Project Coordinator: ENRG Consultants Ltd
The Old Rectory, Mill Lane, Monks Risborough, Bucks HP27 9LG
info@LASTFIRE.org

LASTFIRE Ongoing Testing of New Generation Foams

DFW Large Scale Extended Flow Test Report

November 2018

1. Overall Objective

The end goal of current LASTFIRE research activities is to provide members with a firm basis for future cost effective, long term, sustainable policies regarding the selection and use of fire fighting foam based on rational, relevant and independent, end user driven test programmes.

Thus, test protocols have been developed and extensive testing and research has been carried out with the aim of providing further data for end users regarding the current fire performance of new formulation foam products. The tests detailed here are the next phase of this overall work. Specifically, this test phase and the associated protocol was to focus on the flow capability, in unignited and fire situations, of a foam blanket formed by fluorine free products.

It is recognised that maintaining fire performance and minimising environmental consequences are the key drivers of this process.

2. INTRODUCTION

2.1. October 2018 Test Programme Objectives

Following the research work undertaken by LASTFIRE during 2017 and 2018 it was determined that a further subject that required investigation was how a "new formulation" foam blanket would flow for an extended distance across a fire. Thus, this series of tests was instigated to investigate the flow distance capability of new formulation foams, at normal design application rates using standard equipment for proportioning and both aspirating and CAF based application. The purpose of this was to provide input to design specifications regarding the spacing of equipment for the protection of large areas; such as large atmospheric storage tanks, large bund areas or other spill fire situations.

It has become apparent that some facilities are considering the use of a CAF system for full surface fire extinguishment at storage facilities. This series of tests therefore included testing flow capability using a CAF system at application rates that might be used for a specific project that part funded the work.

After investigating the possible use of various suitable test facilities, it was decided that the fire training area at DFW Fire Training and Research Centre (DFW FTRC) would be used. DFW FTRC has shown itself to be a leader in the aviation fire response industry and capable of assisting with the coordination of this work. In addition, these tests were undertaken using Jet A as the fuel and thus this work also has relevance to the aviation industry. This provided an ideal and unique opportunity to combine resources and data across industry including the aviation industry and potentially military users. Note: It had been identified that in some cases performance with Fluorine Free foams was poorer with Jet A than it was with Gasoline. Although the reason is not yet known, this further justified the use of Jet A for these tests although further test with other fuels are planned in the future.

The purpose of this document is to provide a formal record of these tests.

This series of tests were developed by LASTFIRE in conjunction with the DFW Working Group and input at various stages from LASTFIRE member representatives.

2.2. Safety & Environment

The tests were conducted at the Dallas Fort Worth Fire Training Research Centre (DFW FTRC). As such, DFW took the lead regarding the overall safety, security and environmental aspects of these tests to ensure that they meet site safety requirements. Additional input was provided by LASTFIRE.

A joint risk assessment was conducted, led by DFW FTRC with LASTFIRE members. This determined the minimum PPE requirements together with operator health, safety and environment needs for different zones of the test area. Three zones were identified – the hot zone, warm zone and cold zone. The zones were changed by the DFW Test Manager depending on the fuel or fire conditions at any time.

DFW FTRC also developed Emergency Plans that would be triggered should there be a loss of containment or fire escalation. Different plans were developed for each scenario including loss of ignited fuel or loss of unignited fuel.

2.3. Participants

Certain suppliers, namely Angus International, ACAF Systems, and Firedos, assisted with the test development and implementation, based on their participation in previous research work, specifically during 2017 and 2018.

Supply companies have also provided foam concentrate but these are not named in this document.

It should be clearly noted here that LASTFIRE is a completely independent and unbiased group. The use of any specific equipment or product for these tests implies no form of approval but they have been chosen from previous experience and to provide a current snapshot of what is currently available on the market.

2.4. Confidentiality Agreements

All participants who took part in the 2017 work did so under a strict Confidentiality Agreement and this was extended to include the current tests. In particular, no LASTFIRE report will specifically identify the performance of any foam concentrate.

This policy has been adopted for the following reasons:

1. LASTFIRE recognise that suppliers are always in a process of continual development of their foam concentrates and this test work gave the opportunity to further develop their products based on the test results. Therefore, it would not be appropriate to imply that the performance seen during the tests was necessarily that of normal production batches in the future.
2. LASTFIRE is strongly of the opinion that a detailed procurement specification should include batch testing of fire performance, especially under current conditions of ongoing development.
3. LASTFIRE recognise that anonymity of samples would more clearly identify the independent nature of the test series and encourage more suppliers to be participants.
4. Although LASTFIRE aim to develop associations with preferred suppliers, it is critical that independence is maintained. LASTFIRE consider their role to be the development of realistic and appropriate performance based requirements to include in procurement specifications. It is then up to end users to dictate these requirements and suppliers to meet the specifications and so commercial evaluation of bids can be based on a rational basis.

Note that neither the manufacturer of the equipment or the foam products, nor the product names, will be divulged at any time by LASTFIRE. However, following the tests the manufacturers will be permitted to divulge their involvement. Any release that they make will be approved by LASTFIRE prior to the release.

2.5. Company Representatives

The timing of the large flow testing, in October 2018, was designed to coincide with a Foam Summit at DFW FTRC the following week. The testing was open for all to witness.

Note: during the Foam Summit various demonstrations were carried out by event sponsors. These demonstrations should not be considered as part of the LASTFIRE test programme.

3. LASTFIRE Large Scale Extended Flow Test Protocol

3.1. Definitions

For the purposes of these tests the following definitions are provided.

New Generation Foams These can be broadly categorised into “Fluorine Free” and “High purity (i.e. minimal C8 content), post US EPA Stewardship implementation programme formulations) C6 Fluorosurfactant” types.

Virtual Extinguishment Full surface foam blanket with the general fuel surface extinguished but with flickers at the edge only (300 mm (12”) height or less from test pan edge and no flames over foam blanket, including ghosting or tunnelling.

Fuel These tests were conducted using Jet A as the fuel. Jet A has been chosen as the fuel for these tests as initial small scale testing has indicated that this can be a more difficult fuel to extinguish than, say, gasoline with some new generation foams, even though it has a lower flash point and vapour pressure. Jet A also has a much tighter specification and is thus a more ‘standard’ fuel than gasoline. The use of this fuel also ensures that these tests are relevant to both industry and aviation applications.

Application Rates A table of application rates was developed for these tests based on NFPA 11 for low expansion foams. The application rates for the CAF system were based on NFPA 11 but modified by the system manufacturer and the LASTFIRE coordinator for a specific project and end user in mind.

NOZZLE	SOLUTION FLOW		APPLICATION RATE	
	US gal/min/ft^2	lpm	lpm/m^2	US gal/min/ft^2
Conventional Monitors	500	1,893	6.46	0.16
Conventional Pourer	315	1,192	4.1	0.1
CAF Monitor	157	594	2.03	0.05
CAF Pourer	157	594	2.03	0.05

LASTFIRE Test Manager Dr Niall Ramsden, or his nominated Deputy (if required) to be in charge of technical issues regarding the tests to be undertaken

DFW Test Manager The person nominated by DFW to be in control of the environmental and safety issues regarding these tests and to be the liaison with airport operations

3.1.1. Ambient Test Conditions

As with all testing the aim would be to undertake all tests in similar ambient test conditions. Ideally these would comply with the LASTFIRE test requirements. However, it was accepted that the prevailing conditions at the test facility might not allow for this.

The usual LASTFIRE test limits are that if tests are conducted outside then there shall be no significant precipitation. In addition, measurements of the conditions shall be taken and shall be within these limits:

Ambient temperature:	-	5 $^oC<T_a<20\ ^oC$
Wind speed:	-	less than 3 m/s, gusts less than 5 m/s

Fuel and water substrate temperatures shall be within the following limits:

Fuel & water substrate temperature	-	10 $^oC<T<30\ ^oC$
Premix temperature	-	10 $^oC<T<30\ ^oC$

For these tests a premix cannot be used so the aim was that the foam concentrate temperature and water temperatures would be within the limits of the premix above.

For this series of the 2018 development tests the ambient conditions, temperature, wind speed and wind direction were measured for each test and recorded on the appropriate result sheet.

Due to the safety measures in place for these large scale tests the fuel temperature could not be measured. However, the fuel had come, via road tanker, from a nearby large atmospheric storage tank and was thus assumed to be within the above limits when first loaded into the test pan.

3.2. Test Set Up

This phase of the ongoing LASTFIRE research work will entail a number of large scale foam extended flow tests.

The initial fire test pan was 24 ft wide by x 131 ft long (7.32 m x 40 m) giving an area of approximately 3,140 ft^2 equivalent to 293 m^2. This area is three times greater than that used in the full scale tests at GESIP, France during 2017, thus providing a full scale, real life test of the foam blankets ability to flow an extended distance across a fire.

The fire test pan was formed of a metallic structure that had sides but no base. This was installed within a temporary containment structure (44' x 152' equivalent to 13.41 m x 46.33 m) that was filled with water. This provided at least 20' (6.1 m) water filled barrier between the temporary structure and the fire test pan. The liner of the temporary structure was specified to have a temperature resistance of at least 1,000 ^oC.

The whole assembly was located in an area with surface drains to a closed containment system.

The sides of the test pan were designed to provide at least 24" (610 mm) above the fuel level. This was to contain the foam blanket and also to minimise any fuel splashes in the impact (foam application) area (shown as orange in figure 3.1).

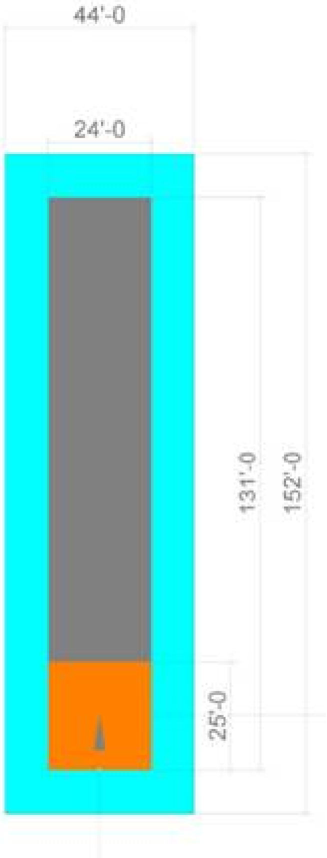

Figure 3.1. Schematic of fire test area

Figure 3.2. Schematic of fire test pan

3.3. Foam Application Techniques

The aim of this series of tests was to investigate the fire performance using four different application techniques:

- Conventional aspirated monitor application – semi-aspirated and aspirated;
- CAF monitor application;
- Conventional pourer application; and
- CAF pourer.

The intention was to use the above order of application techniques first for the 'industrial' product, then for the 'aviation' product. Following these tests, the C6 product was to be tested.

For all tests proportioning was achieved via a proprietary proportioning unit. A second proportioner was on standby in case of equipment issues.

Fig 3.3. Water driven proportioner with calibrated flow meters package used during the tests

The proportioning of the foam was checked during each test by means of flowmeters installed in each inlet and outlet line on the proportioner. In addition, during the pre-test system flows a sample of foam solution was taken for proportioning accuracy test by conductivity.

Prior to any fire test "dry runs" were undertaken applying foam to the pan to ensure that all the test equipment was operational and to make adjustments for flow settings.

Depending on which test was to be carried out the foam solution from the proportioner was fed to either a CAF system where air from a compressor was mixed with it to form Compressed Air Foam or to a conventional aspirating foam discharge device which incorporated aspirating holes.

A diagrammatic representation of the set ups for CAF generation and for conventional aspirating pourer application is shown in the diagrams below.

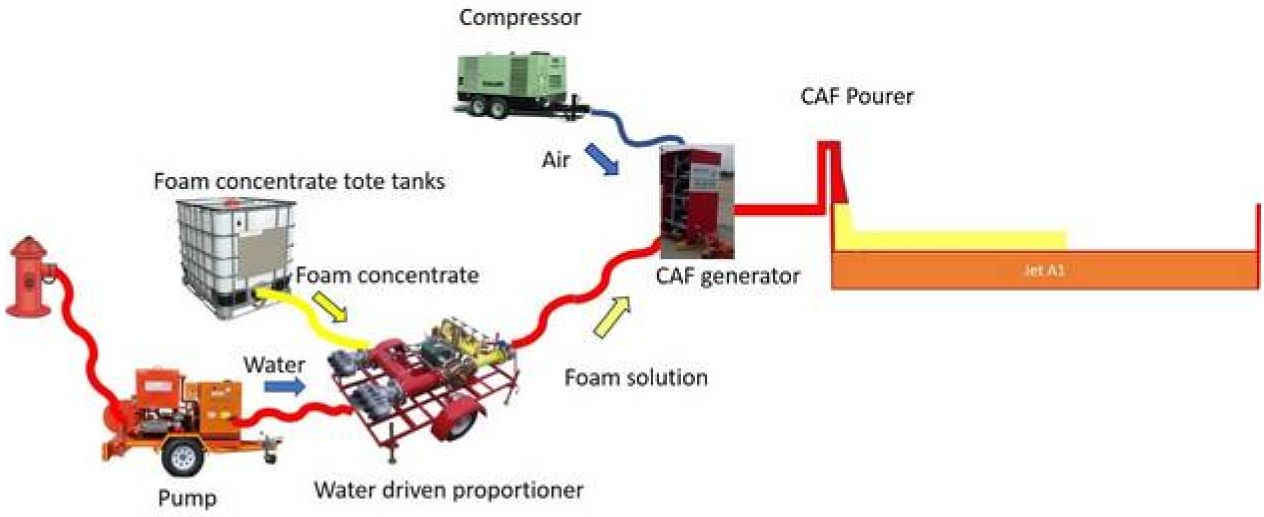

Fig 3.4 Schematic of Test set up for Compressed Air Foam application

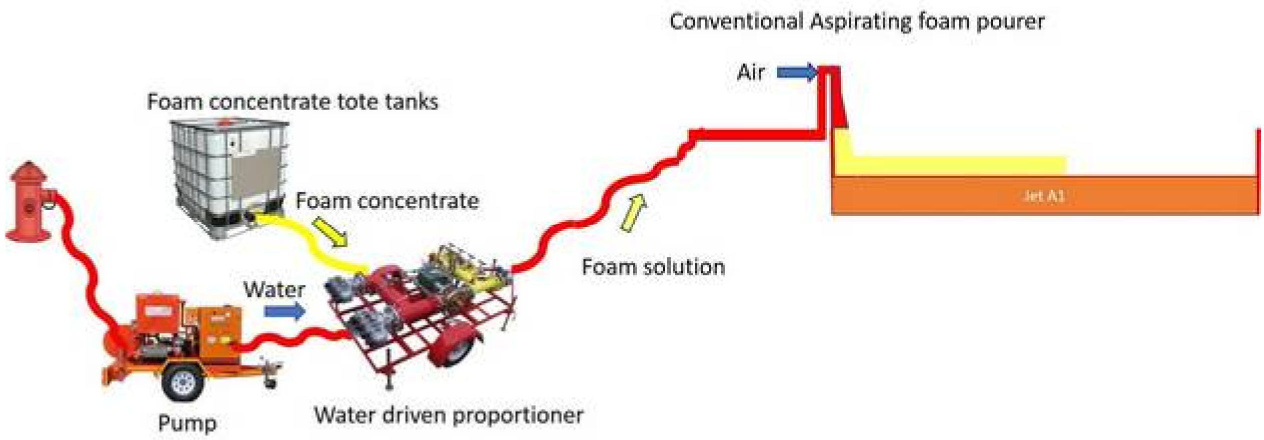

Fig 3.5 Schematic of Test set up for Conventional Aspirating Pourer Application

3.4. Foam Concentrates

Three foam concentrate products were to be used for the tests, two fluorine free products and one C6 based product. Of the two fluorine free products:

- One was specifically for industrial incidents (such as fuel storage tank fire) - It was an alcohol resistant and was the more viscous of the two.
- One was specifically for aviation application and was the less viscous of the two products.

The C6 high purity type AFFF was to be subjected to test using the same general protocols. The application method for this test was to be selected at the discretion of the LASTFIRE Project Coordinator.

3.5. Test Fuel/Depth

The fuel used for this series of tests was Jet A. The aim was for a minimum 6” (150 mm) depth at the start and topped up between each test to provide this minimum depth for any test involving forceful application. A lower depth was accepted for pourer type applications. Some smaller scale testing was carried out to determine if there was any significant difference in extinguishing times after multiple burn/extinguishment cycles using the same fuel. It was found that there were not significant differences but it was decided that top up in between each large test would still be carried out.

3.6. Fire Water

The water for these tests was sourced from the on site fire water hydrant system. This was fresh water.

3.7. Test Records

The measurements recorded for each test were:

- Ambient conditions
- Flow – fire water & foam concentrate
- Timings for each test
- Proportioning – calculated from flows and also by conductivity measurements.

3.8. Fire Test

Back up extinguishing capability was deployed prior to each test in accordance with the DFW FTRC Emergency Plans. For this they had a test specific checklist in place for use prior to the commencement of the ignition sequence. This included ensuring that only personnel required to manage the test were within the designated test zone.

Prior to each test ambient conditions were recorded where possible, depending on access to the test pan:

- Air temperature
- wind speed
- wind direction
- fuel temperature
- water temperature
- concentrate temperature

The fuel was ignited at several locations to ensure a full surface fire within a reasonably short period. The method of ignition was by propane burners.

A preburn time of 10 seconds, after full involvement of the fire test pan, was given. The LASTFIRE Test Manager dictated when foam application was to start.

Foam was applied until full extinguishment had been achieved over the whole test pan. Once this had been confirmed by the DFW Test Manager and the LASTFIRE Test Manager a further foam application period was given for security of the blanket.

Video recordings were made from several locations, including from height for aerial views of each test.

The progress of the foam blanket across the test pan was measured by recording the time to virtual extinguishment and full extinguishment.

Once full extinguishment was confirmed, foam application continued until the LASTFIRE Test Manager gave the instruction for application to stop.

A foam sample was taken to determine the foam quality for each test, that is expansion and 25% drainage time in line with NFPA 11 foam quality testing procedures.

3.9. Test Checklist

A technical test checklist was developed to ensure all safety, environment and technical issues had been addressed prior to each test. All those participating as part of the 'foam team' were involved in the completion of this checklist.

3.10. Physical Properties of Foam Concentrates

A sample of each of the two foam concentrates was taken to determine the physical properties of each product. This included:

- pH
- specific gravity
- refractive index
- viscosity at 50 rpm – cone & plate viscometer
- film formation on cyclohexane and Jet A – conducted in line with MIL-F-24385D (draft)
- surface tension

All measurements were recorded at 20 ^{o}C or at ambient temperature (and this will be recorded). The properties measured for the industrial product (A) were as follows:

Foam Concentrate Characteristics			
S.G. at 20°C	1.03	Viscosity at 20°C - cone & plate @ 50 rpm	100 – 120 cP
R.I. at 20°C	1.3663		
Film formation on cyclohexane	no	S.T. at 3%	23.0 dynes/cm
Film formation on Jet A	no	pH at 20°C	7-8

For the aviation product (B) the physical properties measured were:

Foam Concentrate Characteristics			
S.G. at 20°C	1.0	Viscosity at 20°C - cone & plate @ 50 rpm	60 cP
R.I. at 20°C	1.3838		
Film formation on cyclohexane	limited	S.T. at 3%	21.8 dynes/cm
Film formation on Jet A	yes	pH at 20°C	8 – 8.5

3.11. Chemical Analysis of Foam Concentrates

A one litre sample of foam concentrate from each bulk container used in these tests was taken for investigation using Total Oxidizable Precursor (TOP) Assay Tests.

4. LASTFIRE Large Scale Extended Flow Test Results

4.1. Overview

Three tests were undertaken during this test series.

- Test 1 was an initial fire test over an area of approximately 7.2 m x 10 m. This checked the test equipment and also the effectiveness of a foam blanket generated by the CAF pourer to flow over a fire of 10 m length.
- Test 2 was a full test over the entire area of the fire test pan – approximately 7.2 m x 40 m using the CAF pourer.
- Test 3 was a full test over an area of approximately 33 m x 2.25 m using the conventional pourer.

It should be noted that during the test series period the weather conditions were frequently outside of the preferred ambient test conditions; specifically periods of heavy rain with lightning occurred. During the second week the wind speed and direction became an increasing issue. The DFW International Airport demand that during periods of lightning or when there is a risk of lightning within approximately 12 miles, that all personnel are withdrawn from the test / training area and remain indoors until the all clear is given. Thus there were many long periods when no work could be undertaken outside.

4.2. Test 1

Test 1 was undertaken over a fire area of approximately 72 m^2 with dimensions of approximately 7.2 m x 10 m.

This test enabled all the test equipment to be checked whilst also investigating the effectiveness of a foam blanket generated from the CAF pourer.

The foam solution flow rate was recorded as 562.3 lpm equivalent to an application rate of 7.8 lpm/m^2. Whilst this was much higher than would be proposed for design purposes it enabled the same settings to be used as were envisaged for the full test – Test 2.

Following ignition, once a full surface fire was confirmed a preburn time of approximately 10 seconds was given before the foam application commenced.

The fire was rapidly extinguished and there was therefore sufficient confidence to move to the larger test at lower application rates.

Fig 4.1 Overall view of large test pan (with sections allowing initial smaller test area)

LASTFIRE Large Scale Extended Flow Test Results

TEST NO:	**T1**	**Application Type:**	**CAF pourer**	
FOAM TYPE	**A**	**Application Direction**	**From South**	
Foam Concentrate Characteristics				
Nominal Concentration	3 %		**Fuel Type**	**Jet A**
Actual Concentration:	**By flow**	3.35	**By conductivity**	3.18
Nozzle Flow Calibration	**Actual lpm**	**Actual USgpm**	**Date of Tests**	
568 lpm	562	148.5	**10 October 2018**	
Test Conditions		**Foam Quality**		
Wind Velocity: m/s – gusts to	2.0	**Expansion**	16.6:1	
Temperatures ˚C Ambient	18.5	**25 % Drainage Time**	< 30 mins	
Fuel	-			
Concentrate	26.0			
Relative Humidity	71.1			
Fire Performance Data – Extinguishing - Times From Team Start				
Marker Location (m / ft)	**First Foam Reaches**	**Virtual Extinguishment**	**Extinguishment**	
10 / 32.75		30 s	60 s	
Fire Performance Data – Test Notes				
Expansion ratio result skewed as foam collection pot not completely filled by sample – unable to take further sample at this flow rate.				
Fire extinguished very rapidly but note that this was a much higher application rate than would be used in a formal design of such a system.				
This test should be considered as a test of the equipment rather than a test of the foam blanket to extinguish a fire.				

4.3. Test 2

Test 2 was undertaken over a fire area of approximately 294 m^2 with dimensions of approximately 7.34 m x 40.05 m.

This test enabled the effectiveness of a foam blanket generated from the CAF pourer to be investigated at what is proposed to be the design application rate for a specific project.

The foam solution flow rate was recorded as 554 lpm equivalent to an application rate of 1.9 lpm/m^2.

Following ignition, once a full surface fire was confirmed a preburn time of approximately 20 seconds was given before the foam application commenced.

The fire was again rapidly extinguished but this time using an application rate at approximately 50 % of what would be the design rate for a conventional aspirated pourer.

LASTFIRE Large Scale Extended Flow Test Results					
TEST NO:	**T2**	**Application Type:**	**CAF pourer**		
FOAM TYPE	**A**	**Application Direction**	**From South**		
Foam Concentrate Characteristics					
Nominal Concentration	3 %		**Fuel Type**	**Jet A**	
Actual Concentration:	**By flow**	3.42	**By conductivity**		3.18
Nozzle Flow Calibration	**Actual lpm**	**Actual USgpm**	**Date of Tests**		
568 lpm	553	146	**10 October 2018**		
Test Conditions		**Foam Quality**			
Wind Velocity: m/s – gusts to	3.5	**Expansion**	16.6:1		
Temperatures ˚C Ambient	32	**25 % Drainage Time**	< 30 mins		
Fuel	-				
Concentrate	25.0				
Relative Humidity	40				
Fire Performance Data – Extinguishing - Times From Team Start					
Marker Location (m / ft)	**First Foam Reaches**	**Virtual Extinguishment**	**Extinguishment**		
30 m			2’ 23”		
40 m			3’ 27”		
Fire Performance Data – Test Notes					
Expansion ratio result skewed as foam collection pot not completely filled by sample – unable to take further sample at this flow rate.					
Note that this test was undertaken at approximately 50 % of the design rate for a conventional aspirated pourer.					

In the second (40 m) test the foam, at a rate equivalent to 50% of the design rate applied with conventional aspirated foam, travelled rapidly over the fuel surface extinguishing all areas including the edges of the hot metal pan. The foam travelled the full 40m without any problem. Unfortunately, when the foam had reached approximately 30 -35m, problems began to arise with the integrity of the outer containment area due to a combination of reasons including wind speed and direction giving direct flame impingement, fuel in the area (presumably from a leaking fuel line) igniting, and monitor application to the outer containment leading to damage of the heat resisting covering. Consequently, contingency plans were implemented which included application of additional foam (of the same type) into the area surrounding the actual test pan by handline. Some of this entered the pan itself but did not have any significant effect on the foam flow. As the foam under test reached the 40 m mark the back up foam pourer (again using the same foam) at that end of the test pan was actuated but by then all edges had been extinguished. Further images can be seen in Appendix A – Test Sequences.

Fig 4.2 Large scale test (40m) being carried out – CAF foam applied from right

Fig 4.3 Large scale (40m) test CAF pourer application – extinguishment to ~30m

Fig 4.4 Large scale (40m) test CAF pourer application Virtual extinguishment. Note back up pourer not yet actuated and fire to right hand side outside the actual test pan

. Fig 4.5 Large scale (40m) test CAF pourer application. Full extinguishment in pan. Fire only in outer containment area and back up pourer actuated.

The conclusion was that the foam had performed exceptionally well. From a review of video material, it was concluded that full extinguishment was achieved in 3'27" from time of actuation. (The system was actuated approximately 20 seconds after full surface ignition). The time taken for 30 m pan section to be extinguished was 2'23". (30 m is the maximum distance implied in standards for foam flow to be effective.)

4.4. Test 3

As the original test pan was no longer available, the third test was carried out in a smaller pan. Test 3 was undertaken over a fire area of approximately 73 m^2 with dimensions of approximately 2.23 m x 32.9 m. This was the largest pan that could be constructed within a short time (a matter of a few days) whilst the research team remained on site to help with the arrangements.

This was thus a smaller pan with the narrower width meaning that the foam was channelled more directly in a forward direction. It could thus be considered a less severe test than the previous one. The total foam solution flow rate was adjusted to provide an application rate of approximately 4 lpm/m^2 in accordance with NFPA 11 application rate for aspirated foam pourer application.

This test enabled the effectiveness of a foam blanket generated from a conventional aspirated pourer to be investigated at standard NFPA 11 design application rate.

The foam solution flow rate was recorded as 278.7 lpm equivalent to an application rate of 3.82 lpm/m^2.

Following ignition, once a full surface fire was confirmed a preburn time of approximately 10 seconds was intended before the foam system was started. However it was found that a valve within the hot zone had been closed following the flow setting resulting in a delayed application and the preburn time was extended to 50 seconds. Further images can be seen in Appendix A – Test Sequences.

Fig 4.6 Large scale (30m) test being carried out – Conventional aspirated foam applied from right

Foam travelled rapidly over the fuel surface and gained virtual extinguishment with edge flickers and a small corner only still ignited in 2’32”.

The fire was again rapidly extinguished. This test was undertaken at approximately what would be the design rate for a conventional aspirated pourer in accordance with NFPA 11 system design guidance.

LASTFIRE Large Scale Extended Flow Test Results

TEST NO:	**T3**	**Application Type:**	**Conventional aspirated pourer**	
FOAM TYPE	**A**	**Application Direction**	**From South**	
Foam Concentrate Characteristics				
Nominal Concentration	3 %		**Fuel Type**	**Jet A**
Actual Concentration:	**By flow**	3.11	**By conductivity**	
Nozzle Flow Calibration	**Actual lpm**	**Actual USgpm**	**Date of Tests**	
303 lpm	292		**16 October 2018**	
Test Conditions		**Foam Quality**		
Wind Velocity: m/s – gusts to	2.5	**Expansion**	5.0:1	
Temperatures ˚C Ambient	14.2	**25 % Drainage Time**		
Fuel	17.0			
Concentrate	10.8			
Relative Humidity	67			
Fire Performance Data – Extinguishing - Times From Team Start				
Marker Location (m / ft)	**First Foam Reaches**	**Virtual Extinguishment**	**Extinguishment**	
33 m		2’ 32”	2’ 59”	
Fire Performance Data – Test Notes				
It was not possible to determine 25% drainage time due to test constraints.				
Note that this test was undertaken at approximately 100 % of the design rate for a conventional aspirated pourer.				

4.5. Nozzle Tests

During the period between Tests 2 and 3 the weather conditions were frequently wet and windy with lightning at times. However there were short periods when the lightning risk reduced and the wind and rain also abated.

During these drier periods the foam research team took the opportunity to flow foam through a variety of nozzles to collect foam quality data as well and throw range capability.

The results are provided in note form below. However, it is also worth noting here that, once again, 25% drainage times could not be accurately recorded as the drainage was slow and took several hours in some cases. Whilst conventional foams have frequently been assessed partly based on the long drainage time assumed to provide an indication of the foam blanket stability, it has become increasingly noted that following application to a fire the foam blanket consistency can change from a stiff foam to a more fluid foam. Thus, further tests will be conducted to investigate this property and to study if there are also changes in the vapour suppression capability of the foam blanket.

For the industrial product (A):

a) CAF monitor at 300 lpm (80 gpm) – expansion started at 4.64 : 1 but then improved to 9.03 : 1 when optimised and 3.17% proportioning from the FireDos flow meters – throw was approximately 16 m
b) Aspirated nozzle using the industrial product and got expansion 7.0 : 1 but no drainage time

For the aviation product (B):

c) CAF monitor at 300 lpm (80 gpm) – expansion 7.44 : 1; throw approximately 16 m
d) Aspirated monitor at 480 lpm (128 gpm) – expansion 8.6 : 1, drainage 3' 59" – proportioning 3.3%
e) Semi aspirated monitor (automatic nozzle):
    a. 1st sample - non aspirated – expansion 11.4 : 1
    b. 2nd sample - straight stream - 7.7 : 1, drainage was so quick that it could not be recorded but drainage times were taken for increasing drained solution – the throw of this was about 42 m

It can be seen here that for the aviation product the non aspirated stream gave a higher expansion and throw than the aspirated nozzle. The discharge pattern of the nozzle was obviously such that it did entrain air and hence cause expansion.

Note that these tests will need to be repeated at more settings with a variety of foam products. These are the results noted from the equipment and foam products available at the test site.

4.6. Test 4

Test 4 was to be conducted using a non-aspirated monitor applying foam to the 73 m^2 fire test pan. Unfortunately on the day for this test the weather conditions, specifically the wind speed and direction, changed. At the time that fuel was due to be put in the wind direction changed and gusts increased to a speed approaching 6 m/s. This would have meant that during the fire the thick black smoke would have been driven across to the foam team location. After many discussions it was reluctantly decided that this test would not be conducted and thus this series of tests came to an end.

5. Comparison of CAF Application and Conventional Aspirated Foam Application

As it was not possible to carry out the full 40m length test with the conventional foam application devices, the following is provided as a comparison of time to 30m flow length extinguishment:

- CAF application at 2lpm/m^2 – 2'23"
- Aspirated foam pourer at 4lpm/m^2 – 2'32"

6. Conclusions

The results from all tests conducted show that this particular fluorine free foam performed well in both conventional pourer and CAF pourer modes.

In particular, when used at “standard NFPA” application rates full extinguishment of a 30m length fire using a conventional pourer system was achieved in 2 minutes 32 seconds. (30m is considered to be the normal maximum flow length in recognised system design standards.) Based on this work and previous tests carried out by LASTFIRE, much greater distances are obviously possible given appropriate application equipment. It should be noted that in NFPA 11 for foam application to a storage tank fire using a conventional pourer for a product such as Jet A (flash point approximately 38 ^{o}C) then the run time would be 30 minutes (55 minutes for lower flash point fuels). For a bunded area it would be 20 minutes (30 minutes for lower flash point fuels).

Thus the fire was extinguished in a much shorter time than these standard minimum requirements for foam capacity. It should be noted if course that the preburn time was relatively short. It must be concluded though that this foam/pourer application demonstrated sufficient fire extinguishing performance such that it could be used in accordance with standard NFPA application rates for the fuel type tested.

It is clear from the results that CAF pourer application using this particular Fluorine Free foam is very effective at the rates tested on Jet A hydrocarbon and can flow distances of at least 40 m and still provide extinguishment of fuel and sealing against hot metal surfaces.

It is also very clear that this application technique is as effective or better than using the same foam with standard aspirating equipment in full accordance with NFPA 11 design rates. It therefore potentially offers the capability of providing more efficient foam application without jeopardising fire extinguishing performance.

It is emphasised that this particular work has been carried out with one specific Fluorine Free foam on one fuel type but the results are in line with those obtained in the earlier tests comparing performance (with both pourer and monitor application) with that of fluorosurfactant containing foams. It is important to emphasise again that different foams perform differently even when using the same equipment (proportioning, foam nozzle etc). There can be no generic conclusions drawn from these or earlier LASTFIRE test phases.

It is hoped that this test series can be completed in early 2019 (possibly May) within a revised fire test pan. Whilst problems were encountered with the fire test pans that were built at DFW FRTC it has highlighted the problems of constructing a fire test pan of this size that will survive a number of intense fires. Those present at the tests realised the importance of this work and that a permanent facility to undertake these tests is required and work is ongoing to resolve this. Such an asset would enable other foam concentrates to be tested using Jet A or other fuels.

LASTFIRE continue to plan for a further series of tests to be conducted in Hungary to take this work forward. These tests will be small scale, using the LASTFIRE test pan, and will be focussed on optimising fire performance against application rates, expansion and drainage, including those relevant to crude oil. It is also envisaged that the effect of variations in preburn times will also be investigated.

Appendix A – Fire Control and Extinguishment Sequences

1) *40m length fire, CAF application, 2lpm/m²*

Back up pourer operating after extinguishment

2) *30m length fire, Aspirating pourer application, 4lpm/m²*