Challenges and Implementation of a Long Horizontal Water Mist Discharge System

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Introduction

The U.S. Air Force is planning to retire the currently installed Halon 1301 fixed fire protection systems from Aviation Engine Test Facilities (AETF), also known as hush houses. Due to its high ODP (Ozone Depleting Potential), Halon 1301 is no longer manufactured and existing installations are being progressively phased out. Replacement of Halon 1301 has spawned numerous research activities in the past 15 years to identify one or several viable replacements[1]. Water mist is one of the possible technologies under consideration. Water mist is a promising alternative both from technical and environmental standpoints but has had difficulties gaining traction outside a few niche markets. Cost is often cited as a hurdle to wider deployment as water mist usually requires stainless steel piping to limit corrosion issues. Water mist has also frequently been designed and implemented assuming an overhead discharge position. In certain situations however, a horizontal discharge, rather than vertical, might be more desirable, both for performance and cost reasons. For example, in the case of a fighter jet engine test facility, the jet's wings usually present a large horizontal surface to overhead nozzles potentially shielding an underbody fire. Discharging water mist from the building sides would allow the mist to more easily reach fires beneath the wings, where it can better fight a fire and cool the wing surfaces in the process. Modern composite aircraft surfaces need to be effectively thermally managed in order to avoid irreversible and costly damage to the structure. The maximum allowable temperature for such materials is generally believed to be about 250°C for a maximum of 30 seconds[2]. In a horizontal discharge configuration a key challenge to be overcome is for the mist to travel sufficiently far horizontally to reach the center of the test enclosure. From a cost standpoint, that approach is also attractive. It drastically reduces the length of piping to be installed since no nozzle would need to be installed higher than approximately the wing height (8 to 10'). Moreover, the concrete floor would not need to be broken to install pipes and nozzles to protect the underbody area. In order to adequately protect the entire floor area of a USAF hush house, a horizontal throw of 35 feet needs to be achieved (Figure 1). This paper presents an innovative and effective approach to water atomization and discharge to deal with this challenge, and is supported by both experimental validation and state-of-the-art CFD modeling.

Experimental demonstration

The ADA team was able to generate a water mist plume capable of travelling horizontally over 35 feet using a two-phase flow approach largely compatible with NFPA 750, operating between 200 and 400 psi, in what is defined as the intermediate pressure range by the standard (Figure 2).

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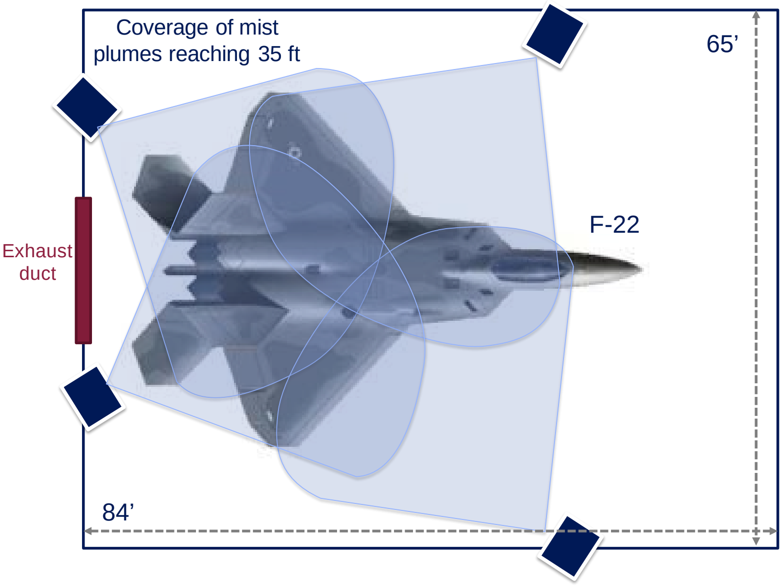
[1] Gann, R.G., "Next Generation Fire Suppression Technology Program (NGP) Collected Publications", NIST Special Publication 1069, National Institute of Standards and Technology, Gaithersburg, MD, June 2007

[2] J.L. Sheffey; Extinguishing Agent Alternatives to Address Environmental Concerns; International Forum on Fire Protection and Risk Management; Singapore, January 26, 2000.



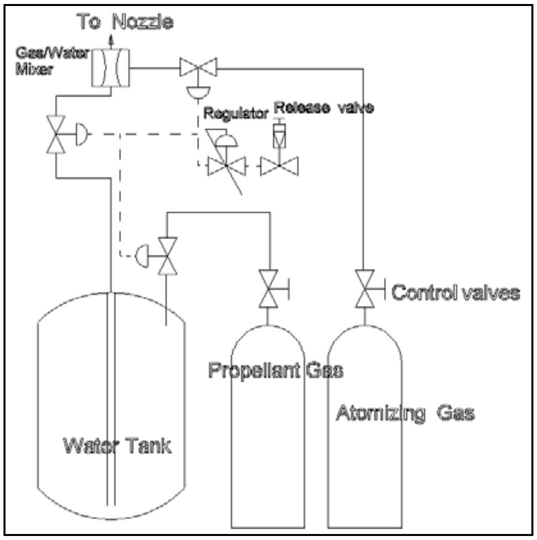


Figure 1: Sketch of desired water mist coverage **Figure 2: Diagram of the experimental water mist module**

A critical technological element not considered in the current NFPA standard is the mixing of water with an atomizing gas *upstream* of the nozzle to produce a two-phase flow at the nozzle *inlet*. This effervescent mixture then travels through the nozzle and upon exiting the nozzle orifices, generates water ligaments that are immediately shattered by the expanding action of the atomizing gas. The resulting water mist is made of fine droplets, primarily below 100 microns, has high velocity, and benefits from the rapid gas expansion to maintain its momentum via droplets entrainment. This effect is able to overcome the significant drag force exerted on the droplets by the ambient air. The water mist generated in this fashion was observed to travel the required 35 feet (Figure 3). In fact, under certain experimental conditions the mist can be projected beyond 40 feet before the droplets lose their momentum. The proof-of-concept system built for these experiments covers a sector of roughly 90 degrees, over a distance of 35 feet as illustrated in Figure 1. At this early point in the project, two identical prototype modules have been built. The successful demonstration of the long horizontal mist throw mostly using off-the-shelf parts now allows the team to progress to the next stage of the project which is to evaluate the cooling and extinguishing capabilities of these modules in relevant fire scenarios. The results will guide the final system design and sizing for a complete installation protecting hush house in lieu of the current Halon 1301 system.

Figure 3: Demonstration of 35 feet throw

Water Mist Plume Modeling

Detailed CFD modeling of both the gas-water mixing region and Lagrangian particles in the near and far field provide additional insights into the physics of the generation of the high-velocity two-phase flow and the transport of the water mist droplets in quiescent air. A two prong approach is taken with regards to the numerical simulation of the water mist system due to the differing size scales involved.

The first portion to be modeled is the mixing region upstream of the nozzle and the nozzle itself. In this region, the Volume of Fluid models in Fluent are used to simulate the mixing of the water and gas phases. This two-phase flow then travels through the system nozzle, where it is broken into droplets. Figure 4 shows a two dimensional Cartesian simulation of the mixing region. This calculation was run as a proof of concept for the methods to be used in modeling the mixing region. The figure shows the density of the materials and their non-linear interactions as they flow from left to right through the mixing region. It is clear that the water and gas are well mixed before entering the nozzle, which would exist at the far right end of the mixing region. Due to the complex nature of the geometry, three dimensional calculations will be required to accurately model this complex flow. Once the simulations are complete, the droplet sizes and velocities can be used as input into the second phase of the numerical modeling.

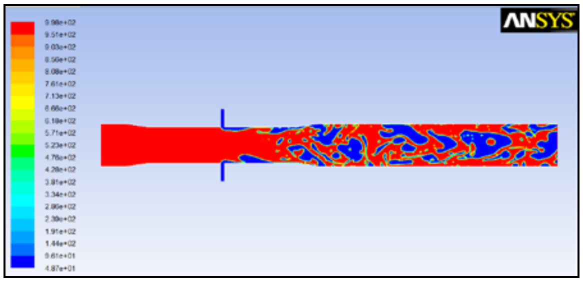


Figure 4. Fluent Simulation of the Mixing Region

The second portion deals with the modeling of the water droplet distribution and horizontal throw of the mist, once discharged from the nozzle. The package used for this numerical modeling and analysis is OpenFOAM, a free and open source CFD toolbox. It can solve complex fluid flow problems such as multiphase flows involving turbulence, heat transfer and chemical reactions. The dieselFOAM solver was selected for this task. Water mist droplets were modeled as Lagrangian particles which can be tracked through time and space. Since droplet tracking is a computationally intensive process, the problem was executed in parallel utilizing many processors. The model includes inlets for the gas, Lagrangian injectors for water droplets and a room of initially quiescent air. Inlets and injectors represent the actual nozzles, having the same diameters, orientation angles, flow rate and pressure. The model injector type is the common rail injector, which calculates the injection velocity for the droplets based on the pressure inside the nozzle. Water droplet distribution exiting the injector nozzle follows the Rosin-Rammler distribution with maximum diameter of 100 microns, minimum of 10 microns and a mean of 70 microns. The droplets are subjected to a standard drag model which effectively reduces the velocities of the droplets throughout their paths. Meanwhile, the gas enters the room through the inlets with velocities dictated by mass flow rates and inlet pressures. The gas imparts additional momentum and serves as carrier fluids for entrained droplets enabling them to travel further. Preliminary simulations confirm the experimental observations that the proof-of-concept system can deliver water mist beyond 10 meters (30 feet).

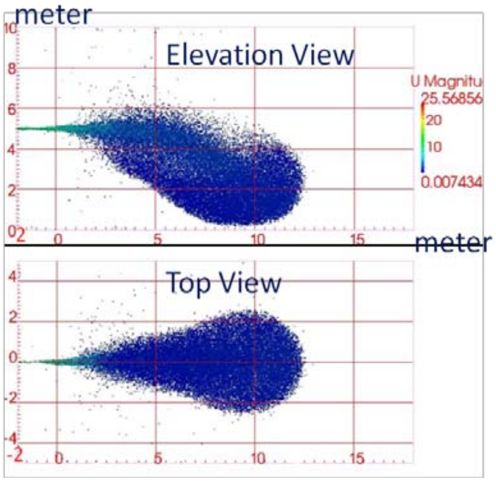


Figure 5. OpenFOAM modeling of the Water Mist plume penetration

Conclusions

At this point of the project, it appears that water mist discharged horizontally at distances over 35 feet is technically feasible. This mode of discharge may offer an attractive alternative to traditional overhead water mist discharge in specific fire hazards situations.

Acknowledgment

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