

## MODEL DEVELOPMENT FOR PREDICTING FIRE HOSE STREAM CHARACTERISTICS

Y. Zheng, 240-688-4638, yzheng94@gmail.com

N. Ryder\*, A. W. Marshall

Department of Fire Protection Engineering, University of Maryland, College Park, MD, USA

\*Delta Q Fire & Explosion Consultants, Inc.

### **Introduction**

Fire hose streams are used as the primary weapon for fire fighting. These hose streams deliver water to fire targets in order to control and ultimately extinguish the fire through wetting and cooling of burning materials. The suppression performance of the fire hose stream is determined by its ability to deliver water to burning targets possibly over long distances and even with interference such as wind or fire plumes. The initial drop size and velocity characteristics are critical to the throw (or the penetration) and dispersion (or coverage) of the hose stream. Meanwhile, the initial spray of the hose stream depends largely on the nozzle configurations and injection conditions. Despite the wide application of the fire hose system, there has been little research on the hose stream characteristics and the fire extinguishing mechanism [1-4]. Most of the designs of the nozzles are based on NFPA codes and the usage by the fire fighters in the real fire scenarios is from empirical experience. Research on the hose stream behaviors could provide a deeper understanding of the relationship between spray characteristics and nozzle geometry for manufactures to design hose nozzle with optimal spray patterns for specific fire scenarios. At the same time, study on the effect of injection conditions on hose stream also provides insights for firefighters to improve the firefighting tactics.

### **Experimental Study**

A scaled fire hose system (Fig. 1) was established to study the discharge characteristics of the initial sprays from fire hoses. The configurations of the smooth bore nozzle system (size of the nozzle, flow rate of the pump, pressure lose) were designed to produce a stream in the shear breakup mode, consistent with real hose streams. The experiments were conducted at the midpoint between the nozzle exit and the solid core breakup location. Images of the liquid jet and resulting spray are recorded and processed using a LaVison shadowgraphy-based direct imaging system, which gives the drop size and velocity distributions. A patternator was used to measure the spatial distribution of volume flux in the horizontal direction.

### **Analytical Modeling**

An analytical model was developed to predict the penetration and the dispersion of the spray. The physics based modeling approach will meet the transport dynamics of the core, spray and entrained air. The model consists of sub-models for the core trajectory, the spray, and the coupling between the air and the spray along with the trajectory. The sub-model for the core trajectory was first developed and coupled by a spray sub-model, with estimated mass loss and drag force from the surrounding air. The sub-model for the entrained air calculation was then developed to couple the spray with the surrounding air. The model iterates until it reaches a steady state, which produces reasonable air velocity. This analytical hose stream model provides the core trajectory, core column flux, core diameter, spray volume flux, drop velocities and diameters. Since the model has the ability to obtain results in a short time capability, it will allow real time update for the stream simulation, which wouldn't be achievable for any other method.

### **Results and Discussion**

As shown in Fig. 2, images of the stream at different locations are captured and post-processed by the imaging system. Disturbances appear on the surface of the liquid jet right after the nozzle. Drops start to form along the liquid core, which disintegrates into major ligaments and drops downstream. The volume flux of the spray at the midpoint of the core breakup distance (Fig. 2c) was analyzed and found to decrease radially away from the liquid core. A high flow inner region and low flow outer region around the liquid core were defined according to the volume flux value. Drop characteristics at the same location were also investigated. The characteristic drop diameter,  $d_{v50}/D$ , was found to be 0.13. Drop size was found to be close to symmetric with respect to the liquid core and with larger drops in the high flow region. The streamwise drop velocity was found to decrease vertically further from the liquid core.

The trajectory of the hose stream with an injecting angle of  $32^\circ$  is calculated using the Physics Based Model. As shown in Fig. 3, the predicted trajectory agrees well with the result from experimental test [5]. During the model calculation, the drag force term on the liquid core is varied to produce appropriate amount of drag force which brings in the deviation between the theoretical (without any drag) and the actual trajectory. Fig. 4 illustrates the hose stream with core and spray calculated by the Physics Based Model. The mass loss rate is set larger than 1 to allow the core of the stream end before it touches the floor. In this case, the length of the core is about two thirds of the whole spray path. The plotting of the core is according to the core diameter and the color on the core surface represents the core velocity, which decreases when the core climbs up and increases when the core goes down. The drops are generated on the core surface by a drop generating sub-model, and are tracked by a drop tracking sub-model. The diameters of the drops are determined according to a combination of log-normal and Rosin-Rammler distributions. The spray from the Physics Based Model agrees well with a real life hose stream, with consistent drop size and velocity distribution, core breakup location. This information is used to calculate the coverage of the water spray on the target applied by the hose stream, which will be compared with the experimental water distribution on the target.

## Conclusion

In this study, a scaled fire hose system and an analytical model were investigated to study the discharge characteristics of the initial sprays from fire hoses. The experimental study provides core and spray characteristics, including drop size and velocity distribution, volume flux distribution, which is used as supporting data to develop the analytical model for predicting the penetration and the dispersion of the spray. The model consists of sub-models for the core trajectory, the spray, and the coupling between the entrained air and the spray. Furthermore, the column trajectory, core column flux, core diameter, spray volume flux, drop velocities and diameters can be obtained by the model as well.

## Reference

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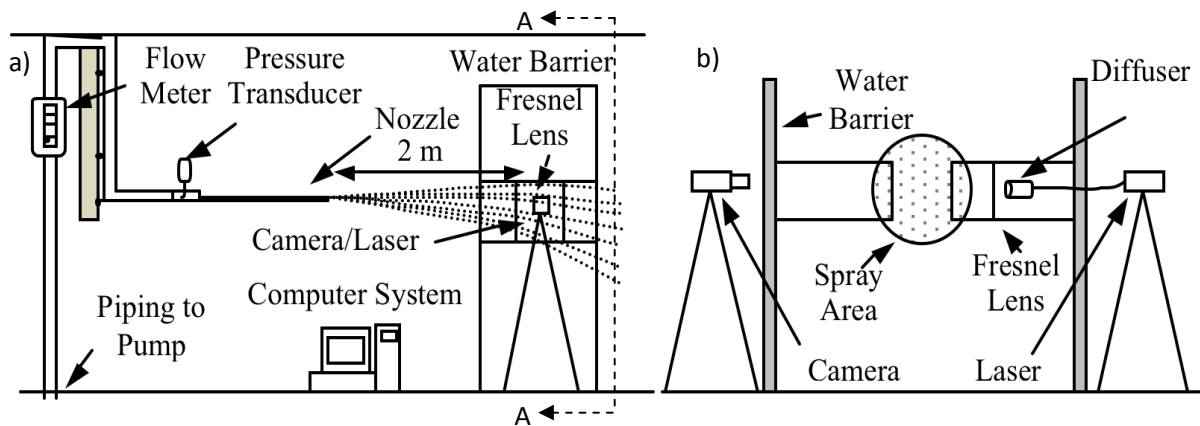


Fig. 1. Schematic diagram of the experimental setup a) Side view b) A-A view

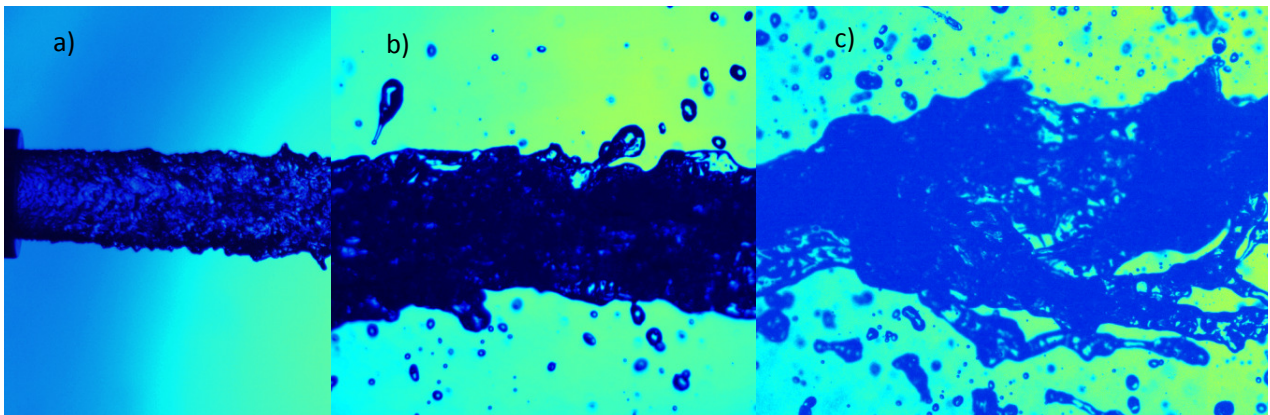


Fig. 2. Visualization of the hose stream, with nozzle diameter ( $D$ )  
 a)  $x/D=0$  b)  $x/D=76$  c)  $x/D=317$

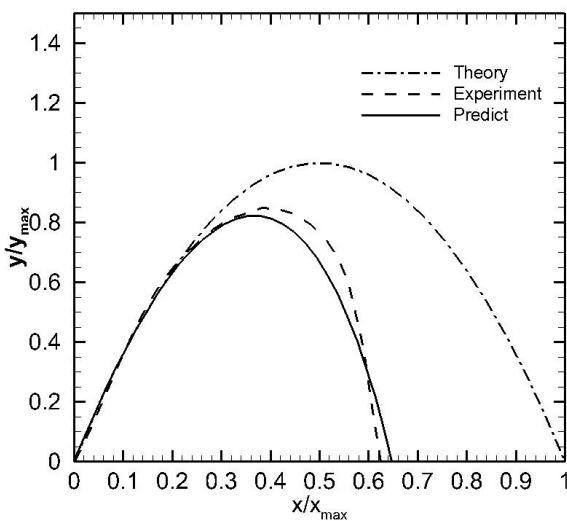


Fig. 3. Stream trajectories comparison

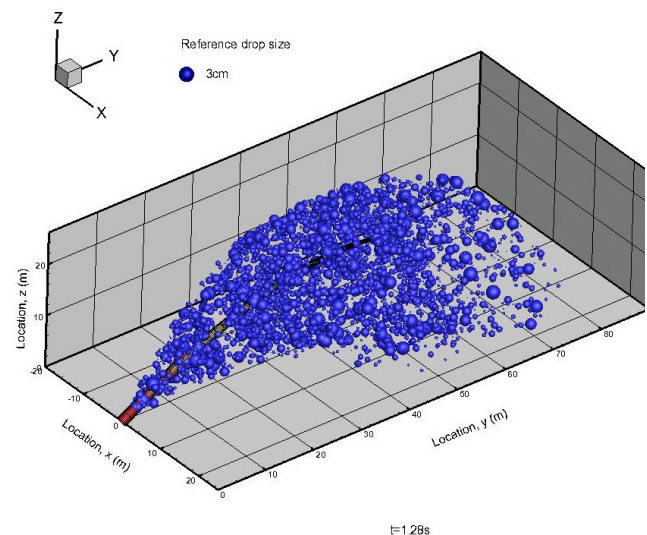


Fig. 4. Prediction of the hose stream with sprays