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PERFORMANCE EVALUATION OF THE COMBINED AGENT FIRE FIGHTING SYSTEM (CAFFS)

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14. ABSTRACT

Due to the size and weight of the vehicle, only one P-19 can be transported on a C-130, translating to limited crash fire protection for the first aircraft flying in and out of the location. The Combined Agent Fire Fighting System (CAFFS) employs innovations in nozzle design, lightweight composites and combination agents to design a system with extinguishment capabilities of much larger ARFF vehicles. Evaluations were conducted to characterize overall CAFFS performance so that a comprehensive specification can be written for potential commercialization of the system. Based on flow rate, throw distance and expansion ratio, the air injection setting for the handline and turret foam discharge was optimal at 50% full open. For both the handline and turret operations, the dry chemical flow rate remained linear up to 700 lbs of discharge. The data showed that the pressure on the dry chemical tank could be reduced to 80 psi without affecting the flow rate, which significantly reduced the reaction force the firefighter experienced at the nozzle. Overall, the CAFFS operated very closely to the design parameters for flow rates, expansion ratios and throw distances.

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Abstract

Due to the size and weight of the vehicle, only one P-19 can be transported on a C-130, translating to limited crash fire protection for the first aircraft flying in and out of the location. The Combined Agent Fire Fighting System (CAFFS) employs innovations in nozzle design, lightweight composites and combination agents to design a system with extinguishment capabilities of much larger ARFF vehicles. Evaluations were conducted to characterize overall CAFFS performance so that a comprehensive specification can be written for potential commercialization of the system. Based on flow rate, throw distance and expansion ratio, the air injection setting for the handline and turret foam discharge was optimal at 50% full open. For both the handline and turret operations, the dry chemical flow rate remained linear up to 700 lbs of discharge. The data showed that the pressure on the dry chemical tank could be reduced to 80 psi without affecting the flow rate, which significantly reduced the reaction force the firefighter experienced at the nozzle. Overall, the CAFFS operated very closely to the design parameters for flow rates, expansion ratios and throw distances.

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Summary

Introduction

The P-19 is the primary aircraft rescue and fire fighting vehicle (ARFF) deployed by the Air Force. Due to the size and weight of the vehicle, only one P-19 can be transported on a C-130. For initial deployments, this often translates to limited crash fire protection for the first aircraft flying in and out of the location. The Air Force Research Laboratory, Fire Research Group initiated a project in 2000 to explore the research and development of a compact, lightweight, deployable fire fighting system capable of providing initial aircraft fire protection for day one deployments. The Combined Agent Fire Fighting System, or CAFFS, was designed to mount on a wide variety of vehicle platforms including commercially available trucks and trailers. CAFFS employs dual agent technology for effective extinguishment of both pool and running fuel fires using compressed air foam and dry chemical. Evaluations were conducted to characterize overall CAFFS performance so that a comprehensive specification can be written for potential commercialization of the system.

Results

Foam

According to NFPA 412, non air-aspirated AFFF should have a minimum expansion ratio of 3:1 and air-aspirated AFFF should have a minimum expansion ratio of 5:1. Therefore, the CAFFS handline and turret performed within NFPA standards for both non air-aspirated and air-aspirated AFFF. Based on flow rate, throw distance and expansion ratio, the air injection setting for the handline and turret foam discharge was optimal at 50%.

Dry Chemical

For both the handline and turret operations, the dry chemical weight change remained linear up to 700 lbs of discharge. This indicated that the flow rate was constant throughout the duration of discharge.

When the handline and turret dry chemical operations were compared to each other, the turret operated at approximately 1.5 times the flow rate of the handline, regardless of the pressure setting (150, 115 or 80 psi). The data showed that the pressure on the dry chemical tank could be reduced to 80 psi without affecting the flow rate, which significantly reduced the reaction force the firefighter experienced at the nozzle.

Combination Agent Application

The maximum throw distance for combination agent with the handline was 76 feet compared to 84 feet with foam alone (due to a change in the wind speed and direction). The turret showed increased throw distance from 91 feet to 100 feet with combined agent, which was expected since the force from the dry chemical discharge propels the agents further than foam alone.

Expansion ratios for both the handline and turret operations were significantly decreased as a result of the combination agent. Previous laboratory studies have shown that the silicon used to fluidize the potassium bicarbonate breaks down the foam bubbles produced by the injection air.

Conclusions

Overall, the CAFFS operated very closely to the design parameters for flow rates, expansion ratios and throw distances.

Optimal performance for foam discharge for both the handline and turret were achieved from the same air injection setting of 50%.

The dry chemical tank pressure steadily declined as the agent was discharged and did not level off as observed in the foam discharge tests. This indicated that the flow of air from the high pressure cylinder to the dry chemical tank was not sufficient to maintain the pressure set by the regulators. The pressure drop was not significant enough to affect the flow rate of the dry chemical.

While flow rate data indicated compaction of the dry chemical, this did not affect the operation of the system and hard compaction from extended storage, or vibration, was easily reversed by charging the system and discharging 3-5 seconds of agent.

Initial testing on the CAFFS Dry Chemical System indicated the flow rate at the handline and turret was consistent and was not significantly affected by compaction.

While the turret dry chemical discharge performed best at 150 psi, both discharge devices performed well at 80 psi with only a slight decrease flow rate noted at the turret. Decreasing the operation pressure significantly decreased the force on the nozzle experienced by the firefighter, making the handline easier to handle.

Dry chemical decreases the expansion ratio of the foam, which will affect burnback protection.

Recommendations

Because of the variation in dry chemical flow rates, a minimum of three tests should be performed at each pressure, particularly when the first two data points are significantly different (one pps, pounds per second, or greater).

Further testing of full tank discharge for the dry chemical system should be performed for 80 and 115 psi pressure settings for both the handline and turret to determine if the flow rate and consistency will improve over a longer discharge period. Also further testing should be performed to determine the effect of compaction on the system for both the handline and turret.

The stability of the CAFFS on the vehicle should be quantified by tilt table testing to determine safe operational speeds and inclination angles.

If foam and dry chemical are both used for the initial knockdown and extinguishment of the fire, the dry chemical discharge needs to be shut off and a blanket of foam laid down on the fuel surface for burnback protection.

Introduction

Background

Current Deployable Fire Trucks

The P-19 is the primary aircraft rescue and fire fighting vehicle (ARFF) deployed by the Air Force. Due to the size and weight of the vehicle, only one P-19 can be transported on a C-130. For initial deployments, this often translates to limited crash fire protection for the first aircraft flying in and out of the location. In addition to providing critical fire protection overseas, these vehicles are the mainstay of many CONUS bases. Gaps in state-side fire protection are often experienced when these vehicles are sent overseas. With the increase in deployments, these assets are becoming more critical. New ARFF vehicles are expensive, complex and often exceed transport capabilities of the C-130. They often require special skill sets to maintain and operate these vehicles, which may be limited in a deployed environment.

Complexity of Aircraft Accidents

Conventional fire fighting foam agents and equipment are most effective for extinguishing two-dimensional (2-D) fires. However, many aircraft accidents involve some type of three-dimensional (3-D) flowing fuel fires, which can occur when fuel or hydraulic fluid from damaged lines and equipment continuously replenishes dry bay compartments and/or external openings with fuel. Reignition of flowing fuel due to hot metal surfaces can also pose a potential hazard. The 2-D pool fire is constantly resupplied by a 3-D flowing fuel column and, generally, requires constant agent application just for control. These factors make control and extinguishment of combination 2-D/3-D fires virtually impossible when only 2-D foam agent is applied. 3-D agents (such as dry chemical and gaseous streaming agents) are highly effective at extinguishing flowing fuel fires but do not posses adequate throw distance or cooling to effectively extinguish 2-D pool fires.

Purpose

The Air Force Research Laboratory, Fire Research Group initiated a project in 2000 to explore the research and development of a compact, lightweight, deployable fire fighting system capable of providing initial aircraft fire protection for day one deployments. Innovations in nozzle design, lightweight composites and combination agents were employed to design a system with extinguishment capabilities of much larger ARFF vehicles. The Combined Agent Fire Fighting System, or CAFFS, was designed to mount on a wide variety of vehicle platforms including commercially available trucks and trailers.

CAFFS employs dual agent technology for effective extinguishment of both pool and running fuel fires. The system uses compressed air foam and dry chemical. The agents can be used either separately or in combination, depending on the type and size of the emergency. Effective delivery of the dry chemical was improved by the concentric design of both the handline and roof turret nozzles. The stream of dry chemical was encircled by a ring of foam, assuring maximum throw distance and maximum application of both agents to the seat of the fire, even in windy conditions. The motorized roof turret was operated with a two-axis joystick that controls foam and dry chemical discharge. Two levers on the handline control the discharge of either dry chemical or foam or both at the same time.

CAFFS provided two modes of agent delivery. For larger fires, the operator can remotely activate the system with a single switch from inside the truck cab. The motorized roof turret was controlled with an easy to use joystick, with three switches (one maintained and two momentary) that control foam and dry chemical discharge. The system was also equipped with a 100 ft dual-hose handline. The handline can be used for smaller incidents that do not require mass agent application or as a backup system in case electrical failure occurs, which would make the roof turret inoperable. Only the turret would be affected by the loss of electrical power because the CAFFS utilizes air-operated ball valves to control agent application.

Scope

Evaluations were conducted to characterize overall CAFFS performance so that a comprehensive specification can be written for potential commercialization of the system. These evaluations include:

- Foam flow rates for both the handline and turret.
- Dry chemical flow rate as a function of pressure for both the handline and turret.
- Foam throw distance for both the handline and turret as a function of air injection.
- Changes in tank pressure for foam and dry chemical tanks during handline and turret operations.
- Changes in pressure at the handline and turret during operation.
- Foam expansion ratio at various air injection rates for both the handline and turret operation.
- Changes in flow rate for foam or dry chemical as the tanks are emptied of agent.

Methods and Procedures

Foam test procedures

- Open nozzle for 60 seconds and flow agent. Record flow rate of foam, injection air, system pressure, foam tank pressure and pressure at the nozzle. Additional measurements include: foam expansion ratio, throw distance at level and throw distance at maximum.
- Turret Operation. Two additional inserts were fabricated to test whether the throw distance can be increased while maintaining the same pressure. By increasing the outside diameter of the dry chemical discharge tube, the overall cross sectional area of the foam discharge tube decreases and throw distance should increase.
- For both the turret and the handline, the nozzle was opened and a full tank of agent was discharged.

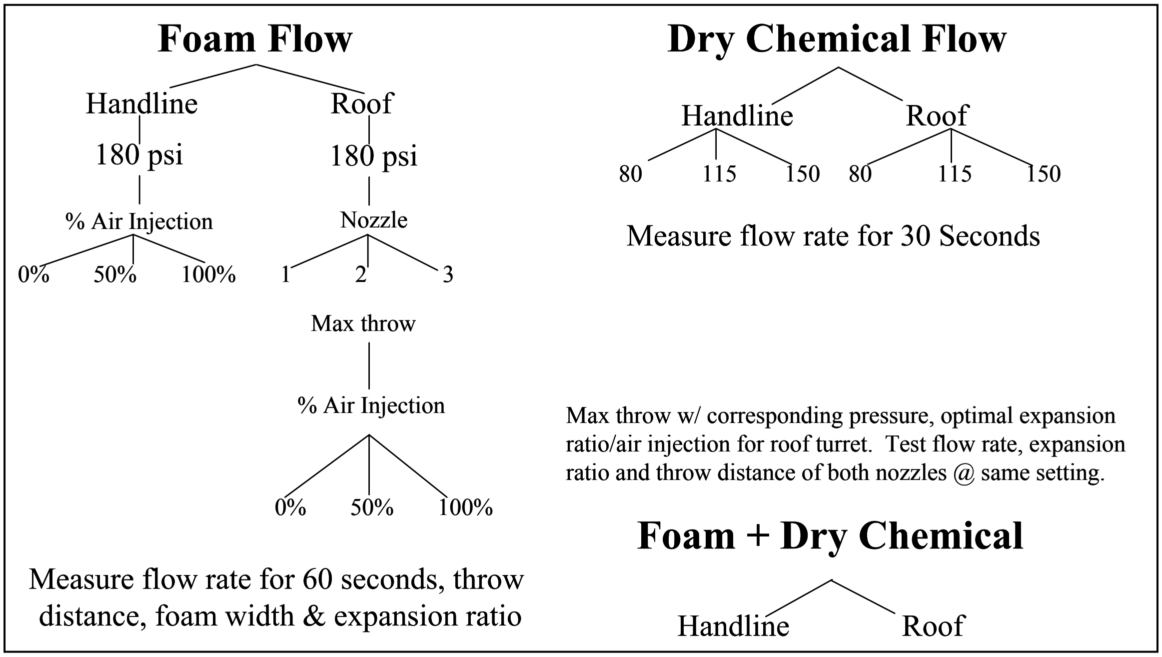
Dry Chemical test procedures

- Open nozzle for 30 seconds and flow agent. Record flow rate system pressure, dry chemical tank pressure and pressure at the nozzle. Do not measure air injection, throw distance, stream pattern width or expansion ratio.
- Flow entire tank of dry chemical to determine changes in flow rate from full to empty tank.

Foam and Dry Chemical test procedures

- Open nozzle for 60 seconds and flow agent. Record flow rate of foam, injection air, system pressure, foam tank pressure and pressure at the nozzle. Additional measurements include: foam expansion ratio, throw distance at level and throw distance at maximum.

In order to minimize the number of tests needed to evaluate the CAFFS, certain parameters were narrowed. The pressure regulator for the control air system was fixed at 100 pounds-per-square-inch (psi) for the extent of the testing period. The control air was the pressure sent to the air-operated ball valves. The foam tank pressure was set at 180 psi for the duration of testing. This parameter was not varied because the force of the foam at the nozzle does decrease significantly with decreased pressure and, therefore, the maximum pressure was maintained. Dry chemical pressure was varied to determine changes in flow rate. Lower dry chemical pressure makes the handline operation much easier to handle. Therefore, if the pressure could be lowered without affecting flow rate then a lower dry chemical operating pressure could be made standard. Air Tank pressures were measured at the beginning and ending of tests (one air tank for the foam and one for the dry chemical), the average charged tank pressure was 2800 psi and the average discharged tank pressure was 700 psi. Figure 1 shows the test schematic used for evaluating the CAFFS.



Measure flow rate for 60 seconds, throw distance, foam width & expansion ratio

Measure flow rate for 30 Seconds

Max throw w/ corresponding pressure, optimal expansion ratio/air injection for roof turret. Test flow rate, expansion ratio and throw distance of both nozzles @ same setting.

Figure 1. Schematic of CAFFS Testing

Data Acquisition

Equipment and software for acquiring, recording and manipulating data included a National Instruments Data Acquisition System (DAQ), Lab View software, Excel and a Dell Computer with monitor. Instrumentation equipment included an Omega LCCB 2K load cell, for measuring the weight of the skid unit and Omega PX605-300GI Pressure transducers for measuring the pressure of the flow at the turret and handline (Table 1).

Table 1. Instrumentation List

Designation	Location	Range	Comments
P1	Foam Tank	0-300 psi	
P2	Dry Chem Tank	0-300 psi	
P3	Injection Air at FM-2	0-300 psi	
P4	Injection Air at mix valve	0-300 psi	
P5	Turret Foam	0-300 psi	
P6	Turret Dry Chem	0-300 psi	
P7	Handline Foam	0-300 psi	
P8	Handline Dry Chem	0-300 psi	
FM1	Foam flow	0-100 gpm	
FM2	Injection air flow	0-60 CFM	
F1	Dry Chem weight	0-2000 lbs	Scale factors to compensate for tank location relative to pivot and load cell
T cjc	Cold Junction Comp	50-100 deg F	
T1	Temperature at FM 2	-60-200 deg F	Use T (blue) thermocouple

Results

Foam Testing, Handline

0% Air Injection

Flow data from the handline foam nozzle showed that the discharge rate when the injection air was set at 0% was approximately 55 gpm (Figure 2). Foam tank pressure readings dropped from 170 psi to approximately 140 psi, where they remained stable for the duration of discharge. The pressure at the nozzle was also consistent throughout the discharge duration at 20 psi. The throw distance was 44.3 ft and the average expansion ratio was 3.57.

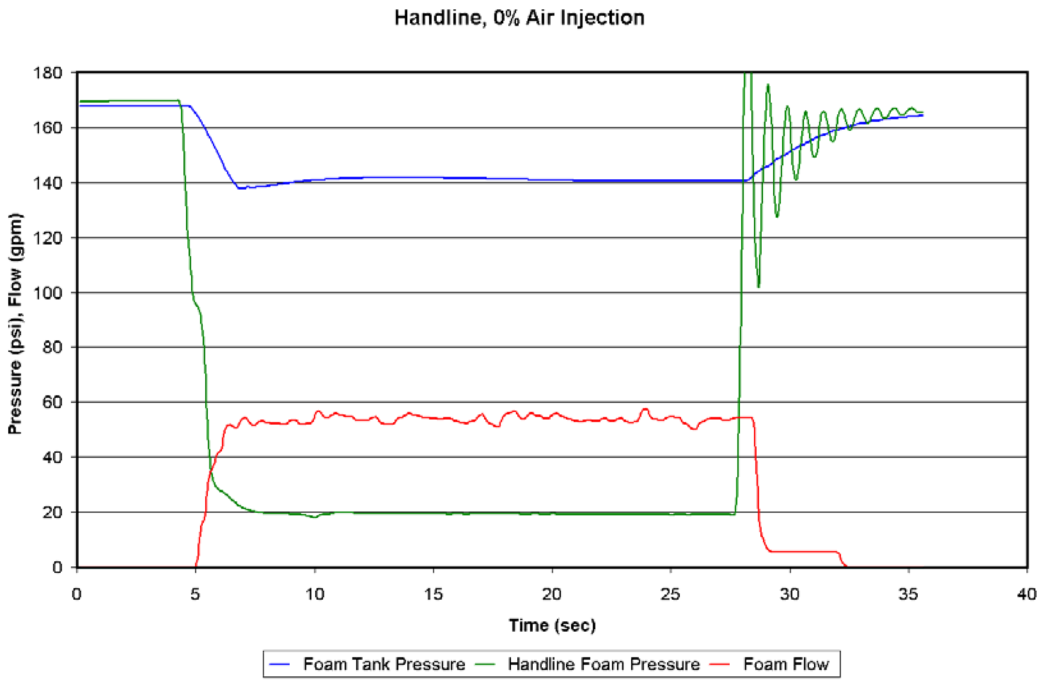


Figure 2. Handline Foam Flow and Pressure Data, 0% Air Injection.

50% Air Injection

Flow data from the handline foam nozzle showed that the discharge rate was approximately 39 gpm when the air injection valve was set at 50% (Figure 3). Foam tank and foam nozzle pressure readings remained constant at approximately 140 psi and 45 psi, respectively. Expansion ratio testing conducted on the 50% injection air foam averaged 7.82. The maximum throw distance achieved was 84 ft.

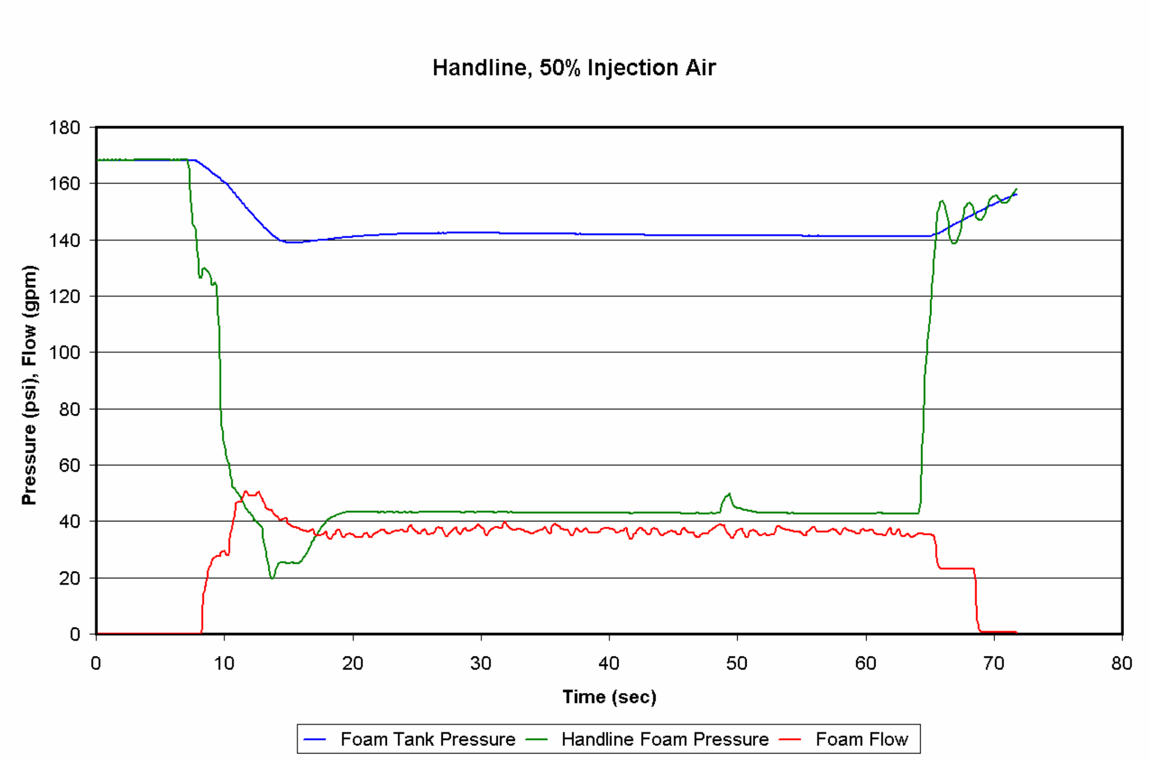


Figure 3. Handline Foam Flow and Pressure Data, 50% Air Injection.

100% Air Injection

The flow rate of the handline at 100% air injection was 29 gpm (Figure 4). The foam tank and nozzle pressure remained constant at 140 psi and 46 psi, respectively. The expansion ratio increased to an average of 9.54. The throw distance increased slightly to 87 ft.

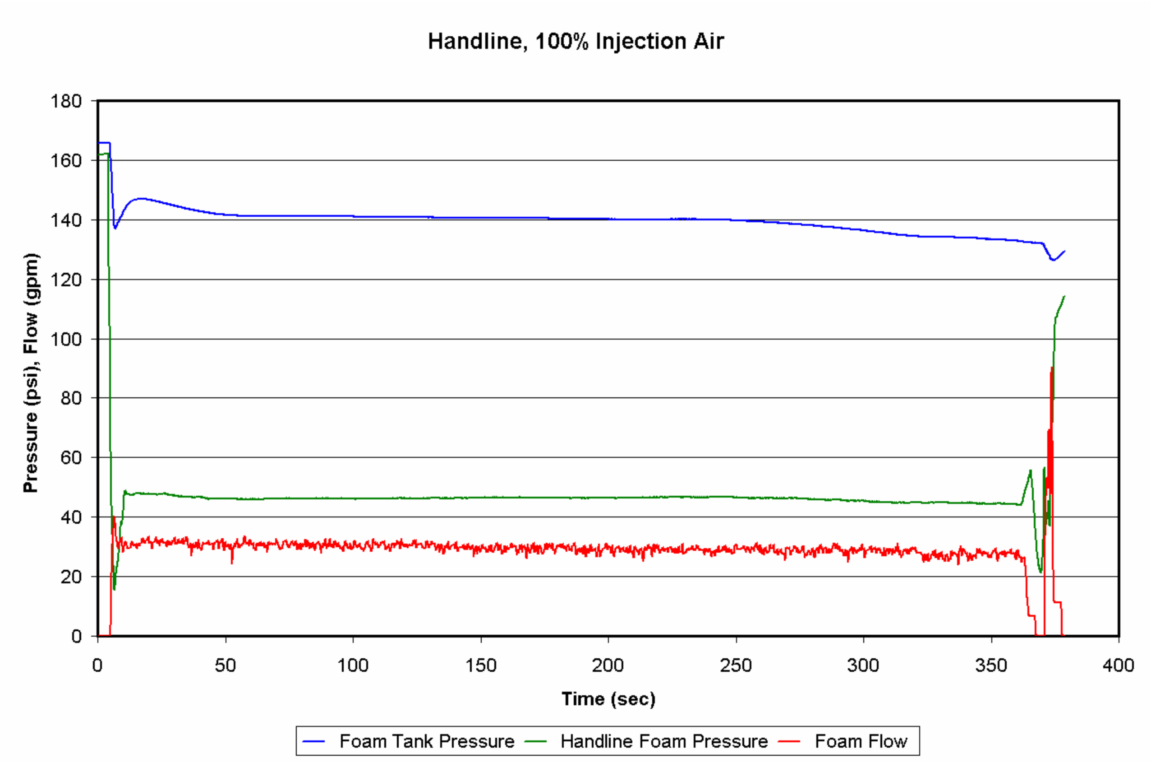


Figure 4. Handline Foam Flow and Pressure Data, 100% Air Injection.

According to NFPA 412, non air-aspirated AFFF should have a minimum expansion ratio of 3:1 and air-aspirated AFFF should have a minimum expansion ratio of 5:1. Therefore, the CAFFS handline performed within NFPA standards for both non air-aspirated and air-aspirated AFFF. Based on flow rate, throw distance and expansion ratio, the air injection setting for the handline was optimal at 50% (Table 2).

Table 2. Summary of Handline Performance.

Injection Air	Tank Pressure (psi)	Nozzle Pressure (psi)	Flow Rate (gpm)	Expansion Ratio	Throw Distance (ft)
0%	140	20	55	3.57	44.3
50%	**140**	**45**	**39**	**7.82**	**84**
100%	140	45	29	9.54	87

Foam Testing, Turret

Turret Throw Distance

The turret throw distance was measured using three different inserts. Two additional dry chemical discharge tubes of varying outside diameter were fabricated in addition to the original insert provided with the turret nozzle. The outside diameters were 1.0625 in (area = 1.437 in^2) for insert #1, 1.4375 in (area = 0.701 in^2) for insert #2 and 1.55 in (area = 0.437 in^2) for insert #3. The purpose of varying the insert was to increase foam throw distance without increasing the pressure. Each insert was tested without injection air and zero elevation. Each insert was tested twice to determine maximum throw distance prior to further evaluation of the turret for flow rate, pressure changes and expansion ratio. Nozzle insert #3 provided 25 feet of additional throw distance compared to insert #1 and 10 feet of additional throw distance compared to insert #2. All foam testing performed with the turret were conducted with insert #3.

0% Air Injection

Figure 5 shows an average flow rate of 86 gpm for the turret using non air-aspirated foam (air injection setting of 0%). The foam tank pressure dropped from 170 psi static to 138 psi flowing. This change in pressure at the tank was in line with that observed during handline operations. The pressure measured at the turret stabilized at approximately 50 psi for the duration of testing. Thow distance measured 73 feet and the foam expansion ratio averaged 3.22.

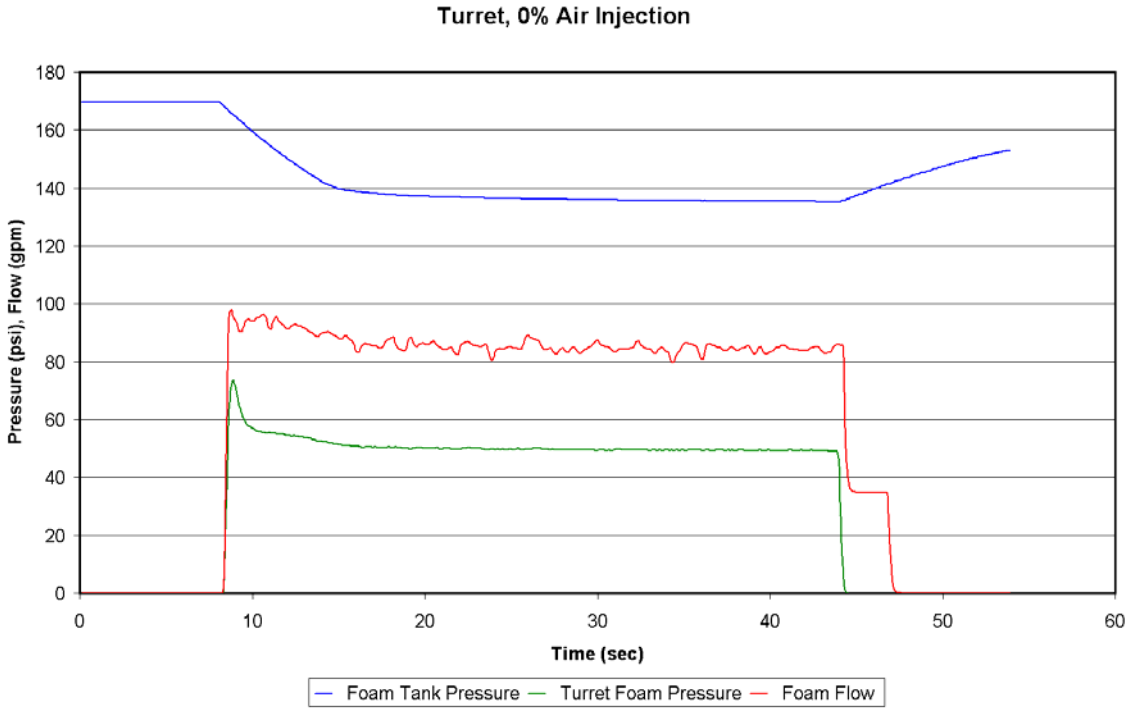


Figure 5. Turret Foam Flow and Pressure Data, 0% Air Injection.

50% Air Injection

Figure 6 shows an average flow rate of 64 gpm when the air injection was set at 50%. The pressure at the foam tank fell slightly compared to 0% air injection to approximately 130 psi. The pressure at the turret nozzle increase to 75 psi, compared to 50 psi at 0% air injection. The expansion ratio and throw distance both increased to 5.82 and 91 feet, respectively.

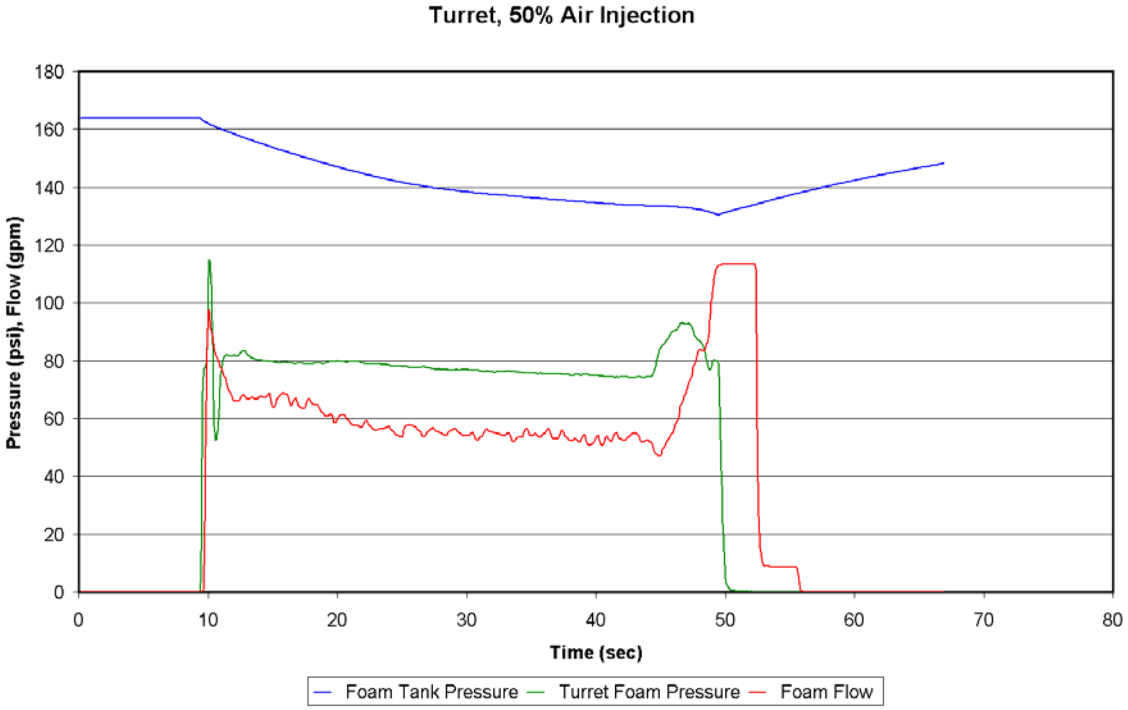


Figure 6. Turret Foam Flow and Pressure Data, 50% Air Injection.

100% Air Injection

Figure 7 showed an average flow rate of 47 gpm with 100% air injection. The tank pressure was approximately 130 psi and the pressure at the turret nozzle increased slightly to 80 psi. The foam flow rate showed considerable variation as a result of the increased air injected into the line, which was not observed during handline evaluations at 100% air injection. The throw distance decreased slightly to 88 feet and the expansion ratio increased to 8.42. Changes in these parameters were expected as the lighter weight foam reduced the throw distance compared to the denser foam and the additional air injection caused the foam to expand to a greater extent.

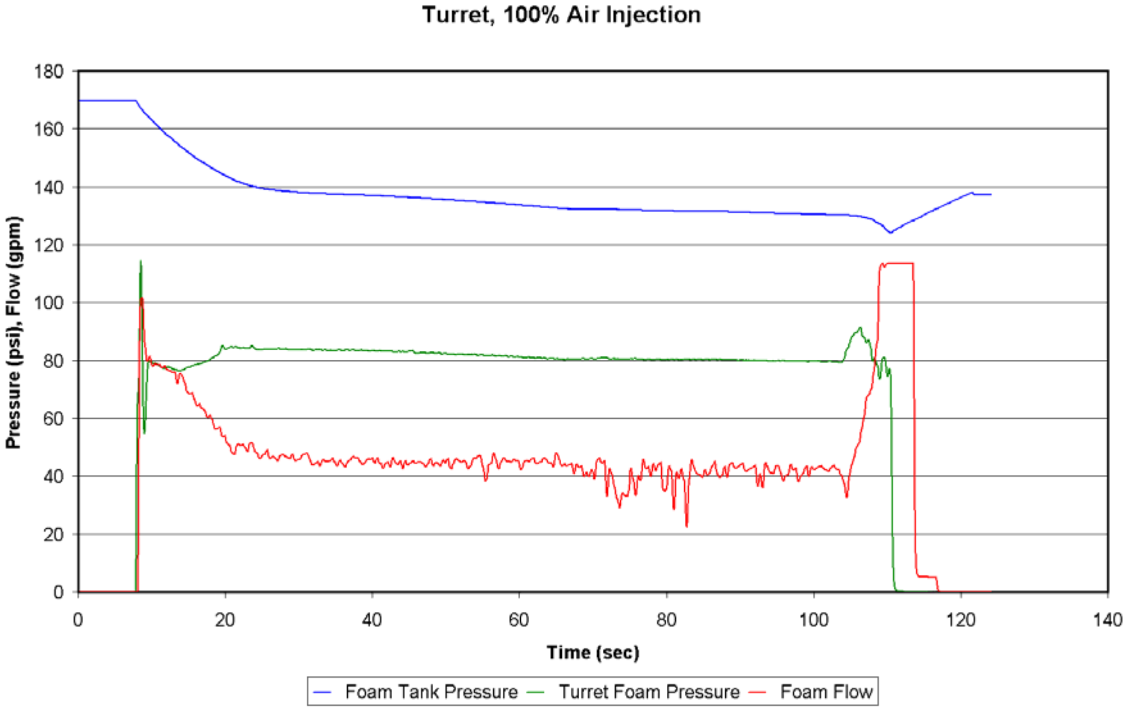


Figure 7. Turret Foam Flow and Pressure Data, 100% Air Injection.

According to NFPA 412, non air-aspirated AFFF should have a minimum expansion ratio of 3:1 and air-aspirated AFFF should have a minimum expansion ratio of 5:1. Therefore, the CAFFS turret performed within NFPA standards for both non air-aspirated and air-aspirated AFFF. Based on flow rate, throw distance and expansion ratio, the air injection setting for the turret was optimal at 50% (Table 3).

Table 3. Summary of Turret Performance.

Injection Air	Tank Pressure (psi)	Nozzle Pressure (psi)	Flow Rate (gpm)	Expansion Ratio	Throw Distance (ft)
0%	135	50	86	3.22	73
50%	**130**	**75**	**64**	**5.82**	**91**
100%	130	80	47	8.42	88

Dry Chemical Testing

All 30 second discharge charts were generated from data collected on May 28, 2003. Several additional dry chemical discharge tests were conducted in January 2003 but were not used in the comparison of flow rates and pressure settings because the full range of pressure measurements was not conducted. These additional charts are included for reference in Figures 17-18 and 20-21 of Appendix A. All dry chemical flow rates indicated were average values of the first thirty seconds of flow.

Full Tank Discharge

Two tests were performed, one for turret (Figure 8) and one for handline (Figure 9), in which the dry chemical tank was filled with PKP, pressurized to 150 psi and then completely discharged. The handline full tank discharge rate averaged 4.31 pps and the turret full tank discharge rate averaged 6.94 pps. The charging of the system, flowing low pressure compressed air into the dry chemical tank, can be seen prior to the opening the nozzles, after which the dry chemical tank pressure and the nozzle pressure decline proportionally as the PKP is discharged. The agitation shown in Figure 8 may be caused by the compaction of PKP powder.

For both the handline and turret operations, the weight change remained fairly linear up to 700 lbs of discharge. This indicated that the flow rate was constant throughout the duration of discharge. At 700 lbs of discharge, the dry chemical tank pressure began to drop rapidly, indicating that the tank was nearly empty of dry chemical. The pressure at the nozzle followed the same trend as the pressure in the tanks decreased.

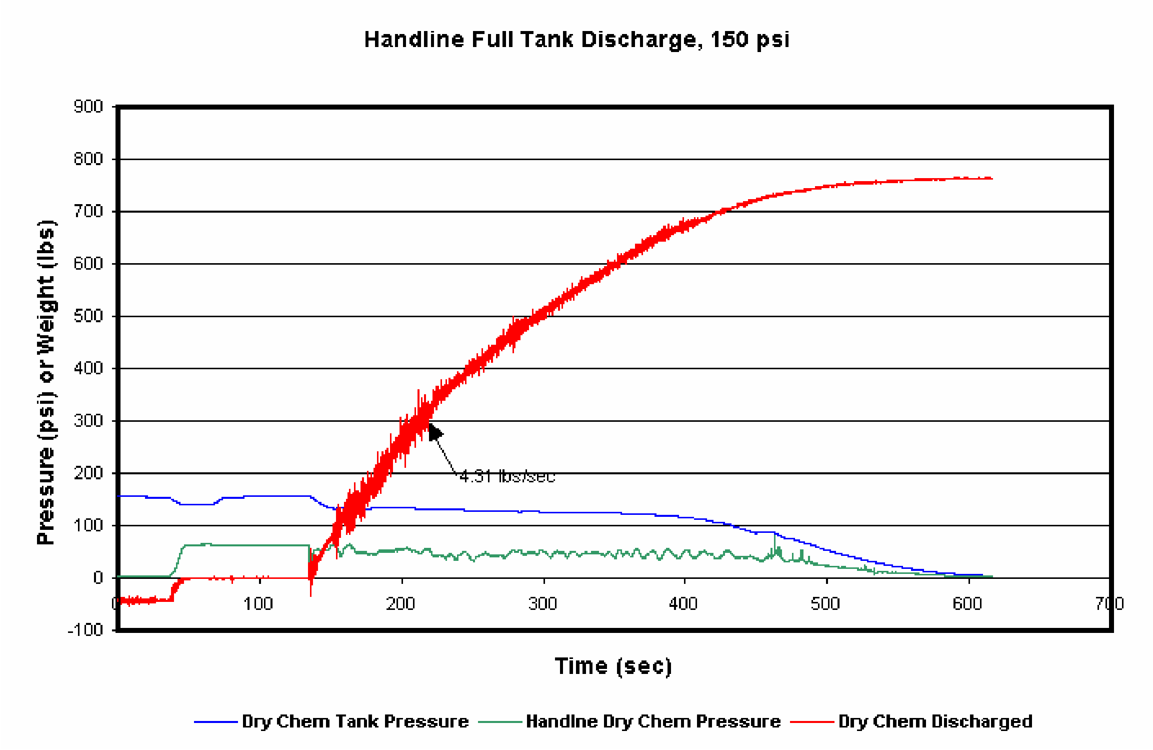


Figure 8. Full Tank Dry Chemical Discharge Using the Handline at 150 psi.

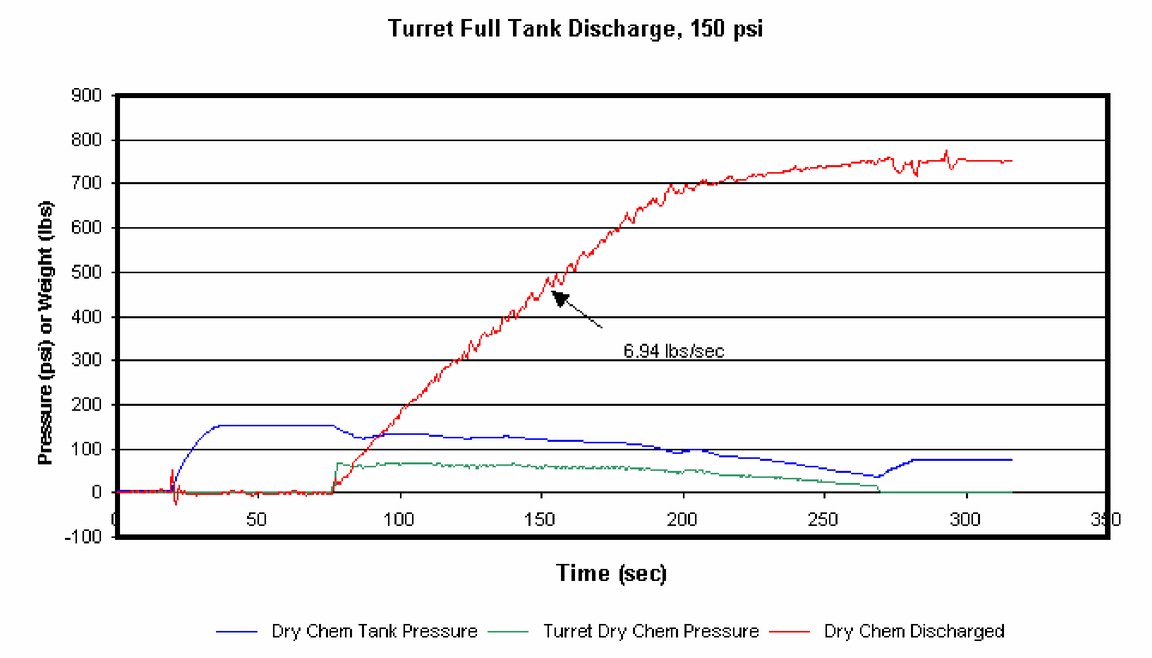


Figure 9. Full Tank Dry Chemical Discharge Using the Turret at 150 psi.

Dry Chemical Testing, Handline

150 psi

Variation of 1 pps was observed between the full tank discharge and 30 second partial tank discharge at 150 psi. The 3.33 pps flow rate at 150 psi (Figure 10) varies slightly from the 3.62 pps flow rate at 115 psi (Figure 11) and 3.57 pps flow rate at 80 psi (Figure 12). Tank pressure steadily declined from 150 psi to 120 psi, at which point, the nozzle was closed and the test terminated. This trend was observed in all subsequent tests. Pressure at the nozzle oscillated between 6-18 psi, which was lower than the nozzle pressure observed during full tank discharge, which averaged 50 psi.

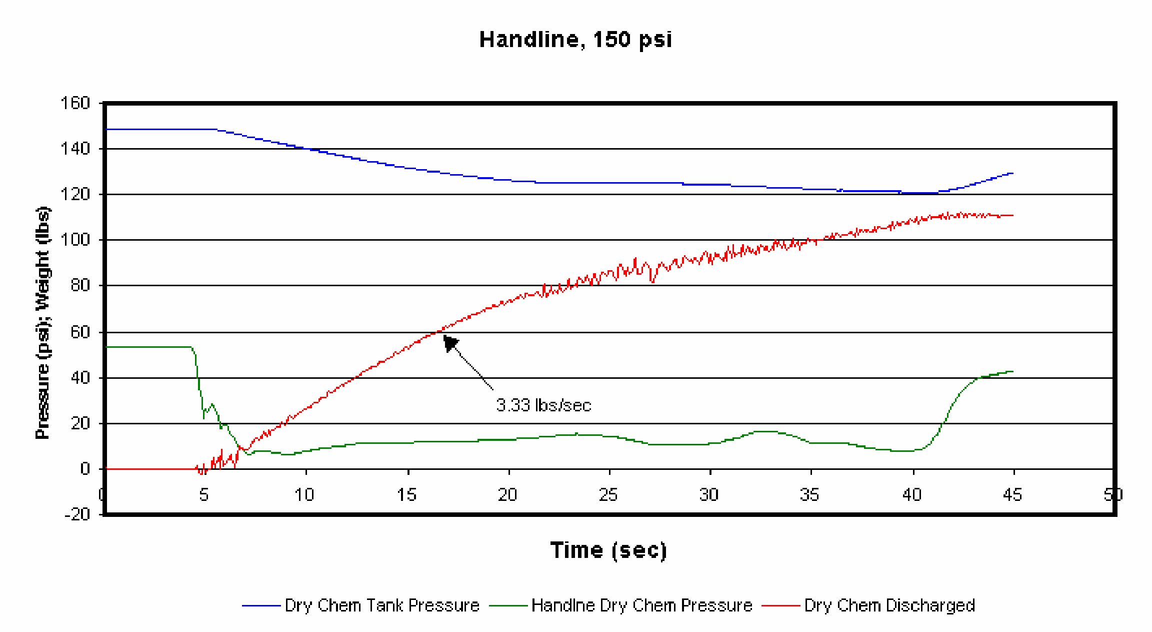


Figure 10. Handline Dry Chemical Flow and Pressure Data, 150 psi.

115 psi

Dry chemical flow rate averaged 3.62 pps during 115 psi testing (Figure 11). Tank and nozzle pressure averaged 98 psi and 8 psi, respectively.

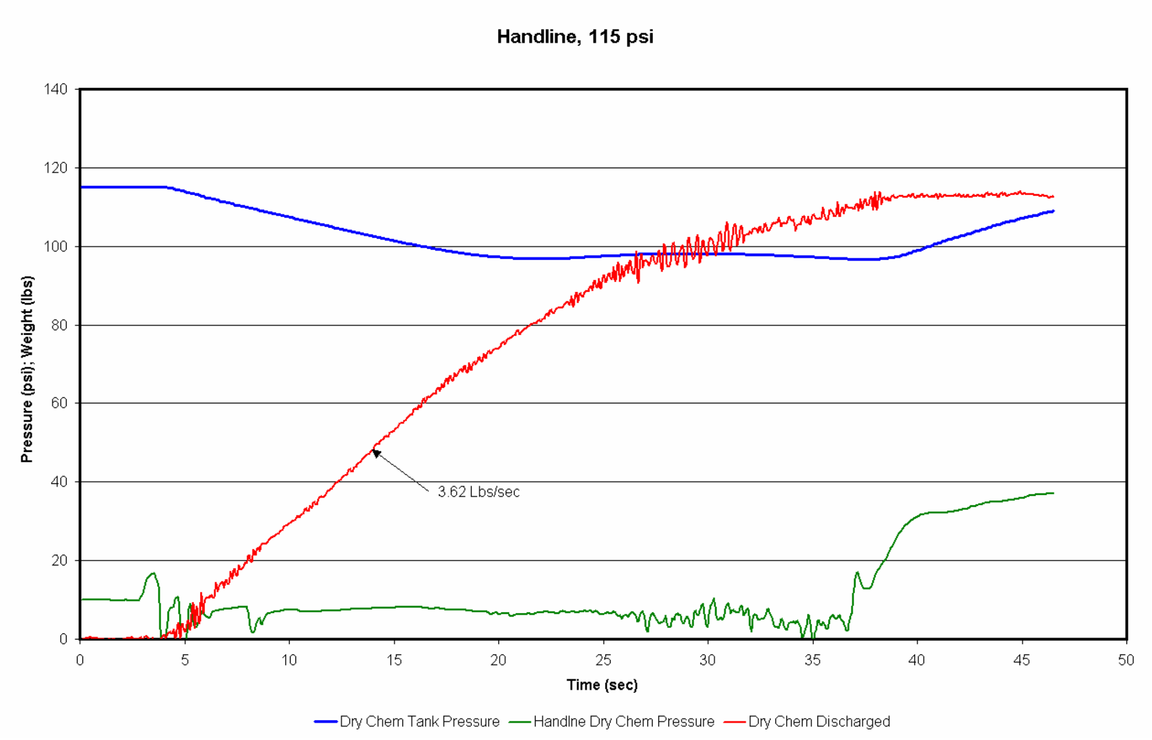


Figure 11. Handline Dry Chemical Flow and Pressure Data, 115 psi.

80 psi

Dry chemical flow rate averaged 3.57 pps during the 80 psi flow test (Figure 12). An additional test was conducted at 80 psi during this same test series. The flows and pressures were similar to those in Figure 12 and the results are shown in Figure 19, Appendix A.

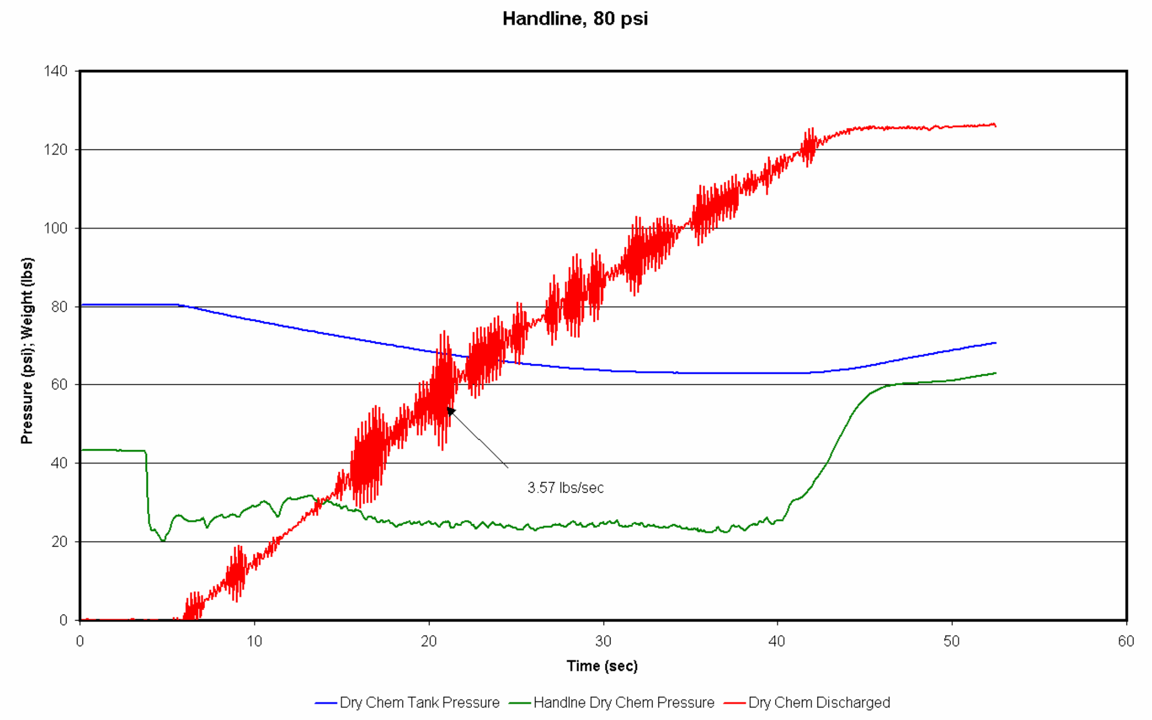


Figure 12. Handline Dry Chemical Flow and Pressure Data, 80 psi.

Dry Chemical Testing, Turret

All dry chemical flow and pressure tests conducted with the turret showed the same trend in the dry chemical discharge data. Initially, as the dry chemical at the turret was activated, a drop in the discharge weight was shown. When the dry chemical flow was stopped, a small spike (20-30 lbs), followed by a dip (20-30 lbs), then a large spike (70-100 lbs) were observed at all pressure settings. Evaluation of the pressure in the tank and the nozzle did not indicate a change in the system that could be attributed to the trend. Therefore, the spikes in the data were a result of a force being applied to the load cell used to measure dry chemical weight because of the changes in reaction forces at the turret. A load cell was place directly under the dry chemical tank to measure changes in tank weight to determine flow rate. A pivot point was attached to the CAFFS at the horizontal center of gravity (CG) of the foam tank. Dry chemical weight change was determined by multiplying the load cell readings by the ratio of the distance to the dry chemical tank divided by the distance to the load cell. The turret nozzle on the CAFFS was attached to an eight foot boom, with an additional four feet to the horizontal CG. The nozzle and the residual dry chemical in the flexible hose in the turret arm created a large reaction force that was transmitted to the load cell. The solenoid valve used to control dry chemical flow took approximately three seconds to close, which directly corresponded to the time of the spikes and dips observed at the end of each test (Figures 13-15). This trend was not observed in the handline operation because the hose line and hose reel were located close to the horizontal CG.

150 psi

The same trend of spikes and dips observed during the full tank turret discharge was also observed during the 30 second turret evaluations (Figures 9, 13, 14). The measured discharge rate of the dry chemical was significantly different between the full tank and 30 second discharge tests. The full tank discharge flow rate was over 2 pps higher than the flow rate measured during the 30 second discharge at 150 psi. Because full tank discharges were not performed at 115 and 80 psi and the 150 psi full tank discharge was not repeated, a trend cannot be established. No determination was made to explain the differences. The flow rate at 150 psi was almost identical to the flow rate at 115 psi during the 30 second discharges, at 4.82 pps and 4.87 pps, respectively.

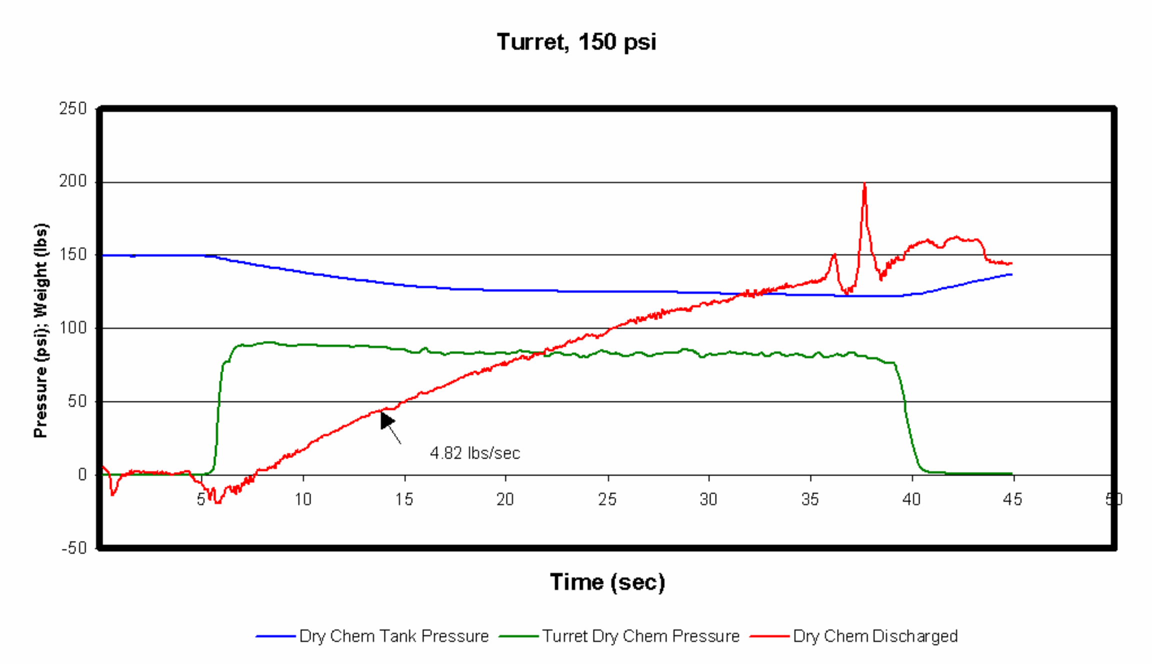


Figure 13. Turret Dry Chemical Flow and Pressure Data, 150 psi.

115 psi

Figure 14 shows the dry chemical flow and pressure data for the turret at 115 psi. While the flow rates at 150 and 115 psi were almost identical, the pressure at the turret nozzle was decreased from 80 to 58 psi. The pressure drop observed in the dry chemical tank was approximately 25 psi, which was the same as the drop observed during the 150 psi test.

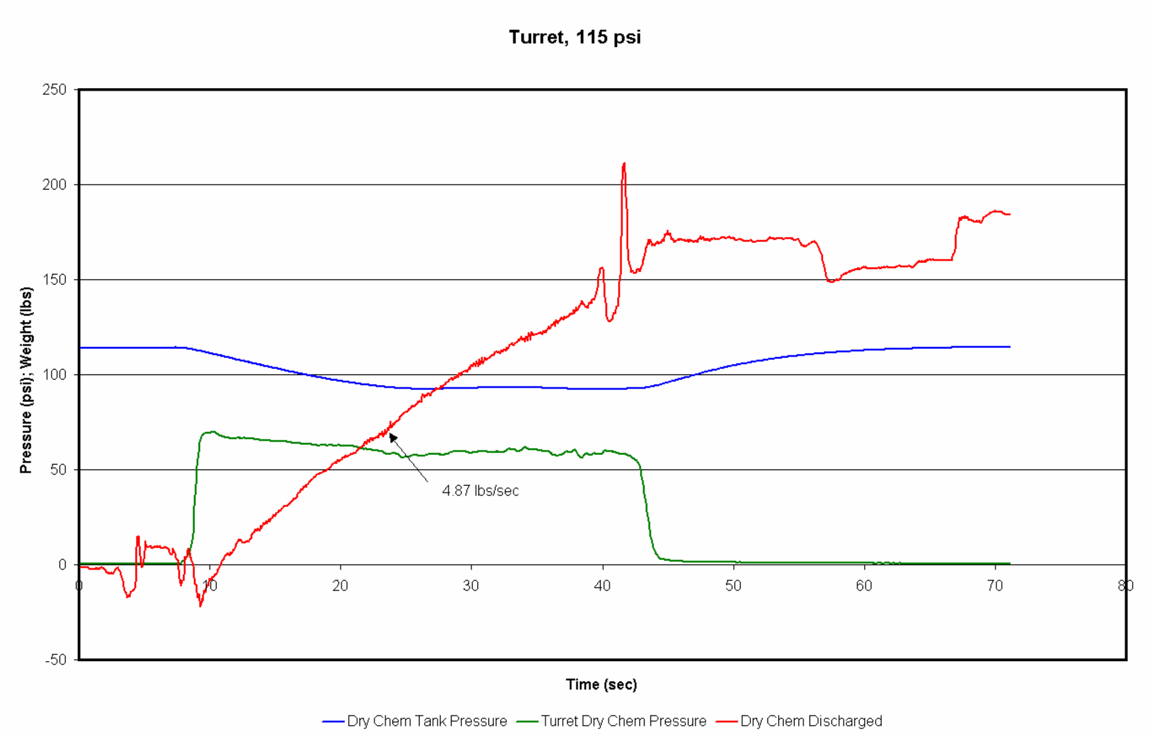


Figure 14. Turret Dry Chemical Flow and Pressure Data, 115 psi.

80 psi

The dry chemical discharge rate dropped from an average of 4.8 pps to 4.0 pps during the 80 psi test (Figure 15). Pressure at the nozzle decreased even more to an average of 35 psi. The pressure drop in the dry chemical tank decreased by 30 psi, which was slightly more than the pressure drops recorded during the 150 and 115 psi tests.

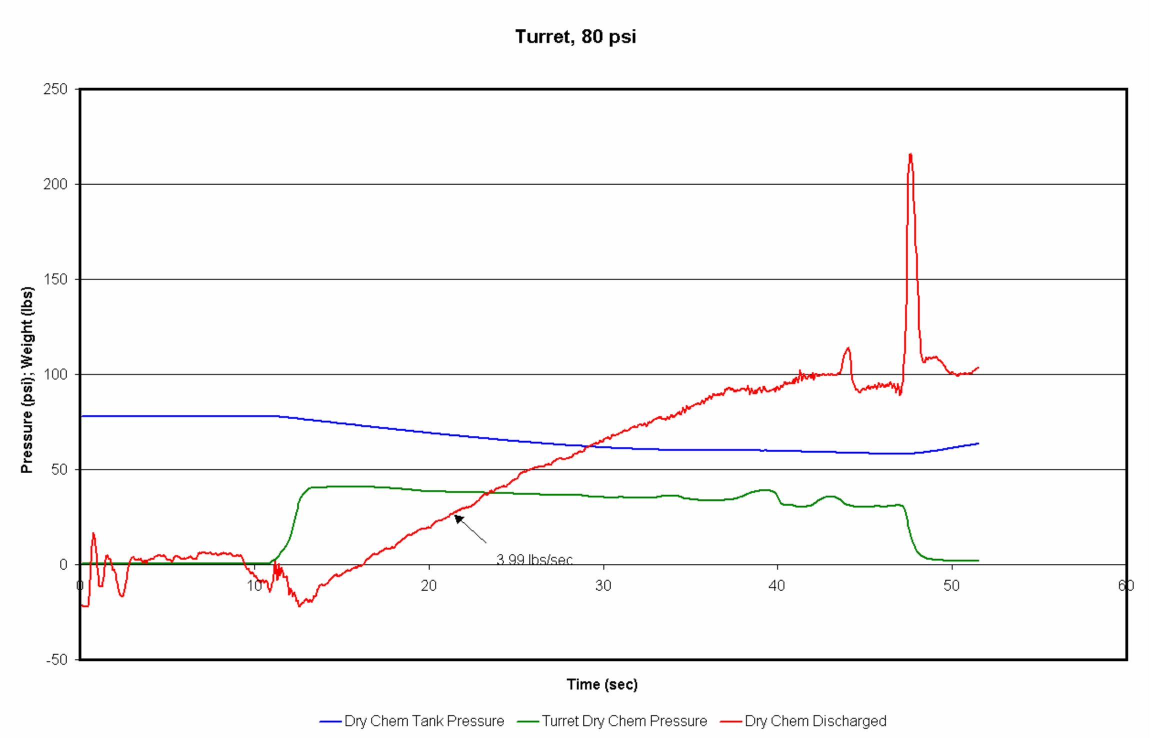


Figure 15. Turret Dry Chemical Flow and Pressure Data, 80 psi.

Figure 16 shows a summary of the dry chemical flow rate for the handline and turret as a function of tank pressure. When the series of three tests for each nozzle were compared, the flow rate changes were minor (3.33-3.62 pps for the handline; 3.99-4.87 pps for the turret). When the handline and turret operations were compared to each other, the turret operated at approximately 1.5 times the flow rate of the handline, regardless of the pressure setting. For optimization of the CAFFS, this data showed that the pressure on the dry chemical tank could be reduced to 80 psi without affecting the flow rate significantly. Reducing the pressure setting was particularly important for the handline operation as this significantly reduced the reaction force the firefighter experienced at the nozzle.

Note: the original CAFFS design specifications included a dry chemical discharge rate of approximately five pps for the handline and eight pps for the turret. These numbers were based on previous commercial off the shelf systems and do not relate to any testing to optimize dry chemical to foam ratios. Testing to determine the optimal ratio needs to be conducted to maximize dual agent performance.

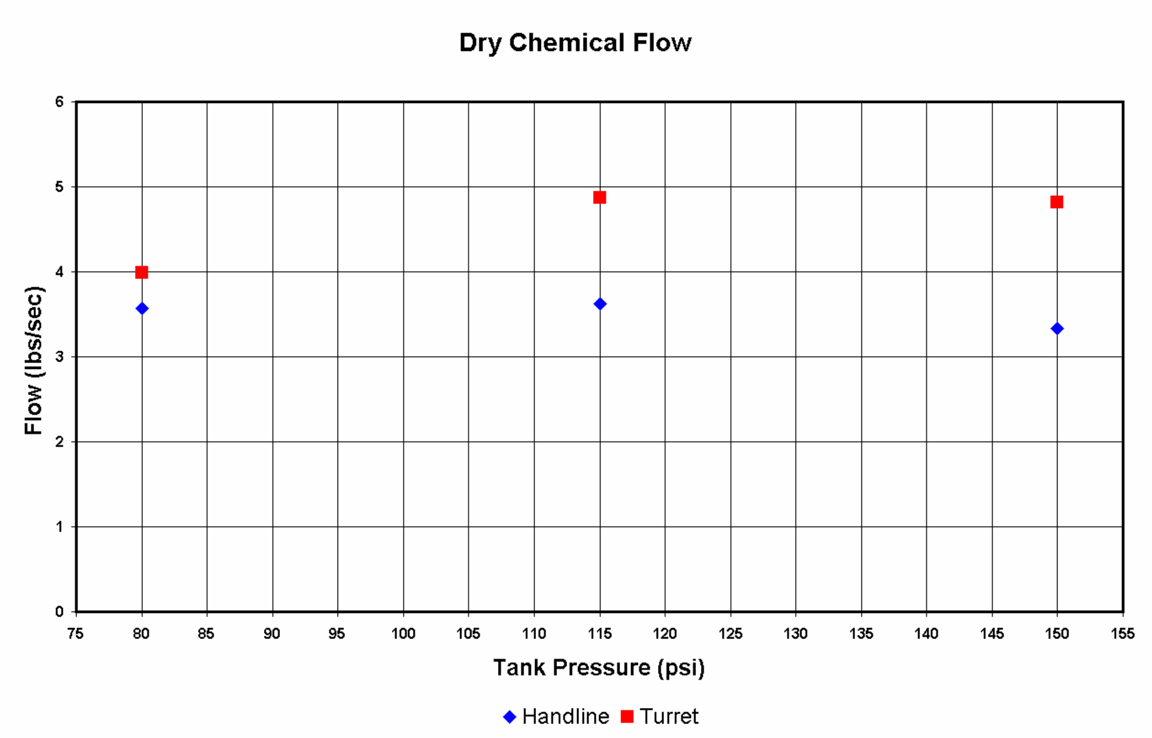


Figure 16. Dry Chemical Flow for Handline and Turret as a Function of Tank Pressure.

Compaction and Caking

Compaction and caking are a concern with any dry chemical system. After four years of research with several combined agent systems, very few problems have been experienced as a result of settling or moisture. All testing conducted in this series were performed at Tyndall AFB, FL, which averages 65-90% humidity during the summer months, using a flight line air compressor with a standard moisture filter to reservice the high pressure air cylinders. While precautions were taken to minimize moisture in the dry chemical tank, some moisture was present given the above conditions. AFRL has not experienced compaction or caking in the dry chemical tank that could not be resolved by pressurizing the tank and flowing some agent. Caking was experienced in the hose line of a previous combined agent system when the dry chemical was not cleaned out of the line after all testing was completed for the day. In that case, a rubber mallet was used to break up the dry chemical enough for the air pressure to finish blowing out the hose line.

During transportation of the CAFFS to Ft Drum, NY from Tyndall AFB, FL, approximately 400 lbs of dry chemical was left in the tank. Upon arrival in New York, the tank was opened to check the compaction of the dry chemical. The dry chemical had settled significantly and could not be loosened with a stirrer. The lid was replaced, the tank was pressured to 80 psi and agent was discharged through the turret for 3-5 seconds. The dry chemical tank was depressurized, the lid removed and the compaction checked. Results showed that simply discharging the agent for a few seconds was enough to fluff the dry chemical and eliminate compaction without using external mechanical mixing.

Combination Agent Application, Foam and Dry Chemical

The final evaluation of the CAFFS involved measuring throw distance and expansion ratio with combination agent application (simultaneous discharge of foam and dry chemical) for both the handline and turret. The results of this testing are shown in Table 4. The maximum throw distance for combination agent with the handline was 76 feet compared to 84 feet with foam alone (Table 2). This decrease in throw distance was due to a change in the wind speed and direction (foam alone = 3 mph, tail; combination = 10 mph, cross). The turret showed increased throw distance from 91 feet to 100 feet with combined agent. This increase was expected since the force from the dry chemical discharge propels the agents further than foam alone. The wind speed during this test was 0 mph and therefore was not a factor in the throw distance measurement.

Expansion ratios for both the handline and turret operations were significantly decreased as a result of the combination agent. Previous laboratory studies have shown that the silicon used to fluidize the potassium bicarbonate breaks down the foam bubbles produced by the injection air. While this breakdown on the foam blanket did not hinder the initial knockdown and extinguishment capabilities of the agents, the burnback protection afforded by the foam blanket was severely compromised.

Table 4. Summary of Combination Agent Application Performance.

	Throw Distance		Expansion Ratio
	0 Elevation	Max Elevation	
Handline	53	76	2.16
Turret	58	100	2.89

Conclusions

Overall, the CAFFS operated very closely to the design parameters for flow rates, expansion ratios and throw distances.

Optimal performance for foam discharge for both the handline and turret were achieved from the same air injection setting of 50% full open, with the use of a large diameter dry chemical insert.

The dry chemical tank pressure steadily declined as the agent was discharged and did not level off as observed in the foam discharge tests. This indicated that the flow of air from the high pressure cylinder to the dry chemical tank was not sufficient to maintain the pressure set by the regulators. This trend was observed at all three pressure settings tested. The drop in pressure was not significant enough to affect the flow rate of the dry chemical.

While flow rate data indicated compaction of the dry chemical, this did not affect the operation of the system and hard compaction from extended storage, or vibration, was easily reversed by charging the system and discharging 3-5 seconds of agent.

Initial testing on the CAFFS Dry Chemical System indicated the flow rate at the handline and turret was consistent and was not significantly affected by compaction. While the turret performed best at 115 psi, both discharge devices performed well at 80 psi with only a slight decrease flow rate noted at the turret. Decreasing the operation pressure significantly decreased the force on the nozzle experienced by the firefighter, making the handline easier to handle.

Dry chemical decreases the expansion ratio of the foam, which will affect burnback protection.

Recommendations

Because of the variation in dry chemical flow rates, a minimum of three tests should be performed at each pressure, particularly when the first two data are significantly different (one pps or greater).

Further testing of full tank discharge for the dry chemical system should be performed for 80 and 115 psi pressure settings for both the handline and turret to determine if the flow rate and consistency will improve over a longer discharge period. Also further testing should be performed to determine the effect of compaction on the system for both the handline and turret.

The stability of the CAFFS on the vehicle should be quantified by tilt table testing to determine safe operational speeds. In addition, the percentage of agent that can be discharged as a function of inclination should be determined.

If foam and dry chemical are both used for the initial knockdown and extinguishment of the fire, the dry chemical discharge needs to be shut off and a blanket of foam laid down on the fuel surface for burnback protection.

Appendix A: Dry Chemical Discharge Charts

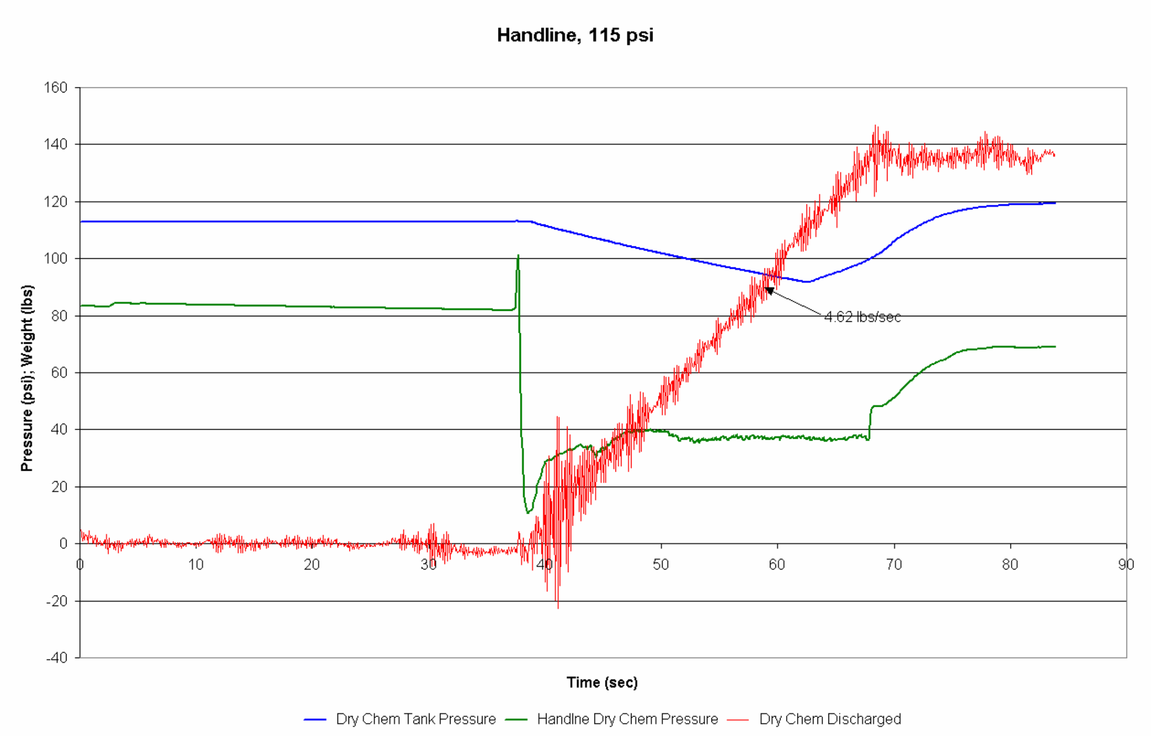


Figure 17. Handline Dry Chemical Flow and Pressure Data, 115 psi.

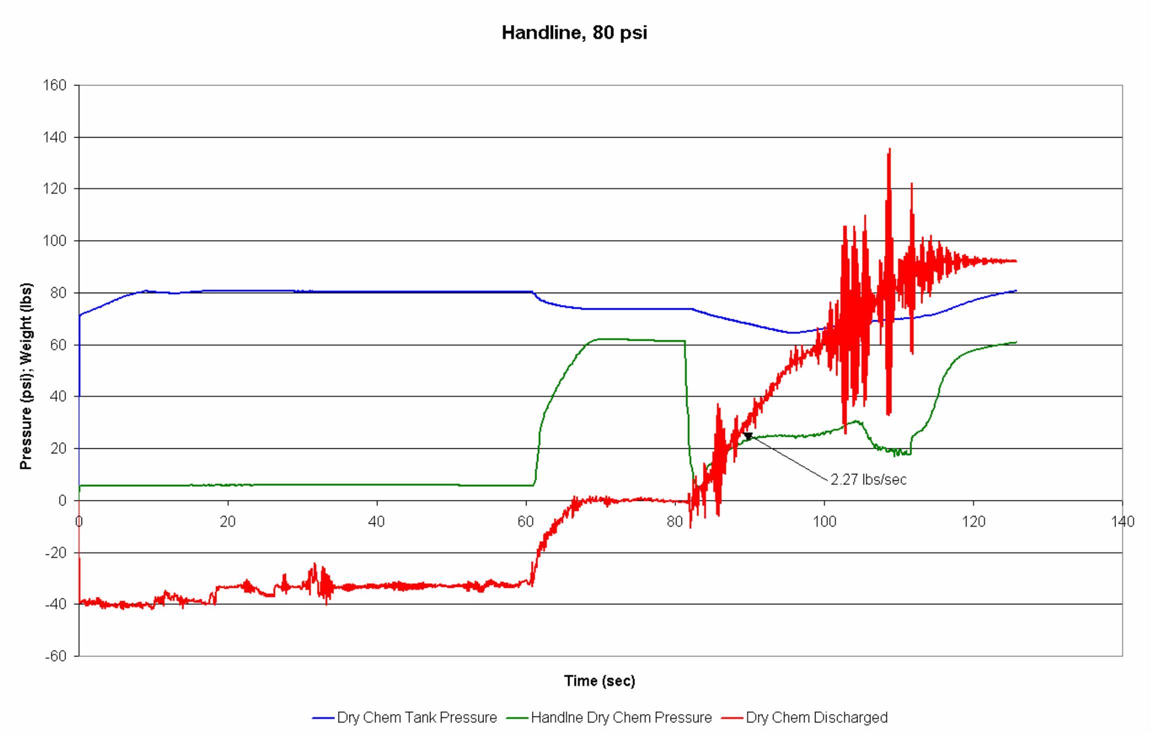


Figure 18. Handline Dry Chemical Flow and Pressure Data, 80 psi.

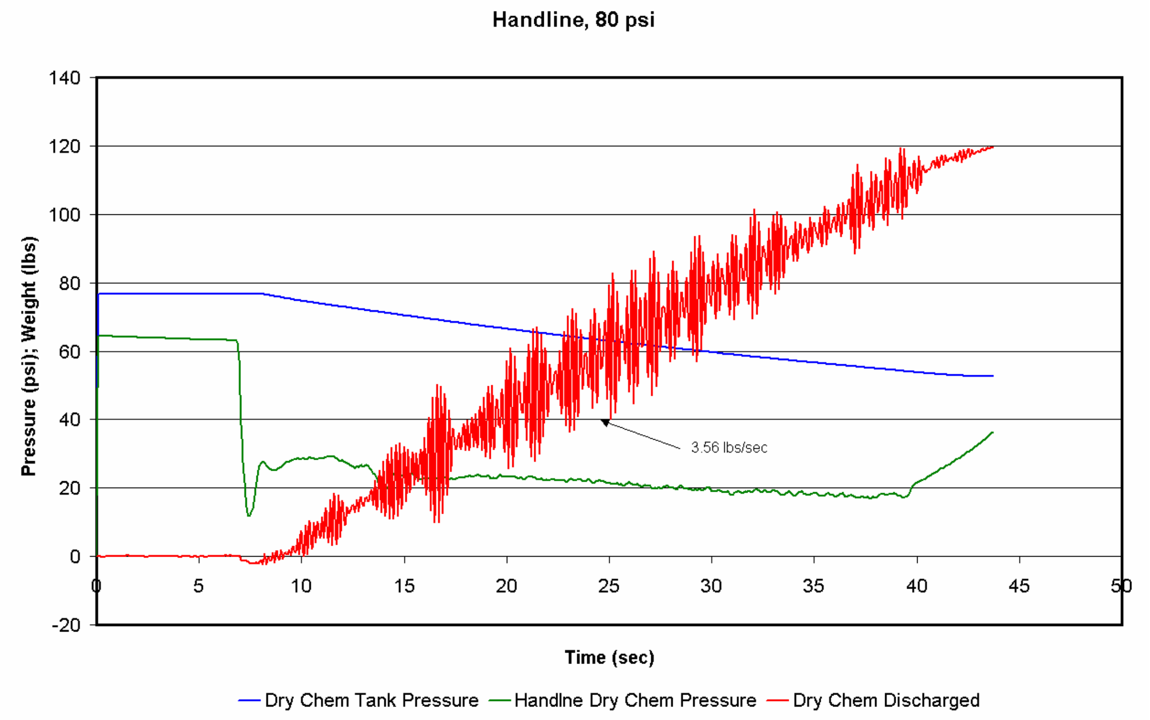


Figure 19. Handline Dry Chemical Flow and Pressure Data, 80 psi.

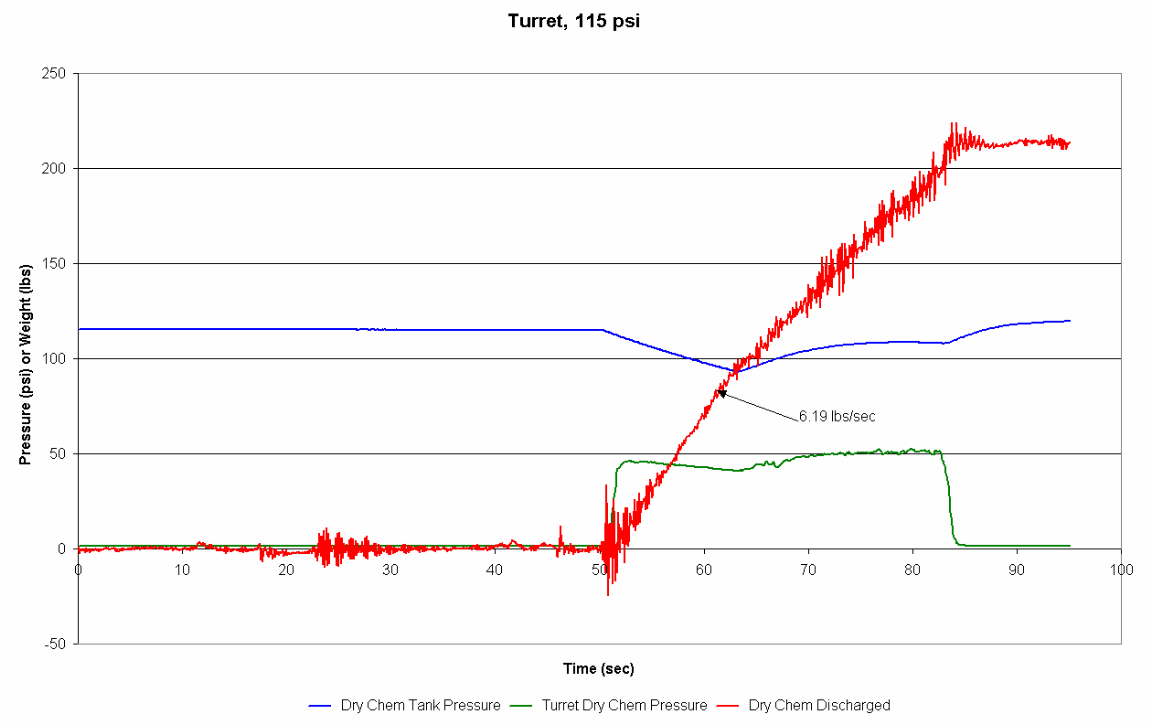


Figure 20. Turret Dry Chemical Flow and Pressure Data, 115 psi.

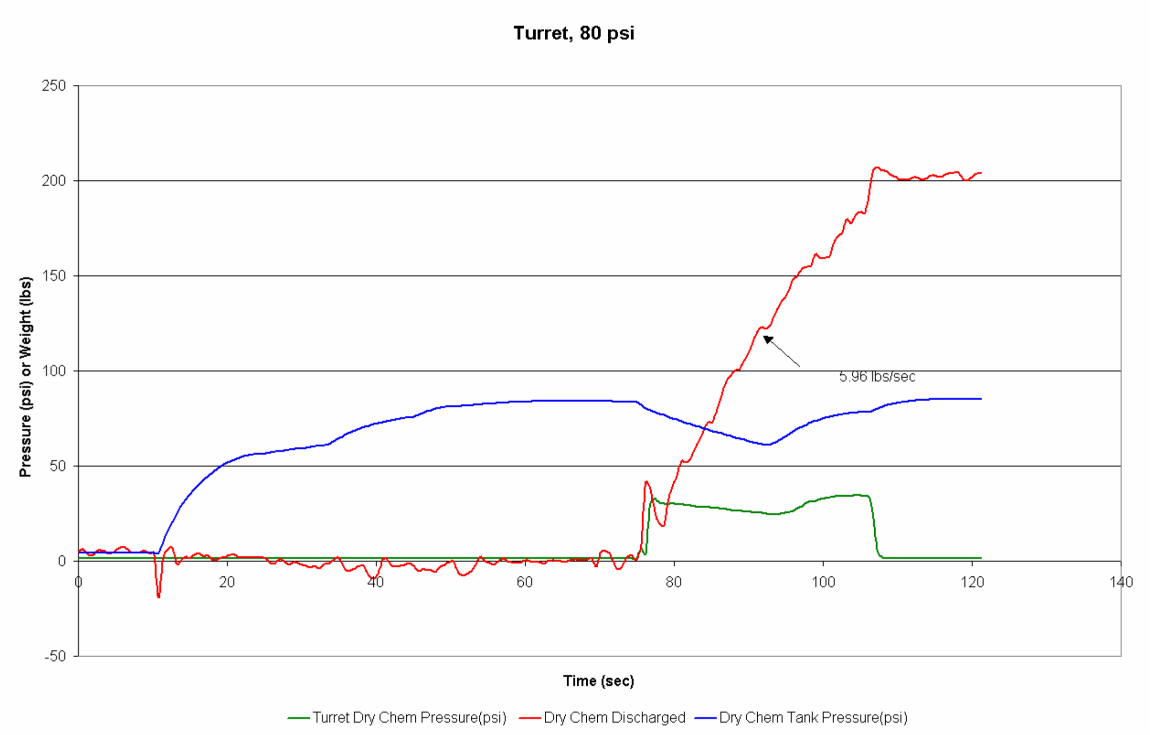


Figure 21. Turret Dry Chemical Flow and Pressure Data, 80 psi.

Appendix B: Expansion Ratio Test Summary

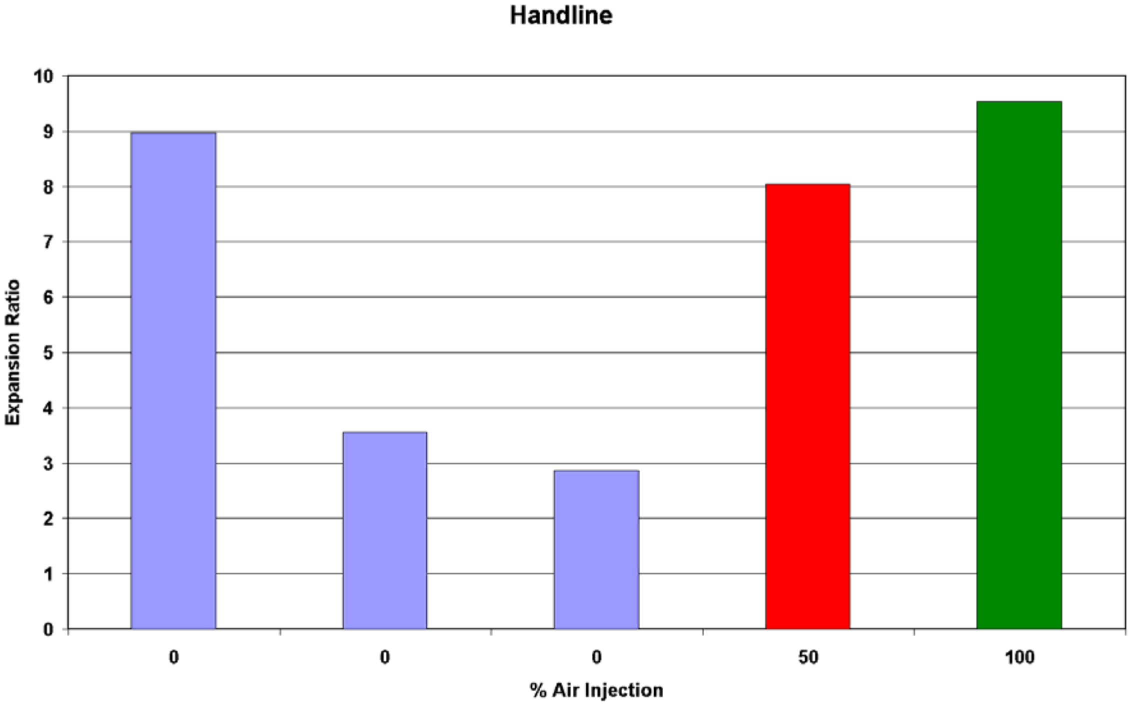


Figure 22. Summary of Expansion Ratios from Handline Testing.

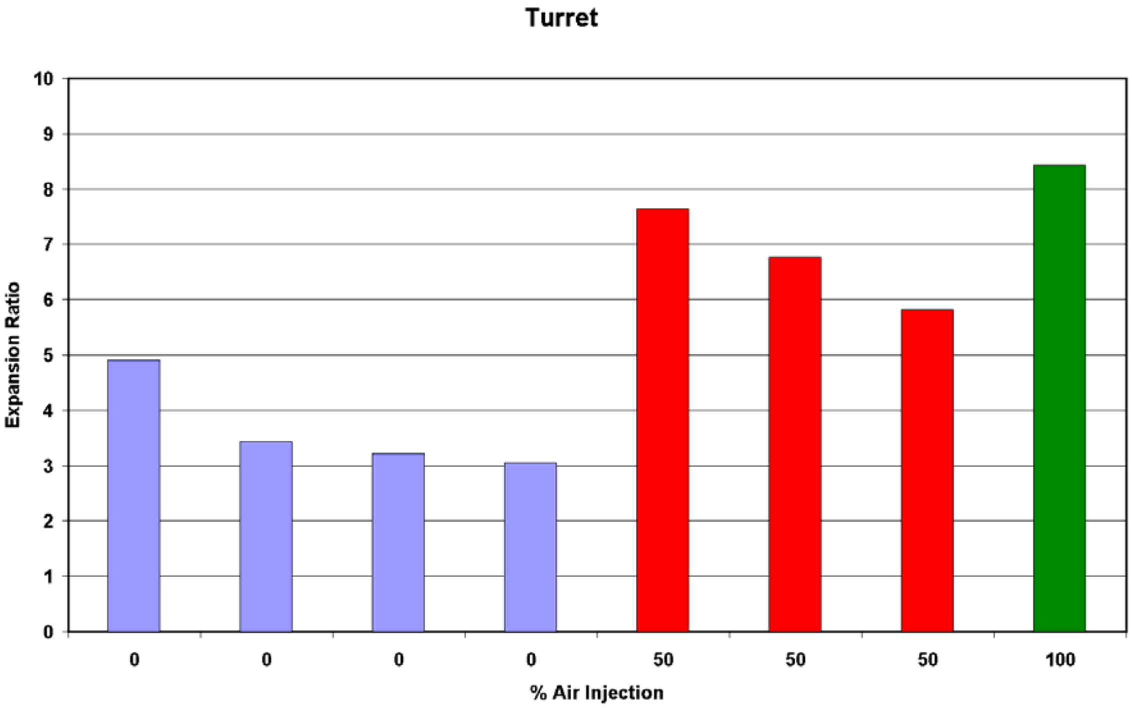
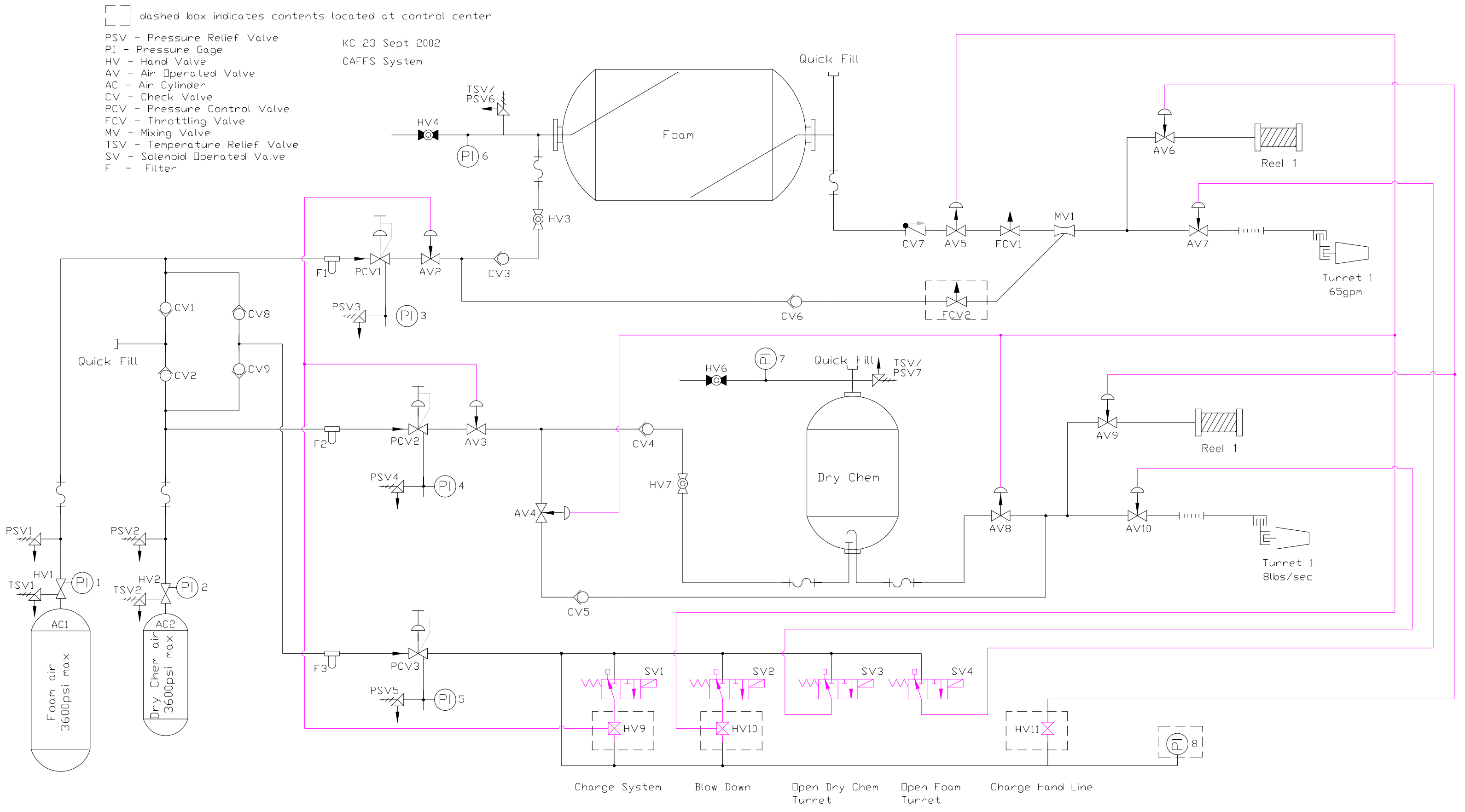


Figure 23. Summary of Expansion Ratios from Turret Testing.

Appendix C: Plumbing and Instrumentation Diagram of the CAFFS



Appendix D: Layout of Major Components