COMPRESSED AIR FOAM SYSTEMS

IN

LIMITED STAFFING CONDITIONS

EXECUTIVE DEVELOPMENT

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ABSTRACT

This research project explored the feasibility of enhancing suppression crews of limited manpower by equipping them with Class-A foam and Compressed Air Foam Systems (CAFS) technology and training.

The problem that was addressed was that, especially in the early stages of fire suppression operations, there were frequently insufficient personnel to employ traditional extinguishment methods safely and efficiently.

The purpose of this research project was to determine if CAFS technology and procedures could be used to increase effectiveness, efficiency, and safety under limited personnel resource conditions.

Descriptive research, including the literature review, was used to explore the safety and operational results of under-staffing, and to clarify the present state of development of compressed air foam and class A foam. Evaluative research was used to measure hoseline handling for CAFS and traditional (plain water) handlines.

The research questions posed were:

1. What are the effects of reduced manpower upon suppression activities with regards to efficiency and safety?
2. What are the recognized advantages and disadvantages of CAFS when used in structural firefighting?
3. How do CAFS hoseline handling characteristics differ from those of plain water hoselines?

4. Can the use of CAFS by an understaffed crew reduce the number of stress and fatigue injuries at suppression incidents?
5. Can the use of CAFS increase the suppression ability of an understaffed firefighting force?

The procedure began with a literature review of staffing practices, including the effects of minimal staffing of suppression crews. Next, the description, history and extinguishment theory of CAFS; the claimed advantages and limitations of CAFS technology; and test data and anecdotal reports of fire experience with CAFS were examined for possible impact on minimum staffing safety and inefficiency problems. CAFS hose handling was field tested.

CAFS was found to provide increased suppression capability to crews of limited manpower and to reduce stress and fatigue of hoseline operators.

Recommendations included investigation and purchase of a CAFS for the Morristown Fire Bureau, and further research into the suppression abilities of CAFS.

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INTRODUCTION

The Morristown, New Jersey Fire Bureau is a combination department, consisting of 29 career suppression personnel and about 20 active volunteer firefighters, maintaining a minimum on-duty staffing of a Captain and four firefighters. The on-duty crew brings the apparatus to the scene, while the volunteers are alerted by pager and respond directly to the scene in their own vehicles.

Usually the on-duty crew of 5 must begin suppression activities before the arrival of the volunteers. Since personnel are in short supply, often some necessary tasks must be delayed; some may be performed inefficiently or even unsafely.

In the early 1990's Compressed Air Foam Systems (CAFS) were being introduced to the structural fire service, with promises of greater fire knock-down power, less water used, lighter hoselines and less water damage (Almer, 1990; Davis, 1991; Fornell, 1991; Liebson, 1990; Rochna, 1990). After almost a decade, this technology has yet to find general acceptance in structural firefighting, at least in the northeastern United States.

The problem prompting this research project was that, especially in the early stages of fire suppression operations, there were frequently insufficient personnel to employ traditional extinguishment methods safely and efficiently. This common problem is articulated by Larry H. Davis, editor of Fire-Rescue Magazine:

> The three-step concept of opening the roof over the fire or letting it burn through, trenching each side far enough ahead of the fire to have some real

> effect and pulling ceilings in front of the fire to apply water is not working.…Why doesn't the three-step process work? We don't have 27 guys on initial attack! (1997a, p. 8)

If CAFS technology were able to deliver on the claims made for it, this innovation could enhance safety and performance in the critical early stages of fire control. **The purpose of this research project was to determine if CAFS technology and procedures could be used to increase effectiveness, efficiency, and safety under limited personnel resource conditions.**

Descriptive research, including the literature review, was used to explore the safety and operational results of under-manning, and to clarify the present state of development of compressed air foam and class A foam apparatus and usage. Several conflicting claims were examined. Evaluative research was used to measure and compare hoseline handling characteristics of weight, nozzle reaction, and bendability for CAFS and traditional (plain water) handlines.

The research questions examined were:

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BACKGROUND AND SIGNIFICANCE

Morristown, New Jersey is a small city/large town of 17,000 residents and 100,000 daily transients. The 1990 census reported 14,633 households with a 1989 median income of $59,413 and $2,448,515,000 aggregate worth of owner-occupied residences (U. S. Census Bureau, 1997). Commercial occupancies include five hi-rise office buildings and one hi-rise hotel. Morristown houses the county seat and jail complex. Morristown's Fire Bureau protects Morristown Memorial Hospital, the regional trauma center, and Morristown Airport, which is the third busiest airport in the state. Finally, there are several buildings of irreplaceable historic value, such as the Ford Mansion, which was Washington's headquarters for two years during the Revolutionary War.

Morristown has a history of strong volunteer fire service. Two hundred years ago, in 1797, a society was organized for the use of buckets, fire hooks, and cisterns. By 1837 the Morristown Fire Association was created by act of legislature and empowered to support two fire companies by special taxation. The six volunteer companies that are in service today were formed between 1867 and 1889. Full time career firefighters were first hired in 1929. As recently as the 1960's, there were waiting lists to serve as one of the town's 200 volunteers, in addition to 18 paid personnel, who functioned mainly as apparatus drivers and pump/aerial operators.

Today Morristown is served by about 20 active volunteers qualified for interior structural firefighting, and an additional 30 in support capacity. The career firefighters, presently numbering 29 divided into four platoons, are no longer merely driver/operators, but generally function as one company at an alarm until volunteers arrive. In 1996 Morristown responded to 1288 alarms, which included 35 structure fires, 59 outside fires, 25 vehicle fires, 32 aircraft emergencies, 25 extrications, and 113 spills, leaks, and hazardous materials incidents.

It has become increasingly difficult to recruit and maintain qualified volunteers who are available to respond during daytime business hours. There is little local blue collar industry (the traditional rich source of volunteer firefighters), and many residents commute to work to surrounding towns and to New York City by rail. The trend toward two-career families has curtailed leisure time, and placed volunteer membership in competition with many other civic and family activities and duties. At the same time, the time commitment for initial and on-going firefighting training has increased, reflecting the progress in suppression understanding, safety and technology. Modern protective gear, SCBA, and communications has given today's firefighter the means to save lives and property which would have been lost a generation ago, but a substantial time commitment to training is required. Increased awareness and changing attitudes about safety (injuries and deaths are no longer considered acceptable costs of doing business) and environmental concerns mandate still more training and practice.

In addition to greater training demands, increased call volume has made it impossible for most volunteers to answer all (1300) calls. The general practice has been for volunteers to respond only after the on-duty crew is on the scene, discovered a serious fire, and called for a general alarm. This means that the five or six man initial crew will be carrying out fire suppression for several more minutes before the volunteers begin to arrive. Furthermore, while evening and weekend response has generally been adequate, although delayed, there have been fires during weekday hours where volunteer response has been at or close to zero.

Some efforts already taken to address this problem have been the formation of mutual aid agreements with the surrounding towns, recruitment efforts, and some conversation with Morristown's closest neighbor to institute limited joint responses. The government of Morristown considers it not feasible to fund more paid personnel.

For the near future, the impact of this problem will be increased requests for mutual aid, some fire loss which could have been prevented with additional early manpower, and injuries suffered when too few firefighters try to do too many tasks as quickly as possible.

While not a panacea, and certainly not a replacement for manpower, the CAFS technology holds the promise of increased efficiency and safety for available personnel. If the claims for CAFS are validated, additional research is vital to implement and refine the technology, application and procedures for structural firefighting. If CAFS is found to be ineffective for structural firefighting use, research will be of great use to prevent fire department executives from committing thousands of dollars to purchase inappropriate CAFS systems.

This paper has been produced to satisfy the applied research project requirement for the Executive Development course at the National Fire Academy. The project relates to the course work on problem-solving, touching many of this unit's themes, including: problem recognition and definition, the barriers and constraints of inadequate and inaccurate information, the tendency to view problems and possible solutions too narrowly, inappropriate comparisons and analogies, and the effects of the organizational culture. Finally, this research will undoubtedly be a resource for Morristown's future apparatus purchase decisions.

LITERATURE REVIEW

Limited Personnel Operations

The current climate of fiscal restraints is prompting fire service leaders to examine the question of what constitutes adequate staffing at emergency incidents. The National Fire Protection Association (NFPA) recommends "An adequate number of personnel to safely conduct emergency scene operations" and that "Members operating in hazardous areas at emergency incidents shall operate in teams of two or more" and "In the initial stages of an incident where only one team is operating in the hazardous area, at least one additional member shall be assigned to stand outside of the hazardous area where the team is operating" (1992, p. 21).

W. E. Clark (1991) notes that the important personnel consideration is the total number of firefighters responding early in the incident, on the first alarm. Ronny Coleman and John Granito (1988) agree:

> Various controlled and statistically based experiments by some cities and universities reveal that if about sixteen trained firefighters are not operating at the scene of a working fire within the critical time period [before flashover], then dollar loss and injuries are significantly increased, as are the square feet of fire spread. (p. 119)

Brunacini (1992) explains:

> Another simple and related reality involves the direct and ongoing relationship between fire fighting capability, the number of fire fighters who respond, and their response times….We are effective to the extent that the system can produce workers quickly; too little and too late produce the same negative effect. (p. 28, 132)

In 1995 W. E. Clark noted, "Recommended minimums for initial response range from 12 to 16; but in actual practice vary from 4 to 35 (p. 623). The relative efficiency of understaffed companies was tested by former New York City Fire Chief John T. O'Hagan in the Dallas Fire Department staffing studies, involving 91 full-scale fire simulations and three full-scale fire tests (1984). He found that the result of understaffing was a forced choice between delaying some critical tasks and attempting to perform all of the original tasks less efficiently. O'Hagan further stated, "The consequences of these delays and omissions could include greater fire growth, delayed search and rescue, extension to the attic space, suspension of interior attack and rescue effort, and involvement of the exposure" (1985a, p. 21); and, "The consequences [of smaller crews] are overexertion to compensate for reduced manpower, early exhaustion, and a loss of effectiveness (1985, part 2, p. 27). Ronny Coleman and John Granito, of the International City Management Association (1988), note that it is the smaller communities which suffer disproportionately large fire losses because they lack the ability to produce sufficient initial attack suppression forces quickly (p. 119).

Bill Clark observes that reduced staffing is also inversely related to safety:

> Every fire requires a given amount of work for the needed results to be accomplished. This work, when divided by the number of firefighters assigned to do it, will show the amount of work each firefighter must perform. It is obvious that the fewer the firefighters, the greater will be the energy expended by each. This increase in physical stress could cause immediate or future heart problems and…other injuries as well. (B. Clark, 1994, p. 24)

Varone (1994) found that increasing the company staffing from three to four in Providence, Rhode Island resulted in a 23.8% reduction in all injuries, a 25% reduction the number of injuries serious enough to cause injury leave, and a 71% decrease in work time lost due to injury. The International Association of Fire Fighters (IAFF) found that fire fighters in companies of less than four were one third more likely to get killed or injured on the job. An injury rate of 13.5 injuries per 100 firefighters was reported for companies staffed at less than four, compared to 10.0 for companies staffed at four or more (1992, p. 21).

William Peterson, writing for the NFPA (1997), reports a nineteen year average of well over 100 firefighter deaths and 100,000 injuries per year. In 1995 heart attack from stress was the cause of half (50.5%) of all fatalities. Of the 1,070 on-duty firefighter fatalities over the last10 years, at least 498 were heart related (p. 10-61). Of non-fatal injuries, Ladford (1996) reports:

> The NFPA statistics also say that each year, strains and sprains are the most common form of injury among firefighters, with slips and falls being the second most common form of injury. These specific injuries can be directly related to firefighter fatigue. As our firefighters become more tired during an incident, their potential for injuries increases. (1997a, p. 15)

This sobering data, combined with the knowledge that it is unlikely that the Morristown Fire Bureau will be able to rapidly increase its personnel strength, motivated the author to investigate other resources, such as CAFS, to maximize the abilities of present personnel.

Description of CAFS

Ron Rochna of the Boise, Idaho Interagency Fire Center defines a compressed air foam system (CAFS) as:

> A standard water pumping system that has an entry point where compressed air can be added to a foam solution to generate foam….The air compressor also

> provides energy, which, gallon for gallon, propels compressed air foam farther than aspirated or standard water nozzles. (1991, p. 14)

Typical components include a centrifugal water pump, a water source, foam concentrate tanks, a rotary air compressor, a direct-injection foam proportioning system on the discharge side of the pump, a mixing chamber or device, and control systems to ensure the correct mixes of concentrate, water, and air (Colletti, 1993a; Colletti, 1996; Grady, 1994; Murdock, 1997).

One of the advantages of CAFS is versatility:

> A major advantage of using CAFS is having the unique ability to produce a wide range of foam qualities or foam types to provide the most appropriate foam response to individual fire situations….This gives the fire officer the advantage of custom tailoring the best foam type for the tactical use and fire problem at hand. (Colletti, 1994b, p. 39)

CAFS is able to deliver a range of useful foam consistencies, labeled from Type 1 (very dry) to type 5 (wet), which are controlled by the air-to-solution ratio, and, to a lesser extent, by the concentrate-to-water percentage. Type 1 and 2 foams have long drain times (i.e., the bubbles do not burst and give up their water quickly) and long duration. Wet foams, Type 4 and 5 drain more quickly in the presence of heat (IFSTA, 1996). After testing a dry Type 2 foam in several situations Johnny Murdock notes:

> The emerging consensus is that the dryer foams (Type II; maybe Type I) should be used to suppress vapors, protect unburned structures, build wildland fire lines involving unburned fuels;…and that structural fire suppression requires a

> wetter foam (Type IV or Type V); and that both structural and wildland overhaul require Type V foam. (1997, p. 9)

For structural firefighting with CAFS, Dominic Colletti recommends, “A 1-3/4-inch hoseline flowing 80 gpm and 80 scfm [standard cubic feet per minute] with Class A foam proportioning at 0.3% will produce a wet, quick draining finished-foam that has excellent flame knockdown” (1994b, p. 39).

History of CAFS

The idea that water is not a perfect tool for extinguishment has been long noted, as by W. E. Clark (1991):

> The process of extinguishing fire by water is cumbersome and generally costly…[including] the cost of installing water mains large enough for required flow, the installation and maintenance of hydrants, and the acquisition and maintenance of fire department pumpers, hose, and nozzles, make water a fairly expensive extinguishing agent….the use of water is hardly the ideal way to extinguish fire….there must be a better method waiting to be discovered. (p. 75)

Liebson (1996) adds, “Water is an inefficient extinguishing agent. It requires the use of large quantities at costs both financial and physical. These costs are imposed on the firefighter and the community” (p. 5).

The use of foam additives to water for extinguishment dates back to an English patent in 1877 for a method to produce chemical foam (Liebson, 1991, p. xi). The

British Navy experimented with agents foamed by means of compressed air in the 1930's (Darley, 1995) and the United States Navy was using compressed air foam systems (CAFS) in the 1940's for flammable liquid fires. By the 1960's do-it-yourself car washes were using CAFS with low pressure, small diameter hoses and nozzles, which flowed about four gallons per minute (gpm) solution and four cubic feet per minute (cfm) of compressed air, with a nozzle reach of about 40 feet (Rochna and Schlobohm, 1992). In the mid 1970's the Texas Forest Service developed a water expansion system known as the Texas Snow Job. This pioneering Class A CAFS used a pine soap derivative, which was readily available as waste from local paper manufacturing industries, as a foaming agent mixed as eight to nine parts agent to 91 to 92 parts water, flowing up to 30 gpm. The duration limited by the use of compressed air cylinders rather than compressors. By the mid 1980's research by the US Bureau of Land Management led to modern design features of rotary air compressors, centrifugal pumps, and direct-injection foam-proportioning systems (Fornell, 1991; IFSTA, 1966). CAFS received national attention in 1988 during the Yellowstone Park wildfires when the four story Old Faithful lodge was successfully protected by blanketing it with compressed air foam (Darley, 1995).

The overview and historical data propelled the research on to a closer look at the claims made for CAFS and the reasons behind them.

Extinguishing mechanism of CAFS

Water has several properties which make it a good extinguishment agent. Water excels at cooling because it has a high thermal inertia and high latent heat of vaporization, which means it can absorb more heat for its mass than most other substances. It can be transported readily by pumping and is generally available anywhere humans are (W. E. Clark, 1991).

The chief limitation of water's ability to extinguish fire is its high surface tension caused by water molecules being attracted only to other water molecules. This is the force that causes water to bead up, form droplets, and roll off surfaces. According to IFSTA (1996, p. 122) and U.S. Department of Agriculture (Darley, 1995, p. 17), only five to ten percent of the water used in structural firefighting actually becomes involved in extinguishment. In addition, this surface tension makes it difficult for water to penetrate many substances, such as fibers, cloth, and upholstery. Water also does not form a protective coating on most substances, and cannot suppress vapor production unless there is enough water to submerse the vapor source.

Class A foam addresses these limitations. It is a synthetic detergent hydrocarbon surfactant (surface active agent). A 0.3% solution reduces surface tension by about two-thirds (Colletti, 1992), which allows the bulk of the droplet to spread out, enabling more of its surface area to contact the fuel, resulting in more rapid heat absorption. These same surfactants emulsify grease, petrochemicals, paints and other barriers to water penetration (Fornell, 1991). As a hydrocarbon surfactant, the foam has an affinity to carbon particles, which facilitates wetting of carbon fuels (Darley, 1995). IFSTA (1996) adds: "Many of the home furnishings and structural finishes in use today are made of synthetic materials that do not absorb water…the nature of finished foam also permits it to coat materials, such as plastics, that will not allow penetration" (p. 44).

The bubble structure in the foam is important to the increased extinguishing abilities. Plain water cools most effectively when the droplet size is very small. "Calculations show that the optimum diameter of a water droplet is in the range of 0.01 to 0.04 in. (0.3 to 1.0 mm), and that the best results are obtained when the droplets are fairly uniform in size" (Wahl, 1997, p. 6-6). The problem is that with conventional application, droplets this size are evaporated in the fire plume and never reach the seat of the fire. Testing by the Osaka, Japan Fire Department concluded that even smaller droplets, in the 250-350 micron range, are even more efficient (Fornell, 1991). When Class A foam is directed into the fire, the air within the bubbles becomes heated and pops, fracturing the water solution into extremely small particles, which are immediately vaporized near the heat source (Colletti, 1994b). "Researchers believe that Class A agents provide the vehicle to deliver a more efficient droplet size into the flame/fuel interface area, without having the droplet evaporate en route" (Fornell, 1991, p. 308). With CAFS, seven bubbles can be made the size of the original droplet. These durable bubbles stay in place releasing moisture as they diminish (Darley, 1995). They are also able to cling to vertical surfaces, which water cannot. "During the breakdown of the foam blanket, the bubbles tend to break down uniformly, with the water migrating towards the source of heat, rather than away from it" (Liebson, 1990, p. 25). As the solution drains out of the bubble mass, it penetrates the fuel. "The net effect is…that the available water supply is efficiently used to cling to and cool the fuel" (Colletti, 1993a, p. 56).

In addition to cooling, CAFS foam has been reported to extinguish or prevent fire in several other ways: by smothering (preventing air and flammable vapors from combining); by separating (intervening between the fuel and the fire); by suppressing (preventing the release of flammable vapors)(IFSTA, 1991); by providing insulation from radiant and convected heat by means of the dead air spaces within the bubbles (Colletti, 1994b); by reflecting radiant heat with the opaque surface of the foam (Liebson, 1996); and by interrupting the chemical chain reaction (Darley, 1995).

CAFS Experience and Testing

The literature contains numerous reports of evaluating CAFS and Class A foam under a variety of fire situations.

In 1992, an acquired structure was burned while instrumented with a thermocouple-strip chart recorder in Salem, Connecticut "to measure the time/temperature-reduction relationships with the application of [plain] water, Class A foam solution, and Class A foam aspirated through a compressed-air foam system (CAFS)" (Colletti, 1993b, p. 41). Identically fire-loaded 11-foot by 10-foot by eight-feet-high rooms were allowed to burn to flashover. In each of the rooms, a 2-minute attack was then initiated, consisting of ceiling cooling for 60 seconds, followed by room and contents application for 60 seconds. The flow rate was 20 gpm of water or solution. At the four-foot high level, where "Heat…would directly affect the stress/survivability of trapped occupants...and also that of firefighting personnel involved in rescue/suppression operations" (Colletti, 1993b, p. 42), CAFS was found to be 480 percent more effective than plain water in lowering the temperature. Unaspirated Class A solution was found to be 110 percent more effective than plain water. If the test had been stopped at the temperature of 212 degrees Fahrenheit, water used would have amounted to 74 gallons of plain water, compared to 34 gallons of Class A solution, compared to 13 gallons of solution as compressed air foam (Colletti, 1993b; 1994b).

At the U.S. Army's Fort Indiantown Gap, in Annville, Pennsylvania, a 150-foot by 25-foot by 12-foot wood frame barracks building was allowed to burn to total building flashover and extinguished with CAFS. "The objective was to prove to the students that CAFS have the capacity to extinguish a large structure fire using only marginal personnel and water-supply resources" (Colletti, 1996, p. 55). Ninety-eight percent extinguishment was achieved with a single 2.5 inch exterior handline flowing 180 gallons per minute (gpm) of 0.04% Class A foam solution and 180 standard cubic feet per minute (cfm) of compressed air within six minutes. An estimated 1,080 gallons of solution was used. Using plain water only, the Iowa Rate-of-Flow formula would require a 450 gpm delivery rate; the more conservative National Fire Academy formula would require 1,041 gpm (Colletti, 1996).

The National Fire Protection Research Foundation, in a 1994 project named "Structural Fire Fighting - Room Burn Tests, Phase II," conducted several test burns in an 8 ft x 12 ft x 8 ft enclosure (National Fire Academy formula required fire flow of 32 gpm) with a calorimeter hood to measure heat release. Upon flashover, plain water or Class A aspirated foam or CAFS was applied until suppression was achieved. It was found that the use of Class A foam solutions was more effective in reducing the amount of heat release and the damage to the combustibles present, as compared to plain water. Additionally, when agents were tested at the low rate of 7 gpm, direct application of Class A foam as CAFS resulted in the shortest time and lowest quantity of agent needed to reduce the rate of heat release to 500 kilowatts. However, when using the indirect method at 10 gpm, aspirated Class A foam was more effective than plain water or CAFS (Carey, 1994).

In a live-fire drill conducted by the Chemeketa Community College Fire Protection School and the St. Paul (Oregon) Rural Fire Protection District, a 60 ft x 80 ft x 30 ft barn (NFA formula required fire flow of 1,600 gpm) was ignited and allowed to progress to full involvement. Knockdown was achieved in 50 seconds with a single 1.5-inch CAFS line flowing about 85 gpm, using less than 100 gallons of water (Liebson, 1991, p. 45).

In 1994, a series of Class B (jet fuel and fuel oil) burns were conducted at Liverpool, England's Speke Airport. One hundred eighty gpm aqueous film forming foam (AFFF) solution discharged through a CAFS was compared with the same AFFF solution flow applied with a conventional variable-gallonage/constant flow nozzle. The CAFS demonstrated superior fire-killing power, extinguishing amounts of fire that conventional application methods could not (Colletti, 1994c).

In Limerick, Pennsylvania, a 25-foot by 30-foot (calling for a 250 gpm Required Fire Flow by National Fire Academy formula) wood frame building with a heavy fire load was attacked with CAFS flowing 120 gpm Class A solution and 120 cfm compressed air, using a 2.5-inch exterior handline. The fire was knocked down in 25 seconds (Colletti, 1994c).

A series of eight standard Underwriters Laboratories “100-AB” 711 crib (each containing 3,300 pounds of lumber) fires were burned from October 2 to 17, 1992 at Vernon Military Camp, Canada. The test fires were extinguished with plain water, Class A solution, and Class A aspirated foam. The objective was to compare the flow rates needed for each agent to achieve fire knockdown. Class A foam was found to have superior extinguishing power: “On a preliminary basis, it appears that 80 gpm of ALEF [Aspirated Low Expansion Foam] is as effective as 160 gpm of plain water, both being applied in a straight stream” (Edwards, 1994, p. 68).

In November, 1993, the Fairfax County, Virginia, Fire and Rescue Department, the U.S. Naval research Laboratory, Washington, DC, and the Fort Belvoir (U.S. Army) Fire Department collaborated on a series of full scale structure fire tests, using single-story balloon frame barracks, 32 ft x 19 ft x 10 ft in size. At identical flows of 53 gallons per minute, CAFS extinguished the fire in less than half the time and with less than half the agent, even though the structure extinguished by CAFS had been significantly more heavily fire-loaded, had a longer pre-burn, and was burning at a higher temperature when extinguished (Jones, 1995; Colletti, 1994b).

Also at Fort Belvoir, Underwriters Laboratory conducted a series of burns of Class 20-A wood cribs, designed to be extinguished by a 33 gpm straight stream hoseline in one minute. Fifteen gpm of Class A solution as nozzle aspirated foam was found adequate to extinguish; fifteen gpm of water could not extinguish these fires. UL concluded:

> The limited tests did demonstrate the ability of hand hoselines supplied with Class A foam solutions to provide enhanced fire fighting performance compared to hand hoselines supplied with water. The results of the wood crib fire tests demonstrated the ability of the Class A foam solutions to reduce the time required to control the fire as compared to water only. (Underwriters Laboratories Inc., 1994, p. 2)

A training exercise conducted in Montgomery County, Maryland involved burning a 10 ft x 40 ft (National Fire Academy required fire flow of 133 gpm) room loaded with 25 wooden pallets and 15 bales of straw. The fire was knocked down with a one inch smooth bore nozzle on 1.5 inch hose flowing only 40 gpm Class A solution as CAFS, with 40 cubic feet per minute compressed air. Knockdown time was five seconds (Colletti, 1992).

In Sikeston, Missouri, four identical rooms of a single story motel were instrumented and burned to flashover and attacked with plain water and with Class A solution. The attack was terminated when temperatures were reduced to 150 degrees Fahrenheit, and the rekindle time was measured. The Class A agent provided knockdown in 29% to 52% less time than plain water. Class A also used 77 gallons of treated water, compared to 242 gallons in the plain water attack (Almer, 1990; Fornell, 1991).

In 1995, Johnny I. Murdock tested a dry (20 to 1 expansion) CAFS on two identical test fires, each an 11 ft x 13 ft x 8 ft (NFA formula required fire flow of 48 gpm) bedroom. The 0.8% solution CAF flowing less than 10 gpm solution produced knockdown in 22 seconds, and complete extinguishment in 106 seconds, compared with knockdown in 7 seconds and extinguishment in 42 seconds for 150 gpm plain water (1997).

Concerning defensive fire fighting operations, Daniel Madrzykowski (1988), conducted ignition retardation (exposure protection) tests for the U.S. Department of Commerce, National Institute of Standards and Technology. Employing the Lateral Ignition and Flame Spread Test (LIFT) apparatus, he exposed samples of T1-11 textural exterior wooden siding material to heat radiation. The samples were either sprayed with plain water, Class A solution, or dry (14 to 1 expansion) Class A CAF. The foam exhibited a mass retention efficiency (ability to remain on the vertical surface) approximately 20 times that of water. Although the foam layer used was thin (6 mm), the foam treatment delayed ignition twice as long as plain water. There was no significant difference in the delay times of plain water and unaspirated Class A solution.

Advantages of CAFS

Many claims have been made for the increased firefighting performance of CAFS and Class A foam. Jeff Stern and J. Gordon Routley, in Report 083 of the US

Fire Administration's Major Fires Investigation Project (1996), surveyed several fire departments using CAFS. The reported advantages of include:

1. Class A foams allow faster fire suppression and extinguishment than plain water.
2. Class A foam increases efficiency and conservation of water supply.
3. Class A foam can be produced at a relatively low cost. One department estimated that the cost of Class A concentrate was probably offset by the savings in their use of diesel fuel resulting from reduced operating time on the fireground.
4. Class A foam forms a protective blanket.
5. Foam is visible during and after application.
6. Foam clings to most surfaces and protects exposures much longer than plain water.
7. CAFS attack lines are lighter than plain water hose lines.
8. Foam use may help to preserve evidence of fire cause.
9. Class A foam can be used on flammable liquid fires.
10. Class A foam aids wildland/urban interface attack.
11. Class A foam may provide long term cost savings and reduced property damage.
12. Firefighter stress and fatigue may be reduced. (p. 13-15)

The literature contains many opinions and estimates of the relative extinguishing power of CAFS compared to water. John Liebson (1991, p. xii) summarizes comparisons between CAFS, Class A foam without compressed air (also known as nozzle aspirated foam) and water in this chart:

Extinguishing Agent	Time to Knock-down, Minutes	Gallons of Water used	Amount of Foam Agent Used

Plain Water	X	Y	N/A
Class A Foam	.7 X	.5 Y	Z
Compressed Air Foam	.25 X	.3 Y	.35 Z

This chart indicates that CAFS will knock down a fire in one quarter of the time with and thirty percent of the water needed when plain water only is used for extinguishment.

A selection of other estimates, quoted directly because terminology and units of measure are not standardized, include:

- "The addition of Class A foam and compressed air to a plain water fire stream multiplies the fire-killing power of the stream and the meatware [personnel] using it from 5 to 10 times (Davis, 1997b, p. 77);

- "Class A foam systems and CAFS may knock down up to 10 times more fire with a tenth of the water traditionally used" (Edwards, 1994, p. 66);

- "Effectiveness per gallon of water is estimated in the literature as high as 5 to 10 times over plain water for some applications" (Stern & Routley, 1996, p. 13);

- "Advanced Class A fire suppression technology allows a nozzleman to darken between three and 20 times as much fire as the conventional plain water system (Edwards, 1992, p. 97);

- “Anecdotal/empirical evidence and limited comparative testing have yielded a ‘three to five times more effective than plain water guideline’” (Colletti, 1993b, p. 1);

- “CAFS has a firefighting capability eight to ten times that of plain water” (Liebson, 1991, p. 23);

- “It has been estimated that when combined as solution with water, Class “A” foams are up to twenty times more effective than plain water alone” (Darley, 1995, p. 16);

- “The foam industry is saying it’s ‘three to five times more effective than plain water’…in my experience with using CAFS and contrasting flows on structures with Iowa Supply methods, the general range has been a fivefold increase in efficiency—but not scientifically quantified” (Colletti, 1992, p. 7-8);

- “It has been estimated that the use of Class A foam allows interior structural fires to be suppressed three to five times faster” (Davis, 1991, p. 50);

- “When Class-A agents are added to water, the resulting solution increases knockdown and holding potential anywhere from 3 to 15 times over plain water alone….If a fully involved room could be knocked down in 45 seconds using plain water, the use of Class-A solution will black out the fire in about a third of the time” (Fornell, 1991, p. 301,309);

- "They [Fairfax County Fire and Rescue Department] estimate that the CAFS unit will prove to be 60-100 percent more effective than a plain water engine, effectively giving them a fire suppression capability equivalent to two fire engines" (Stern & Routley, 1996, p. 11).

There are currently no test methods or requirements specified by NFPA in 298, Standard for Foam Chemicals For Wildland Fire Control, or elsewhere, to evaluate Class A foams and CAFS for effectiveness. Perhaps one assessment with which all writers would agree is provided by Samuel Duncan after evaluating CAFS for the US Army Tank-Automotive Command in 1994: "Based on the results and conclusions of this evaluation, it is the unanimous recommendation of the project members of the CRADA [Cooperative Research and Development Agreement] that CAFS technology would significantly improve the performance of most fire trucks….The technology is…effective enough in extinguishing fires to be of great value" (p. 19).

Although still new to the structural fire service, CAFS experience, in both test burns and in actual hostile fires, has been favorable. "With proper training, Class A foam can be utilized very effectively for both interior and exterior structure attack" (Colletti, 1993a).

IFSTA (1996) finds:

> Early indications show that many of the same advantages realized in wildland fire fighting are duplicated when applying Class A foam to structure fires….The following are four main areas of tactical application:
>
> - Interior (offensive) attacks
> - Exterior (defensive) attacks
> - Protection of exposures
> - Overhaul operations (p. 140).

Duncan (1994) reports, "CAFS generated foam in structural firefighting proved to be capable of knocking the fire down faster, using less water, reducing the weight of the hose and increasing discharge distance over standard equipment" (p. 17). Carothers (1996) found that as much as 90 percent of water used to extinguish structure fires did not reduce any of the heat necessary for extinguishment. Darley (1995) agrees:

> According to U.S. Department of Agriculture studies, when fighting an unconfined fire, less than 10 percent of the water applied to the fire actually goes toward extinguishment….The use of compressed air foam can reduce the amount of wasted water to about 20 percent. This means that 80 percent of the water is used to extinguish the fire. (p. 17)

The reason for this great increase in extinguishing agent efficiency is that the foam holds its water on the fuel, where it penetrates or is evaporated cooling the fire (Colletti, 1994b). Colletti (1993b) also estimated that this efficiency of CAFS increased suppression effectiveness of booster tank water by 300 to 500 percent. This in turn leads to less need for tanker support (Darley, 1995). Since less water is needed when using Class A foam, the risk of building collapse from runoff water is reduced (Brackin et al., 1992; Colletti, 1992).

This quicker knockdown translates into shorter exposure to fire hazards by firefighters, less damage to property, and less insurance losses (Brackin et al., 1992; Jones, 1990). Other claimed benefits include less firefighter exposure to higher heat environment, increased firefighter safety, increased operational efficiency, and increased chances for victim survivability (Colletti, 1992; Fornell, 1991). Quicker knockdown also extends the useful life of available water: "Water conservation appears to be a significant advantage of CAFS. The reduced flow rate effectively doubles the capability of tank water" (Stern & Routley, 1996, p. 3). Overhaul is also quicker and more water-efficient: " Because firefighters can see where and how much foam has been applied, the tendency to apply more than necessary is reduced" (IFSTA, 1996. p. 143).

CAFS may reduce the hazards of firefighting in several ways. As previously noted, a large percentage of firefighter injuries and deaths are related to stress and fatigue. Stern & Routley (1996, p. 11) report reduced firefighter fatigue through diminished suppression and overhaul times, causing less exposure to heat and products of combustion. Colletti (1994a) claims: " [CAFS] can reduce flame knockdown times, increase fire stream reach, and provide lighter-weight hoselines, all of which increase firefighter safety through stress reduction" (p. 66). A Federal Emergency Management Agency (FEMA) study concluded:

> Attack lines that are used to deliver compressed air foam are significantly lighter and easier to handle than plain water hand lines, because the product inside the hose is mostly air. The line weighs approximately half the weight of a regular hose line of the same diameter. The reduced weight and increased maneuverability can reduce firefighter fatigue and stress. (Stern & Routley, 1966, p. 15)

A report from the U.S. Army Tank-Automotive Command Research, Development and Engineering Center concurs: “Hose line weight is significantly reduced thus mitigating one of the primary physical stressors of fire fighting” (Duncan, 1994, p. 18). Darley (1995) claims that CAFS can reduce hoseline weight up to one quarter that of plain water, producing less firefighter strain. Colletti (1994b) notes that a CAFS 1.75 inch hoseline weighs about the same as a one-inch booster line filled with plain water, and that “On an interior structural attack the lightweight hoseline can reduce physical exertion and stress of attack team personnel advancing it” (p. 39). The International Society of Fire Service Instructors (1997) reported that “CAFS diminishes the amount of work required to handle hose lines” (1997, p. 2). Westlake, Texas and Fairfax County, Virginia also reported light weight and easy hose management characteristics of CAFS lines (Stern and Routley, 1996). IFSTA (1996) notes that CAFS hoselines have the advantage of being lighter than both plain water hoselines and also nozzle-aspirated Class A solution hoselines.

CAFS increases the probability of success of a "blitz" attack with fewer personnel, in many cases avoiding the alternative of subjecting personnel to large defensive tactical operations (Davis, 1991).

As observed in the Sikeston tests (Almer, 1990), covering uninvolved portions of a structure as advance is made reduces the risk of being trapped by re-ignition. Although "It takes repeated applications of [plain] water in order to keep a well-involved structure from re-igniting" (Jones, 1990, p. 7), fire areas extinguished by foam have a greater tendency to stay extinguished, since the foam insulates the fuel from the remaining heat sources.

This property of resistance to re-ignition also makes possible an extinguishment technique known as panel soaking, here described by Fornell (1991):

> The idea is to tackle one panel at a time….The ceiling should be taken care of first….One wall panel at a time can then be soaked…reduce[ing] not only the fuel load but also its radiation ability. A panel penetrated by Class-A agent radiates almost no heat and can no longer contribute to the total heat load, helping reduce the chances of flashover….Removing the fire's fuel by panel soaking does have a cumulative heat-reducing effect. By eliminating heat and fuel piece by piece, large fires can sometimes be successfully extinguished piece by piece. (p. 324,325)

Furthermore, when overhauling with foam, "Once the fire has been knocked down, a maintenance blanket of foam can be applied….This protective cover allows water to seep out as needed….Blow-holes will form in the blanket as steam is released, indicating hot spots below" (Fornell, 1991, p. 326). The threat of re-kindle is reduced (Darley, 1995; ISFSI, 1997).

The use of Class A foam and CAFS can create improved conditions for structural fire attack crews, including increased visibility, decreased steam generation, decreased combustion by-products, and quicker temperature reduction (Colletti, 1992; Colletti, 1994b; Darley, 1995; Fornell, 1991; IFSTA, 1996).

However, there have also been reports of an increase in residual heat after structural extinguishment (Brackin et al., 1992); a retention of residual heat (Liebson, 1990); and "Reports of hotter steam conditions as the fire is knocked down (by 25 or 30 degrees). It has not been determined if this increased temperature is real or a perception; it may relate to firefighters going more deeply and aggressively into hot areas" (Stern & Routley, 1996, p. 10).

One of the effects of energizing Class A foam with compressed air is greatly increased stream reach (Rochna, 1991). "Tests indicate that the reach of the CAFS fire stream can be greater than twice the reach of a low-energy [e.g., plain water or nozzle-aspirated foam] fire stream" (IFSTA, 1996, p. 72). Colletti (1992) states: "Forty gpm of water produces four brake-horsepower; an additional 20 cfm of air adds 10 brake-horsepower and will propel the stream approximately three times farther" (p. 53). Darley (1995) reports a reach of 100 feet for 25 to 50 gpm streams. At the Idaho State Fire School, Davis achieved a reach of over 200 feet for 180 gpm through a deck gun's 1.5 inch smooth bore nozzle (1991).

When an interior attack is not feasible (e.g., too few personnel, lightweight building construction, advanced fire conditions), this increased reach provides for enhanced fire fighter safety during an exterior attack. "CAFS can allow fires to be knocked down quickly from a relatively safe distance outside the burning structure" (International Society of Fire Service Instructors, 1997, p. 2). IFSTA (1996) notes: "The extended reach of the CAFS stream assures that the foam is delivered deep into the structure and to the seat of the fire" (p. 142). Stern and Routley add:

> Fires that occur in unstable or unsafe buildings could be fought from a greater distance by using the long reach of CAFS foam streams. Crews could remain at a safe distance outside of the collapse zone….The rapid and enhanced fire suppression capability of nozzle-aspirated foam systems and CAFS could improve fire suppression when fighting fires in modern, lightweight construction or trussed-roof structures. (1996, p. 8-9)

An additional safety benefit is provided by the stored energy of the compressed air in the hoseline, which in emergency conditions, can function similar to a pressurized water extinguisher: "When you run out of water, or lose prime, or run out of fuel, or any reason the truck or pump quits—the firefighter is still safe for a while because of the stored energy in the hose. The more hose installed means more time available" (Darley, 1995, p. 21).

Relatively dry, slow-draining CAF has excellent protection and fire-confining ability when used to blanket uninvolved structures exposed to fire. CAF can hold its moisture for 20 minutes to 10 hours depending on the application, wind and temperature (Carothers, 1996; Fornell, 1991). It adheres to fuel and resists heat longer than low energy foams (IFSTA, 1996). It also has the advantage of being able to cling to non-water accepting building materials such as vinyl siding, glass, and painted surfaces (Clark, W. E., 1991).

This durability of CAF yields important manpower savings. Similar in concept to panel soaking described above, exterior exposures may be protected sequentially, rather than simultaneously. "Once the structure is coated, firefighters may move on to the next structure. When plain water is used, firefighters must remain with each structure and continue to apply water" (IFSTA, 1996, p. 139).

In addition to safety concerns, the use of CAFS has been found to reduce damage of all kinds. This reduced damage and firefighter injury is claimed to save taxpayers substantial money (Darley, 1995). The Boise (Idaho) Interagency Fire Center found that 75 cents out of each dollar paid out by Oregon insurance companies was spent on water damage and not direct fire damage (Jones, 1990). Water damage to structures is reduced by using CAFS (Liebson, 1990). An analysis of several fires in Idaho and Wyoming, confirmed by insurance adjusters, indicated that operations conducted with CAFS resulted in only 10 to 20 percent of water damage considered normal (Grady, 1994). Darley (1995) Claimed that the use of CAFS also produced reduced smoke emissions and smoke damage.

Claims have been made that the use of CAFS may reduce wear and tear on other standard equipment by:

"a. Lower truck operating rpm

b. Less pressure needed, due to lack of friction

c. CAFS does not allow water hammer

d. Reduced fire ground times, less spare air bottles needed

e. More efficient mopup, less tools needed” (Darley, 1995, p. 22).

Extinguishment with CAFS instead of plain water has been claimed to reduce environmental damage (Colletti, 1993a; Darley, 1995). When using plain water as the extinguishing agent, “You also carry with the wasted water all the carbon deposits and unburned particles that pollute lakes and streams, and also can get into our city water systems (Carothers, 1996, p.24). The use of CAFS reduces the amount of toxic gases, smoke and particulates put into the air by the fire, reduces the loss of natural resources, and reduces pollutants through reduced apparatus use (Colletti, 1992; International Society of Fire Service Instructors, 1997).

CAFS Limitations and Disadvantages

The literature contains references to several problems, concerns, and questions about the use of Class-A foam and CAFS. Health and safety topics include corrosiveness, slipping and falling hazards, and effects of equipment malfunctions.

Class-A foam concentrate is a hazardous material and should be treated as such, with the manufacturer’s Material Safety Data Sheet available. The corrosiveness of modern Class-A foam concentrate is described as comparable to triple strength dish soap (Colletti, 1992). It can be irritating to the skin, eyes, and upper respiratory tract; can cause contact dermatitis and sensitization dermatitis; it can be corrosive to some metals and may reduce the life expectancy of leather products (Brackin et al., 1992; Darley, 1995). Foam concentrate could corrode apparatus paint and finish, as well as metal tanks and pump parts (Stern & Routley, 1996), which is why CAFS are designed to inject foam concentrate on the discharge side of the pump. Studies by the U.S. Department of Agriculture Forest Service specify protective equipment, including eye goggles, or shields, water proof gloves, and rubber boots (Brackinet et al., 1992). When Class-A foam is used, full turnout gear and SCBA should be worn. Gear should be thoroughly cleaned after contact with concentrate or solution, but not necessarily after contact with finished foam (Colletti, 1992). Class-A foam concentrate has been reported as a falling or slipping hazard (Brackinet al., 1992), but in the FEMA study (Stern & Routley, 1996), “Some departments felt the foam created somewhat of a slip hazard beyond plain water, and others did not note any additional hazard” (p. 16).

In the event of a malfunction preventing the flow of foam solution, a dangerous condition can occur. Known as slug flow, the compressed air and plain water separate inside the hose resulting in a violent serpentine hose movement and a completely ineffective fire stream (Colletti, 1996; Liebson, 1991). Fornell (1991) warns: “If a hose line bursts or a coupling blows off, the increased pressure of the moving force will cause the broken ends to whip about in a much more dangerous manner than a split [plain] water line” (p. 320). Newer systems, such as the one used by this author in this project, have automatic shutdown of compressed air when foam solution is not flowing.

In concentrate form, spills need to be kept out of ground water. Although modern Class-A finished foam produced from concentrates that meet NFPA 298, and have been approved by the USDA Forrest Service, is considered biodegradable (Darley, 1995; IFSTA 1996), long term environmental impacts are still uncertain (Stern & Routley, 1996).

A CAFS increases complexity of pumping operations, doubling the amount of operator calculations necessary to produce effective fire streams (Fornell, 1991). Much of this complexity has been removed in 2nd and 3rd generation systems.

A costly error is possible when Class-A and Class-B concentrate tanks are available on an apparatus. The Nashville, Tennessee Fire Department and others reported:

> Severe damage to foam system components occurred in instances when firefighters, by mistake, added class B foam concentrate to a class A foam concentrate tank. The mixing of the different concentrates caused the concentrated AFFF to congeal, gel, and clog the foam tank and system, requiring the entire system to be removed and cleaned. (Stern & Routley, 1966, p. 9)

There is some evidence that hose wear may be accelerated from chatter and slug flow, possibly leading to earlier coupling failure and separation of interior hose liners; only hose approved for CAFS by the manufacturer should be used (Colletti, 1996).

The use of CAFS requires considerable initial expense for equipment, foam and training. The full sized unit may cost $35,000 or more; foam concentrate may cost $10 per gallon (Stern & Routley, 1996). Duncan (1994) reported that CAFS can be specified in a new pumper for about an additional 15% of the base price.

The descriptions, experiences, and claimed attributes of CAFS led to a consideration of how the advantages identified could counteract the operational and safety disadvantages of minimal staffing. The absence of any published data, or even theoretical formulas, for CAFS hoseline handling characteristics led to consideration of hands-on measurements.

PROCEDURES

The research procedure used in this study began with a literature review initially conducted at the Learning Resource Center (LRC) at the National Emergency Training Center in June and October of 1997. Additional information was gathered from the Lloyd George Sealy Library, John Jay College of Criminal Justice, City University of New York; from the Morristown Fire Bureau library; and from the author's personal library.

Personal and telephone interviews were conducted in November and December, 1997 with Mr. Jack Alderton of the Brookside Engine Company of Morris County, New Jersey; with Mr. Kieth Danis of the Rochelle Park, New Jersey Fire Department; and with Mr. Dominic Colletti, fire protection systems engineer at Hale Fire Pump Company, Conshohocken, Pennsylvania.

The literature review focused on two areas: an overview of the development and current state of Class-A foam systems and especially compressed air foam systems (CAFS); and staffing levels and the safety and operational shortcomings of limited staffing. This study attempts to explore the interrelationship between the special needs/problems of limited staffing and the advantages of CAFS.

No measured data about the hose handling characteristics of weight, nozzle reaction and resistance to bending applied to CAFS were found in the literature. These characteristics are important contributors to stress and fatigue of firefighters. Therefore it was decided to attempt to take measurements under simulated conditions.

Definition of Terms

Compressed Air Foam System (CAFS) - A pumping and delivery system that mixes water, foam solution and compressed air.

Class-A foam - "Foam intended for use on Class A or woody fuels; made from hydrocarbon-based surfactants—therefore lacking the strong filming properties of Class B foams, but possessing excellent wetting properties" (Liebson, 1991, p. xii).

Cfm or scfm - Cubic feet per minute, or standard (@ 0 degrees Celsius, 14.7 psi pressure) cubic feet per minute - a measure of the flow of compressed air, similar to gpm of a liquid.

Gpm - Gallons per minute, the standard measure of flow of a liquid.

Handline - A hoseline intended to be hand held by one to three firefighters, rather than supported by a mechanical tool or appliance; usually limited to 350 gpm flow.

Nozzle reaction - The backward thrusting force caused by the mass and velocity of the water discharged from the nozzle.

Pressure (psi) - A force per unit area, commonly expressed in pounds per square inch.

Research Methodology

This research was historical in that data from the literature review was used to understand the current state of development of Class-A extinguishment systems, and how their attributes can be used to enhance suppression efforts with today's limited staffing.

The evaluative methodology was used to test three CAFS hose line handling characteristics, and to compare with plain water hose lines. The characteristics were weight, nozzle reaction, and resistance to bending.

Weight was calculated by first weighing dry hose, and then calculating and adding the weight of foam. This was compared to similar calculations for plain water.

Nozzle reaction was measured under actual flow by means of two dial spring scales attached by nylon webbing to the hose immediately behind the nozzle, and anchored to a utility pole by chain at waist height. Fifty feet of Ponn Conquest hose of 1.75 and 2.0 inch diameter was laid out straight behind the nozzle in a slightly serpentine pattern. 3-M Class-A foam concentrate was used, injected at 0.3 and 0.5 percent. Nozzles and pressures were chosen to reflect the needs of a limited manpower attack.

Resistance to bending was measured by a reading from the spring scale of the force required to pull 10 feet of pressurized hose into a 90 and a 180 degree bend. Force was measured at waist height.

Plain water hose lines were tested on December 4, 1997 at the Morristown Fire Bureau's parking lot. CAFS hose lines were tested with the same measuring apparatus on December 5 and 8, 1997 at Rochelle Park Fire Department's parking lot/training ground.

Assumptions and Limitations

The testing and comparing of the handling characteristics of CAFS and plain water hoselines was intended, as far as possible, to approximate actual firefighting conditions of "working" a hoseline in a structure fire. Nozzle reaction, hose weight and resistance to bending are forces that stress and fatigue firefighters and impede progress and efficiency at real fires.

All force and weight measurements were rounded off to the nearest pound. The spring scales were not certified for commercial use, but in measuring loads with known weights they were found to be accurate within plus or minus four percent. Each dial recorded zero to 50 pounds in one-half pound increments.

A limitation of the accuracy of the nozzle reaction measurements relates to the friction between the hose and the ground surface. This friction tends to take some of the nozzle reaction force, and the interior floor surface of a fire building could be much more slippery than the asphalt at the sites of these tests. The test set-up was pre-tested by comparing plain water hoseline readings to values predicted by formula and were found to be within plus or minus six percent of the predicted values. Similar formulas relating nozzle diameter, pressure and gallons per minute flow do not yet exist for CAFS.

Other limitations include the author's lack of experience with CAFS and limited knowledge of pneumo-hydraulics; the accuracy of the pumping engines' flow meters and pressure gages; the variability of friction loss of individual lengths of hose; human error in reading gages; and the limited number of runs for each set up, caused by time and cost constraints.

RESULTS

1. What are the effects of reduced manpower upon suppression activities with regards to efficiency and safety?

The effects of reduced manpower upon suppression activities were found to be well-documented in the literature and consistently observed, both in actual fireground situations and in simulated exercises, extending back to Clark's Wisconsin tests in 1960 (Clark, 1995). As the number of firefighters available at an incident decreases, significant increases have been noted in fire spread, dollar loss and injuries. Critical tasks, including search and rescue, were delayed or performed inefficiently. Physical stress was increased, which contributed to exhaustion of work crews. Greater number of injuries, greater rate of serious injuries and death, and longer injury leave have been found to occur when manpower is scarce.

2. What are the recognized advantages and disadvantages of CAFS when used in structural firefighting?

In the literature CAFS was found to provide more efficient fuel wetting and more rapid fire knockdown than plain water. After knockdown, foam was able to cling to fuel, even fuel arranged as vertical surfaces, preventing re-ignition for extended periods. While plain water extinguishes fire almost exclusively by cooling, CAFS was found also to smother, separate fuel from oxygen and heat, reflect heat, insulate fuel from heat, and suppress burning by interrupting chemical chain reactions.

All sources found in the literature review agreed that CAFS had exhibited greater fire knockdown power with less agent than had plain water. Attempts to quantify this advantage ranged from a factor of two to a factor of fifteen.

This enhanced extinguishment ability was found to result in less exposure time to heat and combustion byproducts, less stress and fatigue, and fewer injuries. The greater stream reach of the high energy system allowed extinguishment from greater distance to danger areas.

Losses due to fire, water and smoke damage were found to be reduced by the use of CAFS. Other benefits included less environmental damage from runoff water, greater operational efficiency, and reduced wear and tear of equipment.

Disadvantages of CAFS were also noted. Class-A foam concentrate has been found to be corrosive to some substances and an irritant to unprotected skin and eyes. The concentrate was found in some cases to present a slip and fall hazard. CAFS technology was found to complicate pumping operations, requiring additional training and extending possibilities of operator error and mechanical malfunction. Certain malfunctions were noted to have presented hazards to firefighters. Although biodegradable, Class-A concentrate has raised some long term environmental concerns.

3. How do CAFS hoseline handling characteristics differ from those of plain water hoselines?

Three hoseline handling characteristics were examined: weight, nozzle reaction force, and resistance to bending.

Table 1 - Weight of Hoseline

Per 50 feet length

Diameter (inches)	Hose (pounds)	Couplings (pounds)	Agent (pounds)	Total (pounds)
1.75 inch:	13	2	52 (water)	67
1.75 inch:	13	2	26 (CAFS)	41
2.0 inch:	17	2	68 (water)	87
2.0 inch:	17	2	34 (CAFS)	53

As can be seen in **Table 1**, attack lines of equal size are considerably lighter when charged with CAF than with plain water. The above weights are calculated on a recommended air mixture ratio of one cfm to one gpm of foam solution under 110 psi. The pumping pressure of 110 psi equals 7.48 atmospheres and compresses the air by that factor. A cubic foot of water also contains 7.48 gallons. This means that the hose contains a pressurized foam mixture of very nearly half liquid and half air by volume. Upon expulsion from the nozzle, the air in the foam expands to seven times the volume it had occupied under pressure in the hose.

The CAFS line weighs 60 to 61 percent of the water line of equal size, and flows half the amount of liquid.

A 2.0-inch CAFS line's weight is 79 percent of the 1.75-inch water hose's weight, and flows 65 percent of the liquid of a 1.75-inch water hoseline.

Table 2 - Nozzle Reaction

Hose Diameter	Agent	Nozzle Diameter	GPM Flow	Nozzle Reaction (pounds)
1.75 inch	water	15/16	185	66
1.75 inch	CAFS	15/16	130	70
1.75 inch	CAFS	1 3/8	130	66
1.75 inch	CAFS	1 ½ shut off	130	44
1.75 inch	CAFS	1 3/8	150	70
2.0 inch	water	1 1/8	250	94
2.0 inch	water	100 psi fog	150	79
2.0 inch	CAFS	1 1/8	130	50
2.0 inch	CAFS	1 1/8	170	70
2.0 inch	CAFS	1 1/8	250	100+

Table 2 shows a number of combinations of flows and nozzle sizes which were selected to approximate conditions that would be appropriate for hoselines handled by only one or two firefighters. All nozzles were smooth bore except as noted. Plain water lines were charged with 50 psi at the nozzle (smooth bore) and 100 psi

(combination fog). CAFS lines were charged with varying pressures to achieve the flows shown.

To achieve the same gpm of solution as plain water hose lines, CAFS lines were found to produce greater nozzle reactions.

Larger nozzles produced less nozzle reaction at equivalent flows. At a flow of 130 gpm of foam solution, the 1.5 inch shut off valve without a nozzle produced an acceptable stream with only 67 percent of the nozzle reaction of a 1 3/8-inch nozzle, and only 63 percent of nozzle reaction of the 15/16-inch nozzle.

Table 3 - Resistance to Bending

Hose Diameter	Agent	PSI	Force at 90 degrees (pounds)	Force at 180 degrees (pounds)
1.75 inch	water	50	6	10
1.75 inch	CAFS	110	10	14
2.0 inch	water	50	5	6
2.0 inch	CAFS	110	14	18

Table 3 presents the results of the bending tests. The pressures (static) were chosen to reflect those actually used for CAFS and water. At the 50 psi pressure used with water, required bending forces are lower than those at 110 psi used with CAFS. This is true for both hose sizes.

Unexpectedly, at the 50 psi pressure, the larger hose required less force to make both the 90 and 180 degree bend than did the smaller hose.

4. Can the use of CAFS by an understaffed crew reduce the number of stress and fatigue injuries at suppression incidents?

Understaffed crews were found to be under increased physical stress resulting from overexertion and early exhaustion. Unavailability of relief personnel further increased fatigue. Smaller firefighting forces, especially during initial attack, were shown to be at more risk of death and injury, both serious and moderate, than were a more adequate force of 16 firefighters, comprised of four-person companies

The National Fire Protection Association reported that just over half of the on-duty firefighter deaths that occurred in 1995 (and 47 percent over the previous 10 years) were caused by stress-related heart attack. The most common fireground form of injury was found to be strains and sprains; the second most common form was slips and falls. The NFPA related these injuries directly to firefighter fatigue.

The use of CAFS was found to reduce stress and fatigue by shortening suppression and overhaul times, thereby reducing firefighter exposure to heat, exertion, and products of combustion. CAFS lines were found to be lighter in weight and easier to handle than water lines of the same size. The durability of foam was shown to eliminate the need for constant soaking of fuels to prevent both fire extension and re-ignition. Better visibility, a key to reducing slipping and falling injuries, was noted when using CAFS for interior operations.

5. Can the use of CAFS increase the suppression ability of an understaffed firefighting force?

Smaller suppression crews were found to be less efficient than crews of adequate staffing. Critical tasks were delayed or performed inefficiently.

CAFS was found to have a greater extinguishing ability than plain water by a factor estimated between two and fifteen. Even accepting the lowest of these estimates, a one- or two-person hoseline crew equipped with CAFS has fire extinguishing power considerably superior to that of a plain water hoseline of equal weight and nozzle reaction.

In situations where interior operations were not possible for a small crew, CAFS was found to significantly out-perform plain water exterior fire streams in the amount of fire extinguished.

DISCUSSION

In several accounts in the literature, one of the advantages claimed for CAFS is lighter, more maneuverable hose lines. The measurements resulting from this study's empirical testing indicate that, at equal gallonage flows (plain water compared to foam solution, not finished foam), the CAFS lines need to be larger and heavier (to carry an equivalent flow of liquid, **plus** compressed air), and exhibit greater nozzle reaction and bending resistance forces caused by higher pumping pressures. This discrepancy points to a controversy surrounding the enhanced extinguishment power of CAFS. Several authorities, with strong evidence, hold that less gallonage is needed with CAFS for a given amount of fire (Edwards, 1994; Stern and Routley, 1996). The literature reports many test fires promptly extinguished with less than 1/10 of the minimum gallonage required by the Iowa State Formula, or even the more demanding National Fire Academy required flow formula. This reduced flow can indeed be delivered by smaller, lighter, more maneuverable lines. However, other sources (Colletti, 1992; Fornell, 1991; International Fire Service Training Association, 1996; Liebson, 1992, 1996) hold that when using CAFS, the foam solution must equal the minimum required flow of plain water. This school of thought advocates exploiting the extinguishment “premium” of CAFS in the form of quicker fire knockdown, rather than smaller, lighter and less fatiguing hoselines.

The reason that this is such an important question is that fire suppression is a threshold event—either a suppression crew has enough knockdown power to stop combustion and damage, or the crew does not, in which case the fire and damage continues until the fire has burned itself down to the threshold of available extinguishing power. A relatively small increase of extinguishing power from just below to just above this threshold can make all the difference between stopping a fire and total loss with extension to other properties. This threshold of extinguishing power has been quantified for water by several required flow formulas relating minimum gpm water flow to area or volume of fire. At this time, there is not a consensus on how these minimum flow formulas may, or may not, be adjusted for flows delivered as Class-A foam by CAFS. As Liebson wrote in 1991:

> The greatest lack at the time of the writing of this book is quantitative data…for specific fire scenarios. Given a specific type of building, with a known fire load, what quantifiable improvement in fire suppression might be expected when using Class A or CAFS, contrasted to the traditional use of plain water? (p. xi)

Seven years later, in spite of a large body of research, this question remains unresolved.

The first line of **Table 2** represents a benchmark. Fornell (1991) considers 185 gpm at 50 psi nozzle pressure on 1.75-inch hose with a 15/16-inch smooth bore nozzle to be the most efficient one-person plain water fire stream. It has a computed nozzle reaction of 69 pounds, and a measured nozzle reaction of 66 pounds in this study. Fornell (1991) considers this amount nozzle reaction force the upper limit for the average firefighter to successfully overcome for approximately 10 minutes of continuous firefighting. For a larger firefighter, the rule of thumb is that the nozzle reaction can range up to one half the firefighter's body weight. This flow of 185 gpm (of foam solution) could not be achieved within this nozzle reaction limit with the 1.75 inch CAFS lines under the conditions and nozzles tested. CAFS options within the nozzle reaction limit for the single firefighter include 150 gpm via the 1.75 inch handline or 170 gpm via the 2.0 inch line. Indications (e.g., the low 44 pound nozzle reaction with the nozzle removed) are that a 185 gpm CAFS flow with the 1.75 inch handline might be approached with larger diameter nozzles. If so, the CAFS 1.75 inch line would still be under much more pressure than the 50 psi water line, and so would be much more resistant to bending.

CAFS appears to be well suited to the initially limited manpower response of the Morristown Fire Bureau. Noted CAFS expert Dominic Colletti recommended (in telephone interview, January 7, 1998) using an initial attack line of 1.75 diameter hose, 95 gpm foam solution, 80 cfm air at about 110 psi pumping pressure for a typical one or two room-and-contents house fire. This is a fairly easily handled stream, satisfies the traditional 95 gpm minimum interior attack flow, has an actual extinguishment power probably beyond the 185 gpm of plain water, and can be increased up to 150 gpm as necessary. Larger diameter nozzles specifically designed for CAFS can provide options to optimize a balance between nozzle reaction and fire stream requirements.

There is a response time component to the required flow threshold discussed above. The typical fire is continuously growing, and the later the suppression activities are begun, the higher the needed flow. O'Hagan found (1985b) that a single 150 gpm hose line, on the average, has reached the limit of its extinguishment ability when the average fire has been burning 10 minutes after flaming ignition. The use of CAFS in Morristown would help alleviate the problem of delayed response by volunteer forces. Fairfax County Fire and Rescue Department, after an evaluation phase, employed CAFS in areas characterized by long second-in company response times (Stern and Routley, 1996). Davis (1997a) reports that the Brookside Engine Company of Morris County, N.J. uses CAFS to "maximize its fire suppression capability with minimal personnel—especially during daytime hours when manpower is short" (p. 29).

Numerous authors (Colletti, 1994b; Duncan, 1994; IFSTA, 1996) warn that CAFS is not a panacea and is not a replacement for personnel. Liebson (1996) describes this approach as “a great danger as far as injuring or killing firefighters” (p. 6).

In 1998 Morristown’s Engine Two is scheduled for refurbishment. Initial inquiries indicate that retrofitting with CAFS is feasible. This engine is assigned to protect Morristown Airport and is now equipped with a roof turret and Class-B foam tank. The CAFS would also enhance the Class-B foam delivery and reach at aircraft fuel and other flammable liquid incidents.

RECOMMENDATIONS

It is the recommendation of this author that Morristown proceed with plans to incorporate CAFS technology into the Engine Two refurbishing project. Additional research into the most appropriate brand, model and features will be necessary.

Time and funds must be allotted for training both the career and volunteer divisions in CAFS operations. Pump operators in particular will need time and practice foam to develop additional skills. Tactical considerations and standard operating procedures will need to be developed.

There will soon be at least five CAFS units in operation in northern New Jersey. An attempt should be made to network and share information and experience in this new technology.

The problem of limited manpower on the initial response will need to be monitored and addressed. Unless present trends are changed, increased reliance on mutual aid and additional career firefighters will become necessary.

Longer-range recommendations include more research into CAFS extinguishment ability. Whatever further testing is necessary for various authorities to achieve consensus on evaluating the CAFS extinguishment "premium" should be identified and performed. Modified critical flow formulas should be developed and incorporated into texts and courses explaining pneumo-hydraulics. As the fire suppression community gains experience with CAFS, fireground and training evolutions should be developed and refined.

An aggressive interior attack at a structure fire is presently the hallmark of a competent suppression force. With current technology, this is how victims are saved and damage is minimized. The Morristown Fire Bureau prides itself on this ability, even when minimum manpower is present. However, several anecdotal accounts in the literature relate very rapid extinguishment of structural fires by means of exterior attack with small CAFS handlines. For several decades, it has been the dream of the fire service to discover an effective method of extinguishment (fog injection, high pressure guns) which does not require interior operations before fire control is achieved. Delaying entry into this dangerous and uncontrolled environment until the fire is knocked down would prevent firefighter injury and death. Although there will probably always be some need for interior operations, this phenomenon must be thoroughly studied.

In investigating such controversial material, the fire community should maintain the healthy skepticism expressed by David Fornell (1991):

> Some claim that a 39 GPM water flow rate when used with CAFS can be as effective as 200 GPM of plain water applied by conventional means. Similar claims were made forty years ago for high-pressure fog. Experience later proved that flow rate, not pressure, is what extinguished the fire. High-pressure delivery may have increased distribution effectiveness but put out little more fire than the same gallonage delivered at normal pressures. While Class-A agents increase knockdown times and help seal burning surfaces more efficiently than plain water, exaggerated claims for the foam's efficiency should be investigated closely. (p. 320)

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