ULTRA FINE WATER MIST APPLICATION IN AIRCRAFT HIDDEN FIRES

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ABSTRACT

Ultra fine water mist research in recent years raised significant interest in its application to telecom industries, aerospace, and other selected industrial fire protection applications. The objective of this work was to explore the fire suppression behavior of ultra fine water mist in aircraft hidden area fires. The work was focused on CFD simulations and experimental work in an attic space mockup of a 727 aircraft. The ultra fine mist (UFM) transport within the mockup was simulated using a dense gaseous species model published earlier. In the CFD model, UFM was discharged with a flow rate of 1.0 L/min, having mass concentrations 10, 20, and 25%. The time-dependent water concentrations were computed within the volume. The attic volume attained cup burner minimum extinguishing concentration (MEC) of UFM (0.15 ~0.2 L/m3) within a minute, depending on the inlet mist flow rate and the mass loading. Experiments were conducted on energized cable bundle fires using a proprietary ultra fine water mist generator (NanoMist®). The experiments showed extinguishment times of roughly 1-mintute for mist flow rates in the range of 400-700 ml/min. This is similar to CFD predictions of time-to-reach extinction concentrations

INTRODUCTION

In-flight fires frequently originate in the hidden areas of the airplane such as the attic above the cabin ceiling, beneath the floor, and in or around the lavatories. There have been several incidents involving the successful extinguishment of hidden fires by halon handheld extinguishers [1, 2]. Because of the demonstrated risk of these “hidden” fires, the FAA has specified that agents replacing halon must exhibit a similar degree of protection against these fires.

An environmentally friendly water fog fire suppression agent can address aircraft hidden areas around the cabin. Work for the last half a decade on ultra fine water mist (droplet diameters below 10 μm) has created significant interest in using Ultra Fine Mist (UFM) as a viable alternative to halon [3-9]. A considerable amount of work has been reported on the characterization, droplet behavior and mist fire suppression behavior of UFM under different laboratory conditions [10-14]. UFM can function as an effective suppression agent for aerospace applications such as cargo bays, cabins and hidden areas. Experimental studies on UFM with a controlled discharge momentum have indicated gas-like behavior by the ultra fine droplets. The observed volume filling flow behavior and relatively low mist drop-out and plating-out losses in flow-obstructed volumes shows the potential for selected fire protection scenarios as a total flooding agent.

Beyond the use of UFM as a stand-alone fire protection system, UFM can also be used in a hybrid system along with Nitrogen Enriched Air (NEA) as an integrated fire protection system. The FAA is currently looking at the feasibility of using an existing OBIGGS system to provide protection to inaccessible areas of the aircraft in case of in-flight fires, focusing on flow rates and purities of nitrogen enriched air (NEA) that should be available on different sized aircrafts [15-16]. The integrated UFM and NEA can effectively address issues such as weight, relatively low volume nitrogen production rates and improve the effectiveness of NEA for in-flight fire protection.

OBJECTIVE

The objective of this work was to conduct a feasibility study of the effectiveness of ultrafine water mist (droplets below 10 μm) as a total flooding agent in extinguishing fires in hidden areas focusing on aircraft attic space.

APPROACH

First, CFD modeling was conducted to explore and understand the ultra fine mist transport inside a mockup of attic space and estimate time-scales for the attainment of typical cup burner extinguishing concentrations for UFM reported earlier [10,11]. The input mist properties utilized included droplet size, mass flow, and mass loading of water in the inlet stream of the mist.

Next, experiments were conducted on the extinguishing behavior of UFM on energized cable bundle fires inside the mockup using a proprietary ultra fine water mist generator, NanoMist® [17, 18]. The experimental results of fire extinguishment time-scales were compared with time-to-attain minimum extinguishing concentration predictions of the CFD results.

CFD Work on Ultra Fine Mist Transport

727 mockup geometry provided by FAA Technical Center is shown in Figure 1. This geometry as used in the CFD work is shown in Figure 2A**.** CFD simulations used attic dimensions of 22 ft long, 6 ft wide and maximum height of 1 ft with a central duct of 21-inch x 6-inch along the length. The geometry was read as an IGES file into the Gambit preprocessor of the Fluent CFD package [19].

Figure 1: Courtesy - FAA Technical Center 727 Mockup for overhead (attic) space

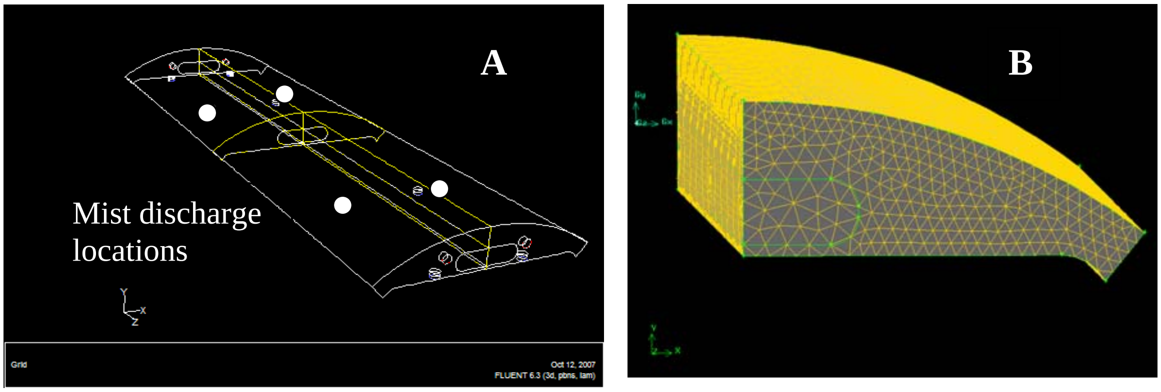

Figure 2: A) Attic space geometry and B) grid topology used for CFD

Four mist discharge outlets are located on the floor. Mist discharge is pointed upwards. The centerline has a tube of dimension as seen in original drawing from FAA. An unstructured mesh topology is shown in Figure 2B. The methodology and approach to the CFD simulations for UFM was explained in earlier work [3]. As described in prior work, a dense gas model approach was used to treat extremely fine mist droplets (below 10 μm) as opposed to a Discrete Phase Model (DPM) available in CFD packages. This modeling work was focused on exploring total flooding behavior of the mist as functions of mist mass loading under pre-determined ventilation conditions. The model explored the effect of mist mass loading of 10, 20, and 25 % with a mist flow rate of 1.0 LPM (liter/min).

The simulation results of the time-dependent mass concentrations of water within the attic space are shown in Figures 3A, B, and C. The centerline concentration inside the attic space for a mist discharge of 1.0 LPM with a 20% inlet mist loading is shown in Figure 3A at various times. Figure 3B shows the mid-level peak concentration for various mist mass concentrations. These results show a fairly steady concentration close to 60 s. Figure 3C shows the mapped concentration of water mass fraction in the middle-plane of the attic space. As seen, roughly after 60s, the concentrations are fairly steady. Based on extinguishing cup burner concentrations of 0.14-0.2 kg/m3 [10, 11], these concentrations are attained fairly quickly for mist mass loading above 20% or higher.

The CFD simulations are focused on ultra fine mist transport and concentration distribution rather than the extinguishing behavior of cable fires within the volume. The estimated time-to-attain extinguishing concentrations will be used as a rough estimate of extinguishing time scales in experimental fire tests inside the mockup. In a total flooding scenario, these predictions provide a meaningful trend in predicting the attainment of extinguishing concentrations for specific fire threats such as Class A (cable fires), class B (liquid fuel) and Class C fires.

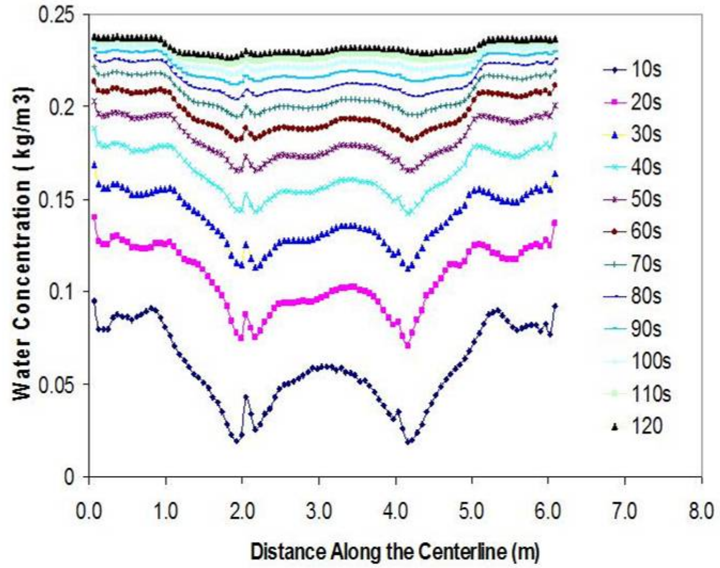

Figure 3A: Time dependent water concentration along the centerline of mockup

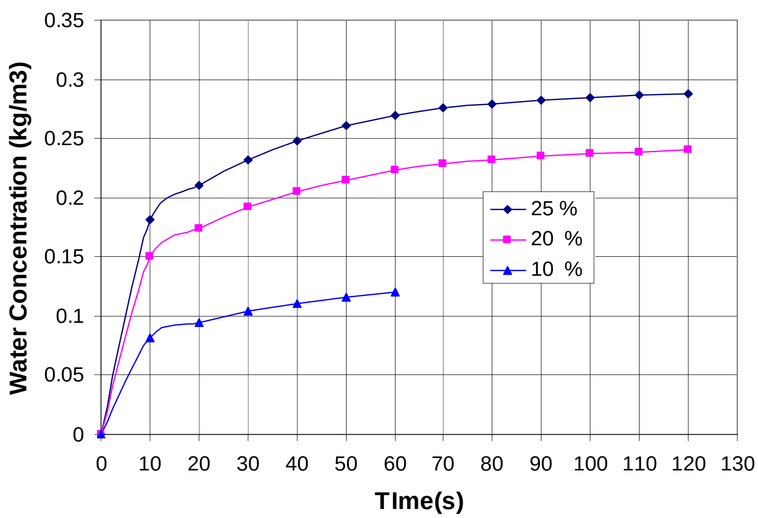

Figure 3B: Water concentration at mid-level for mist with different mass loading.

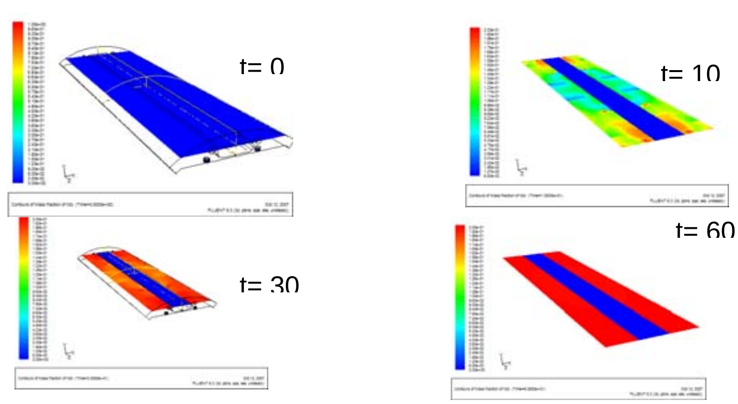

Figure 3C: Time dependent water contours at the mid-level of attic space

The next sections describes experimental work on cable fires in an attic space mockup and compare the actual extinguishing behavior with predicted time-dependent water concentrations by CFD modeling.

EXPERIMENTS

Test Mockup

The geometry of the mockup used for the fire tests was slightly modified relative to the top hemi-spherical geometry of the CFD model while keeping the volume and general shape close to the one used for CFD, and also the 727 attic space. The mockup is illustrated in Figure 4A. The volume of the attic space is ~ 160 ft^3 or 4.5 m^3.

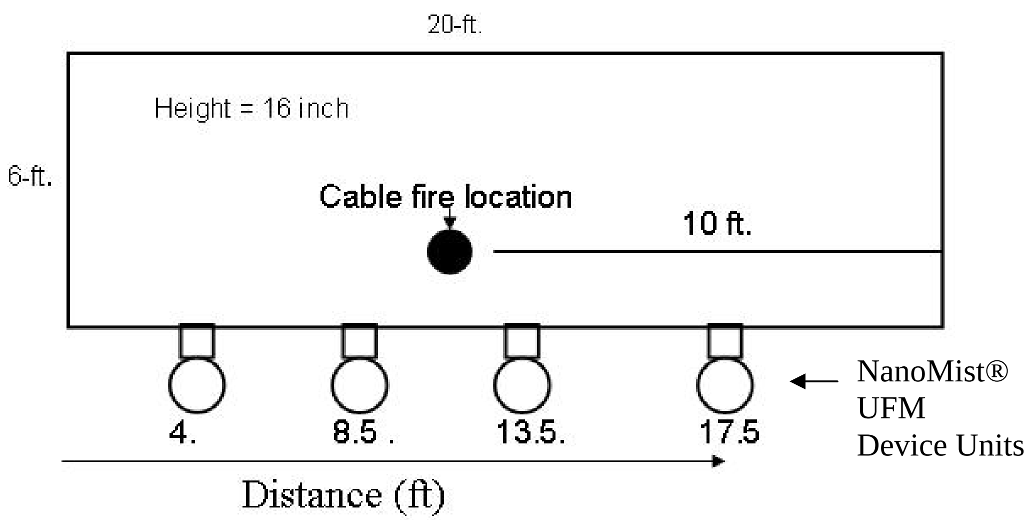

Figure 4A: Attic space fire test mockup

Figure 4B: NanoMist® ultra fine water mist generators

Nanomist® ultra fine water mist with 20% mist loading was discharged at four side inlets as shown in Figure 4A. The photographs of ultra fine mist generators are shown in Figure 4B. The total mist discharge capability was 1.00 liter per minute. The geometry also shows the cable fire location at the center of the mist inlet side of the central symmetry line.

A cable bundle fire was utilized in these tests. The cable bundle consisted of twenty-five or fifty pieces of 6-inch length of RG-6 coaxial cable with a nominal exterior diameter of 0.3 cm. The cable lengths were tied with three lengths of tie wire to a 500 Watt electric heating element as shown in Figures 5A and 5B. The heater was energized and left as such until the experiment was terminated. The setup is illustrated as shown in Fig 5A and Fig 5B. Four type K thermocouples were installed; one on the heater and rest hanging just (approx 1 inch) above the cable bundle. Cable bundles typically ignited within 3-5 minutes. In some cases, a pilot flame was used to ignite the bundles, if the cables did not ignite after about 4-5 minutes.

Figure 5: A. Cable bundle on the energized heater and thermocouples above it: B. Cable bundle after extinguishment of fire

Temperature histories were recorded for 20 minutes using Omega data loggers.

RESULTS AND DISCUSSION

Figure 6 shows the temperature history of cable bundles as a baseline case, without using UFM discharge. The thermocouple contacting the heater shows a relatively steady temperature of about 800 C. Cables bundle ignited ~ 5 min after turning on the heater. Fire temperatures were close to 800 C or lower depending on the location and unsteady fire movements. In the absence of any suppression agent, the fire continued for at least 12 minutes.

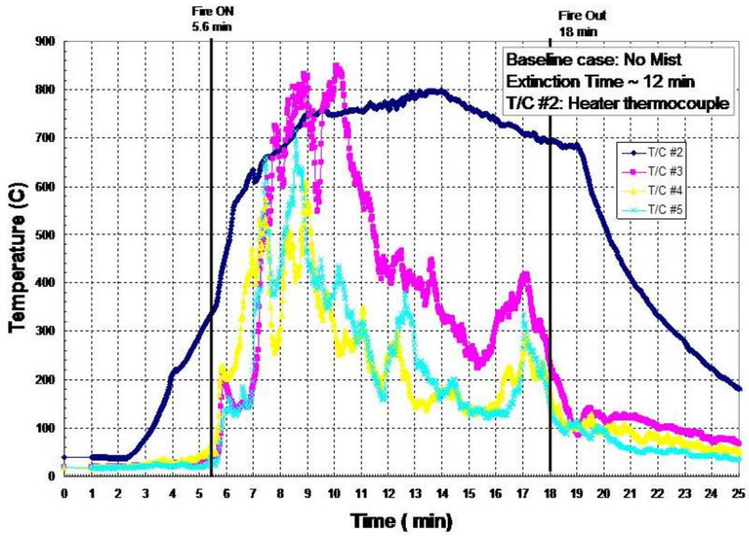

Figure 6: Temperature history of baseline cable fire scenario, without mist discharge

Figure 7 shows the cable fire scenario with 200 ml/min of mist discharge. The mist discharge location was the left-most in Figure 4 (4-ft from left). The mist was not effective in extinguishing the fire even up to 9-minutes. Please note that the cable bundle burns for 12 min without a suppression agent as shown in Fig. 6 -baseline.

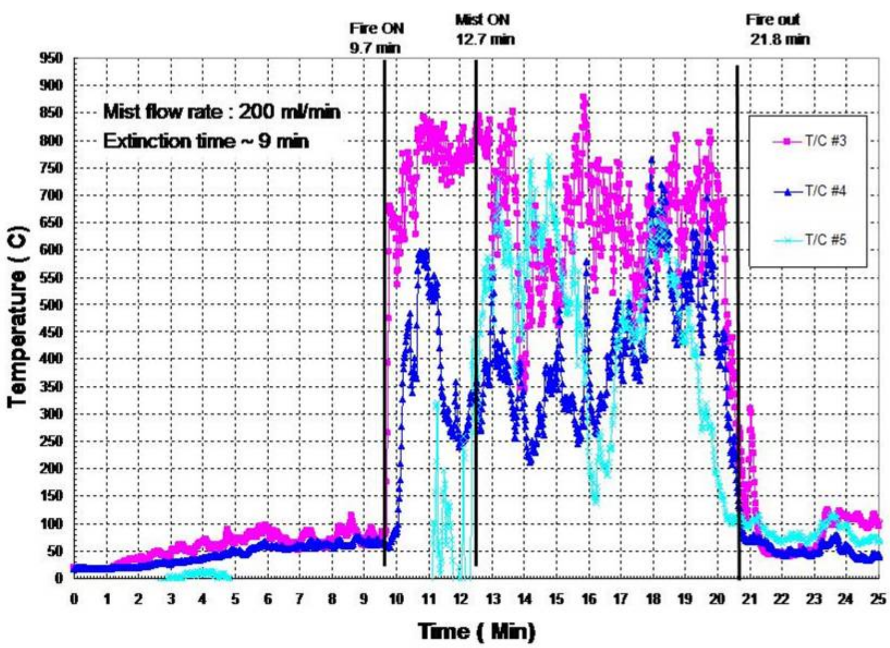

Figure 7: Temperature history of cable fires: 200 ml/min mist discharge

Figure 8 shows cable fire behavior at higher mist discharge rate, 430 ml/min. As seen, the fire was out within 1-minute.

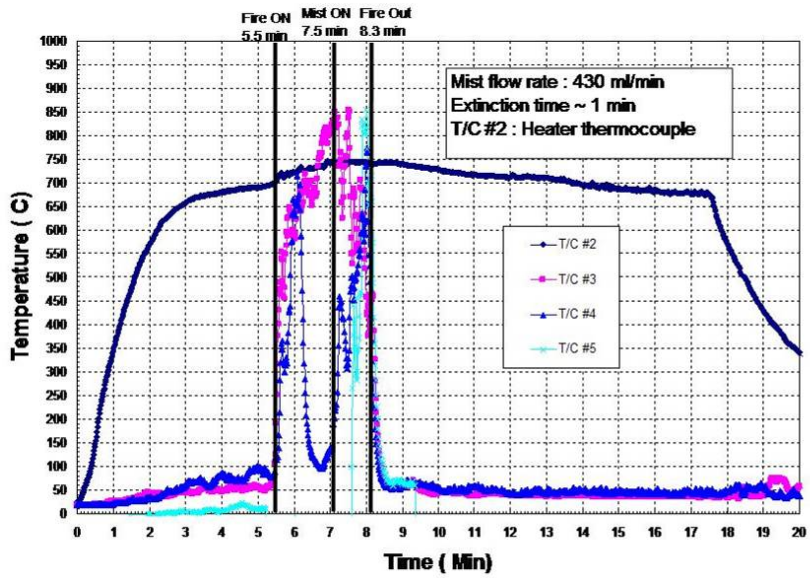

Figure 8: Temperature history of cable fires: 430 ml/min mist discharge

Figure 9 shows yet a higher mist rate of 670 ml/min, but also used a cable bundle with about twice the mass (50 cut pieces of cables of 6-inch). The extinguishment was quick, less than a minute. The extinguishment time of cable bundles above a certain mist rate of 200 ml/min is significantly low.

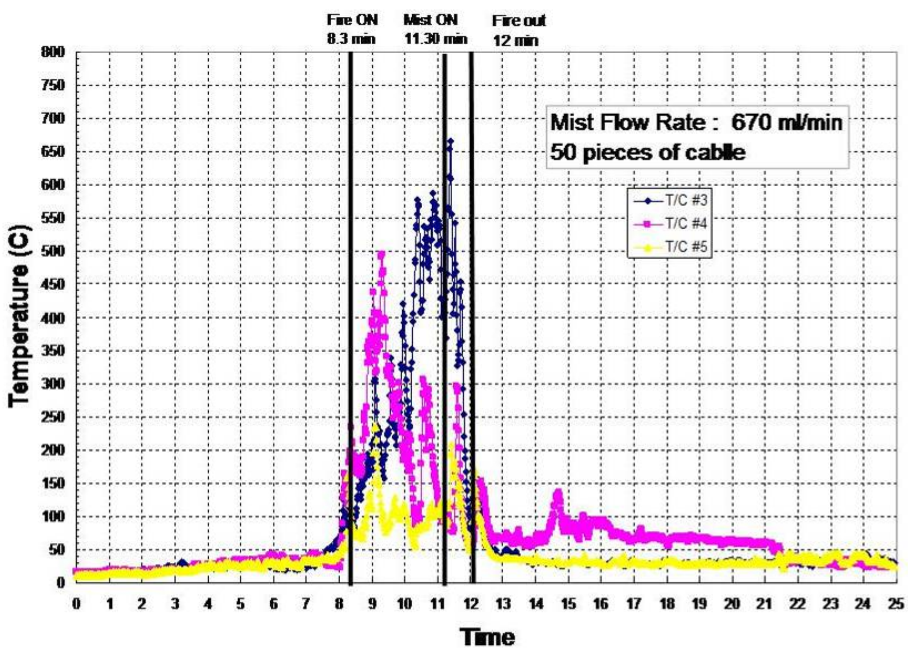

Figure 9: Temperature history of cable fires: 670 ml/min mist discharge; roughly twice the mass of cable bundle used in Figure 6-8.

The extent of cable burn-through and the degree of damage can be qualitatively assessed by looking at samples before and after the test, as shown in Figure 10.

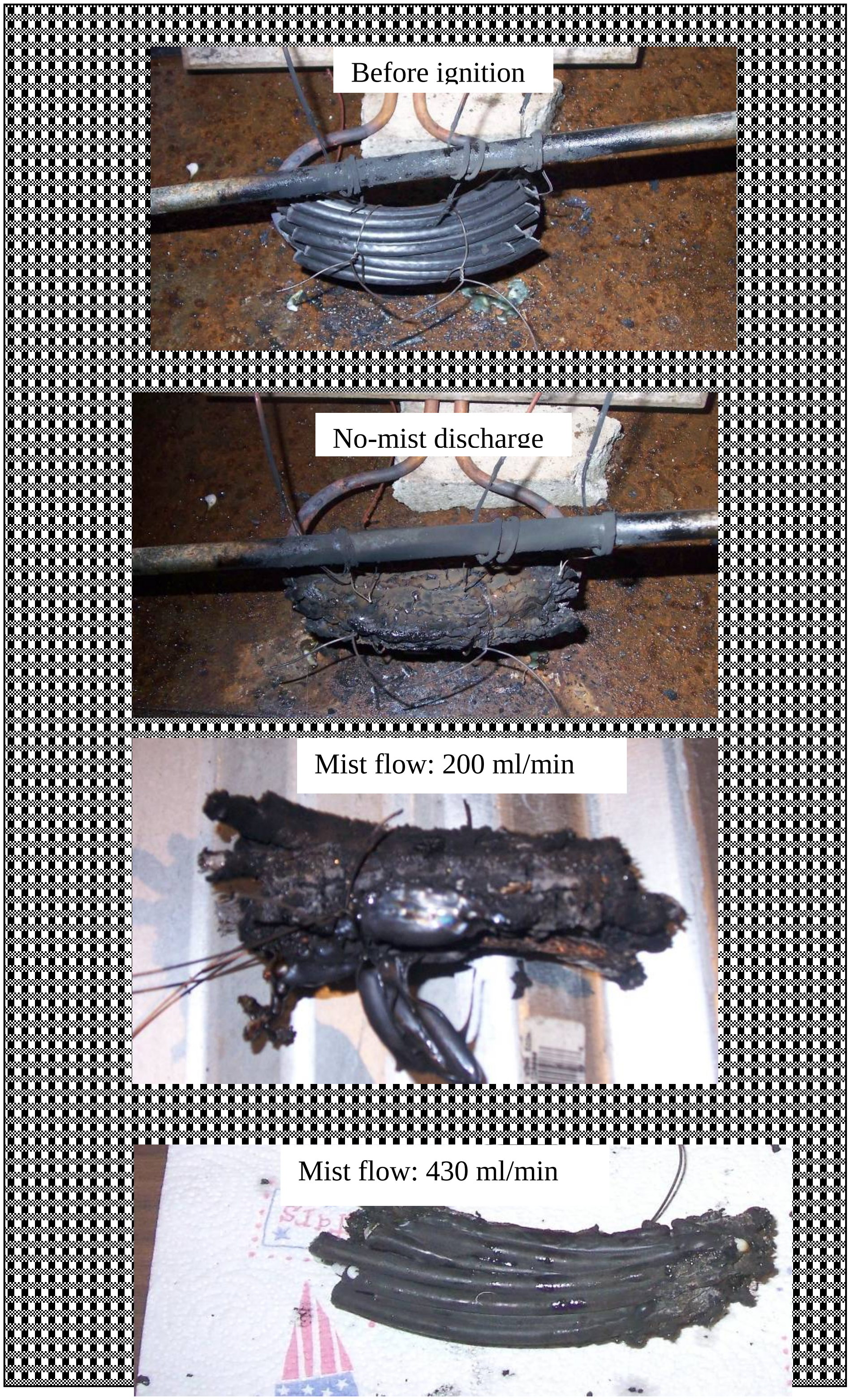

Figure 10: Cable bundle burn through photographs at various mist flow rates

The photographs show cable samples recovered after the test. They show a decreasing degree of burn-through (or damage) with increasing mist mass flux, consistent with the temperature histories of the various cable fire scenarios Figs 7-9.

Figure 11 shows similar behavior at a higher cable mass loading and a higher mist flow rate. These residual cable bundles reflect the capability of UFM (Nanomist®) to suppress fires at fairly low mass flow rates such as 400-700 g/min.

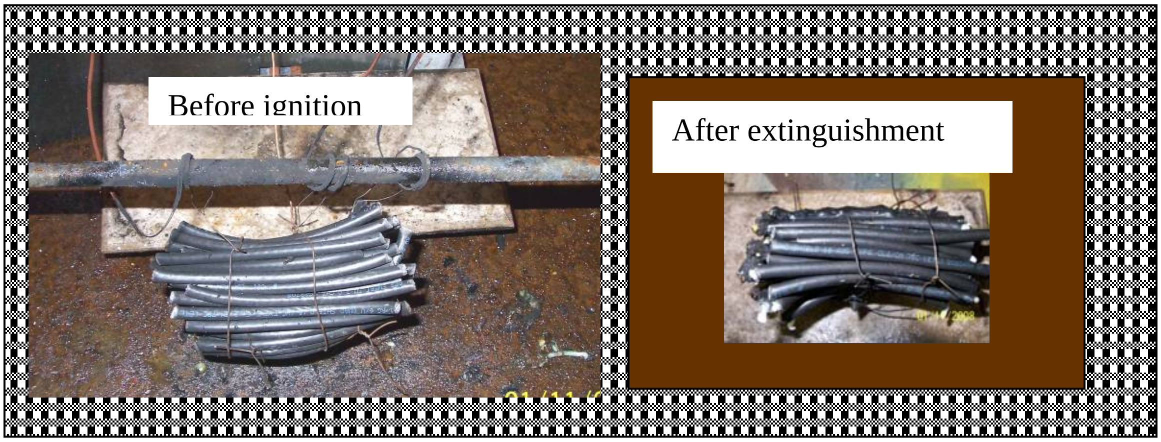

Figure 11: Cable bundle, roughly twice the mass used in Figures 6-8 at mist flow of 630 ml/min

CONCLUSIONS

CFD modeling results of the total flooding behavior of ultra fine water mist inside a 727 aircraft attic space mockup showed that a target extinguishing concentration of approximately 0.14-0.2 L/m3 is attained fairly quickly (within 1-minute), at a mist flow rate of 1 LPM and mass loadings of 20-25 %. The time dependent concentration distribution depended on the inlet mist flow rate (LPM) and mist mass loading in the discharged mist. Experimental extinguishment behavior of energized cable bundles using proprietary UFM water mist generator, NanoMist®, showed similar extinguishment times. The results showed that the extinguishment times depend on the time taken to attain the UFM minimum extinguishing concentration similar to a gaseous total flooding scenario. Future work will focus on detailed CFD work and hybrid NanoMist® and nitrogen mixtures.

ACKNOWLEDGEMENTS

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