MODIFICATION, SCALE-UP AND TESTING OF A 100 BBL/DAY SWIRLFIRE BURNER

by

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BACKGROUND

In 1987/88 a study of spill-generated oily material disposal requirements was conducted for the Coast Guard (S.L. Ross 1988); in it a recommendation was made to test the SWIRLFIRE rotary cup burner concept and ultimately produce a version capable of flaring 7 L/min (10 m^3/day = 63 bbl/day) of a wide variety of recovered oils, including emulsions.

In 1988/89, a prototype SWIRLFIRE (denoted here as Mark I) was built by Energetex Engineering and tested with a variety of oils and emulsions (S.L. Ross 1989). The burner proved capable of cleanly burning: water-free weathered crude oil at rates of 1.3 to 1.4 L/min (12 to 13 bbl/day); water-in-crude oil emulsions at rates, depending on the water content, up to 4.2 L/min (40 bbl/day); diesel fuel at a rate of 1.9 L/min (17 bbl/day) and waste engine oil at 1.24 L/min (11 bbl/day). A number of minor modifications to the burner design were suggested as were additional, maximum-capacity tests (i.e., disregarding smoke generation). The development and testing of a larger version was also suggested.

OBJECTIVE OF THE PRESENT STUDY

The objective of the present study was to develop a heli-transportable SWIRLFIRE rotary cup burner capable of disposing of 11 L/min (100 bbl/day) of crude oil, emulsion or petroleum product recovered from an oil spill.

GOALS

More specifically, the goals of the study were to:

- determine the maximum burn rate (i.e., disregarding smoke generation) of the Mark I SWIRLFIRE burner with low, medium and high viscosity oils and conduct long (about 1 hr) burns to test the mechanical reliability of the device.

- design and build an 11 L/min (100 bbl/day) version (denoted as Mark II) capable of being transported by a Bell-206 helicopter (ca 400 kg).

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- test the Mark II SWIRLFIRE burner using a variety of fresh and weathered crudes, water-in-oil emulsions and oil products.

MAXIMUM BURN RATE TESTS WITH MARK I PROTOTYPE

Methods

The tests were conducted at a private residence near Woodlawn, Ontario on September 24, 1990. Diesel fuel and an Ontario crude oil, from which 10% of its volume had been artificially evaporated, were used to test the burner. Bunker "A" fuel oil was also tried but could not be drawn up the suction hose by the Mark I's gear pump at the prevailing temperatures (between 0 and 10°C). The properties of the two oils successfully burned were:

Test Oil	**Viscosity (mPas = cP)**	**Density (kg/m^3)**
10% evaporated crude[1]	10 @ 23.4°C	834 @ 21.8°C
Diesel[2]	3.9 @ 0°C	838 @ 0°C

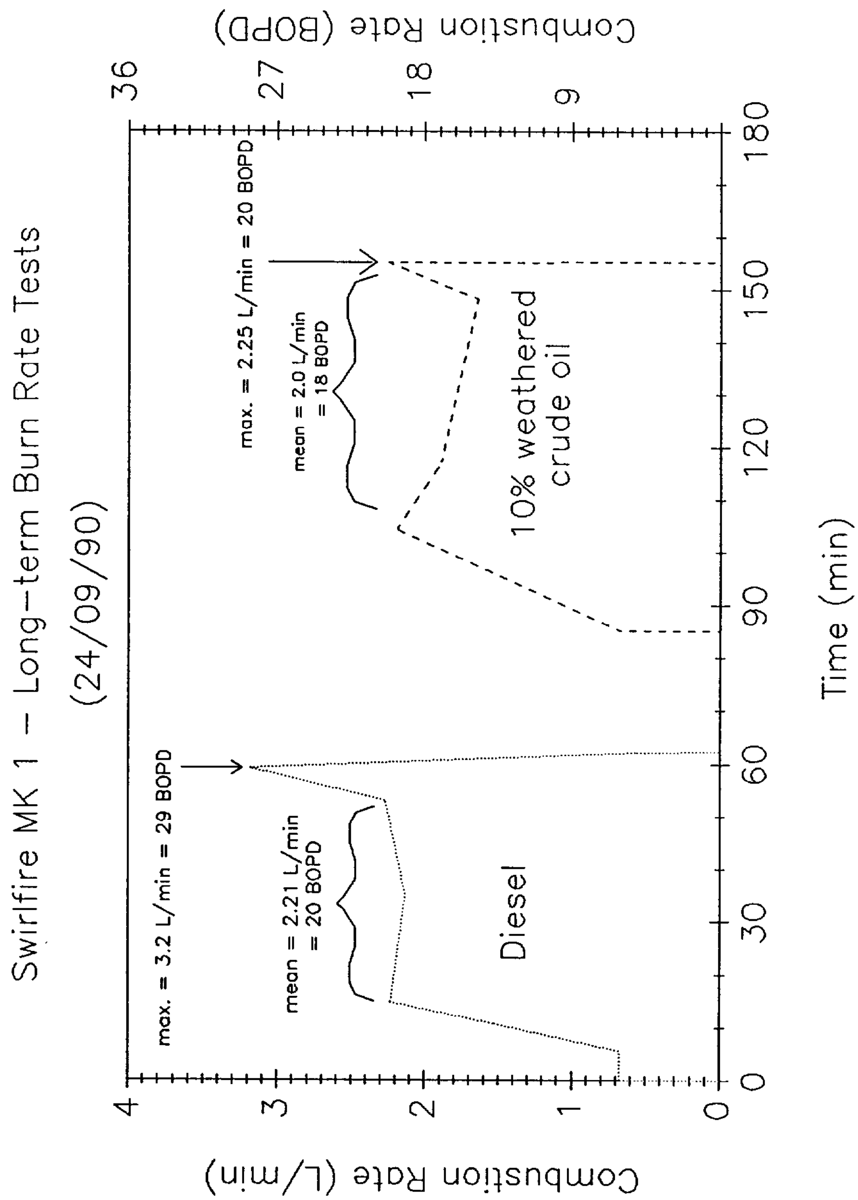
1 from S.L. Ross 1991
2 from Bobra 1990

Results

Figure 1 shows the results of the tests. Diesel fuel was burned at a mean rate of 2.2 L/min (20 bbl/day or BOPD = Barrels of Oil Per Day) for a period of about 55 minutes followed by a 5 minute burn at 3.2 L/min (29 bbl/day). Figure 2 shows the Mark I SWIRLFIRE burning diesel oil at a rate of 2.2 L/min (20 bbl/day); note that very little smoke is being emitted, the steam rising from the ground is from rainwater on the sand pad in front of the burner. Some smoke was being emitted from the end of the flame at a burn rate of 3.2 L/min (29 bbl/day). The opacity of this smoke was Ringelmann No. 1 or less. All the oil was burning in the flame even at this flowrate; no fallout was visible. At a flowrate of 3.2 L/min the radiant heat from the flame caused the rubber wheels at the front of the burner to smoke. A sheet of corrugated steel was placed in front of the burner wheels to prevent this.

During the second half of the tests the Mark I SWIRLFIRE burned 10% evaporated Ontario crude oil at a mean rate of 2.0 L/min (18 bbl/day) with a peak rate of 2.25 L/min (20 bbl/day) at the end of the tests. At a burn rate of 2.0 L/min no smoke or fallout was noted; at 2.25 L/min some smoke (Ringelmann 1 to 2) was observed coming from the end of the flame, although no fallout was noted.

Figure 1


Swirlfire MK 1 — Long-term Burn Rate Tests
(24/09/90)
max. = 3.2 L/min = 29 BOPD
mean = 2.21 L/min
= 20 BOPD
Diesel
max. = 2.25 L/min = 20 BOPD
mean = 2.0 L/min
= 18 BOPD
10% weathered
crude oil
Time (min)
Combustion Rate (L/min)
Combustion Rate (BOPD)
0
30
60
90
120
150
180
0
1
2
3
4
9
18
27
36

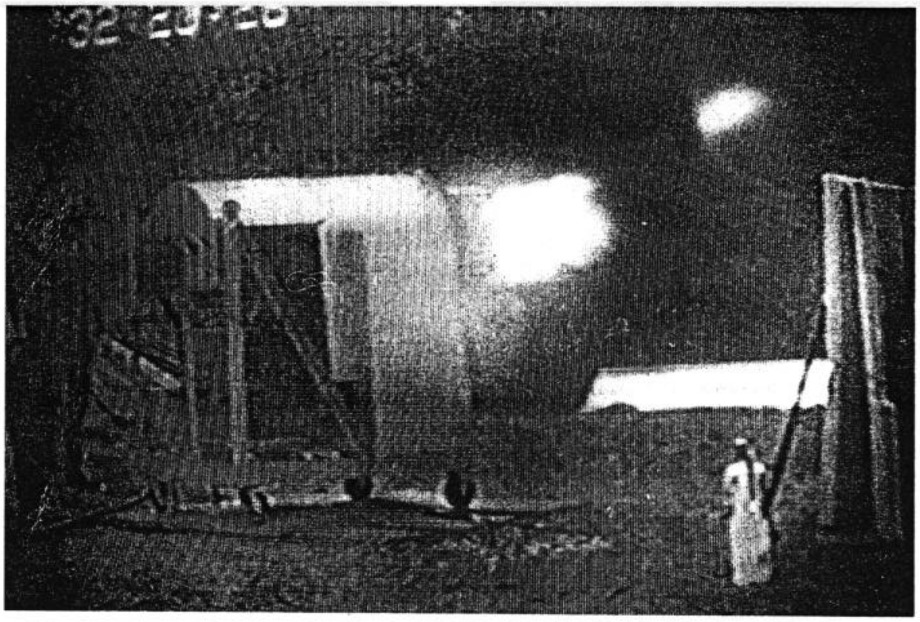


Figure 2 - Mark I prototype burning 2.2 L/min of diesel

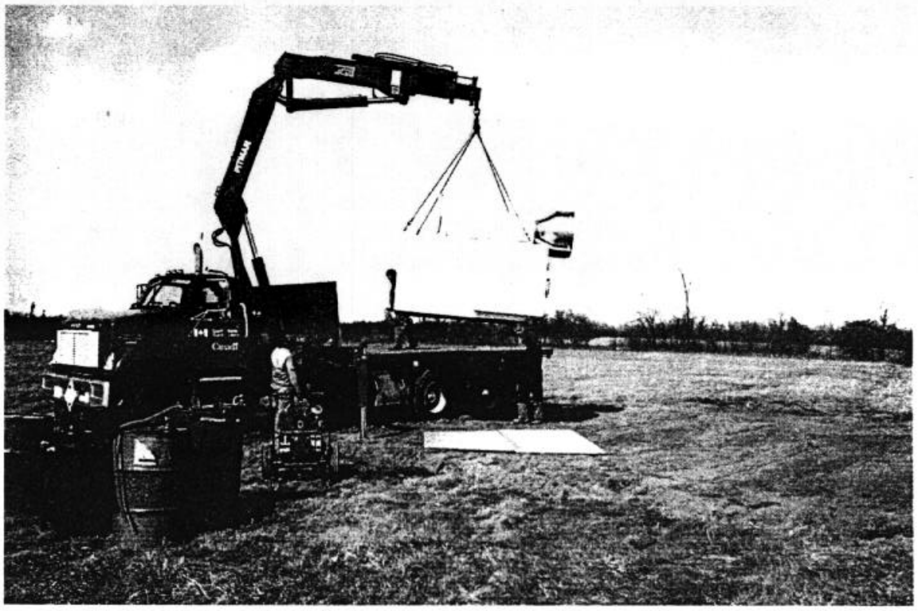


Figure 3 - The Mark II prototype SWIRLFIRE burner

In general, with the exception of a small leakage from the bolt holes in the collar on the rotating seal (noted previously in S.L. Ross 1989) and the need to provide a radiation seal for the front wheels, the Mark I SWIRLFIRE proved to be durable.

Based on these test results the nominal capacity of this burner would be 2.2 L/min (20 bbl/day) of water-free oil.

GENERAL LAYOUT OF MARK II PROTOTYPE

As a result of the Mark I tests, a prototype 100 bbl/day SWIRLFIRE (denoted here as Mark II) was designed and constructed by Energetex Engineering. This version incorporated many of the previous recommendations (Buist 1989).

Figure 3 shows the Mark II SWIRLFIRE prototype being lifted off a truck. The Mark II prototype weighs 1590 kg, including fuel, and is a fully self-contained unit. The 1.5 m high x 1.6 m x 2.6 m mechanical compartment, mounted on steel wheels, supports the 1.1 m long x 0.6 m diameter plenum which in turn supports the 0.8 m diameter stainless steel combustion head. The burner was also supplied with an external diesel tank which was not used during the tests.

Figure 4 shows the inside of the mechanical compartment looking into the rear through the opened wire-mesh doors. On the left is the radiator for the water-cooled diesel (Lister-Petter Model LPWS4), a 4-cylinder model producing 23 kW (31 HP) @ 2500 rpm and 28 kW (37.5 HP) @ 3600 rpm. Just to the right of the centre strut is the engine and flow control panel, consisting of a key, glow-plug activator switch, tachometer (0-3500 rpm) and throttle for the diesel and a needle-type flow control valve, a ball valve, a pressure meter (0-100 psi) and a pressure relief valve (for flow recycling back to the pump suction) for control of the fluid to the combustion head. The engine drives the feed pump, fan and rotary cup via "V" belts and sheaves at the following speed ratios:

Engine Speed	Fan Speed	Pump Speed	Cup Speed
min. 1000 rpm	600 rpm	480 rpm	1600 rpm
max. 2500 rpm	1500 rpm	1200 rpm	4000 rpm

On the right-hand wall of the mechanical compartment is the internal diesel fuel tank for the engine; below the fuel tank is the suction hose for the oil feed pump to the burner head.

Just visible in Figure 4 at the far end of the mechanical compartment is the Buffalo Forge Model MW45 centrifugal fan capable of moving 243 m^3/min (8600 cfm) of air against a pressure of 3 kPa (12 inches of water) at a speed of 1600 rpm while drawing 19.4 kW (26 hp). Between the fan and the engine/flow control panel is a priming funnel/valve for the feed pump.

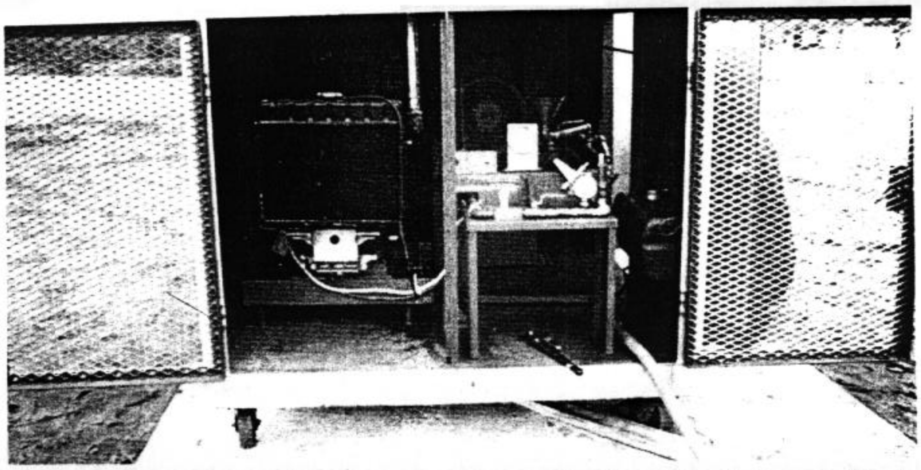


Figure 4 - Rear-view of Mark II prototype looking into mechanical compartment

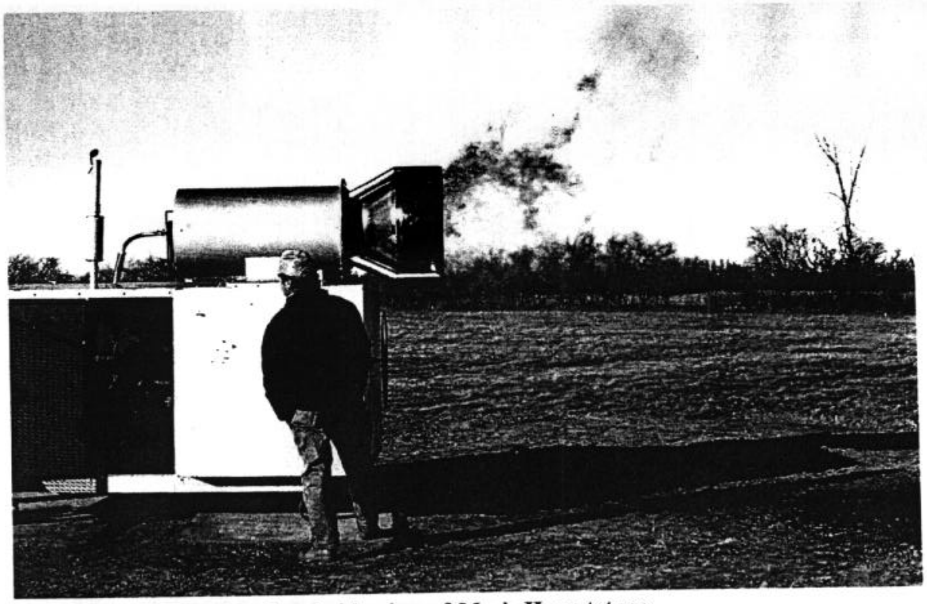


Figure 5 - Right-hand side view of Mark II prototype

Figure 5 shows the burner with the right-hand (with reference to Figure 4) compartment door open. Just visible is the Albany Pump size 10 gear pump used to feed oil to the burner head. With the engine at 1400 rpm the pump discharges 18.9 L/min of 1000 mPas (cP) fluid against a head of 350 kPa (50 psi); under the same conditions the pump discharges 17.0 L/min of 10,000 mPas fluid. At the maximum engine speed of 2500 rpm the pump discharges 31 L/min of 1000 mPas (cp) fluid against a head of 350 kPa (50 psi); under these conditions the pump draws 0.75 kW (1 hp).

The stainless steel combustion head (Figure 6) includes an ignition port, through which a burning torch is inserted, the cylindrical combustion chamber and air recirculation tubes. Beneath the combustion head is the wheel that operates a damper on the blower to regulate air flow to the combustion head. Air is blown up into the bottom of the plenum through a square transition piece; from there the air enters the combustion head through an annulus past the rotating cup. Droplets of fuel are atomized off the edge of the cup by this air and ignite in the combustion chamber. There is a short steel cylinder mounted inside the combustion head that acts as a secondary atomization area (using the principle of "hot plate" atomization) for viscous fuels. Four recirculation tubes direct air from the plenum backwards from the front of the combustion head towards the rotating cup to provide enhanced fuel/air mixing.

TESTING OF THE MARK II PROTOTYPE

Methods

These tests were conducted at the site of the Coast Guard Marine Radio Station in Cardinal, Ontario on March 19 and 20, 1991. The site was prepared by the placement of a 10 m x 10 m x 15 cm sand pad. The Mark II prototype was placed on 2 sheets of plywood (to allow its rotation in response to changes in wind direction) at the upwind corner of the sand pad.

The test oils used included diesel, Hibernia crude oil and Alberta Sweet Mixed Blend (ASMB) crude oil; it had been intended to test a Bunker "C" oil but, at the ambient temperatures of about 0°C, the Bunker "C" had gelled and was not tested. The properties of the fresh oils were (Bobra 1990):

Test Oil	**Viscosity (mPas = cP @ 0°C)**	**Density (kg/m^3 @ 0°C)**
Diesel	3.9	838
ASMB	47	847
Hibernia	10,000	877

A sample of the ASMB crude was artificially weathered by sparging air through it until it had lost 13% of its volume to evaporation. This would increase its viscosity to about 5000 cp at 0°C (Bobra 1990). Samples of the Hibernia oil were artificially weathered to

Figure 6 -Front-end view of Mark II prototype

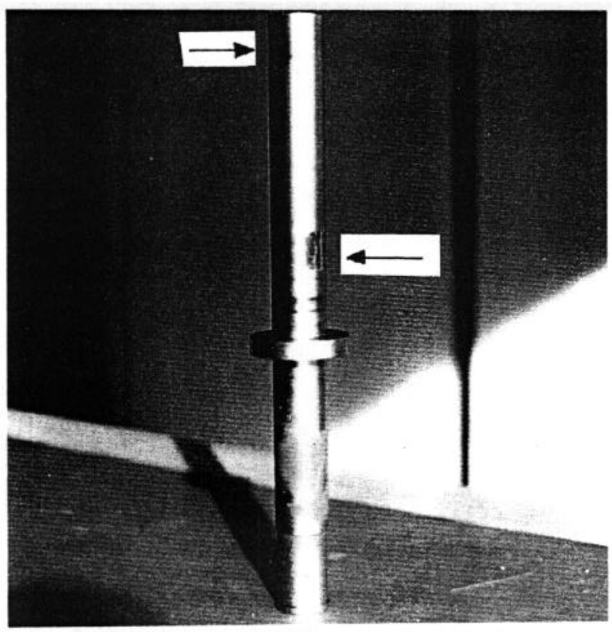


Figure 7-Worn shaft of hose connector

13% and 20% evaporated; the viscosity of these samples would be in the 100,000 to 300,000 cP range (Bobra 1990). These high viscosities are a direct result of the pour points of these weathered oils greatly exceeding ambient (0°C) temperatures.

Water-in-oil emulsions, created in a 50 L plastic garbage can using a paint mixing attachment on a ½" electric drill, were also tested. Emulsions of 33% and 50% by volume water were used.

Results

Pre-Test Adjustments. Prior to commencing the tests three relatively minor problems with the Mark II prototype had to be corrected. The first involved a slow, but steady leakage of oil from the rotating seal located in the shaft at the back of the plenum. The assembly was taken apart and the cause of the leakage determined to be wear on the shaft of the hose connector (Figure 7). The wear was concluded to have been caused by overtightening of the U-bolt holding the connector.

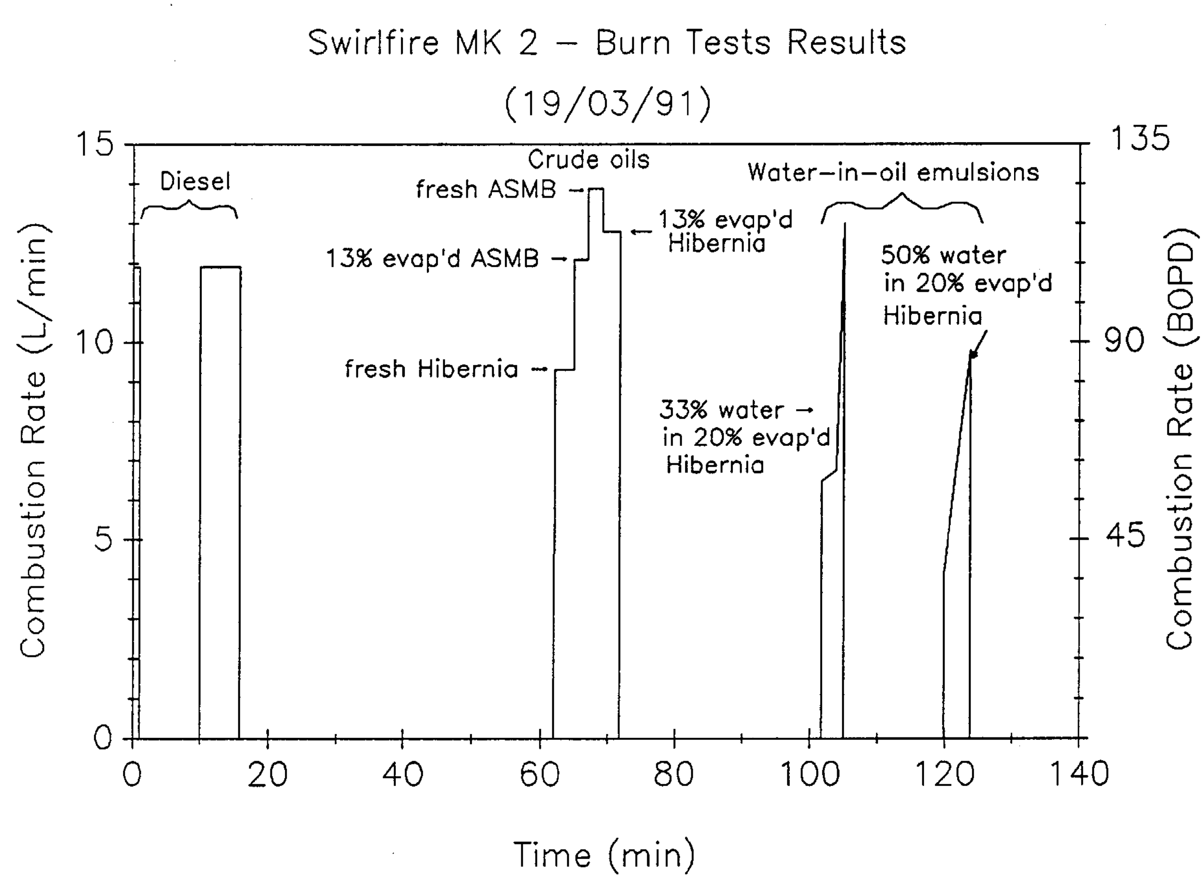
The second problem was an air bubble in the pump recirculation line that could not be purged. This resulted in sporadic failure of the pump to deliver fuel to the burner and flame extinction.

The third problem related to achieving the proper air flowrate and distribution for burning. A damper had been retrofitted to the Mark II prototype because, even with the engine idling, the air velocity in the combustion head was too high for a rag torch or oxy-acetylene torch to remain lit. It took several attempts to determine the proper balance of air flow and fuel flow to provide a stable flame.

Oil Burning Tests. Figure 8 and Table 1 show a summary of the test burn results. The first oil tested was diesel fuel; a maximum burn rate (with the flow control valve fully open) of 11.9 L/min (108 bbl/day) was achieved. This test was interrupted by a small grass fire ignited by diesel fuel sprayed onto the sand pad and grass in front of the burner during previous trial runs. The burn itself was very clean with no smoke (Figure 9); however it was clear that the fuel atomization for the Mark II prototype was not as good as in the Mark I prototype (note the burning fuel droplets at the bottom end of the flame in Figure 9) and that the swirling action of the flame noted during the Mark I prototype trials was not evident during these tests. These shortcomings should be easily overcome by simple changes in the combustion head and plenum; these possible changes are listed in the next section.

Figure 10 shows the Mark II prototype consuming 9.3 L/min (84 bbl/day) of fresh Hibernia crude oil. The less than perfect atomization is evident as is some smoke; some droplet fallout was also observed. Figure 11 shows the prototype burning 12.1 L/min (110 bbl/day) of 13% evaporated ASMB crude. With this less viscous oil better atomization was achieved allowing a higher burn rate (the flow control valve was fully open). The highest burn rate (13.9 L/min = 126 bbl/day) was achieved with fresh ASMB, the least viscous of the crudes tested. With this oil a clean burn was produced but oil droplets were still ejected from the flame (Figure 12).

Figure 8



Swirlfire MK 2 – Burn Tests Results
(19/03/91)
Diesel
Crude oils
fresh ASMB →
13% evap'd ASMB →
fresh Hibernia →
← 13% evap'd Hibernia
Water–in–oil emulsions
50% water in 20% evap'd Hibernia
33% water → in 20% evap'd Hibernia
Combustion Rate (L/min)
Combustion Rate (BOPD)
Time (min)
0
5
10
15
45
90
135
0
20
40
60
80
100
120
140

TABLE 1

Preliminary Test Results
Swirlfire MK II
Cardinal, Ontario - March 19,1991

Oil Type	Time (min:sec)	Oil Level (cm)	Volumetric Flowrate (L/min)	(BOPD)
Diesel	0:00	76*		
			11.9	108
	5:46	48		
Fresh Hibernia	0:00	30		
			9.3	84
	2:52	11		
13 % Evap'd Hibernia	0:00	33		
			12.8	116
	2:39	9		
20 % Evap'd Hibernia with 33 % emulsified water	0:00	25		
			6.46	59
	1:05	18		
			6.74	61
	2:05	13		
			13.0	118
	3:10	2		
20 % Evap'd Hibernia with 50 % emulsified water	0:00	30		
			4.1	37
	3:20	22		
			9.8	89
	3:55	18		
Fresh ASMB	0:00	32		
			13.9	126
	2:07	11		
13 % Evap'd ASMB	0:00	30		
			12.1	110
	2:05	12		

* diesel drawn from a 220 L drum; all crudes drawn from a 50 L garbage can

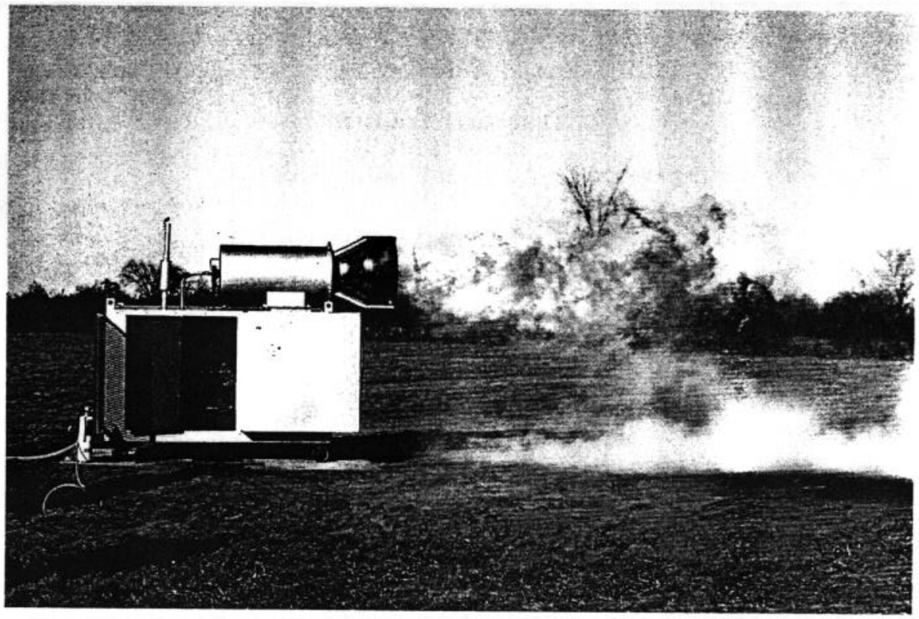


Figure 9 - Mark II prototype burning diesel fuel at 11.9 L/min

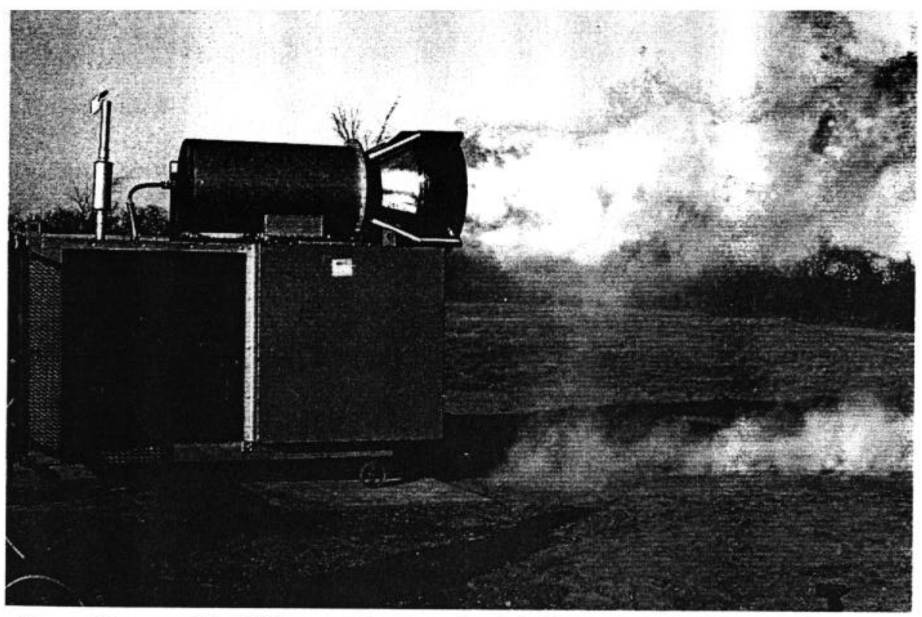


Figure 10 - Mark II prototype burning fresh Hibernia crude at 9.3 L/min

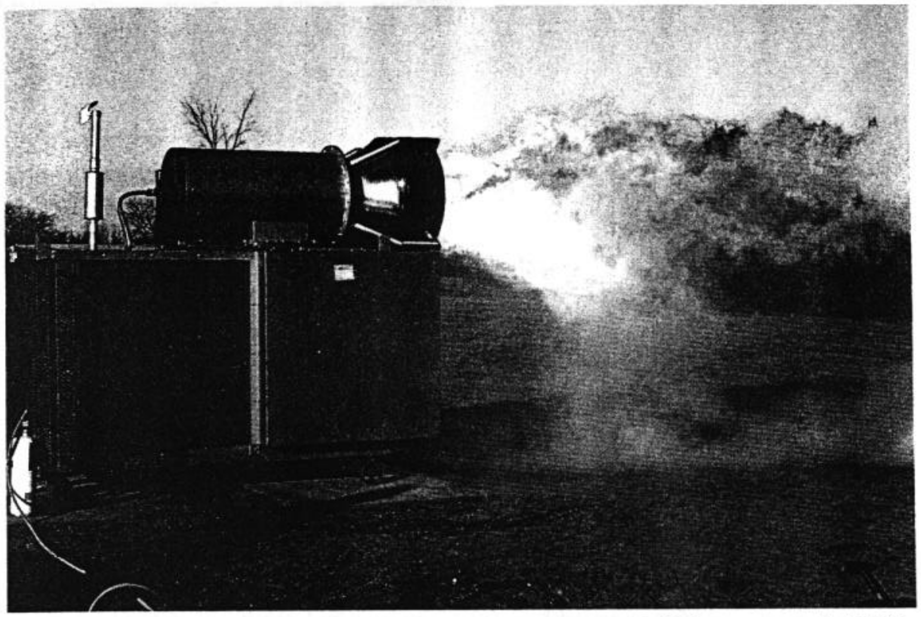


Figure 11 - Mark II prototype burning 12.1 L/min of 13% evaporated ASMB crude

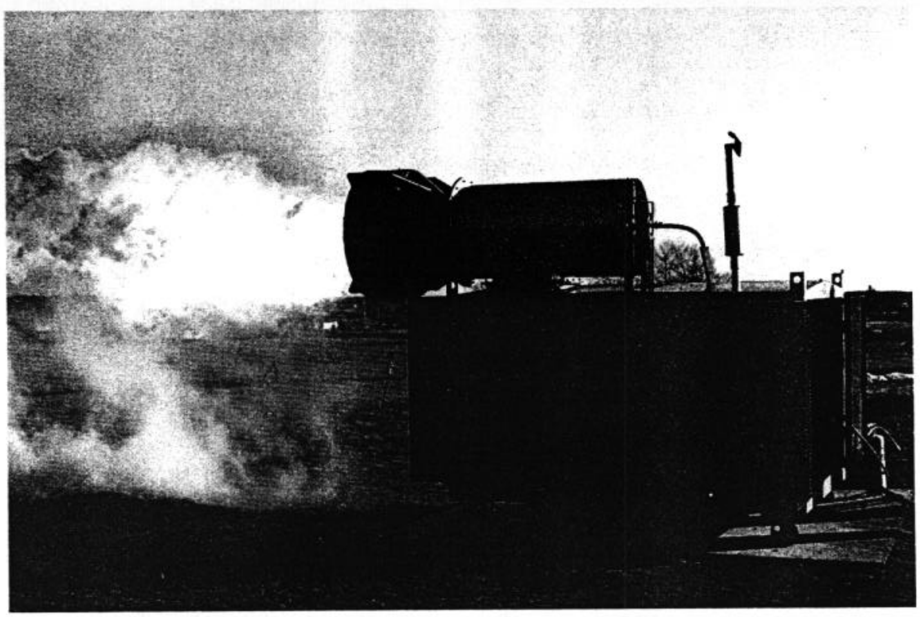


Figure 12 - Mark II prototype burning 13.9 L/min of fresh ASMB crude

Figure 13 shows the burn of 13% evaporated Hibernia oil at the same air and fuel settings as for the previous test; a clean burn was achieved but the fuel flow seemed to be restricted by the needle valve. A burn rate of 12.8 L/min (116 bbl/day) was measured.

The last two tests involved burning water-in-oil emulsions. The first of these resulted in the successful, clean burn of up to 13 L/min (118 bbl/day) of 33% water in 20% evaporated Hibernia crude. Significant numbers of droplets were ejected from the flame (Figure 14).

The final test involved burning a 50% water-in-20% evaporated Hibernia crude oil emulsion (Figure 15). This mixture did burn with a stable flame; however large droplets and foam were ejected from the flame (sufficient to pool and ignite on the sand pad) and the flame was somewhat smokey at a consumption rate of 9.8 L/min (89 bbl/day). Again, the maximum burn rate seemed to be fuel flowrate limited (probably due to restricted flow of this very viscous fuel through the needle valve). A slug of water drawn from the bottom of the pail in which the emulsion was mixed terminated this test by extinguishing the flame.

In general the prototype worked best at a reduced air flow (i.e., with the damper partially closed) and with the fuel flow control needle valve fully open. The needle valve seems to restrict the maximum possible flowrate to the combustion head to about 40 to 70% of the pump's rated capacity. It also seems that, as presently configured, more air enters the top of the combustion head than the bottom. Performance seemed to improve at higher engine speeds (2000 rpm vs. 1400 rpm). It was noted that a resonant vibration was set up at an engine speed of 1500 rpm.

Recommendations Arising from the Mark II Prototype Tests

As a result of the tests 14 recommendations for improvements to the prototype have been made. These are:

1. The existing model should be retrofitted with a larger diameter rotary cup in order to increase atomizing air velocity, reduce overall air flowrate and improve air/fuel droplet mixing.
2. Vanes should be retrofitted to the existing prototype in the plenum itself or on the rotating shaft behind the combustion head to impart a swirling action to the forced air as it enters the combustion head.
3. The needle valve regulating fuel flow to the combustion head should be replaced on the existing version with a valve that offers less resistance to flow (such as a ball or gate valve).
4. The fan on the existing model should be slowed down by replacement of its sheaves with larger ones.
5. The existing prototype should be retested with diesel fuel; during these tests each of the modifications in recommendations 1-4 should be made one at a time to determine their individual effect on the combustion process.
6. The existing U-bolt holding the hose connector in the rotating shaft should be modified to incorporate a sponge or soft rubber lining to allow a friction grip on the connector without imposing a vertical or lateral load on the internal needle bearings.

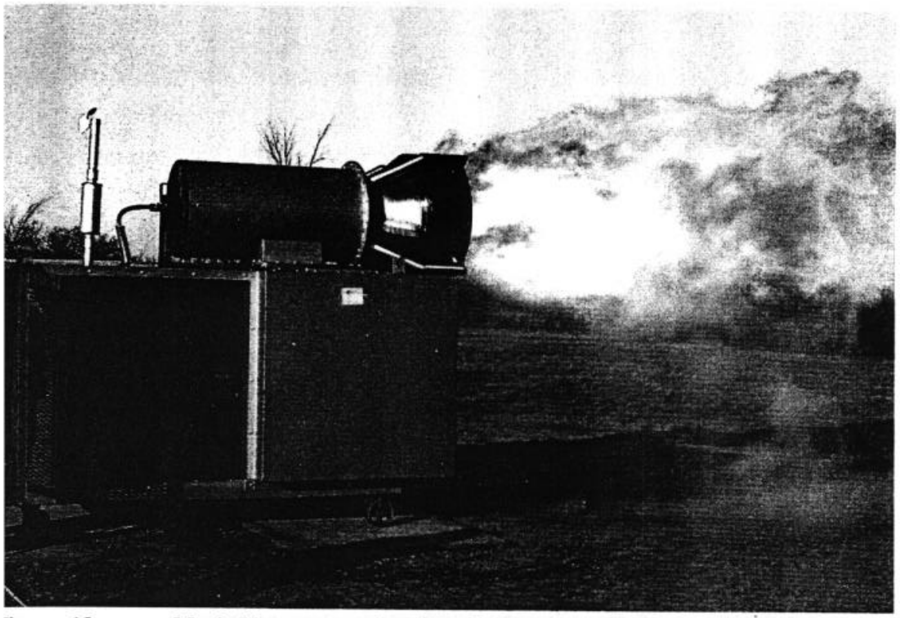


Figure 13 - Mark II prototype burning 12.8 L/min of 13% evaporated Hibernia crude

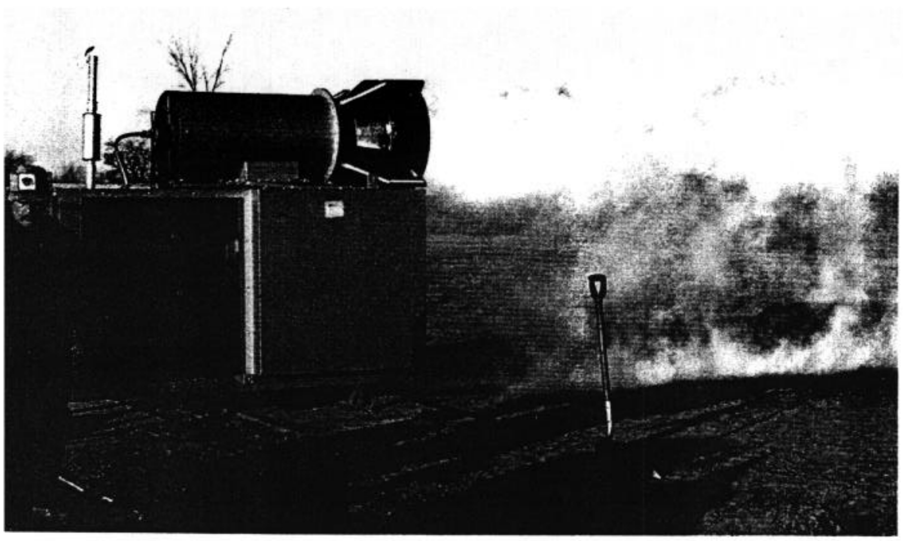


Figure 14 - Mark II prototype burning 13 L/min of 33% water-in-20% evaporated Hibernia crude emulsion

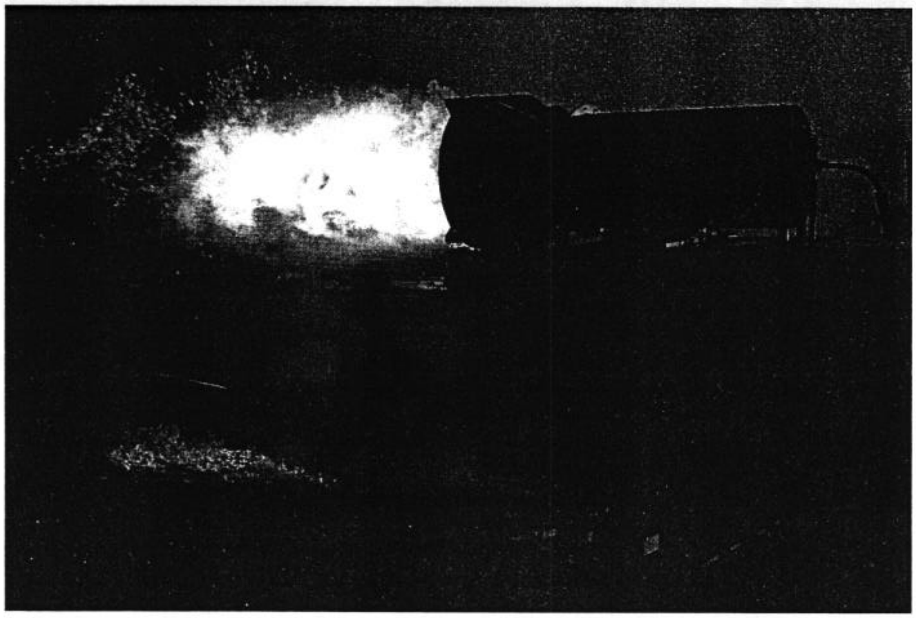


Figure 15 - Mark II prototype burning 50% water-in-20% evaporated Hibernia crude emulsion at 9.8 L/min.

7. An air distribution system may be required in the plenum to more evenly distribute air between the top and bottom halves of the combustion head.
8. Consideration should be given to increasing the number, size and/or location of the combustion air recycling tubes in the combustion head.
9. The feed pump recirculation system needs redesign, including moving the priming system for better access, allowing recycle back to the oil source (i.e., drum, porta-tank, etc.) and provision of an air bleed in the recycle system.
10. A slot is required to allow passage of the suction hose out of the burner housing when the access doors are closed.
11. The suction line from the oil source to the pump inlet should be of all 1" hose or pipe not a mix of 1" and ½" sizes.
12. The damper control wheel for the fan (if it is still required in future models) needs to be relocated to the side or back of the burner.
13. The geometry of the combustion head could be altered for better fuel/air mixing (i.e., a longer cylindrical section and/or a smaller, venturi-shaped outlet).
14. Consideration should be given to developing an optional preheater element to be placed on the ground under the flame for preheating.

It is noted that the weight goal (400 kg) for the 100 bbl/day prototype was not achieved; it was decided during the design stage for the Mark II prototype that the simplicity of design and operation offered by a single, self-contained unit was worth the weight penalty. The existing prototype is still portable by medium-lift helicopters such as the Bell 212 or 205A-1 (Huey), Aerospatiale AS 332L (Super Puma) and the Sikorski S-61 and Sea King.

If required, the 100 bbl/day SWIRLFIRE could be redesigned into two packages, each weighing less than 900 kg; however it is unlikely that it could be redesigned to meet the goal of heliportability by a Bell 206.

SUMMARY

The original Mark I prototype SWIRLFIRE burner was tested for its maximum capacity for long-term operations. The device successfully burned up to 2.25 L/min (20 bbl/day) of a weathered crude oil and up to 3.2 L/min (29 bbl/day) of diesel fuel.

With this data and recommendations from previous trials a 100 bbl/day prototype was designed and constructed by Energetex Engineering. This Mark II prototype was tested with a variety of oils and proved successful in burning diesel fuel at 11.9 L/min (109 bbl/day); crude oils at up to 13.9 L/min (126 bbl/day); and, emulsions with water contents up to 50% at rates up to 13 L/min (118 bbl/day).

Recommendations were made to improve fuel atomization and air/fuel mixing in the Mark II prototype and thus eliminate droplet fallout and flame blowout. Suggestions to further enhance the prototypes capabilities were also made.

ACKNOWLEDGEMENTS

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