ARCTIC RESPONSE TECHNOLOGY
OIL SPILL PREPAREDNESS

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IOGP JIP RESEARCH PROJECT 6: INTEGRATED IGNITER/HERDER APPLICATION SYSTEM

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1. INTRODUCTION

In-situ burning (ISB) has been considered a viable spill response option for oil spills in Arctic waters since offshore drilling began in the Beaufort Sea in the 1970s. Technologies developed over the past few decades have provided robust booming systems that can withstand the intense heat and stresses while containing oil during combustion. Ancillary support by means of vessels and personnel has been an accepted requirement to initiate and maintain in-situ combustion during a burn.

More recently, a concept has been developed that includes the application of a chemical herding agent around the periphery of a spill. The chemical herder causes the oil to contract, resulting in the thickening of the spilled oil. Once oil is thickened beyond a critical thickness, it can sustain combustion because heat losses to the water below the burning oil are insulated by the oil layer. A helicopter deployable system of herder application followed by ignition was demonstrated in 2015 at a purpose built test tank outside of Fairbanks, AK (Potter *et al*. 2016). These tests required two flights: one to apply the herder and one to drop igniters into the herded oil with a helitorch. These tests validated the concept, allowing ultimate burning of slicks without the need for mechanical containment and the ancillary equipment associated with that task.

This approach is not a practical field operation as it either requires two helicopters or one helicopter making two trips from a base location; time is a critical factor for success. Unless the base is within a few minutes flying time of the slick, too much time will elapse between applying the herder and igniting the oil. Flying with a sling load (required for the helitorch) will significantly constrain the range and speed of the helicopter. The ideal solution would be an integrated herder delivery and ignition system that won't significantly impact the range and speed of the helicopter. This would allow the helicopter to transit to and from the spill site at or near its normal cruise speed and perform both activities without returning to pick up the ISB system.

Ultimately the integrated system should be placed within the cabin of a helicopter to minimize adverse impacts on speed and range; however, this will likely require significant time for US FAA and European EASA review and approval – a process that could take several years. As a temporary solution this research and development project seeks to develop an interim integrated system that can achieve more rapid regulatory approvals. The interim system would be designed in a way that allows it to be easily adapted to fit within or firmly attached outside a helicopter once regulatory approval is achieved.

The present research project, initiated in 2015, advances oil spill remediation technologies by developing a combined unit incorporating a herder sprayer and spill igniter dispenser that is helicopter deployable. This report describes the development and testing of the integrated herder / igniter system.

1.1 Background

Small-scale laboratory experiments were completed in 2003 and 2005 (SL Ross 2004 and SL Ross 2005) to examine the concept of using herding agents to thicken oil slicks among drift ice for the purpose of ISB burning. Encouraging results prompted further mid-scale testing in 2006 and 2007 at the US Army Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, NH; at Ohmsett, the National Oil Spill Response Research & Renewable Energy Test Facility in Leonardo, NJ; and, at the Fire Training Grounds in Prudhoe Bay, AK (SL Ross 2007).

The non-proprietary hydrocarbon-based herder formulation (now called ThickSlick 6535) used in these experiments proved effective in considerably contracting oil slicks in brash and slush ice concentrations of up to 70% coverage. Slicks in excess of 3 mm thick, the minimum required for ignition of weathered crude oil on water, were routinely achieved. Herded slicks were ignited, and burned equally well in both light brash and light slush ice conditions at air temperatures as low as –17°C. The burn efficiencies measured for the herded slicks were only slightly less than the theoretical maximums achievable for equivalent-sized, physically contained slicks on open water.

Successful mid-scale field trials of the technique were carried out in the Barents Sea off Svalbard in the spring of 2008 as one facet of a large joint industry project on oil spill response in ice coordinated by SINTEF (Buist *et al.* 2010a). These larger field experiments included one release of 630 L of fresh Heidrun crude onto water in a large lead. The free-drifting oil was allowed to spread for 15 minutes until it was far too thin to ignite (0.4 mm), and then the hydrocarbon-based herder was applied around the slick periphery from a small boat using garden sprayers. The slick contracted and thickened for approximately 10 minutes at which time the upwind end was ignited. A 9-minute long burn ensued that consumed an estimated 90% of the oil.

From 2007 to 2009 experiments were carried out in the laboratory and at CRREL comparing the efficacy of herding agents formulated with silicone-based surfactants, herding agents formulated with second-generation fluorosurfactants, and the hydrocarbon-based herder (Buist et al 2010b). The results showed that the fluorosurfactant-based herders did not function better than the hydrocarbon-based herder; however, the new silicone surfactant formulations successfully outperformed the hydrocarbon-based herder. More recently (2009), experiments were conducted to determine if herding agents could: a) improve skimming of spilled oil in drift ice; b) clear oil from salt marshes; and, c) improve the efficiency of dispersant application operations (Buist et al 2010c).

Ohmsett experiments in 2010 on the use of herders as a rapid-response technique for use in open water (SL Ross 2012) showed that:

- Herders on open water contain a slick for more than 45 minutes in calm waters,
- Herders on open water restrain a slick in a non-breaking swell condition, but the constant stretching and contracting of the herded slick by the waves elongates and slowly breaks it into smaller fragments.
- Breaking or cresting waves rapidly disrupt the herder's monomolecular layer, and the oil slick itself, quickly resulting in many small unrestrained slicks.

Two herding agents (ThickSlick 6535 and SilTech OP-40) have been placed on the U.S. EPA National Oil and Hazardous Substances Pollution Contingency Plan (NCP) Product Schedule for consideration for use in U.S. waters and were commercially available as of June, 2012. A herder application system, consisting of a pump, controls and reservoir has been designed to be placed inside an appropriate helicopter (Figure 1). It incorporates a reel-able hose that is used to lower the application nozzle to the target elevation above the water for herder application (unlike dispersants, herders must be applied in a narrow swath on the water around the periphery of a slick to be effective). Dry land, static trials were conducted in September 2013 and successful full-scale (with 75 and 150-L crude oil slicks) helicopter flight trials, including herded slick ignition with a helitorch, were carried out in a shallow test basin in Poker Flat, Alaska in 2015 (Potter *et al.* 2016). Figure 2 shows a collage of photos from these large-scale trials in Alaska.

Figure 1. Mark II Herder Application System

Figure 2. Field Test of Helicopter Herder Application and Crude Oil Ignition.

(A) - Aerial view of test basin;

(B) - Herder application device with herder nozzle magnified in inset;

(C) - Application of gelled gasoline igniter via helitorch;

(D) - Free-floating ISB viewed from ground level observation point

(E) - Close up of free floating ISB

1.2 Objective

The objective of the research and development programme was to develop, test and refine an interim integrated herder delivery and ignition system for helicopter operation. The interim system will be designed and operated to facilitate more rapid regulatory certification for commercial use. One method that might allow rapid certification is to operate the integrated system as a slung load.

1.3 Goals

- Review the history and development of oil slick ignition.

- Design an integrated herder delivery and igniter system that can execute both functions from a single helicopter on a single flight.

- The system should be designed for use as a slung load to provide an interim operational system. The interim system design should be compatible with a final system design that can be carried inside the helicopter, or hard-mounter outside.

- The aim of the ignition system is to provide the greatest potential for ignition of herded slicks.

- The system should include a downward looking camera that can video the oil on the water surface during the herder spray and ignition operation.

- The system should be designed with enough ignition capacity to balance the herder delivery capacity to the extent possible. Ideally, the integrated system should be capable of treating multiple slicks.

- The system should include instrumentation that allows quantification and cataloguing of the amount of herder delivered during each spray pass and the coordinates and track of the system while herder is being sprayed and ignition devices are being deployed.

- After review and approval of the optimal system design, build and test the ignition system at a suitable location that allows the system to be suspended at an appropriate height. The herder delivery part of the system can spray water during the test to show that the integrated system can both spray a liquid and delivery incendiary device/s. The minimum test would be to ignite 3 – 5 mm thick oil on water in at least a 10 m x 10 m pan/tank on the ground.

- Identify FAA testing requirements and steps to achieve certification for the interim and final integrated ignition / herder delivery systems.

2. IGNITER LITERATURE REVIEW SUMMARY

This review summarized the technologies available for initiating in-situ burning (ISB). The focus of the report was on oil spill igniters reported in the available open literature, which basically encompasses North American and European research and development efforts. The authors are not aware of any literature on oil spill igniters in Russia, or Asia, other than reports of using ad-hoc ignition techniques (oily rags, torches, fuel oil in containers, etc.) during actual spill responses in these areas. Much of the technology was conceived as a result of in-situ burning attempts at specific spill incidents. For example, the *Torrey Canyon* incident in 1967 prompted considerable research on both sides of the Atlantic on the subject of oil slick ignition.

Over the intervening 50-year period a greater understanding has developed of the processes involved in the ignition, steady burning, vigorous burning, and extinction phases of in-situ combustion, and this has led to a refinement of existing ignition equipment and new tools and techniques. The recent *Deepwater Horizon* (Macondo) response has already generated a new round of technological refinements and operational guidelines for open-water burning of oil. Additional details may be found in the IOGP Arctic JIP Report - In Situ Burning in Ice-Affected Waters: State of Knowledge Report (http://www.arcticresponsetechnology.org/wp-content/uploads/2013/10/Report-7.1.1-OGP_State_of_Knowledge_ISB_Ice_Oct_14_2013.pdf)

The purpose of this review was to provide technical guidance for the development of an oil-slick ignition system to be combined with a recently developed herding agent application system for helicopters. The system is to be designed so that a single helicopter can first apply herder and contract the slick, and later ignite and burn oil slicks without the need for booms or surface vessels. The concept of contracting slicks in open water and in drift ice conditions with herding agents and then igniting them offers the possibility of a rapid aerial response to spills. The following is a brief summary of the literature review; full details may be found in the full IOGP Arctic JIP report at:

http://www.arcticresponsetechnology.org/wp-content/uploads/2016/06/Igniters-Report-Final.pdf

2.1 Summary and Conclusions

Successful ignition of oil slicks on water for ISB requires at least 2 to 3 mm of oil thickness to support combustion, an igniter that heats the oil layer above its Fire Point and provides an open flame to ignite the oil vapours, and effective flame spreading to cover as much as possible of the slick.

The presently-available igniters for ISB operations are summarized in Table 1. Of these, the four that depend on gelled fuel are commercially available: stockpiles of the Dome igniter have existed in Alaska and Northern Canada since the mid-1980s.

The three hand-held igniters employing gelled fuel require that gelling agent, fuel (gasoline or diesel) and a marine flare be added onsite in order to be made functional. Since they contain no hazardous materials prior to being readied, they can be shipped empty without the need for hazardous material handling and documentation. These igniters are suited to initiating ISB in fire booms on water with one or two units released in from of, or directly onto the contained oil.

Table 1. SUMMARY OF PREVIOUSLY AVAILABLE IGNITERS FOR ISB

Name	*Fuel*	*Components*	*Firing Method*	*Intended Use*	*History*	
AFTI Igniter	Gelled gasoline and/or diesel (gel and fuel supplied by user)	Cardboard box containing two plastic 3.8 L jugs, polyethylene foam packing, ballast weight, receptacle for marine flare	Marine flare (supplied by used)	Activated by hand and surface-deployed, allowed to drift or placed into oil contained in towed fire boom.	Developed during Macondo spill in 2010	
Elastec Safe Start	Gasoline and/or diesel (fuel supplied by user)	3.8 L plastic jug pre-filled with non-hazardous gelling agent fitted with foam collar and receptacle for marine flare	Marine flare (supplied by used)	Activated by hand and surface-deployed, allowed to drift or placed into oil contained in towed fire boom.	Developed during Macondo spill in 2010	
Simplex Model 901 Hand-held	Gelled gasoline and/or diesel fuel, with demulsifiers or anti-foaming agent additives (all supplied by user)	1 L plastic jug pre-filled with non-hazardous gelling agent fitted with foam collar and receptacle for marine flare	Marine flare (supplied by used)	Activated by hand and surface-deployed, allowed to drift or placed into oil contained in towed fire boom.	Developed in early 1990s after *Exxon Valdez* spill.	

Name	*Fuel*	*Components*	*Firing Method*	*Intended Use*	*History*	
Dome Igniter (stockpiled in Alaska and Canada)	Gelled kerosene	Metal juice can floatation, wire basket containing fuel, and fuse for firing.	Safety fuse, igniter wire, solid propellant	Activated by hand and thrown from helicopter or surface-deployed, on to oil contained on ice or in fire boom	Developed in late 1970s/early 1980s for ISB on ice	
Simplex Helitorch	Gelled gasoline and/or diesel fuel, with demulsifiers or anti-foaming agent additives (supplied by user)	Frame, sling, 205-L drum, pump, valves, 28V power, controls, propane for lighter	Gelled fuel pumped past propane flame	Operated as a sling load under helicopter. Loaded and propane flame started on ground. Burning fuel released over target by pilot.	Adapted from forest fire fighting in early 1980s for ISB on ice and water	

The helitorch is the only presently-available system for deploying a large number of ignition sources from the air over larger areas of a spill in a relatively short time. The helitorch is suitable for use on oil contained on or among ice, contained by herding agents or contained by fire boom.

2.2 Regulatory Requirements

The carriage and use of aerial igniters by aircraft (fixed or rotary wing) will likely require approvals from the relevant aviation authorities. For example, the use of a helitorch in the United States requires that the pilot hold a current US Government training certificate, no passengers be in the helicopter during operations and the helicopter must avoid flying over populated areas.

3. INTEGRATED IGNITER / HERDER APPLICATION SYSTEM DESIGN AND PROTOTYPE CONSTRUCTION

The original design of the herder applicator system harkens back to an ExxonMobil sponsored project in 2011. At that time it was desired to have a system that could be placed in a helicopter of opportunity and spray herder from several hundred feet above the ground with the nozzles located 10 to 20 feet above the ground. The design integrated a tank and pump assembly in the aircraft with a spool that could be retracted inside the helicopter (Figure 1). The assumption at the time was that larger twin engine; flat-floor helicopters would be used.

As it turned out, the first helicopter used was the Hughes 600 NOTAR which had a flat floor, but was not large enough to operate with the spool retracted. Testing showed that the orientation of the hose to the direction of flight was important. The other important consideration is the balance of the helicopter from left to right as the center of gravity has to be within the helicopter's design centerline. It can be detrimental if too much weight is located far from the helicopter centerline. However, these initial tests did show that it was possible to spray herder with some level of accuracy at speeds of 20-30 knots. It was also learned that a heavier weight on the end of the hose was necessary to maintain a reasonable catenary in the hose. Other learnings were related to the pump system, the winder and braking. The most important discovery was the need for the system to be able to extend and recover the hose easily.

Further development of the spray system was conducted in order to mount the system in a Bell 407 model helicopter for the Poker Flat, AK demonstration. The spool was re-aligned to the direction of flight, weight was added to the end of the hose using a 12 lb. down rigger weight and appropriate check and flow control valves were included in the hose system to enable better control over the fluid flow. A brake assembly was created to enable good control over the launch and recovery of the hose, and a rudimentary control box was designed for this function.

Testing at the Poker Flat facility during the months of March and April 2015 demonstrated that fairly accurate application of the herders could be accomplished using the hose system operated from a helicopter altitude of 200 feet (60 m). Also learned during this testing was:

1. Incompatible materials such as herder and water would be significant impediments when changing herder fluids. Isopropyl alcohol (98% anhydrous) was necessary to enable system flushing between operations. Diesel fuel would be appropriate as well.
2. Flow control needed to be addressed at the nozzle end of the system whereby fluid pressure in the system was maintained with a pump, but flow restricted at the nozzle. This is for more immediate on/off control of the fluid being used.
3. An emergency jettison system needed to be incorporated into the spool design to enable the pilot to eject the hose/nozzle assembly in the event of ground entanglement.
4. Some method of track and deposition of chemical needed to be included in the system (e.g., GPS)
5. Video recording of the view from the nozzle would be desirable from a targeting standpoint.

After the Poker Flat testing, the development of the integrated Igniter Launcher module was initiated.

An underslung module appeared to be the best approach given that dropping igniters from heights more than 10 or 15 meters might be detrimental to the integrity of the igniter itself, and also be more difficult to be accurate. The applicator system needed to be developed around the igniter which was designed on a separate track. Desired dimension for the igniter were assigned after a preliminary design for the module was complete. The igniters had to incorporate commercially available materials, be shipped using non-explosive shipping classifications, stored for extended periods of time, and at the same time be able to reliably set fire to a herded slick.

Target dimensions of the igniter settled upon 5 inches diameter and 10 inches in length (Figure 3). The finished dimension allowed for a standard 3" mailing tube to be used as the internal container. Inside of this would be a timer/arming and ignition circuit, a 9V battery and a commercial road or marine flare. The internal volume of the igniter design was intended to accommodate 350 mL of gelled gasoline in a plastic bag. Cartridge Activated Devices (CAD) was the contractor of choice due to their experience in the development of numerous military and commercial explosive and incendiary devices.

The dimensions of the launcher module were dictated by the size of the igniter and the desired number of igniters to be carried. Several shapes and sizes were evaluated which ended with the two-tier conveyor system which launched the igniter horizontally. A minimum of 15 igniters were desired. The overall size and shape also had to be carried alongside or beneath the skids, in this case, of the Bell 407 Helicopter.

DESMI developed the module to be self-contained which also had the nozzle arrangement, camera, conveyor system and batteries to operate the conveyor and flow control valve (Figure 4). All controls had to be wireless due to the difficulty of running a co-axial cable and hose from the winder module in the aircraft. The wireless control system (Figure 5) was developed by CAVOTEC, a German company.

Figure 3. First Generation CAD igniter.

Figure 4. First generation launcher module before field mods.

Figure 5. Wireless control unit.

Simultaneously with the development of the launcher module, modifications to the spool assembly were undertaken to address the shortcomings identified during the experiments at Poker Flat. These included better flow control on the pump assembly, wireless control of the spool to launch, recover and stop at any point with a secure lock of the spool. The system is controlled by an operator console with various functions on the touch screen. Also, the video is recorded, waypoints designated when an igniter is dropped and herder consumption is recorded.

3.1 Igniter Development

In November 2015, DESMI entered into agreement with Cartridge Activated Devices (CAD) to develop the igniter. CAD had previously developed an oil spill igniter for the US Navy Supervisor of Salvage that never went into production. The design parameters were:

- Use as many commercially available components as possible.
- Develop a device that could be dropped on to water from as high as 15 meters and maintain integrity.
- Have an indefinite shelf life without consumables, i.e., batteries, fuel or flare installed.

- Be shippable by normal freight or air freight without explosive or hazardous classification.
- Have all necessary safety and time delay circuitry to ignite approximately 2 min after launch.

Tests at the CAD test facility of the initial design (Figure 6) in February 2016 indicated that it met the original design criteria. Further tests at SL Ross - as described later in Section 5.0 -indicated a number of design and assembly features that needed to be addressed. Section 5.5 addresses recommendations derived from the SL Ross testing.

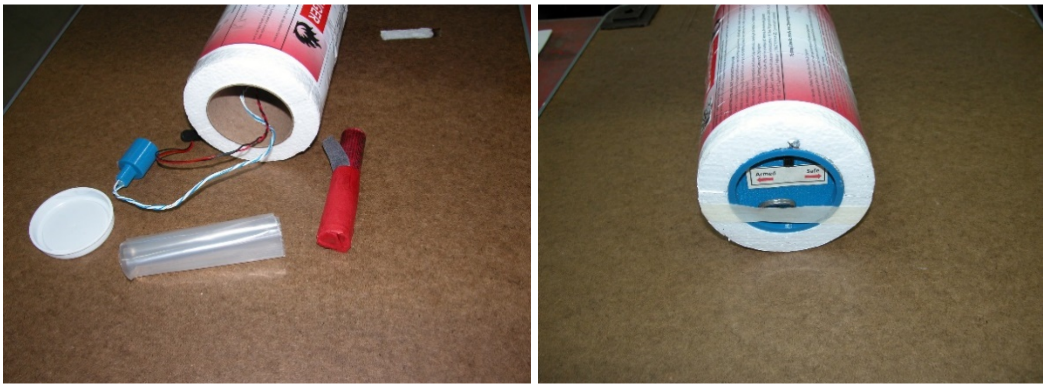


Figure 6. Igniter Details of end cap and contents. (Control end left – Igniter end right)

After the laboratory testing at SL Ross, further meso-scale outdoor testing of the igniters at CRREL was undertaken. A full review of the igniter design was undertaken after the CRREL testing and several modifications were deemed necessary before the actual flight tests were undertaken (Figure 7). A meeting with CAD was held with the objective of making the necessary changes. The changes deemed necessary were

- Improve the durability of the container. There were issues with the end caps popping off due to the inertia of the liquid held in the plastic bag within the device. Some suggestions were made relative to the end cap being more robust and having barbed fasteners to hold the cap more firmly.
- Change the design of the safety pin and switch mechanism so that is was more secure and more able to be readily extracted from the igniter by the applicator.
- Change the arming switch to a recessed switch that was more positive and durable
- Examine the circuitry to determine the reason for the fast discharge rate on the batteries.
- Make a more positive ignition of the flare.

Figure 7. Revised Igniter Modification 3

Changes made include:

1. Recessed arming switch
2. Revised safety pin
3. Deeper and more robust cap

4. LABORATORY IGNITER TESTING

4.1 Multiple Fuel Testing with Gelling Agent

Laboratory testing was conducted to determine appropriate fuels to be incorporated into the design of the igniter sub-system, and recommended concentrations of gelling agent. Previous work has shown that temperature will have a dramatic impact on the time it takes to gel as fuel, as will the concentration of gelling agent and the presence of ethanol in the fuels. This report provides data on laboratory scale testing using six fuels, a range of gelling agent concentrations, and three operating temperatures.

The purpose of these experiments was to determine appropriate fuels and gelling agent concentrations for the active component of the proposed igniter.

More specifically, the aim was to:

- Perform tests with multiple fuels to determine their propensity to become gelled within a reasonably short timeframe for use in the electronically controlled igniters being developed.
- Determine the impact of temperature on the rate of gelling and the ultimate gelled condition of the tested fuels.
- Investigate the impact of gelling agent concentration on the speed of gelling and the ultimate gelled condition of the tested fuels.

4.2 Methods

A number of bench scale tests were performed using the following equipment:

- Multiple laboratory balances with wide weighing ranges (0 to 4000 g, and 0 to 40 kg).
- Graduated cylinders, 100 mL.
- Glass vials, 50 mL.
- Multiple thermometers and thermocouples.
- Sorbent pads.
- Stopwatch.
- Video camera system.
- Still camera system.
- Anton Parr DMA 35 densitometer to measure density of fuel samples.
- Temperature controlled environmental chamber.

A total of six distilled fuels were selected for testing purposes (Table 2 and Figure 8).

Table 2. FUEL FOR GELLING EXPERIMENTS

Fuel #	Description	Density at 0.5°C
1	diesel (winter grade)	0.8355
2	regular unleaded (up to 10% Ethanol)	0.7297
3	premium unleaded (no Ethanol)	0.7478
4	AVGAS (100LL)	0.7291
5	Jet A1	0.8158
6	80% reg. unleaded, 20% diesel	0.7509

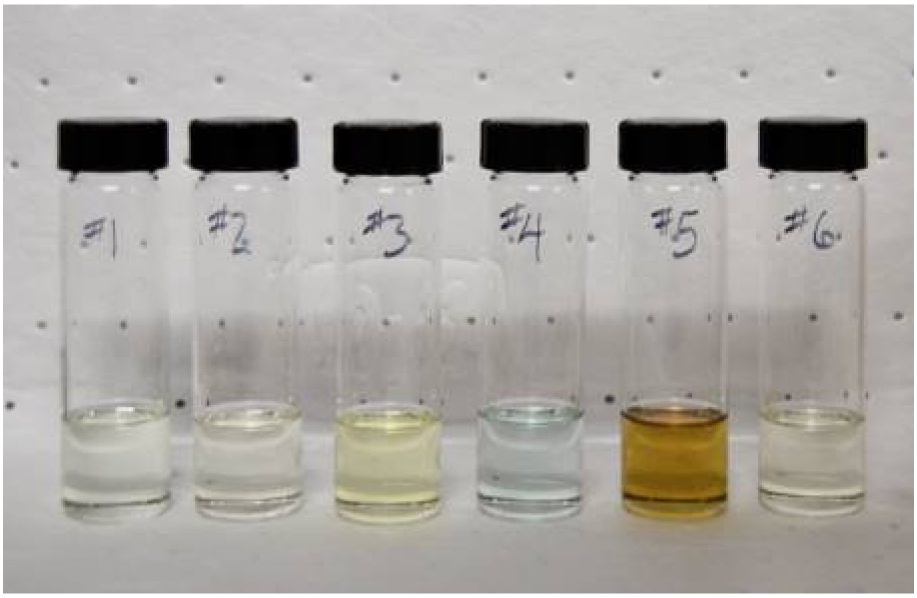


Figure 8. Fuel samples prior to gelling agent addition

Test Procedures

A review of readily available literature provided the following information on starting concentrations for producing gelled fuel for use in the new igniter. According to the USDA Forest Service – Engineering[1] as part of the Batch Mixer/Terra Torch Operation Manual, the following are the general recommended quantities of Firegel/Fire-Trol[2] (SureFire) needed per barrel (or approximately 200L of fuel):

[1] http://www.fs.fed.us/eng/aerial_ign/fuelgel/equip/firecon/manual/append_b.htm

[2] Fire-Trol Holdings, L.L.C. is the exclusive U.S.A. distributor for FIRE-TROL Fuel Gelling Agent. This product was previously sold as SUREFIRE®.

Table 3. GELLING CONCENTRATIONS

Fuel Temperature	Firegel/Fire-Trol/SureFire per 200L	Equivalent (g) per 10mL
Over 15.6°C	1.4 - 1.8kg	0.08
between 4.4°C and 15.6°C	1.8 - 2.3kg	0.10
Under 4.4°C	2.7 - 3.2kg	0.15

EZFire Gelling Agent (formerly referred to as SureFire and Fire-Trol) has a recommended mix ratio of 4.4 lb./55 US Gal[3] drum, or 2 kg/200L, which translates to 0.10g/10mL. For the initial series of tests at multiple temperatures, 0.15g/10mL was selected as the starting concentration of gelling agent to fuel mixture.

A total of 28 tests were performed to address a number of factors including fuel type, temperature, and concentration of gelling agent. Testing was performed using 10mL samples of fuel in a 50mL sealable vial. Once the initial quantity of gelling agent was added to the fuel in the vial, it was shaken vigorously for approximately 5 seconds then left to settle and polymerize. Photos and video was taken at specific time intervals over the first hour in order to ascertain whether the liquid had reached a sufficiently gelled consistency.

4.3 Results

4.3.1 Testing at -10°C

For this series of tests, 0.15 g of gelling agent was introduced to a 10mL fuel sample at the target temperature, shaken vigorously for 5 seconds, and then left in the environmental chamber.

- After 5 minutes, the gelling action had started in some of the vials, but all were deemed too runny at this point.
- By the 20 minute mark, the premium gasoline was close to reaching a sufficiently gelled stated.
- At 30 minutes the diesel was still too runny, as was the regular gasoline (and also somewhat non-homogeneous in that there were many small gelled blobs in the liquid). Premium gasoline was reasonably gelled at this point, but the AVGAS was not (in spite of many very small particles – almost like the gelling agent was sediment). The jet fuel and regular unleaded/diesel mix were still too runny.
- After 60 minutes there was minimal additional change in the diesel, regular gasoline, and premium gasoline. The AVGAS had gelled a bit more and reached a more viscous consistency. The jet fuel and mix of regular gasoline with diesel remained too runny.

A final review was conducted after a 24 hour period. At this time, the AVGAS continued to gel, surpassing the premium gasoline by reaching a consistency that was very resistant to flow.

[3] http://www.westernhelicopterservices.com/EZfire_mixing_instructions.pdf

4.3.2 Testing at 0°C

For this series of tests, 0.15 g of gelling agent was also introduced to a 10mL fuel sample at the target temperature, shaken vigorously for 5 seconds, and then left in the environmental chamber.

- After 5 minutes, the gelling action started in some of the vials, but all were deemed too runny at this point.
- After 20 minutes the regular gasoline had gelled blobs, but was generally too runny. The premium gasoline and AVGAS were nicely gelled. Both of the vials of jet fuel and blend of regular gasoline/diesel had started gelling, but were still too runny.
- After 30 minutes the diesel seemed slightly thickened, but not really gelled. The regular gasoline exhibited some gelling, but was non-homogeneous and a bit too runny. The premium gasoline was nicely gelled, but still flowed slowly and was sticking to the glass surface of the vial. The AVGAS was stiffly gelled, with very slow flow. The jet fuel was also a bit non-homogeneous and still too runny. The final vial of regular unleaded gasoline and diesel blend also remained too runny.
- After 1 hour the diesel had minimal, if any, gelling. The regular gasoline was more homogeneous, but still a bit too runny. The premium gasoline was nicely gelled, while the AVGAS was stiffly gelled and stuck to the lid of the vial. The jet A1 was nicely gelled, and finally, the mix of 80% regular gasoline and 20% diesel was slightly gelled, but still runny.

A final review was done at the 24 hour mark, and the premium gasoline, AVGAS, and Jet A1 were all sufficiently gelled, while the remaining vials were all too runny.

4.3.3 Testing at 15°C

For this series of tests, 0.15 g of gelling agent was introduced to a 10 mL fuel sample at the target temperature, shaken vigorously for 5 seconds, and then left in the environmental chamber.

- After 5 minutes, the gelling action started in some of the vials. The diesel was barely reacting to the gelling agent, while the regular unleaded gasoline (with ethanol) had small gelled clumps, but remained runny. The premium gasoline was gelled quite nicely, while the AVGAS was starting to gel, but still remained too runny. The Jet A1 fuel was barely reacting, and the blend of 80% regular gasoline plus 20% diesel contained gelled clumps, but also remained runny at this point.
- At 10 minutes, minimal change was noted in the diesel sample. The regular gasoline had slightly larger gelled clumps, but remained runny. The premium gasoline and the AVGAS were both gelled nicely, while the Jet A1 was still slightly runny as was the blend of regular gasoline with diesel.
- After 20 minutes, the diesel still hardly had any gelling taking place. The regular gasoline had obviously started gelling with lumpy components, but remained slightly runny. The premium gasoline was nicely gelled, but still flowed (albeit slowly) and stuck to the glass walls of the vial. The AVGAS was stiffly gelled, clinging to the underside of the lid and, to a lesser extent, to the glass walls. The Jet A1 was nicely gelled (with some flow noted), while the mix of regular gasoline (80%) plus diesel (20%) was weakly gelled (a bit too runny).
- At 30 minutes the AVGAS was stiffly gelled, followed by the Jet A1 then the premium gasoline. The remaining vials were deemed too runny, with hardly any noticeable change in the diesel vial.

- At the 60 minute mark, the gelled states seemed to progress slightly, with the three vials (AVGAS, Jet A1, and premium gasoline) identified earlier maintaining their gelled states, with the other vials still being deemed too runny for use as an igniter fuel.

After a period of 24 hours, the diesel was mostly converted to a gelled blob, with a thin layer of liquid on the surface that was not gelled. The two remaining vials containing regular gasoline (as pure product or as a mixture with diesel) were still too runny. The premium gasoline seemed to be less strongly gelled, but still adequate, while the AVGAS and Jet A1 did not appear to substantially change from the 60 minute examination.

4.3.4 Testing with pure fuels, range of gelling agent concentrations

This series of testing involved regular gasoline and diesel with a range of gelling agent concentrations from 0.10 g/10 mL through 0.30 g/10 mL in 0.05 g/10 mL steps. Testing was performed at 15°C (laboratory room temperature).

Gasoline testing at the 5 minute mark

- 0.10g/10mL: still runny with a couple of gelled blobs, overall still runny (see Figure 9)
- 0.15g/10mL: better, but not homogeneous. Still very runny (see Figure 10)
- 0.20g/10mL: starting to thicken up, but still too runny (see Figure 11)
- 0.25g/10mL: starting to gel nicely but not homogeneous (see Figure 12)
- 0.30g/10mL: gelling nicely, thickened, but appears a bit clumpy (see Figure 13)
-

Gasoline testing at the 20 minute mark:

- 0.10g/10mL: still runny with a large gelled blob at bottom (see Figure 14)
- 0.15g/10mL: becoming more homogeneous, starting to thicken (see Figure 15)
- 0.20g/10mL: even more homogeneous, thickening nicely (see Figure 16)
- 0.25g/10mL: gelling nicely, portion sticking to bottom glass, viscous (see Figure 17)
- 0.30g/10mL: gelling nicely, thickened, still a bit clumpy, viscous (see Figure 18)
-

Gasoline testing at the 30 minute mark:

- 0.10g/10mL: not a lot of change, slightly better mixing but still runny with gelled blobs (see Figure 19)
- 0.15g/10mL: slightly more homogeneous, still slightly runny (see Figure 20)
- 0.20g/10mL: continuing to thicken, but still slightly too runny (see Figure 21)
- 0.25g/10mL: gelled nicely, still has fluidity (see Figure 22)
- 0.30g/10mL: gelled nicely, thickened, still appears slightly clumpy (see Figure 23)
-

Gasoline testing at the 60 minute mark:

- 0.10g/10mL: single large blob settled at bottom, overall still runny (see Figure 24)
- 0.15g/10mL: better, but not homogeneous. Still too runny (see Figure 25)
- 0.20g/10mL: good gelling, but non-homogeneous and still slightly runny (see Figure 26)
- 0.25g/10mL: gelled nicely, better consistency (see Figure 27)
- 0.30g/10mL: gelled nicely, thickened, good consistency (see Figure 28)

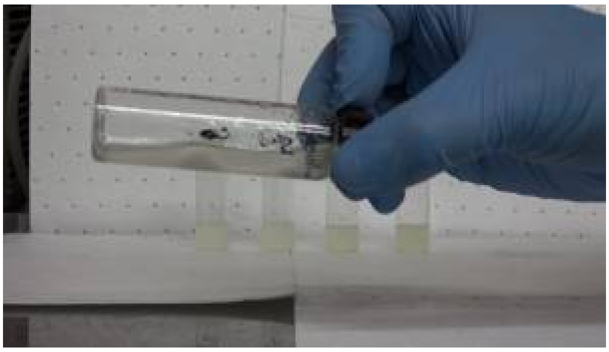


Figure 9. 15°C Gasoline at 5 minutes with 0.10g gel

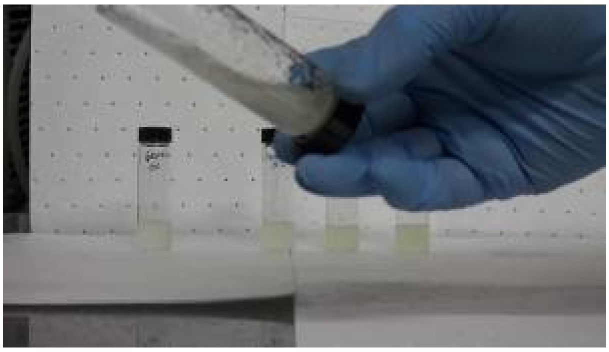


Figure 10. 15°C Gasoline at 5 minutes with 0.15g gel

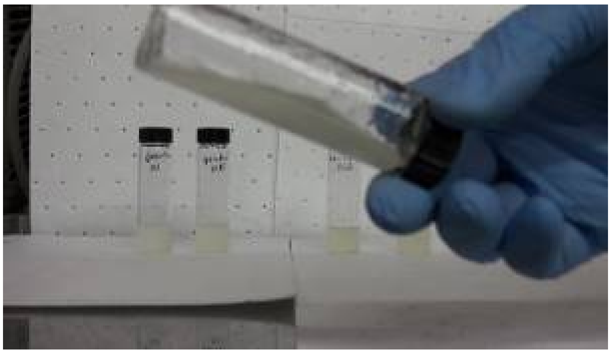


Figure 11. 15°C Gasoline at 5 minutes with 0.20g gel

Figure 12. 15°C Gasoline at 5 minutes with 0.25g gel

Figure 13. 15°C Gasoline at 5 minutes with 0.30g gel

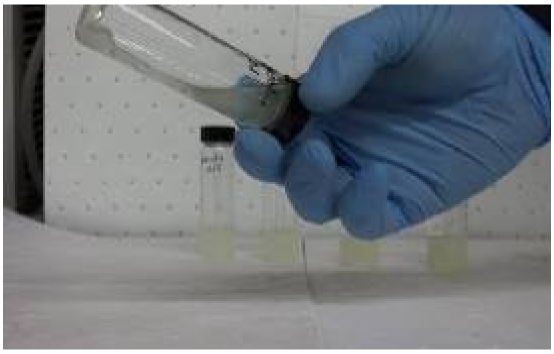


Figure 14. 15°C Gasoline at 20 minutes with 0.10g gel

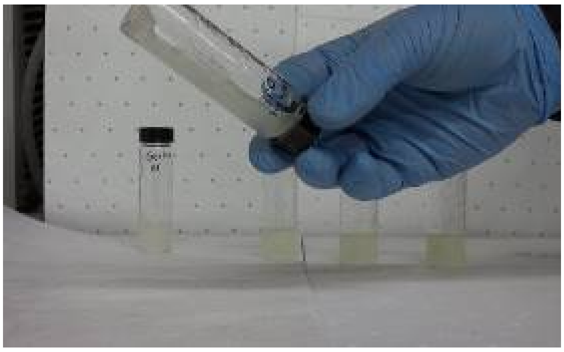


Figure 15. 15°C Gasoline at 20 minutes with 0.15g gel

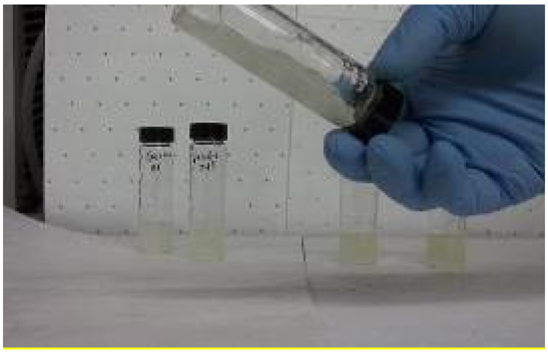


Figure 16. 15°C Gasoline at 20 minutes with 0.20g gel

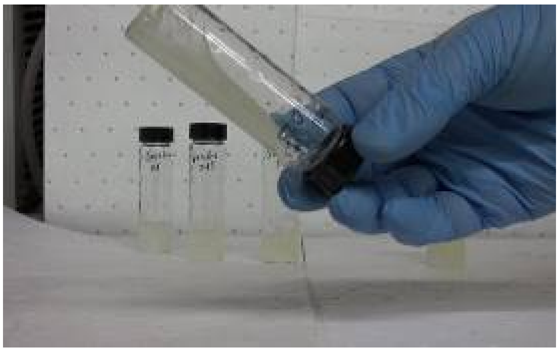


Figure 17. 15°C Gasoline at 20 minutes with 0.25g gel

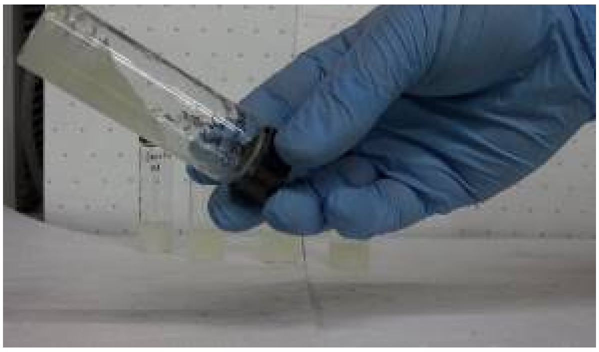


Figure 18. 15°C Gasoline at 20 minutes with 0.30g gel

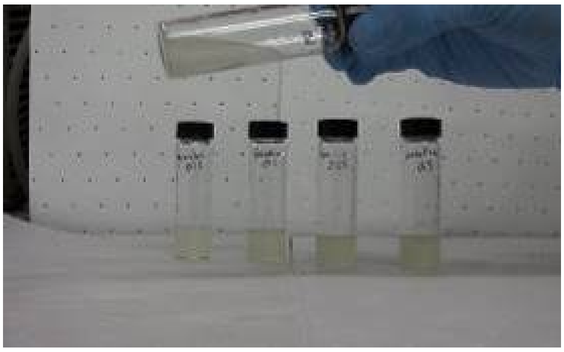


Figure 19. 15°C Gasoline at 30 minutes with 0.10g gel

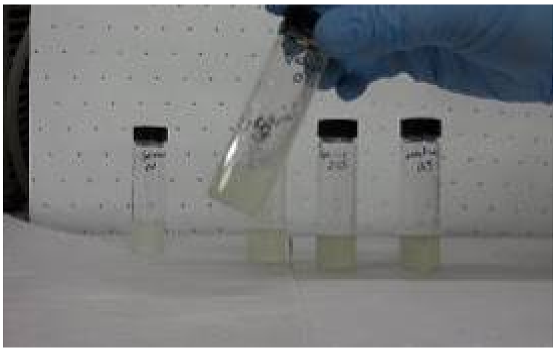


Figure 20. 15°C Gasoline at 30 minutes with 0.15g gel

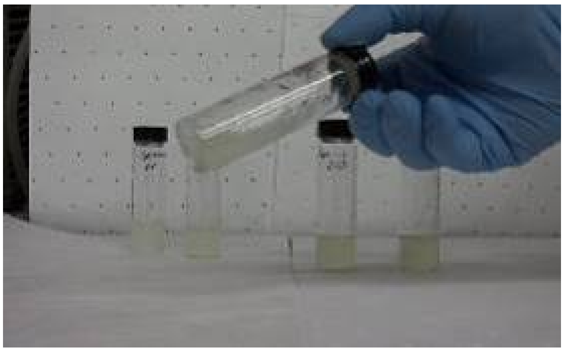


Figure 21. 15°C Gasoline at 30 minutes with 0.20g gel

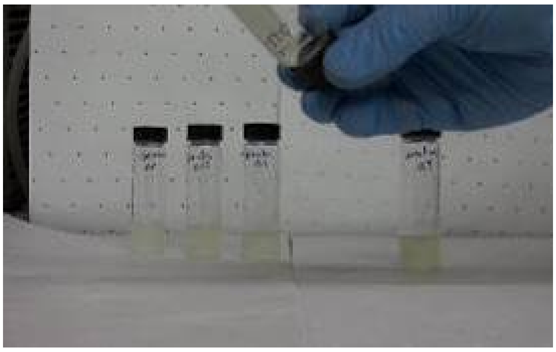


Figure 22. 15°C Gasoline at 30 minutes with 0.25g gel

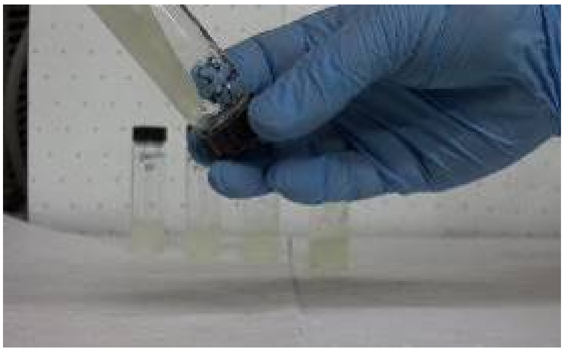


Figure 23. 15°C Gasoline at 30 minutes with 0.30g gel

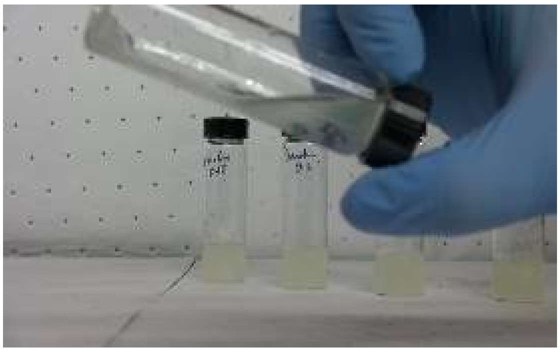


Figure 24. 15°C Gasoline at 60 minutes with 0.10g gel

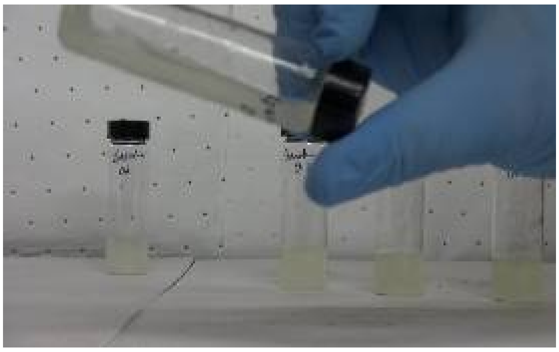


Figure 25. 15°C Gasoline at 60 minutes with 0.15g gel

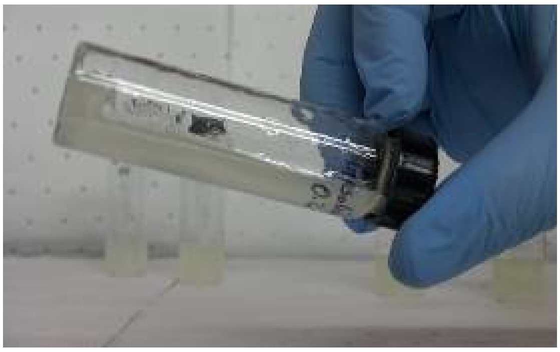


Figure 26. 15°C Gasoline at 60 minutes with 0.20g gel

Figure 27. 15°C Gasoline at 60 minutes with 0.25g gel

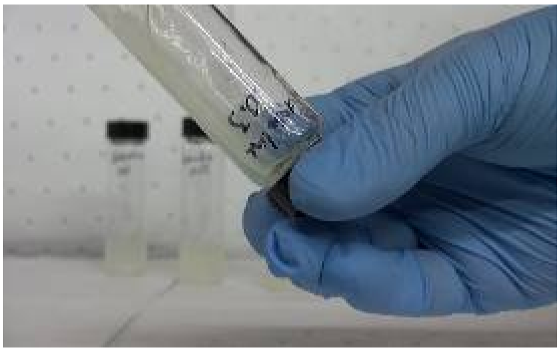


Figure 28. 15°C Gasoline at 60 minutes with 0.30g gel

Diesel testing at the 5 minute mark:

- 0.10g/10mL: still runny, no discernable effects (see Figure 29)
- 0.15g/10mL: still runny, no discernable effects, sediments on bottom (see Figure 30)
- 0.20g/10mL: still runny, no discernable effects, sediments on bottom (see Figure 31)
- 0.25g/10mL: still runny, no discernable effects, sediments on bottom (see Figure 32)
- 0.30g/10mL: still runny, no discernable effects, sediments on bottom (see Figure 33)

Diesel testing at the 20 minute mark:

- 0.10g/10mL: still runny, no discernable effects (see Figure 34)
- 0.15g/10mL: still runny, some sediment on bottom, no discernable effects (see Figure 35)
- 0.20g/10mL: no gelling happening yet, sediment on bottom (see Figure 36)
- 0.25g/10mL: no gelling happening yet, sediment on bottom (see Figure 37)
- 0.30g/10mL: no gelling happening yet, sediment on bottom (see Figure 38)

Diesel testing at the 30 minute mark:

- 0.10g/10mL: still no discernable effects, with some particles seen at bottom (Figure 39)
- 0.15g/10mL: no discernable effects, some particles seen at bottom (Figure 40)
- 0.20g/10mL: no apparent change in viscosity, particles seen at bottom (Figure 41)
- 0.25g/10mL: still no gelling, additional particles seen at bottom of vial (Figure 42)
- 0.30g/10mL: still no gelling, additional particles seen at bottom of vial (Figure 43)

Diesel testing at the 60 minute mark:

- 0.10g/10mL: still no discernable effects, with some particles seen at bottom (Figure 44)
- 0.15g/10mL: still no discernable effects, with particles seen at bottom (Figure 45)
- 0.20g/10mL: no discernable effects, with additional particles seen at bottom (Figure 46)
- 0.25g/10mL: no gelling, additional sediment particles seen at bottom of vial (Figure 47)
- 0.30g/10mL: no gelling, additional sediment particles seen at bottom of vial (Figure 48)

Diesel testing at the 24 hour mark:

- 0.10g/10mL: gelled blob at bottom encompassing approximately 50% of the volume with approximately 50% fee liquid layer on top (Figure 49)
- 0.15g/10mL: gelled volume encompassing most of the diesel, small quantity of free liquid as a layer on top (Figure 50)
- 0.20g/10mL: gelled nicely, small layer of free liquid at top (see Figure 51)
- 0.25g/10mL: gelled nicely, small layer of free liquid at top (see Figure 52)
- 0.30g/10mL: gelled nicely, few drops of free liquid at top (see Figure 53)

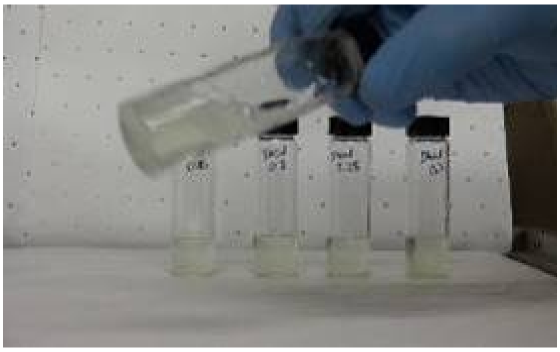


Figure 29. 15°C Diesel at 5 minutes with 0.10g gel

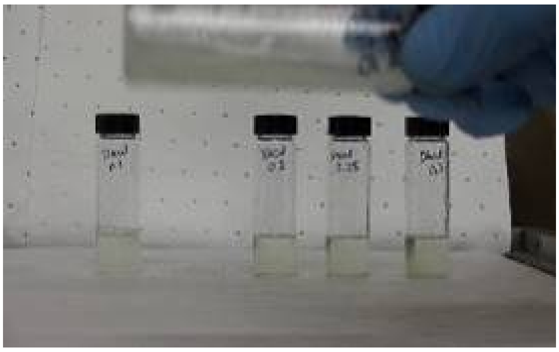


Figure 30. 15°C Diesel at 5 minutes with 0.15g gel

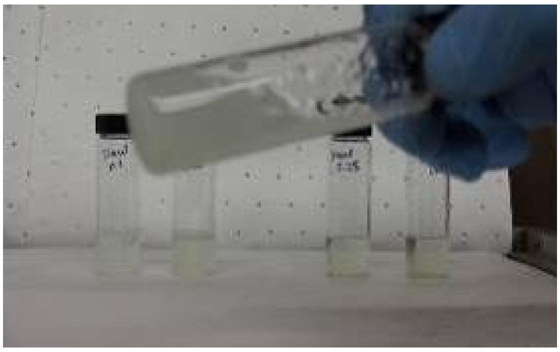


Figure 31. 15°C Diesel at 5 minutes with 0.20g gel

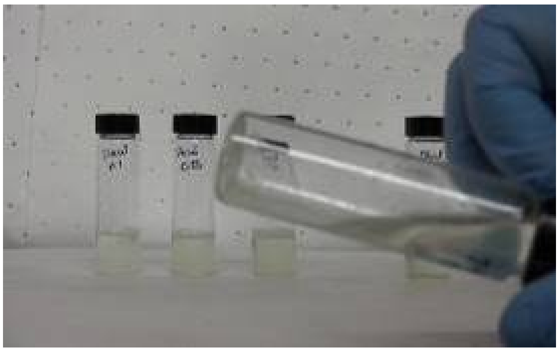


Figure 32. 15°C Diesel at 5 minutes with 0.25g gel

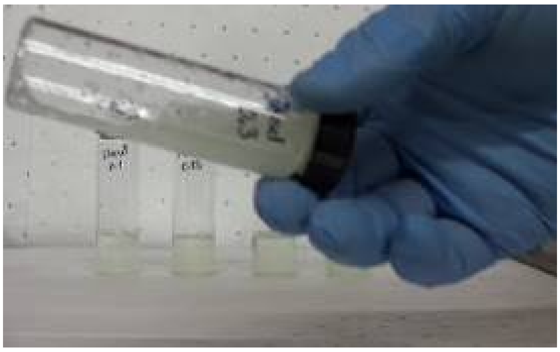


Figure 33. 15°C Diesel at 5 minutes with 0.30g gel

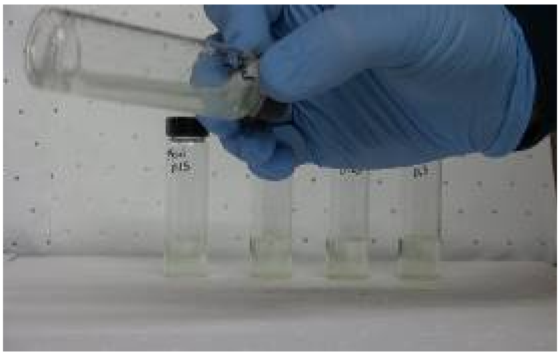


Figure 34. 15°C Diesel at 20 minutes with 0.10g gel

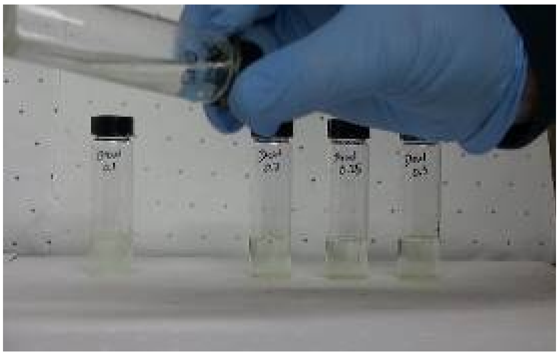


Figure 35. 15°C Diesel at 20 minutes with 0.15g gel

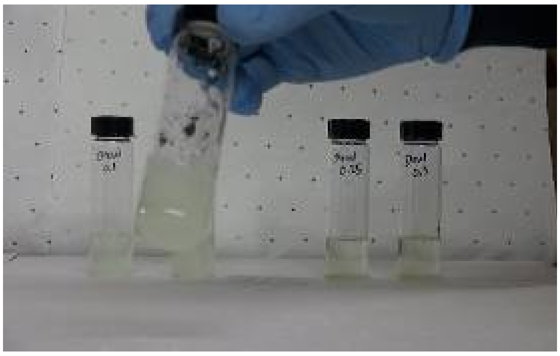


Figure 36. 15°C Diesel at 20 minutes with 0.20g gel

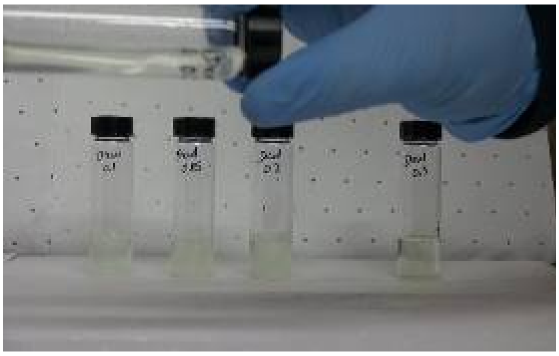


Figure 37. 15°C Diesel at 20 minutes with 0.25g gel

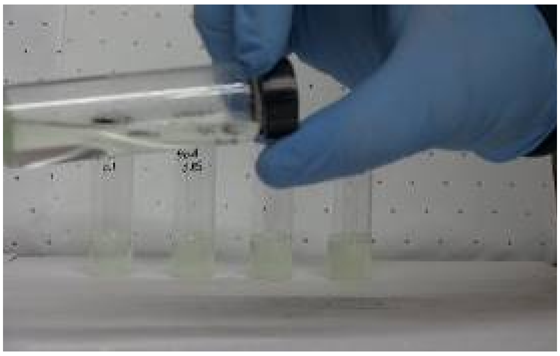


Figure 38. 15°C Diesel at 20 minutes with 0.30g gel

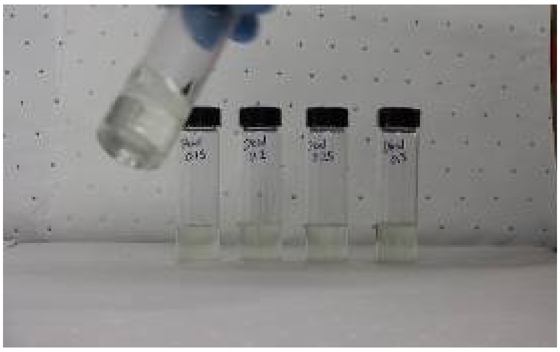


Figure 39. 15°C Diesel at 30 minutes with 0.10g gel

Figure 40. 15°C Diesel at 30 minutes with 0.15g gel

Figure 41. 15°C Diesel at 30 minutes with 0.20g gel

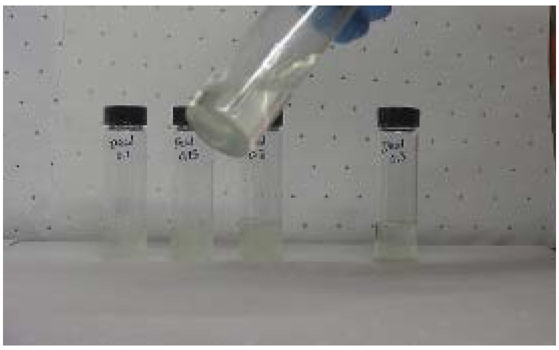


Figure 42. 15°C Diesel at 30 minutes with 0.25g gel

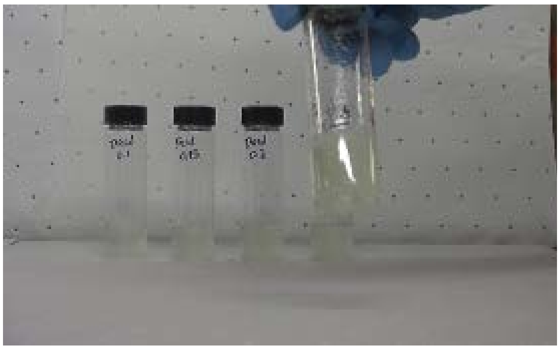


Figure 43. 15°C Diesel at 30 minutes with 0.30g gel

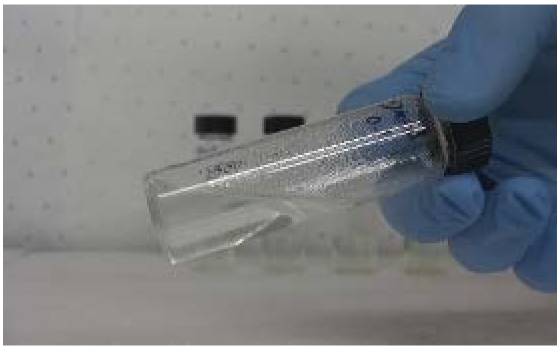


Figure 44. 15°C Diesel at 60 minutes with 0.10g gel

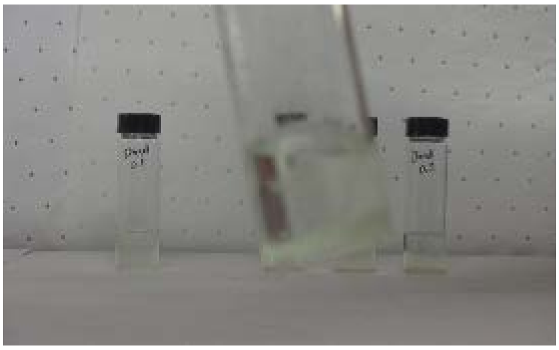


Figure 45. 15°C Diesel at 60 minutes with 0.15g gel

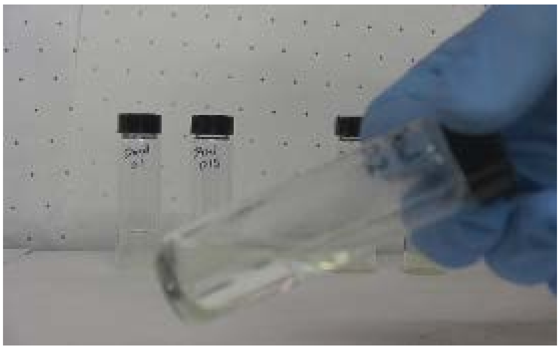


Figure 46. 15°C Diesel at 60 minutes with 0.20g gel

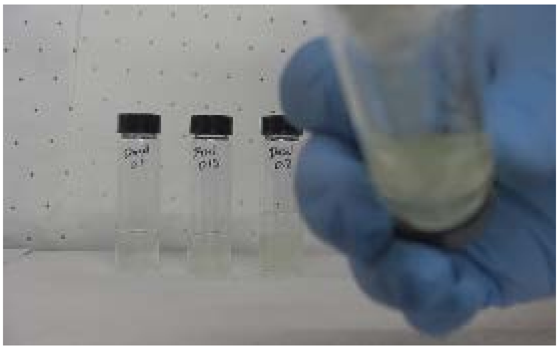


Figure 47. 15°C Diesel at 60 minutes with 0.25g gel

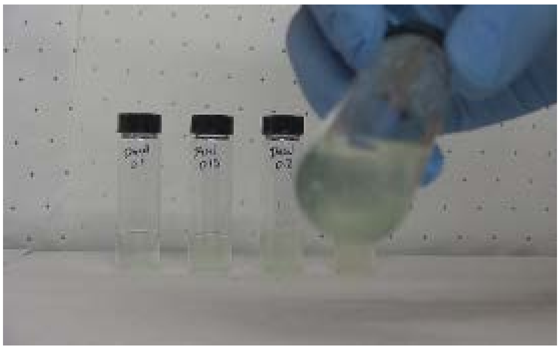


Figure 48. 15°C Diesel at 60 minutes with 0.30g gel

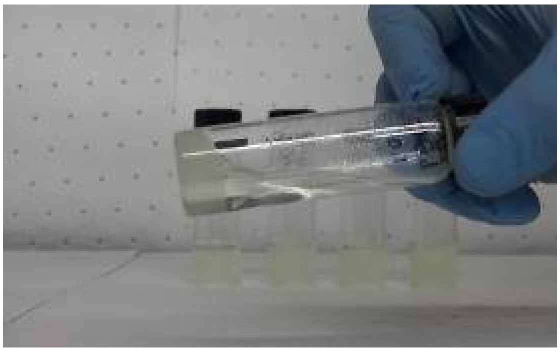


Figure 49. 15°C Diesel at 24 hours with 0.10g gel

Figure 50. 15°C Diesel at 24 hours with 0.15g gel

Figure 51. 15°C Diesel at 24 hours with 0.20g gel

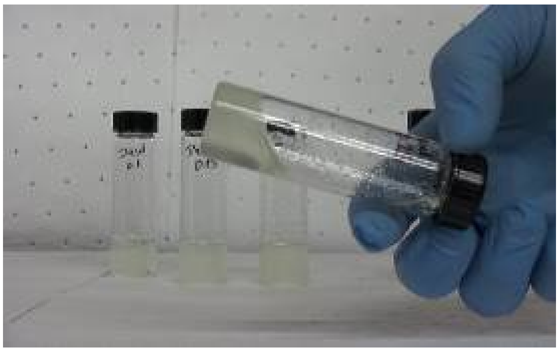


Figure 52. 15°C Diesel at 24 hours with 0.25 gel

Figure 53. 15°C Diesel at 24 hours with 0.30g gel

4.4 Discussion and Conclusions

The first series of tests showed three fuels that were effectively gelled within "operational" time periods, specifically the premium gasoline, the AVGAS and the Jet A1 fuel. None of these contain ethanol. Other fuels were either too slow gelling, possibly posing logistical issues in the event of their use, or they did not thicken to a sufficiently gelled end state where they may not provide a long enough burn time to initiate burning of weathered or emulsified crude oil.

Results from the temperature related testing showed that very low temperatures (-10°C) had a pronounced impact on the time for sufficient gelling to occur, with the premium gasoline taking 30 minutes to reach a properly gelled state, the AVGAS requiring 60 minutes, and the Jet A1 actually failing to gel sufficiently by the end of the test. At freezing temperatures (0°C) the premium gas required 20 minutes to gel, while both the AVGAS and the Jet A1 required 30 minutes to reach a sufficiently gelled state. These time periods further diminished as the temperature was warmed to 15°C. At this point, the premium gas only required 5 minutes, while the AVGAS needed 10 minutes and the Jet A1 needed 20 minutes, respectively, to reach a proper gelled state.

Additional testing was performed using regular gasoline (containing ethanol) and diesel fuel due to their widespread availability and ease of access for gelled fuel production in quantity. At the 5 minute mark of the gelling tests involving regular gasoline, 0.30g/mL was required for gelling to begin. After 20 minutes 0.25 g/mL was required to reach a properly gelled state. By 60 minutes, the 0.20g/mL sample was adequately gelled. By the 60 minute mark of the diesel tests, none of the samples were gelled. Additional time was added to the test and results from the 24 hour mark showed good gelling for samples with 0.15g/mL and above, and good gelling for one half of the volume of the sample with 0.10g/mL of gelling agent, with the rest as a layer of free liquid floating on top. This information is useful in that it shows regular gasoline (containing ethanol) and /or diesel can be used, but the time to achieving a gelled state will be severely impacted.

4.5 Recommendations

A number of recommendations can be made based upon the results of this series of tests:

- Perform testing of the igniter system using premium gasoline, AVGAS, or jet A1 fuel.
- Use the recommended concentration of gelling agent (0.10 to 0.15g/mL) as a starting point.
- Maintain a 30 minute rest period for the gelling agent to react with the fuel prior to firing the igniter.

5. LABORATORY PROTOTYPE IGNITER TESTING

The purpose of these tests was to:

- Perform tests with the prototype igniters produced by Cartridge Activated Devices to determine the splash profiles by dropping the igniter in different orientations. The impact of the igniter hitting the water surface after deployment will cause a short term open water or thin area within the slick. Minimizing the impact can help ensure successful ignition.
- Test a suite of gelled fuels to determine any performance issues.
- Test multiple igniters to identify any design issues that may impede their safe and effective operation.

5.1 Equipment and Apparatus

A number of bench scale tests were performed using the following equipment:

- Refrigerated wind/wave tank with 85 cm deep water
- Multiple laboratory balances with wide ranges (0 to 4000 g, and 0 to 40 kg)
- Multiple beakers, 100 mL – 2,000 mL range
- Thermometer
- Sorbent pads
- Stopwatch
- Video camera system
- Still camera system
- Test tank with ventilation system sufficient to deal with ignited oil
- Containment ring with support
- Multiple fuel samples (Table 4)
- Multiple oil samples (Table 5)
- Micro-pipettes
- Herder (OP40 and ThickSlick 6535)

Table 4. FUEL FOR GELLING EXPERIMENTS

Fuel #	Description	Density at 0.5°C
1	premium unleaded (no ethanol)	0.7478
2	AVGAS (100LL)	0.7291
3	Jet A1	0.8158

Table 5. CRUDE OIL USED FOR IGNITION TESTS

Oil #	Description
1	Kuparuk Crude, Fresh
2	Kuparuk Crude, Weathered
3	Endicott Crude, Weathered 1.35%
4	Endicott Crude, Weathered 6.17%

5.2 Test Procedures

The first set of tests centered on dropping an igniter from a height of approximately 3 m (10 ft.) to determine the impact of the igniter weight and shape on the size of the splash (see Table 6). The igniter was released while cameras mounted to capture two different angles recorded the splash. Comparisons are made between the runs to determine the best orientation for entry into the water surface. A surrogate igniter was developed to supplement the limited number of actual igniters available for live testing. The surrogate matched in size and weight, with an exterior of hard foam – just like the prototype igniter (see Figures 54 and 55). A bag of gelled water was added to the surrogates to mimic the gelled fuel of the actual igniter, and match the weight of the original igniter.

Table 6. DROP TESTS

Test	Description
1	Simple manual release
2	Platform release
3	Modified platform release (horizontal)
4	Modified platform release (vertical)
5	Modified platform release (vertical)

Figure 54. Igniter ready for testing

Figure 55. Surrogate igniter

The weight of the surrogate igniter (starting weight 568 g) was maintained to within 5% of the original igniter weight (567 g) during subsequent runs. If the surrogate gained too much weight through water ingress, the surrogate was replaced with another and the starting weight of the new surrogate was made to be 567 ± 5 g.

The next set of tests was performed to confirm that the igniters would function as designed and actually ignite a contained spill of oil (Table 7). Gelled fuel packs were prepared in advance of each experiment and loaded into the igniter assembly, and then the igniter was sealed with its end cap. Meanwhile a test volume of oil was added to a contained area. A small dose of herder (100 µL of OP40 or ThickSlick 6535 herder) was added around the perimeter of the spilled oil (400 mL). The igniter was activated, and then placed in the slick to determine if the timing mechanism would fire at the appropriate time, and if the igniter would light the spill on fire.

Table 7. IGNITION TESTS

Test	*Description*	*Fuel Type/ Quantity*	*Gel Agent/ Concentration*	*Crude Oil/ Quantity*	*Herder/ Quantity*
6	Igniter test in containment ring	n/a	n/a	n/a	n/a
6b	Manual flare firing	n/a	n/a	n/a	n/a
7	Igniter test in containment ring	n/a	n/a	n/a	n/a
8	Igniter test in containment ring	Shell Premium gas (201g)	Surefire (0.13g/10mL)	North Star fresh (400mL)	OP40 (100µL)
9	Igniter test in containment ring	AVGAS 100LL (210g)	Surefire (0.15g/10mL)	Kuparuk fresh (400 mL)	Thickslick 6535 (100µL)
10	Igniter test in containment ring	AVGAS 100LL (247g)	Surefire (0.11g/10mL)	Kuparuk weath. (400 mL)	Thickslick 6535 (100µL)
11	Igniter test in containment ring	AVGAS 100LL (207g)	Surefire (0.06g/10mL)	Kuparuk fresh (400 mL)	Thickslick 6535 (100µL)
12	Igniter test in containment ring	Jet A1 (240g)	Surefire (0.07g/10mL)	Endicott weath. 1.35% (400 mL)	OP40 (100µL)
13	Igniter test in containment ring	Shell Premium gas (209g)	Surefire (0.07g/10mL)	Endicott weath. 6.17% (400 mL)	OP40 (100µL)

5.3 Results and Observations

5.3.1 *Test #1*

This simple drop test was performed using the surrogate igniter which entered the water surface slightly offset from vertical. Splashing was localized and directed in an upwards pattern as opposed to out and away from the source of impact. Given the relatively low weight and high buoyancy of the igniter, it resurfaced immediately (see photo cluster in Figure 56).

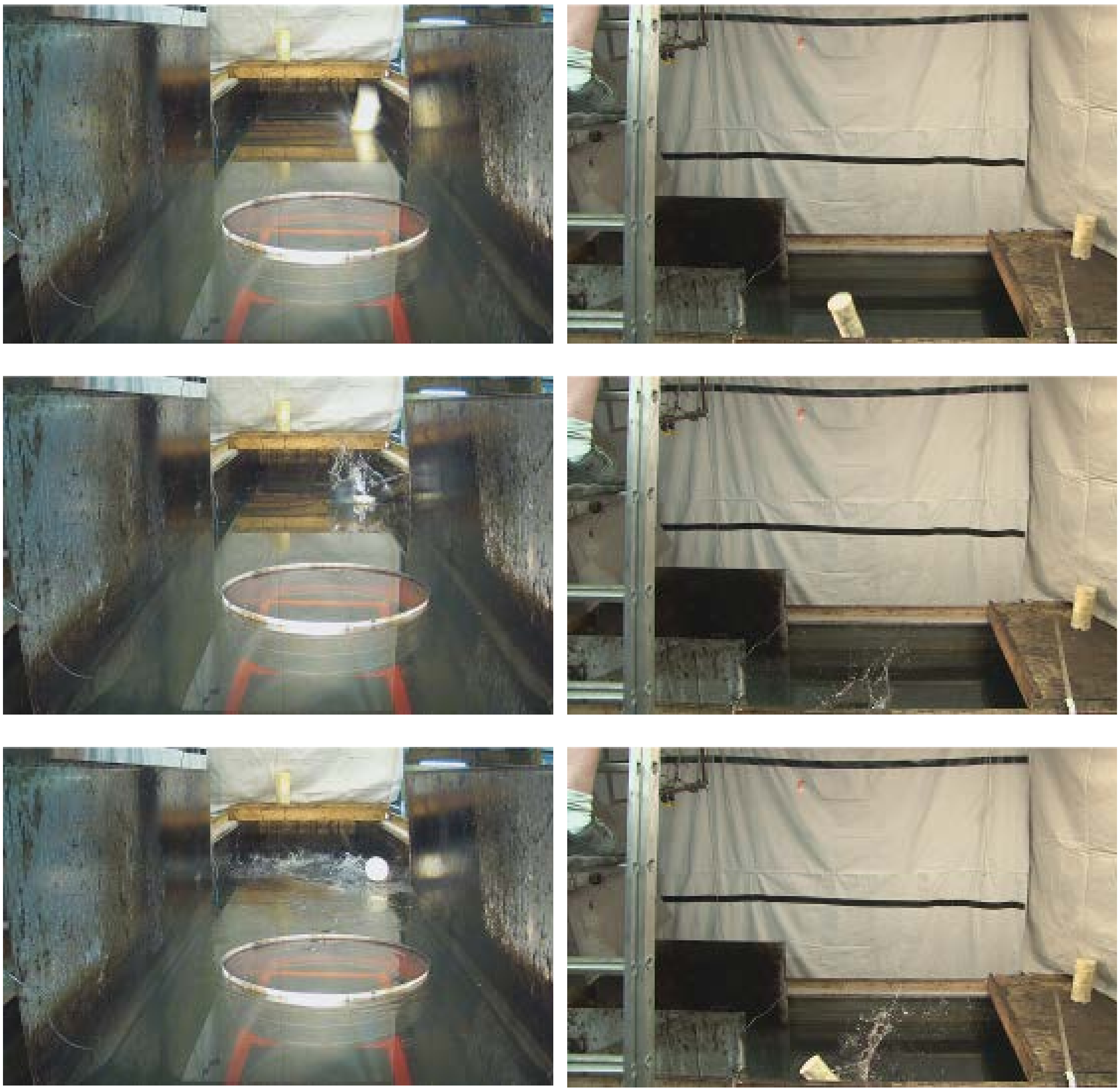


Figure 56. Test #1 Igniter drop (horizontal)

5.3.2 Test #2

The second drop test (Figure 57) was a release from a platform mechanism, and resulted in a slightly offset horizontal orientation of the surrogate igniter at the point of impact on the water surface. This resulted in a fan-like spray pattern out and away from the igniter, resulting in a larger area of disruption.

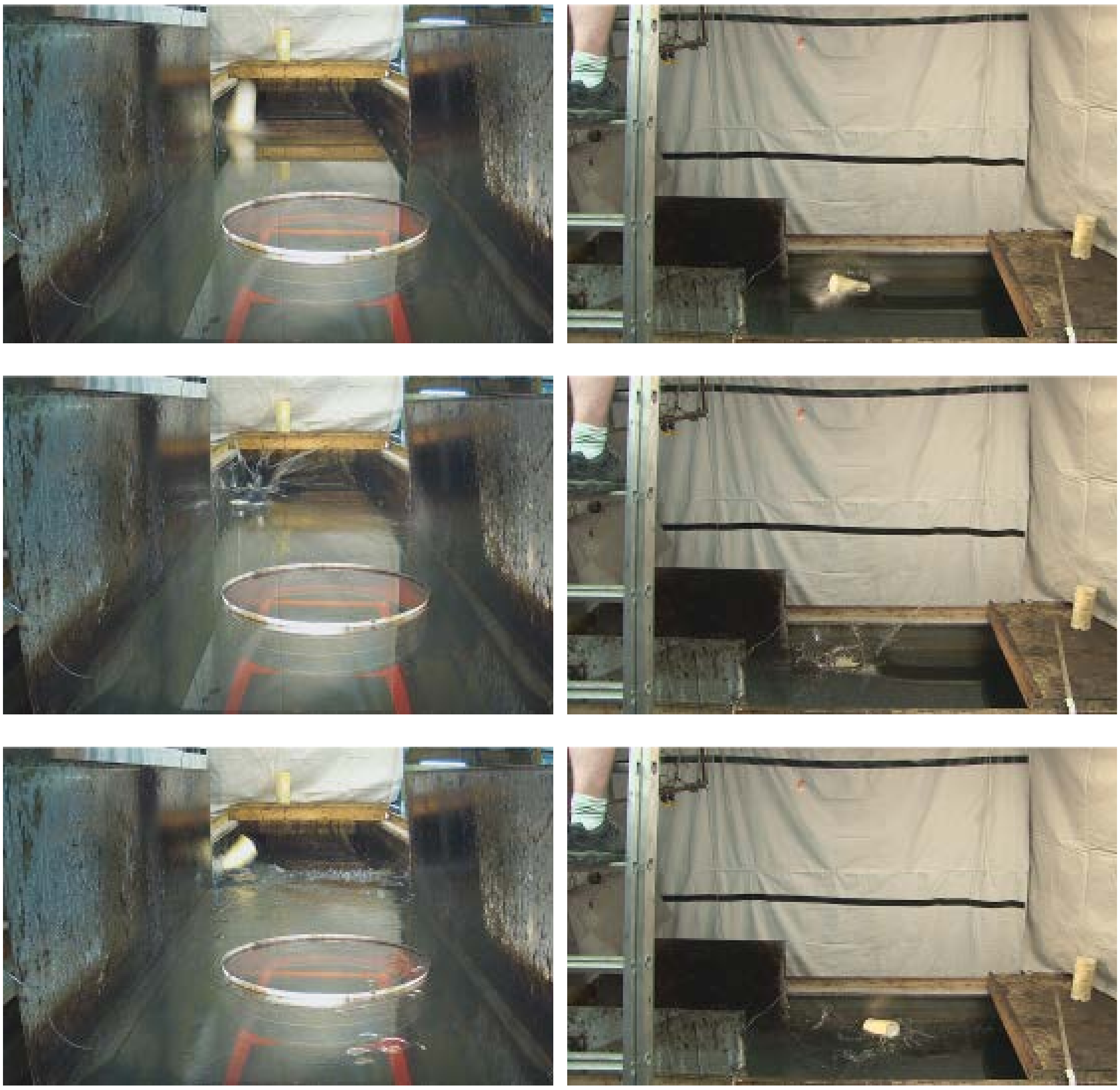


Figure 57. Test #2 Platform release

5.3.3 Test #3

The third test resulted in a horizontal impact on the water surface and a wide spray of water away from the impact area. As shown in the photo cluster below (see Figure 58), this resulted in a large area of disruption on the water surface.

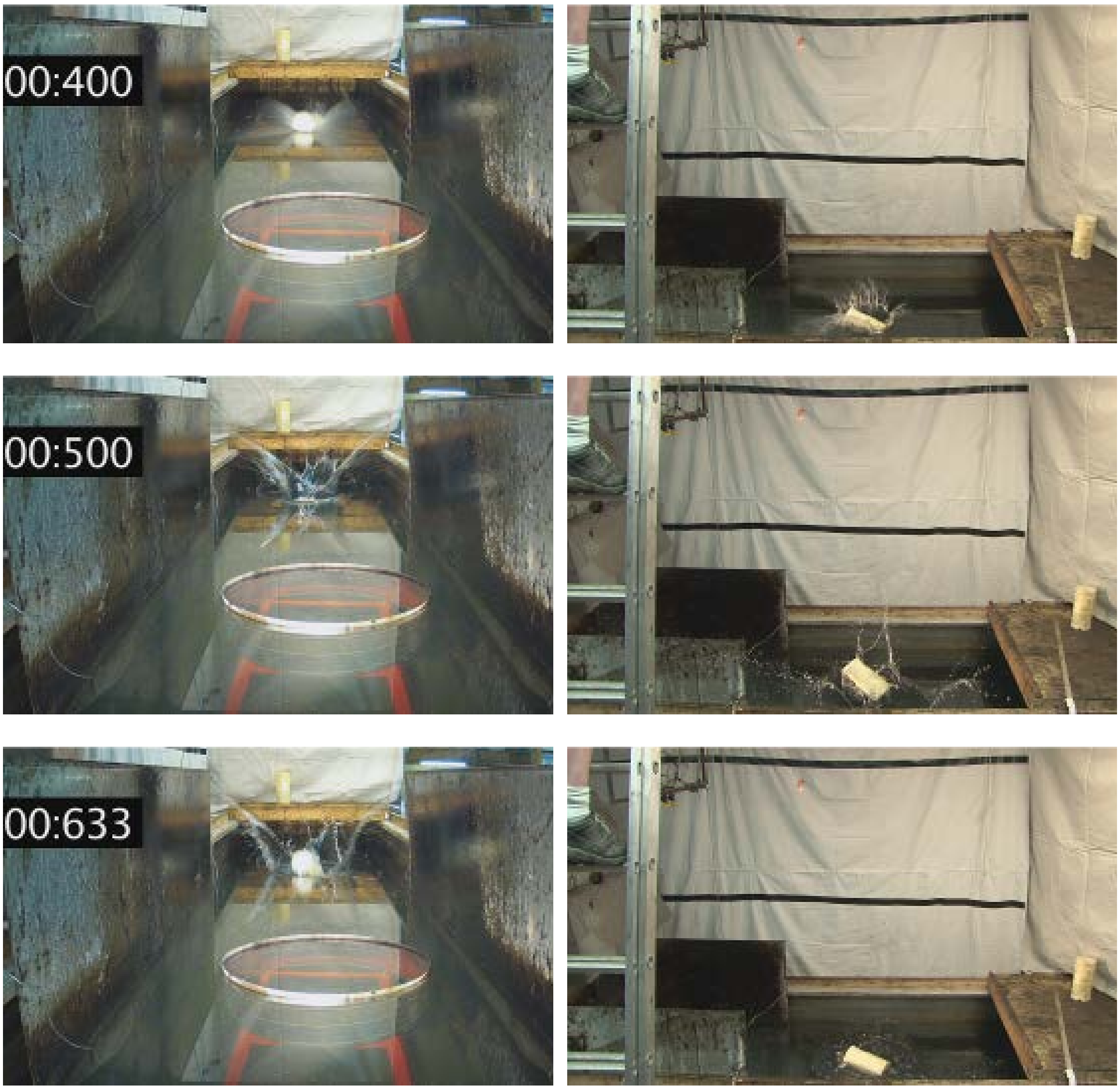


Figure 58. Test #3 Modified platform release (horizontal)

5.3.4 Test #4

The fourth drop test resulted in the simulated igniter hitting the water surface at an angle of approximately 45° from horizontal (Figure 59). As the igniter hit the surface, it continued to rotate towards a horizontal orientation. This resulted in a splash that combined aspects of both the results of the vertical entry (Test #1), and horizontal entry (Test #2 and Test #3).

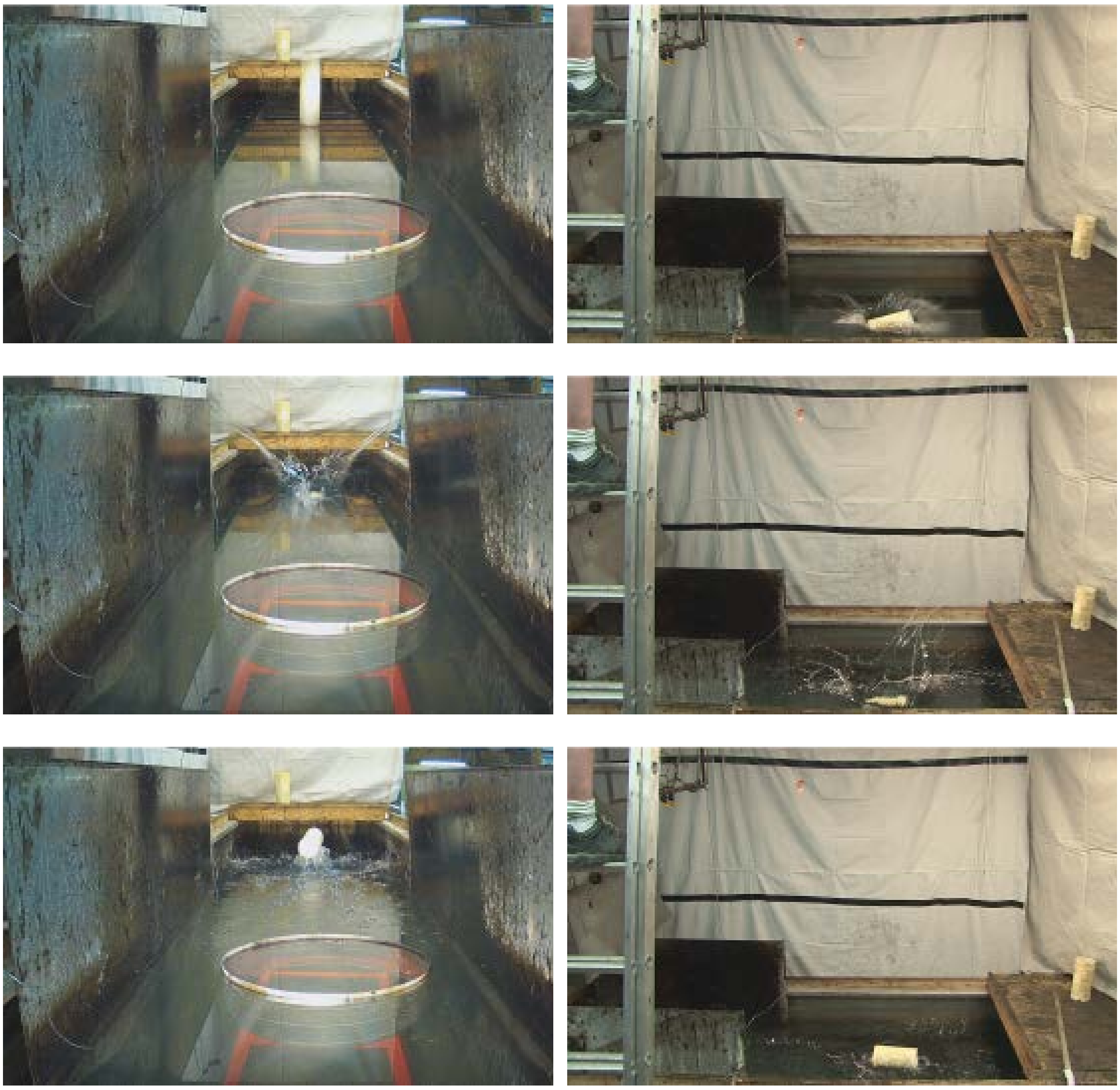


Figure 59. Test #4 Modified platform release (angled)

5.3.5 Test #5

The fifth drop test also resulted in the surrogate igniter hitting the water surface at an angle of approximately 45° from horizontal. The splash pattern (Figure 60) was similar to Test #4 in that the splash effects seemed to split the difference between a preferred vertical entry (resulting in a splash that directs upwards as opposed to outwards) and a horizontal entry.

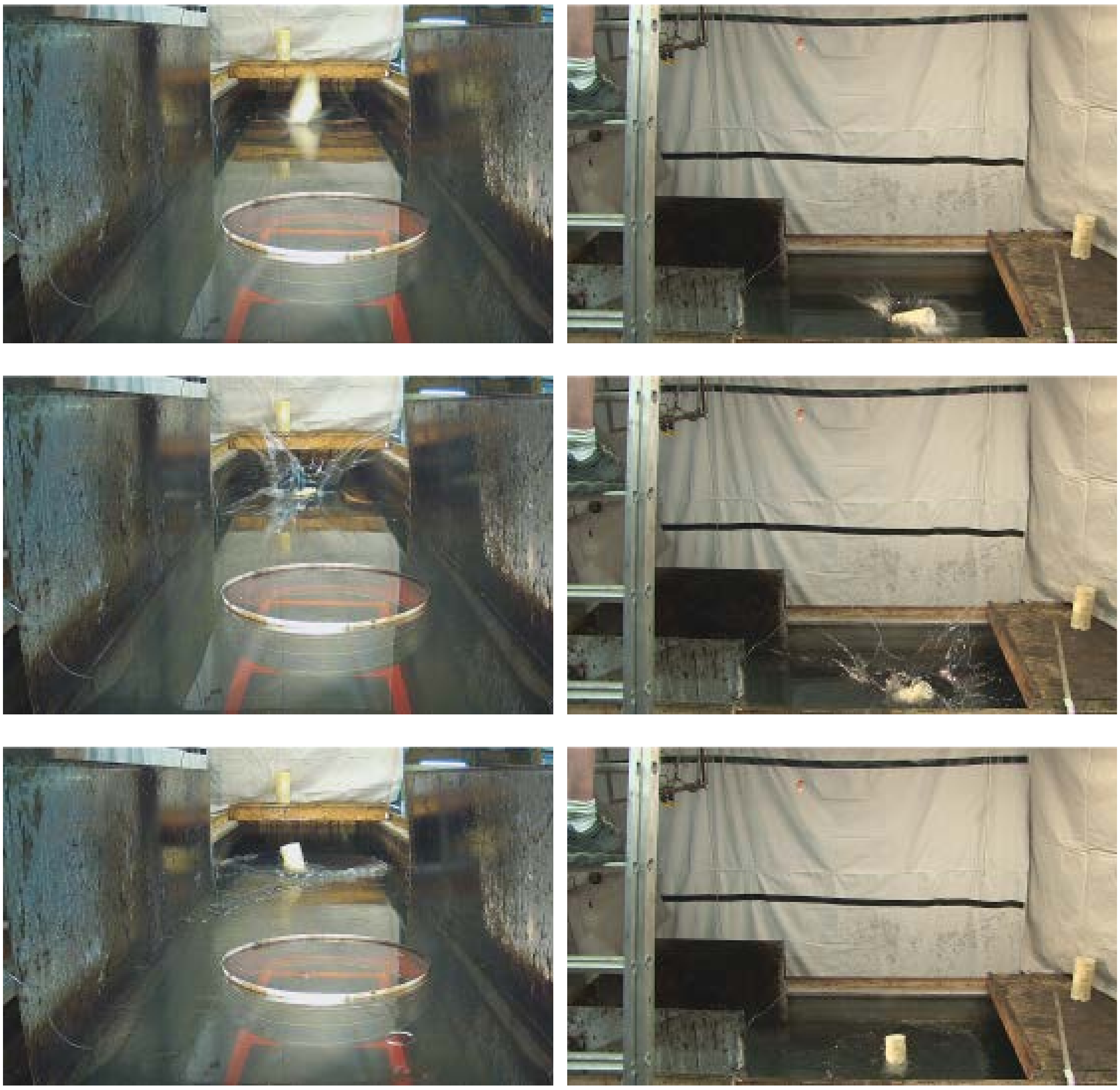


Figure 60. Test #5 Modified platform release (angled)

5.3.6 Test #6

There was no apparent ignition at the 2 minute mark of the test. The igniter was left in the testing area for an additional 5 minutes (see Figure 61). The test was halted and the igniter was disassembled to determine why it failed to fire. It was quickly discovered that the squib had gone off, but the flare never ignited. Review of the video shows a slight puff of smoke emanating from the control end of the igniter just after the 2 minute mark, and a slight movement of the water. It was discovered that the flare had not been seated properly on the squib, as it was a tight fit. Procedures were modified to ensure this problem did not repeat for the rest of the tests.

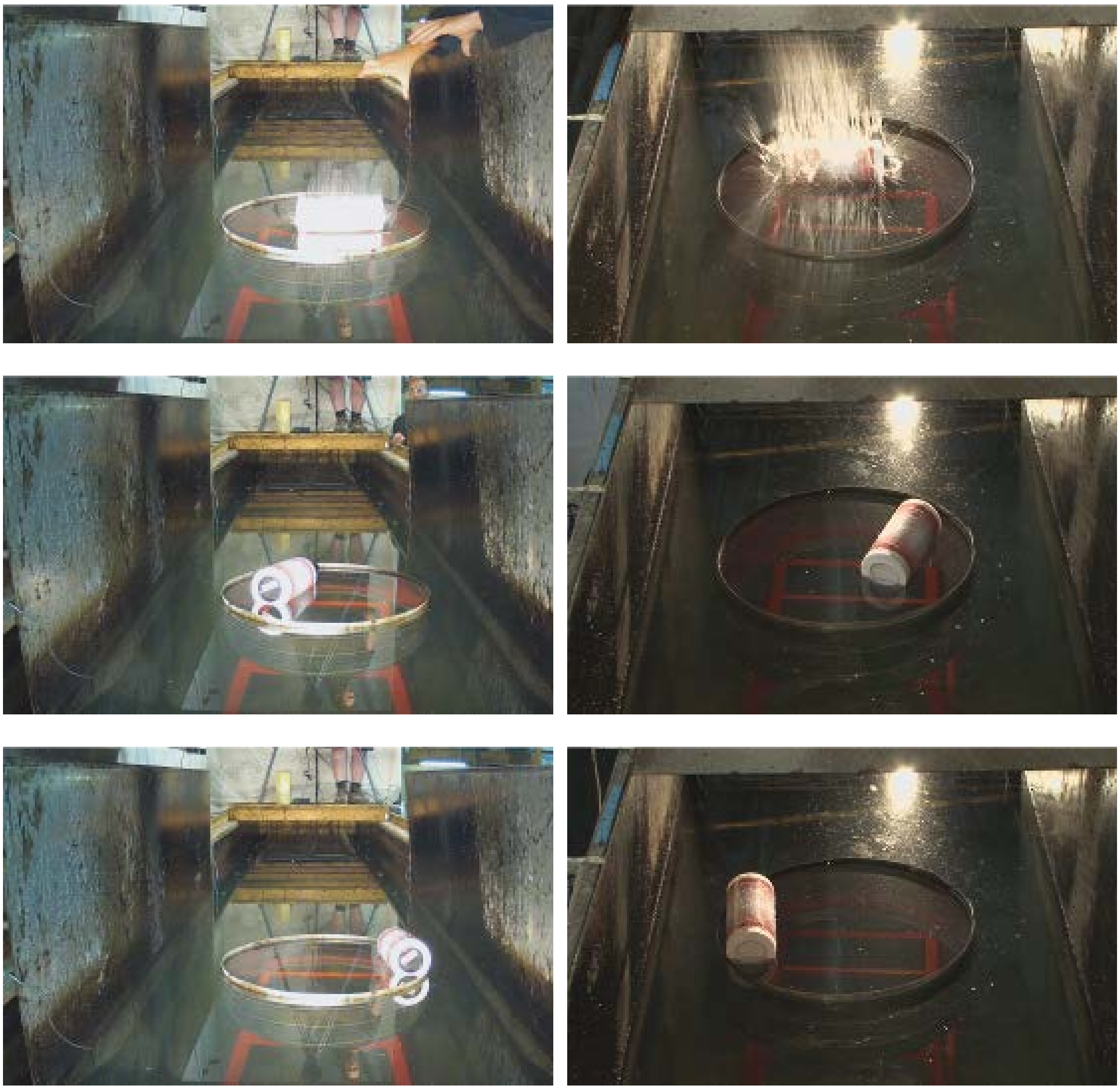


Figure 61. Test #6 igniter test in containment ring

5.3.7 Test #6b

The flare from Test #6 was manually ignited to confirm that the flare was in good working condition and provide some visual representation of the burning characteristics of the flare (see Figure 62).

Figure 62. Test #6b Flare test in pan

5.3.8 Test #7

This simple igniter test was a repeat of the previous test – no gelled fuel or oil was provided for combustion. The igniter was triggered to ensure that the timing mechanism was working, and that the integrated flare would ignite. Frame grabs from the two cameras at three points are shown below in Figure 63. The first pair shows the initial presence of smoke indicating the triggering mechanism has successfully deployed. The second pair shows the first flame outside the igniter body. The third pair shows the burning gelled fuel.

Figure 63. Test #7 Simple igniter test

5.3.9 Test #8

Test #8 included premium gasoline as the primary component of the gelled fuel, and fresh North Star crude oil comprised the slick. Smoke was detected shortly after the 2 minute mark, and the white end cap blew off approximately 12 seconds later. The bag of gelled gasoline remained confined to the interior of the igniter as the flare continued to burn. It was approximately 40 seconds from the initial detection of smoke from the control cap of the igniter that the crude oil finally ignited and began to burn (see Figure 64).

Figure 64. Test #8 Successful burn with premium gasoline

5.3.10 Test #9

Test #9 included AVGAS (100LL) as the primary component of the gelled fuel, and fresh Kuparuk crude oil as the slick. Smoke was detected shortly after the 2 minute mark, exiting primarily from the blue control plug (with the on/off switch and starting pin). The igniter smoked, but the white end cap did not blow off. After approximately 50 seconds a hole burned through the end cap and smoke began emanating from both ends of the igniter, but no flames were detected outside the igniter. Ultimately the flare burned out and the crude oil did not ignite (Figure 65).

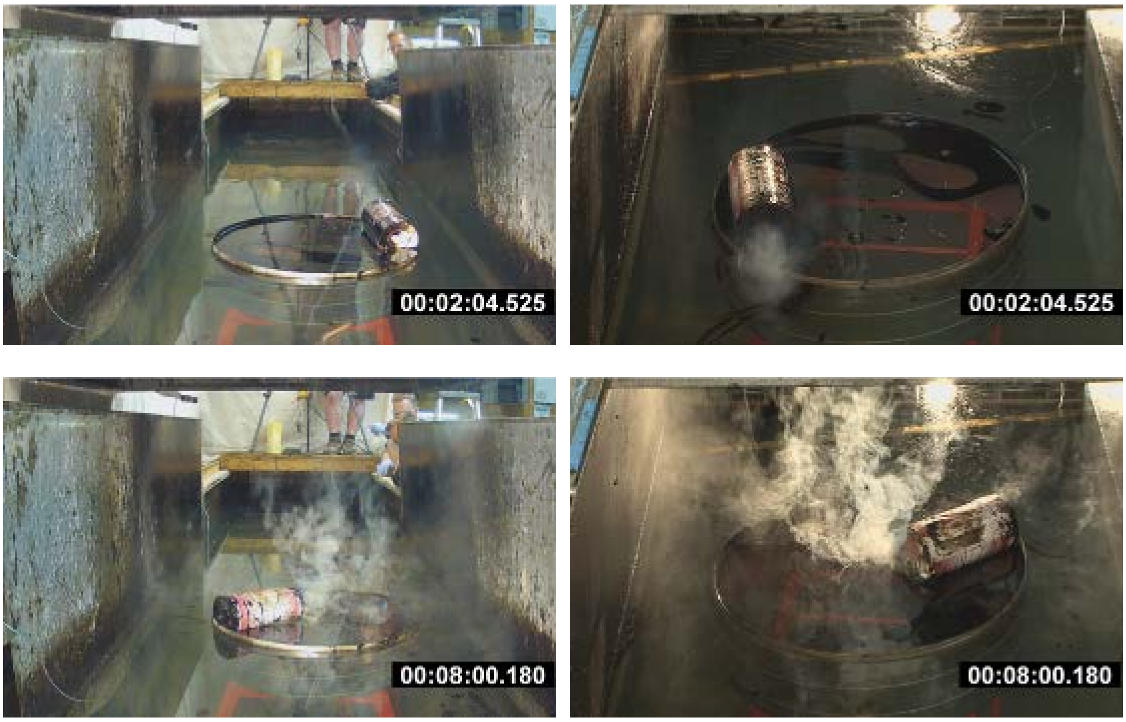


Figure 65. Test #9 Unsuccessful burn with AVGAS

5.3.11 Test #10

Test #10 included AVGAS (100LL) as the primary component of the gelled fuel, and weathered Kuparuk crude oil as the slick. Smoke was detected shortly after the 2 minute mark, exiting primarily from the blue control plug (with the on/off switch and starting pin). The igniter smoked, but the end cap did not blow off until approximately 35 seconds after firing. Intense red glow from the flare was seen through the end, and the bag of gelled gasoline was just in front of the flare but the gelled fuel did not catch fire: neither did the crude oil. By the 5 minute mark the interior of the igniter was glowing red/white, yet no flames were seen to be exiting the body of the igniter. At approximately 8 minutes and 25 seconds the ignition was deemed a failure, and the oil was ignited by a hand-held propane torch (Figure 66).

Figure 66. Test #10 Unsuccessful igniter test: crude lit with propane torch

5.3.12 Test #11

Test #11 was a repeat of Test #9 (AVGAS as the main gelled fuel component), with two important modifications. The first was a change of the recipe used to create the gelled fuel to create a much runnier product that would flow out of the igniter more easily. The gelled fuel had both a runny component, mixed with more strongly gelled clumps. The second modification was a reorientation of the gelled fuel bag within the igniter. Tests #8 through Test #10 had the bag essentially wrapped around the flare, while in this test the flare was pushed deeper into the foam support near the blue control plug end. A gap was thus created at the white end cap, enabling the bag of gelled fuel to form a plug under the end cap, essentially at the firing end of the flare. Smoke was initially detected at 2:10 of the run. Within 2 seconds the end cap blew off and the gelled fuel bag was partially ejected out of the igniter. About 24 seconds later the flare ignited the gelled fuel which quickly spread to the crude oil (Figure 67).

Figure 67. Test #11 Successful test with AVGAS

5.3.13 Test #12

Test #12 (Figure 68) used Jet A1 as the main component of the gelled fuel, using the recipe from Test #11 to create a semi-gelled liquid. The oil slick was weathered Endicott crude (1.35%). Modified gel placement was used (gel bag all at one end, with the flare embedded at opposite end of the igniter). Smoke was detected immediately following the end cap blowing off at 2:10. It took approximately 18 seconds before the heat from the flare melted the partially ejected bag of gelled fuel which then burst into flames. Burning gelled fuel spread over the water within the containment cell, contacting the crude oil which then began to burn too.

Figure 68. Test #12 Successful burn with Jet A1

5.3.14 Test #13

The final test included premium gasoline as the loosely gelled fuel. Endicott weathered 6.17% was used as the crude oil. Smoke was detected at the 2:02 mark of the test, and began coming out of the blue control end of the igniter. It was not until 2:35 that the white end cap popped open slightly, allowing smoke to come out the end of the igniter. Over the next 10 seconds the igniter developed a bit of a list, possibly due to the more liquid component of the gelled fuel running back to the blue control end of the igniter. Ultimately the igniter settled into a position angling the white end cap slightly in the air. By 3:07 the end cap finally ejected and the edge of the gelled fuel bag can be seen approximately 2cm outside the opening. Within the igniter, the flare can be seen intensifying and in 11 seconds the gelled fuel ignites. Flames quickly spread to engulf both ends of the igniter. The igniter slowly rotates in the contained area, and it is not until 3:46 that flames from the igniter begin to impinge on the slick. By 4:20 a corner of the slick appears to catch fire. By 4:45 approximately half of the oil slick is on fire, and by 6:04 most of the area is burning intensely (see Figure 69).

Figure 69. Test #13 Successful burn with premium gas

5.4 Discussion and Conclusions

The first five tests show different orientations of the igniter will affect the direction of resultant impact spray. The preferred entry orientation is vertical, like a competition diver attempting to minimize splash. Given the relatively light weight of the device and high buoyancy, the igniter assembly should quickly resurface irrespective of the orientation of impact. The time delay of 2 minutes should be ample to allow any oil that has been splashed away during water entry of the igniter to recover and re-establish the slick right up the igniter.

The problem with the squib not igniting the flare was successfully addressed by a change in procedure. Some modifications (slight enlargement or smoothing) to the squib end holding the flare may also help minimize this issue from re-occurring.

Problems also occurred with the igniter failing to ignite the oil on two occasions, Test #9 and Test #10. Both of these used AVGAS (100LL) gelled using the recipe concentration that appeared to work well during the lab scale gelling experiments performed earlier (specifically 0.15 g/10 mL fuel). These experiments showed that the gelling agent was particularly effective on AVGAS; compared with some other fuels tested, and was producing a highly gelled product that did not flow easily. The solution employed to solve this was to reduce the gelling concentration by approximately half and intentionally achieve a loosely gelled fuel. Additionally, the internal configuration of the igniter was modified to have the bag of gelled gas right at the end of the flare, as opposed to being wrapped around it. Care was also used not to overfill the gelled fuel bags, avoiding compacting the bag too severely when the white end cap is installed. If too full, the plastic bag can be damaged when pushing it into the cartridge.

It was noted that a type of road flare was used in this iteration of the prototype igniter design. It is strongly suggested that they be replaced with a type of marine flare, which have much better resistance to water contact and humidity. Samples of marine flares available at Ottawa retailers had too large a diameter to allow installation of the squib cap. The length of the marine flare in stock can easily be modified to fit inside the prototype igniter as the lower half of the marine flare is hollow and could be cut. Different marine flares are readily available at marine equipment suppliers that can meet these needs.

5.5 Recommendations

A number of recommendations were made based upon the results of this series of tests:

- Modify the design of the squib cap to ensure good contact with the flare ignition material (and also to fit a waterproof flare).
- Either use a lower than recommended concentration of gelling agent for the three fuels identified (premium gasoline without ethanol, AVGAS 100LL, or Jet A1), or use the recommended concentration of gelling agent with regular unleaded gasoline (with ethanol) or regular unleaded gasoline (with ethanol) / diesel blends. This should result in loosely gelled fuel - which was ultimately successful in these tests, while the igniter carrying the strongly gelled AVGAS failed to ignite properly on two occasions.
- Change the type of flare to a marine flare to minimize any problems with water.

6. MESO-SCALE OUTDOOR TESTS AT CRREL

The purpose of the outdoor tests at CRREL was to test and verify that the proposed igniters can be dropped and fired successfully in cold conditions and ignite a herded oil slick.

6.1 Equipment and Apparatus

The tests were conducted in the Geophysical Research Facility (GRF) outdoor basin at CRREL (Figure 70). At the time of the testing, a cover of ice had been excavated from the surface of the basin and all but the edges of the tank were open water. The basin water was 20‰ brackish water.

Figure 70 Geophysical Research Facility Outdoor Basin with Ice Removed

The equipment for the tests included:

- The prototype Integrated Igniter/Herder Application System (IIHAS), 14 igniters, gelling agent, fuel, controls and 24 V power supply (Figures 71, 72 and 73)
- ThickSlick 6535 and Siltech OP 40
- DuNuoy Ring Tensiometer, digital weighing scales, digital cameras, digital video cameras, and disposable 10 mL syringes,
- Sorbents (pads), buckets, garbage bags,
- Fresh ANS crude oil (from IOGP-provided drums)
- A person-lift telescoping crane to raise the Prototype Integrated Igniter/Herder Application system and operate it from a 5 and 10-m (15 and 30-foot) height above the outdoor basin (Figure 74)

- A hose and nozzle for post-test residue collection and daily herder film dispersal
- Daily safety checks and fire department notifications.

Figure 71 Integrated Igniter/Herder Application System with cover on

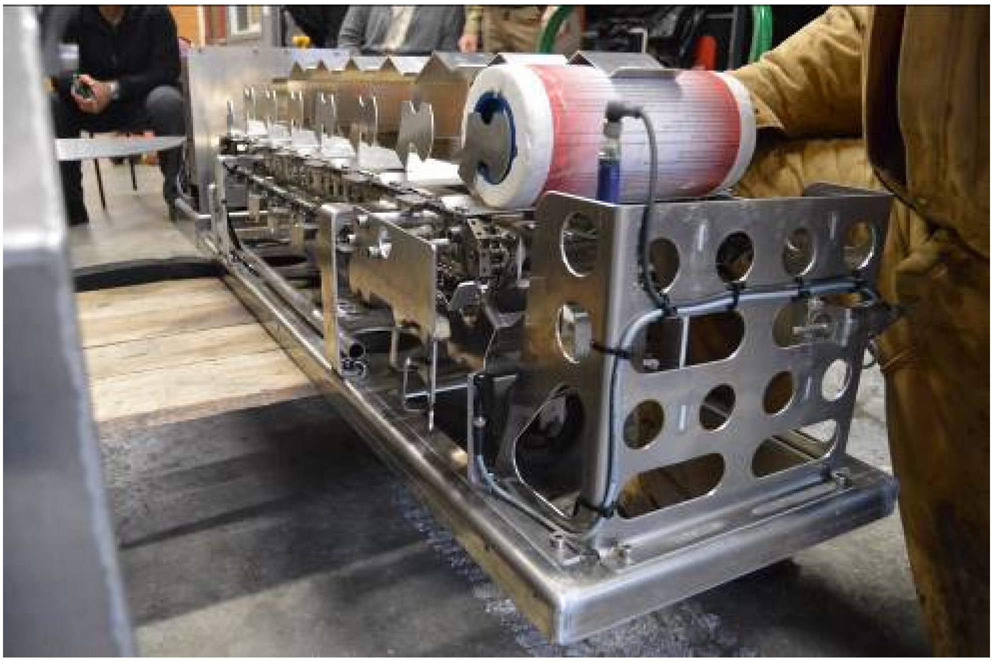


Figure 72 Integrated Igniter/Herder Application System with cover off

Figure 73 Control Pad

Figure 74 Person Lift Telescoping Crane used to Raise Unit Over GRF Basin

6.2 Test Set-up, Instrumentation and Procedures

The tests were guided by a written Test Plan and a site-specific Health Safety and Environment (HSE) plan drawn from the overarching CRREL HSE plan.

The first step in each test was to ensure that the IIHAS was securely strapped to the safety rails of the person-lift basket, had been powered up, and had been loaded with one or more activated igniters (Figure 75).

Figure 75 IIHAS strapped to person-lift basket and loaded with activated igniters

Each test spill involved either 10L (2.5 gallons) or 20 L (5 gallons) of pre-weighed fresh ANS crude poured onto the water surface that has already been pretreated with a 150 μm thick film of herder (about 10 grams or 10 mL was applied). A spill plate was used to eliminate penetration of the oil under the water surface during pouring (Figure 76).

In order to minimize drift of the test slick due to winds, the oil was released from the upwind side of the basin once the IIHAS was loaded and ready to function. Once the slick was poured, the person-lift was raised to the specified test height (5 or 10 m – 15 or 30 feet, as measured by a weighted string attached to the basket) and the IIHAS positioned over the herder slick (Figure 77). Next, the IIHAS was activated and an igniter released to fall into the slick, the slick allowed to re-herd and the igniter activated (Figure 78).

Figure 76 Spill plate to pour oil onto water surface

Figure 77 Positioning IIHAS on person-lift over herded slick

Figure 78. Igniter landing on slick

Two fixed video cameras were positioned at 90° to each other on adjacent sides of the basin to record each test (Figure 79). Just before the oil was released to spread, the digital video cameras were started. Several people with handheld digital cameras took still photographs and video clips from a variety of positions around the basin throughout each test. Time- and date-stamped digital videos (encompassing the basin) were recorded continuously. Hand-held video and stills focussed on the interaction of the slick and igniter and the ignition and burning of the slick. Video cameras and one digital still camera were time synchronized every day.

The air and water temperatures and wind speed (at a height of 2 m, were monitored and recorded. The general weather was also noted.

At the end of each experiment, the crude oil and residue was sorbed off the water surface using pre-weighed sorbent and placed in large, contractor garbage bags. The water allowed to drain from the garbage bag and the recovered oil and sorbent were weighed to estimate oil removal efficiency by burning.

At the end of each test day, the water surface was vigorously agitated with Ice Eater propellers suspended from the movable bridge to disperse any residual herder films. These also ensured that the basin did not freeze over during the night.

Figure 79 Position of fixed video cameras around basin

The sequence of events for a typical test was:

- Load one or more igniters into the IIHAS, power it up and advance an igniter to the ready position.
- For the first test of the day, turn off and remove Ice Eater propellers.
- Also for the first test of the day, take a sample of the water from the surface using a Petri dish and measure the water-air interfacial tension (IFT) using the DuNuoy Ring Tensiometer. If the IFT reading is less than 60, re-clean the test area.
- Record weather and temperatures.
- Maneuver the moveable bridge to the upwind end of the basin and position the scaffold platform beside it.
- A volume of 10 L or 20Lof fresh ANS crude oil is measured into a tared plastic bucket and weighed.
- Start video cameras.
- Add 10 mL of herder (TS 6535 or OP-40, depending on the test) of herder on to the water surface using a disposable syringe, from the scaffold platform, and allow the herder to spread out over the water surface.
- Carefully pour the ANS crude oil from the bucket down an angled board onto the surface of the tank and into the herder monolayer from the portable platform. The momentum of the oil is to be directed downwind from the platform.
- Remove the scaffold platform and the moveable bridge.
- Raise the person-lift to the desired height (5 or 10 m) above the water and rotate it out over the basin so that the end that the igniter falls from is above the herded slick. Confirm the correct height with the weighted string.

- Activate the IIHAS and deploy one igniter onto the herded oil slick.
- Rotate the person-lift back to the side of the basin, lower it to the rest position and turn off the IIHAS.
- Note behaviour and firing of igniter, ignition of igniter and appearance of flames on gelled fuel.
- Note Ignition and spreading of flame over oil slick.
- After extinction of the flame, pre-weighed pads of sorbent are used to recover the residue and unburned oil from the basin surface. After use, each pad is placed in a plastic garbage bag. At the end of the cleanup, the garbage bag is drained to remove as much free water as possible. Then the pads were reweighed to determine the mass of residue.
- At the end of the last test of each day redeploy the Ice Eater propellers and turn them on overnight to agitate water surface and prevent freezing.

Tests will be repeated until three successful consecutive ignitions are achieved from each release height. A successful ignition is defined as:

- The igniter being released from the Integrated Igniter/Herder Application System;
- The igniter landing in the slick;
- The igniter firing autonomously; and,
- Igniting at least 1 m^2 of herded crude oil slick.

The test matrix variables were:

- One crude oil (fresh ANS)
- Two oil volumes (10 L and 20 L)
- Two herders (ThickSlick 6535 and OP 40) applied at 150 mg/m^2 or 10 mL/test)
- Two drop heights: 5 and 10 m (15 and 30 feet)

6.3 Results

Tables 8 and 9 present the results of the one pre-test, 11 scheduled tests, and one final drop test on ice carried out with the IIHAS. In the first scheduled test an igniter inexplicably fired inside the IIHAS resulting in a cancelled test. In the 10 subsequent scheduled tests four igniter failures occurred. Three consecutive successful ignitions were achieved from a release height of 10 m (30 feet). Each test is briefly discussed below and a short video clip of the key events is presented as a hyperlink.

Table 8. CRREL TEST RESULTS SUMMARY

TEST	Test date	Test time (approximate)	Height	Herder	Oil	Comment	Cap	Description
pretest	12-Dec-16	4:00pm	3m/10'	none	none	Success		Igniter successfully deployed from launcher assembly
TEST 1	13-Dec-16	1:00pm	5m/15'	10 mL OP 40	10L ANS	Igniter Fail		Igniter self-triggered inside launcher assembly. 1 igniter destroyed, 2 damaged but repairable.
TEST 1R	13-Dec-16	1:48pm	5m/15'	10 mL OP 40	10L ANS	Success	Cap fell off	Cap fell off igniter on impact. Flames manifest approximately 5 minutes after igniter impacts water surface.
TEST 2	13-Dec-16	2:56pm	5m/15'	10 mL OP 40	10L ANS	Success	Cap fell off	Cap fell off igniter on impact. Flames manifest approximately 4 minutes after igniter impacts water surface.
TEST 3	13-Dec-16	3:53pm	5m/15'	10 mL OP 40	10L ANS	Igniter Fail	Cap fell off	Cap fell off igniter on impact. Red light flashing - but no igniter smoke after 4 minutes... fail. Manual ignition
TEST 4	14-Dec-16	10:05am	10m/30'	10 mL OP 40	20L ANS	Two Igniters Fail	Cap fell off	First igniter had faulty on switch and was replaced before loading. Cap fell off second igniter on impact. Red light flashing - but no igniter smoke after 3 minutes... fail. Left oil for 4R test (continuation)
TEST 4R	14-Dec-16	10:37am	10m/30'	10 mL OP 40	20L ANS	Success	Cap fell off	Cap fell off igniter on impact. Flames manifest approximately 2.5 minutes after igniter impacts water surface.
TEST 5	14-Dec-16	11:45am	10m/30'	10 mL OP 40	20L ANS	Success	Cap fell off	Cap fell off igniter on impact. Flames manifest approximately 3.5 minutes after igniter impacts water surface.
TEST 6	14-Dec-16	1:36pm	10m/30'	10 mL OP 40	20L ANS	Igniter Fail	Cap fell off	Cap fell off igniter on impact. Red light flashing. Confirmed from video no gaff impact on switch during movement. Manually turned switch back on and igniter smoked, then triggered fire.
TEST 7	14-Dec-16	2:40pm	10m/30'	10 mL ThickSlick 6535	20L ANS	Success	Cap retained	Cap stayed on. Flames manifest approximately 4.25 minutes after igniter impacts water. Flames burn through cap.
TEST 8	14-Dec-16	3:35pm	10m/30'	10 mL ThickSlick 6535	20L ANS	Success	Cap fell off	Cap fell off igniter on impact. Flames manifest approximately 3 minutes after igniter impacts water surface.
TEST 9	15-Dec-16	9:45am	10m/30'	10 mL ThickSlick 6535	20L ANS	Success	Cap fell off	Cap fell off igniter on impact. Flames manifest just over 2 minutes after igniter impacts water surface.
DROP TEST	15-Dec-16	10:15am	12m/40'	none	none	Igniter Fail	Cap fell off	Igniter bounced off ice, ejected cap and gelled Avgas bag. Mechanical failure to retain fuel to support combustion, switch went to "off" on impact

Table 9. CRREL TEST DATA SUMMARY

Test	Date	Time (EST)	Herder	Air T (°C)	Water (T°C)	Wind Speed (m/s at 2 m)	Weather Conditions	IFT Reading	Igniter Drop Height (feet)	ANS Nominal Volume (L)
Test 1	13/12/2016	11:00	OP-40	4.5	0	0.8-1	Sunny	71.9, 72, 71.5 Tank is 20 ppt salt	15	10
Test 1R	13/12/2016	13:45	OP-40	6	0	0.5 - 0.9	Sunny	see above	15	10
Test 2	13/12/2016	15:15	OP-40	6	0	0.5 - 0.9	Sunny	see above	15	10
Test 3	13/12/2016	16:00	OP-40	3.5	0	0	Cloudy	see above	15	10
Test 4	14/12/2016	10:00	OP-40	2	0	1.5 - 2.5	sunny	62.9, 63.7, 62.2, 66.6	30	20
Test 5	14/12/2016	11:30	OP-40	1.3	0	1.5 - 2	sunny	see above	30	20
Test 6	14/12/2016	13:30	OP-40	3	0	1	sunny	see above	30	20
Test 7	14/12/2016	14:30	TS6535	3.4	0	0.5 - 0.7	NR	see above	30	20
Test 8	14/12/2016	16:00	TS6535	0.6	0	0 - 1.5	cloudy	see above	30	20
Test 9	15/12/2016	10:00	TS6535	-6	0	0.5 - 1	sunny	75.8, 72.2, 71.9	30	20

Test		Fresh ANS Bucket Weights (kg) #1	Fresh ANS Bucket Weights (kg) #2	Totals Weight (kg)	Totals Volume (L)		Herder Weights (g) 30 mL Syringe	Total		Residue Recovered (kg) Bag #1	Bag #2	Total	% Removed Est.
Test 1	Gross	8.985				Gross	23		Gross				
	Tare	0.058				Tare	13		Tare				
	Net	8.927		8.93	10.04	Net	10	10	Net				
Test 1R	Gross	9.255				Gross	24		Gross	7.27			
	Tare	0.03				Tare	13		Tare	1.46			
	Net	9.225		9.23	10.38	Net	11	11	Net	5.81		5.81	37%
Test 2	Gross	9.635				Gross	24		Gross	6.083		6.083	
	Tare	0.041				Tare	14		Tare	1.257		1.257	
	Net	9.594		9.59	10.79	Net	10	10	Net	4.826		4.83	50%
Test 3	Gross	9.638				Gross	24		Gross	6.08		6.08	
	Tare	0.877				Tare	13		Tare	1.134		1.134	
	Net	8.761		8.76	9.85	Net	11	11	Net	4.946		4.95	44%
Test 4	Gross	8.955	8.787			Gross	24		Gross	15.42	4.375	19.795	
	Tare	0.065	0.075			Tare	11		Tare	3.948		3.948	
	Net	8.89	8.712	17.60	19.80	Net	13	13	Net	11.472	4.375	15.85	10%
Test 5	Gross	8.89	8.603			Gross	24		Gross	10.28		10.28	
	Tare	0.0975	0.0806			Tare	14		Tare	1.528		1.528	
	Net	8.7925	8.5224	17.31	19.48	Net	10	10	Net	8.752		8.75	49%
Test 6	Gross	8.968	8.775			Gross	25		Gross	12.143		12.143	
	Tare	0.0962	0.0959			Tare	15		Tare	2.122		2.122	
	Net	8.8718	8.6791	17.55	19.74	Net	10	10	Net	10.021		10.02	43%
Test 7	Gross	9.081	9.065			Gross	23		Gross	10.375		10.375	
	Tare	0.0975	0.095			Tare	14		Tare	1.879		1.879	
	Net	8.9835	8.97	17.95	20.20	Net	9	9	Net	8.496		8.50	53%
Test 8	Gross	8.885	8.854			Gross	24		Gross	9.324		9.324	
	Tare	0.0115	0.116			Tare	14		Tare	1.935		1.935	
	Net	8.8735	8.738	17.61	19.81	Net	10	10	Net	7.389		7.39	58%
Test 9	Gross	8.37	8.57			Gross	24		Gross	10.58		10.58	
	Tare	0.158	0.14			Tare	14		Tare	1.552		1.552	
	Net	8.212	8.43	16.64	18.72	Net	10	10	Net	9.028		9.03	46%

Test	Comments
Test 1	Igniter fired inside dispenser - test cancelled Oil burned oof using manually applied gelled gas igniters lit with propane soldering torch Residue collected, but not weighed.
Test 1R	Repeat of Test 1
Test 2	Igniter fired, successful ignition
Test 3	Igniter failed, manual ignition to remove oil
Test 4	On switch failed on first igniter: replaced with second in dispenser. Second igniter failed after release and replaced with third. Third igniter successful.
Test 5	Succesful ignition by igniter from 30 feet
Test 6	After several minutes switch on igniter failed. Confirmed from video switch not touched by gaff during maneuvring. Switch turned back on manually - instant ignition and thrown back into slick . Successful burn.
Test 7	New drum of crude opened. Successful ignition from 30 feet.
Test 8	Succesful ignition by igniter from 30 feet
Test 9	Succesful ignition by igniter from 30 feet

6.3.1 Pretest

After the field modifications to the IIHAS to allow access for igniter loading and positioning (Figure 80) the system was strapped onto the basket of the person lift to test its operation. One igniter had the original firing ring replaced with the new steel firing pin, was loaded into the IIHAS and activated. The IIHAS was then raised, swung out over the basin and activated to release the igniter. The action of the IIHAS successfully pulled the firing pin and the activated igniter fell onto the water (Figure 81). The igniter floated on the water with the warning light blinking for 1 minute 54 seconds, then the flare ignites and the white end cap pops off (Figure 82). After another 58 seconds, the gelled gasoline ignites Figure 83).

Figure 80 Loading IIHAS on to person lift for pre-test (note access port cut into side)

Figure 81 Activated igniter hitting water during pre-test

Figure 82 Flare fires after 1:54

Figure 83 Gelled gas ignites 58 seconds after flare fired (2 minutes 52 seconds since release)

6.3.2 Test 1

In the first test an igniter went off prematurely in the IIHAS resulting in a cancelled test. Water was sprayed inside the IIHAS to contain the fire to only one igniter. No injuries were recorded. Four igniters had been activated and loaded into the IIHAS in preparation for the test. The OP-40 herder had been applied to the basin water surface and the oil was being poured when one igniter fired unexpectedly while the IIHAS was still on the ground. A short video clip can be found here Summary CRREL Test1.mp4. Once the fire was extinguished and the cover removed from the IIHAS no explanation for the firing was immediately apparent: the steel firing pin was still in place and the activation switch was on. The igniter that fired was damaged beyond repair and the two adjacent were singed, and with some minor repair/modifications, reusable (Figure 84).

DESMI and CAD discussed at length what had been done to this igniter prior to placing it in the IIHAS. This was one of the igniters where it was necessary to change the original safety pin from the ring-topped ball lock pin to the straight steel pin fabricated by DESMI. During changing the pins at CRREL, a process was established whereby the timer assembly was removed from the igniter tube to make the pin change possible. During the development of this process, several different methods were attempted, the first of which was to simply remove the ball lock pin and push the straight pin back into the assembly. This was difficult and most likely resulted in damage to the safety switch which is held open by the inserted pin. In addition, the replacement straight pin, being slightly smaller diameter than the ball lock pin most likely did not keep the circuit open constantly. When the launcher was placed on the railing of the person lift, there was vibration of the pin within the timer assembly which would have caused the safety switch to open and close intermittently, causing the timer to run on and off until it reached the end of the 2 minute time delay. Once that point was reached, the ignition circuit would have closed and the ignition process began, even with the pin still in the safety switch.

The herded oil was lit manually with a hand-held propane soldering torch and burned off. The residue was collected, but not weighed.

For subsequent tests the cover of the IIHAS was removed and typically only one igniter was loaded at a time to prevent damage to nearby igniters if a pre-ignition occurred again.

Figure 84 Igniter damage after Test 1 misfire (second from left went off)

6.3.3 Test 1R

Test 1 was repeated after necessary repairs and adjustments were made to the IIHAS and its proper operation confirmed. Prior to the test 10 mL of OP-40 herder was applied to the water surface and allowed to spread, then 10 L of fresh ANS crude was released into the herder monolayer. The IIHAS was loaded with one activated igniter and readied for operation. It was then raised to a height of 5 m (15 ft.) and positioned over the basin to drop the igniter into the herded slick. A video of the test can be found here Summary CRRELTest1R.mp4. The video shows the firing pin falling from the IIHAS, followed by the igniter itself.

The igniter was successfully released and fell into the herded oil slick. The impact of the igniter created a considerable splash, throwing oil 2 to 3 m outwards from the point of impact, leaving the igniter surrounded by clear water. The impact knocked the white end cap out of the igniter. In approximately one minute the slick had reformed around the igniter. In the ensuing time the higher freeboard of the igniter allowed the gentle wind to move it away from the herded slick. One minute and 57 seconds after being released, the flare inside the igniter lit and the igniter began to produce whitish smoke or vapour. Three minutes later the gelled gasoline ignited. The igniter, which had drifted away from the herded slick in the meantime, was maneuvered back to the main body of the herded slick with a long metal pole and successfully ignited it. An estimated 37% of the original 10L of oil was burned off.

6.3.4 Test 2

Prior to this test 10 mL of OP-40 herder was applied to the water surface and allowed to spread, then 10 L of fresh ANS crude was released into the herder monolayer. For Test 2 the IIHAS was loaded with one activated igniter and readied for operation. It was then raised to a height of 5 m (15 ft.) and positioned over the basin to drop the igniter into the herded slick. A video of the test can be found here Summary CRRELTest2.mp4

The igniter successfully fell onto the edge of the herded oil slick. The impact of the igniter created a considerable splash, throwing oil and water 1 to 2 m outwards from the point of impact, leaving the igniter surrounded by clear water. The impact knocked the white end cap out of the igniter. In approximately one minute the slick had reformed around the igniter. One minute and 53 seconds after being released, the flare inside the igniter lit and the igniter began to produce whitish smoke or vapour. A jet effect was created by the flare which tended to move the igniter in a circular motion independent of any sail effect of the wind. Two minutes and 16 seconds later the gelled gasoline ignited. The igniter, which had drifted against an edge of the basin near a corner where the herded oil was contained, successfully ignited it. An estimated 50% of the original 10L of oil was burned off.

6.3.5 Test 3

Prior to the test 10 mL of OP-40 herder was applied to the water surface and allowed to spread, then 10 L of fresh ANS crude was released into the herder monolayer. For Test 3 the IIHAS was again loaded with one activated igniter and readied for operation. It was then raised to a height of 5 m (15 ft.) and positioned over the basin to drop the igniter into the herded slick. A video of the test can be found here Summary CRREL Test3.mp4. The video shows the firing pin falling from the IIHAS, followed by the igniter itself.

The igniter fell onto water beside the edge of the oil slick which was herded against an ice edge at one end of the basin. The impact of the igniter created a considerable splash, throwing water 2 to 3 m outwards from the point of impact. The impact knocked the white end cap out of the igniter. After approximately one minute the igniter was gently moved with the metal pole into a slick of herded oil in the corner of the basin. At no time during the ensuing 5 minutes did the flare give any indication that it fired, despite the red light on the igniter continuously blinking throughout the test. The igniter was recovered from the basin and the oil was ignited manually. An estimated 44% of the original 10L of oil was burned off.

6.3.6 Test 4

For this and all subsequent tests the oil volume was increased to 20 L to present a larger target. Prior to the test 10 mL of OP-40 herder was applied to the water surface and allowed to spread, then the 20 L of fresh ANS crude was released into the herder monolayer. The first igniter for Test 4 had a faulty on switch that failed to operate correctly. This was replaced with a second igniter that did turn on correctly. For Test 4 the IIHAS was loaded with the second activated igniter and readied for operation. It was then raised to a height of 10 m (30 ft.) and positioned over the basin to drop the igniter into the herded slick. A video of the test can be found here Summary CRREL Test4.mp4.

The igniter fell onto the edge of the herded oil slick. The impact of the igniter created a smaller splash than before as it entered the water end on, throwing oil and water up to 1 m outwards from the point of impact, and leaving the igniter surrounded by clear water. The impact knocked the white end cap out of the igniter. The slight breeze moved the igniter around in the basin. In approximately one minute the slick had reformed around the igniter. At no time during the ensuing 5 minutes did the flare give any indication that it fired, despite the red light on the igniter continuously blinking throughout the test. The igniter was recovered from the basin and the oil left for a repeat test with another igniter.

6.3.7 Test 4R

For Test 4R the IIHAS was reloaded with a third igniter and re-readied for operation. It was then raised to a height of 10 m (30 ft.) and positioned over the basin to drop the igniter into the herded slick. A video of the test can be found here Summary CRREL Test4R.mp4.

The igniter successfully fell onto the edge of the herded oil slick. The impact of the igniter created a considerable splash, throwing oil and water 2 to 3 m outwards from the point of impact, leaving the igniter surrounded by clear water. The impact knocked the white end cap out of the igniter. The firing pin fell from the IIHAS about 8 seconds after the igniter. In approximately 15 seconds the slick had reformed around the igniter. One minute and 50 seconds after being released, the flare inside the igniter lit and the igniter began to produce whitish smoke or vapour. Forty seven seconds later the gelled gasoline ignited. The igniter successfully set one section of the discontinuous herded slick on fire. An estimated 10% of the original 20L of oil was burned off: the remainder was not ignited.

6.3.8 Test 5

Prior to the test 10 mL of OP-40 herder was applied to the water surface and allowed to spread, then 20 L of fresh ANS crude was released into the herder monolayer. For Test 5 the IIHAS was again loaded with one activated igniter and readied for operation. It was then raised to a height of 10 m (30 ft.) and positioned over the basin to drop the igniter into the herded slick. A video of the test can be found here Summary CRREL Test5.mp4. The video shows the firing pin falling from the IIHAS, followed shortly by the igniter itself.

The igniter fell on to the herded oil slick which was free-floating near the middle of the basin. The impact of the igniter created a considerable splash, throwing oil and water 2 to 3 m outwards from the point of impact. The impact knocked the white end cap out of the igniter. Approximately 1:55 after being released, the flare inside the igniter fired and the igniter began to produce whitish smoke or vapour. A jet effect was created by the flare which tended to move the igniter in a circular motion independent of any sail effect of the wind. One minute and 36 seconds later the gelled gasoline lit. The herded slick was successfully ignited. An estimated 49% of the original 20L of oil was burned off.

6.3.9 Test 6

Prior to the test 10 mL of OP-40 herder was applied to the water surface and allowed to spread, then 20 L of fresh ANS crude was released into the herder monolayer. For Test 6 the IIHAS was again loaded with one activated igniter and readied for operation. It was then raised to a height of 10 m (30 ft.) and positioned over the basin to drop the igniter into the herded slick. A video of the test can be found here Summary CRREL Test6.mp4. The video shows the firing pin falling from the IIHAS, followed shortly by the igniter itself.

The igniter fell on to the herded oil slick which was free-floating near the end of the basin. The impact of the igniter created a considerable splash, throwing oil and water 2 to 3 m outwards from the point of impact. The impact knocked the white end cap out of the igniter. The slight breeze moved the igniter around in the slick and its position was readjusted with the metal pole. At no time during the ensuing 5 minutes did the flare give any indication that it fired. It was noted at approximately 1:50 sec that the light had stopped blinking. Review of the video and photos indicates that the light was on until approximately 1:38 after release. Further scrutiny of the video and photographs gives no visually apparent reason for the light to turn off. The igniter was recovered from the basin and the on/off switch was noted to be in the off position. The switch was slid on, at which point the flare fired. The igniter was tossed back into the herded slick. Approximately 17 seconds later the gelled gas ignited and the crude oil began to burn. An estimated 43% of the original 20L of oil was burned off.

6.3.10 Test 7

Prior to the test 10 mL of OP-40 herder was applied to the water surface and allowed to spread, then 20 L of fresh ANS crude was released into the herder monolayer. For Test 7 the IIHAS was again loaded with one activated igniter and readied for operation. It was then raised to a height of 10 m (30 ft.) and positioned over the basin to drop the igniter into the herded slick. A video of the test can be found here Summary CRREL Test7.mp4.

The igniter fell at the edge of the oil herded against one end of the basin. The impact of the igniter created a considerable splash, throwing oil and water 2 to 3 m outwards from the point of impact. The white end cap stayed in the igniter. The slight breeze moved the igniter slowly around in the slick. Approximately 2:05 after being released, the flare inside the igniter fired and the igniter began to produce whitish smoke or vapour. A jet effect was created by the flare which tended to move the igniter. Two minutes and 25 seconds later the gelled gasoline lit. The white end cap had melted through. The herded slick was successfully ignited. An estimated 53% of the original 20L of oil was burned off.

6.3.11 Test 8

Prior to the test 10 mL of OP-40 herder was applied to the water surface and allowed to spread, then 20 L of fresh ANS crude was released into the herder monolayer. For Test 8 the IIHAS was again loaded with one activated igniter and readied for operation. It was then raised to a height of 10 m (30 ft.) and positioned over the basin to drop the igniter into the herded slick. A video of the test can be found here Summary CRREL Test8.mp4. The video shows the firing pin falling from the IIHAS, followed shortly by the igniter itself.

The igniter fell into the free-floating herded slick in the center of the basin. The impact of the igniter created a moderate splash, throwing oil and water 1 to 2 m outwards from the point of impact. The impact knocked the white end cap out of the igniter. The slight breeze moved the igniter slowly around in the slick. Approximately 1:48 after being released, the flare inside the igniter fired and the igniter began to produce whitish smoke and/or vapour. A jet effect was created by the flare which tended to move the igniter. One minutes and 19 seconds later the gelled gasoline lit. The herded slick was successfully ignited. An estimated 59% of the original 20L of oil was burned off.

6.3.12 Test 9

In preparation for the test 10 mL of OP-40 herder was applied to the water surface and allowed to spread, and then 20 L of fresh ANS crude was released into the herder monolayer. For Test 9 the IIHAS was again loaded with one activated igniter and readied for operation. It was then raised to a height of 10 m (30 ft.) and positioned over the basin to drop the igniter into the herded slick. A video of the test can be found here [Summary CRREL Test9.mp4]. The video shows the firing pin falling from the IIHAS, followed shortly by the igniter itself.

The igniter fell into the free-floating herded slick in the centre of the basin. The impact of the igniter created a moderate splash, throwing oil and water 1 to 2 m outwards from the point of impact. The impact knocked the white end cap out of the igniter. The slight breeze moved the igniter slowly around in the slick. Approximately 1:53 after being released, the flare inside the igniter fired and the igniter began to produce whitish smoke and/or vapour. A jet effect was created by the flare which tended to move the igniter. Twenty six seconds later the gelled gasoline lit. The herded slick was successfully ignited. An estimated 46% of the original 20L of oil was burned off.

6.3.13 Ice Drop Test 10

The last remaining igniter was subjected to a drop test onto ice to determine what would happen. The drop test did not involve oil or herder. For the drop test the IIHAS was loaded with the last activated igniter and readied for operation. It was then raised to a height of approximately 12 m (40 ft.) and positioned over the ice sheet at the one end of the GRF basin. A video of the test can be found here [Summary CRREL Test10.mp4]. On impact with the igniter bounced up approximately 0.5 m and over about 2 m and landed in the water beside the ice. The white end cap popped of and the baggie of gelled gasoline was ejected from the body of the igniter by the force of the impact on the ice. Subsequent examination of the igniter also showed that the activation switch had moved to the off position as a result of the impact.

6.4 Discussion and Recommendations

In summary: in the first scheduled test an igniter inexplicably fired inside the IIHAS resulting in a fire and heat damage to adjacent igniters and the IIHAS itself. No injuries occurred as a result of the igniter failure. In the 10 subsequent scheduled tests four igniter failures occurred. Three consecutive successful ignitions were achieved from a release height of 10 m (30 feet), the standard set for success.

Following the tests, the participants convened a meeting to review and discuss the results and recommendations. These are documented below

Modifications to the IIHAS

- The cover of the IIHAS needs to have access ports with lockable covers/doors designed into it so the igniters can be loaded and the firing pins lined up properly.
- The electrical cables inside the IIHAS need to be protected from exposure to heat and fire in conduits.
- The IIHAS should be fitted out with waterproof electronic components throughout, with particular attention to the back of the unit where several controls, motors and batteries are grouped.
- The IIHAS should be fitted out with an automatic fire suppression system.
- The heat sensor should be repositioned or duplicated – the misfire of one igniter in the first test was not detected by the existing heat sensor in its present location.

- The firing pin extraction system should be redesigned to retain the pulled pins within the IIHAS.
- A built-in 24V charging plug needs to be added to the IIHAS electrical system to alleviate the need for two 12V chargers to recharge the 24V batteries. A 24V charger should be supplied with the IIHAS.
- The reverse on the igniter conveyor system need to be improved. A software rewrite is required to only allow the conveyor system to revers one position at a time.
- One of the two downward-looking video cameras in the IIHAS should be replaced with an IR camera.

Modifications to the Igniters

The following items need to be addressed:

- An "autopsy" should be performed by the manufacturer on the igniter that misfired during the first test to determine the cause. This was completed, the problem identified and solved. CAD was unable to re-create a similar unintended ignition with the pin in place with the re-designed timer assembly and the heavier and more secure safety pin and locking ring built into the revised timing and ignition assembly.
- A better quality, more positive acting switch needs to be used in the blue end cap (several of the recorded igniter failures were traced to this switch failing). Perhaps a recessed or locking switch can prevent movement on impact.
- The igniter end caps need to be firmly secured into the igniter body to prevent their pooing off on impact and provide waterproofing to the igniter internal components (the present design caps – both blue and white – had to be hot-glued in place before each test and still had a tendency to come off on impact with water or ice even if taped and glued).
- The endcap that fits over the flare was loose-fitting and needed to be hot glued in place to ensure it stayed on during impact. This end cap should be snug-fitting with a positive grip on the end of the flare. This could be accomplished by utilizing "barbs" or a threaded plug.
- The plastic bags to hold the gelled fuel need to be better quality. They should not leak or be affected by the gelled fuel.
- Between 250 and 300 mL of gelled fuel seems to be a suitable amount for each igniter,
- The wiring of the igniter battery needs to be modified so that the power does not start draining from the 9V battery as soon as it is connected to the harness. This relates to the relay being powered as soon as the 9V battery is connected. There is far too much battery voltage drawdown with the existing system design: the 9V battery voltage would drop below that required to fire the squib that ignites the flare in less than an hour.
- Only cold-weather heavy-duty 9V batteries should be specified for use.
- The loose wires in the igniter body need to be bundled.
- The firing pin, as delivered, needs to be replaced with a long pin that can be pulled by the mechanism in the IIHAS. Repositioning this pin from the edge of the blue cap to the centre would be beneficial.
- Waterproof marine flares, rather than the presently supplied road flares, should be used for the igniter.

Other Items

- Future tests should be conducted with a full load of igniters and herder (or water) to check balance and flyability
- The ultimate design of the igniter and all the components should be subjected to testing at a laboratory or similar testing facility that can simulate heat, cold, vibration, humidity, altitude and other movements that provides more certainty of their reliability and effectiveness, and ensures safety during the storage, handling, and operational use. This should also provide information on how to properly store these components, their shelf life and other factors that need to be considered as they would be stocked for time periods (months to years) until needed for a spill response.
- A detailed written procedure should be prepared and provided on how to handle, load, activate, and deactivate the cartridges.
- At present there is a mismatch in the herder and ignition capacities of the prototype IIHAS: the unit can carry up to 75 L (20 gallons) of herder, sufficient to produce a strip of herder at the recommended linear dose rate of 15 L/km that is 5 km (3 miles) long and surround many individual slicks, yet it carries only 15 igniters. In all likelihood, many igniters spaced closely across the upwind edge of each herded slick will be necessary to ensure maximum flame coverage and efficient in situ burning. It would appear that the IIHAS will run out of igniters long before it runs out of herder.

7. FLIGHT TESTING

The original schedule called for flight testing before the Meso Scale testing at CRREL. The HSE and test plan for the testing of the system in the Bell 407 aircraft at JBI is attached as Appendix A.

The test program was scheduled for the week of January 30, 2017. The original HSE plan had not been completed at the time of the Weight & Balance review so no flight testing would have been possible. When the system was compared to the to the test helicopter it became apparent that there would be some operating issues that needed to be addressed and rectified before flying the entire system in the aircraft.

Weight and Balance

It was decided that a thorough weight and balance calculation would be advisable before attempting a flight test of the entire module. After careful measurement of the module and weighing of each of the components both full and empty it was determined that while the aircraft was capable of carrying the load, the additional weight of the spool and the module set the system outside of the Lateral Center of Gravity (CG) limits. It was decided to send the system to CRREL for the igniter testing before any further attempt to put the system in the aircraft. This would also allow time to make system modifications to enable the system to fit in the aircraft with the system weight re-distributed toward the centerline of the aircraft.

The meso-scale testing of the igniters at CRREL during the week of December 7, 2016 also indicated that a number of changes would be necessary for the Spray and Igniter Module (SIM) system as well.

The system was returned to DESMI Ro Clean at Orchard Park, New York on December 22, 2016, to complete modifications to both the tank/spool module and the SIM. Modifications included:

- Re-orientation of the spool to move the weight of the brake and motor to a more inboard location which moved the CG somewhat as well as making it easier to establish the cable centering system.
- Installation of the cable cutter system on the spool.
- Design of a centerline sheave arrangement to move the SIM to the center of lift of the aircraft.
- Installation of a door over the igniter loading cut outs.
- Installation of a harness to make the lift point a 4 point lift.
- Install the batteries on the tank of the Tank Winder module.
- Install a bull nose and bottom pan on the SIM.
- Install feet on the SIM.

All modifications necessary were completed before delivering the system to Concord, New Hampshire, the home base for JBI Helicopters.

7.1 TEST OBJECTIVES & OUTCOMES

It was anticipated that all of the test plan could be completed at JBI and/or the Concord airport. In attendance at JBI for the testing starting January 30, 2017 were: Peter Lane from DESMI RO Clean, Peter Velez from Peter Velez Engineering LLC representing the IOGP JIP Programme, Lance Van Ness from CAD, and the JBI operations crew. Three days with a weather alternative date were scheduled. A Bell 407 helicopter owned by JBI was on site and scheduled for the full 4 days.

The goals of the test plan were to:

- Determine the airworthiness of the system on a helicopter.

OUTCOME: The system installation in the helicopter went very well (Figure 85). The skid in the helicopter worked well with some minor adjustments to satisfy center of gravity and balance required when flying with an external load. The pilot did not have a problem carrying the SIM launcher from a weight or airworthiness aspect. The spinning of the SIM in forward flight made deciding when to drop the cartridge difficult.

Figure 85. System installed in Bell 407.

- Establish flight characteristics of the Spray and Igniter Module (SIM).

OUTCOME: The launcher flying in the original horizontal orientation did not perform well due to continuous rotation that damaged the cable used to deploy it. This was due to the shape of the SIM (like a long box), the forward motion of the helicopter, and the rotor wash turbulence (Figure 86).

Figure 86. SIM in flight in original horizontal configuration.

- Establish spray characteristics, speeds and height above ground requirements, i.e. effects of rotor wash on the spray or on the drop characteristics of the igniter.

OUTCOME: The spray characteristic test was not done because of the damage to the fluid line in the cable that holds the launcher during the first test (Figure 87). Deploying the cartridges from 20′ to 40′ on the targets was very good. The cartridges were dropped on a snow/grass location and depending on the angle of impact they had some bounce; this was more pronounced if the cartridge landed on one of the corners. The rotor wash impacted the launcher spinning and the ground (snow blowing) when using the 150′ sling. When the 200′ sling was used the rotor wash did not affect the ground snow. The pilot indicated that the rotor wash is very variable between helicopter models and that some of the larger helicopters have less impact on the ground or water surface than the Bell 407 that was used for this test.

Figure 8770. Braided steel hose twisted during flight tests.

- Test all of the operating systems in a real world environment, i.e. winter/cold conditions.

OUTCOME: The temps during the testing varied between 15 and 35 degrees F. The system operated well in these operating conditions. It should be noted that the helicopter internal temperature for the skid was also in this range because of the removed doors required to fit the skid and the cable winch.

- Test launch and drop characteristics of the igniters in flight and their performance after landing. Test igniter integrity and reliability after being dropped.

OUTCOME: With the exception of the one cartridge that wedged inside the launcher (see Figure 93 below) all other cartridges deployed out of the launcher with no issues. The test heights above the ground ranged from 20 ft. to 40 ft. The cartridges rotate on the way down to the ground and some of the end caps in the side used to install the battery, flare, and gelled fuel came off when it hit the ground. A larger bounce was noticed when it impacted on the edge or corner rather than along the length of the cartridge.

7.2 TEST RESULTS

7.2.1 Flight test #1

The purpose of this test was to determine flying characteristics of the SIM, including any effect on aircraft stability in forward flight, and hover stability with the SIM retracted. It was also desired to check the control systems near ground in hover flight by:

- Extending the SIM in hover flight from altitudes of 100 and 200 feet.
- Retracting the SIM at an altitude of 200 feet while hovering.
- Check braking; retract speed and recovery to in-flight location under the skid.
- Observe the effect of rotor wash on the stability of the SIM and effects on flight stability.

The test was conducted as planned. The aircraft stability was very good including during forward movement and when hovering. No cartridges were released during this test as per the test plan. The SIM was moved up and down but the speed of the travel was deemed to be slower than expected. The major problem found during this test was the constant spinning of the SIM (as previously discussed) and the damage to the cable supporting the SIM launcher which impacted the integrity of the fluid hose which was located inside of the cable (see Figure 87 above).

7.2.2 Flight Test #2.

The purpose of this test was to:

- Extend the SIM to length of 100 feet, fly forward at speeds of 10-30 knots and observe the flying characteristics of the SIM.
- Extend the SIM to length of 200 feet. Repeat part a. at similar speeds
- Retract SIM at a forward speed of 20 knots and observe flight characteristics while retracting the SIM in proximity to the aircraft.

This test was essentially conducted at the same time as test #1 because of the flight pattern and maneuvers conducted. The results are summarized under test #1.

7.2.3 Flight test #3.

This test was to be undertaken to examine the water droplet distribution produced by the spray nozzles in the SIM from different heights and speeds. Six strips of Kraft paper 48” wide x 50 feet long were to be spaced out along the landing strip to enable 6 different passes. Colored water was to be used as the spray medium. The strips were to be retrieved and a droplet counts made for each pass.

This test was not performed because of the damage to the fluid line that carries the herder from the herder tank mounted on the skid located inside the helicopter to the SIM launcher.

7.2.4 Flight test #4.

The goal of this test was to drop dummy igniters from hover on a fixed target from different heights. Drops were made over a snow target from heights of 10 feet and 20 feet. The location for the drop testing was at the JBI facility to enable easy recovery of the dud igniters.

Visual observations of the drop were conducted by observers (3 in total from different angles) from a distance as per the safety plan. The target was designated as orange spray paint circles of 10′ and 20′ diameter and a center bullseye (Figure 88), with measurement taken if the igniter fell outside of the target. Fifteen cartridges were dropped with several dropping inside the 10′diameter circle and most dropping inside the 20′ diameter circle. The one cartridge that jammed was launched by moving the track slightly in reverse and then forward and it dropped about 60′ from the center point. It should be noted that the cartridges sometimes bounced away several feet from their initial impact point and the rotor wash also moved them further when making the next pass over the drop target. Therefore, the observations of the initial drop point were used to assess the drop effectiveness.

Figure 88. Igniter target on snow

7.2.5 Flight test #5.

Up to five igniters were prepared for live drop at the JBI facility near Concord Airport. The tests were done there in order to have ample space. A target area was arranged to enable sequential dropping of igniters, the first from hover at a height of 10-15 feet, and then proceed to the second drop at about 10 knots. Two tests were to be performed from a cable extension height of 100 and 200 feet. The purpose of the test was to review the effect of rotor wash on the drop characteristics of the igniters at hover and 10 knots and the two different heights.

All five cartridges were dropped successfully, with four released from a 20 ft. height and one from a 40 ft. height (Figure 89). Cartridge #3 appeared to also jam but again the track was moved back and forth and it released. Three of the cartridges fell inside the 10′ diameter circle, one inside the 20′ diameter circle, and one inside the 35′ diameter. Four of the igniters successfully ignited at the two-minute mark per the design of the cartridge. The remaining cartridge did not ignite, most likely because the fuel was too gelled and it had partially fallen out from the cartridge on impact with the ground.

Figure 89. Igniter firing on ground

7.2.6 Flight test #6.

After the scheduled tests were completed, a discussion was held to determine if the SIM would fly better in a vertical position. JBI had a variety of different sling and swivel arrangements available and it was decided that further flight test using 200 feet of sling rope and a swivel (Figure 90) attached to a sling on the end of the SIM would give us some idea of what the flight characteristics of the SIM would be.

Four lift eyes were attached to the control (square) end of the system through the cover. A load rated sling was secured to the lift eyes and attached to a swivel on the end of the lift rope. The rope was a DYNEEMA double braid rope which is virtually impervious to twisting. That coupled with the swivel would allow the SIM to fly as normally as possible.

The pilot lifted the system to a height about 50 feet off the ground and flew several circuits of the JBI operations site (Figure 91). The SIM exhibited very little tendency to spin in the vertical orientation. The general consensus of the group was that the vertical orientation was nearly immune to rotor wash at the distances and elevations flown. It was easy to control and did not exhibit any unusual flight or operating characteristics. Observations by the flight and ground crew indicated that an ideal shape for the SIM would be round.

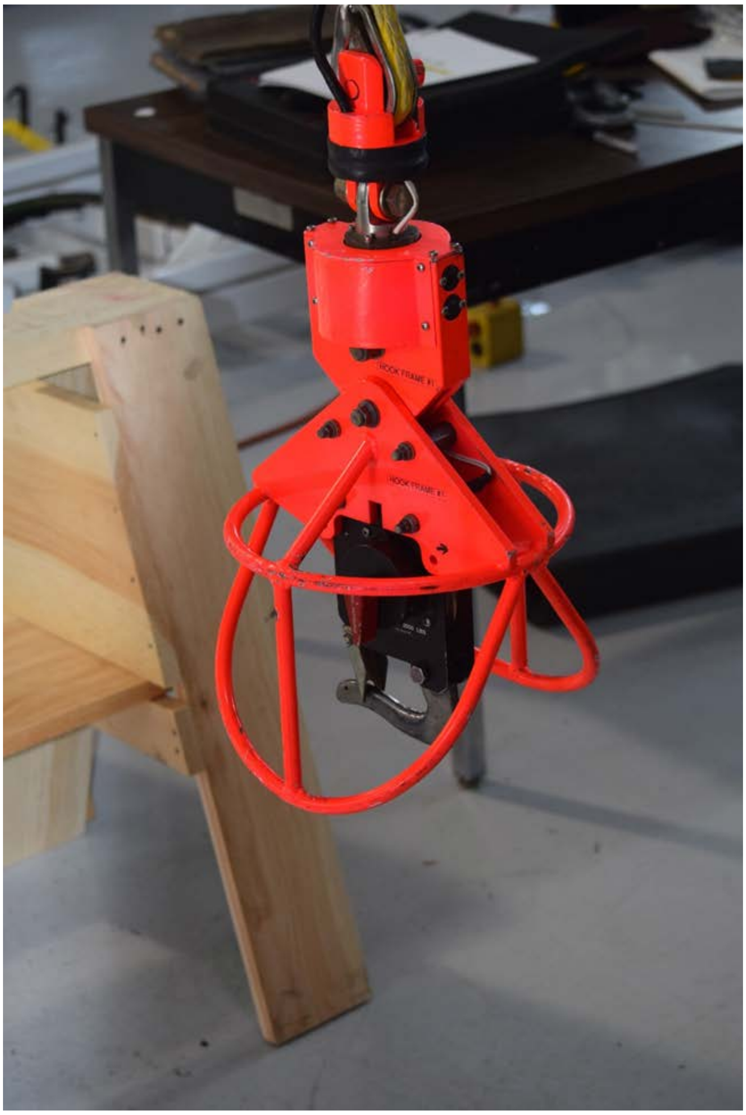


Figure 90. Close-up of swivel used in vertical SIM Flight Test

Figure 91. SIM in vertical flight mode.

7.3 Conclusions and Recommendations from Flight Testing

7.3.1 Igniter Cartridges

- The ignition switch used was improved to a more durable/hardy version, better secured, and the knob to turn it on is recessed, requires a small screwdriver to move it from OFF to ARMED, and has a larger plastic cap at the control end. None of the improved cartridge igniter switches moved from ARMED to OFF because of the impact with the ground or by movement inside of the launcher.
- The new pin (Figure 92) was made out of aluminum and locks in more securely with a spring clip type of lock that helps avoid it slipping out. During dry runs in the helicopter hangar, the pins still at times hung up on the launcher's metal slot that extracts the pin. This caused the entire igniter to get crooked inside the launcher (Figure 93). Also, during testing, some of the pins missed the pin extractor slot if they had not been positioned all the way to one side. This issue could potentially cause CAD cartridge to ignite inside the launcher if it does not eject from the launcher because it is stuck in the ejection slot.

Figure 92. New CAD Igniter end cap

Figure 93. SIM with Jammed Igniter Cartridge

RECOMMENDATION: Investigate if the pin can be made out of hard plastic to avoid metal on metal damage with the launcher. The angle used for the pin removal device and the materials used needs to be examined in the shop to improve the efficiency of the cartridge release and eliminate the wedging. Some Teflon or similar material can also be added to the pin retractor and the cartridge drop system to avoid metal on metal friction and wear.

- The external length of the cartridge could be 3/8" longer so that it fills the space that it sits in the tray. One dud cartridge wedged at an angle when being released which resulted in the pin being bent and not coming off, the cartridge wedging in the launcher. This required the operator to reverse the belt momentarily, and then go forward again to drop the igniter without the pin extracted (Figure 94). The same jammed cartridge also caused damage to two of the holders (made of sheet metal) which bent during the attempted release (Figure 95) and required them to be removed from the launcher which effectively reduced the capacity from 15 to 13 cartridges.

Figure 94. Damage to pin and cartridge

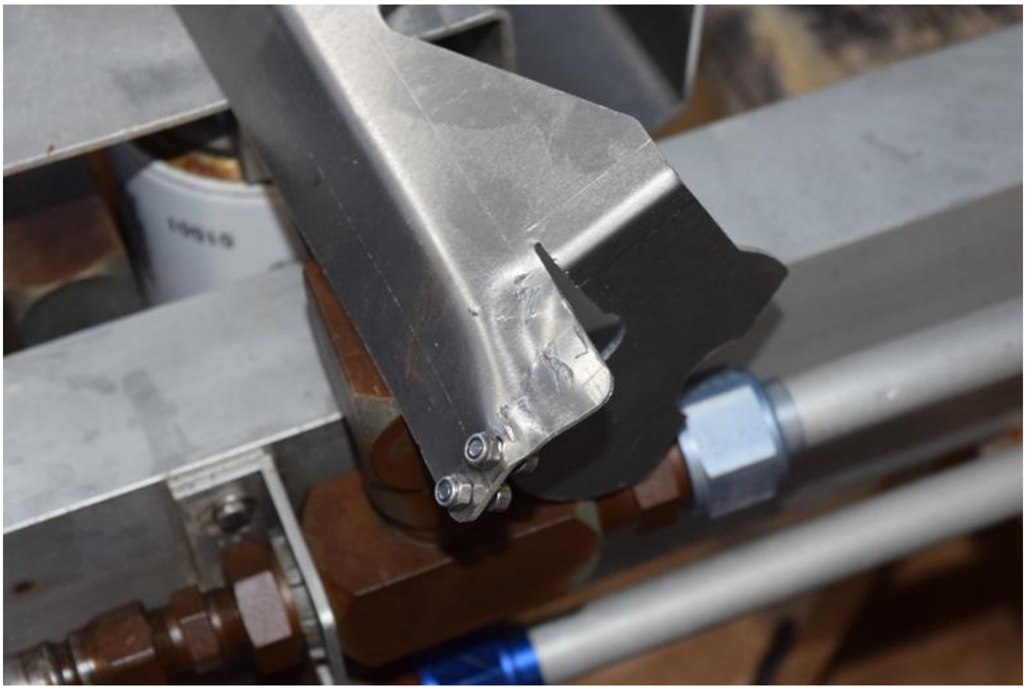


Figure 95. Damage to SIM from Jammed Cartridge

RECOMMENDATION: Extend the foam of the cartridge to the entire length of the holder. Use foam of higher density so that it does not break up easily if it becomes wedged.

- Regular alkaline 9V batteries used for this testing drained below the 9V required to fire the igniter.

RECOMMENDATION: A better 9V battery is available which is lithium based and designed to work in very low temperatures. One link to them is:

https://www.homedepot.ca/en/home/p.advanced-lithium-9-volt-battery---1-pack.1000668677.html

- The tests conducted at CRREL and JBI did not have as an objective to determine how much oil could be burned both in volume and area (square feet or miles) with one cartridge. Different opinions may exist because of factor such as the thickness of the oil throughout the spill area, wind speed and direction, booming, effect of ice in Arctic areas that works as a boom, etc. Some estimates may range from several hundred square feet to much larger areas. The CRREL tests used 5 gallons of oil in a confined tank and one cartridge but resulted in a very active, hot and fast moving fire.

RECOMMENDATION: The wide-ranging estimates need to be better studied as this can help in making a decision of how many cartridges should be included in the system. Alternatively, systems with different number of cartridges can be designed to address small and large areas of spilled oil.

- The plastic cap at the end from which the gelled fuel exits the cartridge was not changed from the earlier tests and still comes off too easily, even when glued with a glue gun after loading.

RECOMMENDATION: CAD should get a better end cap that can withstand better the drop of 20' – 40' to the surface. The end cap that opens up to release the gelled fuel should be longer and tighter fitting than the one used at CRREL and for the JBI testing.

- CAD's representative attended the Monday setup and the Tuesday testing but then departed. He returned with him some of the observations from the shop testing, but did not see the cartridges being dropped armed.

RECOMMENDATION: CAD needs to be advised of the additional issues encountered and the need to improve their product for durability and reliability.

7.3.2 Spray and Igniter Module (SIM)

- The new access doors in the system (Figure 96) helped load/view cartridges, access the interior, and monitor the launcher. The procedure to take the launcher cover off and put it back on was slow and tedious.

RECOMMENDATION: A commercial version needs to have quick access to all the internal parts of the SIM. If the vertical cylindrical design is chosen this can be accomplished with side opening doors secured with latches.

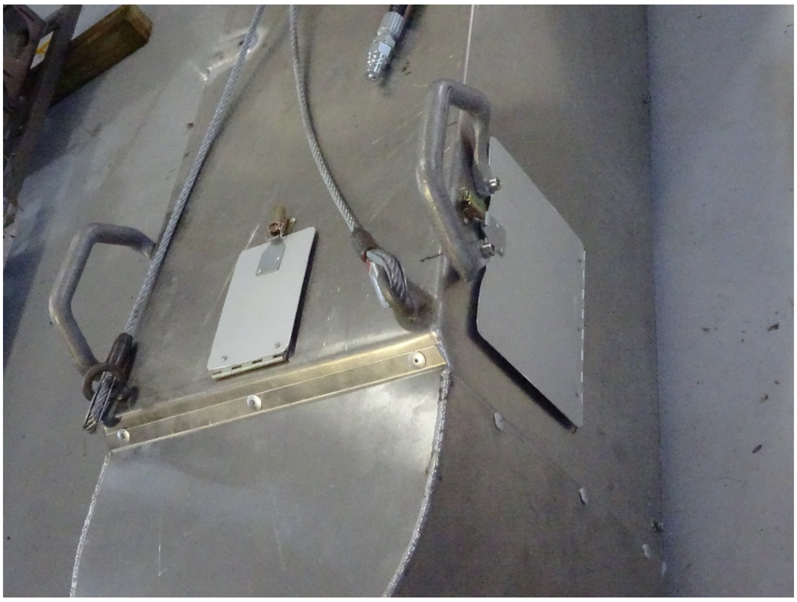


Figure 96. Access doors added to SIM

- The SIM when flown in the horizontal position as designed spun constantly under the helicopter. DESMI used a 4-point sling and removed some original fins from the model tested at CRREL (Figure 97). The spinning was caused both by its shape and being horizontal, but was also impacted by the rotor wash. This caused the cable and herder fluid line to twist and damage beyond repair (unless a section was cut off and the ends re-fitted which could not be done quickly or in the field). During the debrief ways were brainstormed to mitigate this problem and added a swivel hook which can carry the load but not as designed the liquid line. To better understand this issue, the group planned an additional flight Test 6. JBI provided 150' and 200' load lines used for the remainder of the testing along with a swivel assembly.

RECOMMENDATION: DESMI should consider a redesign of the SIM as a vertical cylinder (about 36" in diameter) with the controls at the top and the launch belt and cartridges in the lower part. The existing system could be modified for testing with the 15-cartridge belt and the drop end at the bottom. The system would have dimensions of 3ft. diameter by approximately 7 ft. long. If more cartridges are desired, the system could easily be made longer.

Figure 97. Flight Testing of SIM

- The cartridge holders made from sheet metal need to be revised to be sturdier and to better hold the cartridge and not allow rotation.

RECOMMENDATION: The cartridge holders (Figure 98) need to be strengthened so that the sheet metal is sturdier. In addition, an additional finger/holder is needed to better hold the cartridge in place in the end from which the fuel ignites. Some of the steep angles in the device that dislodge the firing pin need to be reduced.

Figure 98. Igniter cartridges in holders on belt

- The launcher contains two 12V batteries that operate in series. The system used to charge them was modified after the last CRREL test so that one 12V charger could be used to charge both batteries at the same time. During charging of these batteries, smoke appeared from the rear of the launcher and the charging bridle wire insulation was damaged. This occurred when the system was turned on with the batteries still charging. The damaged wires were removed and the batteries charged individually which required the cover of the launcher to be removed. The charred wires were of smaller gauge than the cables providing the power to the launcher.

RECOMMENDATION: The charging system needs to be rearranged to allow external charging of the batteries and upgraded so that the wiring is the appropriate gauge for the charger.

7.3.3 Herder Tank, Reel, and Control Skid (in helicopter)

- The skid's center of gravity for this type of helicopter, even after the post-CRREL modifications, is still too much to the left side of the aircraft (Figure 99). After several iterations, JBI was proposing that the hose reel be moved farther inboard which would have required significant work on site. After further discussions, 200 pounds of weight was added to the right side of the helicopter and that solved the balance problem.

RECOMMENDATION: The center of gravity of the skid and the SIM should always be evaluated as part of the flight operations and the HSE Plan.

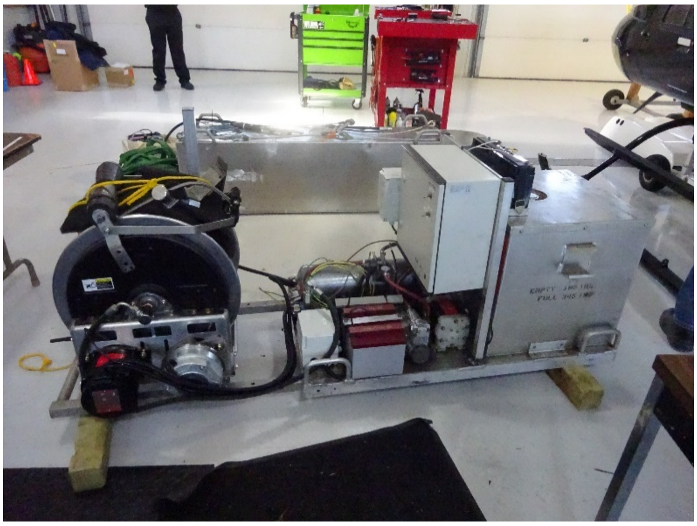


Figure 99. Herder Tank, Reel, and Control Skid

- The installation of the skid into the helicopter (Figure 100) was smooth. It required the removal of the seats, console and the left hand rear door. The electrical and communication connections for the explosive wire cutter and other items were also easily accomplished with the JBI personnel.

Figure 100. Installation in back of Bell 407

- The herder tank was not used in the testing because the line that is part of the cable going to the launcher was twisted in the first set of testing. It appears that the herder tank could either be on the skid or relocated to the launcher. Since the communication between the skid and the launcher is by Wi-Fi, the herder tanks(s) could be located inside the launcher with a positive displacement pump.

RECOMMENDATION: Consider moving the herder tank to the vertical launcher. This would simplify the design and operational process as a plain wire rope cable (most likely smaller and lighter in weight) could be used to deploy the launcher without the need to run a fluid line inside of the cable. It would also significantly reduce the size of the skid which also mitigates the center of gravity issue since more of the skid can be located inside the helicopter as well as being much smaller. See discussion later regarding tank volume and insulation/heating of herder tank.

- The wire retrieval speed after use was slow, based on the opinion of the operator.

RECOMMENDATION: Since at least 200' have to be released to avoid prop wash issues, the speed of the winch should be evaluated and considered in the commercial design to minimize the reel back process.

- The altimeter in the launcher did not work properly, only reading either 0 or 5 meters regardless of the height. The altitude of the launcher was provided by the ground crew visually by estimating it or by the use of a pre-measured line with a shackle tied to the launcher.

RECOMMENDATION: Replace the altimeter device with one that operates correctly. Larger helicopters typically used in the oil industry have a radar altimeter that provides the pilot more accurate reading than the gauge in the Bell 407.

7.3.4 Other Issues

- The herder tank could be relocated from the skid to the launcher. The potential volume of herder needed can range from 10 to 40 gallons. This can be easily accommodated inside a vertical launcher that is 3' in diameter. Because one type of herder may gel (impacting how it can be pumped) in colder temperatures, the system may need to be insulated and provided some heat (such as heat tracing) that can be powered by a battery located near the tank(s). Estimates of how much herder is required range from 1 to 6 gallons per mile of perimeter applied. This range can result in different volumes that need to be discussed and the best choice selected. Additional herder can be quickly resupplied to the system tank(s) when the helicopter lands for reloading of cartridges.

RECOMMENDATION: DESMI should seek input with herder experts to better determine what the best path forward is regarding volume needed, location, and if a PD pump or other application system would be preferred.

- When the one cartridge became wedged during release, it appears that the launcher belt blew a 5 amp fuse in its control system. This resulted in the communication between the helicopter control system and the skid not operating at all, which delayed the testing.

The information was communicated and sent to the DESMI designer in Denmark that afternoon and early the next day he communicated that it could be a fuse. An inspection yielded that the 5 amp fuse appeared to be damaged. JBI had a similar fuse but only of 3 amps which was installed and the system returned to operation. A search that morning for a replacement 5 amp fuse (European model) in Concord, NH did not yield any. After discussions with the DESMI designer, he confirmed that that fuse should only see 1.1 amps so we proceeded the testing with the 3 amp fuse and it worked fine.

RECOMMENDATION: The DESMI system had some spare components and fuses. After checking the spares, it was determined that none of the 5-amp ones were included. A better set of spare key components (fuses, belt, cartridge holder, etc.) should be part of the spares.

- To advance the launcher the separate skid system must also be turned on and done remotely.

RECOMMENDATION: The launcher should be equipped with a small recessed and protected panel that includes switches to advance or reverse the launcher belt and run the herder pump if relocated to the launcher.

- The camera located on the launcher near the control end did not yield a high enough quality picture for the operator to see the target, mainly due to its location, the spinning of the launcher, the launcher's nose being higher than the view from under the helicopter, and the camera not being of good resolution.

RECOMMENDATION: A better higher resolution camera should be installed that provides a better picture when the launcher is 20' to 40' above the water. An infrared camera would be preferable to better detect the oil in the water. The picture that appears in the handheld display used by the operator was also not very good and a better screen should be considered.

- The SIM launcher was carefully lowered during landing by the helicopter pilot on the concrete helideck with no noticeable damage.

RECOMMENDATION: If the design used is a cylinder shape vertical launcher, the cylinder should be designed to withstand bumps and bruises, therefore fiberglass or PVC should not be used. With a sturdy shell, 15 cartridges, herder tank(s) and herder liquid it is estimated that the external SIM launcher will weigh 300-400 pounds which is not a problem for this type of helicopter or larger helicopters as an external load. The winch and transmitter components will be internal to the aircraft and can be mounted centerline in almost any helicopter with lifting capacity of 1000 lbs. divided between the internal module and the SIM external module

- Estimates of what area can be ignited by each igniter vary based on the situation. This will depend on the thickness of the oil, the location at which the igniter drops relative to the spill, and how it is moving. In Arctic locations with ice present the ice may also act as a natural boom that can result in much higher volumes that can be burned.

RECOMMENDATION: The JIP Technical Working Group needs to consider this to better define when this SIM is advantageous over a Helitorch system. Having seen both operate would indicate that each has potential applications that add additional capabilities to the toolbox for the responder team to consider and utilize. Part of this review needs to consider what area / oil volume that can potentially be burned by a single or multiple cartridges.

- The CAD cartridges have a written procedure for loading and arming the system. The skid and SIM system does not have a written procedure for operating the system.

RECOMMENDATION: DESMI needs to provide detailed written procedures that describe how to install the system, how to charge it, how to load the cartridges, how to charge the batteries, how to troubleshoot the system, etc.

- The flares used for this testing were regular road flares.

RECOMMENDATION: For use in water the flares should be marine type so that the water does not cause a cartridge to fail.

- During the testing, no communication or Wi-Fi[33] interference between the SMI system and the helicopter was detected by the pilot or the operator.

- The launcher can be reloaded with new cartridges with the helicopter still running if the offshore deck has space on it or if done at an onshore airport or heliport. This reduces the reloading time to about 5 minutes and the helicopter can be back out to a site. The previously mentioned switch on the launcher to advance the belt would speed up this operation.

- A launcher with the herder tank built in along with a smaller skid could be easily be transported offshore inside a larger Bell or Sikorsky helicopter to provide for a faster response than transporting it via a vessel. After it arrives at an offshore facility, it could be offloaded, rigged up, and made operational at a remote site.

8. CONCLUSIONS AND RECOMMENDATIONS

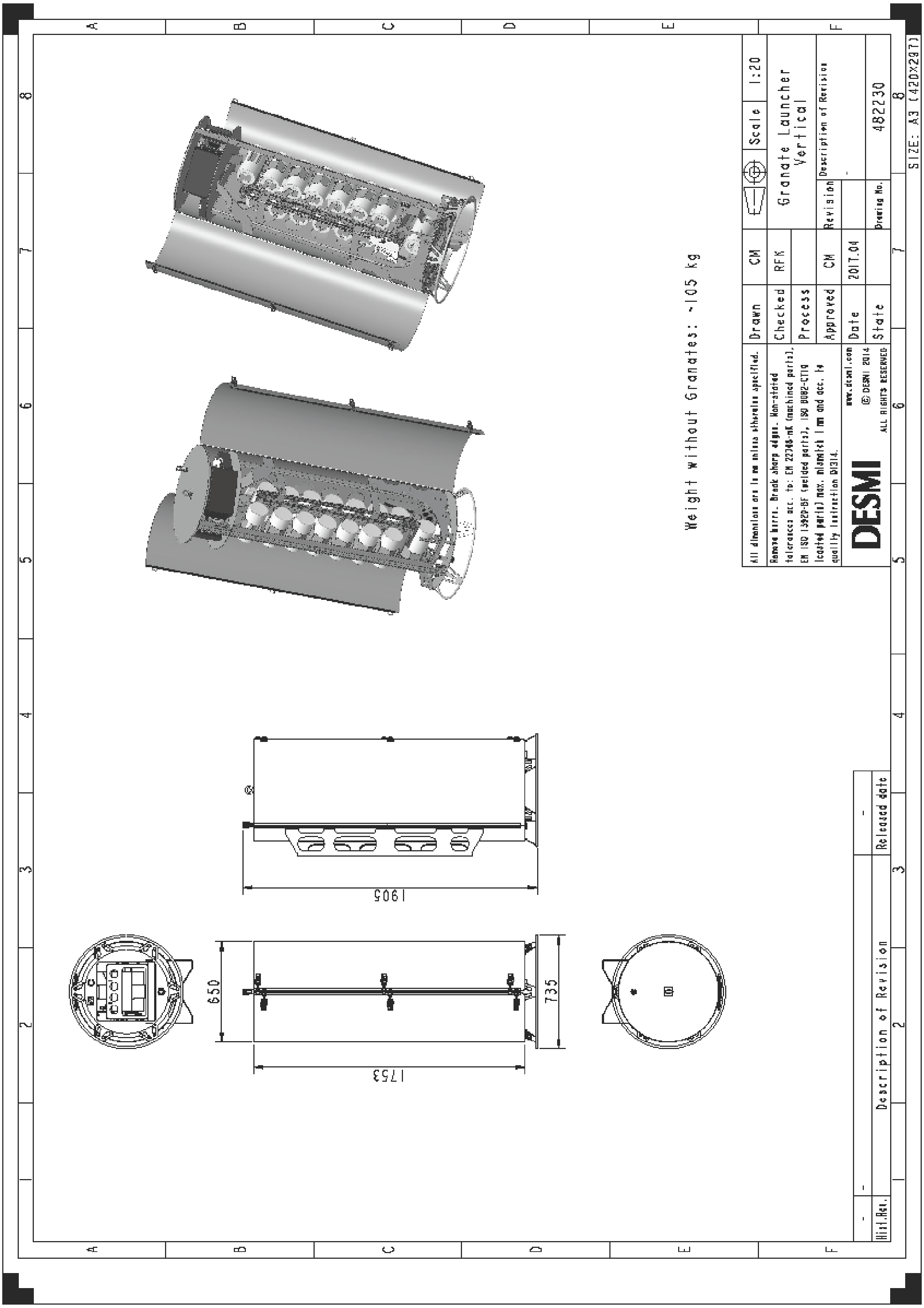
8.1 CONCLUSIONS

- Upon completion of the testing of the integrated system it is clear that an integrated system is feasible and can be built using the components tested as part of this test program. Re-configuration of the SIM to enable vertical operation is paramount. Spinning of the SIM led to the integrated cable/ hose arrangement being damaged. This re-configuration of the SIM should be fairly simple. Preliminary conceptual designs are presented on pages 89 through 92.
- The developed igniter works effectively to ignite fresh crude of various types under temperate and cold conditions. Modifications made through the test program indicate that reliability of the igniter can be achieved, and that the igniter meets all of the original design criteria.
- Testing of the spray applicator system, outside of the JBI field test indicates that spraying from the helicopter from a height of 150-200 feet AGL can be done (Potter *et al.* 2016)
- An integrated external load system mounted vertically will fly effectively and can be operated by the system operator and pilot.
- The remote Wi Fi system works well. If it were desired that the system be integrated into a single point underslung load, it can be modified using existing components in a revised operating system using an underslung winch powered from the aircraft and its own internal power supply mounted inside the aircraft
- From the pilot perspective, flying the system and aiming from the pilot position was not too difficult, but 200 feet seems to be about the limit. A radar altimeter would be a useful or even necessary item in the aircraft. While laser pointers on the SIM might be useful, they are not readily available in the commercial market
- A height of 5-8 meters seems to be a good height for launching the existing igniters as currently configured, but incorporating some recommended improvements to improve the durability. The same height above ground would be a good height for spray application of herder as well.

8.2 RECOMMENDATIONS

- Reconfigure the SIM using a vertically oriented round shape lifted from the center on the control end. This would allow the SIM components to be re-arranged and re-oriented to enable the same conveyor to be used in a vertical orientation. This would require new igniter holders to be fabricated and a revised pin extractor to be designed. Also, internal clearances need to be reviewed to ensure that igniter jams are not likely.
- The electrical system needs to be completely autonomous of the rest of the system for loading and arming of the system.
- Easy access to the conveyor system from the side is necessary. In a round configuration a hinged door would be simple to make with the operating switches being readily accessible to personnel. The projected cost for making the modifications to the SIM and hose assembly is $38,000.

- Potential users should plan on using a twin-engine helicopter with a flat floor for easier loading and operations. The SIM can be carried internally and easily offloaded by two personnel for flight operations.
- The igniter needs to have a defined service life of the battery, and the arming circuit needs to be evaluated for extending battery life.
- A more robust end cap needs to be provided to ensure that the cap does not pop off with subsequent ejection of the fuel load.
- Internal configuration of the location of the flare will enable a larger fuel load of as much as 350 ml.
- Clear instructions for fuel/gellant mixing needs to be provided, including quantities in simple volumetric terms, mixing and gel times, and recommended temperatures.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Checked RFK
Process
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Date 2017.04
State
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DESMI
© DESMI 2014
ALL RIGHTS RESERVED
www.desmi.com
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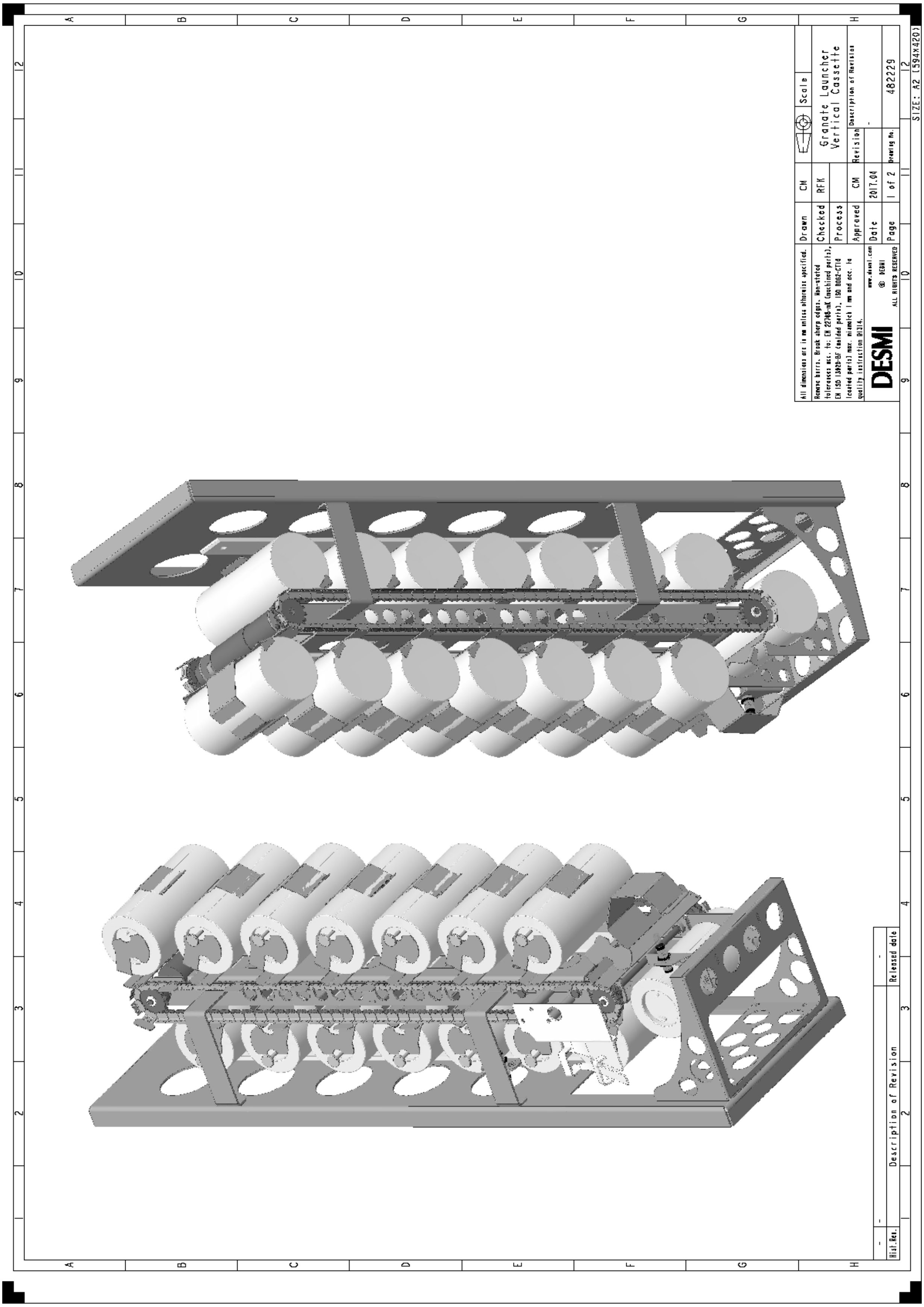
Hist.Rev.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482229
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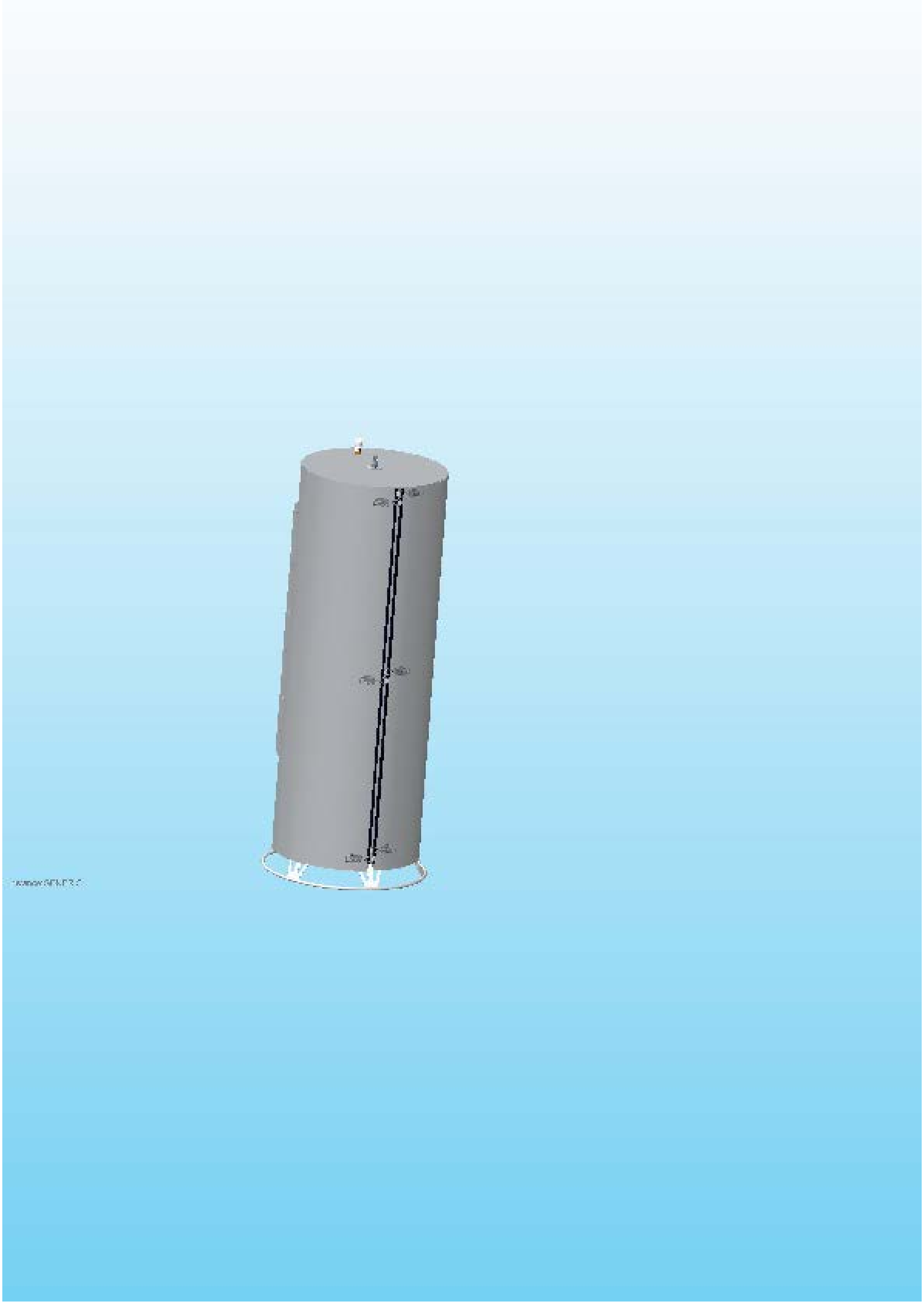

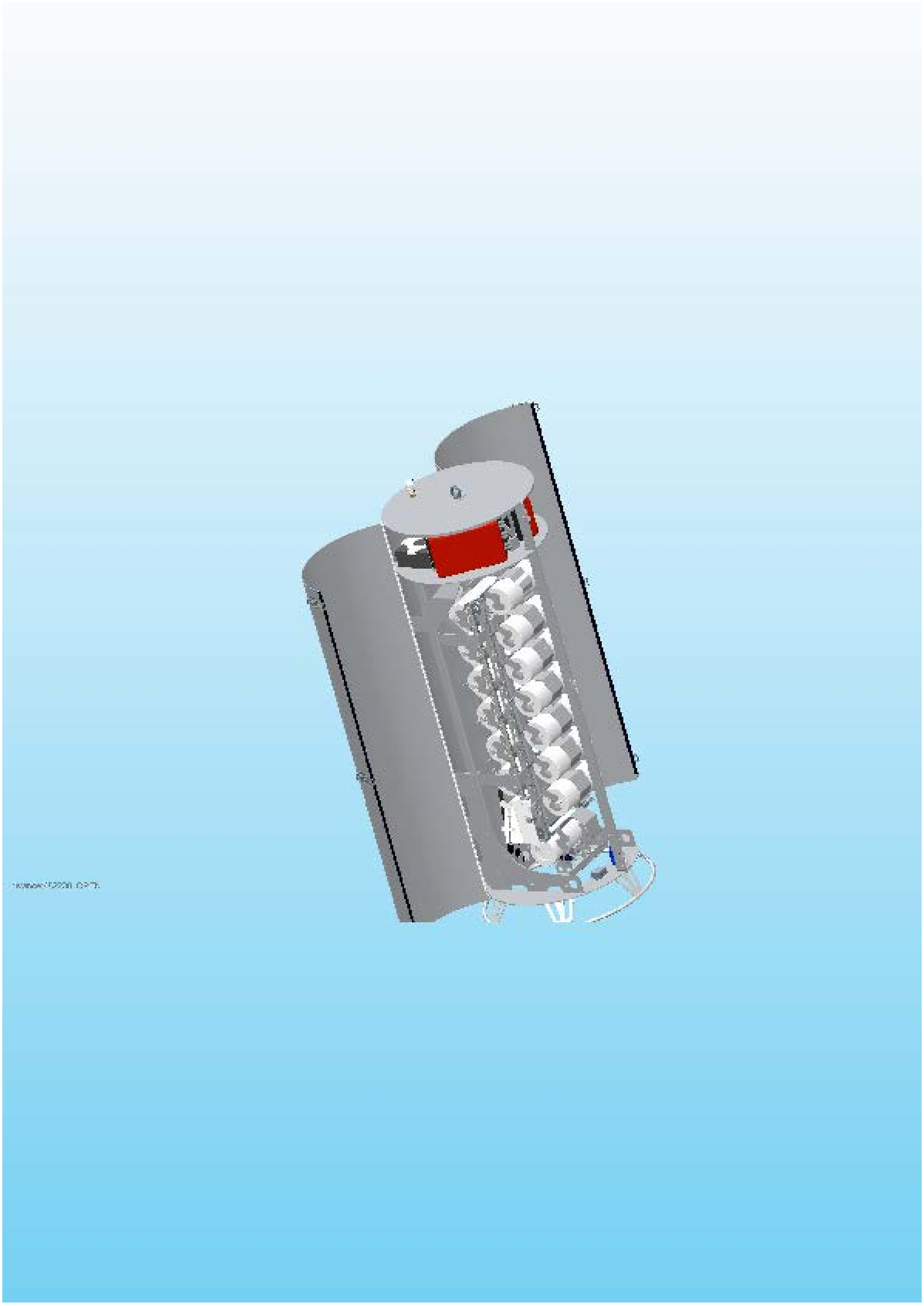

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Buist, I., S. Potter, R. Belore, A Guarino, P. Meyer and J. Mullin, 2010c. Employing Chemical Herders To Improve Other Marine Oil Spill Response Operations. Proceedings of the Thirty-third AMOP Technical Seminar on Environmental Contamination and Response, Environment Canada, Ottawa, pp 1109-1134.

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APPENDIX A – FLIGHT TEST PLAN AND HSE PLAN

TEST PLAN FOR THE DESMI HERDER APPLICATOR AT JBI HELICOPTERS, CONCORD, NEW HAMPSHIRE JANUARY 30- FEBRUARY 2, 2017

BACKGROUND

The DESMI Ro-Clean herder applicator system has been developed to be able to sequentially spray oil herder chemical and subsequently drop igniters containing gelled gasoline on a herded slick. This system is the third prototype and is near production stage. The controls are all FCC accepted wireless controls designed to operate the entire system from the observer station in the cockpit of the selected Bell 407 helicopter.

Controls include:

- Winder in and out
- Spray pump on/off
- Spool brakes for intermediate cable stop and emergency operation
- Visual observation/recording of the spray from the launcher module. A camera is mounted on the Spray module with a 2.4 GHz Wi-Fi connection to enable video viewing and recording. See the Attached FCC grant of equipment authorization, Appendix C.
- Line purge
- Launcher for up to 15 igniters.
- GPS positioning of spray track and igniter location
- Pilot operated cable cutter for emergency jettison of the launcher module.

FEATURES OF THE SYSTEM

A. 20 gallon insulated storage tank for herder chemical
B. Positive displacement electric gear pump for herder.
C. 28V powered hose/cable winder with 60 meters of Teflon lined braided stainless steel 13mm (1/2”) hose
D. Up to 8 spray nozzles. Easy change out ¼” NPT fittings
E. Complete wireless remote control
F. Capacity of 16 igniters
G. Integral air compressor for line purge
H. Pilot activated integral cable cutter on hose.
I. Positive on/off flow control at the spray module
J. Emergency electrical cable brake
K. Video observation, recording and GPS positioning and target tagging.
L. 28V integral battery and accessory cable for taking power from the aircraft

OBJECTIVES OF THE TEST PLAN:

1. Determine the flyability of the system on a helicopter.

2. Establish flight characteristics of Spray/igniter module. (SIM)

3. Establish spray characteristics, speeds and height above ground requirements, i.e. effects of rotor wash on the spray or on the drop characteristics of the igniter.

4. Test all of the operating systems in a “real world” environment, i.e. winter/cold conditions.

5. Test launch and drop characteristics of the igniters in flight and their performance after landing. Test igniter integrity and reliability after being dropped.

Appendix 3 is a schedule of planned flight testing.

FLIGHT OPERATIONS

All of the flight testing will be conducted at JBI Helicopters facility and the nearby Concord, NH Municipal Airport (KCON). Appendix E is a copy of an email authorizing this activity.

A HSE plan for JBI is included in Appendix A. A Google earth map showing the locations of the two test sites is part of appendix A.

A. The aircraft to be used for this test is the Bell model 407 single engine aircraft which is identical to the one which was used previously at JBI, and which is the same model also used at Poker Flat, Alaska testing in April 2015. The deck previously produced for testing is being returned with the spray system so that the pump/tank module which was designed around this system can be installed in the same aircraft. The only change we have made is the installation of high skids on the helicopter to accommodate the height of the SIM Module.

B. The primary difference between the original hose/nozzle arrangement and this spray/igniter launcher module is the addition of the 100 KG weight on the end of the hose/cable system. In order to accommodate the heavier line load, a winch motor with 5 x the lift capacity of the previous cable winder was added to the system.

C. The system has also been fitted with a CAD explosive cable cutting system originally designed for the Sikorsky S-61 which has a ¾” steel hoist cable. Our wire braided hose with internal 3/16” stainless steel cable is far less substantial than the S-61 cable. CAD tested the ability of the system to cut the hose/cable assembly, which was completed to their satisfaction. The cable cutter is pilot activated and entirely separate from the electronics and electrical system of the applicator.

D. The JBI pilot operating the aircraft has many hours operating under slung loads and delivering heavy loads (cement) from the helicopter. The only other person in the aircraft during operations will be the system operator Peter Lane.

E. Ground support personnel will be provided by JBI. All JBI personnel are intimately familiar with the safe ground and aircraft marshalling characteristics of the helicopters. All air testing will be conducted near or overhead the JBI strip or the Concord, NH municipal airport which has a fire training facility on the field. If targets are set up on the field, only JBI or DESMI personnel, and any authorized observers will be present during drop operations.
F. All flight operations will be briefed prior to embarking on a test. A designated safety officer will be established prior to briefings. Only those activities briefed prior to flight will be conducted during any specific flight test profile. All flight testing will be conducted under daylight VFR flight conditions.
G. For spray testing, only colored water will be used. Spray patterning will be conducted using water sensitive cards and/ or Kraft paper. ASTM Standard E642, Standard Practice for Determining Application Rates and Distribution Patterns from Aerial Application Equipment will be used as the general guideline for data gathering and site layout.
H. For drop testing of the igniters both live and dud igniters will be used. Live igniters will be limited in fuel capacity to 300ml or less to limit burn time and smoke emissions. Duds will be weighted to simulate the weight and balance of a fully loaded live igniter. Drop testing will be confined to dropping the igniters into a 10 ft. diameter circle to determine the potential accuracy of the system. Some coordination of the pilot and observer and some practice will be required to determine the level of accuracy to be achieved.

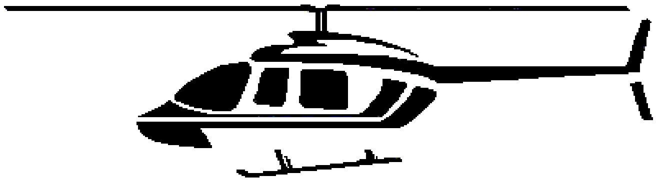
EVALUATION CRITERIA

While there are no pass/fail criteria, the characteristics of the system that we are looking for are:

1. Flyability of the SIM. While most operations will be done at fairly slow forward speeds, i.e. 10-20 knots, evaluation will be done at speeds not to exceed 40 knots.
2. Enroute flight characteristics. Due to changes in the installation the SIM will only be carried beneath the helicopter. Flight characteristics will be observed and videotaped.
3. Performance of the winch/cable/hose system. Since the system must be operated at various heights above the surface and be able to stop at intermediate points, the performance of the winch/winder will be evaluated, including braking, launch and recovery at various lengths below the helicopter.
4. Evaluate any effects on the flight characteristics of the helicopter. Speeds forward and hover will be evaluated at different altitudes, in order to determine transit speeds for the system.
5. Develop operating procedures for the system.
6. Coordination of procedures between the pilot and observer and potential ground observers.

APPENDIX A

JBI HSE PLAN FOR TESTING OF THE DESMI OIL HERDER APPLICATOR AND IGNITER LAUNCHER



JBI HELICOPTER SERVICES
720 CLOUGH MILL ROAD
PEMBROKE, NEW HAMPSHIRE
03275
603-225-3134

DESMI RO-CLEAN HERDER APPLICATOR TEST
HEALTH AND SAFETY PLAN
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JBI HELICOPER SERVICES
HEALTH AND SAFETY WORK PLAN

1.0 Scope of Work

The scope of work to be performed by JBI Helicopter Services is that of testing and evaluating the flight characteristics of the Desmi Ro-Clean Herder Applicator System.

2.0 Project Personnel

2.1 Roles and Responsibilities:

JBI Helicopter Services will be responsible for the safety of its employees and all those in attendance for the flight tests. JBI HELICOPTER SERVICES will ensure that all employees on site will have the skills and qualifications necessary to perform their job safely and effectively and in accordance with all regulatory requirements. Below is a list of Pilots and Ground Crew. The Company Safety Officer or his Designee on site will be responsible for the health and safety of all JBI Employees.

PILOTS	GROUND CREW
Ray Newcomb	Eric Niquette
Carl Svenson	*Kurt West (Company Safety Officer Designee)*
Douglas MacIver	Douglas Beaudreau

Note: All Pilots are FAA Licensed Commercial Pilots, and are FAR Part 133 qualified for external load operations with Hazardous Materials.

Pilot in Command The Pilot in command will have the responsibility for monitoring and enforcing all applicable safety requirements. The Pilot in Command has full authority to immediately correct any safety hazard as they deem necessary and has the authority to order a work stoppage in the event of a serious safety issue.

Ground Crew Foreman (Competent Person)

The Ground Crew Foreman will be designated by the Pilot in Command. He will be able to identify hazards and has the authority to take prompt corrective action to include stopping the operation at any time. He will monitor ground and air operations and notify the Pilot in Command of any hazards or noncompliance. The Ground Crew Foreman will be in radio contact with the pilot in command always when the helicopter is operating.

<u>Company Safety Officer</u>

The Company Safety Officer or his Designee shall review and approve all flight plans. The Company Safety Officer or his Designee shall be on site before during and after all flight operations to ensure that all safety procedures are adhered to and the safety of all personnel on site is never compromised.

<u>All Personnel (Pilots, Ground Crew, Technicians, Company Representatives)</u>

- Are responsible for following all safety requirements outlined in this plan.
- Are responsible for reporting to the JBI Company Safety Officer or his Designee any incidents including near-miss incidents.
- Have the authority to refuse to work or to request that others stop work if that person believes the conditions to be unsafe.

2.2 Qualifications

The following is a list of qualifications required of JBI Pilots and Ground Crew;

Pilots:

FAA Commercial Pilot Certificate, Rotorcraft Helicopter

First or Second Class Medical Certificate (current)

Current Biennial Flight Review or Current FAR 135.293, 135.299 Evaluation

Aircraft Currency as per FAR's

Current External Load Certificate IAW 133.37 (a) (1)

Subject to random drug and alcohol testing IAW FAA and DOT regulations

HAZMAT Training if handling Hazardous Materials

Ground Crew:

Valid Commercial Driver's License. (If driving)

Valid and current DOT Physical (if driving)

Subject to random drug and alcohol testing IAW FAA and DOT regulations

HAZMAT Training if handling HAZMAT

3.0 Hazard Identification and Risk Assessment

JBI helicopters utilizes the Helicopter Association International (HAI) Safety Guide, developed by the Utilities Patrol and Construction Committee (UPAC) when performing external load with HAZMAT. JBI helicopters uses the provisions set forth in our **Special Permit** Issued by the Pipeline Hazardous Materials Safety Administration. Special Permit Number (DOT-SP 15181). This permit is carried on all aircraft and will be reviewed prior to operations involving HAZMAT.

3.1 Initial Assessment

Task Risk Analysis - (Class B) External Load; Desmi Ro-Clean Herder Applicator System			
Operation: Basic Flight Characteristics Test of Desmi Ro-Clean Herder Application System (Non-HazMat Flight)		Prepared by: Carl Svenson (PIC) Prepared Date: 11/21/2016	
Risks Normally Associated Operation		Risks Associated After Mitigation	
Hazards	Risk	Mitigation	Residual Risk
Loss of Communications Between Pilot and Ground Crew	2B	Ground Crew trained on proper hand signals. Pilot will land as soon as practicable, evaluate, repair and restore communications	2A
Load entanglement followed by improper pilot actions.	3B	Extensive pilot training. Above standard maintenance on Hook/Releases.	2B
Engine failure/power loss during exposed operations.	3B	JBI's engine failure prevention techniques. Daily power trend checks. Helicopter can pull away at any time.	2B
Longline/suspended load loss of control and or contact with tail rotor	2B	Use of weighted remote hooks/Grapples.	2B
Tail Rotor/ Tail rotor drive failure.	2B	Manufacturer's Maintenance Program. A&P daily inspections.	2B
Inadvertent release causing damage or injury to persons or property on the ground.	3C	Above standard maintenance on Hook/Releases. Extensive pilot training.	2C
Injury to persons on the ground/structure from suspended load.	3C	Ground Crew Training. PPE (Eye Protection, Hard Hats, High Visibility Clothing)	2C
Cold weather induced issues on personnel	1A	Provide personnel with appropriate PPE for the weather conditions on site at the time	1A
Exposure to gasoline vapors or skin exposure during mixing of gelled fuel	2A	Proper PPE to be worn by personnel mixing fuels. Very low quantities will be handled for this experiment, less than 2 liters	1A
Surrounding inhabitants complaining of smoke or other issues	1A	Burns will be done nearby the fire training school. The smoke plume from 300 ml of gas and the flare is minimal	1A
Loss of the SIM	2A	Proper test planning, weight and balance plans, and operations over a flat open test area are conducive to ensuring that the SIM is	1A
The following mitigating factors were also taken into consideration in determining residual risk			
1. BHT 407 extraordinary record performance characteristics and crash survivability 2. Statistics derived from accident analysis 3. JBI's past safety record			
Proprietary and Confidential - JBI			
Overall Evaluation of Task Risk		Authorized By	
Medium Risk- Acceptable		Chris Thresher – Company Safety Officer	

3.1 Initial Assessment (Continued)

Task Risk Analysis - (Class B) External Load; Desmi Ro-Clean Herder Applicator System			
Operation: Spray Test and Ignitor Drop Test of Desmi Ro-Clean Herder Application System (HazMat Flight)		Prepared by: Carl Svenson (PIC) Prepared Date: 11/21/2016	
Risks Normally Associated Operation		Risks Associated After Mitigation	
Hazards	Risk	Mitigation	Residual Risk
Off-site movement of spray droplets (drift)	3C	Use water with food grade dye; Limit operations to sustained winds of 10 Knots or less; Perform operations away from sensitive	2B
Entanglement of Spray Igniter module with ground objects	3B	Perform operation at local airport with minimal hazards to flight. Ground crew has continuous communication with pilot to aid in preventing entanglements; Pilot can jettison device with CAD explosive	3A
Entanglement of Spray Igniter Module hose or cable in tail rotor	4B	Maintain safe flying speed obtained from Basic Flight Characteristics Test; Pilot enhanced emergency procedure training	4A
Live and Dud Ignitors drop off target	3A	Tests shall be performed on hard surface with highly visible drop zone; Test shall be limited to sustained winds of 10	2A
Live Ignitor Unintentional Fire and or Fuel Spill or it ignites prematurely in the ignitor system	3A	Operation shall be performed on and over hard surface, away from sensitive environmental areas; Minimal fuel used; Ground Crew trained in Hazardous Material	3A
Potential for liquid fuel spill on ground	2A	Sorbent materials will be on hand to mitigate any fuel spills. Gelled fuels and the minimal quantities used reduce the potential for any significant ground contamination. Also, the ground is frozen this time of year and will reduce any potential ground saturation	2A
The following mitigating factors were also taken into consideration in determining residual risk			
1. BHT 407 extraordinary record of performance characteristics and crash survivability 2. Statistics derived from accident analysis 3. JBI's past safety record 4. Results from Basic Flight Characteristics Test Considered and Applied			
Proprietary and Confidential - JBI			
Overall Evaluation of Task Risk		Authorized By	
Medium Risk- Acceptable		Chris Thresher- Company Safety Officer	

ARCTIC RESPONSE TECHNOLOGY JIP		**HSE ADVISORY PANEL**			
CONSEQUENCE MATRIX					
CRITERIA FOR SEVERITY RATING					

CONSEQUENCE	NEGLIGIBLE = 1	MINOR=2	MODERATE=3	MAJOR=4	MASSIVE=5
HUMAN	First aid injury or occupational illness/effect with minor impact on health and ability to function	Medical treatment injury or occupational illness.	Serious injury, or illness with possible permanent effects.	1-2 fatalities on workforce, resulting in significant effect. Permanent Total Disability	2 or more Fatalities. Multiple illnesses with permanent health effects
ENVIRONMENTAL	No or very limited impact on natural habitats.	Adverse short term impact on natural habitats	Adverse medium or long term impacts on significant part of habitats (e g restitution time 1-3 years)	Adverse long term impacts on ecologically valuable natural habitats (e g restitution time 3-10 years)	Adverse permanent impacts on key ecosystem functions and services in larger natural habitats (e g restitution time >10 years)
ASSETS (Direct Cost)	<20K $	>20K $	>200K $	>2M $	>10M $
REPUTATION	Negative exposure with limited importance	Local/regional negative exposure in media or from authorities.	National negative exposure in media. Negative exposure from national authorities/regulators.	Negative coverage in media. Negative attention from important organisations. Negative reputation impacts on JIP organisations.	Legal proceedings with possible major impact. Extensive negative media coverage.

Draft Risk Assessment Legend – see following risk matrix

Consequence/Severity Rating and Frequency/Likelihood Scale

Consequence		**Increasing Annual Frequency/Likelihood**				
Severity rating	**People, Environment, Assets, Reputation**	**A**	**B**	**C**	**D**	**E**
		Rare failure	Credible failure		Probable failure	Frequent failure
		Has rarely occurred in operations or research	Has occurred at least once in past experience	Has occurred several times	May occur several times a year	Will occur routinely
1	Slight Consequence			**LOW**		
2	Minor Consequence					
3	Considerable Consequence			**MEDIUM**		
4	Major Consequence				**HIGH**	
5	International Consequence					

Low Risk	No further improvements necessary provided control measures are in place and maintained
Medium Risk	Risk is tolerable when control measures have been identified and implemented
High Risk	Further Risk Reduction Measures must be undertaken

4.0. Communication

Good communication is imperative to a safe and successful operation. It starts at the tailboard and continues throughout the job until the debriefing at mission completion. Communication and phraseology will be in accordance with the UPAC Safety Guide.

5.0 Emergencies

Prior to the start of the job, all radios will be checked. All employees will be familiar with the job location and can give directions to emergency services if required. Additionally, the location and directions to the nearest medical facility must be available on site. In the event of an emergency, personnel will ensure safety of themselves and others prior to approaching. Emergency services when applicable will be contacted by the most expeditious means possible.

6.0 Incident Reporting and Analysis

Any injuries, accidents, near misses, damage to property public or private will be reported to the Company Safety Officer, the Director of Operations, and to any other appropriate agencies as deemed necessary. A written report of events leading to or casual factors involved in injuries/accidents will be submitted to Company Safety Officer, to assist in mitigation and reoccurrence.

7.0 Safety Meetings and Job Briefings:

All JBI employees and Non-JBI Personnel attending these testing procedures are required to be present for the Job Briefing (tailboard). The Pilot In Command shall conduct the Job Brief and identify key personnel and their roles and responsibilities. A job specific brief for the testing of the Desmi Ro-Clean Herder Application System shall be reviewed and signed by all personnel in attendance. Tailboard Brief and Attendance Sheet is in Appendix B of this Plan.

8.0 Health and Safety Plan

JBI Helicopters is committed to ensure employees are familiar with the contents of this Health Plan and Safety Plan. "Safety is no Accident". The contents of this Safety and Health Plan will be reviewed by all personnel in attendance, before the start of the project, when new person(s) are in attendance, or when there is a significant change in the operation.

8.1 Changes to Health and Safety Plan

Whenever there is a significant change in the project the plans will be re-written, a Job Brief shall be conducted and signed by all in attendance. The review will focus on the work tasks, significant changes, and associated hazards, risks and control measures.

9.0 Safety Compliance

It is incumbent upon all JBI employees to ensure that we are operating in compliance with regulatory requirements. The requirements are that of our own, Federal, State and local. On the spot corrections, should be made as soon as a deviation from approved safety standards has been recognized. Safety will not be compromised for mission accomplishment.

10.0 Environmental Compliance

Employees must be vigilant to environmental concerns, and compliance. Some examples of environmental concerns would be keeping fuel and chemicals away from water sources, and densely populated areas. Any potential problems should be addressed as soon as practicable.

– Emergency Contact Information

SAFETY AND HEALTH PLAN

EMERGENCY CONTACT INFORMATION

Location Concord Airport 71 Airport Rd, Concord NH 03301 603-229-1760	
Description of Work: Aerial Test of DESMI Ro-Cleaner Applicator System	
EMERGENCY CONTACT INFORMATION	
CONTACT NAME	TELEPHONE NUMBER
Local Emergency Medical Services Police Emergency Fire Emergency	911
Local Police Non-Emergency Number	Concord Police Department 603-225-8600
Local Fire Dept. Non-Emergency Number	Concord Fire Department 603-225-8600
Nearest Hospital Name: Location: Directions: Refer to Attached Map	Concord Hospital 250 Pleasant St. Concord, NH 03301
JBI HELICOPTER SERVICES Pilot in Command Name:	Carl Svenson
JBI HELICOPTER SERVICES Company Safety Officer	Chris Thresher

JBI HELICOPTER SERVICES Company Safety Officer Designee	Kurt West
JBI HELICOPTER SERVICES Ground Crew Foreman	Eric Niquette
JBI HELICOPTER SERVICES Main Office	603-225-3134

Appendix B – Desmi Ro-Clean Herder Mission – Daily Tail Board Brief

Daily Tail Board Brief shall be performed prior to the start of each day and whenever there is a change in the operation or personnel on site. All persons attending the test (Pilots, Ground Crew, Technicians, and Customer Representatives) must sign attendance sheet at the completion of the brief.

<u>Aircraft Specific</u>

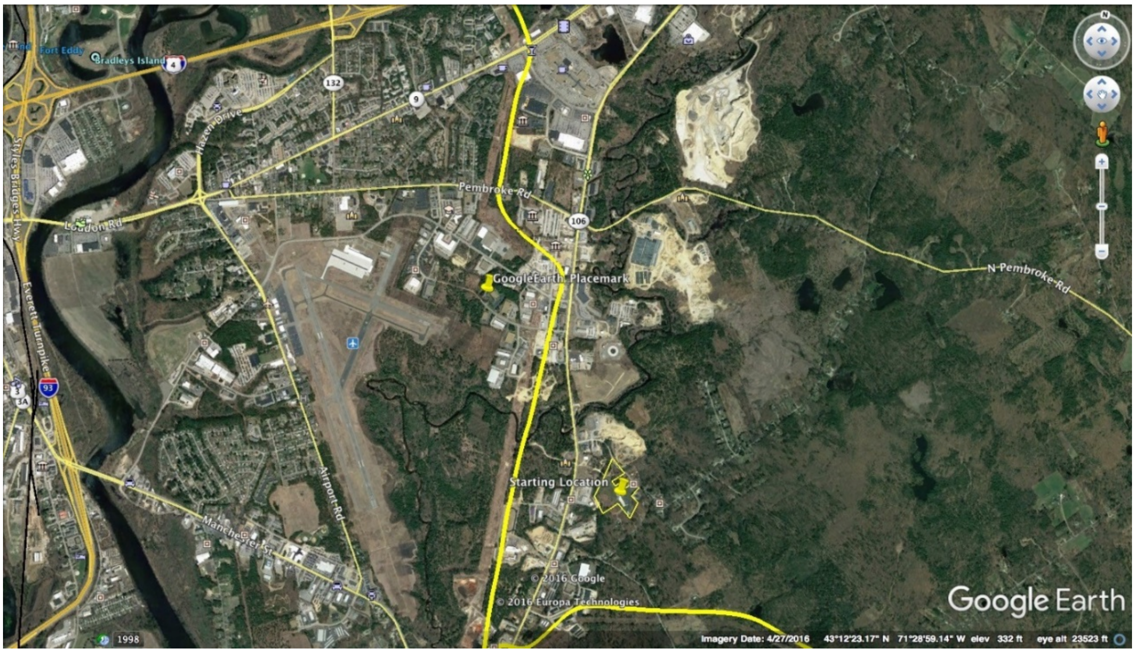
1. Introductions/ Pilot in Command/ Safety Officer/ Customer Representatives
2. Responsibilities of accountable parties
3. Landing Zone Identified/ Operation Area Identified/ Observation Area Identified
4. Approaching/departing helicopter/ Tail rotor avoidance
5. Loose blowing items secured
6. Radio Frequencies to be used/ Radios Tested
7. Hand Signals reviewed
8. Required PPE (Hard Hats, Eye Protection, Hearing Protection, High Visibility Clothing)
9. Aircraft Capabilities Reviewed/ Performance Charts Checked
10. Refueling Procedures
11. Flight Path explained, and Sensitive areas identified
12. Notice To Airmen Filed and Active
13. Emergency Procedures reviewed

<u>Mission Specific</u>

1. Mission discussed and maps reviewed
2. Any mission changes will be discussed in detail prior to execution
3. Weather/ current/ forecasted/ within prescribed limitations
4. Discuss possible complications with Desmi Ro-Clean Herder and procedure for handling complications
5. Emergency Contact numbers reviewed; 911
6. Emergency Procedures/ Entanglements/ Load Instability/ Inadvertent Ignitor Drop
7. Procedures for Fuel Spill discussed
8. Fuel Spill Kit identified and procedure for use

Desmi Ro-Cleaner Herder Application Test Daily Tail Board Brief Attendance Form			
Date	Name (Printed)	Name(Signed)	Company Representing

JBI Plot Plan



APPENDIX C – FCC Grant of Equipment Authorization

TCB GRANT OF EQUIPMENT AUTHORIZATION **TCB**

Certification
Issued Under the Authority of the
Federal Communications Commission
By:

UL Verification Services Inc. (formerly UL CCS)
47173 Benicia Street
Fremont, CA 94538

Date of Grant: 08/07/2015

Application Dated: 08/07/2015

Circuit Design, Inc.
7557-1, Hotaka
Azumino, Nagano, 399-8303
Japan

Attention: Yukinaga Koike

NOT TRANSFERABLE

EQUIPMENT AUTHORIZATION is hereby issued to the named GRANTEE, and is VALID ONLY for the equipment identified hereon for use under the Commission's Rules and Regulations listed below.

FCC IDENTIFIER: V9X-LMD400RC
Name of Grantee: Circuit Design, Inc.
Equipment Class: **Licensed Non-Broadcast Station Transmitter**
Notes: **UHF Narrow Band Multi Channel Transceiver**
Modular Type: **Single Modular**

Grant Notes	FCC Rule Parts	Frequency Range (MHZ)	Output Watts	Frequency Tolerance	Emission Designator
	90.217	458.0 - 462.5	0.011	5.0 PM	8K29F1D

Single Modular Approval. Output power listed is Conducted(Peak). End-users must be provided with specific operating instructions for satisfying RF exposure compliance.

APPENDIX D – FLIGHT TEST SCHEDULE AND PROFILES FOR THE DESMI INTEGRATED HERDER APPLICATOR AND IGNITER SYSTEM

JANUARY 30 - FEBRUARY 2, 2017

GENERAL OPERATIONS REQUIREMENTS

Before any operations are undertaken the following general requirements will be followed.

a. Standard PPE will be worn by all personnel directly involved in the test. PPE will include hard hats, safety glasses, safety shoes or boots, appropriate protective clothing and a high visibility vest.
b. A safety zone will be established around each test area and will be enforced by the designated safety officer.
c. Passengers in the aircraft will be limited to the pilot and systems operator.
d. Safety briefings will be conducted and recorded prior to each operation
e. Lessons learned will follow each operation and will be recorded.

1. Monday, January 30
   a. Project briefing, set up of system in helicopter, testing of electrical and telemetry.
   b. Briefing of test plan, designation of site manager, pilots, observers and support personnel.
   c. Review of HSE plan, response to any emergency condition, layout of test area and targets.
   d. Designation of observer sites, photo recording of test flights and gathering of test data points.

2. Tuesday January 31

Flight test 1.

Determine flyability of system to include any effect on aircraft stability, including forward flight, and hover stability with SIM up. Check the control systems near ground in hover flight.

a. Extend the SIM in hover flight from heights of 100 and 200 feet.
b. Retract SIM at height of 200 feet in hover flight. Check braking, retract speed and recovery to in flight location under the skid. Observe the effect of rotor wash on the stability of the SIM and effects on flight stability.

Flight Test 2.

a. Extend SIM to length of 100 feet, fly forward at speeds of 10-30 knots and observe the flyability of the SIM at 100 feet
b. Extend SIM to length of 200 feet. Repeat test a. at similar speeds
c. Retract SIM at forward speed of 20 knots. Observe flight characteristics while retracting the SIM in proximity to the aircraft.

Flight test 3.

Droplet distribution test. This test will be undertaken to examine the water droplet distribution from different heights and speeds. 6 strips of Kraft paper 48” wide x 50 feet long will be spaced out along the landing strip to enable 6 different passes. Colored

water will be used as the spray medium. The strips will be retrieved and a droplet count made for each pass.
The spray system will be configured for all 8 nozzles at 0.2 GPM each with all spraying vertically.

a. Layout paper strips on the landing strip to allow 3 consecutive flight tests at 100 feet AGL. The objective is to observe the spray pattern and droplet density at speeds of 10, 20 and 30 knots. Proposed height AGL for the SIM is 10-15 feet.
b. Repeat test at full cable extension at the same speeds but raise height AGL to 20-25 feet.

Flight test 4.
Dropping of dummy igniters. The objective of this test is to drop dud igniters from hover on a fixed target from different heights. Drops will be made over grass or a soft target from heights of 10 feet and 20 feet. The suggested location for drop testing is at the JBI facility to enable easy recovery of the dud igniters.

Wednesday February 1
Flight test 5.
Dropping of live igniters. Up to 5 igniters will be prepared for live drop at the Concord Airport. A target area will be arranged to enable sequential dropping of igniters, the first from hover at a height of 10-15 feet, and then proceed to the second drop at about 10 knots. Two tests will be performed from a cable extension height of 100 and 200 feet. The objective of the test is to review the effect of rotor wash on the drop characteristics of the igniters at hover and 10 knots and the two different heights.

Review of test observations and video, pilot and observer reaction to the flyability of the system and potential for further use.

Notes. February 2 has been reserved as an alternate weather date in the event that either Tuesday or Wednesday are outside of the operating envelope of 2000 ft. ceiling and 5 mi visibility with little or no precipitation and wind of less than 15 knots. The operating parameters of using herders fall within this wind speed range and it would be difficult to evaluate any droplet distribution if there is any other precipitation.

APPENDIX E – AGREEMENT FROM CONCORD AIRPORT TO ENABLE USE OF THE CLOSED RUNWAY AT CONCORD NEW HAMPSHIRE AIRPORT (KCON)

Begin forwarded message:

From: "DRolla" <dmr@confbo.com>

Subject: KCON airport operations

Date: November 21, 2016 at 11:38:25 AM EST

To: <kurt@jbihelicopters.com>

Cc: "DRolla" <dmr@confbo.com>

Good Morning Mr. West,

As we discussed this morning, JBI Helicopters, Inc is permitted to conduct flight test operations at Concord Municipal Airport, KCON, and more specifically on and above abandoned runway 3/21. If you have any other questions, please do not hesitate to call me.

Regards,

David M. Rolla, Manager

Concord Municipal Airport