Evaluation of Fine Water Mist for Aircraft Dry Bay Fire Suppression

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Introduction

The objective of this test program is to assess the fire-extinguishing capability of Fine Water Mist (FWM) for realistic dry bay fires. Three FWM systems were evaluated, two hydraulic-atomizing and one air-atomizing configuration. Tests were conducted in the Walter Kidde Aerospace Dry Bay Fire Simulator located in Wilson, North Carolina.

Background

The Navy is investigating the use of FWM for the protection of aircraft engine nacelles and dry bays. FWM has no ozone depletion nor global warming potential and no toxicity concerns. Water has a high heat capacity and a high latent heat of vaporization which are favorable characteristics for fire suppression. Water distributed as a fine mist is even more effective because it exposes a very large surface area of water to the heat source or flame and the heat transfer rate is inversely proportional to the size of a water droplet. The mechanisms of extinguishment with FWM are physical as opposed to the primarily chemical mechanisms used by traditional agents such as Halon 1301. The physical mechanisms of extinguishment are air/gas cooling, rapid expansion of steam causing oxygen depletion, and the cooling of surrounding hot surfaces.

Recent testing has shown FWM to be very effective in suppressing Class B pool fires, however, the effectiveness against rapid-growth fires, such as those encountered in an aircraft dry bay has yet to be proven. A dry bay is a compartment or an internal volume, inaccessible during flight, adjacent to a fuel tank or containing fuel lines subject to fluid leakage from combat damage or equipment failure. Dry bays are heavily cluttered and pose a significant challenge for FWM extinguishing systems. FWM droplets have been shown to adhere to surfaces. Therefore, the distribution system is significantly more important for a FWM system than for a traditional Halon system. In addition, aircraft design specifications require that the system be operational at -65°F. The performance of FWM has not been evaluated at this low temperature condition.

Dry Bay Fire Threat

The primary threat mechanism for fire and explosion in a dry bay is combat damage from ballistic impact. High-Explosive Incendiary (HEI) rounds are designed to cause combustion after impact. A HEI round impacts and penetrates the outer skin of an aircraft causing a damage area for the outer surface. Approximately 0.4 milliseconds after impact the HEI detonates creating a blast pressure and causing the outer casing of the projectile to break into fragments. These fragments can penetrate fuel tank surfaces and create two possible fire threats. Fuel can spray back into the dry bay from multiple exit holes and ignite from hot surfaces or incendiary particles creating a fuel spray fire. Also, the incendiary fragments can cause ignition of fuel tank/line ullage creating a fuel/air explosion. Fuel spray fires are used as the threat for this program.

A number of variables determine the severity of the dry bay fire. The size and orientation of the damage area and the amount of both external and internal airflow affects the supply of oxygen available to support combustion. Also the fuel type, flow rate, pressure and droplet size all affect the size and intensity of the flame.

Test Parameters

Dry Bay Simulator Volume* -** The rectangular vessel has a total volume of 12 ft^3 with 40% clutter. The clutter package consists of ***6 in. x ***6*** in. x 12 in. metal boxes, **3** in. diameter pipe and 0.5 in. diameter pipe.

External Airflow* - *300 knot airflow is supplied over the 1 ft^2 damage area for ***5*** seconds.

***Internal Airfow* - 4** lb/s is supplied internally to simulate bleed air duct rupture. The bleed air outlet is located directly opposite the damage area.

Air Temperatures* -** Two test conditions are used: ambient (approximately ***55 - 65 ^oF) and cold (approximately -40 ^oF). Surface temperatures of -20 ^oF were achieved during the cold temperature tests. To achieve the cold air condition the vessel was sealed and air was circulated through a dry ice/alcohol chiller.

***Fuel /Nozzle* -** Jet-A fuel was supplied to the simulator through a Spraying Systems 7N-26 multi-orifice spray nozzle. The fuel was heated to approximately 100 ^oF and pressurized to 10 psig.

***Simulator Ignition Energy* - A** 5 or 10 KJ Sobbe chemical igniter was used to initiate the dry bay fire. The igniter was located directly in front of the fuel nozzle.

Figure 1 shows a schematic of the simulator.

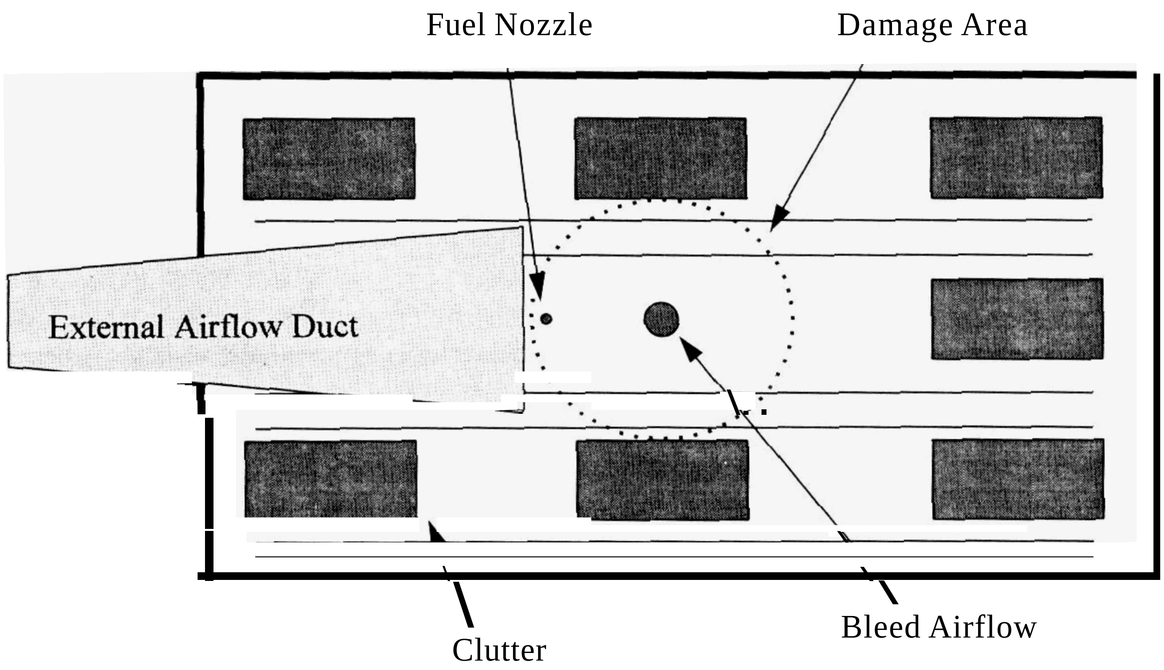

Figure 1. Dry Bay Simulator

FWM Extinguishing Systems

Hydraulic-Atomizing Nozzles - Water is contained in a 2500 in^3 pressure vessel which is pressurized to 1000 psig. Upon activation water flows into a 1.5 in. diameter, 18 in. long cylindrical manifold. The manifold is furnished with eight 3/8 in. pipe connection ports. **A** six foot long flexible hose connects the nozzles to the manifold. The measured pressure at the nozzles was between 875-900 psig. Two types of hydraulic nozzles were used: Spraying Systems LN14 and LN26. Flow information is provided in Table I.

Table I
Hydraulic Nozzle Flow Rate Data

Nozzle	Flow Rate (gps) @ 900 psi	System Flow Rate (gps)
LN14	.019	.152
LN26	.034	.272

***Air-Atomizing Nozzles* -** The water supply system is the same as that for the hydraulic nozzles. The nozzle air supply consisted of **an** 8 ft^3 supply tank pressurized to 30 psig. Upon activation air flows into a **0.5** in. diameter, 1 ft. long cylindrical manifold fitted with eight 0.5 in. connection ports. The nozzles were connected by 8 ft. flexible hose to the distribution manifold.

The air-atomizing nozzles operating at 25 psig air, 25 psig water have a flow of .007 gallons per second. The system flow rate with six nozzles is .042 gallons per second.

The simulator has 16 port locations for the FWM nozzles (Figure 2). The hydraulic systems each consist of **8** nozzles and the air-atomizing system has 6 CD nozzles.

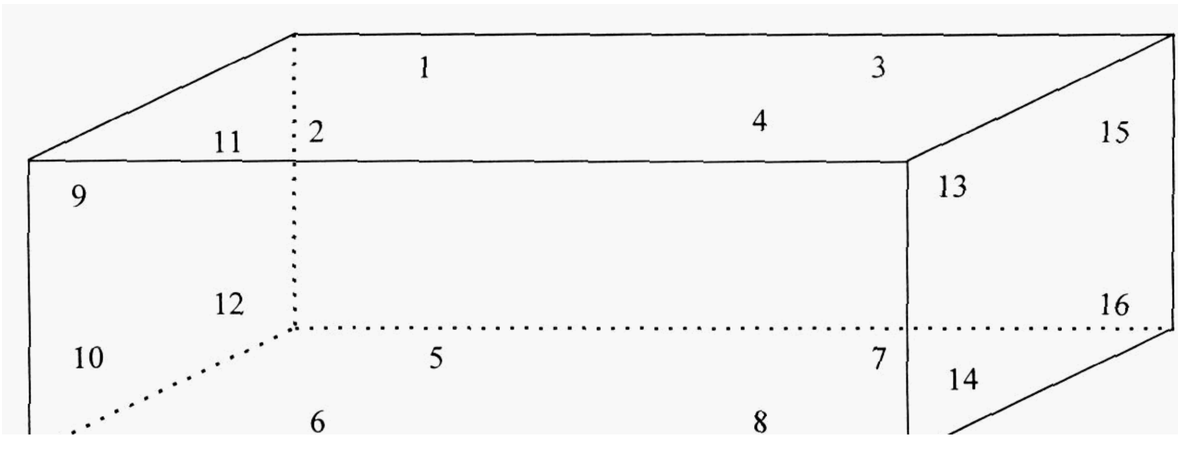

Figure 2. FWM Nozzle Locations

The nozzles were distributed in four patterns throughout the test volume.

Configuration I : 1,4,6,7,10,11,13,16

Configuration II : 1,4,6,7,9,12,14,15

Configuration III : 9,10,11,12,13,14,15,16

Configuration IV : 1,6,9,10,11,12

Instrumentation - Data Acquisition

a.) 0-15 psig pressure transducer - external airflow.

b.) 0-200 psig pressure transducer - bleed airflow.

c.) 0-50 psig pressure transducer - simulator vessel pressure.

d.) 0-1500 psig pressure transducer - water pressure.

e.) 0-50 psig pressure transducer - air line pressure.

f.) Fuel flow and ignition event markers.

g.) Fast response (.005 in. diameter) type "K" thermocouples - simulator temperatures

h.) **NAC** hi-speed video operating at 500 frames per second.

Test Fire Conditions

Four different fire challenges are used for the test program

Class i: Ambient temperature (55-65 ^{o}F), long pre-bum time (350 ms).

Class ii: Ambient temperature (55-65 ^{o}F), short pre-bum time (50 ms).

Class iii: Cold Temperature (-40 ^{o}F), long pre-bum time (350 ms).

Class iv: Cold Temperature (-40 ^{o}F), short pre-bum time (50 ms).

Pre-bum times are modeled for two different proposed system configurations. The short (SO ms) pre-bum time is modeled on the expected response and discharge time of a system utilizing a separate water reservoir for each FWM nozzle. The long pre-bum time (350 ms) is modeled on a system utilizing a central reservoir to supply all FWM nozzles.

Test Results

Water Mist Discharge Tests -

A low temperature discharge test was performed with air-atomizing nozzles to study the distribution of the mist at -40°F. The mist appeared to freeze and form small hail particles. Visual inspection of the simulator confirmed that ice was formed around the nozzles and small ice particles were found on the bottom surface.

*Fire **Tests*** - Table II presents the summary of all tests performed.

*Class **i** Fires* -

All three nozzle configurations were able to successfully extinguish the Class i fire challenge. The average extinguishment time varied for the different configurations. The average extinguishment time for the LN26 nozzle is 35 ms, 43 ms for the LN14 nozzles and 167 ms for the CD air-atomizing nozzles. Nozzle location is shown to be important variable. In tests #5 and #7 Configuration I is used, the results are no extinguishment and the longest extinguishment time recorded. In tests #8 and #9, Configuration II is used and complete extinguishment is achieved.

Class ii Fires -

The LN26 nozzle configuration was able to successfully extinguish the Class ii fire challenge. The average extinguishment time is 300 ms, approximately 10 times longer than for the Class i fire challenge. The LN14 and CD air-atomizing nozzles were unable to successfully extinguish this fire scenario.

The results suggest that the Class ii fire challenge was more severe than the Class i fire challenge. The length of pre-burn time is the only difference between the two scenarios. The short pre-bum time is more difficult to extinguish because less oxygen depletion occurs during pre-burn combustion. The shorter pre-bum time also results in lower vessel temperatures during FWM discharge. Higher surface temperatures may enhance mist performance by increasing steam formation, resulting in more oxygen dilution.

The flame characteristics at 50 ms resemble a rapid-growing flame ball rather than the established spray fire seen at 350 ms. The mass flow of the LN14 and CD air-atomizing nozzles is too low to suppress the initial, intense fire ball. The flame is pushed behind the clutter in the simulator where there is low mist concentration. When the FWM system is turned off, the fire re-emerges throughout the chamber.

Table II
Fire Test Results

Run #	Nozzle Type	Fire Class	Result
1	LN 26 (locations I)	ii	Aborted run
2	LN 26 (locations I)	ii	Complete extinguishment, 40 ms
3	LN 26 (locations I)	ii	Complete extinguishment, 40 ms
4	LN 26 (locations I)	ii	Aborted run
5	LN 26 (locations I)	ii	Complete extinguishment, 1000 ms
6	LN 26 (locations I)	ii	Aborted run
7	LN 26 (locations I)	ii	No extinguishment
8	LN 26 (locations II)	ii	Complete extinguishment, 500 ms
9	LN 26 (locations II)	ii	Complete extinguishment, 100 ms
10	LN 26 (locations II)	ii	Aborted run
11	LN 26 (locations II)	i	Complete extinguishment, 40 ms
12	LN 26 (locations II)	i	Complete extinguishment, 30 ms
13	LN 14 (locations II)	i	Complete extinguishment, 48 ms
14	LN 14 (locations II)	i	Complete extinguishment, 38 ms
15	LN 14 (locations II)	iii	No extinguishment
16	LN 14 (locations II)	ii	No extinguishment
17	LN 14 (locations II)	ii	No extinguishment
18	LN 14 (locations II)	ii	Aborted run
19	LN 26 (locations II)	iii	Complete extinguishment, 64 ms
20	LN 26 (locations II)	iii	No extinguishment, lower pressure (750 psi)
21	LN 26 (locations II)	iii	Complete extinguishment, 40 ms
22	LN 26 (locations II)	iv	No extinguishment
23	CD (locations II)	i	Complete extinguishment, 144 ms
24	CD (locations II)	ii	No extinguishment
25	CD (locations II)	ii	No extinguishment
26	CD (locations II)	i	Complete extinguishment, 190 ms
27	LN 26 (locations II)	iv	Complete extinguishment, mist on before ignition
28	LN 26(locations III)	iv	No extinguishment
29	CD (locations IV)	iv	No extinguishment
30	CD (locations IV)	iv	No extinguishment

Class iii Fires -

The LN26 nozzles successfully extinguished the fires in 52 ms. The time was longer than for the ambient Class i fires, but significantly less than the Class ii fires. In test #20 the pressure at the nozzles was approximately 750 psi as opposed to 900 psi in previous tests. The lower pressure and subsequent lower flow resulted in failed extinguishment.

The LN14 and CD air-atomizing nozzles failed to extinguish the fire. The low temperature Class iii tests are more sever than the Class i ambient tests. The FWM does not disperse throughout the bay as well in the form of ice particles. In addition, a more intense fire results in a low temperature environment. The number of moles of oxygen available to support combustion is increased at low temperature.

Class iv Fires -

All three nozzle configurations failed to extinguish the Class iv fire challenge. This is the most severe fire challenge for the same reasons discussed above:

a) short pre-bum time resulting in less oxygen dilution
b) intense rapid-growth fire ball
c) high oxygen concentration
d) poor FWM distribution
e) lower surface temperatures resulting in less steam generation

Conclusions

FWM systems can be designed successfully for applications in aircraft dry bays. A design specification will be difficult to produce for FWM because of the strong dependence on nozzle location. Optimum configurations must be determined for individual applications based on geometry and clutter arrangements.

FWM is not a true “total flooding” extinguishing agent. FWM system performance is strongly dependent on nozzle locations. Since FWM adheres to surfaces, in a highly cluttered area such as a dry bay, nozzle location is a critical design factor.

FWM performance is dependent on mass flow. Higher mass flows are more effective in extinguishing the dry bay fire threats. Previous analysis shows the three nozzle configurations tested produce very similar mist characteristics. Droplet sizes and velocities are comparable for each nozzle. The high-flow LN26 nozzles are the most effective in extinguishing the spray fires.

Longer pre-bum times produce a less severe fire threat. **System** initiation delay time should be investigated further to determine the optimum time for FWM to engage the fire.

FWM is capable of operating successfully at low temperatures. Performance is reduced at low temperatures; however, extinguishment can be achieved. The high-flow LN26 nozzles were successful in extinguishing fires at -40 °F.

References

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