Review of Foam Fire Suppression System Discharges in Aircraft Hangars

by

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Executive Summary

This report is a product of a research study on the impacts of low-expansion and high-expansion foam fire suppression systems in aircraft hangars. Included in the report is a review of the requirements for foam systems in hangars in the International Building Code, International Fire Code and NFPA 409. In the 1984 Report on Proposals for NFPA 409, the Technical Committee justified requiring foam systems in hangars to provide an effective fire suppression system to meet the challenges posed by fires involving fuel spills.

In this research study, two surveys were conducted to provide information on the frequency and costs associated with foam discharges, either accidentally or in response to a fire. The research team from the University of Maryland distributed a data collection form (see Appendix) to seven insurance companies, two Fixed Base Operators (FBOs), and media outlets. From these sources, the research team received 174 incident reports. A second survey, distributed by the National Air Transportation Association (NATA), received 72 responses.

One key takeaway from the two surveys is that there has been 39 fire incidents with a foam discharge in response to a fire over the last 16 years, with only one of those incidents involving a pooled spill fire. The foam suppression system did not discharge in this incident.

Further insight into the potential frequency of fires involving fuel spills can be gleaned from a tabulation of fuel spills by the United States Coast Guard (USCG) that have occurred in the first ten months of 2019. The USCG database, there have been 147 fuel spills thus far in 2019, none of which have occurred in an aircraft hangar. Therefore, if fuel spills are not occurring in aircraft hangars, then ignitions of fuel spills in hangars are not possible.

The University of Maryland survey yielded information on the frequency and cost of foam discharges, whether the foam discharge was in response to fire or accidental, i.e. no fire was present. The 174 incidents from 2004-2019 included 37 incidents where the foam system discharged in response to a fire and 137 incidents where there was an accidental foam discharge. Annually, there were 8.56 incidents involving accidental foam discharges, while there were 2.31 foam discharges in response to fire. Hence, on an annual basis, there were 3.7 times the number of accidental foam discharges versus those responding to fire.

The UMD study also revealed the trend in the frequency and costs per year associated with foam system discharges. Over the 16-year period covered by the survey, there has been a substantial increase in the number of incidents involving accidental foam discharges occurring per year (by approximately 1 per year), while the annual number of foam discharges in response to a fire has been virtually constant. The most frequent cause noted for the accidental discharge was a "suppression system failure."

Damage estimates for the aircraft or building/building systems were provided for 89 of the incidents involving accidental foam discharges and 30 of the foam discharges in response to a fire. The total damage estimates for incidents with accidental foam discharges was $66.3M, with

an average loss of $0.745M per incident. In comparison, the total of all damage estimates for the incidents involving foam discharges in response to fire was $22.2M, for an average loss of $0.740M per incident. These damage estimates, as with all damage estimates provided in this report, typically only considered damage to aircraft or building/building systems and neglected clean-up costs. Hence, these numbers should only be viewed as the minimum for loss during the last 16 years; actual losses may be significantly higher.

While the average loss per incident is similar in the incidents involving accidental foam discharges to those in response to a fire, the sum of the damage from the two incidents with the greatest loss estimates involving an accidental foam discharge is approximately the same as the sum of damage estimates for all of the incidents involving a foam discharge in response to a fire. Combining the frequency of incidents and the damage per incident, the cost of accidental foam discharges annually is on average $6.4M, while the cost for foam discharges in response to fire is $1.7M. Comparing the total annual loses for the two types of incidents, the cost associated with accidental foam discharges is 3.7 times greater than that for loses in incidents where the foam discharge is in response to fire.

The trends for accidental foam discharges and foam discharges in response to fire are similar to the trends observed in the annual frequency of the incidents. However the annual costs associated with foam discharge in response to fire have been decreasing over the 16 years included in the survey, while the costs associated with accidental foam discharges have been increasing appreciably over the same time period.

The cost of clean-up and mitigation due to environmental damage from a foam discharge was not captured in the UMD research study. The NATA survey did capture clean-up (but not environmental mitigation) costs in nine incidents being up to $1M.

All foams, whether or not they are fluorine-free, pose risks to the environment and human health. These risks include toxicity, biodegradability, persistence, treatability in wastewater treatment plants, and nutrient loading according to the NFPA (2016). A principal exposure pathway for individuals to foam is via drinking water. The consequences of such exposure can be lethal. For individuals submerged in high-expansion foam, disorientation and asphyxiation may occur.

1. Background

This report provides an overview of the code requirements for fixed foam fire suppression systems in Group II[1] aircraft hangars and an analysis of the performance of the fixed foam fire suppression systems in those applications. Industry stakeholders, including insurance companies, aircraft owners, hangar owners, aircraft manufacturers, local jurisdictions, and the general public, have expressed concern over the tendency for these systems to inadvertently discharge causing significant life safety concerns, property damage, and major financial and environmental impacts.

The principal concern is that inadvertent discharges of fixed foam fire suppression systems in Group II aircraft hangars may be causing a considerable amount of collateral damage to aircraft in hangars, other contents and the hangar itself, along with deaths and injuries, cleanup cost and harm to the environment. Furthermore, questions have been raised as to whether such consequences outweigh the benefits of the protection provided by the systems (Methven, 2019). The report also contains an overview of health hazards to individuals who are exposed to firefighting foams and the impact of firefighting foams on the environment. Finally, a compilation of data extracted from the incident reports supplied by insurance companies and aviation businesses is included in this report.

1.1. Code Provisions

A review of the requirements included in NFPA 409 (NFPA 2016a), the International Building Code (IBC) (ICC 2018a), and the International Fire Code (IFC)(ICC 2018b) are provided to identify the source of the requirements for fixed foam fire suppression systems in Group II hangars (ICC 2018a)(ICC 2018b)(NFPA 2016a). The design, installation, and maintenance of fire safety requirements for aircraft hangars throughout most of the United States follows the terms included in these documents.

In addition to reviewing the current provisions in NFPA 409, the IBC, and IFC, this report reviews the history of the justification for the requirements for foam systems in NFPA 409. The intent of such a review is to identify basic design goals that form the basis of the requirements included in NFPA 409. Possible design goals may include one or more of the following: protection of one or more aircraft, protection of the building, etc., and to understand the design basis for foam fire suppression systems, including the design fire scenario, such as fuel spill fires, ordinary commodity fires, or other sources, that is envisioned by the NFPA committee.

<u>IBC and IFC (ICC 2018a)(ICC 2018b)</u>

Section 412.3.6 of the IBC and Section 914.8.3 of the IFC include requirements for fire suppression systems in Group I, II, and III hangars, depending on the construction type and size

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[1] A Group II aircraft hangar is classified in NFPA 409 (NFPA 2016a) as a hangar with an aircraft access door height of 28 ft or less and a single fire area limited by the type of construction. More details of the definition of Group II hangars are provided in Section 1.1 of this report.

(floor area) of the hangar. These sections also stipulate the size and construction for Group I, II, and III hangars. While the IBC and IFC do not explicitly specify the type of fire suppression system to be installed, both codes require that all fire suppression systems be installed in accordance with NFPA 409 (which does address the type of fire suppression agent to be used). In the case of a Group II hangar operated by a fixed based operator (FBO) used only for storage of transient aircraft where the FBO also has separate repair facilities on site, both the IBC and IFC provide an exception that stipulate that the hangar need only have a fire suppression system, but the system need not be a foam fire suppression system.

Additionally, the IFC includes restrictions on the type of operations that may occur within a hangar so as to limit the degree of hazard posed by such operations. For example, section 2004.5 of the IFC requires that aircraft engines cannot be run in aircraft hangars except in approved engine test areas. Similarly, section 2003.2 of the IFC prohibits smoking in aircraft hangars and section 2003.6 requires that all combustible materials to be stored in approved locations and containers.

NFPA 409 (NFPA 2016a)

Before 1985, both Group I and II hangars required water deluge systems. In the 1985 version of NFPA 409, the requirement for Group I hangars was changed to require a foam-water deluge system while Group II hangars could have either a foam-water deluge system or a sprinkler system combined with a low-level foam system. The justification in the 1984 Report on Proposals (ROP) for this change was that “available test data has never shown water to be an effective suppressant for potentially large flammable liquid spill fires.”

For the 2001 edition, the requirements were updated so that Group I hangars also had the choice between a foam-water deluge system or a sprinkler system combined with a low-level foam system. In the 2001 ROP, the justification for this change was “to better cover entire hangar floor area when random parking positions are used and to cut back on fire protection water demand.”

A Group II aircraft hangar is classified as one with an aircraft access door height of 28 ft or less and a single fire area based on its type of construction, in agreement with Table 4.1.2 of NFPA 409 (provided as Table 1 in this report). The floor area of a Group II hangar cannot exceed 40,000 ft^2. In Chapter 7 of NFPA 409, a Group II hangar is required to have any of the following methods of protection for aircraft storage and servicing areas if aircraft in the hangar contain any fuel:

- Foam-water deluge system
- Combination of automatic sprinkler protection and automatic, low-level, low-expansion foam system
- Combination of automatic sprinkler protection and automatic, high-expansion foam system
- Closed-head foam-water system

Table 1. Fire Areas for Group II Hangars from NFPA 409 (NFPA 2016a)

	Single Fire Area	
Type of Construction	**m²**	**ft²**
Type I (443) & (332)	2,878-3,716	30,001-40,000
Type II (222)	1,858-3,716	20,001-40,000
Type I (111), Type III (211), Type IV (2HH)	1,394-3,716	15,001-40,000
Type II (000) & Type III (200)	1,115-3,716	12,001-40,000
Type V (111)	743-3,716	8,001-40,000
Type V (000)	465-3,716	5,001-40,000

An overview of the requirements for the suppression system options from Chapter 7 of NFPA 409 are included in Table 2.

Chapter 12, "Unfueled Aircraft Hangars," of NFPA 409 applies where aircraft have either never been fueled or all fuel has been removed from the aircraft. Such Group II aircraft hangars are required to be provided with automatic sprinkler protection. The minimum design density for such a sprinkler system is 0.17 gpm/ft^2 over any 5,000 ft^2 area. Sprinklers must have a minimum nominal K-factor of 5.6 and have a temperature rating of 175°F.

The NFPA Technical Committee on Airport Facilities justification for requiring foam fire suppression systems in Group II hangars was to provide protection from fires involving fuel spills. Data collected by the United States Coast Guard (USCG) on fuel spills in the U.S. illustrates the frequency and location of fuel spills. In the first ten months of 2019, the USCG data base recorded 147 spills involving jet fuel or aviation fuel. An overview of the circumstances associated with the 147 spills is provided in Table 3. It is noteworthy that none of these spills occurred in a hangar.

Table 2. Summary of Suppression System Requirements for Group II Hangars (Chapter 7, NFPA 2016a)

Suppression System Type	Requirements
Foam-Water Deluge System	• Maximum projected floor area under an individual deluge system cannot exceed 15,000 ft^2. • Minimum discharge density of air-aspirating and non-air-aspirating discharge devices using protein foam, fluoroprotein foam, or aqueous film-forming foam (AFFF) solutions is 0.16 gpm/ft^2 of floor area.
Automatic Sprinkler System	• Either wet pipe or preaction system. • The minimum design density of the water from the sprinkler systems is 0.17 gpm/ft^2 over any 5,000 ft^2 area, including the hydraulically most demanding area. • Nominal K-5.6 or K-8.0 sprinklers are required with a temperature rating of 325°F to 375°F.
Automatic Low-Level, Low-Expansion Foam System	• Low-level discharge nozzles are required • If monitor nozzles are used, they must have an individual manual shutoff valve for each nozzle. The discharge nozzles are arranged to achieve initial foam coverage in the expected aircraft parking area. • Minimum application rate of foam solution is 0.16 gpm/ft^2 where protein-based or fluoroprotein-based concentrate is used and 0.10 gpm/ft^2 where AFFF concentrate is used. • Low-level foam system must distribute foam over entire aircraft storage and service area. Design objective is to achieve coverage of entire aircraft storage arid servicing area to within 5 ft of the perimeter walls and doors within 3 minutes of system actuation.
Automatic High-Expansion Foam System	• High-expansion foam generators are arranged to achieve initial foam coverage in the anticipated aircraft parking area. • Minimum application rate is 3 ft^3/min/ft^2. • Foam generators must be powered by reliable water driven or electric motors and supplied with air from outside the aircraft storage and servicing area. Roof vents need to be located to avoid recirculation of combustion products into the air inlets of the foam generators.
Closed-Head Foam-Water System	• AFFF is required • Minimum discharge density of foam solution is 0.16 gpm/ft^2 over the entire storage and service area. • In aircraft storage and servicing areas, maximum projected floor area under an individual sprinkler system cannot exceed 15,000 ft^2. • Each individual system must have its own foam concentrate proportioner. • Temperature rating of sprinklers must be between l75°F to 225°F.

Table 3. Jet and Aviation Fuel Spills in the U.S. (Jan.-Oct. 2019) (USCG 2019)

Circumstance	**Number of Incidents**
Airliner at Gate	37
Fuel Island or Fuel Truck	20
Unknown (Outdoors)	22
Military (Base or Aircraft Outdoors)	22
Refinery or Pipeline	11
Aircraft Crash	22
Aircraft Maintenance or Defueling in Hangar	6
Natural Phenomenon or Weather	4
Fuel Truck Crash	2
Intentional/Improper Disposal	1
Total	**147**

1.2. Environmental Impact

All foams, whether or not they are fluorine-free, pose risks to the environment or human health. These risks include toxicity, biodegradability, persistence, treatability in wastewater treatment plants, and nutrient loading according to the NFPA (2016). Undesired, direct releases of firefighting foam into the environment do occur, in both training exercises and firefighting activities. As a result, where foams are used, the foam must be contained to prevent migration from the fire scene to the surrounding environment and interaction with people.

The principal environmental issues of firefighting foams concern the family of man-made per- and polyfluoroalkyl chemicals (PFAS). Some PFAS used in firefighting foams bioaccumulate and biomagnify after seeping into the soil or water. Drinking water is the primary route of exposure to humans (Steenland, Fletcher, & Savitz, 2010). PFAS are included in firefighting foams as they improve the fire suppression effectiveness of the agent. However, their molecular structure that allows them to spread easily over a burning fuel surface also makes it difficult to eliminate the foam agent once it is introduced into the natural environment (ITRC, 2019). A subset of PFAS, perfluoroalkyl acids (PFAAs), such as perfluorooctanoate (PFOA) and perfluorooctane sulfonate (PFOS), have received the most attention because of their significant environmental effects. A recent study found more than 10,000 tons of PFOS-based foam in stock or use today (Seoq, 2013). Alternatives have been slow to be accepted, partly because of established supplier relationships with foam manufacturers using these materials (UNEP, 2011).

As a result of the change in the manufacturing process for one type of foam, Aqueous Film Forming Foam (AFFF), the EPA has indicated that AFFF is not a likely source of PFOA (Scheffey, 2008). As such, it’s important to recognize that there are several different types of foams which have different levels of fire suppression effectiveness on different fuels. Fires involving aircraft fuel are Class B fires, as aircraft fuel is a flammable or combustible liquid.

The types of foams used for Class B fires include protein foam, fluoroprotein foam (FP), Aqueous Film Forming Foam (AFFF), Film Forming Fluoroprotein Foam (FFFP), and Alcohol-Resistant Aqueous Film-Forming Foam (AR-AFFF), all with varying environmental effects. Characteristics of these foams and their environmental impact are included in Tables 4 and 5 and Figure 1.

The fluorine-based foam agents are very effective in fire extinguishment due to their ability to form a film on the surface of the liquid. Contemporary firefighting foams proportionately contain less fluorine, do not break down into PFOS, and are not made with any chemicals currently considered to be persistent, bioaccumulative, or toxic. However, the EPA has indicated that some of fluorochemicals transform in the environment into PFOA or other perfluorocarboxylic acids (PFCA) (Melkote et al., 2012), so still might be troublesome.

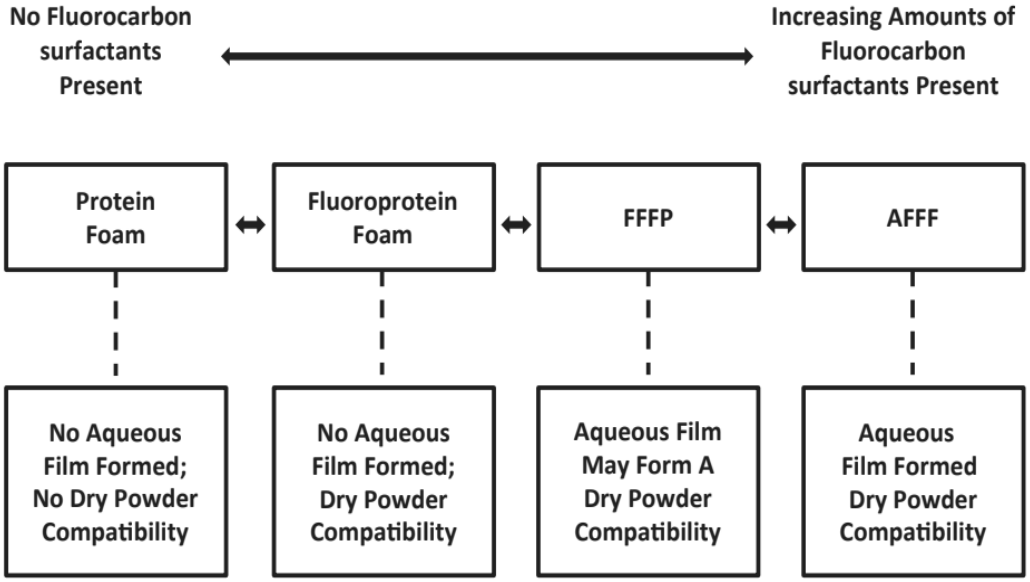

Figure 1. Fluorocarbon Surfactant Content, Film Formation Capability, and Dry Powder Capability of Foam Agents (NASEM, 2017)

Compounds present in FP, FFFP, AFFF, and AR-AFFF foams may break down into fluorotelomer sulfonate (FTS). While fluorotelomers do not tend to remain inside the human body, they can remain in the environment because degradation of the perfluorinated chains occurs at a slow rate (Blum et al., 2015). One study showed the half-life of FTS to be at least a decade (Seow, 2013). Thus, the switch to shorter-chains in the contemporary foams may not reduce PFAS in the environment and larger quantities of foam may be required to achieve the same level of fire suppression effectiveness.

Table 4. Characteristics of Fire Fighting Foams used in Aircraft Hangars

Properties	**Protein Foam (PF)**	**Fluoroprotein Foam (FP)**	**Aqueous Film Forming Foam (AFFF)**	**Film Forming Flouro-Protein (FFFP)**	**Alcohol-Resistant AFFF (AR-AFFF)**
Type	Protein	Protein	Synthetic	Protein Based	Synthetic
Description	Made of protein products, such as soybeans & animal hooves, plus stabilizing additives.	Combination of protein-based foam & fluorochemical surfactants. Fluorochemicals reduce surface tension to allow more fluid movement.	Synthetic foam of fluorochemical & hydrocarbon surfactants. Designed for rapid knockdown, sacrificing heat resistance and long-term stability.	Based on fluoroprotein technology with AFFF knockdown power. Contains added fluorocarbon surfactants.	AFFF concentrate, with added high molecular weight polymers. Applied to a polar solvent fuel, AR foams create a polymeric membrane rather than a film over the fuel, to smother fire.
Knock-down	Fair	Good	Excellent	Good	Excellent
Heat Resistance	Excellent	Excellent	Fair	Good	Good
Fuel Tolerance	Fair	Excellent	Moderate	Good	Good
Vapor Suppression	Excellent	Excellent	Good	Good	Good
Alcohol Tolerance	None	None	None	None	Excellent

Source: (Fuels, 2017)

Table 5. Summary of Environmental Impact of Fire Fighting Foams used in Aircraft Hangars

Properties	Fluorine-Free Foams	Protein Foam (PF)	Fluoroprotein Foam (FP)	Film Forming Flouroprotein (FFFP)	Aqueous Film Forming Foam (AFFF)	Alcohol-Resistant AFFF (AR-AFFF)
Materials	Water-soluble, non-fluorinated polymer additives; hydrocarbon surfactants	Hydrolyzed protein (i.e. hoof and horn meal); foam stabilizers; preservatives to prevent bacterial decomposition and corrosion	Protein Foam; fluorocarbon surfactants	Protein Foam; increased quantity of fluorocarbon surfactants	Synthetic foaming agents (hydrocarbon surfactants); solvents); fluorocarbon surfactants; small amounts of salts; foam stabilizers	Similar inputs to AFFF concentrate; Polysaccharide polymer
Waste Treatment Consider-ations	Considered to be biodegradable, low in toxicity, and can be treated in sewage treatment plants.	Considered to be biodegradable and low in toxicity.	Contains stable, environmentally persistent fluorinated degradation products. May require pre-treatment prior to standard wastewater treatment plants.	Contains stable, environmentally persistent fluorinated degradation products. May require treatment prior to standard wastewater treatment plants.	Contains stable, environmentally persistent fluorinated degradation products. May require treatment prior to standard wastewater treatment plants.	Contains stable, environmentally persistent fluorinated degradation products. Requires treatment prior to standard wastewater treatment plants.

Source: (NASEM, 2017)

Fluorine-free agents are thought to be an environmentally-friendly alternative, but these foams have less fire suppression effectiveness than fluorinated foams. While PFOS or PFOA are not generated, some of the Class B fluorine-free foams containing only hydrocarbon surfactants may be are more acutely toxic to aquatic organisms. These fluorine-free foams will emulsify with oil-based fuels in water, creating higher biochemical oxygen demands (NASEM, 2017).

Once firefighting foam reaches wastewater treatment plants after cleanup following application of foam, processing can pose several issues. Many foams are toxic to the bacteria used in wastewater treatment plants. Also, the foam can suspend the activated sludge solids used to remove pollutants, resulting in the pollutants continuing through the plant and exiting into the water distribution system for a community. Firefighting foams have a greater biological oxygen demand, which can cause the capacity of the wastewater treatment plant to be exceeded. (NFPA, 2016b**)**. The plant operator needs to be contacted before disposal to correctly adjust for the unique characteristics of the foam. A summary of the different foams and their waste treatment considerations is presented in Table 4.

PFAS are resistant to several conventional treatment strategies including direct oxidation, biodegradation, air stripping and vapor extraction, and direct photolysis. Hence, remediation of any foam discharge needs to be specific to the type of foam. At this time, a universally applicable, effective remediation approach is not available (NASEM, 2017). There is disagreement on the effectiveness of technologies such as activated carbon adsorption, ion exchange resins, and high-pressure membranes to remove PFAS from waste. A summary of these methods is presented in Table 6.

Table 6. Effectiveness of Removal Options for PFAS in Water Sources (de Silva, 2019)

Treatment Method	PFOA	PFOS	Comments
Granular Activated Carbon	48-90%	89-98%	Regeneration or replacement and disposal required; may release PFAS into atmosphere
Anionic Exchange	51-90%	90-99%	Resins need to be regenerated or replaced
Membrane Filtration	10-50%	0-23%	Waste stream contains salts; filtrates require disposal
Reverse Osmosis	90%	93-99%	Waste stream contains salts; filtrates require disposal

1.3. Health Impacts

Research has linked the chemicals associated with firefighting foam agents to a wide range of health effects in humans, including testicular and kidney cancer, obesity, impaired fertility, thyroid disease, increased cholesterol, and early onset of puberty (Barry, Winquist, & Steenland, 2013) (PHE 2009). Much of the understanding of the potential impact on humans is inferred from animal studies that have shown that PFAS can cause several types of tumors, neonatal death, and may negatively impact the immune, liver, and endocrine systems (Steenland, Fletcher, & Savitz, 2010). Exposure to PFAS has the potential for long-term effects, given that PFAS has a long half-life in the human body; being on 4-5 years PFOS and PFOA (Witteveen and Bos, TTE, 2019). Much of the literature involves chronic exposure to these substances, with the impact of a one-time exposure being uncertain. Irritation of the skin and eyes may occur, while some experience has shown that the liver and gastrointestinal tract may be affected (PHE 2009). For chronic exposures, enlarged livers and DNA damage has been observed in animals (Witteveen and Bos, TTE, 2019).

2. Survey Methodology to Collect Foam System Field Data

The research team requested incident reports of discharges of foam fire suppression systems from several insurance companies and FBOs who provide coverage for either the aircraft and/or aircraft hangar. A form to facilitate data reporting, *The Data Collection Form, Foam Suppression System Discharge Analysis*, developed by the University of Maryland (UMD) was provided to each of the participating organizations. The data form is included in the Appendix. Damage estimates for aircraft and the building/building systems were requested in the form, along with cause of the discharge and cause of the fire.

As a result of these requests, 174 incident reports of foam fire suppression system discharges were provided to the research team by seven insurance companies, two FBOs, and media outlets. The majority (85%) of reports received were from the United States. The remaining 15% of reports originated from 8 other countries.

A second survey, the "Hangar Foam Fire Suppression Survey," was distributed to the members of the National Air Transportation Association (NATA). The 72 respondents that completed the survey operated 118 aircraft hangars, 26 which have foam systems installed. One respondent had a fire (pooled fuel) and the foam did not discharge. 9 respondents had inadvertent discharges.

3. Data Analysis

3.1 UMD Survey

Analysis of the data provided in the incident reports began with a review of the incident reports to check if multiple reports were received from two source for the same incident. In a limited number of cases, using the date and location of the incident, the research team recognized that two incident reports related to the same incident, one which addressed damage to aircraft and another for damage to building/building systems.

A summary of the 174 incident reports of foam system discharges is included in Table 7. The 174 incidents include 37 incidents where the foam system discharged in response to a fire and 137 incidents where there was an accidental foam discharge, i.e. no fire was present. Regarding the 37 incidents where foam discharged in response to a fire, 5 of the incidents originated outside of the hangar space, either in adjacent spaces or outside. The causes of the fires with a foam discharge are listed in Table 8. As indicated in the table, none of the 37 incidents involved a fuel spill.

Annually, there were 8.56 incidents involving accidental foam discharges, while there were 2.31 foam discharges in response to a fire. Hence, on an annual basis, there were 3.7 times the number of foam system discharges without fires versus those with fire.

Table 7. Summary of Incident Reports (2004-2019)

Incident Type	**Number of Incidents**	**% of Total Incidents**	**Annual Rate of Incidents**
Foam Discharge in Response to Fire	37	21.3	2.31
Accidental Foam Discharge	137	78.7	8.56
Total	**174**	100	10.9

Table 8. Summary of Causes of Incidents with Foam Discharge in Response to Fire

Cause	**Number**	**Percent**
Fire from other[2]	15	40.5
Electrical fire	8	21.6
Started in office or living quarters	2	5.4
Boiler	1	2.7
Compressor	1	2.7
GPU short	1	2.7
Hot glue gun left plugged in	1	2.7
Jet crashed into hangar	1	2.7
Paint fumes on roof	1	2.7
Scrubber	1	2.7
Welding set off fire in MRO	1	2.7
Unknown	4	10.8

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[2] On UMD’s Data Collection Form, two choices were provided for fires that caused the foam system to discharge. The two choices were “fire from fuel spill” and “fire from other”. Other causes noted in this table were included in the Data Collection Form by some respondents to provide additional specificity to the “fire from other” response.

A distribution of the year in which incidents occurred and trend line are included in Figure 2. The trend line indicates a substantial increase in the number of incidents involving accidental foam discharges occurring per year (approximately 1 per year). The annual number of foam discharges in response to fire appears to be virtually constant.

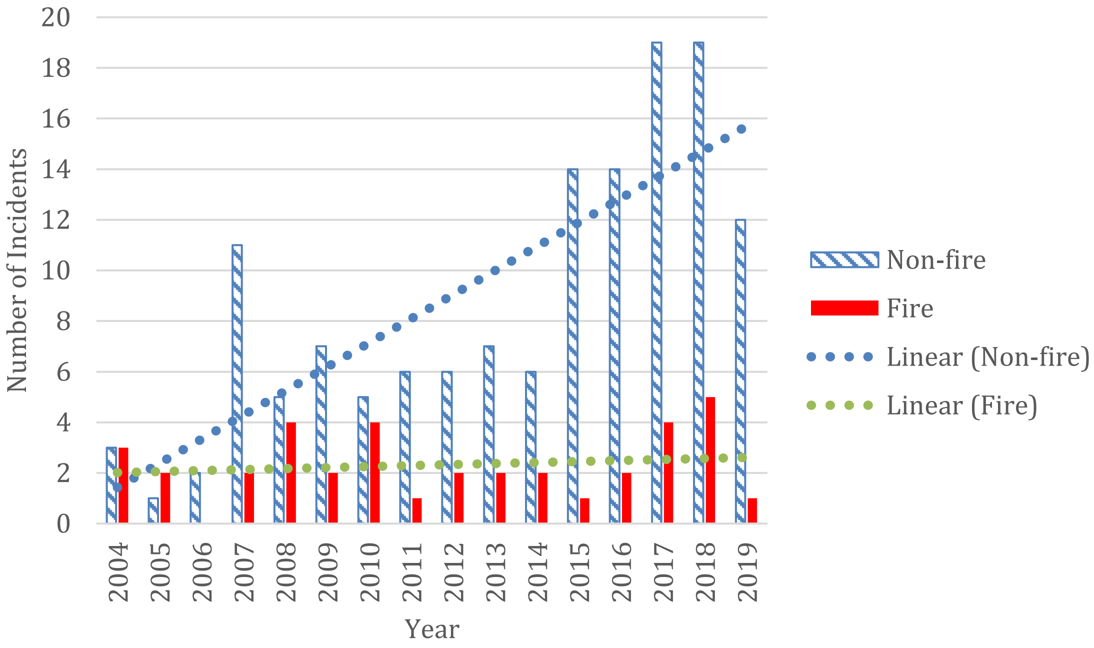

Figure 2. Annual Number of Incidents of Foam Discharge in Response to Fire ("Fire") vs. Accidental Foam Discharge ("Accidental")

Most of the respondents only reported data for losses to either the aircraft or the building/building systems. In no case was the cost of clean-up included in any of the incident reports provided via the UMD survey. Consequently, the damage estimates presented throughout this report should be considered to be only a portion of the loss, not representative estimates of actual losses, where the total cost is expected to be much greater than that reported to the research team.

Damage estimates for the aircraft or building/building systems were provided for 89 of the incidents involving accidental foam discharges and 30 of the foam discharges in response to fire. A summary of the damage estimates is provided in Table 9. The total of all damage estimates for incidents with accidental foam discharges was $66.3M, for an average loss of $0.745M per incident. In comparison, the total of all damage estimates for the incidents involving foam discharges in response to fire was $22.2M, for an average loss of $0.740M per incident.

Table 9. Annual Losses in Incidents with Foam System Discharges in Response to Fire and Accidental Foam Discharges

Incident Type	**Number of Incidents with Reported Loss**	**Total Loss ($M)**	**Average Loss per Incidents ($M)**	**Total Annual Loss ($M)**
Accidental Foam Discharge	89	66.3	0.745	6.38
Foam Discharge in Response to Fire	30	22.2	0.740	1.71

While the average loss per incident is similar in the incidents involving accidental foam discharges with those in response to fire, the sum of the damage from the two incidents with the greatest loss estimates involving an accidental foam discharge are approximately the same as the sum of damage estimates for all of the incidents involving a foam discharge in response to a fire. On an annual basis, the total losses for foam discharges in response to fire and accidental foam discharges is indicated in Table 9. Comparing the total annual losses for the two types of incidents, the cost associated with accidental foam discharges is 3.7 times greater than that for losses in incidents where the foam discharge is in response to fire.

Dollar losses to aircraft and building/building systems, and the sum of both aircraft and building losses associated with incidents that involved accidental foam discharges and foam discharges in response to fires are presented in Figures 3 to 5.

Estimates of the damage to aircraft were provided for 69 incidents with accidental foam discharges. The distribution of the damage to aircraft in incidents with accidental foam discharges is presented in Figure 3. As indicated in the figure, in almost half of the incidents with reported damage to aircraft, the damage was no more than $100,000. However, there were two incidents where the damage to aircraft was in excess of $10M. A separate graph is not provided for damage to aircraft in incidents where foam discharged in response to fire, as estimates were provided in only two incidents, one for $70,000 and another for $85,000.

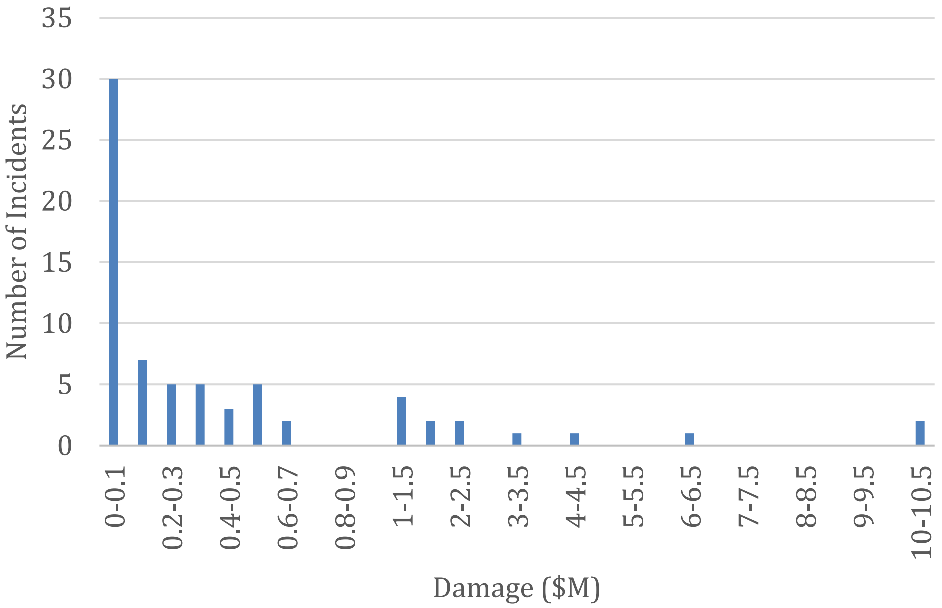

Figure 3. Damage to Aircraft (Accidental Foam Discharge Only)

The distribution of the damage estimates to buildings/building systems is provided in Figure 4. As in the case of damage to aircraft, the damage level in many incidents is $100,000 or less. However, there were greater than 50 incidents with accidental foam discharges at this level, but only 10 incidents involving foam discharges in response to fire.

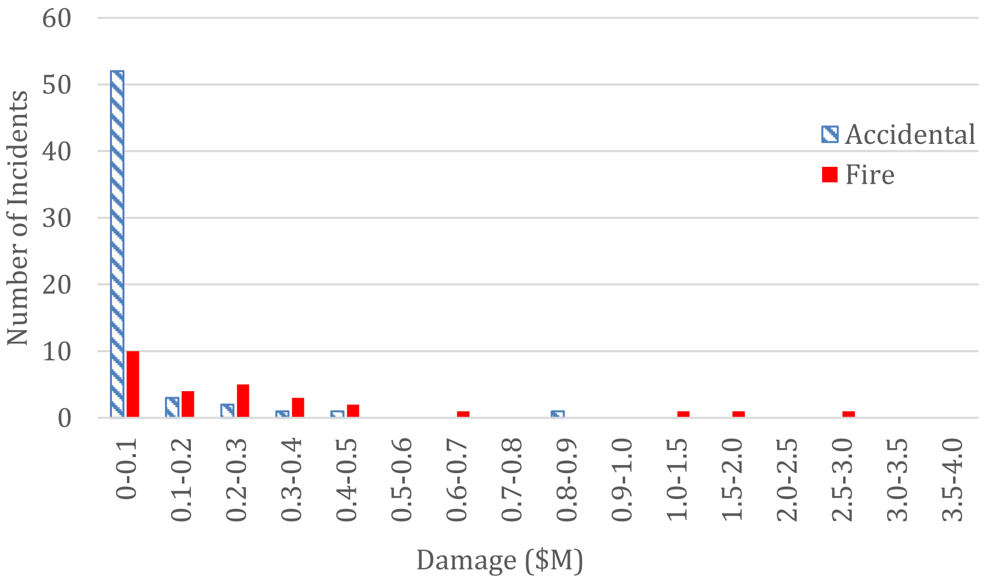

Figure 4. Damage to Building/Building Systems, All Incidents

The distribution of total losses for both types of incidents is provided in Figure 5. As with the other distributions, the greatest number of incidents for both types of incidents within any dollar range is in the lowest range, $0-$0.1M.

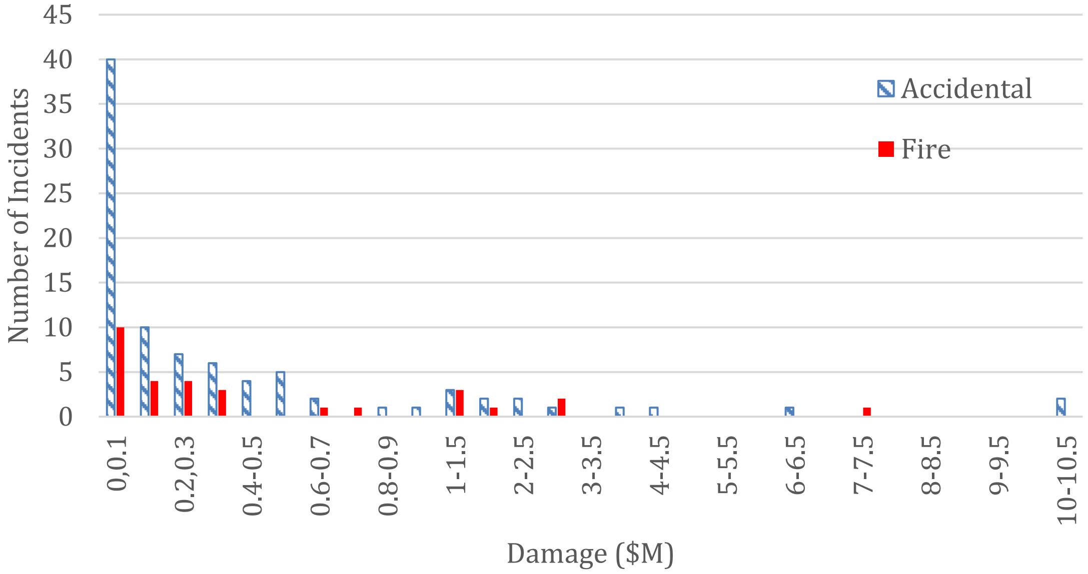

Figure 5. Total Damage All Incidents

Results of an analysis of the trend in annual total damage in accidental foam discharges and those in response to fire is presented in Figure 6. The trends for accidental foam discharges and foam discharges in response to a fire are similar to the trends observed in Figure 2 that addressed the annual frequency of incidents. However the annual costs associated with foam discharge in response to fire have been decreasing over the 16 years included in the survey, while the costs associated with accidental foam discharges have been increasing appreciably over the same time period.[3]

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[3] The trend line and rate of increase approximation include 2019, even though the year is not yet complete and damage assessments are not yet available for many incidents. The impact of including 2019 as a partial year is to decrease the rate of increase given that damage reports are still likely to be posted for this year.

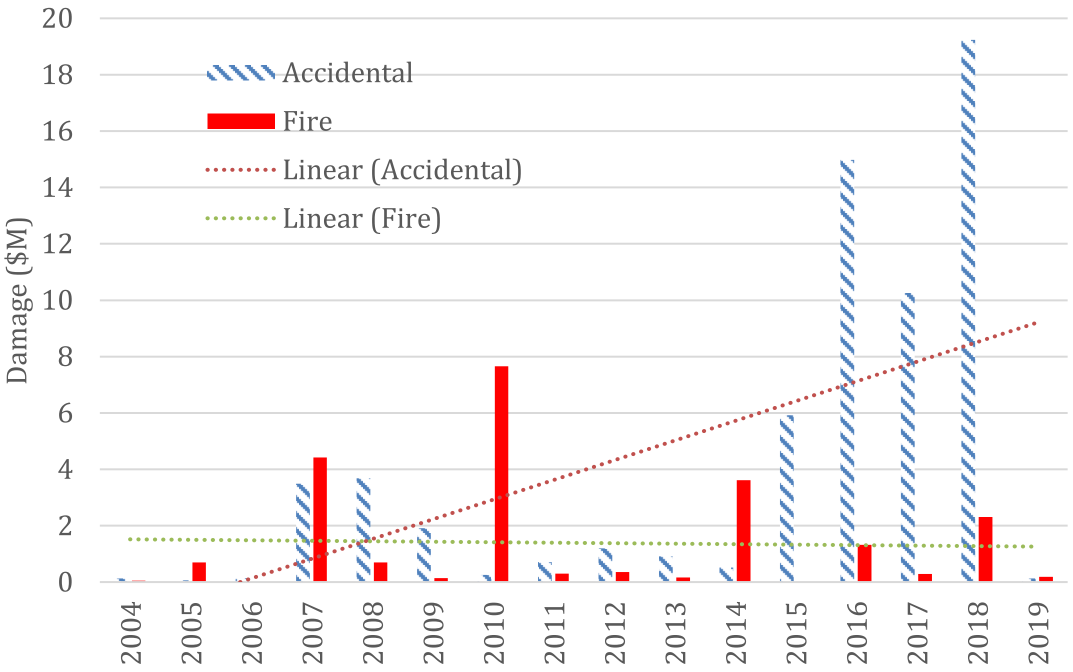

Figure 6. Annual Total Damage

There were a total of five fatalities associated with incidents involving foam system discharges, four from incidents where a foam discharge was in response to fire and one from an accidental foam discharge. The four fatalities that occurred in a single fire incident involved a jet crashing into the hangar. The causes of the fatalities were not noted. No injuries were noted in any of the incident reports.

The cause of accidental foam system discharges was reported by some respondents. A summary of the causes for the discharges is indicated in Figure 7. The cause identified in two-thirds of the cases was “suppression system failure,” though no further explanation was provided. The next most common cause was “unknown.” Human activities, either accidental or intentional, caused 9% of the accidental discharges. Accidental foam discharges due to nuisance alarms from a detection system were cited in a small proportion of the incidents.

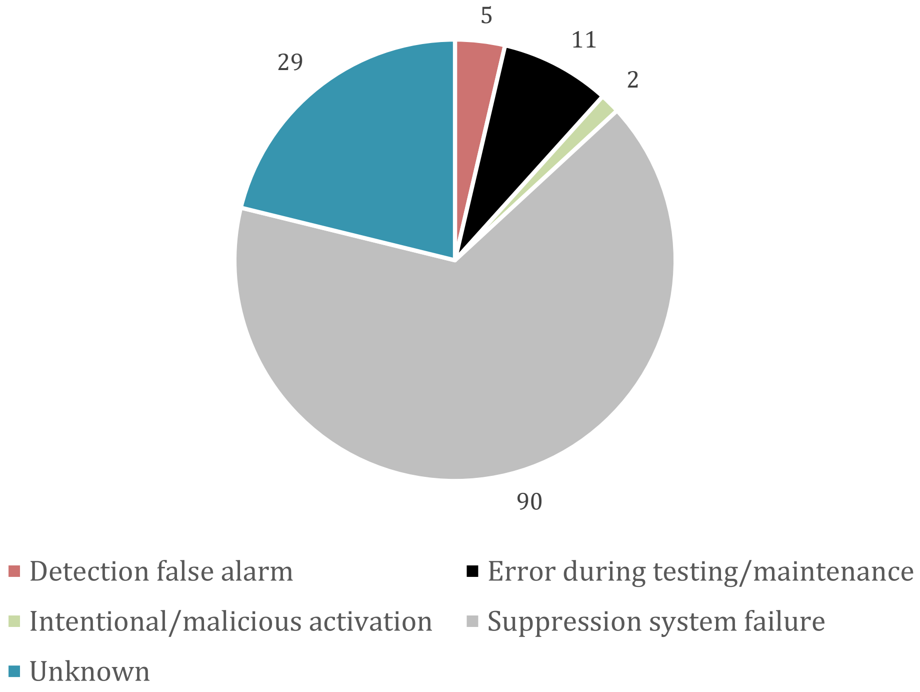

Figure 7. Cause of Accidental Foam Discharge

3.2 NATA Hangar Foam Fire Suppression Survey

NATA received 72 survey responses. In that survey, a series of questions were asked about the presence of fire suppression systems in hangars and whether such systems had ever discharged, then asked for damage estimates from any such incidents. Out of the 72 responses, foam systems were reported to have discharged on 14 occasions, two of which were in response to a fire. In one of the two fires, the fire involved a pooled fuel spill. The activities inside hangars reported in the NATA survey are indicated in Figure 8. Three of the activities in the figure including fueling and maintenance repair and overhaul would result in the respective hangars being labelled hazardous operations hangars.[4] The type of suppression system installed in the hangars is indicated in Figure 9. While automatic sprinklers are included in almost half of the hangars, approximately 25% of the hangars include some form of foam system, either alone or in combination with sprinklers.

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[4] Hazardous operations hangars are considered to include activities such as doping, hot work, such as welding, torch cutting and torch soldering, fuel transfer, fuel tank repair or maintenance not including unfueled tanks, inerted tanks or tanks that have never been fueled and spray finishing operations.

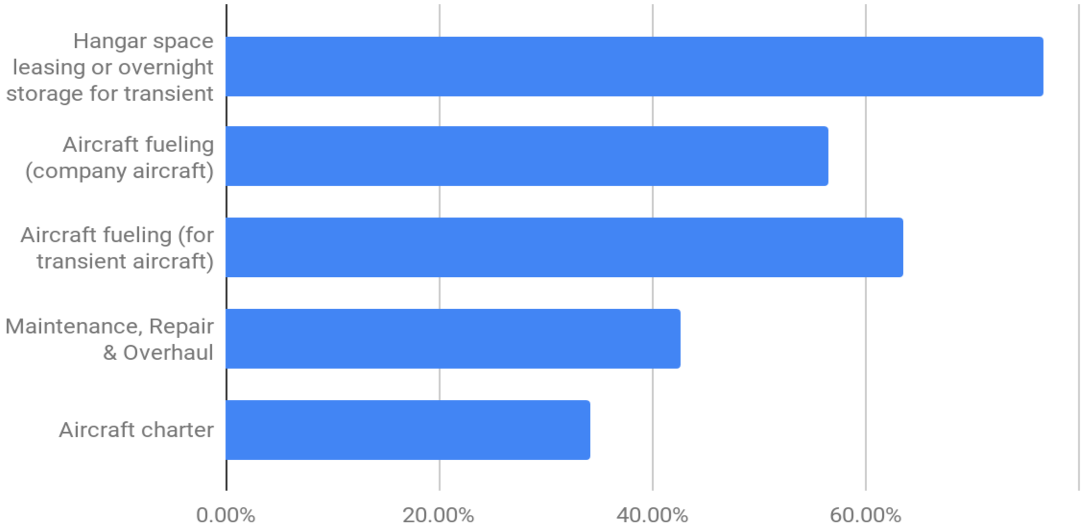

Figure 8. Services Provided in Hangars

The estimated costs of clean-up and damage of aircraft in foam system discharges in accidental foam discharges according to the NATA survey are presented in Figure 10 and 11. The number of estimates varies for these incidents because some respondents either entered “not applicable” or did not answer. As with the University of Maryland survey, the reported damage level to aircraft was $10M in one incident.

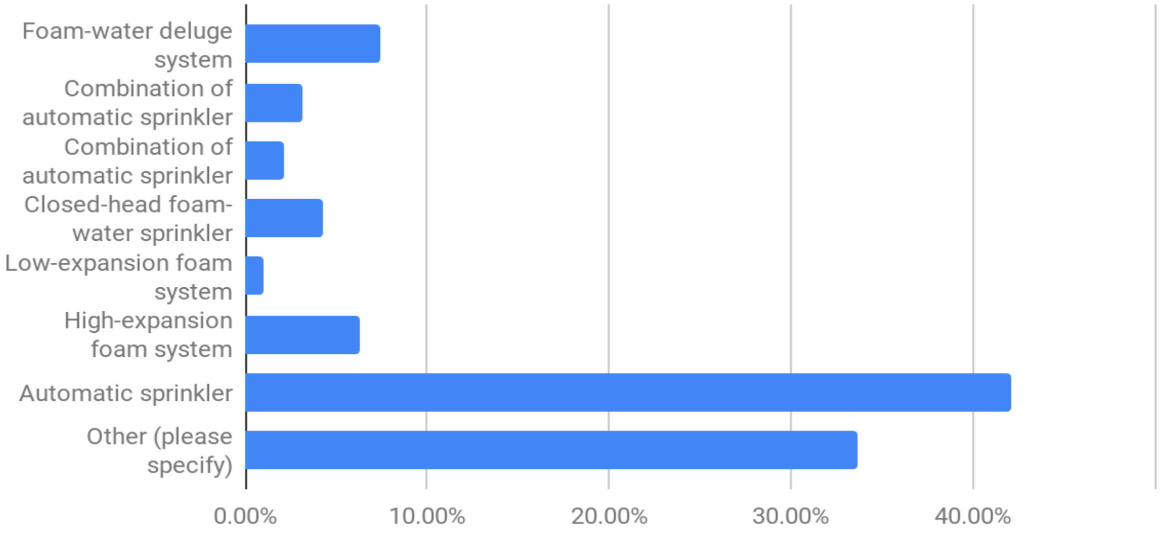

Figure 9. Type of Suppression System in Hangar[5]

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[5] Entries for “Other” included portable extinguishers or specific types of water sprinklers.

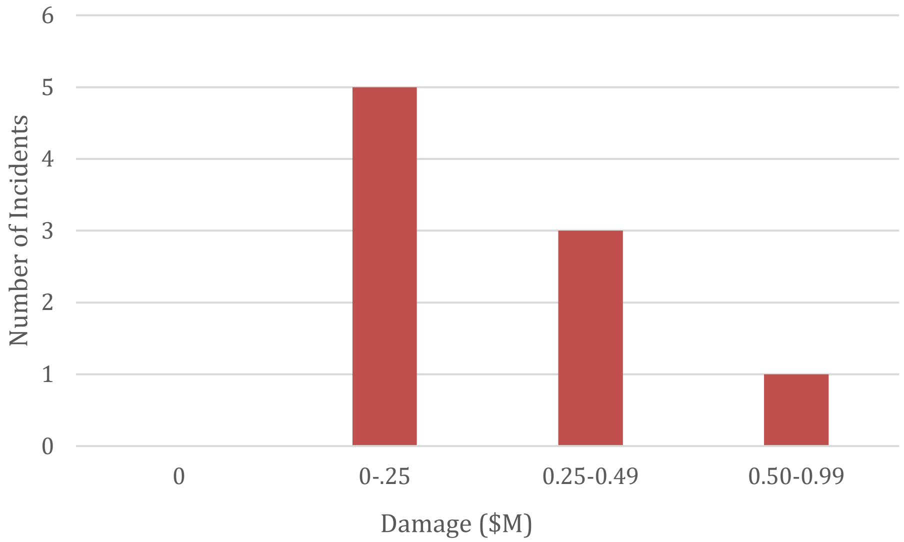

Figure 10. Cost of Clean-up for Accidental Foam Discharge (total: 9 incidents)

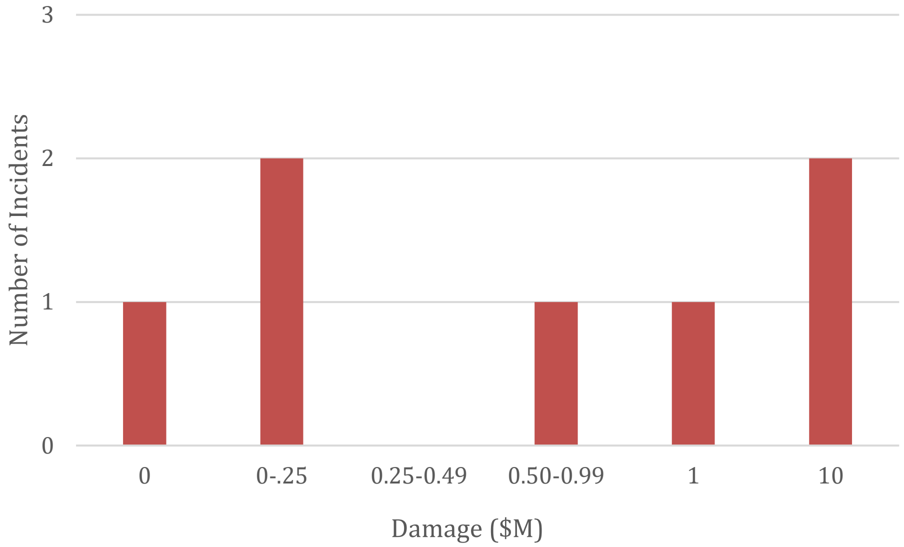

Figure 11. Cost of Damage to Aircraft for Accidental Foam Discharge (total: 7 incidents)

4. Summary

Requirements for foam fire suppression systems in NFPA 409 were initially justified to provide protection from fires involving fuel spills. However, the occurrence of a fuel spill in a hangar in the U.S. is rare and fires involving such spills even less common. While some fires do occur in aircraft hangars, they involve ordinary combustibles or occur in spaces adjacent to the hangar bay.

174 incident reports of foam discharges over the last 16 years, both in response to fires and accidental, were received from 11 sources, mostly reported by insurance companies. The majority (85%) of reports received were from the United States. The remaining 15% of reports originated from 8 other countries. Based on these reports, accidental foam discharges occur about 8.56 times per year, while foam discharges in response to fire occur about 2.31 times per year. It is significant that the number of incidents involving accidental foam discharges occurring annually is increasing by about one per year, while the number of incidents involving a foam discharge due to fire is remaining steady.

The average total cost of damage, i.e. damage to aircraft, building/building systems, reported in incidents with an accidental foam discharge was approximately $0.745M per incident. Hence, on an annual basis, the total costs associated with accidental foam discharges is $6.38M. The two greatest combined losses to aircraft and building/building systems associated with an accidental foam discharge occurred since 2016, each being in excess of $10M. The losses associated with these two incidents involving accidental foam discharges are almost equivalent to the total losses from all incidents involving foam discharges in response to fire. This damage estimate, as with all damage estimates provided in this report, typically only considered damage to aircraft or building/building systems and neglected clean-up costs. Hence, these numbers should only be viewed as the minimum for loss during the last 16 years, actual losses may be significantly higher.

References

Barry, V., Winquist, A., & Steenland, K. (2013). Perfluorooctanoic acid (PFOA) exposures and incident cancers among adults living near a chemical plant. Environmental Health Perspectives. Retrieved from http://dx.doi.org/10.1289/ehp.1306615

Arlene Blum, Simona A. Balan, Martin Scheringer, Xenia Trier, Gretta Goldenman, Ian T. Cousins, Miriam Diamond, Tony Fletcher, Christopher Higgins, Avery E. Lindeman, Graham Peaslee, Pim de Voogt, Zhanyun Wang and Roland Weber (2015). The Madrid Statement on Poly- and Perfluoroalkyl Substances (PFAS). Environmental Perspectives. Retrieved from https://doi.org/10.1289/ehp.1509934

de Silva, V. (2019, March 1). The Environmental Dangers of PFAS and Technologies for Removing Them. Retrieved from Waste Advantage Magazine: https://wasteadvantagemag.com/the-environmental-dangers-of-pfas-and-technologies-for-removing-them/

Fuels, R. (Director). (2017). Module 6: Fire Fighting Foam Principles [Motion Picture]. Retrieved from https://www.youtube.com/watch?v=JKJe7GKLA-U&t=593s

ICC (2018a). International Building Code, Country Club Hills, IL: International Code Council.

ICC (2018b). International Fire Code, Country Club Hills, IL: International Code Council.

Interstate Technology & Regulatory Council. (2019). PFAS Fact Sheet. Washington, DC: Interstate Technology & Regulatory Council, PFAS Team. Retrieved from www.itrcweb.org

Melkote, R. R., Wang, L., & Robinet, N. (2012). Next Generation Fluorine-Free Firefighting Foams. Retrieved from https://www.nfpa.org/-/media/Files/News-and-Research/Archived-proceedings/2012-SUPDET/22MelkoteRobinetWang-presentation.ashx?la=en

Methven, N. (2019). White Paper: Hangar Foam Fire Suppression Systems: More Harm than Good? Parsippany, NJ: Global Aerospace Inc.

National Academies of Sciences, Engineering, and Medicine. (2017). Use and Potential Impacts of AFFF Containing PFASs at Airports. Washington, DC: The National Academies Press. doi:https://doi.org/10.17226/24800

NFPA (2016a). Standard on Aircraft Hangars. NFPA 409. Quincy, MA: National Fire Protection Association.

NFPA (2016b). Standard for Low-, Medium-, and High-Expansion Foams. NFPA 11. Quincy, MA: National Fire Protection Association.

Scheffey, J. (2008). Foam Extinguishing Agents and Systems, National Fire Protection Handbook 20th Edition. Quincy, MA: National Fire Protection Association.

PHE (2009). PFOS and POA Toxicological Overview. Centre for Radiation, Chemical and Environmental Hazards, Public Health England. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/338261/PFOS_and_PFOA_Toxicological_Overview_phe_v1.pdf

Seow, J. (2013). Fire Fighting Foams with Perfluorochemicals - Environmental Review. Semantic Scholar. Retrieved from https://pdfs.semanticscholar.org/9ab7/fec10c91c70b401618dc491ad09411283d8f.pdf?_ga=2.100090140.364687091.1569787702-608453794.1569787702

Steenland, K., Fletcher, T., & Savitz, D. (2010). Epidemiologic evidence on the health effects of perfluorooctanoic acid (PFOA). Epup: US National Library of Medicine National Institutes of Health. doi:10.1289/ehp.0901827

UNEP (2011). Persistent Organic Pollutants Review Committee. Technical Paper on the Identification and Assessment of Alternatives to the Use of Perfluorooctane Sulfonic Acid, Its Salts, Perfluorooctane Sulfonyl Fluoride and Their Related Chemicals in Open Applications (UNEP/POPS/POPRC. 8/INF/17 Rev. 1). Retrieved from http://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC7/POPRC7Followup/Requestsforinformation/RequestsforcommentsbyPOPRC7IWGs/PFOSinopenapplicationsRequestforcomments/tabid/2736/Default.aspx

USCG (2019). National Response Center, United States Coast Guard. Retrieved from: http://nrc.uscg.mil/.

Witteveen and Bos, TTE (2019). Factsheets PFOS and PFOA: Toxicology. Witteveen+Bos and TTE consultants. Netherlands. Retrieved from: https://www.emergingcontaminants.eu/index.php/background-info/Factsheets-PFOS-intro/Factsheets-PFOS-toxicology

Appendix. Data Collection Form

UNIVERSITY OF MARYLAND

Department of Fire Protection Engineering

Data Collection Form, Foam Suppression System Discharge Analysis

Date of incident ___________________ Location (city, state) _____________________

Size hangar (note group or area/door height)

Group (per NFPA 409) ________________

Area _______________ , Door height ______________

Consequences

Injuries

Fatal ______________ Nonfatal ________________

Damage to building, building systems ($) ____________________

Damage to aircraft ($) ____________________

Other damage

Business interruption ($ or describe) ____

Environmental ($ or describe) ____

Cause for activation (place 'X')

Fire

Fire from fuel spill _________

Fire from other _________

Non-fire _________

Intentional/malicious activation _________

Suppression system failure _________

Detection false alarm _________

Improper maintenance _________

Error during testing/maintenance _________

Unknown _________

Note: date and location is requested to check for duplicate reports of same incident. Such information will not be conveyed in any reporting.