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# Analysis of High Bay Hangar Facilities for Detector Sensitivity and Placement

## Background

Existing building and fire codes in the United States offer little or no guidance in the design of fire protection systems in high bay spaces due to the lack of scientific data. Timely detection of a fire is more difficult in large spaces due to the distance heat and other products of combustion must travel to sprinklers or detectors. Possible stratification poses an additional challenge in selecting the optimal location of detectors.

The U.S. Navy and all the military departments within the U.S. Department of Defense have the responsibility for protecting high value military aircraft in high bay hangars. The lack of scientific data and inadequate building and fire codes prompted the Naval Facilities Engineering Command (NAVFAC) to conduct the research needed to design more effective fire protection systems for high bay aircraft hangars. NAVFAC enlisted the services of the Building and Fire Research Laboratory at the National Institute of Standards and Technology (NIST) to conduct a series of full-scale fire experiments in Navy hangars. NIST has been conducting research into the prediction of smoke detector response in high bay spaces since 1991. That research has been comprised of both three-dimensional modeling and experimental studies [1, 2].

The focus of this paper is on the full-scale experiments conducted by NAVFAC and NIST which were designed to assist the Navy in reevaluating its criteria for the protection of high bay aircraft hangars. Previous studies conducted in 15 m and 30.5 m hangars used isopropyl alcohol, involved only one fire size, and were conducted with the hangar doors only in the closed position. The NAVFAC/NIST experiments included numerous fire sizes, aviation fuels, and both open and closed doors. Also participating in these experiments were five fire protection industry sponsors representing the fire alarm and automatic sprinkler industries, representatives from each branch of the U.S. Department of Defense, and representatives from select NFPA technical committees.



Society of Fire Protection Engineers. Honors Lecture Series, May 20, 1996. Proceedings. Engineering Seminars: Fire Protection Design for High Challenge or Special Hazard Applications, May 21-22, 1996. Proceedings. Boston, MA, 1996.

## Scope

This study consisted of 33 full-scale fire experiments in two Navy high bay aircraft hangars, one in a cold climate and one in a warm climate. The purpose of the study was to analyze the movement of smoke and heat as well as the response of detection and suppression devices in high bay hangars under a variety of conditions. The reason for conducting the experiments in two distinctly different climates was to understand how smoke movement and detector sensitivity are impacted by ambient temperature. The set of experiments in the warm climate was conducted in a 15 m high aircraft hangar at the U.S. Naval Air Station in Barbers Point, Hawaii. The set of experiments in the cold climate was conducted in a 22 m high aircraft hangar at the U.S. Naval Air Station in Keflavik, Iceland. The 15 m hangar had a nominally flat roof, while the 22 m hangar had a curved roof.

Previous detection and suppression techniques for military hangars were based on JP-4 fuel which has a flash point of approximately -12 °C. Military aircraft are now fueled primarily with JP-5 and JP-8 whose flash points are approximately 63 °C and 46 °C respectively. The experiments measured the response of numerous detectors and sprinklers to a variety of fire sizes using both JP-5 and JP-8 fuels.

The 15 m tall hangar did not have draft curtains. This allowed for the fabrication and installation of a temporary draft curtain. Key experiments conducted in this facility were repeated with and without the draft curtain. This permitted data to be collected on the effects of draft curtains with respect to smoke and heat build-up in the draft-curtained area, smoke movement in the building, and response characteristics of the various fire protection devices.

Each of the two test hangars was first modeled using the Harwell FLOW3D computational fluid dynamics model to help design the instrumentation plan. The fire sizes were designed based on ceiling height and calculated detector and sprinkler response. In each hangar, one range of fire sizes was selected to determine the threshold response levels of the flame and smoke detectors (i.e., detector fires). A second range of fire sizes was selected to determine the threshold response levels of the heat detectors and automatic sprinklers (i.e., sprinkler fires). In the 15 m hangar, the detector fire sizes ranged from 0.3 m x 0.3 m pans to 0.9 m x 0.9 m pans, and the sprinkler fire sizes ranged from 1.5 m diameter pans to 2.5 m diameter pans. In the 22 m hangar, the detector fire sizes ranged from 0.3 m x 0.3 m pans to 1.2 m x 1.2 m pans, and the sprinkler fire sizes ranged from 2.0 m diameter pans to 4.6 m x 4.6 m pans.

Table 1 summarizes the experiments conducted in both the 15 m and 22 m hangars.

Table 1. Summary of Full-Scale Experiments.

| Test Facility | Pan Size | Fuel | Conditions* | Test Duration |
|---|---|---|---|---|
| 15 m | 0.3 m x 0.3 m | JP-5 | | 977 s |
| 15 m | 0.3 m x 0.3 m | JP-5 | No Draft Curtain | 681 s |
| 15 m | 0.6 m x 0.6 m | JP-5 | | 727 s |
| 15 m | 0.6 m x 0.6 m | JP-5 | No Draft Curtain | 735 s |
| 15 m | 0.9 m x 0.9 m | JP-5 | | 673 s |
| 15 m | 1.5 m diameter | JP-5 | | 578 s |
| 15 m | 2.0 m diameter | JP-5 | | 537 s |
| 15 m | 2.0 m diameter | JP-5 | No Draft Curtain | 744 s |
| 15 m | 2.0 m diameter | JP-5 | No D.C./Open Doors | 155 s |
| 15 m | 2.5 m diameter | JP-5 | | 563 s |
| 15 m | 2.5 m diameter | JP-5 | No Draft Curtain | 517 s |
| 22 m | 0.3 m x 0.3 m | JP-5 | 2 Experiments | 674 s/693 s |
| 22 m | 0.3 m x 0.3 m | JP-8 | | 610 s |
| 22 m | 0.6 m x 0.6 m | JP-5 | 2 Experiments | 620 s/638 s |
| 22 m | 0.6 m x 0.6 m | JP-8 | 2 Experiments | 613 s/618 s |
| 22 m | 0.9 m x 0.9 m | JP-5 | 2 Experiments | 619 s/621 s |
| 22 m | 0.9 m x 0.9 m | JP-8 | | 621 s |
| 22 m | 1.2 m x 1.2 m | JP-5 | 2 Experiments | 609 s/623 s |
| 22 m | 1.2 m x 1.2 m | JP-8 | | 629 s |
| 22 m | 2.0 m diameter | JP-5 | | 679 s |
| 22 m | 2.5 m diameter | JP-5 | | 641 s |
| 22 m | 2.5 m diameter | JP-5 | Open Doors | 383 s |
| 22 m | 2.5 m diameter | JP-5 | Open Doors | 380 s |
| 22 m | 3.0 m x 3.0 m | JP-5 | 2 Experiments | 659 s/665 s |
| 22 m | 3.0 m x 3.0 m | JP-8 | | 668 s |
| 22 m | 4.6 m x 4.6 m | JP-5 | | 294 s |
| 22 m | 4.6 m x 4.6 m | JP-5 | | 424 s |

*Each test was conducted with hangar doors closed and a draft curtain unless stated otherwise.

**Measurements**

Over 200 sampling points were continuously monitored during each of the 33 full-scale experiments. Measurements taken included plume and ceiling jet temperatures, smoke filling, radiation, ceiling jet velocity, mass loss, and wind speed and direction. Measurements were taken using type K, chromel-alumel thermocouples; circular foil, water-cooled, Gardon-type heat flux radiometers; hot wire, temperature-compensated mass flow meters; load cells and anemometers.

In addition, numerous fire detectors and sprinklers were installed and monitored. The type of fire detectors included combination infrared and ultraviolet optical flame detectors, analog addressable smoke detectors, fixed temperature heat detectors, line-type heat detectors, analog addressable heat detectors and projected beam smoke detectors. The automatic sprinklers utilized were wired to determine activation time. The type and temperature of the sprinkler heads varied from 79 °C quick response heads to a 182 °C standard response head. Individual sprinkler heads were piped to simulate both wet-pipe and dry-pipe configurations. Sprinkler heads were not permitted to flow water during the experiments; only their activation times were recorded. In addition, each experiment was fully documented by the use of video cameras at various angles to the fire.

**Parameters Investigated**

The vast amount of data collected during these experiments is presently being analyzed to determine the optimal overall strategy for fire protection for high bay hangars. The following parameters are being investigated:

1. Effectiveness of spot-type and line-type heat detectors for high bay hangars.
2. Spacing of spot-type detectors in high bay hangars.
3. Approximate minimum fire size threshold for each detector type.
4. Effect of fuel type on the response of each type of fire detector.
5. Response distance thresholds of optical detectors to various fire sizes and fuel types.
6. Effects of temperature, stratification and wind on detector performance.
7. Overall performance of heat, smoke and projected beam detectors in high bay hangars.
8. Approximate minimum fire size for sprinkler activation for various sprinkler heads.
9. Effects of draft curtains on sprinkler and detector response.
10. Effects of an open-door fire on detector and sprinkler response.

The effectiveness of spot-type detectors versus line-type detectors or projected beam detectors is an issue due to factors such as transport time of products of combustion, cost and number of detectors installed, and response time of each type of detector. Spacing of spot-type detectors in ceilings above 9.1 m is an issue almost devoid of scientific data prior to these experiments. Determining detector response as a function of fire size is critical if your goals include protection of adjacent aircraft in the hangar. The effects of JP-5 and JP- 8 aviation fuels on the response of each type of detector tested is important in selecting the appropriate fire detection system. The effects of ambient temperature and fire size on possible stratification of the smoke layer were investigated in the 15 m and 22 m hangars. The activation times of different temperature sprinkler heads as a function of fire size and building height are crucial in determining the design parameters associated with ceiling level sprinklers in high bay hangars. The effects of draft curtains have long been debated in the fire protection community with respect to number of sprinklers activated, response time of sprinklers and requirements for sizing water supplies. Finally, the open hangar door scenario was investigated because it poses what may be the most challenging fire in an aircraft hangar due to excessive plume lean and reduced visibility.

**Preliminary Results**

The complete set of documentation and results for this study will be published in a NIST technical report in 1996. Although the data analysis is presently ongoing, the following preliminary results are offered:

1. Heat Release Rates and Maximum Ceiling Temperatures. Mass loss measurements from the load cell were used to calculate the heat release rate by multiplying the steady state rate of mass loss by the heat of combustion for the respective fuel. Estimates of the heat release rates for the various fire sizes are shown in Table 2. Also shown are the maximum sustained ceiling temperatures recorded on the plume center line for each size fire. The heat release rates and maximum ceiling temperatures shown as ranges in the table represent more than one experiment.

Table 2. Heat Release Rates and Maximum Ceiling Temperatures.

| Test Facility | Pan Size | Heat Release Rate Range (MW) | Maximum Ceiling Temp (°C) | Ambient Ceiling Temp (°C) |
|---|---|---|---|---|
| 15 m | 0.3 m x 0.3 m | 0.1[a] | 30-34 | 27-32 |
| 15 m | 0.6 m x 0.6 m | 0.5 | 43-44 | 28-31 |
| 15 m | 0.9 m x 0.9 m | 1.9 | 56 | 27 |
| 15 m | 1.5 m diameter | 2.8 | 71 | 28 |
| 15 m | 2.0 m diameter | 6.8 | 105-112 | 28-29 |
| 15 m | 2.0 m diameter[b] | N/A[c] | 65 | 28 |
| 15 m | 2.5 m diameter | 7.7[a] | 150-157 | 25-30 |
| 22 m | 0.3 m x 0.3 m | 0.1-0.2 | 11-14 | 9-10 |
| 22 m | 0.6 m x 0.6 m | 0.6-0.9 | 18-23 | 9-13 |
| 22 m | 0.9 m x 0.9 m | 1.1-1.6 | 27-34 | 9-17 |
| 22 m | 1.2 m x 1.2 m | 2.6 | 41-49 | 11-17 |
| 22 m | 2.0 m diameter | 4.3 | 71 | 10 |
| 22 m | 2.5 m diameter | 7.9 | 93 | 11 |
| 22 m | 2.5 m diameter[b] | 4.1-8.9 | 59-72 | 9-16 |
| 22 m | 3.0 m x 3.0 m | 13.3-15.1 | 170-176 | 11-16 |
| 22 m | 4.6 m x 4.6 m | 35.5[d] | 272 | 12 |
| 22 m | 4.6 m x 4.6 m | N/A[c] | 60 | 17 |

[a] Heat release rate estimated by comparing input fuel to residual fuel.

[b] Open door test.

[c] The heat release rate data was not recorded.

[d] Heat release rate estimated based on burning rate of JP-5 fuel in 3.0 m x 3.0 m pan.

2. Effects of Draft Curtains. The 2.0 m and 2.5 m diameter pan fires were conducted with and without the draft curtain in the 15 m hangar. In the 2.0 m fire with the draft curtain, 17 sprinklers activated, while only 6 sprinklers activated in the 2.0 m fire without the draft curtain. In both of the 2.5 m pan fires (i.e., with and without the draft curtain), 18 sprinklers activated in each experiment. However, sprinkler activation times outside the fire plume (i.e., 6.1 m or more from fire center) were significantly longer in the fires without the draft curtain. Depending on fire size and the temperature rating of the sprinkler heads, the draft curtains significantly affect either the number of sprinklers activated or the activation time of the sprinklers.

3. Optical Flame Detectors. There were ten optical flame detectors spaced at varying distances from the fire. Detectors were located along the same line from the fire source to the remote corner of the hangar (i.e., 70.1 m). The distances shown below represent the maximum threshold distance at which the detectors alarmed:

| Pan Size | Activation Distance Threshold |
|---|---|
| 0.3 m x 0.3 m pan | 15.2 m |
| 0.6 m x 0.6 m pan | 39.6 m |
| 0.9 m x 0.9 m pan | 48.8 m |
| 1.5 m pan | 54.9 m |
| 2.0 m pan | 54.9 m |
| 2.5 m pan | 61.0 m |

4. Sprinkler Response in the 15 m Hangar. The following is a partial list of the sprinkler responses observed:

| Pan Size | Heat Release Rate | Sprinkler Activations |
|---|---|---|
| 1.5 m pan | 2.8 MW | No Activations |
| 2.0 m pan (Draft Curtain) | 6.8 MW | All 79 °C (175 °F) quick response heads 6.1 m or less from fire center |
| 2.0 m pan (No Draft Curtain) | 6.8 MW | All 79 °C (175 °F) quick response heads at fire center, (2 of 8) 79 °C (175 °F) 3.0 m from the fire center |
| 2.0 m pan (No Draft Curtain-Open Doors) | N/A | No Activations |
| 2.5 m pan (Draft Curtain) | 7.7 MW | All 79 °C (175 °F) quick response heads 6.1 m or less from fire center, (3 of the 4) 79 °C (175 °F) quick response heads at 9.1 m and 8.5 m from fire center |

| | | |
|---|---|---|
| 2.5 m pan (No Draft Curtain) | 7.7 MW | All 79 °C (175 °F) quick response heads 6.1 m or less from fire center, (2 of the 4) 79 °C (175 °F) quick response heads at 9.1 m and 8.5 m from fire center |

5. Sprinkler Response in the 22 m Hangar. The following is a partial list of the sprinkler responses observed:

| Pan Size | Heat Release Rate | Sprinkler Activations |
|---|---|---|
| 2.0 m pan | 4.3 MW | No Activations |
| 2.5 m pan | 7.9 MW | All 79 °C (175 °F) quick response heads at 3.0 m or less from fire center |
| 2.5 m pan (Open Doors) | 4.1 MW | No Activations |
| 2.5 m pan (Open Doors) | 8.9 MW | No Activations |
| 3.0 m x 3.0 m | 15.1 MW | All sprinkler heads at 3.0 m or less from fire center (except the 182 °C (360 °F) standard response head). All 79 °C (175 °F) quick response heads |
| 3.0 m x 3.0 m | 14.4 MW | All sprinkler heads 3.0 m or less from fire center (except the 182 °C (360 °F) standard response head). All 79 °C (175 °F) quick response heads, (2 of the 12) 141 °C (286 °F) heads 6.1 m from fire center |
| 3.0 m x 3.0 m (JP-8 Fuel) | 13.3 MW | All sprinkler heads 3.0 m or less from fire center (except the 182 °C (360 °F) standard response head). All 79 °C (175 °F) quick response heads, (4 of the 12) 141 °C (286 °F) heads 6.1 m from fire center |
| 4.6 m x 4.6 m | 35.5 MW | All sprinkler heads in test area |

**Ongoing Work**

The results of the projected beam smoke detectors, spot-type heat detectors, line-type heat detectors and many of the other parameters investigated are not included in this brief paper. Full documentation of the test procedures, data analysis and conclusions will be available with the publication of the NIST technical report. A professional video is also being produced.

The results of this project will be used in reevaluating fire protection design criteria for all military aircraft hangars. It is anticipated that this data will also be used in evaluating fire protection criteria for commercial aircraft hangars as well.

**References**

1. Notarianni, K. and Davis, W., The Use of Computer Models to Predict Temperature and Smoke Movement in High Bay Spaces. NISTIR 5304, National Institute of Standards and Technology, Gaithersburg, MD 1993.

2. Walton, W. and Notarianni, K., A Comparison of Ceiling Jet Temperatures Measured in an Aircraft Hangar Test Fire with Temperatures Predicted by the DETACT-QS and LAVENT Computer Models. NISTIR 4947, National Institute of Standards and Technology, Gaithersburg, MD 1993.