Design Analysis of an Air Force Fuel Cell Maintenance Hangar

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Keywords

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High Expansion Foam

Property Protection

Executive Summary

A Fuel Cell Maintenance Hangar (FCMH) was constructed in 2013 based on a 2012 design; Figure 1.1.1 is a rendering shown below. This report evaluates the design for life safety, and property protection systems. The facility was designed based on Air Force standard prescriptive methods; the resultant design is compared to minimum prescriptive methods and to as-built drawings. In addition, the property protection design criteria were evaluated by simulating the maximum expected design fire in a hangar bay 1 using Fire Dynamics Simulator (FDS). Section 1 consists of a general overview of the FCMH including descriptions of the facility and the relevant codes and standards. Section 2 consists of detailed design analysis using prescriptive codes and standards. All systems were evaluated using Engineering Technical Letter (ETL) 02-15 and Uniform Facilities Criteria (UFC) 3-600-01. Egress systems were evaluated using National Fire Protection Association (NFPA) 101; the fire detection and notification system was evaluated using NFPA 72; automatic sprinkler system was evaluated using NFPA 13, and FM Global Data Sheet 3-26; the high expansion foam system was evaluated using NFPA 11. Section 3 consists of a performance-based design evaluation. A JP-8 fuel spill in the hangar containing two F-35 Joint Strike Fighters was modeled; the results were used to evaluate the automatic sprinkler and high expansion foam systems. Section 4 consists of conclusions and recommendations to the prescriptive based design of the fuel cell maintenance hangar. Generally, the design was found to comply with codes; however, the prescriptive design analysis revealed the existence of extra fire protection features. The performance-based design evaluation revealed that a high reliance is placed on manual activation of high expansion foam for the purpose of property protection.

Figure 1.1.1 shows a rendering of the Fuel Cell Maintenance Hangar. This is not releasable in accordance with FOIA exemption (b)(4). FOIA exemption (b)(4) refers to those trade secrets or commercial or financial information that a DoD Component receives from a person or organization outside the Government with the understanding that the information or record will be retained on a privileged or confidential basis in accordance with the customary handling of such records.

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Section 1 – Facility Overview

The FCMH is a maintenance hangar attached to a work shop, tool storage, office space, and training room. It is constructed of non-combustible materials with class B finishes. A repair hangar is classified in the International Building Code (IBC) as moderate hazard storage group S-1 and the office area is classified as Business Group B. From IBC Table 503, one can see that the maximum building height is 55ft and the maximum number of stories is 4 (IBC, 2012, s 504.2); because the building is sprinkled the maximum building height can be increased by 20 ft (IBC, 2012, s 504.2); the actual facility has a maximum height of 42.5 ft and is one story. Because the facility is one story tall and sprinkled there is no maximum area (IBC, 2012, s 507.3). There are no fire rated assemblies required (IBC, 2012, s 601). The facility is more than 30 ft away from other facilities so exterior walls are not required to be fire resistance rated (IBC, 2012, s 602). The Air Force requires that all aircraft facilities conform to certain standards; new aircraft facilities must conform to ETL 02-15, presented as Appendix A. This document requires a 1-hour fire rated wall separating aircraft areas from adjacent occupancies, coverage throughout by an automatic sprinkler protection, low-level high expansion foam, audio-visual fire alarm system, and manual pull stations at all exit doors.

Section 2 – Prescriptive Design Analysis

2.1 – Life Safety

2.1.1 – Occupancy Classification

The space use and occupancy classifications are shown in Figure 2.1.1. The hangar bays are separated from the office space and shops by a 1-hour masonry fire rated wall (ETL 02-15). The rest of the facility is considered a mixed occupancy. Each space is classified according to its use and shown in Figure 2.1.1. The office area and restrooms will carry the largest occupant load; business is considered the predominant occupancy. The tool crib contains offices with open storage, the laundry room and janitor's closet are both small storage areas; they are considered part of the predominant occupancy (NFPA 101, 2012, s A.6.1.14.1.3). The training room is incidental to the offices and serves less than 50 people at any time so it can be considered part of the business occupancy (NFPA 101, 2012, s A.6.14.1.3(2)). The fuel cell maintenance area contains high hazard contents. The utility spaces are general purpose industrial occupancies. A business occupancy has the most stringent requirements of those involved; the building complies with those standards.

Figure 2.1.1 shows color coded space uses in the FCMH. The space use and occupancy classification are shown with the color code in Table 1. This is not releasable in accordance with FOIA exemption (b)(4). FOIA exemption (b)(4) refers to those trade secrets or commercial or financial information that a DoD Component receives from a person or organization outside the Government with the understanding that the information or record will be retained on a privileged or confidential basis in accordance with the customary handling of such records.

2.1.2 – Means of Egress

The occupant load was calculated in accordance with NFPA 101 Section 7.3.2 using occupant load factors from Table 7.3.1.2; the egress capacity was calculated in accordance with NFPA 101 7.3.3 using Capacity Factors in Table 7.3.3.1. These calculations are summarized in Table 2.1.1; one can see the egress capacity exceeds the occupant load.

Table 2.1.1 shows each space with its corresponding area, occupant load factor, occupant load and egress capacity

Description	Area (SF)	Occupant Load Factor	Occupant Load	Egress Capacity
Hangar Bays	16,240	100	162	800
Business Area	2,490	100	25	160
Training Area (net)	547	15	36	
Maintenance Area	2,745	100	27	320

According to NFPA 101 40.6.1.2 & 40.6.1.3 exit doors from aircraft servicing areas must be provided 150 ft along the perimeter of all exterior walls, and 100 ft in horizontal exits. Figure 2.1.2 shows that five exits were provided and the required spacing was met. Two exits are required in the business area because the travel distance from the maintenance area to the main exit would exceed 100 ft (NFPA 101, 2012, s 38.2.4.3 (2)). Two or more exits are recommended in this case because some of the hangar bay occupants may exit through business occupancy instead of through exits provided in the hangar bays. As one can see in Figure 2.1.2, two exits from this occupancy are provided.

Figure 2.1.2 is a floor plan that shows the means of egress comply with NFPA 101 criteria for travel distance, number of exits, and remoteness of exits. This is not releasable in accordance with FOIA exemption (b)(4). FOIA exemption (b)(4) refers to those trade secrets or commercial or financial information that a DoD Component receives from a person or organization outside the Government with the understanding that the information or record will be retained on a privileged or confidential basis in accordance with the customary handling of such records.

Figure 2.1.2 also shows the **means of egress** are **arranged** in such a way that prevents a portion of the building from becoming separated from exits. This is achieved by ensuring that the exits are separated by at least 1/2 length of the building diagonal.

In addition, Figure 2.1.2 shows the maximum **travel distance** from each section of the building. The maximum travel distance is 83 feet in each section of the building and each is less than the required travel distance of 100 ft (NFPA 101, 2012, s 38.2.5.3.1 & 40.2.5.3.1).

A **dead-end corridor** is a corridor that that has no egress path in direction of occupant movement. The limit for a dead end corridor in this facility is 50 ft (NFPA 101, 2012, s 38.2.5.2.1 & 40.2.5.2.1); from Figure 2.1.2 one can see that there are no dead-end corridors.

A **common path of travel** is the portion of an exit that must be traveled before the occupant has two distinct choices; the limit in this facility is 100 ft (NFPA 101, 2012, s 38.2.5.3.1 & 40.2.5.3.1). There are no common paths of travel in this facility.

All exits terminate at an exterior **exit discharge** that leads directly to a public way (NFPA 101, 2012, s 38.2.7 & 7.7). Figure 2.1.3 shows that exit discharge in the FCMH is arranged to make clear the direction of egress to a public way.

Figure 2.1.3 shows FCMH exit discharge into various public ways. This is not releasable in accordance with FOIA exemption (b)(4). FOIA exemption (b)(4) refers to those trade secrets or commercial or financial information that a DoD Component receives from a person or organization outside the Government with the understanding that the information or record will be retained on a privileged or confidential basis in accordance with the customary handling of such records.

Both industrial and business occupancies require **illumination of the means of egress** in accordance with NPFA 101 Section 7.8. The entire facility is lit continuously (NFPA 101, 2012, s 7.8.1.2.2) with artificial light (NFPA 101, 2012, s 7.8.1.2.1) during the time that occupants require the means of egress. Neither automatic motion sensors (NFPA 101, 2012, s 7.8.1.2.2) nor energy saving sensors and automatic (NFPA 101, 2012, s 7.8.1.2.3) switches were used. The minimum illumination level of the walking surfaces in the facility is 0.2 ft-candle (NFPA 101, 2012, s 7.8.1.3). A public utility supplies the FCMH with power; that is considered a reliable source (NFPA 101, 2012, s 7.8.2.1).

Emergency lighting is required for business (NFPA 101, 2012, s 38.2.9.1) occupancies if the building has three or more stories in height, there are 50 or more occupants above or below level of exit discharge, or the occupancy has 300 or more total occupants. The business occupancy in fuel cell maintenance hangar does not meet these conditions, so emergency lighting is not required. Neither ETL 02-15 nor NFPA 101 requires emergency lighting for aircraft hangar bays.

Means of egress should be **marked** in accordance with NFPA 101 38.2.10 and 40.2.10, both of which directly reference section 7.10. According to 7.10, exits and exit access that are not obviously identifiable as exits must be marked. The FCMH is small and the occupants are generally familiar with the building layout, so no markings are required.

2.1.3 – Protection

There are several hazards throughout the hangar: hangar bays, fuel cell maintenance area. Highly flammable liquids are handled and stored in the maintenance are. Each of these areas is isolated by a 1 hour fire rated wall and is protected by an automatic sprinkler system (NFPA 101, 2012, s 38.3.2.2). Figure 2.1.4 shows fire rated separations designed by the architect and 2.1.5 shows required fire rated separations. The tool crib is used as routine office supplies and non-combustible materials. Since rooms 113 115, 116, 117 and 118 are considered low hazard and incidental to a business occupancy, no fire rated separation is required for these spaces.

Figure 2.1.4 shows fire rated construction throughout the Fuel Cell Maintenance Hangar designed by the architect. This is not releasable in accordance with FOIA exemption (b)(4). FOIA exemption (b)(4) refers to those trade secrets or commercial or financial information that a DoD Component receives from a person or organization outside the Government with the understanding that the information or record will be retained on a privileged or confidential basis in accordance with the customary handling of such records.

Figure 2.1.5 shows the fire rated construction throughout the Fuel Cell Maintenance Hangar required by ETL 02-15, and NFPA 101. This is not releasable in accordance with FOIA exemption (b)(4). FOIA exemption (b)(4) refers to those trade secrets or commercial or financial information that a DoD Component receives from a person or organization outside the Government with the understanding that the information or record will be retained on a privileged or confidential basis in accordance with the customary handling of such records.

The i**nterior finish** requirements are outlined in NFPA 101 Table A.10.2.2, and 38.3.31. NFPA 101 requires that interior wall and ceiling finishes be class A or B in exits and exit access corridors and A, B, or C in other spaces; it also requires that floor finishes be class I or II in exits. The finishes selected were Class B.

A **fire detection, alarm and communication system** is required to comply with ETL 02-15; in addition, because the occupancy is mixed without separation the facility is also held to the requirements of NFPA 101 40.3.4, which requires a fire alarm system unless the total occupant load is under 100 and fewer than 25 are on a different level than exit discharge. As one can see from Table 2.1.1, there are more than the allowable number of occupants and a Fire Alarm system in accordance with NFPA 101 9.6 is required; furthermore, UFC 3-600-01 (4-1.1) requires a fully addressable fire alarm system capable of transmitting fire alarms, trouble signals and supervisory signals to the base fire reporting system, where fire suppression systems are installed.

The business occupancy of the fuel cell maintenance hangar uses **corridors** as exit access. Normally these corridors are required to be 1-hour fire rated wall. Because the facility is protected by a sprinkler system throughout, that is not required (NFPA 101, 2012, s 38.3.6.1).

2.2 – Detection and Notification

2.2.1 System Overview

The FCMH is one of many protected premises on an Air Force base. It is protected by a fully addressable, automatic fire alarm and reporting system that uses Class A circuits. The [redacted] fire alarm control panel (FACP) is located in mechanical room 115. The fire alarm system is connected to remote station fire alarm system, located at the fire department, through a [redacted] Transmitter. Each alarm signal (i.e. area smoke detector, manual pull station, duct detector, and sprinkler water flow switch) will generate a signal at the FACP, record the event, play the facility fire evacuation pre-recorded message, activate clear strobes, and display information on the remote annunciator and override the public announcement system. The water supply valve, low temperature switch, fire alarm trouble switch, fire alarm power failure, low battery, open circuit, ground fault, and supervised component are supervisory inputs. Upon activation, the valve supervisory switch and low temperature switch actuate the supervisory notification at the FACP, record the event, activates the fire alarm trouble signal, displays the information on the remote annunciator and sends a signal to the supervising station. The power failure, low battery, open circuit ground fault, and component failure activate the trouble notification at the FACP, the fire alarm trouble signal, records information in the history, sends the signal to the supervising station, and displays the information on the remote annunciator. The fire department has the ability to override notification signals and deliver live announcements as well as pre-recorded announcements from the supervising station located in the fire station.

2.2.2 – Initiating Devices

The designed and installed initiation devices are compared in Figures 2.2.1 and 2.2.2, respectively; manual pull stations are located at each exit door; a supervised automatic sprinkler system (NFPA 101, 2012, s 9.6.2.1(3)) provides heat detection throughout the building, and smoke detectors are co-located with fire alarm control unit and notification appliance circuit power supplies (NFPA 72, 2012, s 10.4.4). There is not a significant difference between the planned and installed detection devices. The designed and installed spacing, location, and placement of alarm initiating devices has been evaluated and does meet NFPA 2012: National Fire Alarm and Signaling Code.

Figure 2.2.1 shows the planned layout of heat detection devices (sprinklers) and fire alarm initiation devices: water flow switch, manual pull stations, and smoke detectors. This is not releasable in accordance with FOIA exemption (b)(4). FOIA exemption (b)(4) refers to those trade secrets or commercial or financial information that a DoD Component receives from a person or organization outside the Government with the understanding that the information or record will be retained on a privileged or confidential basis in accordance with the customary handling of such records.

Figure 2.2.2 shows the installed layout of heat detection devices (sprinklers) and fire alarm initiation devices: water flow switch, manual pull stations, and smoke detectors. This is not releasable in accordance with FOIA exemption (b)(4). FOIA exemption (b)(4) refers to those trade secrets or commercial or financial information that a DoD Component receives from a person or organization outside the Government with the understanding that the information or record will be retained on a privileged or confidential basis in accordance with the customary handling of such records.

2.2.3 – Notification Appliances

In order to comply with the Architectural Barriers Act, the notification devices must provide both audio and visual notification. The devices selected were wall mounted speaker/strobes, wall mounted speakers, wall mounted strobes, ceiling mounted speakers, ceiling mounted strobes, and exterior speakers. The designed locations are shown in Figure 2.2.3 and the actual installed locations are shown in Figure 2.2.4. They are located in all normally occupiable spaces throughout the interior of the building. The occupancy throughout is either business, industrial, or assembly; the average ambient noise levels from NFPA 72, s A.18.4.3 are 55 dB, 80 dB, and 55 dB, respectively. The speakers/horns are field adjustable from 76 dB to 90 dB. NFPA 72, s 18.4.3.1, requires that speakers have a sound level at least 15 dB above average ambient sound level. The noise level in industrial use spaces should be measured to confirm proper selection of equipment; based on A.18.4.3, the selected speakers will not produce adequate sound levels. According to acoustic pressure solving software, the sound pressure level will never exceed 95.14 dB. At minimum hearing distance of 4 ft, the sound pressure does not exceed 110 dBA (NFPA 72, 2012, s 18.4.1.2*). Because audio/visual notification was provided in a combination device, the requirements of 18.5.4, determines the location (NFPA 72, 2012, s 18.4.8.3). Figure 2.2.3 shows locations and intensity of notification devices planned by the fire protection engineer as well as the areas that were not adequately covered by prescriptive requirements. Figure 2.2.4 shows the locations and intensity of devices actually installed by the fire alarm contractor and highlights the areas that are not adequately covered by prescriptive requirements. Table 2.2.1 summarizes locations and intensity of devices provided by the designer and the shop contractor, and compares them to both the prescriptive and performance-based requirements; one can see that the strobes in each space meet either the prescriptive requirement or the performance-based requirement of 0.0375 lumens/ft^2 (NFPA 72, 2012, s 18.5.5.4, s 18.5.5.6). Lighting intensity did not exceed 1000 cd (NFPA 72, 2012, s 18.5.3.4*). The fire alarm shop drawings, (Appendix D) detail 2, show that the height of wall-mounted appliances was such that the entire lens is not less than 80 in. (2.03 m) and not greater than 96 in. above finished floor (NFPA 72, 2012, s 18.5.4.1). The maximum corridor length is 38 ft and each corridor has notification within 15 ft of the end (NFPA 72, 2012, s 18.5.5.5.5*). Alarm location, spacing and placement were evaluated based on the criteria of chapter 18, and it was found that the requirements of NFPA 72 have been met.

Figure 2.2.3 shows the designed notification plan. Areas in red are areas not covered adequately by visible signaling, areas in yellow are areas covered by audible sign. This is not releasable in accordance with FOIA exemption (b)(4). FOIA exemption (b)(4) refers to those trade secrets or commercial or financial information that a DoD Component receives from a person or organization outside the Government with the understanding that the information or record will be retained on a privileged or confidential basis in accordance with the customary handling of such records.

Figure 2.2.4 shows the installed notification plan. Areas in red are areas not covered adequately by visible signaling, areas in yellow are considered non-occupiable spaces. This is not releasable in accordance with FOIA exemption (b)(4). FOIA exemption (b)(4) refers to those trade secrets or commercial or financial information that a DoD Component receives from a person or organization outside the Government with the understanding that the information or record will be retained on a privileged or confidential basis in accordance with the customary handling of such records.

Table 2.2.1 Space dimensions compared to prescriptive and performance-based notification appliance coverage.

Room	Designed Intensity	Provided Intensity	Required Effective Intensity	Designed Intensity Meets Required Intensity	Provided Intensity Meets Required Intensity	Designed Intensity Meets Performance Based Alternative	Provided Intensity Meets Performance Based Alternative	Notes
101	[redacted]	[redacted]	75	YES	YES	YES	YES	2
102	[redacted]	[redacted]	30	NO	NO	NO	YES	3
103	[redacted]	[redacted]	30	YES	YES	YES	YES	2
104	[redacted]	[redacted]	30	NO	NO	NO	YES	3
105	[redacted]	[redacted]	15	YES	YES	YES	YES	2
105	[redacted]	[redacted]	30	NO	YES	YES	YES	2,5
106	[redacted]	[redacted]	15	NO	YES	NO	YES	2
107	[redacted]	[redacted]	30	NO	NO	YES	YES	2
108	[redacted]	[redacted]	60	YES	NO	YES	YES	3
109	[redacted]	[redacted]	60	YES	NO	YES	YES	3
110	[redacted]	[redacted]	60	YES	YES	YES	YES	2
112	[redacted]	[redacted]	15	NO	YES	NO	YES	2
113	[redacted]	[redacted]	75	YES	YES	YES	YES	2
113	[redacted]	[redacted]	75	NO	YES	NO	YES	2,5
114	[redacted]	[redacted]	30	YES	YES	YES	YES	2
115	[redacted]	[redacted]	15	NO	YES	NO	YES	2
116	[redacted]	[redacted]	60	YES	YES	YES	YES	2
117	[redacted]	[redacted]	15	YES	YES	YES	YES	2
118	[redacted]	[redacted]	15	YES	YES	YES	YES	2
119	[redacted]	[redacted]	15	YES	YES	YES	YES	2
120	[redacted]	[redacted]	15	NO	YES	NO	YES	2
121	[redacted]	[redacted]	15	NO	YES	NO	YES	3
122	[redacted]	[redacted]	15	YES	YES	YES	YES	3
123	[redacted]	[redacted]	15	NO	YES	NO	YES	3

1. The illumination was calculated by dividing the actual intensity by the square of the greater dimension in accordance with NFPA 72, 2012, s 18.5.5.6.
2. Wall mounted devices.
3. Ceiling mounted devices.
4. Subspace of a larger room.

2.2.4 – Secondary Power

Voltage drop calculations are necessary to ensure that notification appliances function properly. Each notification device is UL 1973; each has an operating range from 16-33 V DC. Point-to-point voltage drop calculations were performed to select wire size and material correctly and ensure that each appliance has the minimum voltage required. The worst-case operating conditions occur when the control unit's primary power supply has reached the end of its useful life and the battery capacity is at its lowest point. ANSI/UL 864, *Standard for Control Units and Accessories for Fire Alarm Systems*, defines a minimum value of 20.4 VDC. A sample calculation to find the maximum allowable resistance is presented in Table 2.2.2. Calculations for other notification appliance circuits are located in Appendix D. The result of the calculation shown in Table 2.2.2 is that the maximum direct-current resistance is 35.99 ohm/kft; all wires listed in NFPA 70 2014 Chapter 9 Table 8 meet this criteria. The selected wire was 14 gage aluminum.

Table 2.2.2 is a sample voltage drop calculation for notification appliance circuit 1. It lists each device, current draw, wire length, and resistance. The maximum direct current resistance was calculated (35.39 ohm/kft) using an iterative newton solver by assuming the minimum voltage at a device is 16V (UL 1973). The results were used to select conductor material and wire gage, ensure that each appliance has the required voltage available to it under load conditions, and to calculate the size of the secondary power supply.

Device	Part Number	Device Load (A)	Load at Device (A)	R[4] (Ohms)	Voltage Drop[1] (V)	Total Voltage Drop[2] (V_T)	Voltage at Device[3] (V_D)
1	[redacted]	0.066	0.874	0.72	0.63	0.63	19.77
2	[redacted]	0.158	0.808	1.08	0.87	1.50	18.90
3	[redacted]	0.066	0.65	0.90	0.58	2.09	18.31
4	[redacted]	0.094	0.584	1.08	0.63	2.72	17.68
5	[redacted]	0.066	0.49	0.90	0.44	3.16	17.24
6	[redacted]	0.066	0.424	0.72	0.31	3.46	16.94
7	[redacted]	0.066	0.358	0.90	0.32	3.79	16.61
8	[redacted]	0.094	0.292	0.72	0.21	4.00	16.40
9	[redacted]	0.066	0.198	0.72	0.14	4.14	16.26
10	[redacted]	0.066	0.132	1.44	0.19	4.33	16.07
11	[redacted]	0.066	0.066	1.08	0.07	4.4	16

1) $V_i = I_i R$
2) $V_{T,i} = \sum_i V_i$
3) $V_{D,i} = V - V_{T,i}$
4) $R = L * R_L$

Because the fire alarm system is a combination mass notification and fire alarm system, UFC 3-600-01 5.35 has precedence over NFPA 72 106.7.2.1; batteries are sized based on a 24 hour standby mode and 15 minute alarm with battery sized for 48 hour standby mode and 10 minute alarm. Table 2.2.3 summarizes alarm and standby current draw for each device; this table was used to calculate total alarm and standby current shown in Table 2.2.4. One can see from Table 2.2.4 that the installed battery exceeds the required size.

Table 2.2.3 is a summary of the current for each alarm device and panel; the alarm and standby currents are calculated from this table to be 3.544 amps, and 0.375 amps respectively.

Part Number	Quantity	Standby Current (A)	Total Standby Current (A)	Alarm Current (A)	Total Alarm Current (A)
[redacted]	1	0.25	0.25	0.25	0.25
[redacted]	1	0.04	0.04	0.04	0.04
[redacted]	1	0.03	0.03	0.158	0.158
[redacted]	1	0.045	0.045	0.098	0.098
[redacted]	11	0.00038	0.00418	0	0
[redacted]	2	0.0003	0.0006	0	0
[redacted]	6	0.00035	0.0021	0	0
[redacted]	4	0.00075	0.003	0	0
[redacted]	1	0	0	0.4	0.4
[redacted]	8	0	0	0.066	0.528
[redacted]	1	0	0	0.094	0.094
[redacted]	3	0	0	0.158	0.474
[redacted]	5	0	0	0.066	0.33
[redacted]	3	0	0	0.094	0.282
[redacted]	1	0	0	0.89	0.89

*Table 2.2.4 compares the required battery size (*IAW NPFA 72 and UFC 3-600-01) to the actual battery installed.

Fire Alarm Control Panel	Total Standby Current (IT,S)	Total Alarm Current (IT,A)	Required Battery Size by NFPA 72[1] (Amp-hours)	Required Battery Size by UFC 3-600-01 (Amp-hours)	Actual Battery Size
[redacted]	0.375	3.544	11.86	22.30	[redacted]

1. Amp-Hours = $1.2(24*I_{T,S}+15/60* I_{T,A})$
2. Amp-Hours = $1.2(48*I_{T,S}+10/60* I_{T,A})$

2.2.5 – Inspection Testing and Maintenance

The inspection, testing, and maintenance requirements for the fire alarm system and components installed in the FCMH are governed by UFC 3-601-02 and are summarized in the Table 2.2.5.

Table 2.2.5 shows the inpsection, testing and maintenance items for fire alarm systems.

Frequency	Component	Tasks
Monthly	Control Panels and Annunciator Equipment (unmonitored only)	• Inspect panel condition (connections, fuses, light-emitting diodes [LED])
Annual	Control Panel and Annunciator Equipment (monitored)	• Test to verify proper receipt of alarm, supervisory, and trouble signals (inputs) and operation of notification appliances and auxiliary functions (outputs). • Verify that all lamps and LEDs are illuminated. • Load test backup batteries (when provided).
	Initiating Devices Manual Fire alarm Station	• Verify station is accessible (visual).
	Notification Appliance and Voice Communication (telephone, speakers, horns, and strobe lights).	• Test to verify operability.
	Digital Alarm Transmitter and receiver	• Test to verify operability.
Bi-Annual	Initiating Devices Manual Fire alarm station	• Operate to verify alarm receipt.
	Heat Detectors (restorable) (Remove devices not required by UFC 3-600-01.)	• Test with a heat source to verify alarm initiating and receipt. • Verify no facility change that affects performance.
	Smoke Detectors (single-station detectors, system detectors, and air sampling detectors) (Remove devices not required by UFC 3-600-01 or other directives.)	• Test with manufacturer-approved smoke simulant to verify smoke entry and alarm initiation and receipt. • Verify no facility change that affects performance.
	Supervisory Devices (low air pressure, temperature, water level)	• Test to verify initiation and receipt of supervisory alarm.
5 Years	Smoke Detectors (Remove devices not required by UFC 3-600-01.)	• Test detector sensitivity to ensure that the detector has remained within its listed and marked sensitivity range (or 4 percent obscuration light gray smoke, if not marked).
Upon Inspection	Entire System	• Visually check: o Detectors unblocked and uncovered. o Panels secured and indicator lamps functional. o Notification appliances in place. o Manual stations in place and unobstructed. o Exercise evacuation notification appliances for audibility, clarity, and visibility.

2.3 – Fire Suppression

2.3.1 – Classification

The FCMH is provided with an automatic sprinkler system (ETL 02-15, 2002, s A1.1.1.2.1) and low-level high expansion foam (ETL 02-15, 2002, s A1.3.3). The facility is divided into three categories of hazard, aircraft servicing center, office space, and maintenance area and utilities. As one can see from Appendices C and E, the shop drawings are not consistent with the design drawings and standards. Figure 2.3.1 shows areas and hazard classifications. The installed discharge density and design area are summarized and compared to the required discharge density and design areas of NFPA 13, UFC 3-600-01 (2013) and UFC 3-600-01 (2009) in Table 2.3.1.

Figure 2.3.1 shows various occupancy hazard classifications used to describe the required design density for automatic sprinkler systems. Reference Table 2.3.1 for the color code. This is not releasable in accordance with FOIA exemption (b)(4). FOIA exemption (b)(4) refers to those trade secrets or commercial or financial information that a DoD Component receives from a person or organization outside the Government with the understanding that the information or record will be retained on a privileged or confidential basis in accordance with the customary handling of such records.

Table 2.3.1 summarizes the occupancy hazard classification and corresponding design desnity of NFPA 13, ETL 02-15, and FM Global Data Sheet 3-26.

Space Use	NFPA 13		AF ETL02-15 or UFC-3-600-01[1]		Installed
	Design Density / Discharg Area (gpm/SF/SF)	Occupancy Hazard	Design Density / Discharge Area	Occupancy Hazard	Design Density / Discharge Area
Hangar Bay	0.2/5000	EH1	0.2/5000	ETL-02-15	[redacted]
Maintenance Area, Tool Crib, and Utility Spaces	0.2/1500	OH2	0.2/2500	HC-2	[redacted]
Office Space	0.1/1500	OH1	0.1/1500	HC-1	[redacted]

1) UFC 3-600-01 was recently revised to reference FM Property Protection Data Sheet 3-26 regarding design densities and discharge areas.

2.3.2 – System Components

The system riser is located in the Fire Protection Room, RM 117. The main is an 8-inch diameter stainless steel pipes that feeds five 6-inch diameter risers. Each set of foam generators, and the sprinkler system of hangar bay 1, is served by its own riser. The shops and hangar bay 2 each share their riser with office space. System risers, cross-mains, and branch lines are shown in Appendix E. The types of sprinklers are identified in Table 2.3.2. Quick response sprinklers are required in light hazard occupancies such as office space (NFPA 13 8.3.3.1); they are more thermally sensitive and will discharge faster, limiting fire damage and potential injuries. Use of quick response sprinklers in Extra Hazard Occupancies are prohibited by NFPA 13 8.4.1.2 because they respond so quickly that the system may become taxed and fail to suppress the fire; conversely, ETL 02-15 mandates their use in hangars. Sprinklers must have a minimum K-Factor of 5.6 (NFPA 13, 2013, s 8.3.4.1) to ensure that enough water is discharged; some exceptions exist, but they were not used in this design. The temperature rating was selected in accordance with ETL 02-15 and NFPA 13.

Table 2.3.2 shows the types sprinklers used with their corresponding characteristics and locations.

Location	K-Factor	Temperature Rating (°F)	Type
Office Space	5.6	[redacted]	Pendent Quick Response
Shops and Utilities	5.6	[redacted]	Upright Quick Response
Hangar Bays[1]	5.6	[redacted]	Upright Quick Response

2.3.3 – High Expansion Foam

The location of each high expansion foam generator is shown in Figure 2.3.2. Foam discharge rate calculations are provided in Appendix G.

Figure 2.3.2 shows the locations of high expansion foam generators. This is not releasable in accordance with FOIA exemption (b)(4). FOIA exemption (b)(4) refers to those trade secrets or commercial or financial information that a DoD Component receives from a person or organization outside the Government with the understanding that the information or record will be retained on a privileged or confidential basis in accordance with the customary handling of such records.

Total foam generation capacity, solution rate, concentrate rate, concentrate quantity, water rate, and water quantity were calculated for each hangar bay in accordance with NFPA 11 and ETL 02-15 and compared to the actual installed discharge in Table 2.3.3. As one can see, the installed system far exceed that required by NFPA 11 and ETL 02-15 in bay 1, and meets the requirements of ETL 02-15 in bay 2. A water flow rate of [redacted] is necessary in order to meet the design foam generation, requiring a pressure of [redacted] at the generator.

Table 2.3.3 shows the minimum design discharge rates from NFPA 11 and ETL 02-15 and compares them with the actual designed discharge rate from the hydraulic calculations assuming an expansion ratio of 500:1. Installed foam discharge rate, solution rate, and concentrate rate were estimated assuming the proportioning is consistent with the design.

	NFPA 11		ETL 02-15		Installed	
	Bay 1	Bay 2	Bay 1	Bay 2	Bay 1	Bay 2
Foam Discharge Rate (cfm)	21,221	17,697	43,558	33,554	51,494	33,971
Solution Rate (gpm)	317	265	652	502	770	508
Foam Concentrate Rate (gpm)	6	5	13	10	15	10
Quantity Foam (gal)	95	79	196	151	231	152
Water Rate (gpm)	311	259	639	492	755	498
Quantity Water (gal)	4,667	3,892	9,580	7,379	11,325	7,471

2.3.4 – Water Supply

Hydraulic calculations were performed by a fire sprinkler contractor and are shown as Appendix E. The contractor determined that the demand at the base of the riser is required to be [redacted] psi in order to ensure the foam generators had a minimum of [redacted] psi. The water supply for this facility is a series of fire pumps. Flow tests demonstrate that if one pump is running it can produce [redacted] gpm at [redacted] psi. The water supply is compared to hydraulically most demanding area in Figure 2.3.3.

Figure 12.3.3 shows the water supply characteristic and compares it to the system demand. System demand was calculated by a contractor using Hydraulic Analyzer of Sprinkler System software. One can see that the required pressure at design flow rate ([redacted]) is below the water supply curve. This is not releasable in accordance with FOIA exemption (b)(4). FOIA exemption (b)(4) refers to those trade secrets or commercial or financial information that a DoD Component receives from a person or organization outside the Government with the understanding that the information or record will be retained on a privileged or confidential basis in accordance with the customary handling of such records.

One can see from Figure 2.3.3 that the available pressure will exceed the required the pressure at the required flow rate. The system demand was calculated by a contractor using the Hazen-Williams formula and compared to that using the Darcy-Weissbach formula. The Hazen-Williams formula was found to be a more conservative estimate. The calculations were repeated without the loop shown in Figure 2.3.4, and with an increase in pipe diameter from 2” to 4” of part of the loop size.

Figure 2.3.4 shows a loop located in hangar bay 2. Hydraulic flow calculations show that this loop is unnecessary. This is not releasable in accordance with FOIA exemption (b)(4). FOIA exemption (b)(4) refers to those trade secrets or commercial or financial information that a DoD Component receives from a person or organization outside the Government with the understanding that the information or record will be retained on a privileged or confidential basis in accordance with the customary handling of such records.

Figure 2.3.3 demonstrates that removing the loop shown in Figure 2.3.4 does not significantly increase the required pressure at the design flow rate; conversely, increasing the entire loop to 4” diameter does substantially decrease the required pressure.

2.3.5 – Inspection Testing and Maintenance

UFC 3-600-02 prescribes inspection, testing, and maintenance (ITM) required for Air Force facilities. Table 2.3.4 summarizes the ITM requirements for wet-pipe automatic sprinkler systems. Some notable differences between this and NFPA 13, Table A.26.1, are that A.26.1 prescribes the inspection of sealed control valves to occur weekly, not monthly, and water flow alarms to be tested quarterly, not inspected annually, and the fire department connection is to be inspected monthly, not annually. The UFC does provide a more detailed description than NFPA 13 Table A.26.1.

Table 2.3.4 shows various required maintenance tasks for automatic sprinkler systems identified in UFC 3-600-02.

Frequency	Component	Tasks
Monthly	Control Valves (without seal, lock, or electric supervision)	• Verify valve position.
Annual	Control Valves (sealed, locked, or electrically supervised)	• Verify valve position.
	Water flow Alarm Devices	• Operate to verify initiation and receipt of alarm. • Verify alarm test valve alignment and tamper switch (if sealed or electrically supervised).
	Alarm Valve and Trim	• Visually check the exterior of valves, gauges, trim alignment. • Verify valve pressure and legibility of the hydraulic nameplate.
	Main Drain	• Conduct a main drain test to verify supply (valve position). • Document static and residual pressure readings on a 3- by 5-inch (3x5) tag and secure it to the system pressure gauge. • Compare results with results from previous main drain tests and original acceptance test. • Verify that the results are within acceptable limits or identify corrective measures.
Annual (Continued)	Fire Department Connection	• Verify accessibility and condition. • If caps are removed or missing, check for obstructions.
2 Years	Control Valves	• Operate valve through entire travel to verify function. • Lubricate valves and stems to ensure operability.
5 Years	Alarm Valve	• Clean and inspect internally to verify condition.
	Anti-freeze Loops	• Confirm correct solution mixture.
10 Years	Gauges	• Recalibrate or replace gauges.
20 Years	Fast Response Sprinklers and Extra High Temperature Sprinklers	• Test sample sprinklers to verify response characteristics.
50 Years	Standard Sprinklers	• Replace or test a sample of sprinklers to verify response characteristics.
Following System Modification or Repair	Main Drain (following maintenance or repair action requiring the water supply to be shut off)	• Conduct main drain test to verify supply (valve position).
As Part of Building Inspection	Entire System	• Visually check: o Pipe hangers. o Sprinklers for obstruction. o Piping for leaks. o Riser condition.

Table 2.3.5 summarizes ITM requirements for high expansion foam. These criteria are also identified in NFPA 11; however, UFC 3-600-02 is more detailed.

Table 2.3.5 shows various required maintenance tasks for high expansion foam systems identified in UFC 3-600-02

Frequency	Component	Tasks
Annual	Foam Concentrate	• Inspect to verify adequate supply. • Take sample and test in accordance with manufacturer's instructions.
	Foam Generator	• Inspect to verify condition and proper valve alignment.
2 Years	Foam Generator	• Conduct test to verify operability. (Water-powered may be done with water only.)
	Actuators	• Verify that all manual and automatic actuators function.
	Foam Proportioning Systems	• Conduct full flow test to ensure proper system function. (Test may be done through a test connection or through the foam generators. Only discharge until full foam flow appears from each generator; then end foam injection.) • Verify proper concentration.
	Control Valve	• Operate valve through entire travel to verify function. • Lubricate stem.
After Activation	Strainers	• Inspect and clean after system actuation or flow test.
Following System Modification or Repair	Main Drain (following maintenance or repair action requiring the water supply to be shut off)	• Conduct main drain test to verify supply (valve position). • Document static and residual pressure readings on a 3x5 tag and secure it to the system pressure gauge.
As Part of Building Inspection	Entire System	• Visually check: o Pipe hangers. o Generators for obstruction (air intake or foam discharge). o Generator nozzles for obstruction and generator screens for damage. o Piping for leaks. o Riser condition. • Ensure: o Detectors unblocked/uncovered. o Panels secured and indicator lamps functional. o Notification appliances in place. o Manual stations in place and unobstructed.

Section 3 Performance-Based Evaluation

3.1 – Scope

This analysis evaluates the existing design and Air Force Prescriptive Design criteria for Aircraft Facilities. The stake holders are: Authority Having Jurisdiction (AHJ), Department of Civil Engineering, facility occupants, Air Force HQ, and US tax payers. Aqueous film forming foam (AFFF) is a viable alternative to high expansion foam. Other entities in the Department of Defense, such as the Navy, have standardized on AFFF. The Air Force AHJ regards AFFF and high expansion foam systems as systems that provide equivalent levels of protection. This report compares high expansion foam to AFFF when evaluating foam agent selection.

3.2 – Goals

Life Safety

Provide life safety for the public, building occupants and emergency responders by minimizing fire-related injuries and preventing undue loss of life.

Property Protection

Minimize damage to property from fire (protect building and contents from fire and exposure to fire from adjacent buildings.)

Environmental Protection

Limit the environmental impact of fire from combustion products and release of hazardous materials.

Reduce Cost

The selected system should result in the lowest life-cycle cost considering risk mitigation, construction, and maintenance costs.

3.3 – Stakeholder and Design Objectives

Life Safety

Minimize feasible loss of life; ensure egress meets life safety code.

Property Protection

Minimize damage to critical assets. Ensure asset availability; at least one of two F-35 jets must survive fully intact. Minimize damage to the facility; ensure critical members integrity of critical structural systems.

Environmental Protection

Minimize environmental impact; select firefighting agents that minimize environmental impact.

Reduce Cost

Minimize cost of selected system.

3.4 – Performance Criteria

Life Safety

Air Force does not have additional performance criteria.

Property Protection

Property protection criteria for F-35 is not publicly releasable. F-35 surface skin is a composite material that consists of epoxy or bismaleimide resins that degrade as the temperature increases[11].

The structural system of the FCMH was designed to withstand hurricane conditions. Typical factors of safety during fully live loaded conditions range from 2 to 4. It is reasonable to assume that a column with will fail when it loses approximately 90% of its integrity. This corresponds to a temperatures of 600°C, assuming that columns are not actively loaded during a fire.

Environmental Protection

Minimize environmental impact by choosing agents that cause the least harm to aquatic life. Choose agents that have minimal contributions to biological oxygen demand (minimize BOD) and agents to which aquatic life is the least susceptible (maximize LC_{50}).

Reduce Cost

Minimize total installation, operation and maintenance costs.

3.5 – Design Fire Scenario

The design fire scenario is based on the worst-case expected fire: a de-fueled F-35 returns from operations into the hangar for maintenance. The fuel dump switch is accidentally activated dumping nearly an infinite supply of JP-8 into a populated hangar, which covers approximately 11,000 SF instantaneously[11]. The fuel is ignited by various electrical equipment present throughout the fuel cell maintenance hangar such as aerospace ground equipment. Fuel is at a normal operating temperature of 71 °C (160 °F)[1]. The flame spread rate for JP-8 at this temperature has been experimentally measured to be 1.5 m/s[9]. JP-8 has an experimentally measured heat release rate per unit area of 2.8 MW/m^2 [13]. Comparing Figure 3.5.1 to Figure 3.5.2 demonstrates how quickly the design fire grows.

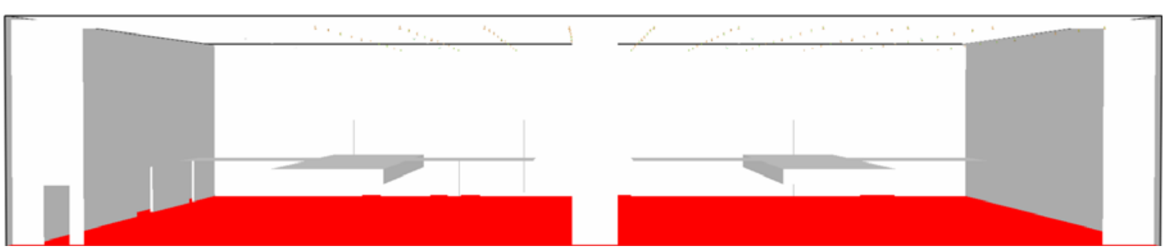

Figure 3.5.1 is a rending of hangar bay 1 at the time of ignition.

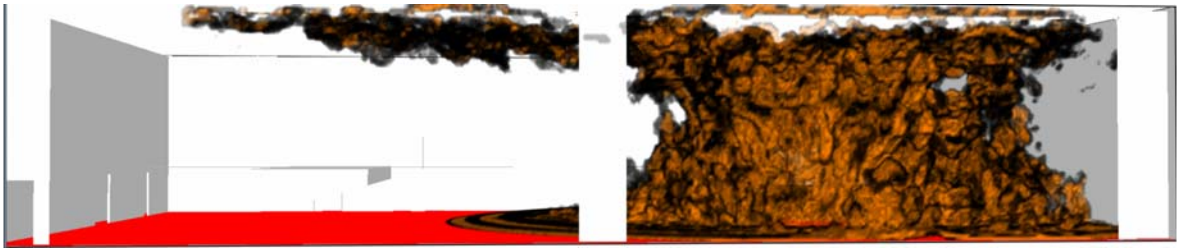

Figure 3.5.2 is a rendering of hangar bay 1 10 seconds after ignition. The fire size is approximately 1,000 MW at this time.

3.6 – Design

The current design requirements are outlined in ETL 02-15 and UFC 3-600-01.

Ignition prevention

Ignition prevention requirements are outlined in NPFA 70, Article 513.

Control fire development

Fire development is not addressed in ETL 02-15.

Spread control and management of smoke.

Smoke spread and management is not addressed in ETL 02-15.

Detection and notification

Fire is either detected manually or by sprinkler system activation. Speakers and strobes are provided for occupant notification.

Suppression

The hangar is protected by a wet-pipe sprinkler system designed to discharge 0.2 gpm/SF over 5000 SF. Manual foam discharge stations and a water flow detecting device with an adjustable retard ranging from 0-90 seconds activate high expansion foam. The high expansion foam system is designed to produce 1 m of foam in the hangar with doors open in 4 minutes.

Occupant Egress

Occupants have access to exits separated by 150 ft on perimeter walls and every 100 ft on interior walls.

Passive fire protection

Structural fire protection is not provided.

3.7 – Design Evaluation

Life Safety

There are no performance-based criteria to evaluate life safety.

Property Protection

Automatic sprinkler systems were found to effectively reduce some damage to aircraft not intimate with ignition. Hangar bay 1 was modeled in FDS both with and without an automatic sprinkler system. As one can see in Figure 3.7.1 the heat release rate was significantly reduced by the cooling effects of an automatic sprinkler system.

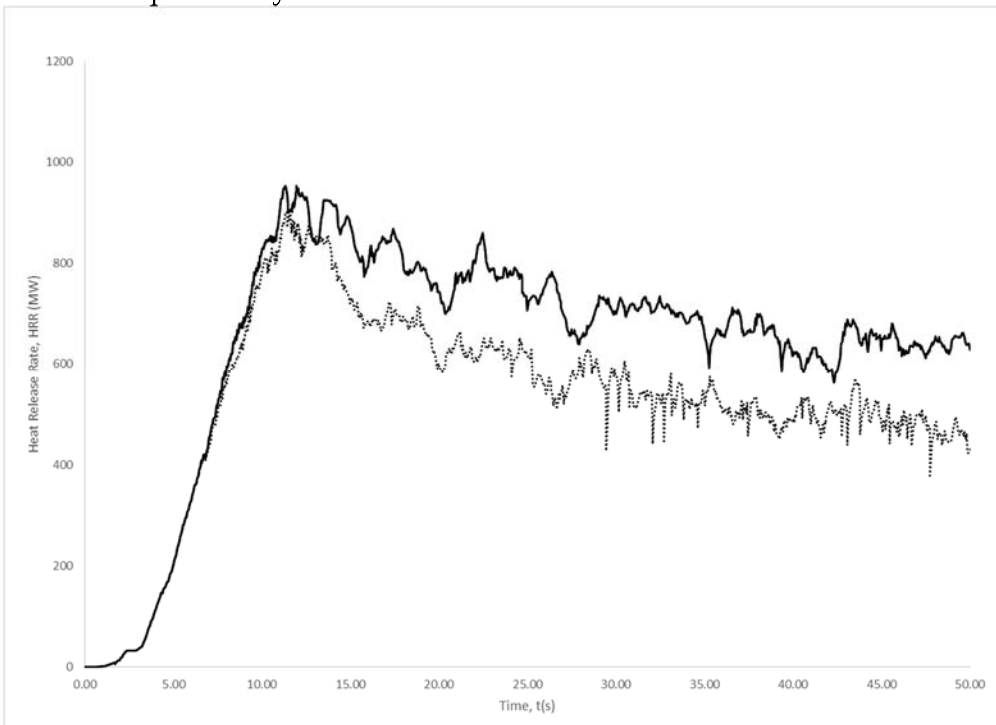

Figure 3.7.1 shows the heat release rate generated by FDS modeling with and without an automatic sprinkler system for the design fire in hangar bay 1.

Figures 3.7.2, 3.7.3, 3.7.4 and 3.7.5 are renderings that show time at initial damage to the lesser susceptible of the two jets without and with sprinkler protection, respectively. Figures 3.7.2 and 3.7.3 shows that damage begins to occur at 15.4 seconds, and continues to complete destruction at 25 seconds.

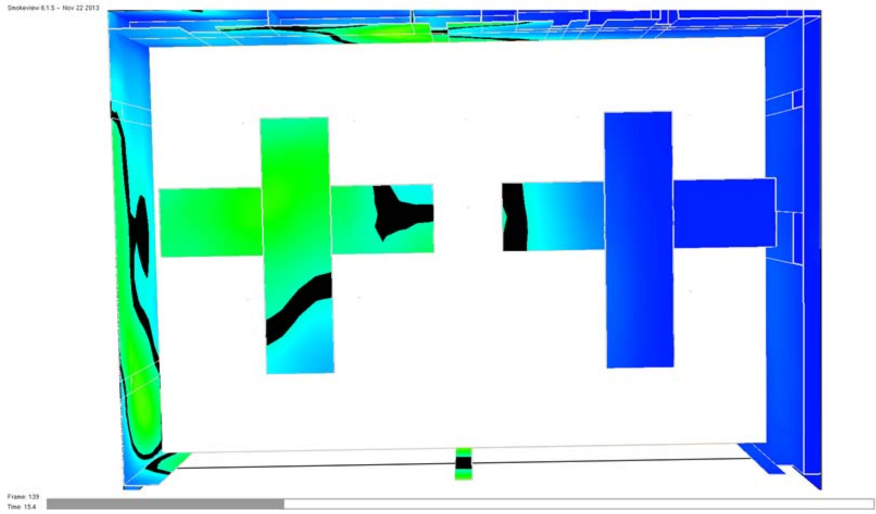

Figure 3.7.2 is a rendering of the FDS model of hangar 1 without sprinkler protection. It shows temperature contours of the time at which unacceptable damage begins to occur (15.4 s) during the maximum expected fire scenario.

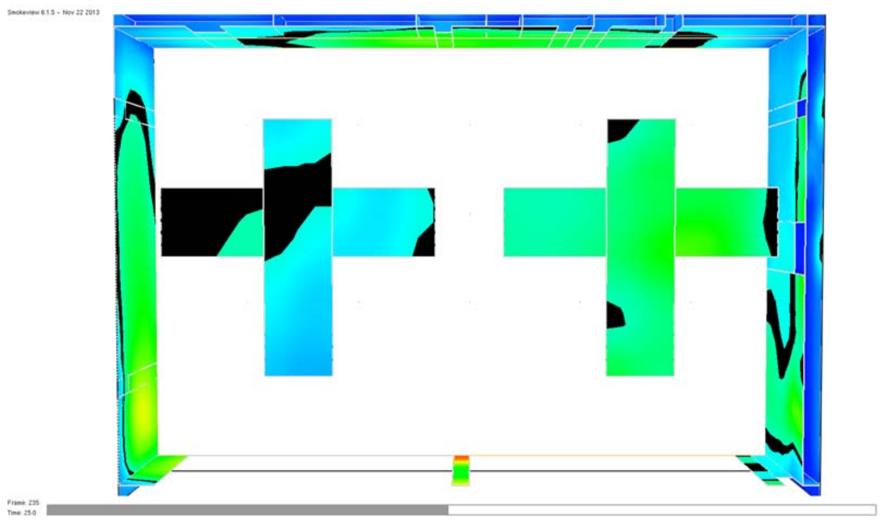

Figure 3.7.3 is a rendering of the FDS model of hangar 1 without sprinkler protection. It shows temperature contours of the time at which complete destruction occurs (25 s) during the maximum expected fire scenario.

Figures 3.7.4 and 3.7.5 show that damage begins at time 13.3 seconds and continues to 20.0, resulting in a maximum of 50% destruction of aircraft skin.

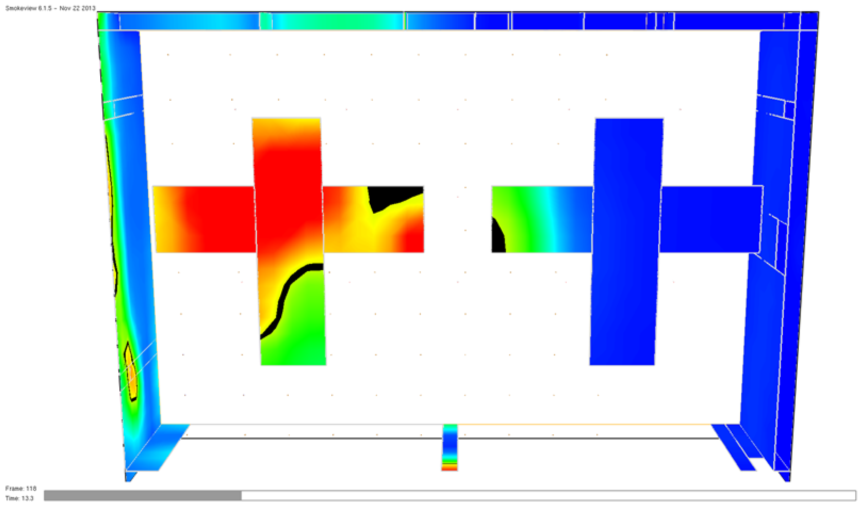

Figure 3.7.4 is a rendering of the FDS model of hangar 1 with sprinkler protection. It shows temperature contours of the time at which unacceptable damage begins to occur (13.3 s) during the maximum expected fire scenario.

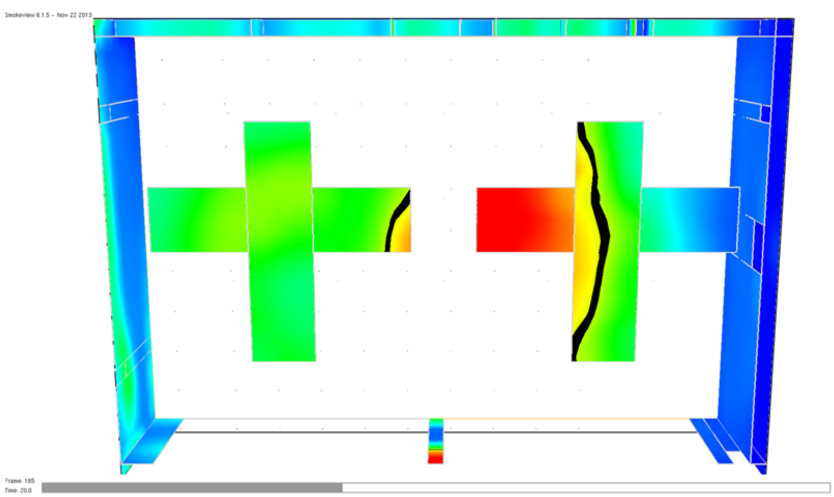

Figure 3.7.5 is a rendering of the FDS model of hangar 1 with sprinkler protection. It shows temperature contours of the time at which maximum damage occurs (20 s) during the maximum expected fire scenario.

FDS modeling indicated that sprinkler activation occurred at 7.6 seconds and that unacceptable damage begins to occur at 15.4 seconds. In order for the fire suppression system to meet the performance criteria high expansion foam must discharge and control the fire before 15.4 seconds. Therefore, either an occupant must discharge the high expansion foam manually or the adjustable retard on the sprinkler system must be set to a maximum of 7.8 seconds. The adjustable retard for this hangar is set to 45 seconds; therefore, this hangar is completely reliant on the ability of an occupant to activate high expansion foam discharge in order to protect property.

Another major requirement in order to protect Air Force asset is facility structural integrity. Thermal response of steel columns to the design fire was modeled in FDS. The maximum temperature of steel column was found to be 57.3 C; well below the structural performance criteria.

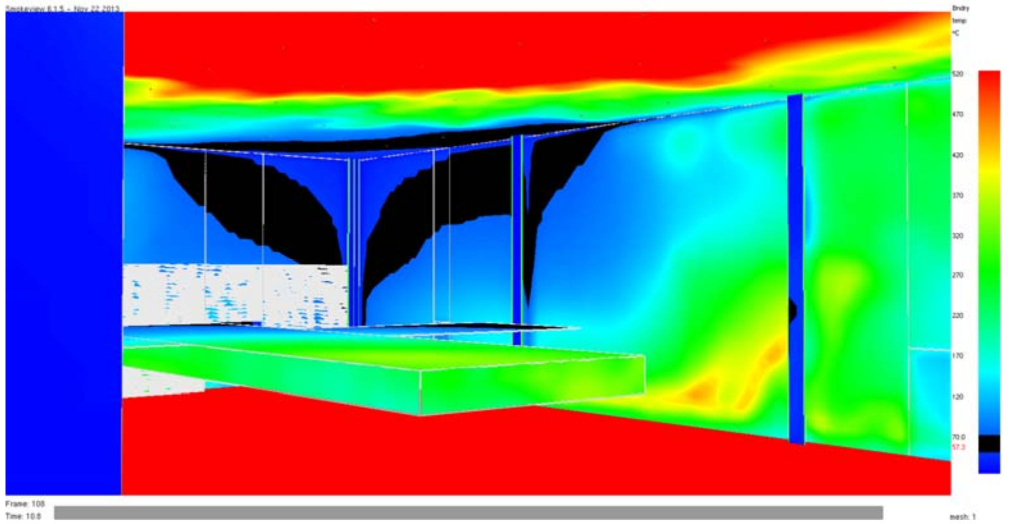

Figure 3.7.8 is a slice file that shows the maximum temperature of that occurs on the surface of a structural steel column.

Environmental Protection

According to SFPE Handbook Table 4-4.4, depending on the discharge outlet type AFFF will require an application rate of 0.10 gpm/ft^2 to 0.16 gpm/ft^2 to extinguish this type of fire. Assuming an optimum expansion rate of 500:1, a high expansion foam system designed in accordance with ETL 02-15 will use 0.071 gpm/ft^2 solution. Relevant environmental properties of MILSPEC AFFF and high expansion foam are compared in Table 3.7.1. Biochemical oxygen demand for each is similar based on the actual use, but high expansion foam is 35 times more toxic to aquatic life. This much more of a concern for Navy vessels than it is for Air Force hangars. After a discharge the residual is collected and dosed into the sanitary sewer system and treated at a waste water treatment plant. There is negligible difference in environmental impact when comparing AFFF and high expansion foam.

Table 3.7.1 summarizes the relevant environmental properties for AFFF and high expansion foam. These values were taken from Material Safety Data Sheets Attached as Appendix I.

	AFFF	High Expansion Foam
BOD (mg/l)	7,818	18,389
LC50 (mg/l)	37,800	1,100

Reduce Cost

Table 2.3.3 compares high expansion foam design criteria for NFPA 11, ETL 02-15 and the actual construction of this hangar. It becomes clear that this system is over designed will produce too much foam. As a result construction and maintenance costs are inflated.

The Air Force Cost Engineering Subject Matter Expert performed a cost analysis demonstrating that AFFF systems are more expensive. Shown in Appendix K. This shows that the initial cost of an AFFF system is approximately $250,000 more than that of high expansion foam. The annualized operating cost of an AFFF system is approximately $40,000; the annualized operating cost of a high expansion foam system is approximately $10,000. Clearly, high expansion foam is initially less expensive.

Section 4 – Conclusion and Recommendations

4.1 – Prescriptive Design

4.1.1 – Conclusion

The fuel cell maintenance hangar design was evaluated and found with few exceptions to comply with the prescriptive requirements of UFC 3-600-01, ETL 02-15, NFPA 101, 72, 13, and 11.

4.1.2 – Recommendations

The architect provided extra fire rated walls surrounding the tool crib, and utility spaces. The fire sprinkler contractor installed approximately 195 ft unnecessary 4” pipe. In addition the contractor provided excess water supply to foam generators located in bay 1, ultimately causing larger quantities of foam and water to be stored and supplied. NFPA 13 requires that hydraulic calculations be performed using the Hazen-Williams equation; the use Darcy-Weissbach equation will result in the use of smaller pipe throughout. Over-design and unnecessary fire protection features inflate construction and maintenance costs. It is recommended that UFC 3-600-01 and ETL 02-15 be modified to reduce over-design.

4.2 – Performance-Based Design.

4.2.1 – Conclusion

Engineering Technical Letter 02-15 was evaluated by FDS modeling of this fuel cell maintenance hangar. The modeling demonstrated that current Air Force criteria does not meet property protection goals. High expansion foam does not discharge quickly enough to control the fire and the current design criteria relies on manual activation.

4.2.2 – Recommendations

In order to protect critical assets the Air Force should consider modifying current criteria to discharge foam faster and reduce reliance on manual activation. ETL 02-15 section A1.3.5.4 requires that high expansion foam is activated by a water flow detecting device with a built-in adjustable retard set between 0 and 90 seconds. If high expansion foam is activated after 15.4 seconds then the system will not satisfy the Air Force’s property protection goals. It is recommended the adjustable retard be set no longer than 7 seconds. Spot type heat detection was modeled in FDS using Fast, Quick, and standard response heat detectors; each produced activation at times 5.95, 7.10 and 7.90 seconds. A rate of rise heat detector would activate at 5.8 seconds. UV/IR fire detectors could provide adequate coverage to the space and based on extrapolation of manufacturer data will respond at approximately 0.39 seconds. Using thermal fire detection to activate high expansion foam will significantly reduce the time to discharge. It is recommended that the Air Force use fire detection to activate the high expansion foam system. Finally, standard orifice or closed head foam-water sprinkler system have been used in aircraft occupancies and have been tested for the purpose of hydro-carbon pool fires in UL 162. As each sprinkler activates it immediately discharges foam and closed head systems are much less susceptible to accidental activation. In order to decrease the time required to apply foam to the fire it is recommended that standard orifice or closed head foam water sprinklers be tested for use with modern foams and research be extended for use with high expansion foam. Further investigation should be performed to evaluate the costs and benefits of trenched foam sprinkler systems which deploy substantially faster but at greater cost.

Appendix A – References

1. Air Force Civil Engineering Center. (2002). AFETL 02-15: *Fire Protection Engineering Criteria – New Aircraft Facilities*

2. International Code Council. (2012). IBC: *International Building Code*

3. National Fire Protection Association. (2012). *NFPA 101: Life Safety Code*

4. National Fire Protection Association. (2013). *NFPA 72:* National Fire Alarm and Signaling Code

5. National Fire Protection Association. (2013). *NFPA 13:* Standard For the Installation Of Sprinkler Systems

6. National Fire Protection Association. (2010). *NFPA 11:* Standard For Low-, Medium-, and High-Expansion Foam

7. Sheffey, J.L., "Foam Agents and AFFF System Design and Considerations," Section 4-4, *The Society of Fire Protection Engineers (SFPE) Handbook of Fire Protection Engineering*, 3rd Edition, Society of Fire Protection Engineers, Bethesda, Maryland, 2002.

8. Yan, Shihong, "Study of the Evolution of Soot from Various Fuels," Departments of Chemical engineering and Chemistry, University of Utah, Salt Lake City, Utah, April 2005.

9. Leonard, J.T., et all, "Fire Hazards of Mixed Fuels on the Flight Deck," Navy Technology Center for Safety and Survivability, April 1992.

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11. Beeson, H.D., et all, "Aircraft Composite material Fire Damage Assessment," New Mexico Engineering Research Institute, University of New Mexico, September 1990.

12. Yarlagadda, S., et all, "Post-Fire Damage Assessment of a Composite Wingbox," Air Force Research Laboratory, May 2004.

13. Blanchat, T., et all, "Large-Scale Open Pool Experimental Data Analysis and for Fire Model Validation and Development," Sandia National Laboratories, Fire and Aerosol Sciences Department, 2008.

14. Buchanan, A., (2002), **Structural Design for Fire Safety**.

Appendix B – Engineering Technical Letter (ETL) 02-15

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

DEC 3 2002

FROM: HQ AFCESA/CES
139 Barnes Drive, Suite 1
Tyndall AFB, FL 32403-5319

SUBJECT: **Engineering Technical Letter (ETL) 02-15: Fire Protection Engineering Criteria - New Aircraft Facilities**

1. Purpose. This ETL provides fire protection criteria for protection of aircraft and facilities in the event of a fuel spill fire. Human intervention is required to minimize damage to incident aircraft.

2. Summary of Revisions. This ETL supersedes ETL 01-2, and includes the following changes: Deleted references to semi-hardened and hardened aircraft shelter now covered in ETL 01-4 (paragraph 3); clarified the aircraft type covered (paragraph 3.5); changed MIL-HDBK 1008C to UFC 3-600-01 (paragraph 4.3 and throughout the ETL); changed the UBC to the IBC (paragraph 4.8 and throughout the ETL); included the complete title and source for the Air Force Standard Design Details (paragraph 6 Note); clarified the requirements for electrical systems (paragraph A1.1.2.3.4); clarified the requirements for fire hydrants in or near airfield pavements (paragraph A1.1.2.4.2); included the use of stabilized landscaped surfaces (paragraph A1.2.1); clarified the meaning of unfueled aircraft (paragraph A1.3.1.1.1); revised the compensation factor for foam leakage loss (paragraph A1.3.3.3); added a note cautioning the designer to consider all transit voltage sources (paragraph A1.3.5.1.2.1 Note); added a requirement for locking manual stations (paragraph A1.3.5.5.1); added specific wording to place manual stations on a sign (paragraph A1.3.5.5.2); revised the graphic of the sign (Figure A5); clarified water source requirements (paragraphs A1.4.1 and A1.4.1.2); and added Figure A2.5 to Attachment 2.

3. Application: All types of aircraft facilities, including, but not limited to, maintenance, servicing, and storage hangars; corrosion control hangars; fuel cell repair hangars; depot overhaul facilities; research and development (R&D)/testing facilities housing aircraft; and all types of aircraft shelters (weather, alert). Compliance with this ETL should be considered for projects in active design beyond project definition (PD). Applying these criteria will result in reduced original construction and life-cycle maintenance costs, and increased overall reliability of the fire protection system. Compliance with this ETL is mandatory for:

- Projects that have not completed the PD phase.
- Projects beyond the PD phase, but not in active design status.

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Appendix C – Fuel Cell Maintenance Hangar Design Drawings

This is not releasable in accordance with FOIA exemption (b)(4). FOIA exemption (b)(4) refers to those trade secrets or commercial or financial information that a DoD Component receives from a person or organization outside the Government with the understanding that the information or record will be retained on a privileged or confidential basis in accordance with the customary handling of such records.

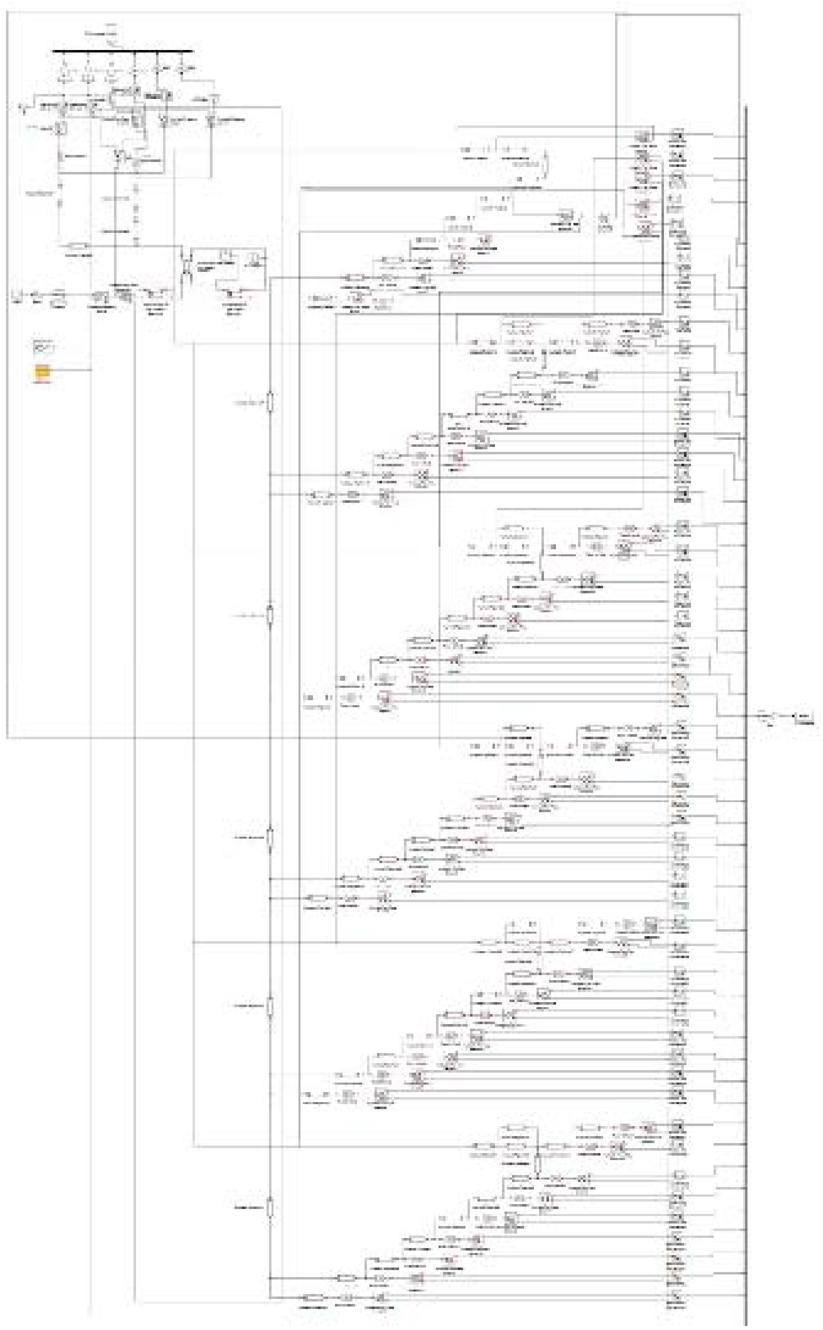
Appendix D – Fire Alarm Shop Drawings, Submittals, and Calculations

This is not releasable in accordance with FOIA exemption (b)(4). FOIA exemption (b)(4) refers to those trade secrets or commercial or financial information that a DoD Component receives from a person or organization outside the Government with the understanding that the information or record will be retained on a privileged or confidential basis in accordance with the customary handling of such records.

Appendix E – Automatic Fire Suppression System Drawings and Submittals

This is not releasable in accordance with FOIA exemption (b)(4). FOIA exemption (b)(4) refers to those trade secrets or commercial or financial information that a DoD Component receives from a person or organization outside the Government with the understanding that the information or record will be retained on a privileged or confidential basis in accordance with the customary handling of such records.

Appendix F – Automatic Fire Suppression System Simulink Model



Appendix G – High Expansion Foam System Calculations

High Expansion Foam Calculation

The total generator capacity was calculated in accordance with ETL 02-15.

$$R = \left[\left(\frac{V}{T}\right) + R_s\right] C_n C_L$$

where:

R = Rate of discharge in m^3/min (ft^3/min)

V = Submergence volume in m^3 (ft^3) determined by the following formula: V = A x D

A = Area of the aircraft servicing floor and adjacent floor areas not cut off from the aircraft servicing floor m^2 (ft^2)

D = Depth = 1 meter (3.28 ft)

T = Submergence time in minutes

RS = Rate of foam breakdown by sprinklers in ft^3/min (m^3/min) determined by the following formula:

RS = S x Q where:

S = Foam breakdown from sprinkler discharge = 0.0748 cubic meters per minute • L/min (10 cubic feet per minute • gpm)

Q = Estimated total discharge from maximum number of sprinklers expected to operate in L/min (gpm).

C_N = Compensation for normal foam shrinkage = 1.15. This is an empirical factor based on average reduction in foam quantity from solution drainage, fire, wetting of surfaces, and absorbency of stock.

C_L = Compensation for loss of foam due to leakage around doors and windows and through unclosable openings determined by the design engineer after proper evaluation of the structure. This factor for Air Force hangars cannot be less than 2.0 for hangars less than 1394 square meters (15,000 square feet), 2.5 for hangars less than 2787 square meters (30,000 square feet), and 3.0 for all other hangars.

$$R = \left[\left(\frac{A * D}{T}\right) + S * Q\right] C_n C_L$$

Hangar Bay 1

$$R = \left[\left(\frac{10755 SF * 3.28\ FT}{4\ min}\right) + 10 CF/gpm * 0.2\ gpm/sf * 5000\ SF\right] 1.15 * 2$$

$$R = 43558\ CFM$$

Hangar Bay 2

$$R = \left[\left(\frac{5649SF * 3.28\ FT}{4\ min}\right) + 10CF/gpm * 0.2\ gpm/sf * 5000\ SF\right] 1.15 * 2$$

$$R = 33554\ CFM$$

This varies from what is prescribed in NFPA 11. The maximum submergence time is given in Table 6.12.7.1. It depends on the protection of structural steel, sprinkler coverage, and hazard flash point. For a fully sprinkled type IIB facility, requiring protection from JP-8 (flashpoint of 46 ºC) the time is 4 minutes; which is consistent with ETL 02-15. NFPA 11 6.12.5.2.1.1 defines the minimum total depth to be no less than 2ft over height of the highest hazard. The Air Force assumes the hazard is on the floor so the NFPA 11 fill depth is 2 ft, and overwrites that with 3.28 ft in all cases. The foam leakage compensation factor CL ranges from 1 to 1.2 depending on the designers evaluation of the structure; however, Air Force has prescribed it to be a function of hangar area. The foam discharge rate according to NFPA 11 are calculated:

Hangar Bay 1

$$R = \left[\left(\frac{10755SF * 2\ FT}{4\ min}\right) + 10CF/gpm * 0.2\ gpm/sf * 5000\ SF\right] 1.15 * 1.2$$

$$R = 21221\ CFM$$

Hangar Bay 2

$$R = \left[\left(\frac{5649SF * 2FT}{4\ min}\right) + 10CF/gpm * 0.2\ gpm/sf * 5000\ SF\right] 1.15 * 1.2$$

$$R = 17697\ CFM$$

As we can see from the calculations, foam discharge rates required by the AFETL 02-15 are nearly twice those required by NFPA 11.

Appendix H – Fire Dynamics Simulator Code

```
&HEAD CHID='J'/
&TIME T_END=50.00/

&MESH ID='1', IJK=400,280,80, XB=0.0, 40.0, 17.00, 45.00, 0.00, 8.00    /

&SURF ID='BURNER', HRRPUA=2799.18, COLOR='RED' /

&REAC FUEL       = 'DODECANE'
    FYI         = 'C_12 H_26'
    SOOT_YIELD = 0.08
    CO_YIELD   = 0.01
    C          = 12.0
    H          = 26.0
    HEAT_OF_COMBUSTION = 44900 /



&SURF ID            = 'FLOOR'
    DEFAULT        = .TRUE.
    RGB            = 200,200,200
    MATL_ID        = 'CONCRETE'
    THICKNESS      = 0.2 /

&MATL ID            = 'CONCRETE'
    CONDUCTIVITY  = 0.48
    SPECIFIC_HEAT = 0.75
    DENSITY       = 2000. /

&SURF ID            = 'WALL'
    DEFAULT        = .TRUE.
    RGB            = 200,200,200
```

MATL_ID = 'GYPSUM PLASTER'
THICKNESS = 0.012 /

&MATL ID = 'GYPSUM PLASTER'
CONDUCTIVITY = 0.48
SPECIFIC_HEAT = 0.84
DENSITY = 1440. /

&SURF ID = 'PLANE'
DEFAULT = .TRUE.
RGB = 200,200,200
MATL_ID = 'FIBERGLASS'
THICKNESS = 0.007112 /

&MATL ID = 'FIBERGLASS'
CONDUCTIVITY = 0.700
SPECIFIC_HEAT = 1.256
DENSITY = 1536.33/ W/(m K), kJ/(kg K), kg/m3)

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/hazards

/jp8 spread rate is 4-4 cm/s around 20c, and 150 cm/s if fuel temp is above flash point i guess we need to model both ways

&VENT XB=0.00, 40.00, 17.00, 45.00, 0.0, 0.0, SURF_ID='BURNER', XYZ=9.64,31.08,0.0, RADIUS=100.00, SPREAD_RATE=1.5/

/spot detectors

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Appendix I – High Expansion Foam Material Safety Data Sheet

MATERIAL SAFETY DATA SHEET

CHEMGUARD C2 or VEE FOAM Revision Date: 5/28/2009

1. PRODUCT IDENTIFICATION
Chemical Family: Surfactant mixture; fire fighting foam concentrate

Product name: Chemguard C2

Manufacturer: Chemguard, Inc.
204 South 6th Ave.
Mansfield, TX 76063
emergency phone: 817-473-9964

2. COMPOSITION / INFORMATION ON INGREDIENTS

		ACGIH/PPM		OSHA/PPM	
CAS NO.	Common Name	TWA	STEL	PEL	% by wt
7732-18-5	water				25 - 35%
112-34-5	diethylene glycol monobutyl ether				3% - 6%
107-21-1	ethylene glycol		C 100mg/m^3		12-17%

proprietary mixture of alkyl sulfates, ethoxylates and solvents

3. HAZARDS IDENTIFICATION
Routes of entry: Dermal, inhalation and ingestion
Potential Health Effects: May cause skin and eye irritation.

Carcinogenicity: Not a carcinogen.

4. FIRST AID MEASURES
Ingestion: Do not induce vomiting. Call a physician.
Inhalation: Remove to fresh air.
Skin: Rinse with water. Wash with soap and water. Contaminated clothing should be washed before re-use.
Eyes: Rinse with water. Call a physician.

Appendix J – AFFF Material Safety Data Sheet

Chemguard C301MS

MATERIAL SAFETY DATA SHEET

Date Prepared: 1/7/2011
Supersedes Date: 9/17/2009

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

Product Name: **Chemguard C301MS**

Chemical Family: Surfactant mixture, fire fighting foam concentrate.

Company Identification: Chemguard, Inc.
204 South 6th Avenue
Mansfield, Texas 76063 USA
(817) 473-9964 (For Product Information)
(817) 473-9964 (For Emergency Information)
www.chemguard.com

For a transport accident or leak, fire or major spill, call CHEMTREC, (800) 424-9300.
For International CHEMTREC assistance, call (703) 527-3887 (collect calls accepted).

2. COMPOSITION / INFORMATION ON INGREDIENTS

CONTAINING: HAZARDOUS AND/OR REGULATED COMPONENTS

Chemical Name	Percentage	CAS Number	OSHA Hazard
Diethylene glycol mono butyl ether	0 - 8%	112-34-5	YES
Magnesium sulfate	0.5 – 1.5 %	7487-88-9	YES
Ethylenediamine tetra acetic acid	0.5 -1.5%	64-02-8	YES
Hydrocarbon Surfactant	Proprietary %	Proprietary	YES
Fluorosurfactant	Proprietary %	Proprietary	YES

3. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW
WARNING! MAY CAUSE EYE AND/OR SKIN IRRITATION

Routes of Exposure:

Eye Contact: Exposure during the handling or mixing may cause immediate or delayed irritation or inflammation.

Skin Contact: Exposure during the handling or mixing may cause immediate or delayed irritation or inflammation.

Ingestion: Ingestion of large quantities may cause abdominal cramps, nausea, vomiting, diarrhea.

Inhalation: Exposure to this product in excess of the applicable TVL or PEL may cause or aggravate other lung conditions. Exposure to this product may cause irritation to the nose, throat, and upper respiratory system.

Chronic: None known

Medical Conditions which May be Aggravated by Inhalation or Dermal Exposure: Persons with unusual (hyper) sensitivity to chemicals may experience adverse reactions to this product.

Page 1 of 6

Appendix K Navy vs. Air Force Fire Protection System Cost Difference

The AFCEC/COSC Cost Engineering SME examined the cost differences between the Navy's fire protection system and the Air Force's fire protection system at Eglin's F-35 AMU Hangar facilities. These facilities were ideally suited for comparison since they are identical sister facilities built under the same MILCON contract. Due to time constraints, only the differences between the systems were examined – the full costs of each of the systems were not analyzed since the primary equipment, materials & configuration of the two systems were similar.

ASSUMPTIONS:

- **Material quantity and sizes of pumps, piping, valves, sprinkers, & water storage tanks are identical**
- **While configuration of the piping is different, the labor and material cost to mount it (trench vs. roof mount) is about the same**

DIFFERENCES:

- **In-floor trench and metal grate for Navy system**
- **AFFF dispensed through floor nozzles for Navy; through roof-mounted foam generators for AF**
- **Primary activation system: Infrared sensors for Navy; manual switch for Air Force**
- **Oil water separator and 30,000 gallon holding tank for Navy system**

SYSTEM COSTS:

Description	Navy		Air Force
	Capital	Annual O&M	Capital
Foam Generators (6, installed)			$146,580
Concrete, for Trench-in-Slab	$21,700		
Additional Reinforcing Steel	$12,000		
Additional Labor for Trench	$21,320		
Trench Grating (480 ft)	$150,000		
AFFF Floor Nozzles (18, installed)	$93,315		
Infrared Sensors (12)	$24,000		
IR System Controller	$10,000		
Oil water Separator (200 GPM, installed)	$14,676	$10,000	
30,000 gal UG Holding Tank	**$44,624**		
Sub-Total:	$391,635	$10,000	$146,580