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POSTPRINT

ULTRA HIGH PRESSURE (UHP) TECHNOLOGY (BRIEFING SLIDES)

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Ultra-High-Pressure (UHP) Technology

Air Force Research Laboratory (AFRL)
Fire Research
25 Aug 2008

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Background



- Planned Experiments
 - Combined Agent
 - AFFF
 - CO₂
 - 100 bar to maintain liquid CO₂
- Control experiment AFFF only
 - Startling Results
 - 70 m² fire
 - 15 l AFFF solution



Since the discovery of the unprecedented effectiveness of 1500 psi Ultra High Pressure (UHP) technology in September of 2002 , AFRL scientists and engineers have sought to increase Aircraft Rescue Fire Fighting (ARFF) performance by moving to higher flow rates to obtain greater throw distance and the ability to fight larger fires. In addition, engineers wanted to develop equivalency or surpass the throw distance of the existing P-19. This has been done with UHP throw distance of approximately 225 ft achieved compared to about 180 for the standard P-19. It is important to remember that a standard P-19 is flowing a stream of agent from a roof mounted turret at 500 gpm compared to 300 gpm from the bumper turret of the upgraded UHP fire truck.



Background



Nov 2002: 14 gpm prototype



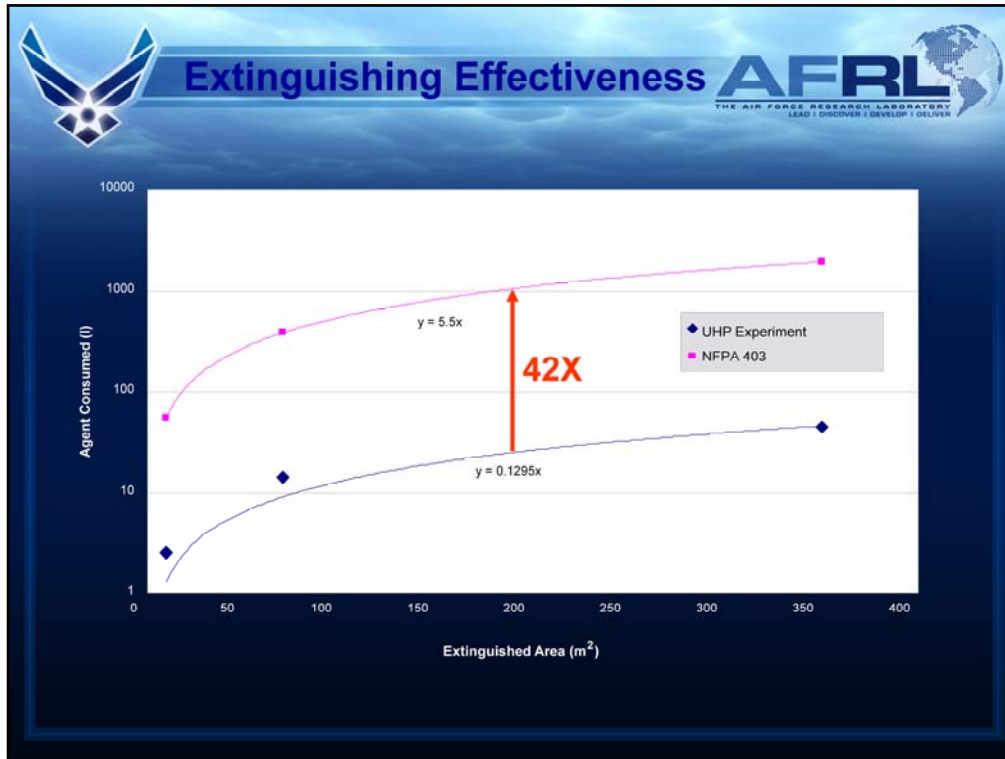
Mar 2003: FRE-Fire deployed in Iraq



Aug 2004: First fire truck 200 gpm
UHP T1500 TRL4

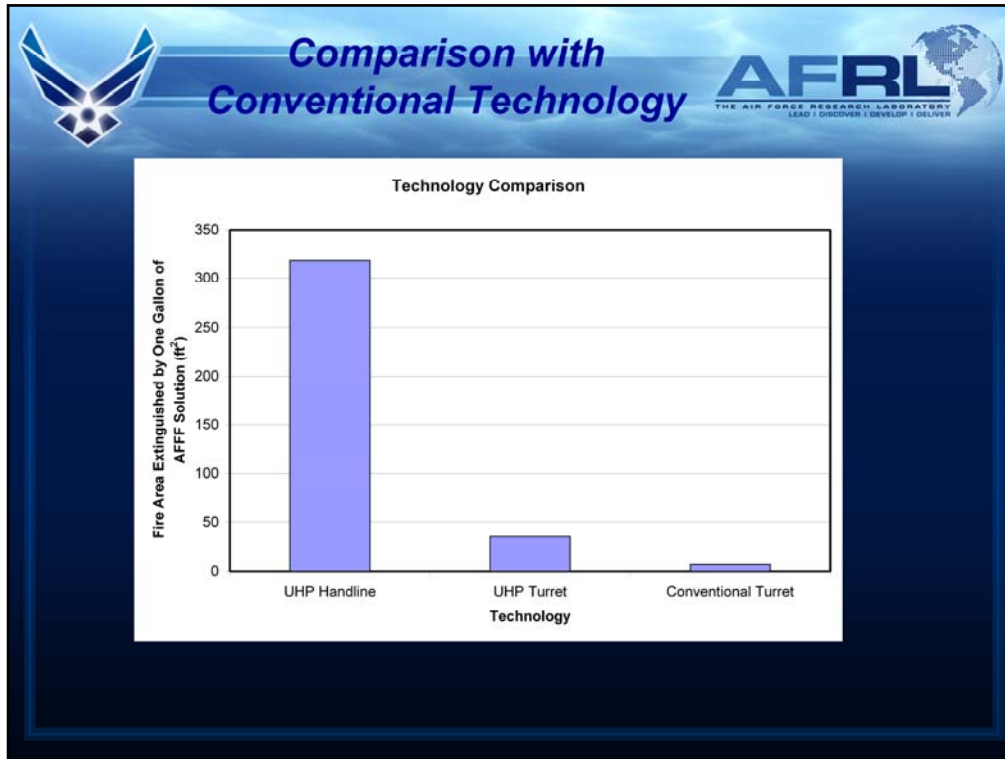


Apr 2004: Scale up
- 100 gpm UHP Skid

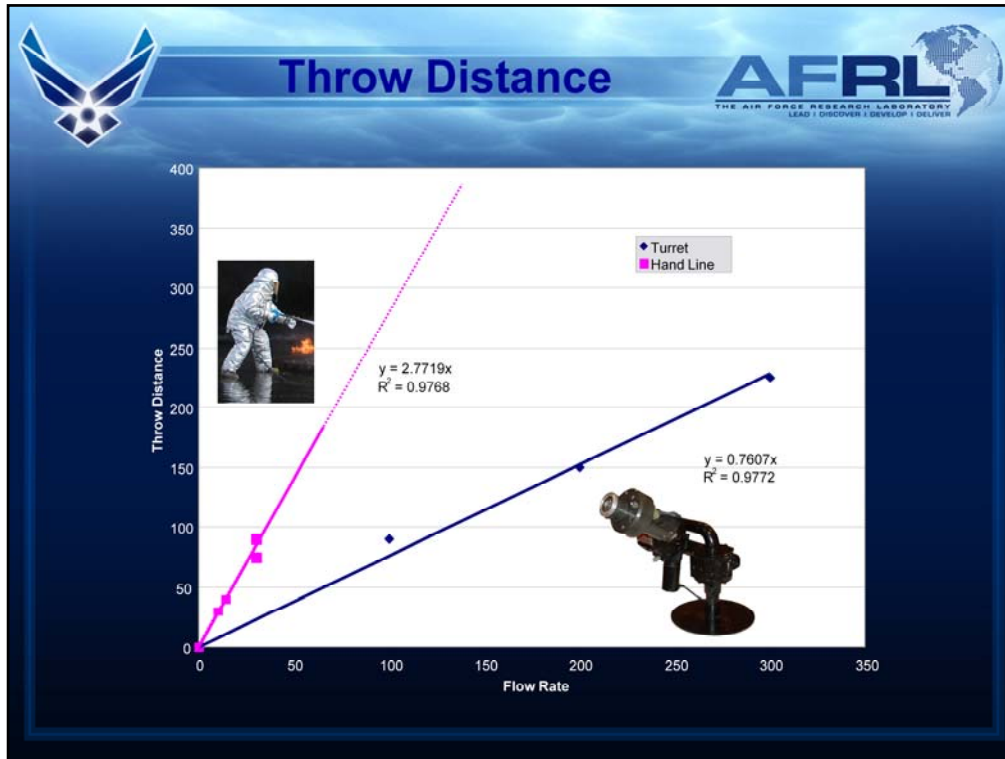


AFRL personnel in cooperation with the equipment manufacturer Rosenbauer America first demonstrated unprecedented fire fighting capabilities on an experimental 10 gpm, 1500 psi fire fighting system that required a two man team of fire fighters using a hose and nozzle (hand line) to operate in close (15 to 30 ft) proximity to burning JP 8 fuel. In these experiments, three to four gallons of 3% Aqueous Film Forming Foam (AFFF) solution would consistently extinguish more than 700 square feet of burning JP 8. Using National Fire Protection Association and Federal Aviation Administration performance ratings for AFFF fire fighting this should have required somewhere between 50 and 100 gallons of the same 3% solution.

Based on these experiments the lab constructed a prototype field deployable fire fighting apparatus based on a 14 gpm, 1500 psi pumping system mounted on a John Deere military gator all terrain vehicle (M-Gator). With a slightly higher flow rate and throw distance fire fighting teams regularly extinguished a 3500 square foot semicircular JP 8 fire in 40 to 50 seconds using eight to eleven gallons of AFFF solution. Using the performance rating listed above, standard ARFF technology would have required 250 to 500 gallons of solution. Based on worst case comparisons UHP technology provides more that 20X improvement in performance.

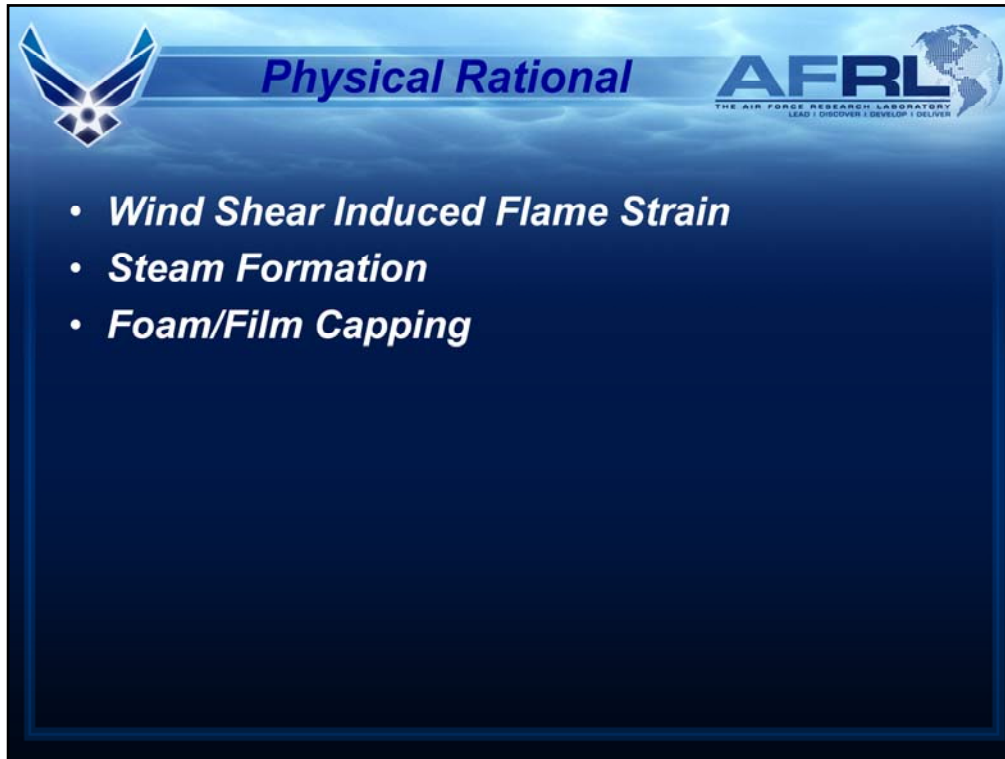


Steam Formation and Foam/Film capping are also major contributors to the extinguishing capability of conventional AFFF technology. The significant difference between UHP and conventional technologies must be the result of the high velocity of the UHP stream.



ARFF fire fighters normally respond to an aircraft crash with very large 1500 to 4500 ARFF vehicles with flow rates of 750 to 1600 gpm. These high flows require trucks equipped with remotely operated exterior turrets. The throw distance of these turrets ranges from 200 to about 350 feet.

During 2003, AFRL started a program to scale up UHP technology with the objective of providing sufficient throw distance for ARFF vehicle application. This required the development of an entirely new generation of turrets and nozzles suitable for operation at 1500 psi versus existing 200 to 300 psi rated equipment. This development was possible only with close cooperation from key turret and nozzle manufacturers, Elkhart Brass and Akron Brass. The scale up took place with incremental increases of flows first 100 gpm, then 200 gpm and finally in 2006 to 300 gpm on the P-19 UHP ARFF truck.



There are several explanations for this difference in performance.

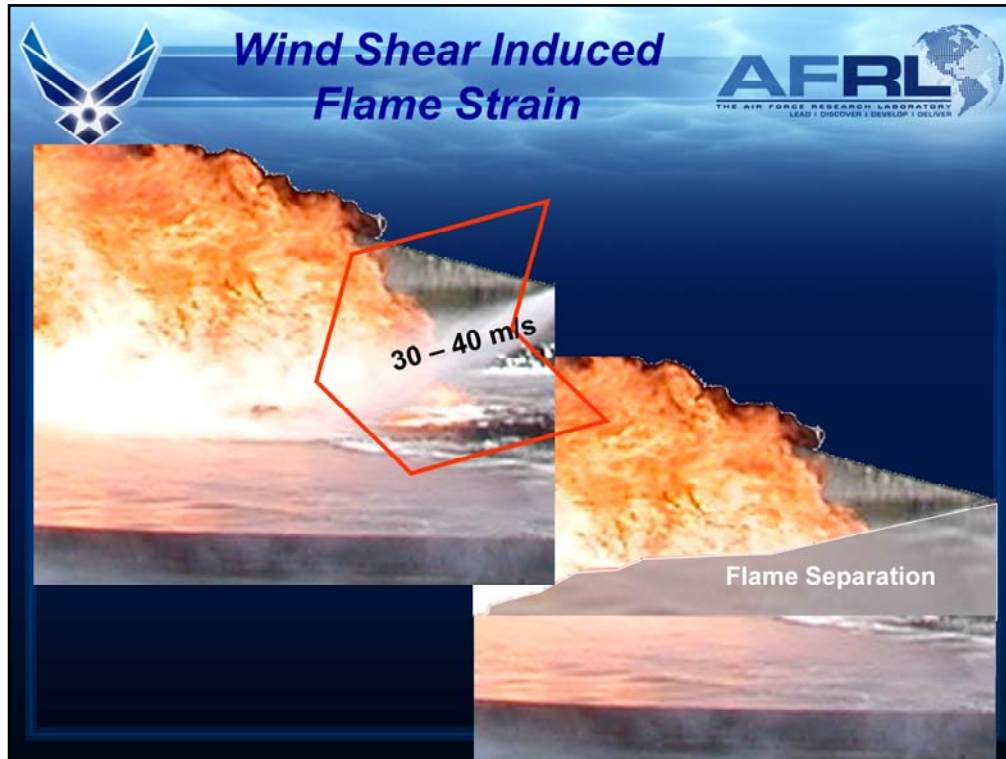
Improved aiming ability because of hands on fire fighter control

For UHP Turret applications, throw distance is the dominant requirement for success.

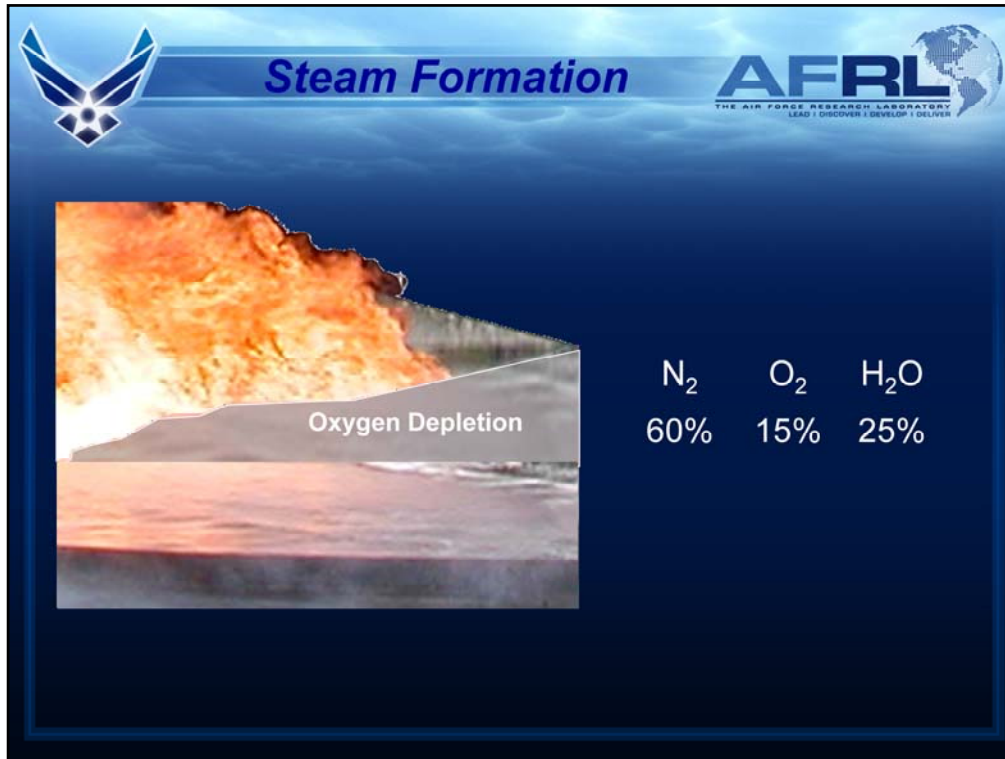
Throw distance is directly proportional to mass and velocity, and inversely proportional to drag and consequently is a function of flow rate when nozzle velocity is constant.

Extinguishing Mechanism

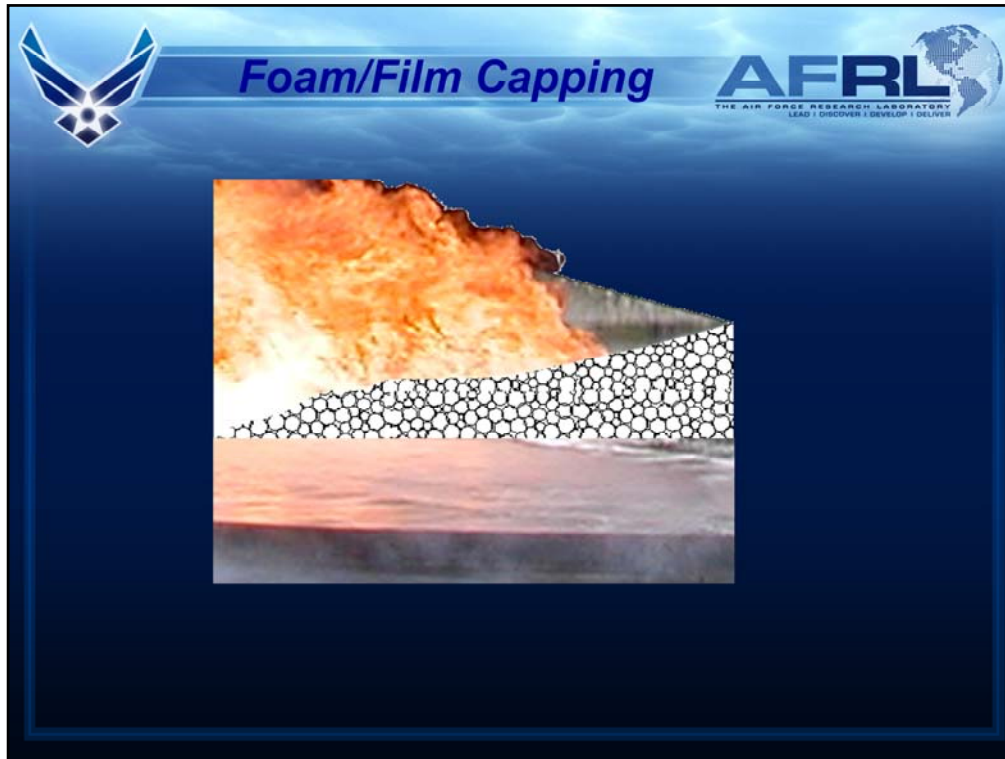
At this time, fire extinguishing with UHP technology has not been numerically modeled and an exact extinguishing mechanism defined. However, a notional model has been published.[1] In this model, three specific components contribute to the overall effectiveness of UHP technology.



UHP technology is based on moving a substantial mass at a high velocity. For example the mass flow at 300 gpm is more than 40 pounds per second and the velocity, about 300 feet per second or 200 miles per hour. As soon as the mass leaves the nozzle it begins to interact with surrounding air, transferring kinetic energy and decreasing in velocity. At the same time, masses of air are being accelerated (entrained) with the water jet. When the water/air stream interacts with the fuel vapor at the fuel flame interface the flame separates from the fuel leaving the fuel to cool and reduce vapor formation.



As the water stream interacts at the fuel/flame interface the water evaporates, removing some heat, but also converting to steam which displaces air and reduces the oxygen concentration to a point where temporarily the fuel vapor/steam/air mixture is too lean to reignite.

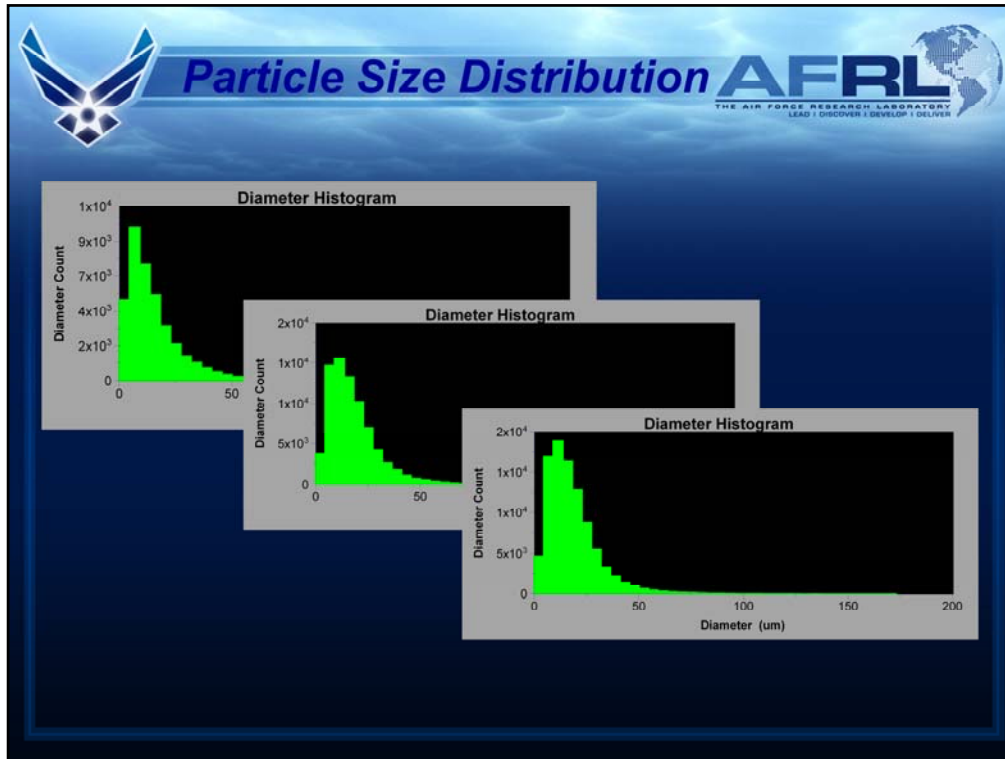


A foam blanket is distributed below and behind the high velocity jet in the area where the fire has been extinguished. This foam insulates the fuel from the flames and acts as a thermal radiation barrier. In addition, the foam puts a film of water on top of the fuel, sealing the fuel below the surface and preventing fuel vapors from mixing with the air.

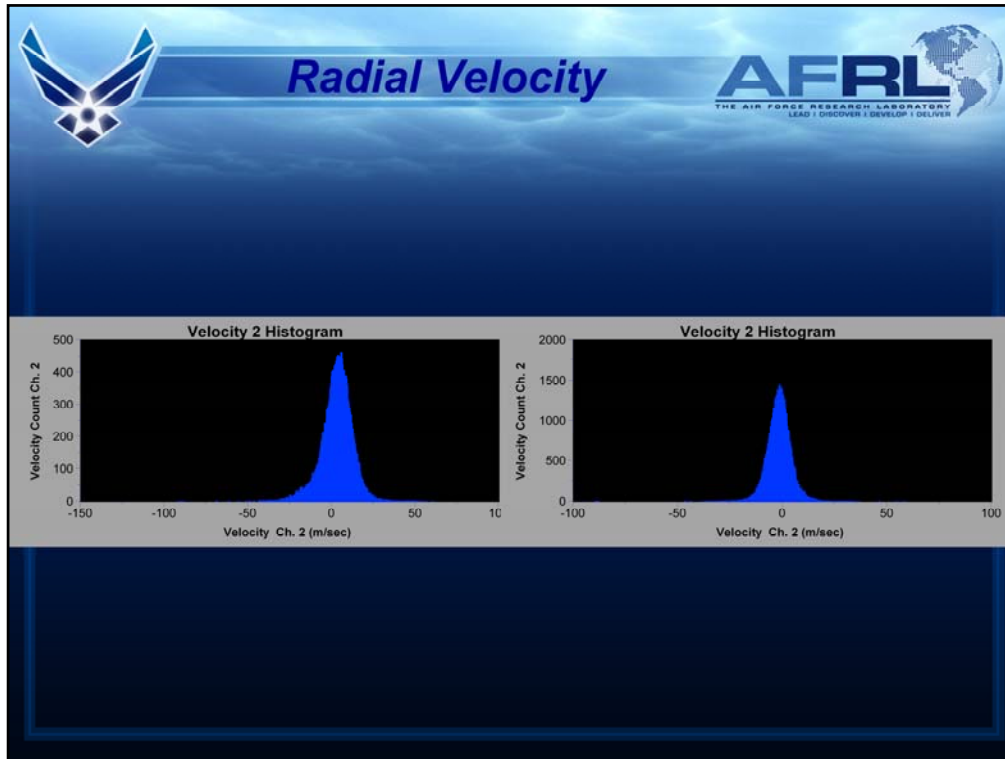


Phase Doppler Particle Analyzer (PDPA) instrument by TSI, Inc. is being used to measure 2-D velocity as well as particle size distribution. This device uses four laser beams (on the left) and detector (on the right) to collect this information. The data collected is used in an analytical model which simulates the foam flow using numerical methods. The validity of the analytical model is verified using the data from the PDPA. Once the model is verified, parameters such as nozzle configuration, wind velocity, and ambient temperature can be varied and the model is used to predict the resultant flow. This method is particularly useful for nozzle design, as numerous designs can be analyzed without building any hardware. Once the design has been optimized analytically, the hardware can be built and the performance verified on an actual fire.

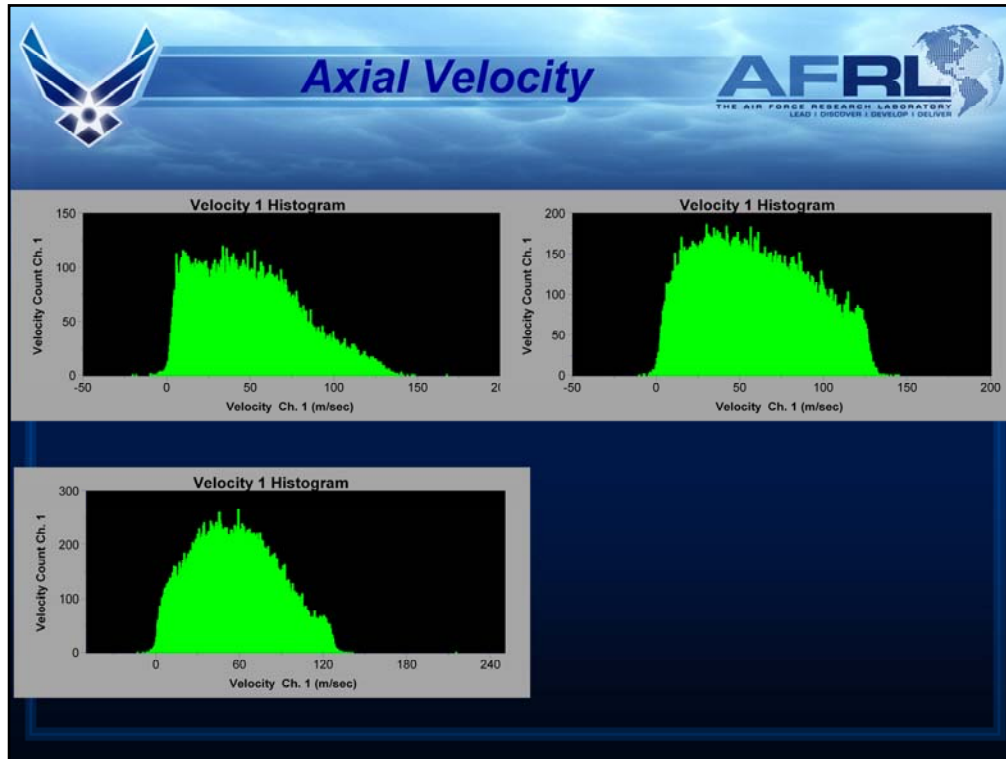
Ultimately, this process will be expanded to include models of the burning fuel, the agent streaming to the fuel, and the interaction between the agent and the fire. This will lead to extinguishing fires “in the computer”. Then, the model will be capable of evaluating various fuels and agents while conducting few full scale fires for verification purposes.



These droplet diameter plots, along with data on the next two slides are typical PDPA results. These plots show the distribution of droplet diameters in the stream. Droplet diameter distribution is important to the analytical model because larger, heavier droplets will travel further and faster than smaller, lighter droplets. Smaller droplets have a larger surface to mass ratio, and will evaporate faster, absorbing more heat and producing more steam.



These plots show the distribution of radial velocity, or the velocity perpendicular to the stream. These data are important because it represents the divergence angle, or spread of the stream. As the stream spreads, the density of the stream decreases, affecting the throw distance.



These plots show the axial velocity of the stream. This strongly affects throw distance and the primary mechanism of Ultra High Pressure fire extinguishment. Higher velocity sweeps the flame away from the fuel faster and further, improving extinguishment characteristics.



Modeling



Complex Multiphase Flow (non-Newtonian fluid flows of a turbulent free multiphase jets that are thixotropic)

- ***Approaches:***
 - ***Commercial Software (Fluent) with population balance module & UDFs***
 - ***Academic or in-house codes (OpenFoam, CARMA)***

These software packages, along with User Defined Functions (UDF's) convert the input data combined with nozzle design and ambient conditions into a modeled stream flow. Throw distance, stream density, and other flow characteristics come from the output of this software.



Conclusions



- *UHP will revolutionize fighting of hydrocarbon pool fires, with 3X efficiency*
- *Technology transition for 1st generation UHP is nearly complete*
- *R&D of next-generation UHP may yield still greater efficiencies*
- *New M&S techniques are needed to accelerate development*