aircraft. On examination of all the tests run inside the A310, no major changes were noted in the weights and balances of the aircraft. The average difference for all the tests was 0.07 inch. The biggest difference observed was for the third test of the prototype nozzle, which was 2.95 inches.

7.6.2 Standoff Distance.

Each standoff distance was measured from the interior ceiling of the ARFF vehicle's cab horizontally to the aircraft fuselage. When using a Snozzle® HRET for the main cargo compartment, the standoff distances ranged from 20 feet, 2 inches to 28 feet, 7 inches. When the Stinger® HRET was used to combat fires in the main cargo compartment, the standoff distances ranged from 25 feet, 7 inches to 29 feet, 10 inches. When this HRET was used for the lower cargo compartment, the standoff distances ranged from 25 feet, 5 inches to 27 feet, 6 inches.

7.6.3 Window Penetration.

Forcible removal of window blanks or removal of overwing exit plugs is not a simple option for gaining access. Tests using the A310 showed that window blanks could be driven into the aircraft with a sledgehammer. The research team also used an HRET to remove the window blanks. In these tests, the ASPN pierced through the window blank rather than knocking it in. The ASPN eventually removed the window blank through manipulation, but the maneuver risked breaking or damaging the tip. Once removed, an entry point for air was created; but because the cargo liner was installed tightly against the window frame, there was still no clear access to the cargo compartment. Additional forces would be needed to rip the cargo liner from its mounts. Depending on the distance from the wall upon which the cargo ULD is mounted, there is a possibility that the cargo liner will not separate from its mounts by this method.

7.6.4 Introduction of Clean Agent.

14 CFR Part 139.317, "Aircraft Rescue and Firefighting Equipment and Agents," requires ARFF at certificated airports to carry complementary agent [9]. Approved complementary agents include a sodium-based dry chemical, Halon® 1211, or other clean agent. Currently, Halotron® is the only other approved clean agent for use on ARFF vehicles. Clean agent may be discharged into the cargo compartment through HRET ASPNs. Certain hand-held penetrating tools can also be attached to portable clean agent extinguishers.

Although Halon® 1211 and Halotron® are clean streaming agents rather than flooding agents, there appears to be some benefit when used in a cargo compartment as a flooding agent. FedEx aircraft use a series of preconnected extinguishers attached to a line that allows flow of

Halon® 1211 directly into the "Haz Can" ULDs located in the most forward cargo positions on the main cargo compartment of their freighter aircraft.

The FAA conducted some preliminary tests using Halotron®, a clean extinguishing agent, through the Snozzle® ASPN installed on the FAA Striker. The results for these tests were inconclusive in determining the effectiveness of Halotron® as a flooding agent, but evidence from some of the tests suggested that Halotron® may have some benefit when used as a flooding agent in a lower cargo compartment.

The effects of clean agents are reduced if ventilation is present inside the compartment since it would cause the agent to leak out of the compartment. If an aircraft lands after having discharged agent into a lower cargo compartment, communications with the pilot will confirm whether the vents or outflow valves associated with the cargo compartment can be secured from the cockpit.

If there is evidence that the fire is not fully extinguished, but there has been no extension of fire into other areas, maintaining the atmosphere of the space could prove to be important. If the flight deck can secure the ventilation, the leak rate and the introduction of air can be reduced. If the vents cannot be closed from the flight deck, attempts can be made to physically seal the outflow valves. The locations of these valves should be included in aircraft familiarization training on each aircraft with service to the airport. Sealing the outflow valves with tape and plastic, and securing the doors to the aircraft will reduce the degradation of the atmosphere in the compartment.

8. CONCLUSIONS.

After all cargo tests were completed and analyzed, the following conclusions were determined for each objective listed in section 3.

- Oxygen deprivation tests proved to be inconclusive. Although oxygen levels decreased in each test, an oxygen-deprived atmosphere (12% oxygen or less) was not achieved after at least 45 minutes of burning.

- All high-reach extendable turret (HRET) piercing technologies successfully pierced through the aircraft, cargo liner, and test container when the test containers were adjacent to the interior fuselage wall. Once all piercing technologies penetrated the test container in the main cargo compartment, the Aircraft Skin-Penetrating Nozzles (ASPN) successfully controlled the fire inside the test container. ASPNs with longer penetration depth provided better extinguishment efficiency when compared to their shorter depth counterparts. When penetrating an LD3 container in the lower cargo compartment, the Stinger® ASPN was not able to effectively control the fire inside the container. Extinguishing the fire from this position posed a challenge since water discharge was from below the boxes, which obstructed the ASPN stream.

- When commercially available ASPNs were used for an indirect attack, some water spray reached the test container, but small fires continued to burn inside the test container when water discharge ended. In comparison, a prototype ASPN developed at the Federal Aviation Administration William J. Hughes Technical Center proved to be more effective in controlling the test container fire in indirect attacks when compared to current ASPNs. When attempting to extinguish a pallet fire, an indirect attack proved to be efficient in controlling and almost extinguishing the fire.

Additional findings from the tests were also found.

- Forward-looking infrared and thermal imaging cameras could not detect thermal signatures from the exterior of the aircraft unless fire was impinging directly on the fuselage skin or if the fuselage wall had no liner or insulation.

- The data indicated that most of the weight and balance measurements of the aircraft were not significantly affected during testing. This was attributed to the limited discharge duration.

- Current HRET technologies can successfully pierce through window blanks in a freighter aircraft.

- Halotron® clean agent has the potential of being a flooding agent in a freighter aircraft as long as the compartment is sealed.

These findings will be used to create training material for Aircraft Rescue and Firefighting (ARFF) personnel. This training material will aid ARFF personnel to decide what tactic will be best in future freighter aircraft incidents.

9. REFERENCES.

1. National Transportation Safety Board, "Inflight Cargo Fire, United Parcel Service Company Flight 1307, McDonnell Douglas DC-8-71F, N748UP, Philadelphia, Pennsylvania, February 7, 2006," Aircraft Accident Report NTSB/AAR-07/07, Washington, DC, 2007.

2. Federal Aviation Administration, "Programs for Training of Aircraft Rescue and Firefighting Personnel," Advisory Circular (AC) 150/5210-17B, September 23, 2009.

3. U.S. Federal Register, Title 14 Code of Federal Regulations Part 139.319, "Aircraft Rescue and Fire-Fighting: Operational Requirements," Government Printing Office, Washington, DC, June 2004.

4. National Fire Protection Association (NFPA), *NFPA 414 Standard for Aircraft Rescue and Fire-Fighting Vehicles*, NFPA, Quincy, Massachusetts, 2012.

5. Doig, W., "Aircraft Skin-Penetrating Nozzle Testing of a Freighter Aircraft Cargo Liner," FAA report DOT/FAA/TC-12/48, December 2012.

6. Rosenbauer Firefighting Technology, "Specification Prepared for Base Panther 6x6 Stinger," Rosenbauer America http://www.rosenbaueramerica.com/media/documents/pdf/Base_Panther_6x6_Stinger_specification.pdf (last visited 07/02/2013)

7. Reinhardt, J., "Minimum Performance Standard for Aircraft Cargo Compartment Halon Replacement Fire Suppression System (2nd Update)," FAA report DOT/FAA/AR-TN05/20, June 2005.

8. Torres, J., "Development of Prototype Nozzles for Freighter Aircraft Fire Applications," FAA report DOT/FAA/TC-TN13/11, April 2013.

9. U.S. Federal Register, Title 14 Code of Federal Regulations Part 139.317, "Aircraft Rescue and Fire-Fighting: Equipment and Agents," Government Printing Office, Washington, DC, June 2004.

APPENDIX A—CARGO FIRES ON FREIGHTER AIRCRAFT/HISTORICAL REVIEW/U.S. INCIDENTS

Over the past decades, several incidents influenced the development of Federal Aviation Administration (FAA) Advisory Circular (AC) 150/5210-17B [A-1]. The following paragraphs list some of the more current incidents and the resulting recommendations of the National Transportation Safety Board (NTSB).

1. Accident occurred: September 05, 1996, at Stewart International Airport, Newburgh, NY
   Aircraft: Federal Express (FedEx) McDonnell Douglas DC-10-10CF, registration: N68055
   Cargo fire detected in flight, destroyed the aircraft and the freight on board in spite of a 4-hour firefighting effort. Cargo fire extended to the aircraft.

The NTSB made a number of specific recommendations in response to this incident. The following are those relative to fire prevention, firefighting, and emergency response [A-2].

To the Department of Transportation: Require, within 2 years, that a person offering any shipment for air transportation provide written responses, on shipping papers, to inquiries about hazardous characteristics of the shipment, and develop other procedures and technologies to improve the detection of undeclared hazardous materials offered for transportation. (A-98-71) To the Federal Aviation Administration: Require, within 2 years, that air carriers transporting hazardous materials have the means, 24 hours per day, to quickly retrieve and provide consolidated, specific information about the identity (including proper shipping name), hazard class, quantity, number of packages, and location of all hazardous materials on an airplane in a timely manner to emergency responders. (A-98-75) Require the principal operations inspector for Federal Express (FedEx) to ensure that all FedEx employees who may communicate with emergency responders about a *transportation* accident involving hazardous materials understand that they should provide those emergency responders with any available information about hazardous materials that may be involved. (A-98-76) Require all certificated airports to coordinate with appropriate fire departments, and all State and local agencies that might become involved in responding to an aviation accident involving hazardous materials, to develop and implement a hazardous materials response plan for the airport that specifies the responsibility of each participating local, regional, and State agency, and addresses the dissemination of information about the hazardous materials involved. Such plans should take into consideration the types of hazardous materials incidents that could occur at the airport based on the potential types and sources of hazardous materials passing through the airport. Airports should also be required to coordinate the scheduling of joint exercises to test these hazardous materials emergency plans. (A-98-77)

Reexamine the feasibility of on-board airplane cabin interior fire extinguishing systems for airplanes operating under 14 Code of Federal Regulations Part 121 and, if found feasible, require the use of such systems. (A-98-78)

Review the aircraft cabin interior firefighting policies, tactics, and procedures currently in use, and take action to develop and implement improvements in firefighter training and equipment to enable firefighters to extinguish aircraft interior fires more rapidly. (A-98-79)

To the Research and Special Programs Administration:
Require, within 2 years, that air carriers transporting hazardous materials have the means, 24 hours per day, to quickly retrieve and provide consolidated specific information about the identity (including proper shipping name), hazard class, quantity, number of packages, and location of all hazardous materials on an airplane in a timely manner to emergency responders. (A-98-80)

2. Accident occurred: July 31, 1997, at Newark International Airport, Newark, NJ
   Aircraft: FedEx McDonnell Douglas MD-11, registration: N611FE,
   The Number 3 engine contacted the runway during a rough landing, which caused the aircraft to flip over and catch fire. Fuel fire extended to aircraft [A-3].

3. Accident occurred: December 18, 2003, at Memphis International Airport, Memphis, TN
   Aircraft: FedEx McDonnell Douglas MD-10-10, registration: N364FE
   The right main landing gear collapsed causing the aircraft to veer off the runway. It was destroyed in the subsequent fire. Fuel fire extended to cargo [A-4].

The NTSB made a number of specific recommendations. The following are those relative to firefighting and emergency response [A-4].

The Rural/Metro Fire Department aircraft rescue and firefighting (ARFF) response vehicles were unnecessarily delayed in providing ARFF assistance because the Memphis air traffic control tower ground controller did not give them priority over other nonemergency airport traffic; under other circumstances, this could have adversely affected ARFF efforts.

Inform all air traffic control tower controllers of the circumstances of this accident, including the need to ensure that aircraft rescue and firefighting (ARFF) vehicles are not delayed without good cause when en route to an emergency and the need to relay the number of airplane occupants to ARFF responders. (A-05-017)

Air traffic control tower controllers should recognize the importance of relaying all available pertinent information, including airplane occupant information, to aircraft rescue and firefighting (ARFF) personnel to assist them in ARFF efforts and decision-making.

4. Accident occurred: February 07, 2006, at Philadelphia International Airport, Philadelphia, PA
Aircraft: Douglas DC-8, registration: N748UP
Cargo fire detected in flight, destroyed most of the freight on board in spite of a 4-hour firefighting effort. Cargo fire extended to aircraft.

The NTSB made a number of specific recommendations in response to this incident. The following are those relative to firefighting and emergency response [A-5].

New Safety Recommendations made by the NTSB to the Federal Aviation Administration as a result of its investigation of the February 7, 2006 accident involving United Parcel Service Company flight 1307 are as follows:

Provide clear guidance to operators of passenger and cargo aircraft operating under 14 Code of Federal Regulations Parts 121, 135, and 91K on flight crew procedures for responding to evidence of a fire in the absence of a cockpit alert, based on the guidance developed by the 2004 smoke, fire, and fumes industry initiative. (A-07-97)

Ensure that the performance requirements for smoke and fire detection systems on cargo airplanes account for the effects of cargo containers on airflow around the detection sensors and on the containment of smoke from a fire inside a container, and establish standardized methods of demonstrating compliance with those requirements. (A-07-98)

Require that fire suppression systems be installed in the cargo compartments of all cargo airplanes operating under 14 Code of Federal Regulations Part 121. (A-07-99)

Provide guidance to aircraft rescue and firefighting personnel on the best training methods to obtain and maintain proficiency with the high-reach extendable turret with skin-penetrating nozzle. (A-07-100)

Require airport inspectors to ensure that Part 139 airports with cargo operations include cargo aircraft in their aircraft rescue and firefighting aircraft familiarization training programs. (A-07-101)

Require cargo operators to designate at least one floor level door as a required emergency exit and equip the door with an evacuation slide, when appropriate. (A-07-102)
Require all emergency exits on cargo aircraft that are operable from the outside to have a 2-inch contrasting colored band outlining the exit. (A-07-103)

As a result of this investigation, the National Transportation Safety Board makes the following recommendation to the Cargo Airline Association:

Work with your member airlines and other groups, such as the Air Transport Association, major aircraft manufacturers, and the Aircraft Rescue and Firefighting (ARFF) Working Group, to develop and disseminate accurate and complete airplane Emergency Response Diagrams for ARFF personnel at airports with cargo operations. (A-07-110)

5. Accident occurred: July 28, 2006, at Memphis International Airport, Memphis, TN
Aircraft: McDonnell Douglas MD-10-10, registration: N391FE
Aircraft was severely damaged after its left main landing gear collapsed on landing. After the landing gear failed, the engine contacted the runway, causing a fire and structural damage to the aircraft. Fuel fire extended to cargo [A-6].

These incidents and the ever-growing number of freighter aircraft incidents show the need to improve ARFF training regarding freighter aircraft.

References.

A-1. Federal Aviation Administration, "Programs for Training of Aircraft Rescue and Firefighting Personnel," Advisory Circular (AC) 150/5210-17B, September 23, 2009.

A-2. National Transportation Safety Board, "In-Flight Fire /Emergency Landing, Federal Express Flight 1406, Douglas DC-10-10, N68055, Newburgh, New York, September 5, 1996," Aircraft Accident Report NTSB/AAR-98/03, Washington, DC, 1998.

A-3. National Transportation Safety Board, "Crash During Landing, Federal Express , Inc., McDonnell Douglas MD-11, N611FE, Newark International Airport, Newark, NJ, July 31, 1997," Aircraft Accident Report NTSB/AAR-00-02, Washington, DC, 2000.

A-4. National Transportation Safety Board, "Hard Landing, Gear Collapse, Federal Express Flight 647, Boeing MD-10-10F, N364FE, Memphis, Tennessee, December 18, 2003," Aircraft Accident Report NTSB/AAR-05/01, Washington, DC, 2005.

A-5. National Transportation Safety Board, "Inflight Cargo Fire, United Parcel Service Company Flight 1307, McDonnell Douglas DC-8-71F, N748UP, Philadelphia, Pennsylvania, February 7, 2006," Aircraft Accident Report NTSB/AAR-07/07, Washington, DC, 2007.

A-6. National Transportation Safety Board, "NTSB Identification: DCA06FA058" http://www.ntsb.gov/aviationquery/brief.aspx?ev_id=20060808X01115&key=1 (last visited 07/02/2013).

APPENDIX B—CARGO COMPARTMENT CLASSIFICATIONS

Sec. 25.857 — Cargo compartment classification [B-1].
(a) *Class A.* A Class A cargo or baggage compartment is one in which—
(1) The presence of a fire would be easily discovered by a crewmember while at his station; and
(2) Each part of the compartment is easily accessible in flight.

(b) *Class B.* A Class B cargo or baggage compartment is one in which—
(1) There is sufficient access in flight to enable a crewmember to effectively reach any part of the compartment with the contents of a hand fire extinguisher;
(2) When the access provisions are being used, no hazardous quantity of smoke, flames, or extinguishing agent, will enter any compartment occupied by the crew or passengers;
(3) There is a separate approved smoke detector or fire detector system to give warning at the pilot or flight engineer station.

(c) *Class C.* A Class C cargo or baggage compartment is one not meeting the requirements for either a Class A or B compartment but in which—
(1) There is a separate approved smoke detector or fire detector system to give warning at the pilot or flight engineer station;
(2) There is an approved built-in fire extinguishing or suppression system controllable from the cockpit.
(3) There are means to exclude hazardous quantities of smoke, flames, or extinguishing agent, from any compartment occupied by the crew or passengers;
(4) There are means to control ventilation and drafts within the compartment so that the extinguishing agent used can control any fire that may start within the compartment.

(d) [Reserved]

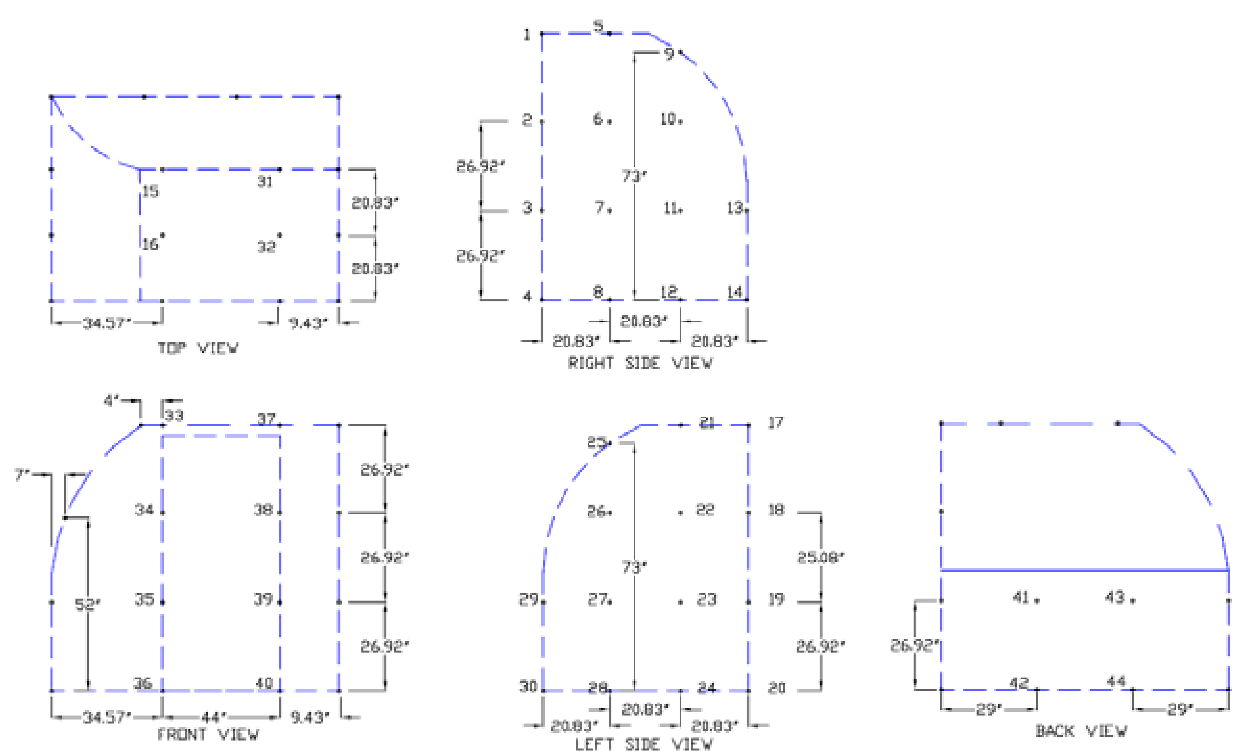
(e) *Class E.* A Class E cargo compartment is one on airplanes used only for the carriage of cargo and in which—
(1) [Reserved]
(2) There is a separate approved smoke or fire detector system to give warning at the pilot or flight engineer station;
(3) There are means to shut off the ventilating airflow to, or within, the compartment, and the controls for these means are accessible to the flight crew in the crew compartment;
(4) There are means to exclude hazardous quantities of smoke, flames, or noxious gases, from the flight crew compartment; and
(5) The required crew emergency exits are accessible under any cargo loading condition.
[Doc. No. 5066, 29 FR 18291, Dec. 24, 1964, as amended

In addition to these regulations, the FAA issued Airworthiness Directive (AD) 93-07-15 that required, among other things, that after November 2, 1996, the Class B cargo compartments on Boeing Models 707, 727, 737, 747, and 757 and McDonnell Douglas Models DC-8, DC-9, and DC-10 series airplanes have improved fire protection features. One of three options available to comply with this AD is to modify Class B cargo compartments on these airplanes to comply with the requirements for Class C compartments. This option would require the installation of a fire suppression system.

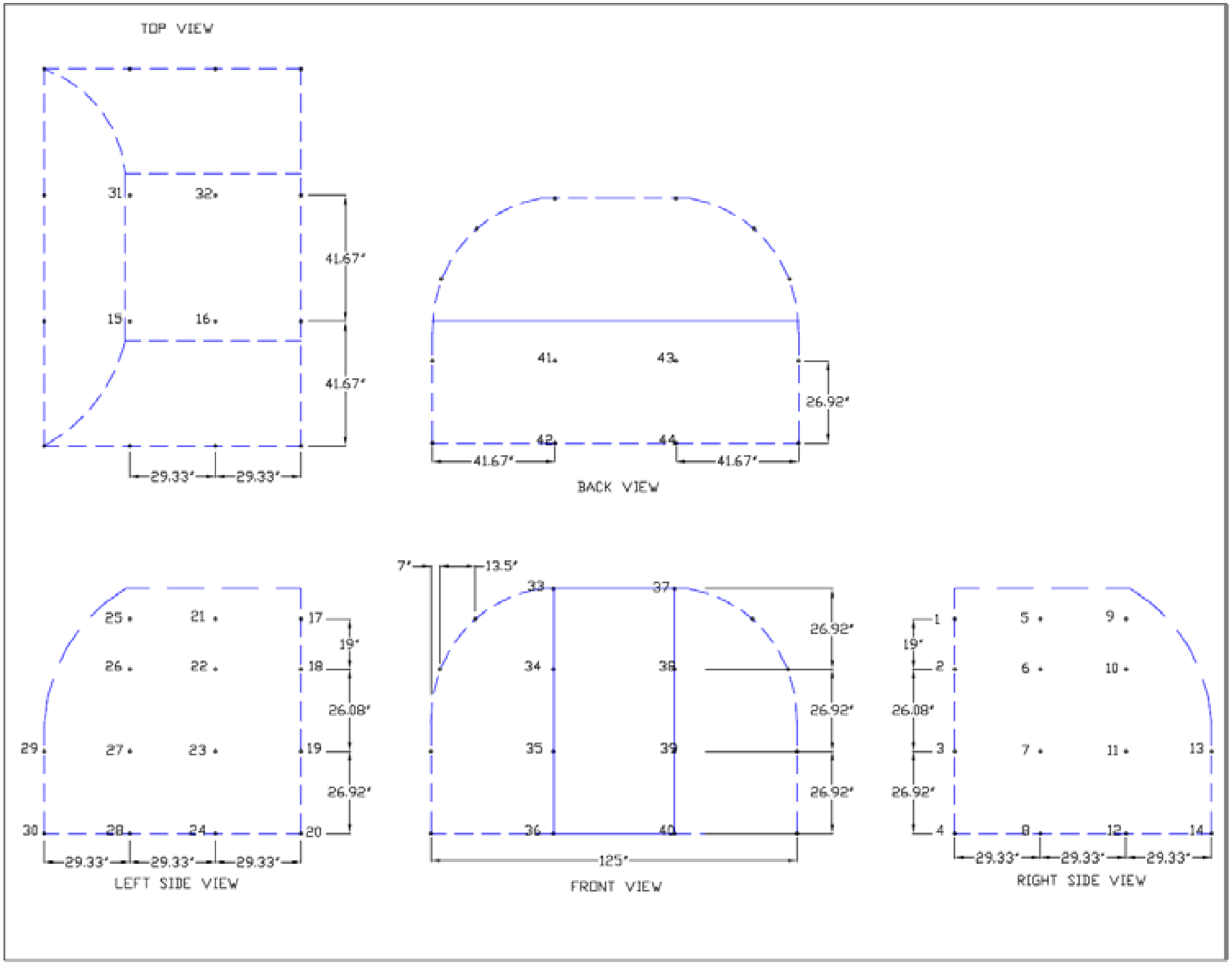
One other area of rulemaking activity relating to cargo compartment suppression system requirements is the “Revised Standards for Cargo or Baggage Compartments in Transport Category Airplanes, Final Rule,” amendments 25-07 and amendments 121-269, effective March 19, 1998. This rule eliminates Class D cargo compartments on newly certified aircraft under 14 CFR Part 25 and requires existing Class D compartments on 14 CFR Part 121 certified passenger aircraft to comply

References.

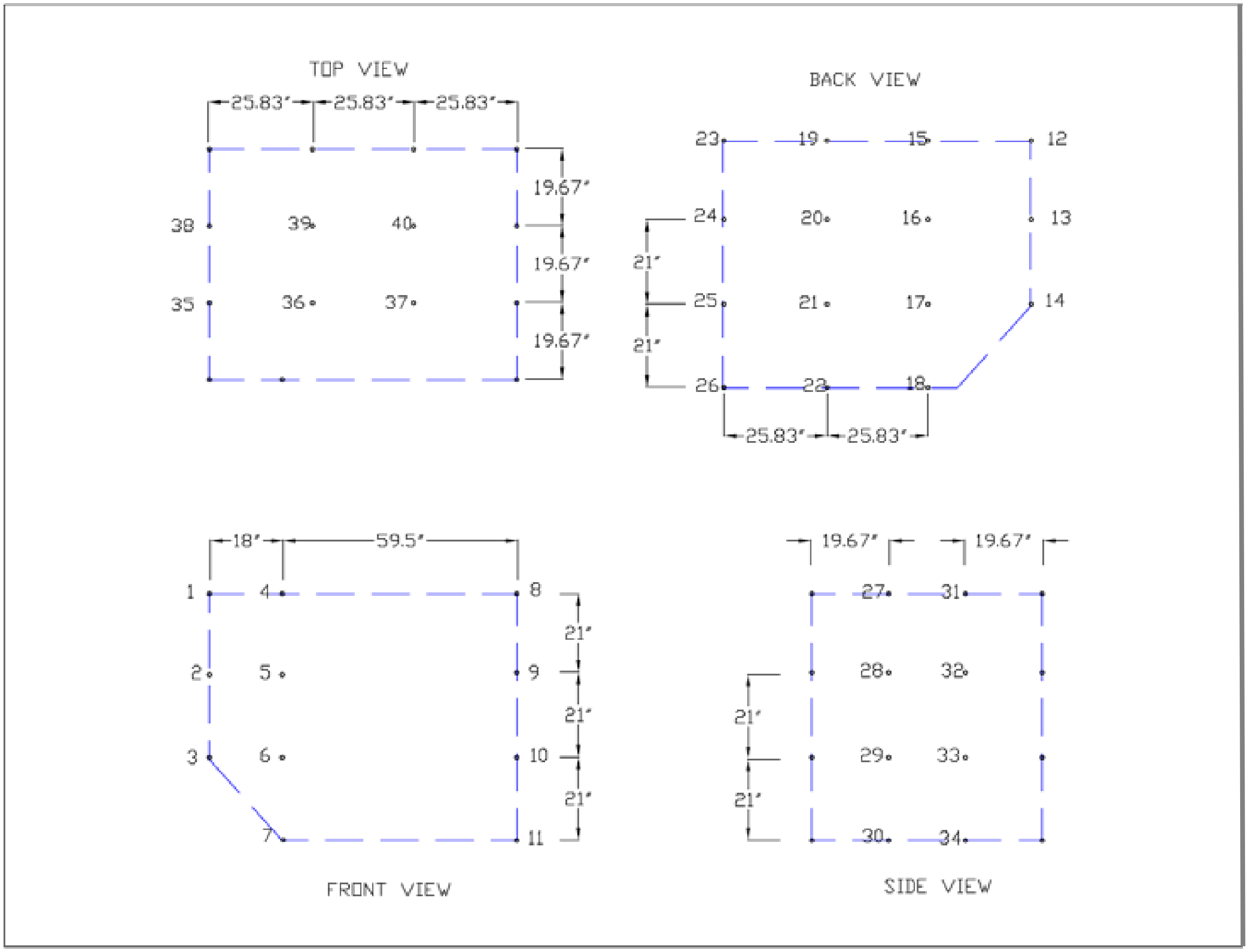
B-1. U.S. Federal Register, Title 14 Code of Federal Regulations Part 25.857, “Airworthiness Standards: Transport Category Airplanes, Subpart D: Design and Construction, Fire Protection, 25.857-Cargo compartment classification,” Government Printing Office, Washington, DC.



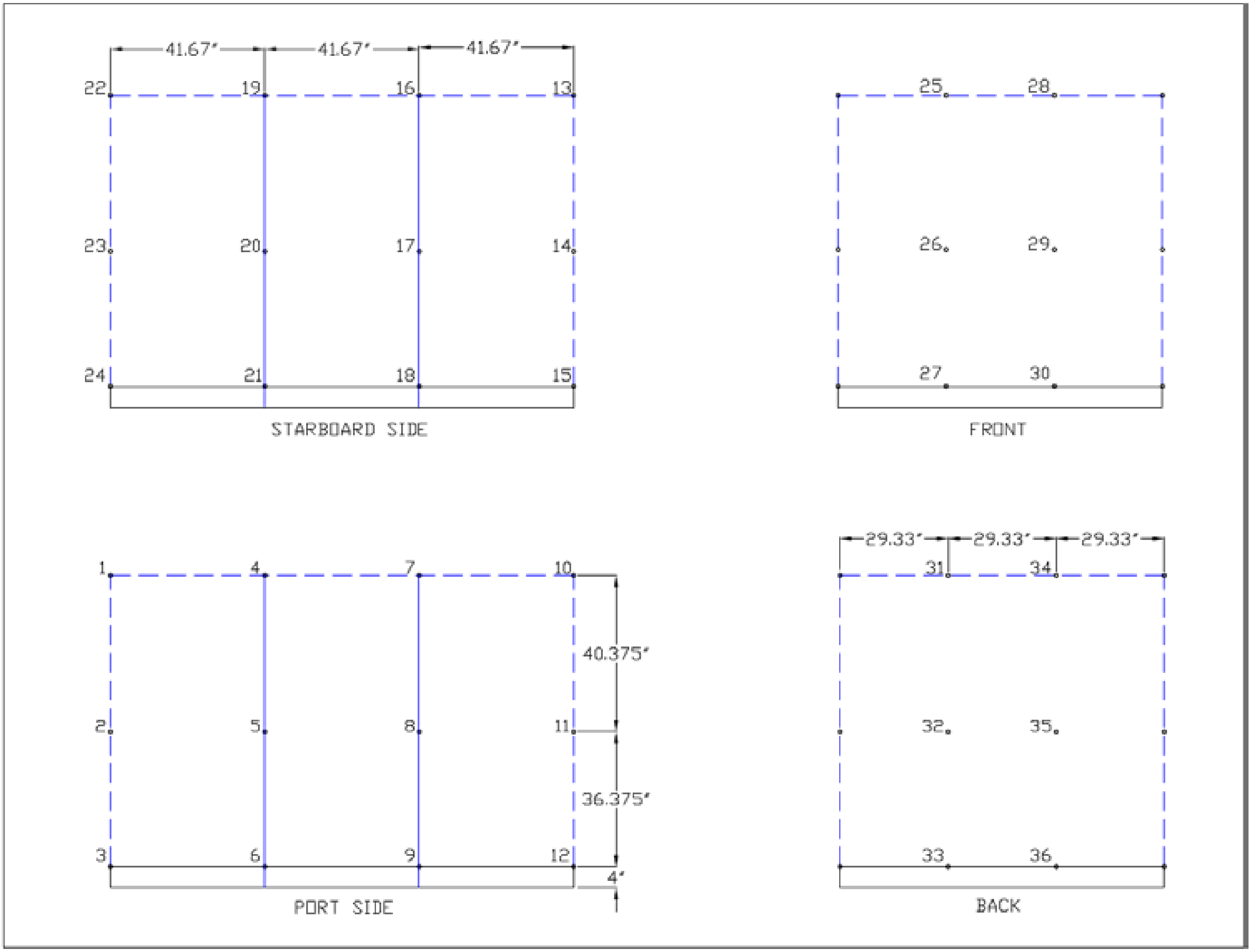
C-1. Thermocouple Locations in the Test Half-Width Container



C-2. Thermocouple Locations in the Test Full-Width Container



C-3. Thermocouple Locations in the Test LD3 Container



C-4. Thermocouple Locations in Thermocouple Tree for Pallet Fires