
The concept of an inert gas/water mist hybrid fire suppression system was described in the review of "False Deck Development Testing of Hybrid Nitrogen-Water Mist Systems, Interim Report" by the same authors. The proposed technology involves the combined use of fine water spray and inert gas fire suppressants (e.g., nitrogen). The earlier tests demonstrated that the water mist systems tested were not effective when applied to complex false deck/sub-floor areas. The interaction between the mist and the compartment boundaries and obstructions in the sub-floor caused excessive mist losses. Only the smallest drops in the mist were able to reach all areas in the protected space. A water mist system that generates smaller drops than other water mist nozzles may result in better dispersion of the mist and provide effective protection throughout false deck/sub-floor spaces.

NanoMist Systems, LLC, has developed a water mist system that utilizes ultrasonic techniques to generate fine water mist with the volumetric mean drop size (Dv0.50) smaller than 10 microns. This drop size is 5 to 10 times lower than generated in more conventional water mist systems that utilize either high fluid velocity or shearing air flows to generate the water mist. The extremely fine mist has no velocity or momentum however. The NanoMist System employs a carrier air stream to deliver the generated mist to the enclosure. By varying the flow rate of the carrier air stream it is possible to generate mist clouds with initial water mass per unit-volume loadings of 10% to 30% by weight or 150 to 470 g/m³.

The objective of this investigation was to evaluate the NanoMist system in sub-floor/false deck applications to determine if the extremely fine mist can be more effective than coarser mists in fire extinguishment and cooling. The objective was also to determine the system design parameters, water mist application flux and initial water concentration required to achieve acceptable performance.

The NanoMist water mist system shows significant promise in this application. The small drop size and high initial mist concentration enabled the mist to extinguish the test fires located behind a baffle spanning a third of the enclosure width and the entire enclosure height.

The NanoMist system was able to provide protection to the sub-floor with a below-deck fire exposure scenario. The system was able to reduce the temperature in the mock-up to approximately 100°C with the lower deck of the mock-up exposed to a 7.4 kW/m² heat flux, when the system was applied at the higher water application flux of 0.056 l/min/m² and a suspended droplet concentration of 308 g/m³. The amount of nitrogen required to extinguish the telltale fires was approximately 50 percent of the amount that was needed without the water mist. [This number should be compared with the Baumac single fluid MX8 system, the system with the finest spray in a previous test series, which reduced the amount of nitrogen required by 47 percent.]

Electronic modems exposed to the generated water mist did shut down after extended exposure. All of the exposed modems continued operating for at least 7 minutes when exposed to the tested water mists. When exposed to the lowest tested water application flux and lowest air flow, the modem continued to operate beyond the normal 10 minute exposure, not shutting down until after 13 minutes of exposure. The exposed modems regained function after thorough drying.

Further work:

Investigate the aspects of scaling of the NanoMist water mist system to protect full scale false deck/sub-floor spaces. Investigate the amount of obstructions that can be tolerated by the NanoMist system, effectiveness in extinguishing fires involving energized/heated electrical cables, and the effects of exposure to operating electronics in more typical geometries and configurations.

Actual sub-floor/false deck spaces typically range in area from approximately 25 m² to 100 m². This range represents a scale-up from the test facility of 6:1 and 25:1, respectively. The design guidelines for water application fluxes and inlet mist water concentration developed in this test series would need to be checked in the larger area, as well as geometrical factors such as the number of mist inlets and inlet positioning in the protected space.

The amount of obstructions that can be tolerated by the NanoMist system needs to be determined. Also, it is necessary to determine the density of obstructions encountered in actual false deck areas. It is known that sub-floor areas in some electronic equipment spaces on navy ships may be entirely filled with cables, so that there is no void space for circulation of mist. Finally, the majority of fire hazards in sub-floor/false deck areas involve overheated or shorted electrical cables. The NanoMist system should be tested for effectiveness on these hazards.
From: Commanding Officer, Naval Research Laboratory  
To: Chief of Naval Research (ONR Code 334 Gagorik)  

Subj: FALSE DECK TESTING OF NANO MIST WATER MIST SYSTEMS  

Encl: (1) Two copies of subject report  

1. Enclosure (1) is forwarded for your review and information.  

2. This work is part of the ongoing FY04 effort in the Advanced Damage Countermeasures ADC program aimed at developing a hybrid water mist system.  

3. The water mist system tested was a fine atomization (10 micron) single fluid water mist system. The NanoMist Water Mist System shows significant promise in this application. The small drop size and high initial mist water concentration enabled the generated mist to extinguish the test fires located behind a baffle spanning a third of the enclosure width and the entire enclosure height.  

The NanoMist system was able to provide protection to the sub-floor with a below deck fire exposure scenario. The system was able to reduce the temperature in the mock-up to approximately 100°C with the lower deck of the mock-up exposed to a 7.4 kW/m² fire when the system was applied at the higher water application flux test of 0.056 LPM/m² and a mist water concentration of 308 g/m³.  

Operating electronics exposed to the generated water mist did shut down after extended exposure. All of the exposed modems continued operating for at least 7 minutes when exposed to the tested water mists. When exposed to the lowest tested water application flux and lowest air flow, the modem continued to operate beyond the normal 10 minute exposure, not shutting down until after 13 minutes of exposure. The exposed modems did, however, regain function after thorough drying.  

4. The Naval Research Laboratory point of contact for the NanoMist Testing is Dr. Frederick W. Williams, Code 6180, (202) 767-2476; email: fwilliam@ccs.nrl.navy.mil.
Subj: FALSE DECK TESTING OF NANO MIST WATER MIST SYSTEMS

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False Deck Testing of NanoMist Water Mist Systems

ERIC W. FORSELL
JOSEPH L. SCHEFFEY
PHILIP J. DINENNO
GERARD G. BACK

Hughes Associates, Inc.
Baltimore, MD

K.C. ADIGA
ROBERT F. HATCHER, JR

NanoMist Systems, LLC
Warner Robins, GA

JOHN P. FARLEY
FREDERICK W. WILLIAMS

Navy Technology Center for Safety and Survivability
Chemistry Division

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1.0 INTRODUCTION

Reduced - manned Naval vessels require automated fire suppression systems to compensate for the reduced size of damage control parties. Fine water spray or water mist systems are attractive from a total ship protection standpoint. Application of this technology to electronics spaces is problematic in terms of collateral damage to equipment, performance for involved cabinets, and performance in sub-floors. A previously conducted fire hazard analysis identified gaseous agent systems as the system of choice for critical/high value spaces in a peacetime fire scenario [1]. However, in wartime scenarios where the enclosure integrity cannot be assured, or the primary fire threat is in an adjacent space, the effectiveness of gaseous agent systems is severely compromised. A recent analysis of protection options for the DD(X) class destroyer could not identify a system providing adequate protection when all factors of manning, automation, and performance are considered for both peacetime and wartime scenarios [2].

The concept of an inert gas/water mist hybrid fire suppression system was proposed to address this issue [3]. The proposed technology involves the combined use of fine water spray and inert gas fire suppressants (e.g., nitrogen).

Fine water spray or mist systems have not been effective when applied to complex false deck/sub-floor areas. The interaction between the applied mist and the compartment boundaries and obstructions in the sub-floor causes excessive mist losses. The obstructed flow paths available cause only the smallest drops in the mist to be able to reach all areas in the protected space. A water mist system that generates smaller drops may yield better dispersion and more even protection throughout false deck/sub-floor spaces.

NanoMist Systems, LLC, has developed a water mist system that utilizes ultrasonic techniques to generate fine water mist with average drop sizes smaller than 10 microns. This drop size is significantly lower than that generated in more conventional water mist systems that utilize either high fluid pressure or shearing air flows to generate the water mist. The NanoMist System employs a carrier air stream to deliver the generated mist to the enclosure. Varying the carrier air stream flow rate results in initial mist water loadings of 10% to 30% water by weight or 150 to 470 g/m$^3$.

2.0 OBJECTIVE

The objective of this investigation is to evaluate the NanoMist system in sub-floor/false deck applications. This evaluation is to determine if the NanoMist system can be effective in these applications and the system design parameters, water mist application flux and initial water mist concentration required to apply these systems successfully.

3.0 APPROACH

In this investigation, the water mist application flux and initial water mist concentration or water loading will be evaluated relative to their impact on the water mist system performance. This performance will be measured with respect to extinguishment of fires within the sub-floor...
space, with respect to the cooling potential relative to exposure to a below deck fire scenario, and with respect to the damage potential to operating electronics.

Preliminary theoretical investigation into the water mist concentration requirements lead to a requirement of 200 g/m\(^3\) or 15.4% water loading at the fire to cause extinguishment by itself. If nitrogen is added along with the water mist, a linear relationship between added nitrogen concentration and water mist concentration requirements is obtained as illustrated in Fig. 1. In determining these requirements, the water mist is assumed to be 100% efficient in that all the mist reaching the fire is vaporized and raised to the flame temperature along with the added nitrogen, absorbing the energy output of the flame until a flame temperature of 1600 K cannot be maintained and the fire is extinguished. For n-heptane burning in air, the combustion reaction is outlined in equation (1) and the adiabatic flame temperature is given by equation (2) [4]:

\[
C_7H_{16} + 11 O_2 + (79/21)11 N_2 \rightarrow 7 CO_2 + 8 H_2O + (79/21)11 N_2 \quad (1)
\]

\[
T_{AFT} = T_{amb} + \Delta Hc / (7 \ C_{pCO2} + 8 \ C_{pH2O} + (79/21)11 \ C_{pN2}) \quad (2)
\]

Where \(T_{AFT}\) is the adiabatic flame temperature [K], \(T_{amb}\) is the ambient temperature [K], \(\Delta Hc\) is the heat produced in the burning of 1 mole of n-heptane [44,600 J/gmol], \(C_{pCO2}\) is the average heat capacity of carbon dioxide [J/gmol K], \(C_{pH2O}\) is the average heat capacity of water vapor [J/gmol K] and \(C_{pN2}\) is the average heat capacity of nitrogen [J/gmol K]. This equation is then adjusted for the presence of the water mist as given in equation (3):

\[
T_{AFT} = T_{amb} + (\Delta Hc - Y_{mist} \Delta Hv) / (7 \ C_{pCO2} + 8 \ C_{pH2O} + (79/21)11 \ C_{pN2} + [Y_{mist} C_{pH2O} + Y_{N2} C_{pN2}]) \quad (3)
\]

where \(Y_{mist}\) is the molar ratio of water in the mist to n-heptane burned, \(Y_{N2}\) is the molar ratio of the added nitrogen to n-heptane burned, and \(\Delta Hv\) is the heat of vaporization of water [J/gmol].

The second aspect of this investigation is the boundary cooling and radiation absorbance provided by the water mist in protecting from an exposure fire below the sub-floor. The effects of the water mist application can be approximated through an estimate of the mist application rate required to limit the temperature in the sub-floor as shown in Fig. 2. These requirements can be estimated through an energy balance in the sub-floor as outlined in equations (4) and (5):

\[
\text{If } T_{SF} \leq T_{sat} \\
Q_{Fire} = (\psi \Delta Hv + C_{H2O,L}(T_{SF} - T_{H2O,amb}))Q_{mist} \\
\text{If } T_{SF} > T_{sat} \\
Q_{Fire} = (\Delta Hv + C_{H2O,L}(T_{Sat} - T_{H2O,amb}) + C_{pH2O,v}(T_{SF} - T_{sat}))Q_{mist} 
\]
Fig. 1 — Water mist and nitrogen concentration requirements to cause extinguishment

Fig. 2 — Required water mist application flux required to limit sub-floor temperature as a function of the below deck fire exposure referenced to heated deck surface area
Where $T_{SF}$ is the temperature in the sub-floor [K], $T_{sat}$ is the saturated water temperature or boiling temperature [K], $T_{\text{H2O,amb}}$ is the ambient water temperature [K], $Q_{\text{Fire}}$ is the heat transferred into the sub-floor due the below deck surface [kW], $\psi$ is the fraction of the water mist that is vaporized, $Q_{\text{mist}}$ is the application rate of the mist (water only) [kg/sec], $C_{\text{H2O,V}}$ if the heat capacity of water vapor [kJ/kg K], and $C_{\text{H2O,L}}$ is the heat capacity of liquid water [kJ/kg K]. Note, this energy balance assumes that all the non-vaporized mist exits the enclosure at the sub-floor air temperature, ignores the effects of air movement into or out of the enclosure, and no heat loss through the unheated compartment boundaries. The fraction of the mist vaporized is also a function of the sub-floor temperature, which can be estimated as shown in equation (6):

$$\psi = \frac{P_{v,T}}{P_{\text{atm}}}$$

Where $P_{v,T}$ is the vapor pressure of water at temperature $T$ [kPa] and $P_{\text{atm}}$ is the atmospheric pressure [kPa].

4.0 TEST SETUP

4.1 Test Enclosure

A simulated false deck 2.0 x 1.9 x 0.3 m (6.5 x 6.1 x 1.0 ft) was constructed from 6.7 mm (1/4”) thick steel plate over an angle iron frame as shown in Figures 3 through 5. The top deck consisted of nine 0.61 x 0.61 m (2 x 2 ft) panels that can be lifted off in order to gain access to the sub-floor area.

The simulated false deck was supported 0.81 m (2.6 ft) above the ground to facilitate the below deck heating. This heating was accomplished with nine propane burners located 7.6 cm (3 in) below the lower deck surface as shown in Fig. 6. Skirts, 0.3 m (1 ft) were attached to two adjacent sides below the deck level of the mock-up to reduce the convective losses from the burners.

4.2 Fire Scenarios

Two fire scenarios were utilized during these tests. The first of these involved a “telltale” n-heptane can fire. This telltale can fire was similar in construction as that specified by Underwriters Laboratories in their clean agent standards UL-2127 [5] and UL-2166 [6]. The cup was 7.6 cm (3 in) in diameter, had a wall thickness of 5.50 mm (0.216 in) corresponding to schedule 40 steel pipe, 10 cm (4 in) in height and fueled with 120 ml of n-heptane floating on a water substrate to result in a 2.5 cm (1 in) freeboard. The telltale cup was placed 10 cm (4 in) from a vertical baffle located 0.61 m (2 ft) from the back wall and 0.61 m (2 ft) in length. This location is shown in Fig. 7.
Fig. 3 — Top view of simulated false deck/sub-floor

Fig. 4 — Elevation schematic of simulated false deck/sub-floor
Fig. 5 — Plan schematic of simulated false deck/sub-floor

Fig. 6 — Schematic of below deck heating system
The second fire scenario consisted of a plastic sheet array similar to that utilized in UL 2127 [5] and UL 2166 [6]. This array was scaled down to utilize two 5 x 10 x 0.95 cm (2 x 4 x 0.375 in) sheets of natural polypropylene with a 1.27 cm (0.5 in) gap between the sheets. The array was held in place by a 6.8 mm (0.25 in) all thread rod suspended from an angle aluminum frame. The array was ignited by a 5 cm (2 in) square pan, fueled with 3 ml of n-heptane. The array was centered behind the baffle with the plastic sheets running parallel to the baffle. The center of the array was 10 cm (4 in) from the baffle. This set-up is shown schematically in Fig. 8.
2 sheets of Polypropylene
5 x 10 x .65 cm
(2 x 4 x .26 in.)
arranged vertically
with 1.27 cm (0.5 in.) gaps

Elevation View Parallel to Baffle
Elevation View Perpendicular to Baffle

Fig. 8 — Plastic array fire schematic

4.3 Water Mist System

The NanoMist system introduced the water mist into the mock-up through a 10 cm (4 in) duct installed in a cover plate 15.2 cm (6 in) beyond the front wall of the mock-up as shown in Figures 9 through 11. The NanoMist system utilizes an ultra-sonic technique to produce water mists with average drop sizes less than 10 microns with water concentrations of 150 to 470 g/m³. This drop size is smaller than that generated with more conventional high pressure or dual fluid atomizing technique and the water concentration is greater than that theoretically required to extinguish hydrocarbon flames. The airflow from the mist generators into the mock-up ran continuously during these tests and was present during all pre-burn periods of these tests.

The NanoMist system parameters as tested are given in Table 1. Note that the mister output was reduced to approximately 55% of the design output of 250 ml/min of water. This reduced output was likely resulting from smoke and heat exposure during previous testing.

Table 1 — NanoMist System Parameters

<table>
<thead>
<tr>
<th>Type</th>
<th>Number of Misters</th>
<th>Flow Rate Per Mister [LPM]</th>
<th>Total Flow Rate [LPM]</th>
<th>Total Flux (Relative to Deck Area) [SLPM/m²]</th>
<th>Air Changes [l/hr]</th>
<th>Water Concentration in Inlet Mist Flow [g/m³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>NanoMist with Original Fans</td>
<td>1</td>
<td>0.16 341</td>
<td>0.16 341</td>
<td>0.043 132</td>
<td>36.4 21.2</td>
<td>19.6% 468.9</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0.16 341</td>
<td>0.16 341</td>
<td>0.043 132</td>
<td>18.2 28.1</td>
<td>36.4 21.2</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.11 438</td>
<td>0.20 876</td>
<td>0.054 238</td>
<td>46.8 16.0%</td>
<td>228.0</td>
</tr>
<tr>
<td>NanoMist with Larger Fans</td>
<td>1</td>
<td>0.14 468</td>
<td>0.14 468</td>
<td>0.038 132</td>
<td>26.0 19.6%</td>
<td>293.4</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.10 438</td>
<td>0.20 876</td>
<td>0.054 238</td>
<td>46.8 16.0%</td>
<td>228.0</td>
</tr>
</tbody>
</table>
Fig. 9 — NanoMist water mist generator configuration
Fig. 10 — Photograph of NanoMist water mist generators as configured for single mist generator operation

Fig. 11 — Photograph of generated water mist entering mock-up
4.4 Instrumentation

Omega Engineering Model KMQSS-062E-120 stainless steel sheathed exposed junction thermocouples were utilized to monitor the test fires for extinguishment.

Type K thermocouples were welded to both the lower and upper surface of the deck plate in three locations to monitor the deck temperature and arranged in three vertical trees with three thermocouples per tree to monitor the air temperature inside the sub-floor space.

Two radiometers with a full scale range of 10 kW/m² (Medtherm Corporation Model 64TP-1-23) and two total heat flux meters with a full scale range of 10 kW/m² (Medtherm Corporation Model 64-1-19) were installed at two locations in the cover plates that make-up the false deck to monitor the flow of heat through the sub-floor.

A Malvern Series 2600 Drop Size Analyzer was utilized to characterize the generated water mists. It was equipped with a 63 mm focal length lens to result in a 1.2 micron to 122 micron drop size range. It was configured for a 25 mm (1 in) active measuring path. The mist was withdrawn from the backside of the mock-up behind the baffle through a 100 mm (4 in) PVC pipe that was reduced down to a 25 mm (1 in) pipe stub. The pipe stub ended prior to encountering the laser from the analyzer.

The instrumentation is outlined in Figures 12 through 14.

4.5 Electronics Exposure Targets

Two types of electronics targets were exposed to the mist generated. The first type was an external modem, Boca Research Model B100, which was monitored during exposure utilizing ULTRA-X QTPRO diagnostic testing software. The modem was removed from its plastic housing and mounted horizontally near the single telltale location. The second type was an uncoated printed circuit board. A comb circuit was imprinted on the board with alternating lines charged with 5 VDC with a line separation distance of 1.6 mm (0.0625 in). The comb circuit covers an area of 30.6 cm² (4.75 in²) on the board. Two boards were exposed in each test, one horizontally oriented and the other vertically oriented. The current across the circuit was monitored during the exposure utilizing a 1 MΩ resistor for an effective range of 0 to 5 μA. This circuit is shown in Figures 15 and 16. A photograph of the modem and the circuit boards as exposed to the mist is shown in Fig. 17.
Fig. 12 — Instrumentation elevation schematic

Fig. 13 — Instrumentation plan schematic
Malvern Drop Size Analyzer

2.5 cm (1 in.) PVC pipe
10 cm (4 in.) PVC pipe

Mist Exhaust

Malvern Drop Size Analyzer

NanoMist Water Mist Generator

10 cm (4 in.) Duct

Fig. 14 — Malvern drop size analyzer configured for mist characterization tests
Fig. 15 — Printed circuit board (dimensions in cm)
Fig. 16 — Comb detail

Fig. 17 — Modem and circuit boards as exposed to water mist
5.0 RESULTS AND DISCUSSION

The NanoMist system tests consisted of telltale and polypropylene array fire extinguishment tests, below deck heating tests, mist characterization tests, and electronics exposure tests. These tests were conducted in accordance with the approved test plan [7].

5.1 Mist Characterization Testing

The measured drop size and concentrations are given in Table 2. The measured concentrations are approximately 20% of the concentration in the mist at the inlet to the mock-up based upon the measured air and water flow rates. This reduction in concentration is due to the mist plating out on the surfaces in the mock-up. This reduction may also be due in part to measurement errors in the inlet flow rates and the concentration measurement by the Malvern.

Table 2 — Mist Characterization

<table>
<thead>
<tr>
<th>Type</th>
<th>Number of Misters</th>
<th>Total Flow Rate</th>
<th>Water Concentration</th>
<th>Drop Size</th>
<th>Concentration</th>
<th>Relative to Theoretical Extinguishing Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Water [LPM]</td>
<td>Air [SLPM]</td>
<td></td>
<td>[Dv10]</td>
<td>[Dv50]</td>
</tr>
<tr>
<td>NanoMist with Original Fans</td>
<td>1</td>
<td>0.16</td>
<td>681</td>
<td>16.3%</td>
<td>234</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0.16</td>
<td>341</td>
<td>28.1%</td>
<td>469</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.22</td>
<td>681</td>
<td>21.2%</td>
<td>322</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0.14</td>
<td>876</td>
<td>11.7%</td>
<td>160</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0.14</td>
<td>486</td>
<td>19.3%</td>
<td>287</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.20</td>
<td>876</td>
<td>16.0%</td>
<td>228</td>
<td>1.5</td>
</tr>
</tbody>
</table>

5.2 Telltale and Polypropylene Extinguishment Tests

During tests with the telltale n-heptane fires, the fire was ignited and allowed to burn for 60 seconds prior to mister activation. The cover plate directly above the telltale was removed during this pre-burn time period to minimize the effects of oxygen depletion. The airflow through the misters was actively pushing air through the mock-up during this time period.

During tests with the polypropylene array, this pre-burn time period was extended to 120 seconds. The 3 ml of n-heptane in the igniter pan provided an approximate 90 second burn duration and had burned out prior to water mist application.

The results from testing the NanoMist system with the telltale fire and the polypropylene array fire are summarized in Tables 3 and 4. The telltale fire was extinguished in all of the tests that utilized two operating misters, but only extinguished once utilizing a configuration involving a single mister. That one test, HYBD141, involved the highest inlet water concentration and the extinguishment of the telltale did not occur until 8.5 min after the mister was activated.
Table 3 — Result Summary from Testing with Telltale Fire

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>HYBD141</td>
<td>1</td>
<td>160</td>
<td>42.78</td>
<td>5.68</td>
<td>17.92</td>
<td>28.1%</td>
<td>469</td>
<td>523</td>
<td>2.60</td>
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<tr>
<td>HYBD152</td>
<td>1</td>
<td>138</td>
<td>36.90</td>
<td>8.11</td>
<td>25.60</td>
<td>19.1%</td>
<td>283</td>
<td>N/E</td>
<td>N/E</td>
</tr>
<tr>
<td>HYBD161</td>
<td>1</td>
<td>100</td>
<td>26.74</td>
<td>11.35</td>
<td>35.84</td>
<td>10.9%</td>
<td>147</td>
<td>N/E</td>
<td>N/E</td>
</tr>
<tr>
<td>HYBD142</td>
<td>1</td>
<td>160</td>
<td>42.78</td>
<td>11.35</td>
<td>35.84</td>
<td>16.3%</td>
<td>234</td>
<td>N/E</td>
<td>N/E</td>
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<tr>
<td>HYBD160</td>
<td>2</td>
<td>200</td>
<td>53.47</td>
<td>11.35</td>
<td>35.84</td>
<td>19.1%</td>
<td>293</td>
<td>183</td>
<td>1.82</td>
</tr>
<tr>
<td>HYBD139</td>
<td>2</td>
<td>220</td>
<td>58.82</td>
<td>11.35</td>
<td>35.84</td>
<td>21.2%</td>
<td>322</td>
<td>149</td>
<td>1.48</td>
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<tr>
<td>HYBD140</td>
<td>2</td>
<td>220</td>
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<td>35.84</td>
<td>21.2%</td>
<td>322</td>
<td>151</td>
<td>1.50</td>
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<tr>
<td>HYBD154</td>
<td>2</td>
<td>200</td>
<td>53.47</td>
<td>14.59</td>
<td>46.08</td>
<td>16.0%</td>
<td>228</td>
<td>186</td>
<td>2.38</td>
</tr>
</tbody>
</table>

Obstructions Added (Stack of PVC Pipe and Aluminum Duct, 20 cm tall, width of enclosure 45 cm from mist inlet)
HYBD158 1 123 32.89 6.65 20.99 20.4% 308 N/E N/E
HYBD159 2 210 56.15 11.35 35.84 20.4% 308 N/E N/E

Table 4 — Result Summary from Testing with The Polypropylene Array Fire

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>HYBD144</td>
<td>1</td>
<td>160</td>
<td>42.78</td>
<td>5.68</td>
<td>17.92</td>
<td>28.1%</td>
<td>469</td>
<td>172</td>
<td>0.66</td>
</tr>
<tr>
<td>HYBD153</td>
<td>1</td>
<td>140</td>
<td>37.43</td>
<td>8.11</td>
<td>25.60</td>
<td>19.3%</td>
<td>287</td>
<td>95</td>
<td>0.68</td>
</tr>
<tr>
<td>HYBD168</td>
<td>1</td>
<td>128</td>
<td>37.43</td>
<td>11.35</td>
<td>35.84</td>
<td>14.6%</td>
<td>205</td>
<td>464</td>
<td>4.62</td>
</tr>
<tr>
<td>HYBD143</td>
<td>2</td>
<td>220</td>
<td>58.82</td>
<td>11.35</td>
<td>35.84</td>
<td>21.2%</td>
<td>322</td>
<td>94</td>
<td>0.94</td>
</tr>
<tr>
<td>HYBD155</td>
<td>2</td>
<td>200</td>
<td>53.47</td>
<td>14.59</td>
<td>46.08</td>
<td>16.0%</td>
<td>228</td>
<td>69</td>
<td>0.88</td>
</tr>
</tbody>
</table>

The NanoMist parameters that resulted in the extinguishment of the telltale fire are correlated in Fig. 18. The extinguishment time, in terms of air changes, is presented as a function of the mist water concentration in Fig. 19. This figure shows that the extinguishment time is reduced with increasing mist concentrations. Figure 20 illustrates the measured temperature above the telltale cup with ignition, system activation and fire extinguishment times marked for one of the two mister tests with an airflow rate of 11.35 L/s. The measured temperatures above the telltale cup for all of these tests are presented in Appendix A.
Fig. 18 — NanoMist system parameters correlated to extinguishment of the telltale fire

Fig. 19 — Extinguishment times in terms of air changes correlated to mist concentration and application flux with the telltale fire
Fig. 20 — Telltale fire temperature during test with two operating misters with a total water flow of 220 mLPM and 11.35 l/s air flow [HYBD139]

The polypropylene array fire was extinguished successfully in each of the configurations tested. However, the single mister configuration that was diluted with the air flow from the non-activated second mister took nearly 8 min (4.9 air changes) to extinguish the fire. Figure 21 correlates the NanoMist system parameters that resulted in extinguishing the polypropylene array in less than 3 min. Figure 22 correlates the extinguishment time, in terms of air changes, with inlet mist water concentration. This relationship is flat with slightly less than one air change to extinguish the array with the exception of the previously discussed test. Figure 23 illustrates the measured temperature above the polypropylene array with ignition, system activation and fire extinguishment times marked for the two mister test with an airflow rate of 11.35 L/s. The measured temperatures above the polypropylene array for all of these tests are presented in Appendix B.

In order to qualitatively examine the impact of additional obstructions in the sub-floor on the observed system performance, a debris pile spanning the width of the mockup and 20 cm (8 in) high consisting of 10 cm (4 in) diameter expandable aluminum duct and 5 cm to 10 cm (2 in to 4 in) diameter PVC pipe was installed in the mock-up 45 cm (18 in) from the NanoMist System inlet to the Mock-up. A photograph of this debris pile is shown in Fig. 24. Neither configuration tested was able to extinguish the telltale fire. The single mister configuration tested was observed to never completely fill the mock-up with mist as a layer of clear air approximately 5 cm (2 in) in depth was maintained throughout the test on top of the mist.
NanoMist Parameters Effecting Extinguishment of Polypropylene Array Fire

Fig. 21 — NanoMist system parameters correlated to extinguishment of the polypropylene array fire

Polypropylene Array Extinguishment Time Relative to Air Flow Rate as a Function of Inlet Water Concentration and Application Flux

Fig. 22 — Extinguishment times in terms of air changes correlated to mist concentration and application flux with the polypropylene array fire
Fig. 23 — Polypropylene array fire temperature during test with two operating misters with a total water flow of 220 mLPM and 11.35 L/s air flow [HYBD143]

Fig. 24 — Debris pile obstruction added to mock-up
5.3 Telltale Fire Testing with Nitrogen Added to Mister Inlet Air Flow

Table 5 and Fig. 25 show the effects of adding nitrogen to the inlet stream of a single mister on the NanoMist system extinguishing performance with the telltale fire. Figure 26 presents the measured temperature above the telltale for the single mister with 140 mLPM water flow, 11.35 L/s air flow, and 17% by volume nitrogen added to the air flow. The measured temperatures above the telltale during these tests are presented in Appendix C. The NanoMist System configuration utilized for these tests is illustrated in Fig. 27.

The correlation presented in Fig. 25 suggests a higher trade-off with a greater reduction in water mist concentration for increases in nitrogen concentration relative to that predicted in Fig. 1. This is primarily due to the plating losses as the mist flows across the mock-up and additional help in extinguishment due to oxygen depletion.

As can be seen from Table 5, approximately 50% of the nitrogen requirements for extinguishment by itself, was required to achieve comparable performance with the single mister configurations as was achieved with the two mister configuration.

Table 5 — Results Summary with Nitrogen Addition to Single Mister Inlet Air Flow

<table>
<thead>
<tr>
<th>Test</th>
<th>Water Flow</th>
<th>Air Flow</th>
<th>Water</th>
<th>N₂ Conc</th>
<th>Ext Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>HYBD166</td>
<td>128</td>
<td>33.42</td>
<td>6.65</td>
<td>20.99</td>
<td>20.7%</td>
</tr>
<tr>
<td>HYBD167</td>
<td>0</td>
<td>0.00</td>
<td>6.65</td>
<td>20.99</td>
<td>0.0%</td>
</tr>
<tr>
<td>HYBD141</td>
<td>160</td>
<td>42.78</td>
<td>5.68</td>
<td>17.92</td>
<td>28.1%</td>
</tr>
</tbody>
</table>

Nitrogen Augmented Telltale Extinguishment Tests with 1 Mister and 1 Fan

<table>
<thead>
<tr>
<th>Test</th>
<th>Water Flow</th>
<th>Air Flow</th>
<th>Water</th>
<th>N₂ Conc</th>
<th>Ext Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>HYBD164</td>
<td>128</td>
<td>26.74</td>
<td>11.35</td>
<td>35.84</td>
<td>10.9%</td>
</tr>
<tr>
<td>HYBD162</td>
<td>128</td>
<td>34.22</td>
<td>11.35</td>
<td>35.84</td>
<td>13.5%</td>
</tr>
<tr>
<td>HYBD163</td>
<td>0</td>
<td>0.00</td>
<td>11.35</td>
<td>35.84</td>
<td>0.0%</td>
</tr>
<tr>
<td>HYBD142</td>
<td>160</td>
<td>42.78</td>
<td>11.35</td>
<td>35.84</td>
<td>16.3%</td>
</tr>
<tr>
<td>HYBD161</td>
<td>100</td>
<td>26.74</td>
<td>11.35</td>
<td>35.84</td>
<td>10.9%</td>
</tr>
<tr>
<td>HYBD165</td>
<td>0</td>
<td>0.00</td>
<td>11.35</td>
<td>35.84</td>
<td>0.0%</td>
</tr>
</tbody>
</table>
Fig. 25 — Added nitrogen requirements with single NanoMist mister and telltale fire

Fig. 26 — Temperature measured above the telltale cup with single mister at 128 mLPM water, 11.35 L/s air, and 17% by volume added nitrogen [HYBD164]
5.4 Electronics Exposure Tests

The results of these exposures are summarized in Table 6 and in Figures 28 through 31. As can be seen from this Table and these figures, the modem continued to operate normally for at least seven minutes in each of these tests. In the test with a single mister with the original fan, the modem continued to function normally for 13 minutes. In all of these tests, the comb circuit on the horizontally oriented board quickly shorted, within two minutes of mister activation, with residual resistances less than 50 kΩ.

The modem failures roughly correlated to the vertically oriented board. In two of the four tests, the measured leakage current was \( \sim 2 \mu A \) at the time of Modem failure, however it had grown to 3.7 \( \mu A \) before modem failure in one test and the actual current was not recorded during the remaining test.

After exposure, the modems were shook and dried with a paper towel. The modems were then tested with the diagnostic software. None of the modems responded at that time. The modems were then set upside down on a paper towel overnight. All four modems responded and passed all of the diagnostic tests the next morning.
Table 6 — Summary of Electronic Exposure Test Results

<table>
<thead>
<tr>
<th>Test</th>
<th>Number Of Misters</th>
<th>Water Flow</th>
<th>Air Flow</th>
<th>Water Fail</th>
<th>Modern Fail Time</th>
<th>Leak Current at Modem Failure</th>
<th>Max Leak Current</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Flow [mLPM]</td>
<td>Flux [mLPM/m²]</td>
<td>Flow Changes [L/hr]</td>
<td>Concentration [%wt]</td>
<td>[g/m³]</td>
<td>[sec]</td>
</tr>
<tr>
<td>HYBD149</td>
<td>1</td>
<td>128</td>
<td>34.22</td>
<td>5.68</td>
<td>17.92</td>
<td>23.8%</td>
<td>375</td>
</tr>
<tr>
<td>HYBD151</td>
<td>1</td>
<td>143</td>
<td>38.23</td>
<td>8.11</td>
<td>25.60</td>
<td>19.6%</td>
<td>293</td>
</tr>
<tr>
<td>HYBD148</td>
<td>2</td>
<td>220</td>
<td>58.62</td>
<td>11.35</td>
<td>35.84</td>
<td>21.2%</td>
<td>322</td>
</tr>
<tr>
<td>HYBD150</td>
<td>2</td>
<td>220</td>
<td>58.62</td>
<td>14.59</td>
<td>46.08</td>
<td>17.3%</td>
<td>251</td>
</tr>
</tbody>
</table>

Fig. 28 — Comb circuit current during single mister test with original fan (HYBD149)
Fig. 29 — Comb circuit current during single mister test with larger fan (HYBD151)

Fig. 30 — Comb circuit current during two mister test with original fans (HYBD148)
5.5 Below Deck Heating Tests

During the below deck heating tests, the nine propane burners heated the lower deck plate of the false deck mock-up. The burners were fed with 18 SLPM (40.1 SCFH) of propane for a total heating rate of 27.3 kW (1730 Btu/min) or 7.4 kW/m² (43.6 Btu/min ft²). The mock-up was heated for 20 minutes prior to mister activation (air flow through the mister into the mock-up was active during this time period). The mist was then actuated and allowed to flow for ten minutes. Note that the propane burners continued to heat the lower deck while the mister(s) were operating.

The results of this testing are summarized in Table 7 and in Figures 32 through 44. While the temperature inside the sub-floor was reduced as a result of the water mist application, only the test involving the operation of two mister and the original, smaller, fans was able to reduce the temperature in the sub-floor to approximately 100°C (212°F), the boiling point for water. The use of the larger fans reduced the mist residence time in the mock-up allowing for a slight loss in heat absorption efficiency.

The application flux for the two misters operating with the original, smaller fans, of 0.059 LPM/m² (0.087 gph/ft²) is lower than the 0.172 LPM/m² (0.254 gph/ft²) minimum requirement calculated for this heat flux based upon Fig. 2. The difference is due to not accounting for the heat absorbed by the air flowing along with the water, the heat lost through the unheated compartment boundaries and efficiency of the burners in transferring heat to the mock-up.
Table 7 — Below Deck Heating Tests Summary

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>HYBD147</td>
<td>1</td>
<td>160</td>
<td>42.8</td>
<td>5.7</td>
<td>17.9</td>
<td>28.1%</td>
<td>469</td>
</tr>
<tr>
<td>HYBD156</td>
<td>1</td>
<td>140</td>
<td>37.4</td>
<td>8.1</td>
<td>25.6</td>
<td>19.3%</td>
<td>287</td>
</tr>
<tr>
<td>HYBD146</td>
<td>2</td>
<td>220</td>
<td>58.8</td>
<td>11.4</td>
<td>35.8</td>
<td>21.2%</td>
<td>322</td>
</tr>
<tr>
<td>HYBD157</td>
<td>2</td>
<td>230</td>
<td>61.5</td>
<td>14.6</td>
<td>46.1</td>
<td>17.9%</td>
<td>262</td>
</tr>
</tbody>
</table>

Fig. 32 — Deck surface temperatures during below deck heating test with one mister and original, smaller fans (HYBD147)
Fig. 33 — Air temperatures in the center of the sub-floor/false deck mock-up during below deck heating test with one mister and original, smaller fans (HYBD147)

Fig. 34 — Deck surface temperatures during below deck heating test with one mister and larger fans (HYBD156)
Fig. 35 — Air temperatures in the center of the sub-floor/false deck mock-up during below deck heating test with one mister and larger fans (HYBD156)

Fig. 36 — Total heat flux at the top of the sub-floor/false deck mock-up during below deck heating test with one mister and larger fans (HYBD156)
Fig. 37 — Deck surface temperatures during below deck heating test with two misters and original, smaller fans (HYBD146)

Fig. 38 — Air temperatures in the center of the sub-floor/false deck mock-up during below deck heating test with two misters and original, smaller fans (HYBD146)
Fig. 39 — Radiant heat flux at the top of the sub-floor/false deck mock-up during below deck heating test with two misters and original, smaller fans (HYBD146)

Fig. 40 — Total heat flux at the top of the sub-floor/false deck mock-up during below deck heating test with two misters and original, smaller fans (HYBD146)
Fig. 41 — Deck surface temperatures during below deck heating test with two misters and larger fans (HYBD157)

Fig. 42 — Air temperatures in the center of the sub-floor/false deck mock-up during below deck heating test with two misters and larger fans (HYBD157)
Fig. 43 — Radiant heat flux at the top of the sub-floor/false deck mock-up during below deck heating test with two misters and larger fans (HYBD157)

Fig. 44 — Total heat flux at the top of the sub-floor/false deck mock-up during below deck heating test with two misters and larger fans (HYBD157)
5.6 Results Summary

The NanoMist water mist system is capable of generating large concentrations of fine water drops. Mist characterization testing on mist samples withdrawn from the back of the mock-up revealed an average drop size, $D_{v50}$, of 7 microns. Mist water concentration in the sample was measured at 20% to 35% of the water concentration at the inlet to the sub-floor/false deck mock-up based upon measured air and water flows. The difference is due to both plating losses in flowing through the mock-up and to measurement errors in both concentration measurements.

The generated water mists were able to extinguish the telltale fire with a 0.053 LPM/m$^2$ water application flux and inlet mist water concentration ranging from 228 g/m$^3$ to 322 g/m$^3$ in approximately 3 minutes, which corresponded to 2.5 air changes in the mock-up. The lower water application flux tested, 0.037 LPM/m$^2$, was only able to extinguish the telltale fire with a higher mist water concentration of 497 g/m$^3$ and after 8.5 minutes, which corresponded to 2.6 air changes.

An added debris pile, 0.2 m (8 in) tall, 0.45 m (1.5 ft) from the mist inlet to the mock-up, spanning the width of the mock-up represented a significant obstruction to the test water mist system, causing the telltale fire to not be extinguished by the 0.056 LPM/m$^2$ water application flux, 308 g/m$^3$ water mist concentration.

The polypropylene array fire was more readily extinguished by the NanoMist systems tested. It was extinguished at times corresponding to less than one air change with the exception of the test with the lowest application flux of 0.037 LPM/m$^2$ and the lowest mist water concentration of 205 g/m$^3$ where the fire was extinguished after 7.7 minutes corresponding to 4.6 air changes.

Approximately 50% of the nitrogen requirements required to extinguish the telltale fire by itself, was required to achieve comparable performance with the single mister, 0.037 LPM/m$^2$ water application flux configurations, as was achieved with the two mister, 0.053 LPM/m$^2$ water application flux configurations.

The external modems exposed to the generated water mists were able to continue operating for at least 7 minutes after mister actuation. With the lowest water application rate and lowest air flow rate, the modem continued to operate for 13 minutes after mister application. The horizontally oriented comb circuit board was quickly shorted during all four exposure tests with leakage currents exceeding 4.0 μA within 2 minutes of mister activation. The vertically oriented comb circuit leakage current was approximately 2 μA at time corresponding to modem failure during two of the three tests where the current was monitored at the time of modem failure. During the remaining test, the leakage current was 3.7 μA at the time of modem failure.

During the below deck heating tests, the two mister configuration, which has a water application flux of 0.056 LPM/m$^2$, and the higher mist water concentration of 308 g/m$^3$, was able to reduce the temperature inside the sub-floor/false deck mock-up to approximately 100°C. This water application flux is less than that calculated 0.172 LPM/m$^2$ to be required to maintain the temperature in the mock-up to 100°C based on the applied 7.4 kW/m$^2$ heat flux based on the burner propane flow rate. This difference likely results from neglecting the heat transfer efficiencies from the burners to the lower deck of the mock-up, the heat absorbed in heating the
6.0 CONCLUSIONS

The NanoMist Water Mist System shows significant promise in this application. The small drop size and high initial mist water concentration enabled the generated mist to extinguish the test fires located behind a baffle spanning a third of the enclosure width and the entire enclosure height.

The NanoMist system was able to provide protection to the sub-floor with a below deck fire exposure scenario. The system was able to reduce the temperature in the mock-up to approximately 100°C with the lower deck of the mock-up exposed to a 7.4 kW/m\(^2\) when the system was applied at the higher water application flux test of 0.056 LPM/m\(^2\) and a mist water concentration of 308 g/m\(^3\).

Operating electronics exposed to the generated water mist did shut down after extended exposure. All of the exposed modems continued operating for at least 7 minutes when exposed to the tested water mists and when exposed to the lowest tested water application flux and lowest air flow, the modem continued to operate beyond the normal 10 minute exposure, not shutting down until after 13 minutes of exposure. The exposed modems did, however, regain function after thorough drying.

7.0 RECOMMENDED FURTHER INVESTIGATIONS

Further investigation is recommended in the aspects of scaling of the NanoMist water mist system to protect larger/full scale false deck/sub-floor spaces, amount of obstructions that can be tolerated by the NanoMist system, effectiveness in extinguishing fires involving energized/heated electrical cables, and the effects of exposure to operating electronics in more typical geometries and configurations.

Actual sub-floor/false deck spaces typically range in area from approximately 25 m\(^2\) (270 ft\(^2\)) to 100 m\(^2\) (1070 ft\(^2\)). This range represents a scale-up of 6:1 at the small end and 25:1. The design guidelines developed in this testing in terms of water application fluxes and inlet mist water concentration would need to be checked in the larger area, as well as geometrical factors such as the number of mist inlets and inlet positioning in the protected space.

A debris pile obstruction spanning the width of the enclosure and 67% of the enclosure height rendered the higher application flux ineffective in extinguishing the telltale fire. The amount of obstructions that can be tolerated and/or compensated for needs to be determined. The amount of obstructions typically encountered in false deck/sub-floor areas also needs to be determined.

Overheated/shorted electrical cables represent the majority of the fire hazards encountered in sub-floor/false deck areas. The NanoMist system should be tested for effectiveness on these hazards.
The electronic exposure tests conducted demonstrated a potential for operating electronic to shut down upon exposure to the generated water mist. The exposure to the mist in these tests did not take into account the protection from exposure offered by electrical cabinets and proximity to other electronics. The external modems test may also be either more tolerant or less tolerant than the electronic encountered. With reference to sub-floor/false deck installations, there may not be a direct connection between the sub-floor and the electronics. All of these factors need to be investigated, to determine the risk to operating electronics represented by the NanoMist system.

8.0 REFERENCES


APPENDIX A — Fire Temperature During Tests with Telltale Fire
Figures A-1 through A-10 give the temperature measured over top of the telltale cup fire with ignition, system activation and fire extinguishment times marked.

Fig. A-1 — Telltale fire temperature with one mister at 160 mL/min water and 5.68 L/s Air [HYBD141]

Fig. A-2 — Telltale fire temperature with one mister at 138 mL/min water and 8.11 L/s air [HYBD152]
Fig. A-3 — Telltale fire temperature with one mister at 100 mL/min water and 11.35 L/s air [HYBD161]

Fig. A-4 — Telltale fire temperature with one mister at 160 mL/min water and 11.35 L/s air [HYBD142]
Fig. A-5 — Telltale fire temperature with two misters totaling 200 mL/min water and 11.35 L/s Air [HYBD160]

Fig. A-6 — Telltale fire temperature with two misters totaling 220 mL/min water and 11.35 L/s air [HYBD139]
Fig. A-7 — Telltale fire temperature with two misters totaling 220 mL/min water and 11.35 L/s air [HYBD140]

Fig. A-8 — Telltale fire temperature with two misters totaling 200 mL/min water and 14.59 L/s air [HYBD154]
Fig. A-9 — Telltale fire temperature with one mister at 123 mL/min water, 6.65 L/s air, and added obstructions [HYBD158]

Fig. A-10 — Telltale fire temperature with two misters totaling 210 mL/min water, 11.35 L/s air, and added obstructions [HYBD159]
APPENDIX B — Fire Temperature During Tests with Polypropylene Array Fire
Figures B-1 through B-5 give the temperature measured over top of the polypropylene array fire with ignition, system activation and fire extinguishment times marked.

Fig. B-1 — Polypropylene fire temperature with one mister at 160 mL/min water and 5.68 L/s air [HYBD144]

Fig. B-2 — Polypropylene fire temperature with one mister at 140 mL/min water and 8.11 L/s air [HYBD153]
Fig. B-3 — Polypropylene fire temperature with one mister at 128 mL/min water and 11.35 L/s air [HYBD168]

Fig. B-4 — Polypropylene fire temperature with two misters totaling 220 mL/min water and 11.35 L/s Air [HYBD143]
Fig. B-5 — Polypropylene fire temperature with two misters totaling 200 ml/min water and 14.59 l/s air [HYBD155]
APPENDIX C — Fire Temperature During Nitrogen Assisted Single Mister Tests with Telltale Fire
Figures C-1 through C-9 present the measured temperature above the telltale fire during tests that utilized a single mister assisted with the addition of nitrogen to the carrier air flow into the mister.

Fig. C-1 — Temperature above the telltale fire during test with single mister at 128 mL/min water, 6.65 L/s air and 9.5% by volume added nitrogen [HYBD166]

Fig. C-2 — Temperature above the telltale fire during test with 6.65 L/s air and 18.9% by volume added nitrogen [HYBD167]
Fig. C-3 — Temperature above the telltale fire during test with single mister at 160 mL/min Water, 5.68 L/s air and no added nitrogen [HYBD141]

Fig. C-4 — Temperature above the telltale fire during test with single mister at 128 mL/min water, 11.35 L/s air and 17% by volume added nitrogen [HYBD164]
Fig. C-5 — Temperature above the telltale fire during test with single mister at 128 mL/min water, 11.35 L/s air and 11.1% by volume added nitrogen [HYBD162]

Fig. C-6 — Temperature above the telltale fire during test with 11.35 L/s air and 22.5% by volume added nitrogen [HYBD163]
Fig. C-7 — Temperature above the telltale fire during test with single mister at 160 mL/min water, 11.35 L/s air and no added nitrogen [HYBD142]

Fig. C-8—Temperature above the telltale fire during test with single mister at 100 mL/min water, 11.35 L/s air and no added nitrogen [HYBD161]
Fig. C-9 — Temperature above the telltale fire during test with 11.35 L/s air and 17% by volume added nitrogen [HYBD165]