TECHNICAL NOTES

Aircraft Loading Walkways – Literature and Information Review

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About the Fire Protection Research Foundation

The Fire Protection Research Foundation plans, manages, and communicates research on a broad range of fire safety issues in collaboration with scientists and laboratories around the world. The Foundation is an affiliate of NFPA.

About the National Fire Protection Association (NFPA)

NFPA is a worldwide leader in fire, electrical, building, and life safety. The mission of the international nonprofit organization founded in 1896 is to reduce the worldwide burden of fire and other hazards on the quality of life by providing and advocating consensus codes and standards, research, training, and education. NFPA develops more than 300 codes and standards to minimize the possibility and effects of fire and other hazards. All NFPA codes and standards can be viewed at no cost at www.nfpa.org/freeaccess.

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1.0 BACKGROUND

1.1 Introduction

There are several manufacturers that build aircraft glass loading walkways, which are currently permitted in countries that have not adopted National Fire Protection Association (NFPA) standards. The Technical Committee for NFPA 415, *Standard on Airport Terminal Buildings, Fueling Ramp Drainage, and Loading Walkways* [NFPA, 2013] desired more information about the global experience of using glass loading walkways, including fire resistance of the loading walkways, fire test methods, use of alternate/additional escape routes from the plane, passenger behavior during actual emergency incidents, and psychology/sociology of occupants that might egress through a glass loading walkway with a large fire outside/below.

The Fire Protection Research Foundation (FPRF) responded to the NFPA 415 committee request by sponsoring a project to investigate the many factors associated with glass loading walkways. This involved a literature search/information gathering project performed by a student intern. This intern was mentored by a senior engineer familiar with aviation safety and fire protection. A technical panel, comprised of professionals in the field of aviation safety and fire protection, was formed to provide input as well as review the results.

1.2 Terminology

- *Aircraft Cab*: The area at the aircraft mating end of the loading walkway in which the controls are located. This area can be raised or lowered, extended or retracted, and may pivot, in order accommodate many different types of aircraft [ThyssenKrupp, 2012a].
- *Aircraft Canopy*: The accordion-like fabric that extends beyond the aircraft cab to ensure a tight seal against the side of the fuselage [ThyssenKrupp, 2012a].
- *Aircraft Loading Walkway* (also called Jet Bridge, Jetway®, Tunnel, or Boarding Bridge): An aboveground device through which passengers move between a point in an airport terminal building and an aircraft. Included in this category are walkways that are essentially fixed and permanently placed, or walkways that are mobile and that fold, telescope, or pivot from a fixed point at the airport terminal building [NFPA, 2013].
- *Airport Ramp*: Any outdoor area, including aprons and hardstands, where aircraft can be positioned, stored, serviced, or maintained, irrespective of the nature of the surface of the area [NFPA, 2013].
- *Arm/disarm aircraft door*: When an aircraft door equipped with a slide is armed, a girt bar is attached to the floor. When the door is disarmed, the girt bar is free from the floor and will not allow the slide to deploy: http://www.ntsb.gov/doclib/recletters/2001/A01_27_28.pdf
- *Girt Bar*: Metal bar that connects the emergency evacuation slide to the floor to initiate deployment upon the door opening: http://www.ntsb.gov/doclib/recletters/2001/A01_27_28.pdf
- *Rotunda*: The rotating portion of the walkway that is fixed to the airport terminal – allows the walkway to move left and right: http://www.ntsb.gov/doclib/recletters/2001/A01_27_28.pdf

1.3 Issues Associated with Glass Loading Walkways

Currently, NFPA 415 Section 6.1.2 requires walkways to be fire resistant, as demonstrated by a fire exposure test specified in Section 6.4. An alternative to a fire resistive enclosure is the installation of an automatically operated deluge water spray or foam fire suppression system. For all walkways, there may be no transparent or translucent walls, windows, or surfaces other than those windows located in the ramp access door and in the cab area, for the purpose of operating the aircraft loading walkway.

The sense of the committee to date, as reflected by the current requirements, is that:

1) A safe egress path must be available at the terminal gate in the event of a fuel spill fire;
2) A fire resistive loading walkway (or walkway with the area protected by an automatic suppression system) is the appropriate means to provide the necessary safe exit; and,
3) Passengers will be afraid or reluctant to exit through a path where they can see a fire (even though it may provide protection against heat and smoke). Therefore, glass should be prohibited as a primary walkway construction material.

NFPA 415 background information provides some history related to the issue. The 2007 NFPA *Report on Proposals* includes some comments regarding the previous decision to prohibit glass in loading walkways [NFPA, 2007]:

One committee member voted negatively stating:

> "I believe the emergency evacuation of the airplane will be slowed with windows in the loading walkways because either people slowing down to look out the windows or people hesitate to exit the airplane when they see fire. It would seem easier to "herd" people through a passageway without any external influences than when people can be distracted by what they see through the glass."

Another committee member had the following comment:

> "To further support some comments I made during our discussion at the meeting in Miami concerning glazing in passenger loading walkways, I would like to pass along the following to the Committee." He distributed the Flight Attendant Training as required by the Federal Aviation Administration (FAA) Regulations; see Section 7.2.2 on flight attendant training.

The prior NFPA Staff Liaison provided further background information:

> "There has always been a prohibition on glass, except a window is permitted in the ramp access door and one in the cab area in order to move the loading walkway around safely. I think the concern of several members is the event where foam is not applied quickly or a problem occurs with actuating the system. Walking through a flaming glass tunnel would potentially create a backup at some point in an evacuation. One member stated, 'The architectural enhancement creates a potential for loss of life.'" [Conroy, 2006].

2.0 OBJECTIVE

The objective of this research is to gather pertinent information and provide insight on the fire safety aspects of glass loading walkways. The overall objective is the safe evacuation of passengers and crew from a fire engulfing an aircraft at or near an airport terminal. The information from this project is intended to provide guidance to the NFPA 415 Technical Committee on the use of glass loading walkways and may be used as the technical basis for the continued prohibition or future inclusion of glass loading walkways in the standard. Ultimately, the information is gathered to support or disprove the following null hypothesis: Current requirements which restrict the use of glass in constructing aircraft loading walkways do not significantly impact the probability of safe evacuation from the aircraft. Aircraft and airport operations are considered, along with the impact of building and fire codes applicable to airports.

3.0 SCOPE/APPROACH

The scope of this project provides information directly related to the construction of both traditional and glass loading walkways, a review of fire history, a discussion of the loading walkway as a means of egress, and the psychological impacts occupants may experience while using the loading walkway as a means of egress during a fire event. A literature search of relevant information that addresses these topics was performed.

4.0 PERFORMANCE-BASED DESIGN

4.1 Goal

Aside from the functional need for passengers' boarding and deplaning, aircraft walkways should provide for safe egress for the passengers and crew members. In order to design a walkway with adequate safety, a performance-based design approach was used to analyze the available protection. It is important to understand that this is simply an approach and not a design method. A performance-based design analysis for fire safety is generally broken into the following four fundamental, yet related, goals:

1) Life safety – minimize injuries as a result of the fire, and prevent undue loss of life;
2) Property protection – minimize the damage to property from fire;
3) Continuity of operations – minimize the time the operation will not be able to perform its job as a result of fire; and,
4) Limit environmental impact – minimize the pollution effects from manufacturing, life cycle, and potential burning of the structure.

Although these four goals are typical for performance-based design, the approach taken for glass loading walkways focuses on the first goal: life safety. The remaining three goals, property protection, continuity of operations, and limited environmental impact, are beneficial if achieved. They are not the overriding objective of this study.

Aircraft loading walkways have a specific role in the routine operations of airports across the globe. The primary fire safety goal of the walkway is to provide protection to all passengers and crew members using the loading walkway. More specifically, NFPA 415 requires that the loading walkway must provide a safe path of egress for five minutes of fire exposure for passengers and crew members, as outlined in Section 5.3.1. The remaining three typical design goals are secondary and do not contribute to the design process of aircraft loading walkways. The protection of the loading walkway structure itself, like that of an aircraft, is not a design goal. If the loading walkway prevents flame penetration and increased surface temperatures for a minimum of five minutes, allowing all the passengers and crew to safely evacuate the aircraft, the loading walkway has achieved an acceptable level of protection. If the minimum level of protection is achieved, the loading walkway is permitted to completely burn to the ground.

4.2 Objective and Performance Criteria

The time in which Aircraft Rescue and Fire Fighting (ARFF) vehicles are supposed to arrive at an aircraft fire and obtain 90% control of the fire is evaluated based on the requirements in NFPA 403 [NFPA, 2009]. ARFF vehicles should arrive and begin applying suppression within two minutes of an alarm and reach 90% control of the fire scenario in under a minute. *(Note: The NFPA 403 Technical Committee recently revised the response time requirement from two minutes to three minutes, as* *reflected in the 2014 Edition.)* As with an aircraft, the maximum time a loading walkway would need to maintain its integrity is three minutes. A more thorough explanation of this analysis will be provided in Section 7.2.5. The performance objective for aircraft loading walkways was established at a minimum of five minutes, which provides a two-minute safety factor compared to the aircraft fuselage.

In order to meet this design objective, the following performance criteria were established, several of which are explicitly included in current NFPA 415 requirements:

1) Prevent flame penetration to unexposed surfaces;
2) Prevent untenable surface temperatures in excess of 250°F (121°C) ;
3) Prevent structural collapse of walkway;
4) Maintain adequate visibility of 13 m or optical density of 0.15 m^{-1} [Jin, 2008]; and,
5) Prevent untenable toxicity levels.

Flame penetration is a critical parameter. If a spill fire occurs below the walkway, the resulting flame has the potential to penetrate through the walkway structure and interfere with passengers and crew members deplaning the aircraft. If a fire were to penetrate the structure, passenger tenability may be affected. Tenability is related to several factors. If the unexposed surface temperatures increase to the 250°F threshold, passengers and crew may be unable to deplane through the loading walkway. Structural integrity of the loading walkway is also a concern in a fire event. If the steel support temperatures are too high for an extended duration, the loading walkway may collapse. Visibility and toxicity can directly obscure an exit path, and affect the decision making of people to choose the loading walkway as a means of egress. In a performance-based design for a glass loading walkways, the above mentioned performance criteria should be met in order to achieve a five-minute minimum safe path of egress.

4.3 Design to Meet Objective

Fire safety for an aircraft loading walkway can be achieved by different techniques and fire protection practices. In order to prevent a fire from penetrating within the structure, passive fire protection principles are often implemented. A passive fire protection system is based on the structural integrity of the walkway. If the steel members, glass or solid panels, and other vital structural components have been tested to withstand a fire for a minimum of five minutes, it is understood that the walkway will be able to provide an adequate level of protection. Section 5.3 provides a more detailed analysis of testing procedures for loading walkways.

Smoke within the loading walkway is another concern for life safety. In the event of a fire emergency, the loading walkway should be designed to prevent smoke infiltration. This could be achieved by maintaining the walkway interior at a positive pressure. In the event that a fire was to penetrate the structure and involve the interior of the walkway, other practices must be put in place to reduce the impact to the passengers trying to reach safety.

Alternate active design approaches might be implemented by using detection and alarm systems or suppression systems. Detection and alarm systems could be used to detect any fire threat, alert the passengers, and initiate evacuation. Suppression could be used to achieve the required five minutes of safety. There are several options outlined within NFPA 415 regarding exterior suppression systems for aircraft loading walkways. Fixed water spray and fixed foam suppression systems are identified as alternatives to provide ample protection against a fire scenario. No automatic detection is required for this option.

4.4 Findings

Two fundamental performance-based design approaches, passive and active, might be used to achieve fire safety goals and provide an acceptable level of safety. NFPA 415 currently emphasizes passive fire protection methods in order to protect a passenger loading walkway. Specific design approaches, as outlined in Section 5.3, provide a method for testing the various components of the loading walkway in order to ensure an acceptable level of protection is maintained during an emergency fire exposure. NFPA 415 specifies a maximum surface temperature of 250°F for a minimum duration of five minutes. The primary method to achieve these specific performance criteria is to conduct full-scale fire tests.

5.0 CONSTRUCTION OF LOADING WALKWAYS

5.1 Traditional Loading Walkways

Manufacturers of traditional loading walkways include:

- Adelte – Barcelona, Spain www.adelte.com
- CIMC Airport Facilities – Eau Claire, WI www.nmc-wollard.com
- JBTAerotech (Jetway®) – Chicago, IL www.jbtaerotech.com
- ThyssenKrupp Airport Systems – Frisco, TX www.thyssenkrupp-airports.com

A representative, mobile walkway of steel design is described by ThyssenKrupp [ThyssenKrupp, 2012b]. A rotunda, supported by a column, is shown in Figure 1. This is the primary support for the loading walkway. It is often attached directly adjacent to the terminal entrance and is constructed from steel. The telescoping tunnel consists of the exterior sides, roof, and floor panels. Each component is manufactured from galvanealed steel panels attached to a framework of steel angle and tubing. Strength is derived from formed sheet metal ribs. The minimum internal clear width of the loading walkway is 58 inches. An internal view of the telescoping tunnel is depicted in Figure 2. Other steel walkways may be fixed with only the cab/canopy being movable.

Figures 1 and 2—Telescoping Boarding Bridge [ThyssenKrupp, 2012a]

The aircraft cab is the portion of the loading walkway that connects to the aircraft. It consists of a bumper that is able to extend and retract in order to ensure a weather-tight fit to the fuselage. It is constructed with laminated safety glass windows in order to assist operation in less than desirable weather conditions. The windows are small and located to allow the loading walkway operator to properly align the loading walkway prior to any passengers or crew members boarding or deplaning the aircraft. The cab is shown in Figure 3. The service access includes a stair leading to the ramp which accommodates the loading walkway operator. This includes a safety wire glass window, and service door. This is shown in Figure 4. All surfaces, internal and external, have a painted finish [ThyssenKrupp, 2012b].

Figures 3 and 4—Walkway cab and service access [ThyssenKrupp, 2012b]

5.2 Glass Loading Walkways

There are several manufacturers of glass loading walkways, including:

- Adelte – Barcelona, Spain www.adelte.com
- Airport Equipment – Lower Hutt, New Zealand www.airport-equipment.com
- JBTAerotech (Jetway®) – Chicago, IL www.jbtaerotech.com
- ThyssenKrupp Airport Systems – Frisco, TX www.thyssenkrupp-airports.com

ThyssenKrupp has a glass apron drive loading walkway that is nearly identical to their traditional loading walkway. Only a few differences exist in the construction [ThyssenKrupp, 2012a]. For instance, the roof and floor panels remain the same, being constructed of galvanealed steel panels attached a framework of steel tubing and angle. The walls, however, are constructed of a diagonal steel tube profile frame with side walls consisting of laminated double glass panes. The panes consist of an outer laminated pane (8 mm), an inner colored pane (6 mm), and an intermediate 8 mm air gap. Both panes are of tempered safety glass. As a result of the varied wall construction, the minimum clear internal width of the glass loading walkway is one inch wider (59 inches) than that of the steel loading walkway (58 inches). The key feature and difference between the traditional steel loading walkway and the glass loading walkways is simply in the fact that the walls are constructed using glass panels instead of steel panels. An example of a ThyssenKrupp glass walkway is shown in Figure 5.

Figure 5—Glass Boarding Bridge [ThyssenKrupp, 2012b]

In correspondence to the NFPA 415 Technical Committee, FMC (now JBTAerotech/Jetway®) indicated that they approached the design and construction of their glass loading walkways with the idea that they incorporated as much of the steel loading walkway design as possible [Smith, 2007]. The intent was to meet NFPA 415 requirements. They described in detailed the design of such a glass walkway, using a wall structure consisting of a truss structure that is skinned with glass panels. It is unclear from this correspondence whether the glass structure was ever subjected to a fire test. Figure 6 is an example of a Jetway® walkway.

Figure 6—Jetway® Glass Loading Walkway
http://www.airport-technology.com/contractors/groundequipment/jbt2/jbt21.html

Other glass loading walkways were identified. Another example is shown in Figure 7. It is not clear that other glass walkways have been subjected to fire testing. The manufacturers' specifications were not readily available to indicate whether they were subjected to the NFPA 415 test criteria. Since NFPA 415 is typically applied in the United States, it is unclear that other countries, where glass loading walkways are commonly used, apply similar standards.

Figure 7—Adelte Glass Loading Walkway
http://www.adelte.com/airports/passenger-boarding-bridges/image-gallery

5.3 Test Criteria and Data

5.3.1 Current Requirements

NFPA 415 provides detailed testing criteria for loading walkways. Tests are required to be conducted to establish the performance of materials and methods of construction and to verify their structural integrity and heat transfer characteristics so as to satisfy the 5-minute exit route criteria. Tests are conducted in several stages, rather than the entire assembly at once. For example, the floor assembly, as discussed below, is tested in a specific manor. Similarly, the wall assembly and cab materials are also individually tested in order to ensure they meet the minimum requirements of construction. Figure 8 shows the required average furnace temperature for the external floor and wall fire test exposure:

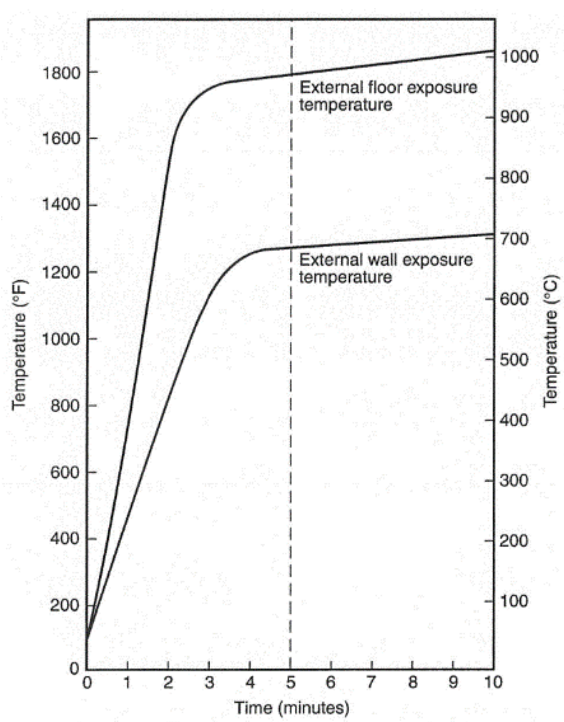

Figure 8—Time-Temperature Curves for Fire Testing of Aircraft Loading Walkways [NFPA, 2013]

The testing methods outlined for the floor and wall assemblies are similar; however, the floor assemblies are exposed to a greater temperature, as shown in Figure 8 (see rationale for this in the section 5.3.2). The test specimen must be representative of the construction for the classification desired in regard to materials, workmanship, and details such as dimensions of parts and it must be built under conditions representative of actual aircraft loading walkway construction and operation. Instrumentation for the testing includes a minimum of nine thermocouples strategically located throughout the test sample. Dimensions of the sample must be chosen based on specific construction features to ensure stress concentrations and separation will not result in failure. A worst case load is applied, derived from the following:

1) Floor live load: 40 lb/ft^2 (195 kg/m^2);
2) Roof load: 25 lb/ft^2 (122 kg/m^2); and,
3) Wind load: 12.5 lb/ft^2 (61 kg/m^2).

The fire-endurance test is continued on the specimen with its applied load, until failure occurs, or until the specimen has withstood the test conditions for a period of 10 minutes. The test is considered successful when the following conditions of acceptance are met:

1) The wall or floor section must have sustained the applied load during the fire-endurance test without passage of flame for a minimum period of five minutes. Flaming must not appear on the unexposed face.
2) The maximum allowable surface temperature of the cool side of the wall or floor section may not exceed 250°F (121°C) during a five-minute exposure as determined by NFPA 415 Section 6.4.4.4.

NFPA 415 outlines specific testing requirements for the other components of a passenger walkway. Testing of the canopy, or flexible closures in NFPA 415 terminology, is conducted similarly to the wall assemblies. The same radiant exposure is produced by the furnace on a minimum sample size of 2 ft x 2 ft. The assembly is considered acceptable when flame penetration is prevented and the structural integrity of the framework is maintained for a minimum of five minutes. Tests of the cab and rotunda materials are exposed to the appropriate external floor or wall exposure outlined in Figure 8. Acceptance conditions are achieved if the specimen can withstand the design fire exposure without flame passage for a minimum of five minutes. Testing of bumper materials shall be conducted with a sample in continuous contact with a simulated aircraft fuselage. Acceptance is achieved if the sample material is capable of preventing flame passage when exposed to the external flooring exposure shown in Figure 8. The testing of miscellaneous seals and weather stripping assemblies requires the construction of a test apparatus. This testing apparatus is comprised of a steel stud wall assembly with a single layer of Type X Gypsum Wallboard on the exposed surface. This assembly has a portion cut out in the middle with a small wall assembly fabricated to fit inside the hole. The seals or weather stripping material is used to fill the gap in between. Conditions of acceptance are when these materials can prevent flame penetration to the unexposed side when exposed to the appropriate time-temperature curve in Figure 8 for a period of five minutes. The specific curve is determined depending on the intended location of the material being assessed.

Compliance may be achieved by other methods such as modeling, calculation, or testing. If this approach is used, it is the responsibility of the submitter to show that the level of safety is at least equal to that of the fire tests. This provides an option for a designer or engineer to develop a loading walkway that provides adequate safety without incurring the costs involved with full-scale testing.

5.3.2 FAA Tests of a Walkway

The FAA conducted tests on a loading walkway assembly [Geyer, 1973]. Fire test requirements already existed in the NFPA Standard on Aircraft Walkways (then NFPA 417). The fire test bed was comprised of a 40-foot cabin section of a four-engine commercial jet aircraft and an aircraft loading walkway positioned over a fire pit. The aircraft was protected by a 0.5 inch thick layer of ceramic insulation and 0.031 inch thick stainless steel. The walkway consisted of a terminal entrance and two telescoping steel sections. The interior of the walkway was maintained at a very low positive pressure. Instrumentation included thermocouples, radiometers, smoke meters, cameras, and a physical metallurgical analysis of steel samples. The fire pit was approximately 30 ft x 32 ft. It contained approximately 960 ft^2 of JP-4 jet fuel spilled under the loading walkway.

The exposure temperatures recorded during the tests are shown in Figure 9, reproduced from the test report. There were wind conditions which averaged 14 knots during the test. This promoted leaning of the fire plume, which resulted in an uneven exposure to the walkway. The thermocouple located below the centerline of the walkway and about 15 feet from the fuselage showed a minimum and maximum flame temperature variation from 1050–2200°F. The thermocouple positions 1 foot from the fuselage and 4 feet on the side of the walkway ranged between 700–1900°F. The steel floor section reached 900°F in approximately 45 seconds. This is shown in the top envelope in Figure 9. The maximum temperature on the downwind side of the walkway was approximately 950°F after 390 seconds. The walls are shown by the center envelope in Figure 9. The maximum inside air temperature was 245°F at 465 seconds, which was considered within tenable limits. This is shown by the bottom envelope in Figure 9. At the conclusion of the fire, the overall structural integrity of the loading walkway remained for the entire ten minute duration of the free burn fire scenario.

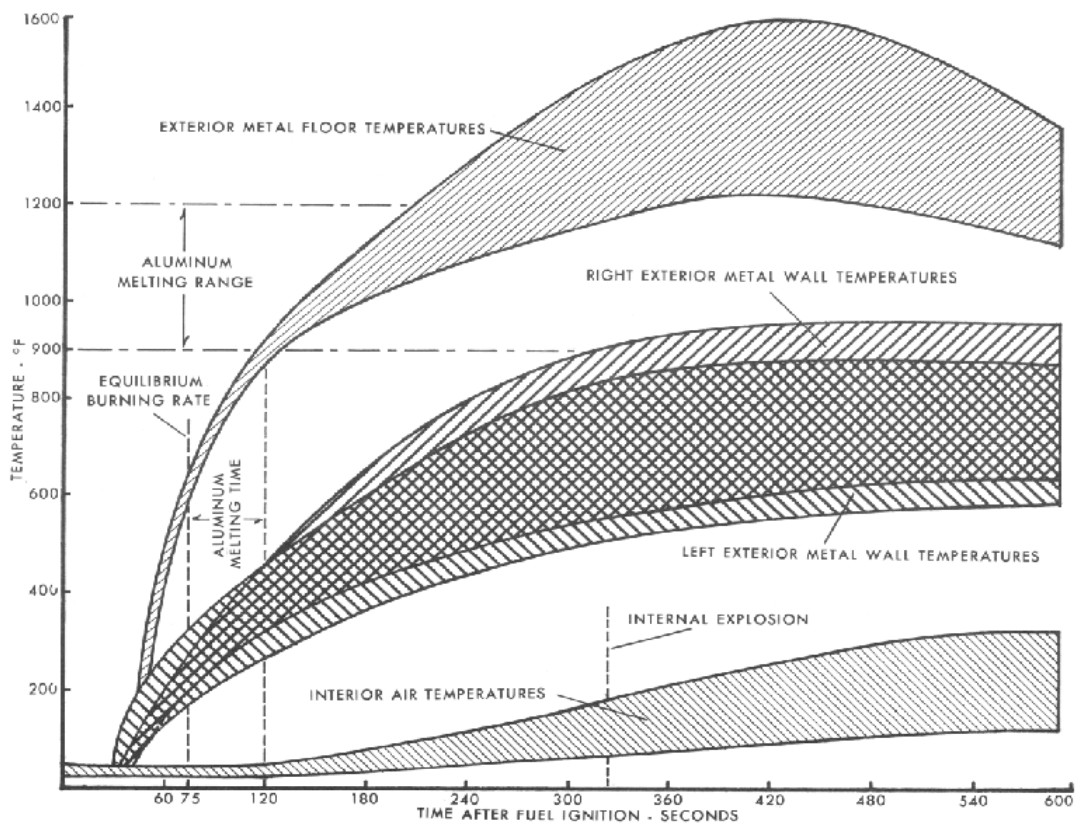

Figure 9—Summary of the Time-Temperature Data Obtained for the Aircraft Loading Walkway during Fire Exposure [Geyer, 1973]

A majority of the seals and weather stripping materials experienced thermal failure which permitted smoke and flame penetration to be present within the loading walkway. Visibility due to smoke obscuration was estimated to be lost within 90–120 seconds. This was due to rapid ignition of wood flooring material (located above the exterior steel assembly), and ignition of bumper seal material between the walkway and the simulated terminal entrance. Small scale testing, including the use of a smoke chamber, was subsequently conducted using alternative construction materials/design of the floor and gasket. It was concluded that designs to prevent flame penetration through the assembly would limit smoke development in the walkway.

5.3.3 Limitations of Current NFPA 415 Criteria

The thermal exposure conditions shown in Figure 9 are very similar to those currently required in NFPA 415, see Figure 6. The wall exposure is lower than the floor exposure. The rationale is that, in a fuel spill fire scenario, the walls may not be exposed to a fire as severe as the floor. This occurred in the Geyer test. This is also the approach used by the Department of Transportation during the implementation of improved burn through criteria for aircraft fuselages: only the lower half of the fuselage must pass the new 4-minute burn through requirement [Federal Register, 2000].

Generally, in aircraft fire hazard analysis, no reduction in exposure temperature from a pool fire to vertical surfaces is assumed. For example, in a recent analysis of jet fuel fire exposures to aircraft to assess firefighting agent requirements, a standardized hydrocarbon exposure condition was assumed (e.g. UL 1709, Figure 10). The exposure was assumed to the entire fuselage profile, with little if any fire growth time assumed [Scheffey, et al. 2011]. This is a conservative approach which provides a safety factor, since jet fuel spill fires generally have some growth period before full fire involvement.

The floor exposure in the NFPA 415 requirements is very similar to the UL 1709 exposure, but the wall exposure is lower. While the current fire exposure requirements in NFPA 415 are non-conservative, it might be considered sufficient for this particular application.

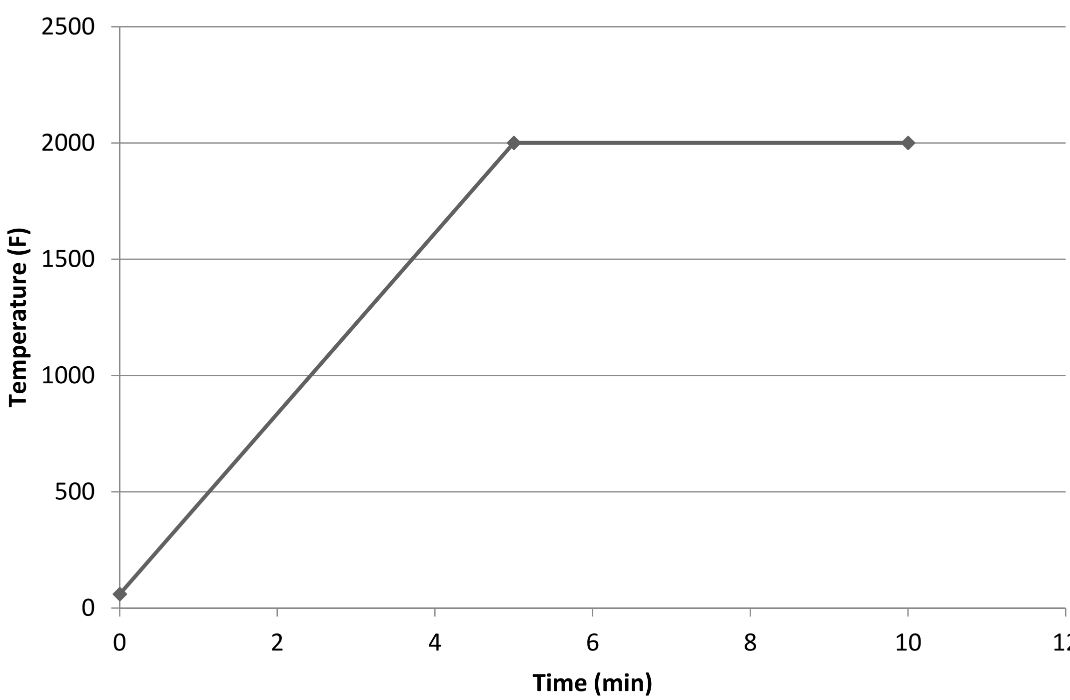

Figure 10—UL 1709 hydrocarbon fuel fire threat [UL, 2011]

The current NFPA 415 allows testing of components of the walkway, in lieu of testing an entire assembly. This is a practical approach; however, the limitation is that reduced tenability due to smoke is not directly assessed. It is only assessed through limitation of flame passage to assemblies which does not necessarily mean smoke will not penetrate into and obscure the walkway.

5.3.4 Fire Testing of Glass Walkways

The Department of Fire Technology at the Southwest Research Institute (SwRI) performed a fire test on a glass loading walkway wall assembly provided by ThyssenKrupp Airport Systems [Luna, 2005]. This report was made available to the NFPA 415 Technical Committee. The testing was conducted on a two-pane glass wall assembly measuring approximately 10 ft wide and 8 ft tall. The assembly framework was constructed from steel framing covered by two layers of glass. In accordance with NFPA 415 testing requirements, the wall assembly was instrumented with an arrangement of nine thermocouples positioned in a symmetric pattern on the unexposed side of the wall. The wall assembly was loaded with an I-beam and steel weights to provide a uniform load of 66.5 lb/ft along the sample. The specimen was subjected to the wall fire exposure conditions described in NFPA 415, which is depicted in Figure 8 of this report. Table 1 provides the visual observations made during the test.

Table 1—Glass Wall Assembly Observations during Fire Test [Luna, 2005]

Time (min:sec)	Observations
0:00	Test Started. Initial temperature of glass is 72°F
1:00	No discoloration of glass observed.
2:00	Glass intact. No significant temperature rise.
3:00	Light smoke. Flaming on inside along gasket.
4:08	Inside layer of glass broke away on right side.
5:00	No flaming on unexposed surface.
5:47	Glass on unexposed side breaks and begins flaming.
6:00	Furnace shut off. Test ended. Remaining glass breaks away.

The glass wall assembly passed the acceptance criteria outlined in NFPA 415. Within the first 5 minutes, the maximum average temperature on the unexposed surface was 193°F, as shown in Figure 11. Additionally, the flame never penetrated the assembly to the unexposed surface. The test continued to run beyond 5 minutes until the average temperature surpassed the maximum of 250°F permitted by NFPA 415 and the flames propagated to the unexposed side of the assembly. This took place at 5.5 minutes and 5.78 minutes, respectively.

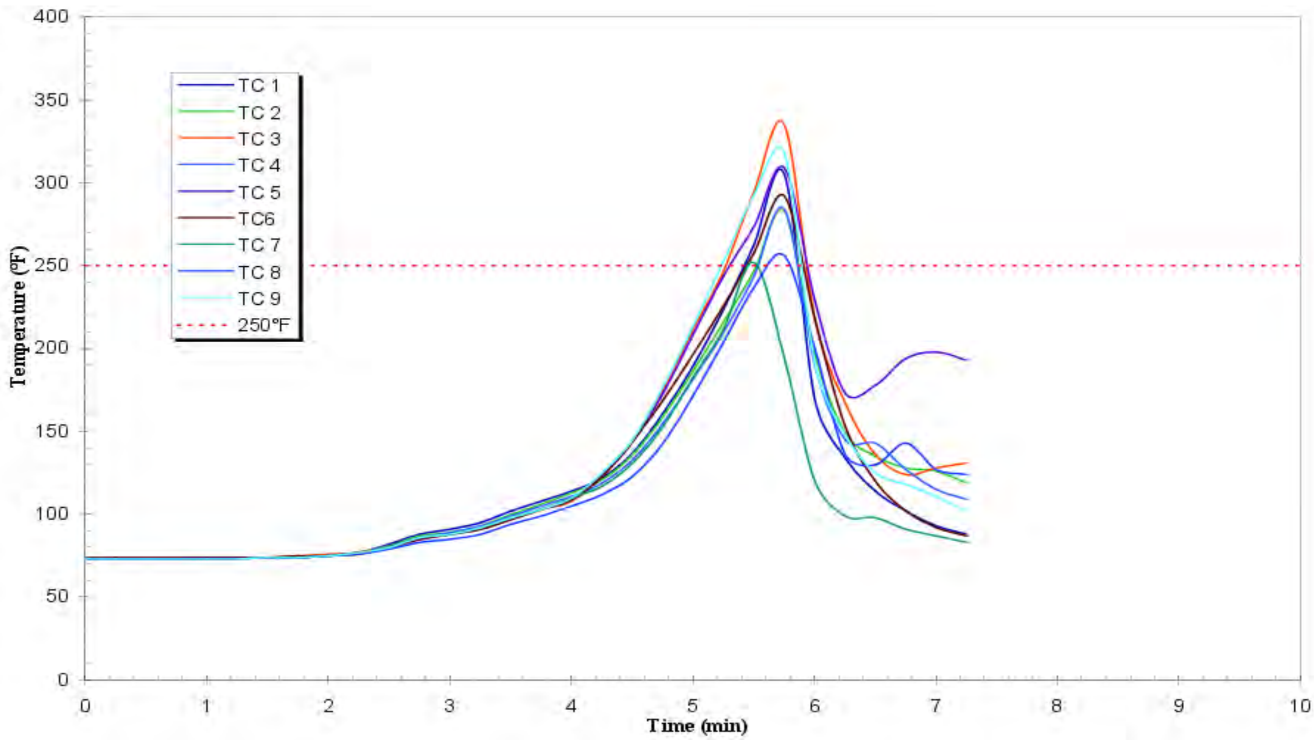

Figure 11—Thermocouple Temperatures during Fire Exposure Test [Luna, 2005]

5.4 Findings

The construction of a representative glass loading walkway uses the same method and materials as the traditional style loading walkway. The difference is in the construction of the glass wall assembly, it is comprised of a steel framework covered by two layers of glass. The walls, ceilings, aircraft cab, aircraft canopy, and rotunda area are very similar. This unit passed the NFPA 415 fire exposure test; however, other glass loading walkways may not. Two representative glass loading walkways were provided that have not clearly endured the acceptance requirements outlined in section 5.3.1.

The thermal threat to the walls in the NFPA 415 test is non-conservative. The requirement in NFPA 415 allows a reduced exposure for the wall sections, based on the exposure observed in a single, wind driven fire test. A conservative approach would be to require a full hydrocarbon fire exposure (UL 1709) to the wall. The current approach might be considered acceptable, since it is similar to the rationale used by the Department of Transportation to implement improved fuselage protection.

NFPA 415 testing procedures for loading walkways allows testing of each component individually, not as an entire unit. Prevention of flame passage and temperature limitations on the unexposed side of the loading walkway is the measure of performance and acceptance. This is a cost effective assessment technique. There is no assessment of tenability related to smoke passage or development on the unexposed side. Visibility and tenability within the loading walkway may be crucial in the evacuation process of the passengers and crew members. If enough smoke develops within the loading walkway, it will greatly limit, or potentially prevent, successful egress due to decreased visibility.

Designing a glass loading walkway is a challenge if it is required to comply with the fire performance regulations of the traditional steel loading walkways. It was found that a glass loading walkway can be designed to pass the NFPA 415 fire acceptance test for loading walkways. There is at least one glass loading walkway currently available to meet the performance requirements of NFPA 415.

6.0 RAMP FIRE AND INCIDENT HISTORY

6.1 Loss History

The following events include ramp fires or incidents where all occupants were required to evacuate the aircraft. These events, both at or near the gate, demonstrate the response by crews to land-based emergency evacuation. Although not necessarily specific for glass loading walkways, these incidents demonstrate human factors in emergency evacuations where there is visible or perceived fire. It has been reported that an average of ten fires annually have occurred at the airport passenger terminal between the years 1999–2002 [Ahrens, 2005]. The following fire and incident history outlines representative events involving a fire or fuel spills associated with an aircraft.

6.1.1 Incidents at the Gate

On November 21, 2012, a small engine fire was reported on JetBlue Airways flight 1329 as it was taxiing to its gate at BWI Thurgood Marshall International Airport. The plane proceeded to taxi to the gate where the fire crews responded and extinguished the fire on the Embraer E190 aircraft. All the passengers and crew members were able to evacuate through the walkway completely unharmed [WBAL TV, 2012]. This is shown in Figure 12.

Figure 12—JetBlue Airways Fire, BWI, November 2012
http://media.nbcwashington.com/images/654*368/jet-blue-1.jpg

On April 20, 1998, at O'Hare International Airport, an American Airlines Boeing 727 incident resulted in an emergency evacuation. Slides were not armed. "While the airplane was at the gate, the auxiliary power unit (APU) torched during start. Passengers saw the flame and proceeded to begin an uncommanded evacuation. The left overwing exits were opened by passengers. The aft flight attendant reported passengers moving toward the aft portion of the airplane. She tried to stop the passengers but could not. She also reported attempting to contact the flight crew. She opened the rear airstairs 'to avoid the stampede.' The flight attendants in the front of the airplane were unaware of why the passengers were evacuating through the forward loading walkway and told the flight crew that a problem existed. In the rear of the airplane, two passengers opened the unarmed L2 door and lowered a passenger out of the exit. The flight crew was able to stop the evacuation and ordered passengers to deplane using the aft airstairs. Passengers on the wing who were unwilling to jump to the ground reentered the cabin and deplaned via the aft airstairs. Two minor injuries were reported, and one passenger sustained a serious injury as a result of jumping off the wing" [NTSB, 2001].

On December 1, 1998, a B747-259B was being refueled in Miami, FL. The entire crew of four was forced to evacuate as a result of a fire. There were no injuries during this event. At the time of the fire, the plane was being loaded with cargo, and part of the crew was manning the flight deck. Once notified, the entire crew on board exited the aircraft unaided via the airstairs to the ramp [NTSB, 2002].

On March 3, 2001, a Thai B737-400 parked at gate 62 of the Bangkok International Airport (BKK) had an explosion and fire in the wing (Figure 13). The plane was destroyed; nine of the ten occupants survived, but sustained some injuries. Two cabin attendants were near the first two passenger rows and exited via the partially blocked passenger door into the passenger walkway. A third cabin attendant was located above the wings during the explosion and was unable to evacuate the aircraft. The subsequent investigation suggests he was incapacitated during the initial explosion and was unable to exit prior to the resulting fire. Two more cabin attendants were located toward the rear of the aircraft. When the explosion occurred, they exited the aircraft by jumping onto the tarmac below; the door was not armed for the slide deployment at this time (see photo). Several other ground support personnel were in the vicinity of the aircraft at the time of the explosion and sustained minor injuries [Thai Airlines, 2001].

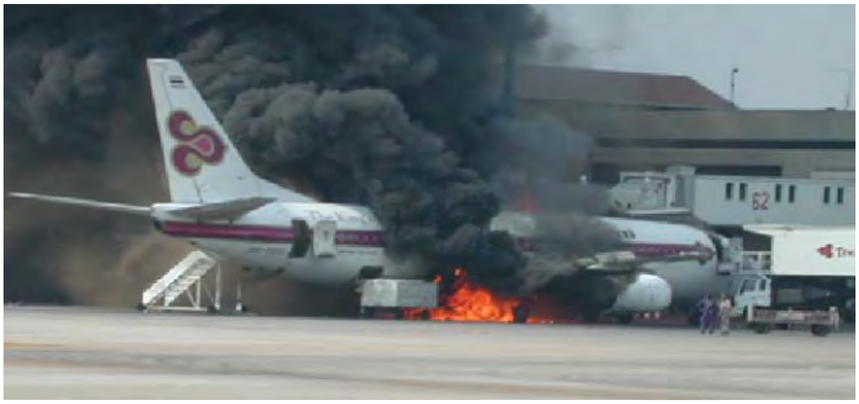

Figure 13—Thai Airways Fire, BKK, March 2001
http://images.usatoday.com/news/washdc/_photos/2001-04-11-ntsb-thaiplane.jpg

At Denver International Airport on September 5, 2001, a British Airways Boeing 777-236ER experienced a refueling fire at the gate while passengers were deplaning. All twenty-six passengers and crew members on board safely evacuated through the walkway; however, the ground service refueler was fatally injured [Aviation Safety Network, 2001].

6.1.2 Taxiway/Runway/Ramp Incidents

China Airlines flight 120 landed in Okinawa on August 20, 2007, and taxied to its designated parking location for the passengers to deplane onto the ramp. The parking brake was set, seat belt sign turned off, and everything was perceived to be normal until the captain was notified of an engine fire. The intent was to have stair departure to the ramp and buses would transport passengers to the terminal. Once the pilot announced passenger evacuation, slides were deployed and all 118 persons evacuated the aircraft without any injury. “During the evacuation, none of the passengers panicked and there was no crying or yelling in the cabin.” The aircraft was totally destroyed in the ensuing fire [JTSB, 2009].

British Airtours flight G-BGJL was ready for take-off in the early morning on August 22, 1985 from Manchester International Airport (MAN). As the co-pilot was commanding the aircraft down the runway at 125 knots, a failure occurred in the left engine which caused a leak in the fuel tank. An audible ‘thud’ was heard by the crew which forced the Boeing 737 to abort take-off. The aircraft was brought to a stop under the assumption that a tire blew out or a bird was ingested in the engine. It was not until the aircraft fuselage began taking on smoke that the crew realized there was a fire involved. The Captain immediately ordered an emergency evacuation from the aircraft on the right hand side. Although prompt action by the crew took place, the fire quickly consumed the fuselage and spread to the inside of the cabin. Additionally, the airport fire service responded quickly to begin controlling the fire. The slides were successfully deployed, as shown in Figures 14 and 15. This allowed eight-two passengers and crew members to safely evacuate the aircraft. Rapid fire growth resulted in the destruction of the aircraft and the loss of fifty-five persons on board [DOT, 1988].

Figures 14 and 15—British Airtours, MAN, August 1985
http://i.idnes.cz/11/111/cl6/VSE3ef239_BritishAirtours28.jpg

On April 14, 1993, American Airlines flight 102 was required to fully evacuate all 189 passengers and 13 crew members from an aborted landing due to an engine fire at Dallas/Fort Worth International Airport in Texas. During the decent, the plane was struck by lightning. This caused a fire to break out and prohibited some of the landing gear from function properly. Immediately upon the plane stopping, the cabin crew began organizing the emergency evacuation, implementing both overwing exits and slides from the doors. Two passengers received serious injuries, and thirty-eight other passengers/crew members sustained minor injuries while evacuating the aircraft. All the injuries were a result of the angle of the evacuation slides due to the position of the plane on landing. Some witnesses stated that slides were nearly vertical in orientation. Although not all exits were usable, the cabin crew successfully directed everyone off the plane in an orderly fashion [NTSB, 1993].

On February 19, 2003, Logan International Airport experienced a large fuel spill in the heart of the cargo transportation center. A 10,000-gallon tanker truck spilled its entire load of jet fuel on the ramp due to a ruptured line as it sat next to an Airborne Express DC-8 aircraft. A safety zone was established and all surrounding buildings within this area were immediately evacuated due to the threat of a large fire. Fortunately, the spill was able to be cleaned up in an orderly fashion while avoiding the ignition of the fuel [Nicholson, 2003].

On August 17, 1995, an SF-340-A aircraft had an engine fire in Philadelphia, PA. The fire was detected after taxiing to the runway, while waiting to be cleared for takeoff. All thirty-one occupants evacuated via the overwing exit without injury [Scheffey, et al, 2012].

In Atlanta, GA on November 29, 2000, a DC-9 experienced smoke and fire in the cabin. All ninety-seven occupants evacuated with only thirteen injuries. Electrical failures were noticed immediately upon take-off. The captain decided to return to the airport and upon landing, smoke was visible within the cabin. Evacuation took place on the ramp, immediately upon landing [NTSB, 2000a].

On November 29, 2000, a DC-9-82 was struck by lightning, at Dulles International Airport, which caused fire and smoke. All sixty-six occupants successfully evacuated the aircraft on the runway without sustaining any injuries [NTSB, 2000b].

6.2 Findings

Based on the summaries of fire and incident history, it is apparent that landside aircraft accidents do occur which result in the emergency evacuation of onboard passengers and crew members. In some of the scenarios identified, fuel spill fires and other threats occur at the airport terminal gate. This finding shows that loading walkways are involved in emergency egress situations. In the limited incident history outlined above, it has been observed that in the event of an emergency evacuation scenario, people will use any means of egress possible to get away from the perceived danger. They will evacuate down slides onto the ramp near the gate or on a ramp area/taxiway/runway, and via the over wing exits. Those who used the slides and over wing exits did so in many cases with a fire threat clearly visible. Passengers and crew members have successfully evacuated the aircraft through the walkway, or, if needed, from aircraft exits. In two cases identified, people evacuated (jumped) from apparently unarmed aircraft exit doors, where the evacuation slide was not deployed. In all other incidents, crew emergency response procedures were evident with the use of aircraft exit slides or loading walkways. This includes situations at the gate.

7.0 MEANS OF EGRESS FROM AIRCRAFT

7.1 Normal Egress

7.1.1 Normal Boarding and Deplaning

A normal means of egress is through an aircraft loading walkway (Figure 16). In most airports, aircraft loading walkways are the primary means for passengers and crew members to board and deplane the aircraft. They are particularly important where passengers need to be protected from inclement weather. There are occasions where the size of the airport or aircraft traffic demands other methods of egress (see China Air incident).

Figure 16—Aircraft Loading Walkway
http://upload.wikimedia.org/wikipedia/commons/0/03/JetwayDenver.jpg

An alternative means of egress from a plane is the use of stairs/ramps instead of an enclosed walkway (Figures 17 and 18). Although most operators prefer a loading walkway since it is better from a customer service perspective, there are no requirements for an enclosed walkway versus apron loading ramps or stairs. According to the participating Technical Panel members, if money is available and space permits the use of a loading walkway, it is very rare to choose alternatives. Smaller airlines/airports tend to use stairs simply because of cost restrictions. Small airports often require some stairs to accommodate the flow of traffic. If an airline or airport can afford the loading walkway, it is uncommon for them to use stairs [Anglin, 2013]. However, they can also be used for larger aircraft as well (Figure 17 is a B757).

The use of apron loading (boarding and deplaning directly from/to the ramp) offers no protection against fires. Aircraft occupants are discharged directly onto the ramp and exposed to any fire situation.

Figure 17—Ramp Loading [Scheffey, 2013a]

Figure 18—Stair Loading [Scheffey, 2013a]

7.1.2 Issues Associated with the Use of Walkways

The FPRF Technical Panel indicated that the FAA regulates building construction through an Airport Improvement Plan – Environmental Impact Statement (AIP-EIS) process. The FAA usually does not get involved in passenger loading walkways unless tower line-of-sight issues are involved. The FAA provides funding for airfields improvements, but typically not terminal renovations. Loading walkways are typically specified in a design package as developed by individual airlines as part of terminal/gate improvements. The FAA has no design requirements, per se, for walkways.

NFPA 415 might also be invoked through an applicable building/fire code requirement, or through reference in a design specification for the walkway. The International Building and Fire Codes (IBC and IFC) do not reference NFPA 415 [IBC, 2012; IFC, 2012]. NFPA 1 *Fire Code* does reference NFPA 415 (NFPA 1, Section 21.2), although it is strictly from an operational standpoint and does not apply to the design or construction of the loading walkways [NFPA, 2012].

It is believed that NFPA 415 is most likely invoked in the United States by the airport authority, or more likely, the operator (airline) who specifies the loading walkway. The airport/airline design agent, such as an engineer or architect, might typically include NFPA 415 by reference in their specifications. This conclusion is based on a discussion with the Technical Panel. It was the opinion of the Technical Panel that none of the US codes, regulations, or jurisdictions (ICC, NFPA, or FAA) requires the use of an enclosed loading walkway versus open stairs or ramps directly to the tarmac. **Unless the use of enclosed loading walkways is mandated, there is no required protected path for passengers and crew members boarding or deplaning from the aircraft.**

When a loading walkway is used as a means to board and deplane the aircraft, there are three factors that diminish its effectiveness as a protected path [Walker, 2001]:

1) Failure to properly use the canopy, especially at airports with stable climates.
2) Food carts being placed in the loading walkway.
3) Fire extinguisher installation within the walkway, restricting the clear width of egress.

"Several air carriers have stopped using the canopy to seal a loading walkway to a plane in order to save time getting in and out of the gate. However, a canopy won't be effective during a fire if it isn't sealed properly" [Walker, 2001]. This scenario is demonstrated in Figure 19. Although weather is not a valid reason to eliminate canopy use, NFPA 415 recognizes that tight fits are not always possible (NFPA 415, Section A.6.2.8).

Figure 19—Gap between Canopy and Aircraft [Scheffey, 2011]

Bridge adapters are often employed when an aircraft parks at a gate not designed for that particular aircraft. Most loading walkways are universal and accommodate many different types of aircraft; however, they cannot incorporate them all. A loading walkway adapter makes it possible for the aircraft to use a loading walkway that is not designed for that specific aircraft. Although this is a very convenient option, the loading walkway adapters typically do not have a tight fit of the canopy to the fuselage. A loose fit or gap will not block potential smoke and flames from entering the loading walkway or aircraft. They may have a significant open gap which ultimately compromises the protected egress path. Figure 20 is an example of a loading walkway adapter that prohibits the proper use of the canopy.

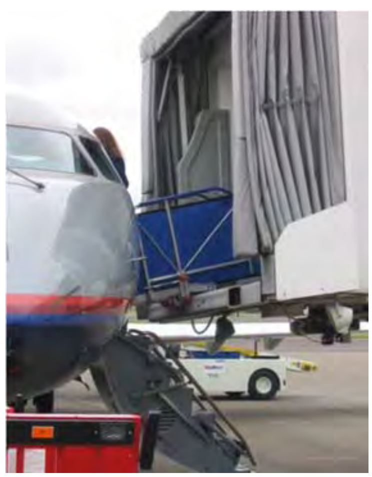

Figure 20—Example loading walkway adapter
http://people.oregonstate.edu/~hunterzk/ncat/pictures/BoardingTech/bridgeramp1.jpg

Another situation occurs where the loading walkway integrity is compromised. Aircraft may use a gate/walkway which can mate to the exit door, but canopy does not provide complete protection. This occurs where the walkway used is not designed for that particular aircraft. An example of this is shown in Figure 21.

Figure 21—Aircraft parked at walkway with incomplete canopy mating [Scheffey, 2013b]

7.2 Emergency Egress

If, for some reason, the walkway is unavailable (e.g., glass, with passengers afraid to exit due to visible fire), would alternative means of egress be readily available? To answer this, the requirements for aircraft exit doors, crew training, and crew response to emergencies were investigated.

7.2.1 Air Crew and Airline Standard Operating Procedures

The Code of Federal Regulation (CFR) Part 121 requires that if at any time there are passengers onboard an aircraft, one door must be ready for evacuation [*Federal Register, 2014)*. This includes when the aircraft is at the gate. This might be:

1) The forward or mid door being used for boarding/deplaning. This door usually has an emergency exit slide, which has been disarmed for the gate side operations;
2) An overwing exit door, which typically does not have an emergency exit slide, and is designed to be operated by passengers; or
3) Other doors (designated as “floor level exits” by the FAA). These are doors located aft, equipped with escape slides, which have been disarmed on arrival at the gate. The forward or mid door being used by passengers would also be categorized as a floor level exit. A flight attendant would likely be needed to assist with operation of a closed, floor level door (see Section 6 on incident history and door operation).

The FAA recognizes the importance of flight attendants and/or crew being available to assist passengers in the event of an emergency when the aircraft is parked at the gate. They require both minimum staffing and training in handling emergencies. CFR 121.394 requires that, during passenger boarding, on each airplane for which more than one flight attendant is required, the operator may reduce the number of required flight attendants by one. This can only occur if:

1) The flight attendant that leaves the aircraft remains within the immediate vicinity of the door through which passengers are boarding;
2) The flight attendant that leaves the aircraft only conducts safety duties related to the flight being boarded;
3) The airplane engines are shut down; and
4) At least one floor level exit remains open to provide for passenger egress.

There are additional requirements related to situations where only one flight attendant is normally required (must stay with the aircraft) and when crew (trained in flight attendant emergency operations) can substitute for a flight attendant. If only one flight attendant is on the airplane during passenger boarding or deplaning, that flight attendant must be located in accordance with the airline's FAA-approved operating procedures. If there is more than one flight attendant, they must be evenly distributed throughout the airplane cabin, in the vicinity of the floor-level exits, to provide the most effective assistance in the event of an emergency.

On arrival to the loading walkway, the flight attendants are to be spaced throughout the cabin to assist passengers with any deplaning related tasks. When the aircraft arrives at the terminal, the seat belt sign is turned off by the Captain, which signifies the parking brake is set. The loading walkway operator aligns the cab with the aircraft exit door. At this point, this door slide is no longer available because the walkway will interfere with inflation. Once the loading walkway is successfully aligned, the operator will signal through the window to the cabin crew that it is safe to disarm the girt bar (this is the steel bar which connects the slide to the doors to automatically deploy when the door is opened). The cabin crew member will then signal back to the loading walkway operator all clear to open the aircraft door. During this time at the terminal, in the case of an emergency, the walkway becomes the primary means of egress, with the exits above the wings serving as secondary exits. Any overwing exit doors would be available for passengers to climb onto the wing and slide down the flaps; no inflatable slide is involved. General practice requires that all emergency exit doors equipped with slides be armed at all times unless the aircraft is at the ramp with the loading walkway attached. When the plane is parked at the ramp, the rear door is often disarmed to allow the catering services to restock the on-board supplies [Anglin, 2013].

Flight attendants are typically responsible for the arming and disarming lever at the gates. They are not generally involved with operating the door control handle; this is performed by the ground service personnel [FAA, 2013]. This can create an issue in the event of an emergency evacuation of the aircraft. Due to the lack of familiarity by the cabin crew in operating the door control handle, several emergency situations have resulted in a failure of egress slides to properly inflate once the door was finally opened [TSB, 2013].

After all passengers are boarded and the loading walkway operator closes the door, it is the responsibility of the flight attendants to engage the girt bar. If the loading walkway or stairs are pulled back, at least one door must be armed [FAA, 2013]. During takeoff and landing, flight attendants must be located as near as practicable to required floor level exits and must be uniformly distributed throughout the airplane in order to provide the most effective egress of passengers in the event of an emergency evacuation [Federal Register, 2014].

During an evacuation, many types of aircraft are equipped with an additional space next to the doors, known as the assist space. This space is designed to allow the cabin crew the ability to direct passengers toward safety while preventing the crew from either being pushed out of the exit or interfere with the flow of the evacuating passengers [Airbus Safety, 2006].

7.2.2 Flight Attendant Training

From the NFPA Report of Proposals [NFPA, 2007], a committee member cited the following FAA flight attendant training requirements [FAA, 2007]. It emphasizes the importance that the flight attendants are at their designated locations throughout the cabin to provide direction to passengers during the emergency evacuation. The requirements include:

<u>Passenger Boarding Duties and Procedures:</u>

- Ensure adherence to all regulatory and company requirements as applicable to specific aircraft.

- Ensuring that a minimum number of flight attendants are at their assigned boarding station.

Prior-to-Movement-on-the-Surface Duties and Procedures:

- The proper operation of the doors and airstairs including latching and arming prior to movement on the surface.

After Arrival Duties and Procedures:

- Ensuring minimum number of required flight attendants are at the assigned arrival station.

Intermediate Stops:

- Determine minimum number of flight attendants required to remain on board at intermediate stops when passengers remain on board the aircraft.
- Ensuring that flight attendants are positioned at designated stations.
- Implementing procedures to ensure passenger safety during fueling and defueling including procedures for emergency evacuation while parked at the gate or ramp.

Procedures for arming exits in emergency mode include the following:

- Ensuring that door is fully closed and locked;
- Checking to see that threshold is free of debris;
- Arming door either manually or automatically;
- Verifying door either manually or automatically armed;
- Verifying girt bar engagement; and,
- Emergency Exit Drill.

The FAA training curriculum outlines specific procedures that must be carried out to effectively prepare and operate exits that are equipped with slides or slide rafts. These include: ensuring that the door is fully closed and locked; checking to see that the threshold is free of debris; arming the door either manually or automatically; and verifying the girt bar is fully engaged. The procedures for opening an exit door in an emergency include: assessing the conditions prior to opening the exit; assuming correct body protective position for the door opening; operating the door controls correctly; and ensuring that the door is in the open and locked position [FAA, 2007].

7.2.3 Research and Testing on Air Crew Performance in Emergency Evacuations

The performance of flight attendants in emergencies can profoundly affect the survival and injury rates of passengers. The National Transportation Safety Board (NTSB) found that flight attendants provided valuable assistance to passengers during emergency situations. The overall record of cabin crews in improving the evacuation process is very good and effective [NTSB, 1992]. In two evacuation cases cited, the actions of some flight attendants contributed to an increase in the number of passenger injuries by their failure to follow their air carrier’s approved emergency procedures or perform their duties in accordance with training.

Additional research is available on the impact of conveying directions to passengers by the crew [Cobbett, 1995]. The following factors are crucial to ensure a successful evacuation:

- The procedural knowledge of the cabin crew: this includes training, experience, and behavior;
- The environment inside and outside of the aircraft (e.g., the presence of smoke, fire, the cabin lighting, and outside conditions);
- The passengers' behavior, age, level of fitness, and motivation; and,
- The aircraft configuration and layout of the cabin.

Cobbett noted that, in the event of an emergency, the cabin crew plays the vital role of directing the passengers to maximize all the usable exits while evacuating the aircraft as quickly as possible. He found that assertive behavior is crucial for initiating rapid evacuation. If the crew members assisted the passengers but did not demonstrate firm direction, the evacuation times were increased. When passengers received no help from cabin crew members, their evacuation times were significantly slower than those passengers who had received help from assertive crew members.

7.2.4 Airport Standard Operating Procedures

The airline, airport, or a third party operator is responsible for operating the loading walkways and positioning them up to the fuselage door. In the event of an emergency, the initial reaction should be to call 911 or the airport emergency number. When the loading walkway has been properly positioned, the walkway operator should knock and wait for confirmation from the flight attendant that the door has been disarmed prior to opening the fuselage door. Regardless of the weather conditions, it is strongly recommended that the loading walkway canopy be properly lowered to ensure an airtight fit [Anglin, 2013].

7.2.5 ARFF Response

Aircraft Rescue and Fire Fighting (ARFF) is an airport firefighting response team specializing in responding to aircraft fire events, mitigating hazards, and assisting with evacuation or possible rescue. Their primary responsibility is to respond to aircraft crash incidents at an airport, rapidly extinguishing a fire so that it does not penetrate the fuselage or endanger evacuating passengers. In a recent review of required ARFF agent requirements, performance metrics for response to a crash were reestablished [Scheffey, et al, 2012]. The response time of vehicles, the control of the exterior fuel fire, and onset of hazardous conditions to occupants can quantitatively be expressed as:

$$T_V + T_E \leq T_B$$

where:

T_V = vehicle response time
T_E = time to extinguish exterior pool fire threat (90% control)
T_B = time occupants are exposed to life threatening conditions

It was reestablished that three minutes is the time when aircraft occupants will be exposed to threatening conditions for an unabated fire. If the ARFF resources arrive at the scene within two minutes, fire control must be achieved in one minute. The performance equation is achieved with fire control in one minute (which is what the ARFF vehicle capacity and equipment is designed to achieve) and vehicle response in two minutes:

$$T_V \text{ (2 min)} + T_e \text{ (1 min)} \leq T_B \text{ (3 min)}$$

The same approach can be applied to the loading walkway scenario. Airport ARFF response provides the suppression capability to assure that an unabated fire does not expose the passengers and crew. Passengers are "protected" for 5 minutes by the loading walkway (if a protected walkway is even provided!). In theory, there is a two-minute safety factor for protection of the loading walkway. But the aircraft itself can only provide protection for three minutes. ARFF response time is measured to the farthest runway, so ARFF stations are positioned to meet that time requirement. Response to the terminal ramp area is a secondary consideration, since it is less likely to be the location of an incident (but is possible, as shown in Section 6). The effectiveness of an ARFF response diminishes rapidly with response times to the scene of a crash in excess of 2 minutes. It would seem prudent to maintain a two minute ARFF response time to the terminal area for protecting occupants within an aircraft, and providing a safety factor for evacuation away from the aircraft.

7.3 Findings

7.3.1 Normal Egress

There is no clear regulatory mandate to provide a fire resistive loading walkway (protected pathway) for passengers and crew members to board or deplane an aircraft. Despite this, design of enclosed loading walkways in the US are believed to be nearly universally in compliance with NFPA 415. With a lack of a regulatory mandate, there is no consistency in the level of protection provided to aircraft passengers boarding or deplaning an aircraft.

The normal means of boarding or deplaning an aircraft is through an aircraft loading walkway or open stair/ramp. The exit path may or may not be protected. Protection by loading walkways designed in accordance with NFPA 415 fire resistance requirements is easily compromised by routine airport operations. The canopy may not be mated properly to the aircraft. A loading walkway adapter might be used with a gap between the aircraft and walkway. An aircraft might use a gate where the walkway is not designed for that particular aircraft. Even if the walkway is designed to properly mate with the desired aircraft, the canopy is not always completely sealed against the fuselage in climates with nice weather.

7.3.2 Emergency Egress

There is an inconsistent level of safety afforded to passengers while evacuating commercial aircraft. There is no regulatory mechanism to compel any authority to enforce such a requirement, if it is deemed necessary. It is often left to the discretion of the airlines and airport operating authority, based on the operational conditions of the airport, to determine which boarding and deplaning method will be used.

What evacuation routes are available if the loading walkway is blocked, or passengers are hesitant to use the walkway because of visible fire? The aircraft evacuation doors with slides will likely be disarmed. The FAA requires that any time there are passengers onboard, one door must be ready for evacuation, typically the door to the walkway. Exits over wings (without slides) are available and designated for emergency evacuation. Flight attendants are required to be available to assist in evacuation; they could arm doors with slides as an additional means of secondary evacuation.

As with any onboard emergency, there is reliance on trained crew to assist passengers. Flight attendants are required to be trained in emergency evacuation procedures, including situations where a protected loading walkway is unavailable. The FAA training curriculum outlines specific procedures that must be carried out to effectively prepare and operate exits, particularly those that are equipped with slides or slide rafts. These regulations demonstrate the degree to which flight attendants and crews are available and trained in the situation where a fire may occur, at the gate, with floor level doors disarmed. They are available to guide passengers and operate alternative means of evacuation.

Research identifies the importance of crew actions in an emergency. An assertive cabin crew is needed to effectively guide all the passengers towards safety away from the aircraft. Several studies have shown that the performance of flight attendants in emergencies can affect the survival and injury rates of passengers. Cabin crew behavior was found to have a significant effect on evacuation times.

It is the responsibility of the airport ARFF services to respond to and control/extinguish a ramp spill fire exposing the aircraft, the loading walkway if provided, and passengers/crew escaping onto the ramp. NFPA 403 recognizes the time-dependent nature of this response for aircraft. A two-minute response has been shown to be the appropriate response time to allow time for fire control before burn through of the fuselage. The same principle applies to the loading walkway, where a 5-minute protection time, established through fire tests, may be provided. There are a number of situations where this protection is not provided. The timely response of ARFF to the ramp/gate area is an important aspect of the emergency evacuation performance design.

8.0 HUMAN FACTORS RELATED TO EGRESS

8.1 Human Factors Related to Typical Building Fires

Human response to fire and emergency situations is a complex dynamic. The response of people involved in fire events have been observed for many years. This research has helped explain a ‘typical’ outcome that one may expect for those in a fire emergency. Bryan states that one’s reaction during a fire is dependent upon many factors [Bryan, 2008]. These factors include previous fire experience, his or her perceived role in the environment, education, and personality. He continues to describe that the perceived threat of the fire, the physical building characteristics, and the actions of others sharing the same experience play a vital role in reaction of the occupants intimate with a fire event [Bryan, 2008].

Throughout the course of many years of observing the human behavioral patterns of occupants in fire scenarios, one particular trend tends to stand out. Fire investigations show that people often choose a relatively poor escape route to exit the burning building even if a better and safer egress path is available. Researchers have concluded that this poorer escape route was chosen based on unfamiliarity of the building layout. Most people have a tendency to evacuate by means of his or her entrance path, regardless of the safety of this route. The familiarity of the path outweighs the increased safety of an unfamiliar escape route [Levin, 1984]. O’Connor observed that occupants are more likely to attempt to leave by their familiar route because they know the location of discharge. He believes that, since people are so often exposed to exit signs but rarely, if ever, have actually paid attention to them, they become immune to noticing marked egress paths and are unprepared to seek a different escape path in an emergency [O’Connor, 2003]. Occupants have been observed to occasionally seek an alternate path in a fire situation, but often turn back to a more familiar route on facing danger. People evacuate towards light and brighter, more spacious areas to find safety. Some people tend to follow other evacuees [Yoshimura, 2000].

The behavior of people in groups seems to differ from that of those attempting to evacuate individually. People will tend to follow a crowd when evacuating a building [Ghosh, 1995]. Another behavior that has been observed is people looking to authority figures for information and direction. People will instinctively expect those of authority in a work place or other regular dwelling to provide direction in an emergency situation [Ghosh, 1995].

Actions taken by occupants attempting to evacuate a perceived emergency threat have been found to be linked to a behavioral or decision-making process, rather than being completely random. Figure 22 outlines a simple decision-making tree that details the thought process many individuals subconsciously step through during a building fire evacuation. The first phase requires the occupant to recognize and perceive the cues. Secondly, the cues must be interpreted to better understand the situation and associated risk involved. Next the occupant must make a decision about how to respond to the threat. Finally, an action must be performed based upon the previous phases in order to evacuate the area of the fire [Kuligowski, 2009].

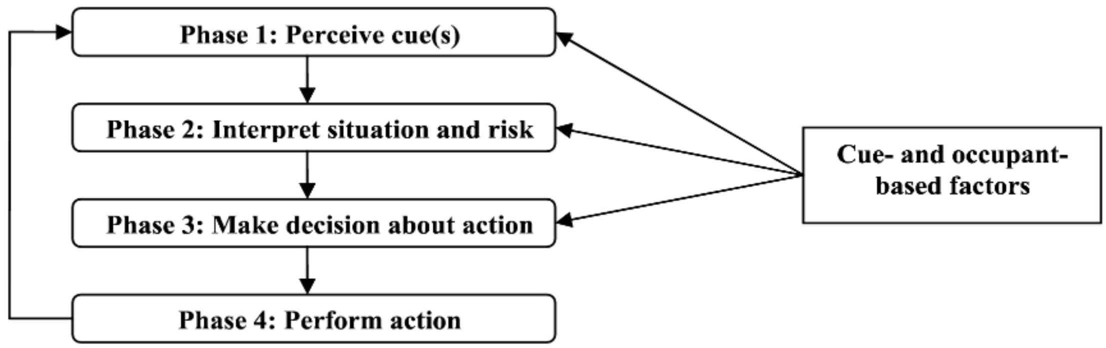

Figure 22—Process of Behavioral Cues [Kuligowski, 2009]

8.2 Human Factors Related to Aircraft Situations

The concern has been raised that passengers and crew members will not evacuate via a loading walkway if a fire is visible. This notion is that people will consider the walkway as an unsafe means of egress if a fire threat is visible while evacuating from the aircraft. When this issue was raised by the NFPA 415 Technical Committee, one of walkway manufacturers, FMC Technologies, was consulted regarding this concern [Smith, 2007]. They contended that there is a high degree of surety that passengers in the plane will know that there is a fire and will be able to see any fire from the windows of the aircraft prior to entering the loading walkway. They did not consider this as a valid concern because passengers will be aware of the fire regardless of the loading walkway design; glass or traditional steel. Additionally, due to the lower degree of apron visibility from the cab and the likely locations of the fire centering around the fuel pits and/or the fuel trucks close to the wings of the aircraft, there is an opportunity for the passengers to be significantly down the loading walkway in the direction of the terminal before the first sight of the fire. Most international operators using glass loading walkways assume that the passenger will realize at this point that safety is ahead of them and will continue to the safety of the terminal.

It was desired to quantify passenger reaction based on the emergency evacuation literature. There is an abundance data in the literature of emergency evacuation data for aircraft. It has been performed primarily by the FAA and Civil Aviation Authority (CAA), and their sponsored researchers. The overview by Blake [Blake, 2003], in his research for the EXODUS aircraft evacuation model and associated behavioral modeling, provides nearly 200 references on the subject. There are countless accounts from both passengers and crew members recorded after an actual fire emergency scenario. The general finding is that on recognition of danger, many passengers begin seeking any means of egress, even if it requires climbing over seats and using force to reach safety. Many passengers reported that part way through his or her evacuation, a crew member provided redirection towards a different means of escape. This often included direction away from exits that had become too dangerous or had a backup of other passengers attempting to exit the aircraft. Passengers are redirected due to a change to the environment or scenario, changes to exit availability, congestion levels within the cabin, or environmental conditions. Redirection of passengers, either from the guidance of crew members or ones own intuition, is found to occur frequently.

The data examined suggests that, in scenarios without fire, the behavior of passengers was quite different to those in which fire was present. The following two scenarious provide broad but distinct categories in which passenger evacuation behavior can be assessed:

- Non-fire/external fire scenarios; and,
- Burn-through/internal fire scenarios.

In the non-fire/external cases, it was apparent that cabin crew members were able to redirect passengers to alternative exits with relative ease and that the majority of the passengers appeared to do as instructed. However, “disobedience” was occassionally observed and was related to passengers deciding that he or she had a better evacuation route than that proposed by the crew. Passengers sometimes chose to redirect themselves, but these passengers were generally willing to abandon their plan and obey orders from cabin crew when instructed. Numerous passenger interviews indicated that initially, direction from crew members was not present. Choosing a path of egress was up to each passenger. On hearing direction from crew members, most passengers abandoned their own approach and followed instructions using the directed path of egress to reach safety [Blake, 2003].

In burn-through fire scenarios, the passenger response is entirely different. Passengers tend to be extremely insubordinate to crew instructions. In these recorded burn through scenarios, “passengers were very **unlikely** to obey crew commands.” Several reports state that passengers who changed direction did so regardless of the commands from crew members. The passengers believed they located a more effective path of egress from the aircraft. The general consensus of crew members was that the effectiveness of their instruction was significantly reduced in burn-through scenarios because of the smoke filling the cabin. Passenger disobedience does not always occur as a result of a direct fire/smoke threat, as described in an incident at John F. Kennedy International Airport in 1992. Several cabin crew members reported being successful in redirecting passengers towards the front of the plane in order to reach a safe and useable exit [Blake, 2003].

In an early attempt to model passenger and crew member evacution, Snow et al. found that many passengers sacrificed an initial advantage by attempting to escape from more distant exits and thereby became fatalities. In other words, many passengers attempted to proceed to a more familiar exit instead of exiting through the closest exit path. Some of these decision may have been made because passengers believed nearby exits were blocked or crowded, but evidence shows in was often more closely related to panic and an unfamiliarity to alternative exit options [Snow, et al., 1970]. The NTSB believes that the increased stress levels may have led to ineffective and inappropriate flight attendant responses [NTSB, 1992].

The U.S. Army Leadership Human Research Unit attempted to evaluate situations that produced a “fear-effect” and “the contribution which this fear component makes to effectiveness and persistence of performance in stress” [Berkum, 1964]. Three test scenarios were developed to monitor test subjects performing various tasks while being exposed to both normal and simulated life-threatening events. One test scenario involved a real flight with a simulated engine failure and anticipated ditching. The results of the tests showed noticable differences in the performance of tasks, including the correct completion of a complicated equipment repair. A trend of decreased accuracy and reduced performance was seen from test subjects exposed to perceived life-threatening scenarios [Berkun, 1964]. NTSB has not identified research on the performance of flight attendants under stress, but they pose that the Army research might be applied to flight attendant training programs [NTSB, 1992].

As part of this project, a noted researcher in the field was interviewed and asked his general thoughts on emergency egress for the aircraft scenario [Gwynne, 2013]. Steven Gwynne, Ph.D., an expert Senior Scientist on people movement working at the University of Greenwich, noted the following:

1) Contrary to expectation, people do actually move through smoke. Therefore, people may still use the glass loading walkway (glass or otherwise) even if it begins to fill with smoke and might be deemed unsafe. He based this on the work of Purser [Purser, 2008].
2) People tend to move slower through smoke, so if the walkway is used as a means of egress, it is likely it will be at a reduced velocity. This is based on the work by Jin [Jin, 2008].

3) There is some evidence that people hesitate when using slides or stepping down from ledges, as a result of the perceived change in conditions. However, they will generally not refuse to escape.
4) Confusion may take place if the loading walkway is completely filled with smoke.
5) Where options are limited, people are willing to expose themselves to smoke in order to reach safety.

8.3 Findings

In building emergency situations, people tend to exit through his/her entrance point, even if this path is more dangerous than alternative paths. It has also been observed that people have a tendency to follow the crowd or look to authority figures. Fire investigations show that people often choose a poorer escape route to exit the burning building even if a better and safer egress path is available, due to a higher familiarity of his or her entrance path.

There is an abundance of literature on aircraft evacuation behavior. Human behavior in these emergencies appears to differ compared to behavior in building evacuations. Redirection of passengers, either from the guidance of crew members or ones own intuition, is found to be relatively frequent. Passenger behavior in aircraft fire incidents is a function of two very different scenarios: non-fire/external fire; and, internal burn-through emergencies. In non-fire or external fire situations, passengers will likely listen to the direction of the cabin crew regarding which exit to utilize. However, when the fire situation involves a burn-through scenario with fire or smoke inside the fuselage, passengers may take evacuation into their own hands. On recognition of danger, passengers may seek any means of egress even if it required climbing over seats and using force to reach safety. The presence of smoke may make passengers unaware that cabin crew members are providing evacuation instructions. Feeling directly threatened, they may not respond to the direction of the crew members.

Flight attendant reaction in emergencies has generally been found to be appropriate and effective. In a few cases, increased stress level, e.g. from fuselage burn through, has led to ineffective and inappropriate flight attendant responses. A test series, performed to assess the proficiency of people performing various tasks in a simulated life-threatening environment, resulted in noticable differences in the performance of tasks. A trend of decreased accuracy and reduced performance was observed from test subjects exposed to perceived life-threatening scenarios.

9.0 SUMMARY OF FINDINGS

1) The NFPA 415 committee is concerned that emergency evacuation will be impeded if exiting passengers can see a fire, if glass is used in a loading walkway.
2) A performance based approach can be applied to this situation. The current NFPA 415 provides much of the basis for this performance (5-minute fire resistance). The missing information is the reaction of passengers to visible fire when evacuating an aircraft.
3) In current NFPA 415 fire test requirements, the fire threat to wall assemblies is non-conservative, and there are no criteria for explicitly limiting smoke obscuration.
4) Glass loading walkways are widely available and used throughout the world. They can be designed to meet the NFPA 415 fire test requirements.
5) Fire loss events of aircraft at or near the gate were identified. Except where fire/smoke has penetrated the fuselage, all occupants in identified incidents involving aircraft at or near the gate have successfully evacuated the aircraft, using the primary walkway or secondary exits (overwing or slide exits).

6) There is no US building/fire code, FAA, or other regulatory provision to require fire resistive loading walkways in accordance with NFPA 415. It is believed that most enclosed walkways in the US comply with NFPA 415.

7) Some operators intentionally discharge passengers directly to the ramp area via unprotected stairs/walkways. There is no regulatory prohibition for this. The fire resistive integrity of walkways are routinely compromised by airport operations. There is no consistency in the level of protection provided to aircraft passengers boarding or deplaning an aircraft.

8) A minimum of one exit pathway, staffed by a trained flight attendant, must be available any time passengers are on board an aircraft. Should the loading walkway be blocked, secondary exits are available through overwing door exits (passenger-operated) or floor level exits (requiring flight attendant assistance to re-arm the evacuation slide).

9) The FAA requires flight attendant/crew training for emergency evacuation situations. Crew response, instructions, and assertiveness is important.

10) Timely ARFF response is an important element to passenger safety for aircraft parked at the gate.

11) Occupant evacuation behavior differs depending on the perceived threat:

   a. Where there is no fire or the threat has not penetrated the enclosure, passengers were able to evacuate. They followed crew directions, or used a path they perceived as better. This is the case even where fire is plainly visible.

   b. Where fire/smoke has penetrated the fuselage, passengers tend to be insubordinate to crew instructions. Self–preservation may apply, even if it conflicts with crew evacuation instructions.

   These findings, derived almost entirely from passenger behavior within parked aircraft, would appear to apply for the glass loading walkway element of the evacuation path.

12) The overall findings would seem to support the null hypothesis: current requirements which restrict the use of glass in constructing aircraft loading walkways do not significantly impact the probability of safe evacuation from the aircraft.

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