FINAL REPORT

Report on Fire Boom Tests at Ohmsett in October, 2000

for:

U.S. Department of the Interior
Minerals Management Service
Herndon, VA

by:

SL Ross Environmental Research

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The project described in this report was funded by the U.S. Minerals Management Service (MMS) through Purchase Order 17093.

Executive Summary

The objective of this study was to conduct enhanced-propane burn tests at Ohmsett with two types of fire boom that are currently stockpiled for use in the United States.

The SWEPI fire boom for broken ice conditions passed the fire boom test protocol; however, its performance in the fire test portion was probably greatly influenced by its being frequently over-washed by waves. Such waves would not likely be present in its intended operating environment (among broken ice). The boom was able to contain approximately 56 mm (2.2 inches) of low-viscosity oil after the wave stress and fire tests. It was clear that this was the operational, calm-water draft of the boom.

The version of the Oil Stop, Inc, Auto Boom Fire Model tested was an older model (see Section 3 for a list of changes in newer models). After two hours of exposure to waves prior to the fire tests, it was exhibiting some cracking of the outer stainless steel mesh cover. It failed, by melting of a hole in the pressurized air-inflated flotation chamber membrane, after 1 hour and 24 minutes exposure to flames.

A short test of the minimum water flow required to ensure the survival of a boom covered by a water-cooled blanket was also carried out. The Oil Stop water-cooled blanket section failed in the flames when the cooling water flow was reduced to 16.3 L/min (4.3 gpm).

Acknowledgements

The U.S. Minerals Management Service (MMS) through Purchase Order 17093 funded the project described in this report. The authors of this report were Ian Buist and James McCourt. The authors would like to acknowledge the contributions of Mr. Jim Lane and Mr. Joe Mullin, with MMS, and the staff of MAR, Inc. who operate Ohmsett. As well, Alaska Clean Seas and Oil Stop, Inc. kindly donated sections of fire boom for the tests. The U.S. Navy Supervisor of Salvage generously loaned some equipment for the testing of a small section of water-cooled fire blanket.

Disclaimer

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1. Introduction

1.1 Background

In situ burning is rapidly gaining acceptance as an operational oil spill response tool for eliminating large quantities of spilled oil from the water surface. Many areas of the US Outer Continental Shelf (OCS) have pre-approval, or expedited approval for the use of *in situ* burning in response to such spills. Contingency plans are incorporating the use of burning as a response technique, and burn equipment packages, including fire boom, are being staged for use. This presents regulators with a difficult challenge: in order to assess the adequacy of given response equipment packages, the expected performance and survivability of the various components need to be evaluated. This is particularly important for *in situ* burning in response to blowouts, where the boom would likely be deployed in the path of the escaping oil to burn slicks continuously, as opposed to the batch mode that is recommended for large slicks from vessel spills. In the continuous mode, the fire boom is exposed to a much longer-lasting heat insult.

Much effort has been expended over the last few years by the Minerals Management Service (MMS), the US Coast Guard (USCG), the Canadian Coast Guard (CCG), the US Navy and others on testing prototypes of commercially-available fire boom prototypes. The results have indicated that the refractory fabric-based models tested to date have a limited operational life. Two common refractory fabric fire booms, (Alaska Clean Seas' [ACS] Shell Western Exploration and Production, Inc. [SWEPI] fire boom for ice-covered waters and the Oil Stop, Inc. Auto Boom Fire Model) which collectively make up a significant fraction of existing stockpiles, have never been quantitatively tested in their expected operating environment. Determining the survivability of these untested fire booms was identified as a high priority by an international panel of oil spill experts at the recent workshop on *in situ* burning in New Orleans, LA (Laferriere 1998 in Walton and Jason 1998) and is the subject of this project.

The purpose of this research study was to obtain sections of the two unproven fire booms and subject them to the Ohmsett enhanced-propane fire test protocol. The information obtained on these models will help fill out the matrix of fire boom performance characteristics and permit regulators to make justifiable, scientifically-based decisions on the suitability of burn equipment packages for the intended operating environment.

These two untested models may be the fire booms that will be used in the first actual *in situ* burn operation on the OCS, and knowing their capabilities and limitations in advance will greatly increase the faith of stakeholders in the ability to conduct safe and effective burn operations. Support for *in situ* burning as a viable oil spill cleanup option will be significantly diminished if the first real response fails due to poor boom performance.

The Ohmsett Enhanced-Propane Test Protocol

Recognizing the need for a realistic test to evaluate the performance of fire-resistant boom, MMS and the CCG jointly funded the development of a test protocol and propane-fuelled apparatus.

Following two years of development and refinement that culminated in a successful trial in 1997 (McCourt *et al.* 1997 and 1998), MMS and the US Navy Supervisor of Salvage (SUPSALV) installed the system at Ohmsett.

The main component of the system is an underwater bubbler. The bubbler consists of eight 3.6 m (12-ft) lengths of perforated ¾-in. hose that evenly distribute propane to a 3.6 m by 3.6 m (12 ft by 12 ft) area. The hoses are held parallel to the long dimension of the tank by a welded frame of aluminum angle. The frame is supported on four feet that rest on the bottom of the tank.

Propane is supplied from two 10,500-gallon road tankers. The flow of propane is controlled at a regulator bank, which can feed propane at up to 1800 kg/hr (4000 lb/hr). Twenty cubic metres of air per minute (750 cfm) of air is provided by a portable compressor. The air is injected into the flames by eight air nozzles (four per side) that extend 20 cm (8 in.) above the surface of the water. Injecting compressed air into the flames minimizes smoke and increases the amount of heat produced. The air nozzles are designed to follow the waves.

At the design flow rate of 1500 kg (3300 lb) of propane per hour, the heat flux produced by the fire is identical to that measured during the diesel fire test protocol developed by NIST (Walton *et al.* 1998 and 1999) for the USCG and MMS.

The system was used in 1998 to evaluate the performance of four fire boom systems (McCourt *et al.* 1999). Three of these were actively-cooled blankets that were draped over a conventional inflatable boom. The fourth was a stainless steel fire boom. The candidate booms were deployed lengthwise along the wave tank, centered over the bubbler frame. The booms were exposed to three sessions of one hour of burning in waves followed by one hour of waves alone, as specified in the draft ASTM fire boom test standard. Most recently (August 2000) the system was used to test several different versions of temporary fire protection for conventional containment booms (SL Ross and MAR 2000).

1.2 Objective

The objective of this study was to conduct enhanced-propane burn tests at Ohmsett with two types of fire boom that are currently stockpiled for use in the United States.

1.3 Report Contents

The next section of this report contains a description of the equipment and methods used in the tests. Section 3 describes the 15-minute benchmark burn used to test the system components and confirm the heat flux produced by the fire. Section 4 contains the test results for the Alaska Clean Seas (ACS) Shell Western Exploration and Production, Inc. (SWEPI) fire boom for ice-covered waters. Section 5 summarizes the results for the Oil Stop, Inc. Auto Boom Fire Model. Section 6 describes a minimum water flow test using a short section of the Oil Stop, Inc. blanket. Conclusions and recommendations are contained in Section 7. Test plans, instrument calibrations, raw data and field notes may be found in the Appendices.

2. Summary of Equipment and Methods

2.1 Equipment Layout

The tests were carried out at Ohmsett during October, 2000 using the air-enhanced propane fire test system, (Figure 1) described in McCourt et al. 1999. A detailed test plan documenting the procedures may be found in Appendix A. Compared to the equipment used in 1998, there were a few minor modifications to the test systems for this series: a larger air compressor was used (rated at 750 cfm); the bubbler frame was welded into a stiff, bottom-founded structure (Figures 2 and 3), as opposed to an articulated, floating frame; and the air injection nozzles were modified to only move up and down with wave action, rather than floating tethered at the end of an anchored chain.

Propane was supplied from two 10,500 gallon propane tankers located at the east side of the tank (Figure 4). The flow of propane to the underwater bubbler frame was controlled by a series of pressure regulators and valves also located at the east side of the tank (Figure 5). The flow of compressed air was controlled with a series of valves and flow meters from the same location (also shown in Figure 5).

The following instrumentation was installed to record various data (see McCourt et al. 1999 for specifics):

- Meters to measure the flow of propane gas and compressed air.
- Pressure transducers to monitor the pressures of compressed air manifold and propane gas on both sides of the regulator bank.
- Thermocouples to measure the temperatures of the compressed air in the manifold and propane gas on both sides of the regulator bank.
- Four Type K thermocouples mounted on a moveable instrument stalk at heights of 25, 30, 35 and 40 cm (10", 12", 14" and 16"- denoted as 4, 3, 2, and 1 respectively) above the calm water level to measure flame temperatures.
- Two total heat flux transducers (THFTs - MEDTHERM model 64-20-1080-20) suspended from a chain stretched across the tank above the bubbler frame (Figure 6) to measure the heat flux produced by the flames. The THFTs were mounted to “look” at the flames across the test section of boom.

In addition, readings of the Percent Full, Pressure and Temperature gauges on the two propane tankers were taken periodically. Calibration data for the various instruments may be found in Appendix B.

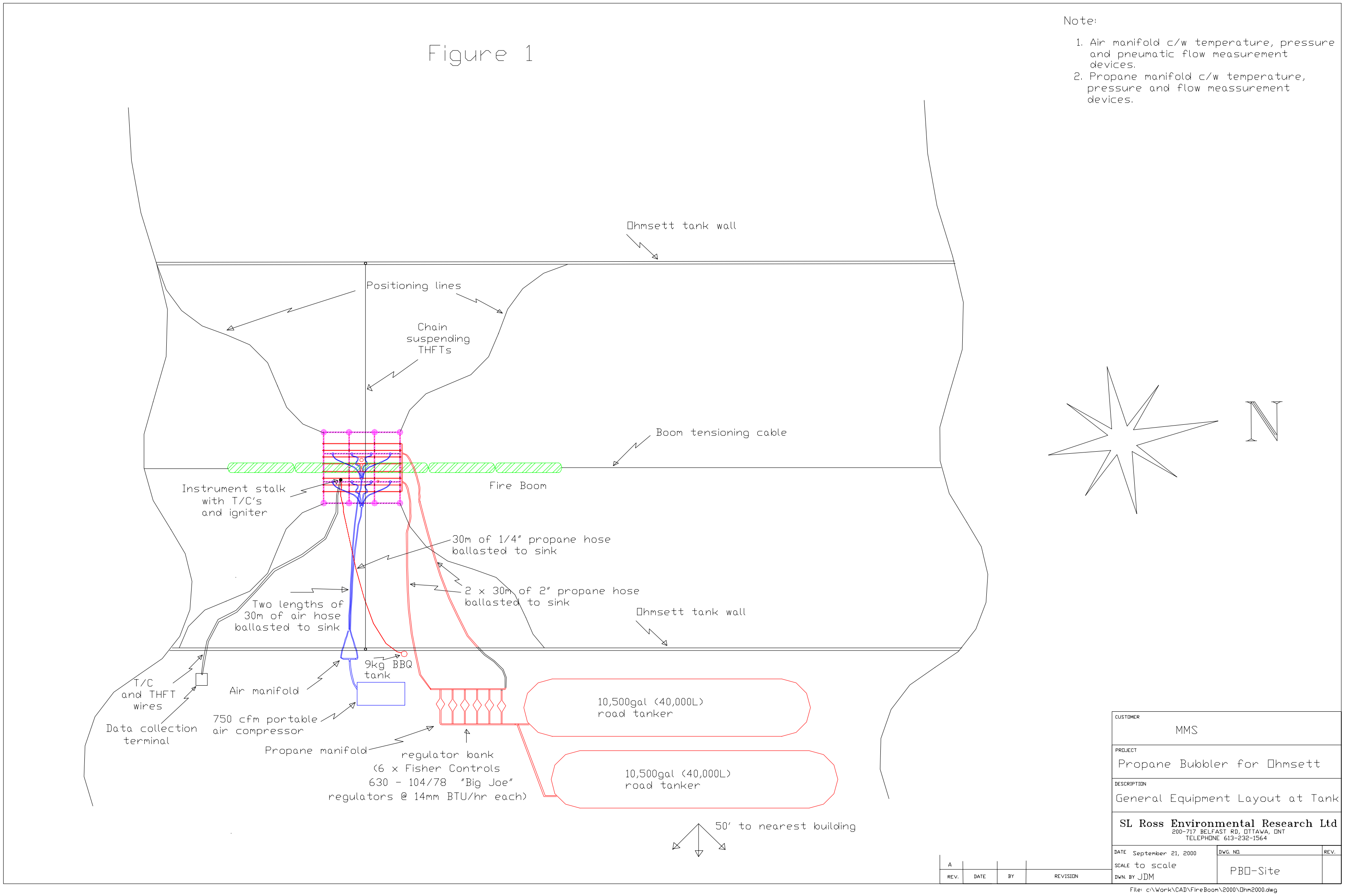


Figure 1

Note:

1. Air manifold c/w temperature, pressure and pneumatic flow measurement devices.
2. Propane manifold c/w temperature, pressure and flow meassurement devices.

CUSTOMER
MMS

PROJECT
Propane Bubbler for Ohmsett

DESCRIPTION
General Equipment Layout at Tank

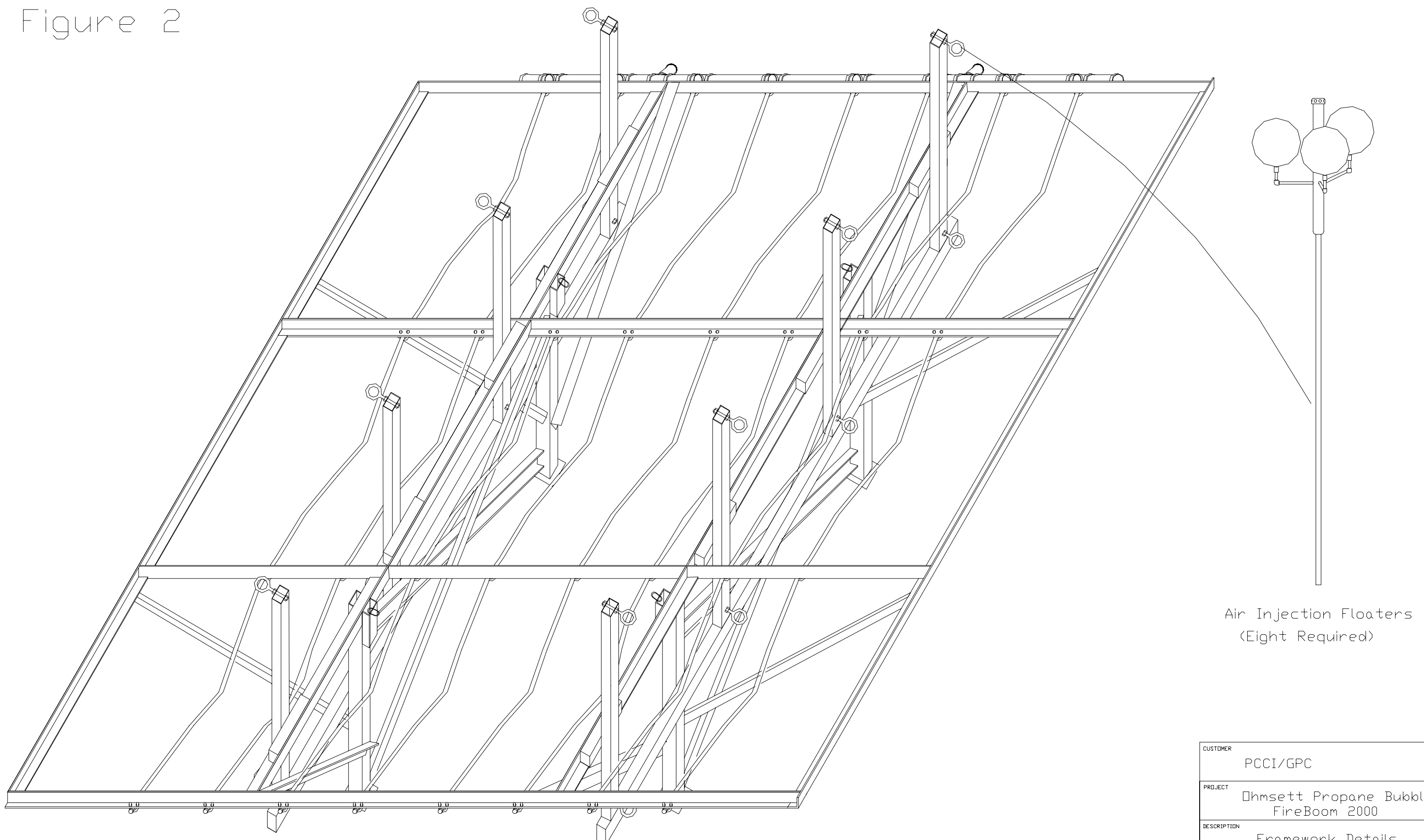
SL Ross Environmental Research Ltd
200-717 BELFAST RD, OTTAWA, ONT
TELEPHONE 613-232-1564

REV.	DATE	BY	REVISION
A			

DATE September 21, 2000
SCALE to scale
DWN. BY JDM
DWG. NO. PBO-Site
REV.

File: c:\Work\CAD\FireBoom\2000\Ohm2000.dwg

Figure 2



Air Injection Floaters
(Eight Required)

CUSTOMER
PCCI/GPC

PROJECT
Ohmsett Propane Bubbler
FireBoom 2000

DESCRIPTION
Framework Details

SL Ross Environmental Research Ltd
200-717 BELFAST RD, OTTAWA, ONT
TELEPHONE 613-232-1564

DATE February 22, 2001
SCALE to scale
DWN. BY JDM
DWG. NO. PBO-FrameDetails
REV.

REV.	DATE	BY	REVISION
A			

File: c:\Work\CAD\FireBoom\2000\Fram2000.dwg

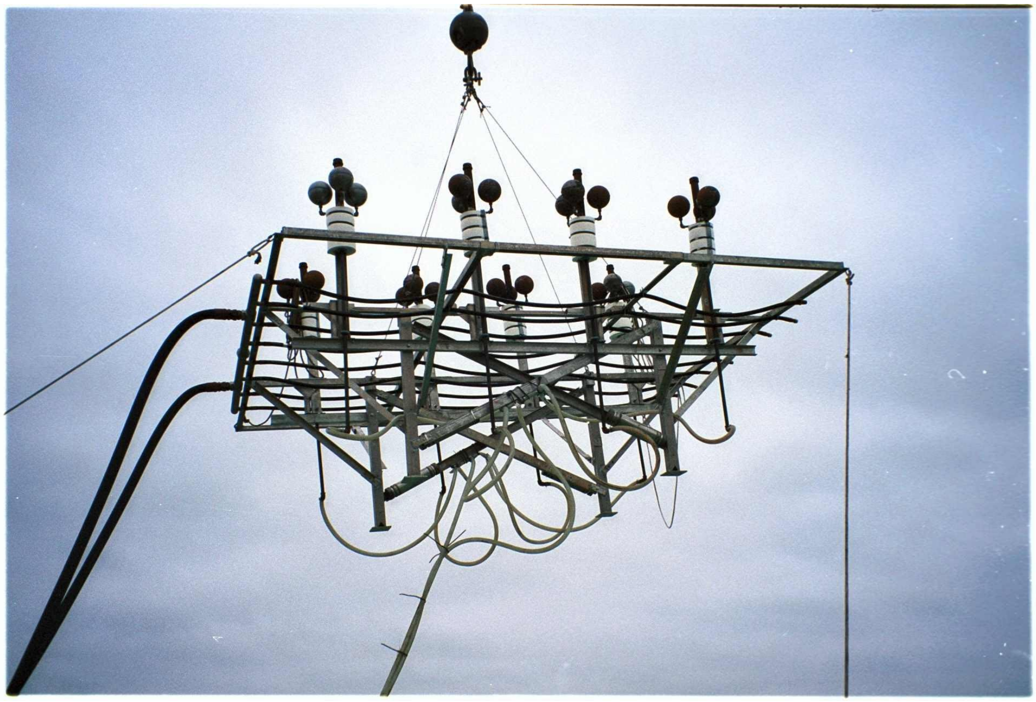


Figure 3 - New welded bubbler frame; note air nozzles telescoping mounts.

Figure 4 - Propane tankers parked on east side of tank.

Figure 5 - Propane regulator bank and compressed air manifold valves.

Figure 6 - THFTs suspended from chain stretched across tank..

2.2 Test Descriptions

The candidate booms were exposed to a four-stage test protocol.

Pre-burn Wave Stress Test

This test involved stressing a long section of the candidate fire boom under realistic tension loads for a period of two hours in large waves. The boom was installed longitudinally in the tank (Figure 7) and tensioned by a win. The tension load imposed was to simulate that expected for a 150-m (500-foot) length of the candidate boom deployed in a "U" configuration at sea in 1-m (3-ft) waves in a 0.75 knot current (or sweeping speed), nominally 1100 N (250 lb_f). The tension was measured by 4000-lb load cells mounted on the south end of the test section of boom. The longitudinal stresses in the boom and the wave characteristics were monitored using the Ohmsett data acquisition system. Short-period waves, approximately 0.4 m (16 in) height, were generated by the wave maker (set at 27 cpm using a 4.5-in stroke). These waves were used to accelerate axial bending and flexing of the test boom and its components, as would happen to a real boom over a much longer time period.

After the test any sacrificial covering was carefully removed so that the underlying fire resistant components could be examined non-destructively. This should not affect the subsequent performance of the boom, since the cover is intended to burn up on exposure to flames. Particular attention was paid to the appearance of the refractory material and structural members, and the presence of any loose fibers. Photographs of the conditions of the boom were taken.

Test in Waves and Flames

The boom was positioned over the propane bubbler frame so the middle 4 to 5 m (13 to 16 feet) would be immersed in flame and then it was re-tensioned using the win to 1,100 N (250 lb_f). The instrument stalk holding the ignitor and the thermocouples was positioned as near as possible to the flame center, but not interfering with the motion of the fire boom (Figure 9).

Electronic signals from the various instruments were brought to a tank-side bank, conditioned, then sent to the Ohmsett data acquisition system in the Control Tower via the Main Bridge. Readings from the THFT's were recorded tank-side with an Omega OM-200 data logger located at the regulator bank.

An in-line load cell was located at the south end of the boom, attached to the Main Bridge. It was used to record boom tensions during the tests. Portable cameras (35 mm still, digital and video) were used to record the testing from various perspectives.

Flames were generated along both sides of the middle of the candidate boom (Figure 8). The width of the flames on each side of the boom was approximately 1.2 m (4 ft). Once the flames had been established, waves were generated at the south end of the Test Basin and controlled by the Bridge Operator in the Control Tower at the north end. The waves were recorded using a

Datasonics ultrasonic distance meter. The signal from the wave meter was conditioned, recorded and analyzed after testing to confirm the wave characteristics.

To summarize, the protocol for this portion of the test was to subject the candidate section of boom to three cycles of flame of one hour duration, interspersed by two cycles of one hour of wave action with no flame, as specified in the draft ASTM fire boom test protocol. Regular waves of approximately 0.3 m (12 in) high with a wave length of 18 m (60 ft) were generated in the tank (with the wave generator operating at 27 cpm with a 4.5-in stroke and the wave beaches raised), simulating Sea State 2.

The following procedures were carried out for each day's testing with propane flames:

1. Notify and coordinate with NWS Earle security and fire departments.
1. Test propane leak detectors.
2. Connect hoses to propane tankers.
3. Turn on water to fire suppression system.
4. Set pre-tension on boom to 1,100 N (250 lb_f).
5. Turn on cooling water to THFT's and visually confirm flow.
6. Start air compressor for air-injection system.
7. Open safety shut-off valves on propane tankers.
8. Open vapor feed valve on propane tankers and leak test fittings.
9. Record % Full, temperature (T) and pressure (P) from gauges on propane tankers.
10. Start wave generator motors.
11. Light pilot.
12. Start data acquisition, synchronize stopwatches with computer elapsed time.
13. Open propane flow valve at manifold to start flow to bubbler; record ignition time.
14. When ignition of propane on both sides of the boom is confirmed, increase flow to maximum with no visible smoke.
15. Start air flow; adjust valves until air is flowing equally to both sides of boom.
16. Increase propane flow to desired setting (generally both valves between ⅜ and ⅝ open).
17. Turn off flow to pilot light.
18. Start waves; record elapsed time as first wave reaches boom.
19. Periodically record air temperature, pressure and flow rate at propane regulators and air manifold; periodically record % Full, T and P from gauges on propane tank.
20. After 1 hour of flames, turn on pilot light flow, turn off propane then turn off compressed air.
21. Record % Full, T and P from gauges on propane trailer.
22. Turn off data acquisition.
23. Turn off cooling water to THFTs
24. Check boom tension (stop waves and re-tension boom if necessary).
25. Re-start waves, if stopped.
26. After one hour cooling off period in waves, check boom tension (stop waves and re-tension if necessary) repeat from Step 4 until three burn cycles have been completed (only two cool-down periods are required).

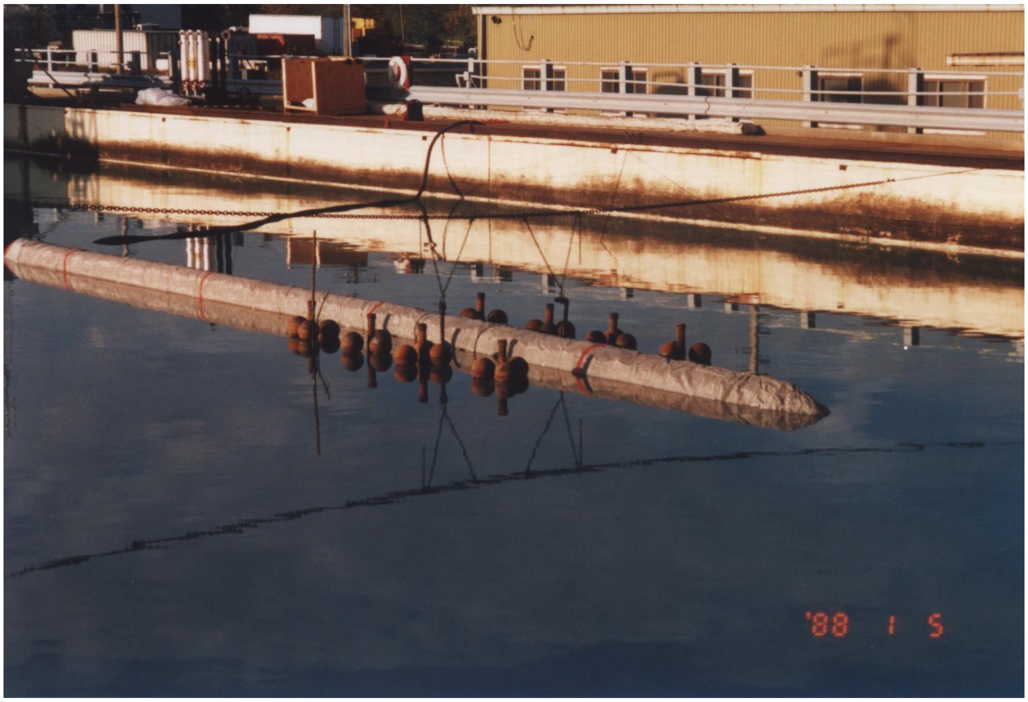

'88 1 5

Figure 7 - Boom deployed in tank for pre-burn wave stress test.

Figure 8 - Boom undergoing burn test in waves.

Figure 9 - Instrument stalk supporting ignitor and flame thermocouples

.
Figure 10 - Boom undergoing thick oil containment test.

27. At end of day turn off propane flow by shutting tanker flow valves, turn off waves, shut down compressor, disengage shut-off valves, disconnect hoses from tankers and join hoses together.

Post-Burn Wave Stress Test

Similar to the pre-burn wave stress test, this test involved subjecting fire boom candidates that passed the fire test to another two hours under tension in large waves. The longitudinal stresses in the boom and the wave characteristics were monitored. The wave generator was set as described above. After this test the booms were removed from the tank and examined.

Static Thick Oil Containment Tests

Boom models that successfully passed the post-burn wave stress test were subjected to a static thick oil containment test. This final test involved assessing the capability of the candidate boom to contain thick slicks of low viscosity oil (a blend of JP-5 and diesel with a viscosity of 10 mPas [cP] was used), simulating a full-scale layer of burning oil in the pocket of a boom under tow. A section of the boom, consisting of at least the 4.6 m (15 feet) that had been exposed to the propane flames was connected in a circle (Figure 10). Measured quantities of the low-viscosity oil were poured onto the water surface inside the circle and the boom examined for leakage after each volume increment. Oil was added until significant leakage was noted. The location and apparent reason for the leakage was recorded.

2.3 Fire Boom Descriptions

The two booms put through the test protocol were: the SWEPI fire boom for use in broken ice conditions; and, an early version of the Oil Stop, Inc. Auto Boom Fire model. A brief description of each is given below. More detailed specifications may be found in Appendix C.

2.3.1 SWEPI Fire Boom for Ice-covered Waters

Several models of this boom were developed and refined in the early 1980s by Shell Western Exploration and Production, Inc. in Alaska for *in situ* burning operations in broken ice situations. It was intended to be deployable without vessel support (i.e., by helicopter) among ice floes to temporarily contain oil and maintain its existing thickness for burning. Several thousand feet of various versions of this boom are stockpiled by Alaska Clean Seas on the North Slope.

The SWEPI boom supplied for these tests (Figure 11) had no skirt, to prevent its snagging on ice floes, and a low freeboard, to reduce weight. Flotation was provided by two 7-in diameter stainless steel paint cans lashed side by side; the membrane consisted of a double layer of refractory fabric wrapped around pairs of paint cans laid end-to-end. The refractory fabric was stitched lengthwise and held on the cans with a metal band. The tension member was a steel

Figure 11 - SWEPI Fire Boom on deck

Figure 12 - Oil Stop, Inc. Auto Boom Fire Model on deck.

chain contained inside the membrane that extended from one end of a section to the other. The chain extended about 15 cm (6 in) beyond the section length to allow connection to another section using shackles; a flap of refractory fabric at the ends of each boom section allowed the connection to be covered with the membrane material (by placing the flap over the next boom section) to prevent oil leakage. The section of boom supplied for the tests was 11 m (36 feet) long with a width of 36 cm (14 in), and a draft of 5 cm (2 in).

2.3.1 Oil Stop, Inc. Auto Boom Fire Model

This fire boom is designed to be deployed from a reel and inflated with a low-pressure blower. The version tested was an older model (estimated by the manufacturer to be about three generations old). The boom tested (Figure 12) consisted of a fire-resistant insulating cover (comprised of a sandwich of stainless steel screen containing a refractory felt mat wrapped with a polyethylene film) over coated glass fabric floatation chamber and skirt membrane. A chain in a pocket in the bottom of the skirt functioned as both ballast and tension member. The boom was inflated at one end, with air communication between all flotation chambers in one section.

According to the manufacturer, the version of the Auto Boom Fire Model that is currently produced incorporates several modifications to the version tested:

- The stainless steel mesh is now laminated to a polyurethane-coated polyester fabric to make the screen more durable prior to exposure to fire, and to make it safer to handle.
- The fabric used to make the air chambers has been changed to an unreinforced film. The coated glass fabric was susceptible to excessive wear where repeated flexing occurred. As well, the new film is much less likely to allow the boltholes at the connectors to wallow.
- The material in which the refractory mat is wrapped was changed to a vinyl-coated polyester fabric for greater protection and stability than the original polyethylene film.

The boom tested had a freeboard of approximately 30 cm (12 in) and a draft of approximately 46 cm (18 in).

3. Benchmark Burn

Part of the protocol for the enhanced-propane burn tests calls for a 15-minute burn to be carried out, without a boom in the bubbler frame, prior to the commencement of the tests. This short-duration burn is used for two purposes: first, it provides a opportunity to confirm correct operation of the test apparatus, safety systems and data acquisition components; and second, it provides a benchmark of the total heat flux produced by the fire, without a candidate boom immersed in the fire.

Figure 13 shows the 15-minute burn at approximately 1:30 pm on October18, 2000. At the time the winds were light (6 mph) and from the east (from left to right in the photograph). A light rain was falling. Figures 14 and 15 show the total heat fluxes recorded from the THFTs positioned on the east and west sides of the center of the fire. Unfortunately, the data acquisition system was not recording the propane flow rate at the manifold for this test, thus no mass flow data is available to correlate with the THFT output. The field notes taken during the test indicate that the propane vapor flow valves were initially set to ½-open. After 3 minutes, the valves were increased to ⅜-open. At the 8-minute mark the valves were closed slightly to ½-open. At 12 minutes, 20 seconds the valves were increased to ¾-open for the remainder of the test.

As the heat from the fire warmed the chain suspending the two THFTs in the flames the chain stretched, lowering the THFTs. Approximately two minutes into the 15-minute test burn this caused the THFTs to submerge. They were raised at the 4 ½-minute mark by re-tensioning the support chain. They were lifted again 10 minutes and 40 seconds into the burn. The mounting system for the THFTs should be modified in future to incorporate a constant-tension system (e.g., using a cable over a pulley attached to a weight suspended in air) to tension the chain.

Despite these problems, the THFT data showed that the fire was producing heat fluxes that satisfy the draft ASTM standard for testing of fire booms, which calls for "...direct fire exposure with an average heat flux of 100 kW/m^2 or greater...with peaks of 100 to 150 kW/m^2...".

Figure 15 shows the flame temperatures recorded during the 15-minute test burn. The temperatures are lower than would normally be expected (in the 800 to 900°C [1500 to 1600°F] range). This was likely due to the placement of the instrument stalk holding the thermocouples on the east side of the bubbler frame and the increased height of the thermocouples above the waterline to account for the larger waves used in these tests, combined with the east wind blowing during the tests.

Figure 13 - 15-minute test burn

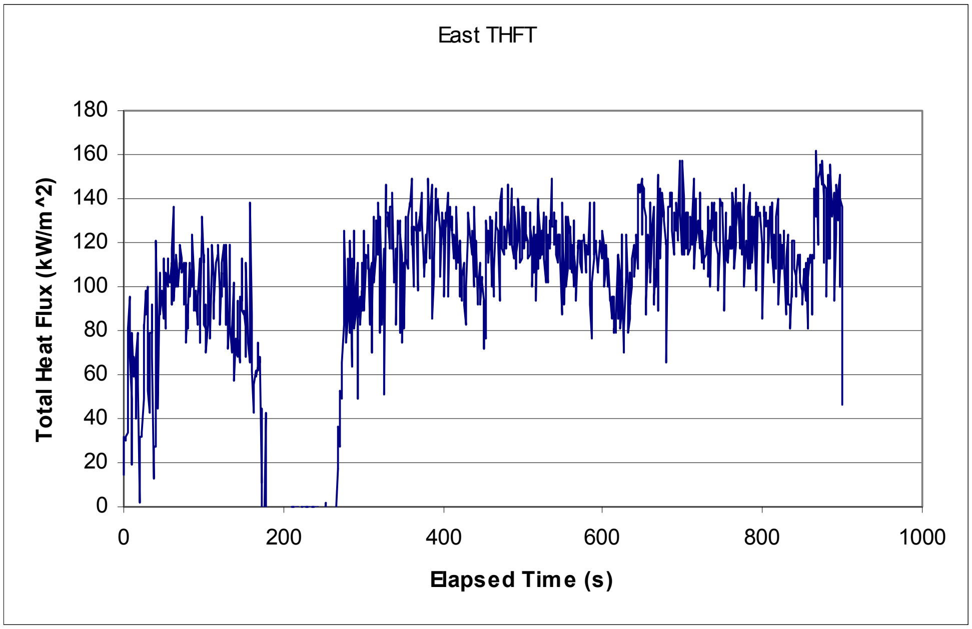


Figure 14 - East THFT

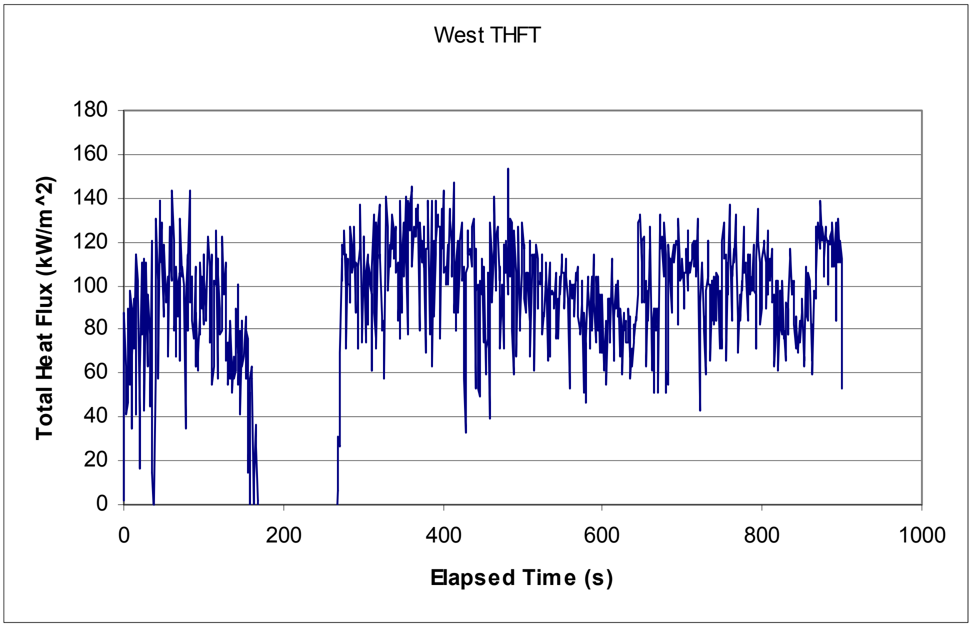


Figure 14 - West THFT

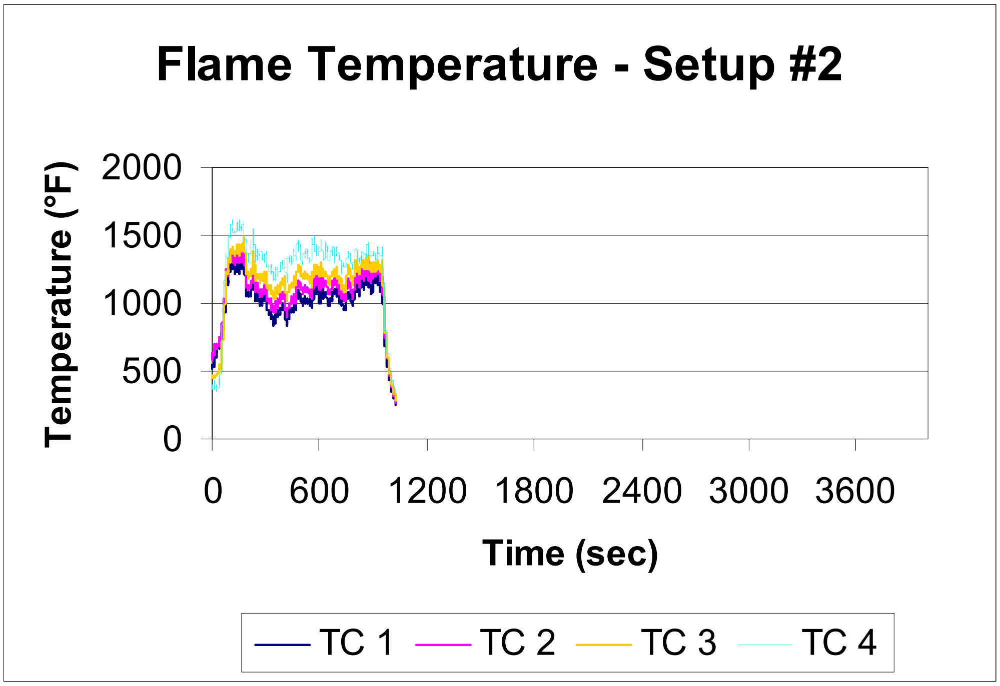


Figure 15 - Flame temperatures

4. SWEPI Fire Boom Results

Summaries of the data for each test and field notes may be found in Appendix D.

4.1 Pre-burn Wave Stress Test

Figures 16 and 17 show the SWEPI fire boom in place over the bubbler frame during the two-hour pre-burn wave stress test on the morning of October 19, 2000. It is clear that the boom was considerably flexed in the harbor chop waves. Figure 17 illustrates how the boom was periodically over-washed by a wave. It should be remembered that this fire boom was designed for use in broken ice conditions, where wave action would be severely damped by the presence of the floes.

Figure 18 shows the wave record obtained during a ten-minute period approximately ¾ of the way through the test (ten minutes was the maximum time the data acquisition computer logging the wave data was run, due to its tendency to "crash" periodically). Despite efforts to filter the signal from the ultrasonic wave probe, some spurious spikes were still present. The wave heights on Figure 18 range from about 0.24 m (9.5 in) to 0.6 m (24 in). Figure 19 shows an expansion of a portion of Figure 18, from 250 to 310 seconds. In this portion of the wave record, the wave heights range from 0.2 m (8.5 in) to 0.5 m (21 in) with an average period of 2.3 seconds.

Figures 20 and 21 show the load cell readings logged for the first 70 minutes of the test (70 minutes was the longest possible sampling time at the sampling rate set) and for the last few minutes of the test. The boom was pre-tensioned to nominally 1100 N (250 lb_f) prior to the test. The tension in the SWEPI boom in the first 70 minutes averaged 1025 N (233 lb_f) with a minimum of 585 N (133 lb_f), a maximum of 1980 N (450 lb_f) and a standard deviation of 200 N (45 lb_f). In the last 11 minutes of the test the tension averaged 970 N (221 lb_f) with a minimum of 610 N (138 lb_f), a maximum of 1790 N (406 lb_f) and a standard deviation of 185 N (42 lb_f).

Inspection of the boom after the test showed no visible damage to the exterior components.

Figure 16 - SWEPI boom in waves.

Figure 17 - Wave over-topping SWEPI boom.

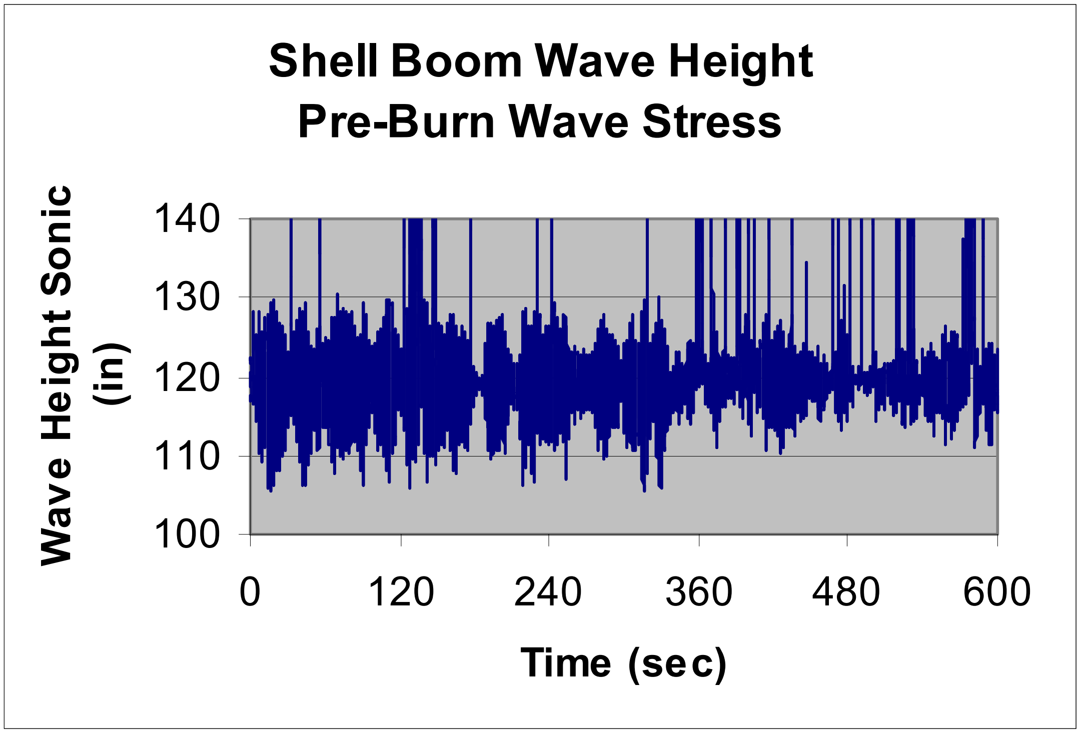


Figure 18 - 10-minute wave record

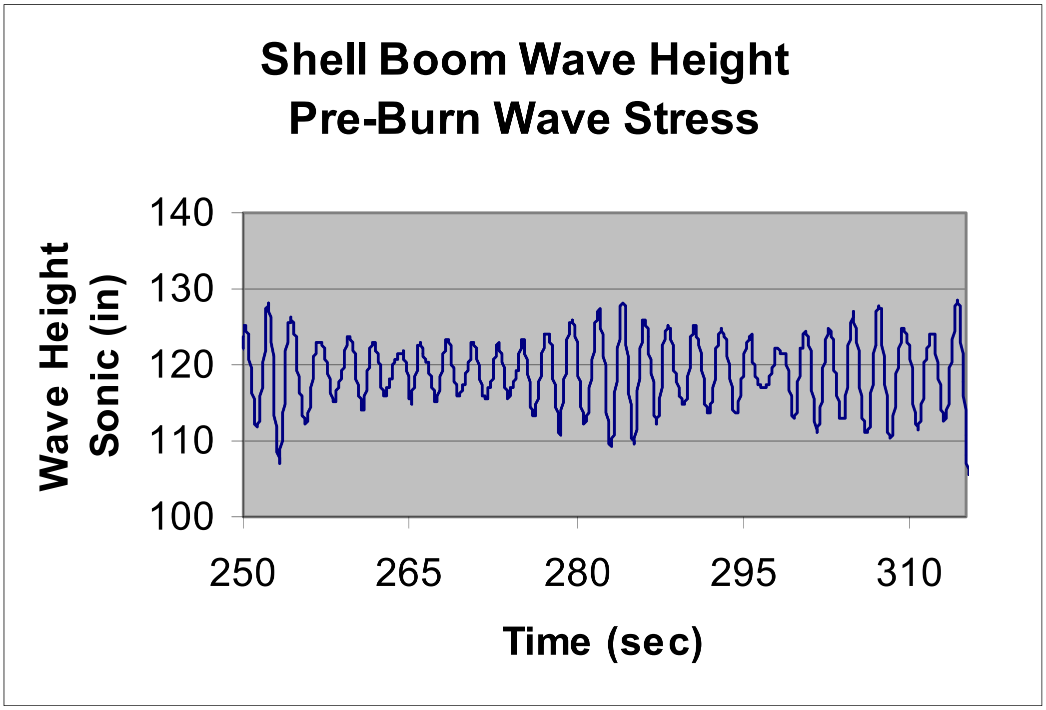


Figure 19 - 60-second wave record

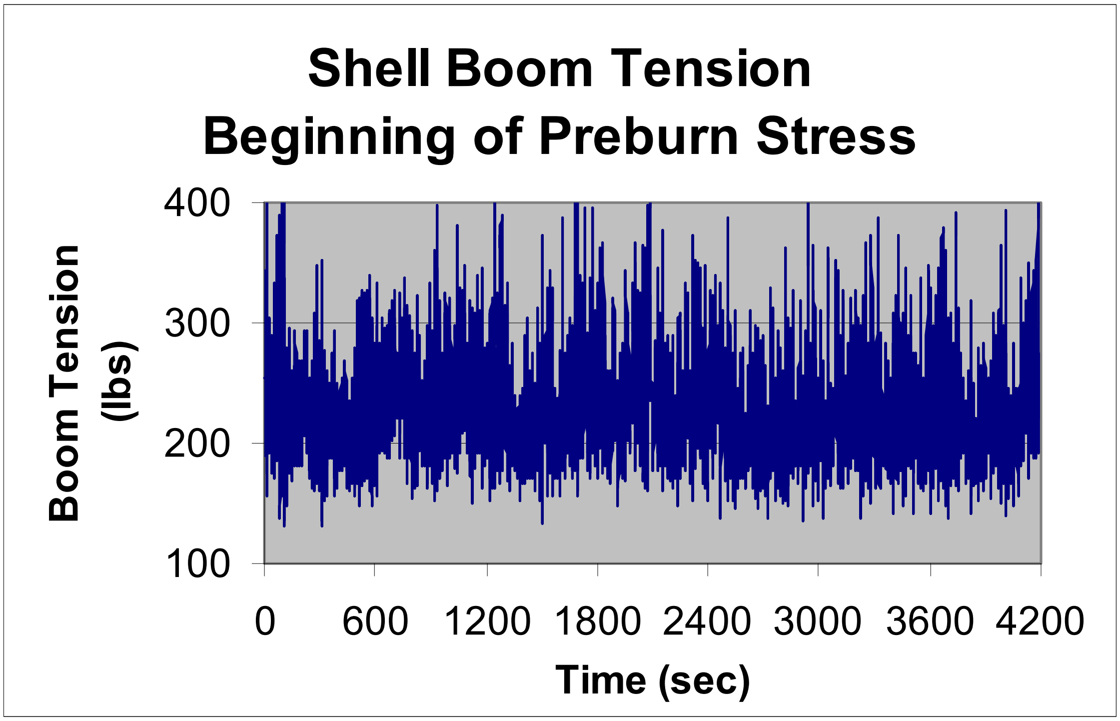


Figure 20 - 70-minute boom tension record

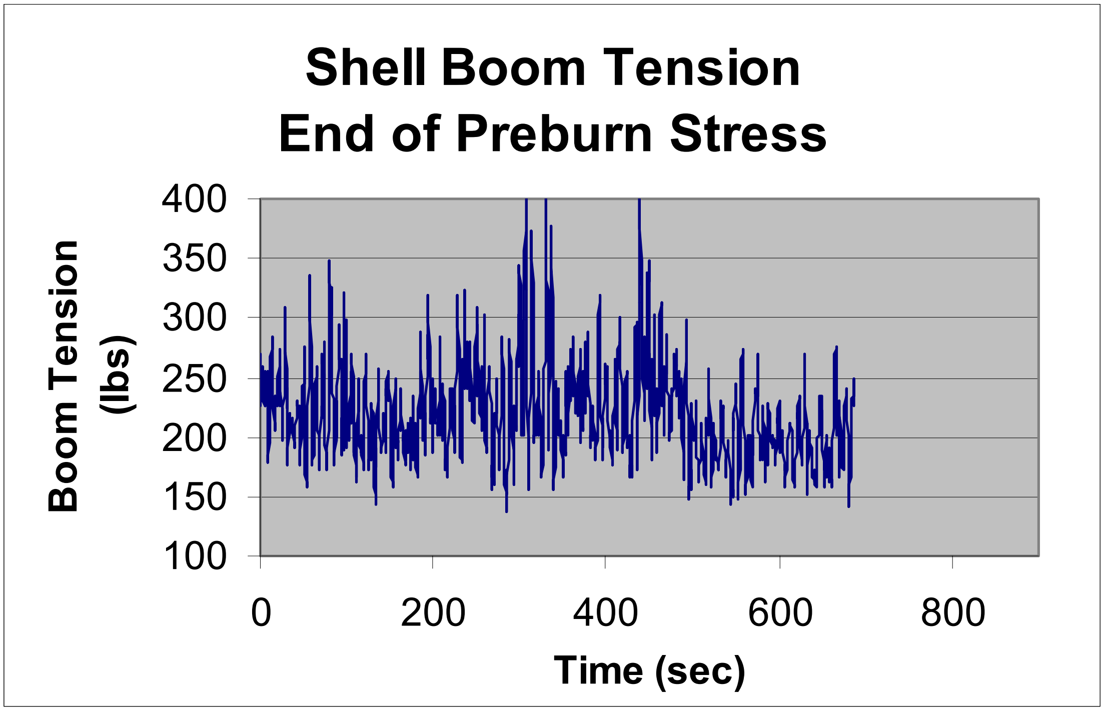


Figure 21 - 10-minute boom tension record

4.2 Burn Test

4.2.1 First Hour Burn

Figures 22 and 23 show the first hour of burn tests with the SWEPI boom. For these tests the wave beaches were raised, to produce regular waves. Figure 24 shows a short section of the wave height record for this test. The wave heights on this graph varied between 0.19 m (7.5 in) and 0.32 m (12.5 in) which appear representative of the heights recorded over a ten-minute period (Appendix D) and were significantly smaller than the waves used for the pre-burn wave stress test. The average wave period on Figure 24 is approximately 2.2 seconds. This equates to wave lengths from 4.2 m (14 ft) to 5.4 m (18 ft). These waves regularly over-washed the entire length of the boom and periodically soaked it with water during the tests. This behavior would not be expected in the boom's intended operating environment (broken ice conditions) and is an artifact of the test protocol that should perhaps be changed for future tests of booms intended for use in ice-covered environments.

The propane valves for this burn were set at ⅜-open and a steady 21 kg/hr (46 lb/min) propane flow was recorded, after the initial adjustments. Figures 25 and 26 show the total heat fluxes recorded during the first hour of burning. The heat fluxes measured on the east side of the boom were higher than on the west side because the wind was blowing from the west-north-west at 16 km/hr (10 mph). Figure 27 gives the flame temperatures recorded at the instrument stalk. It is apparent that the lower two thermocouples were influenced by the waves: the lowest (TC 4) was apparently periodically submerged by wave crests. The "cold zone" at the bottom of the fire (where the combustion reaction has not yet proceeded fully) was seemingly also moved up and down by the waves, as evidenced by the dips in the flame temperatures for the other, lower thermocouples. The temperature recorded by the highest thermocouple (TC1) was on the order of 815°C (1500°F), as expected.

The tension on the boom was set to 100 N (250 lb_f) prior to the test; during the test it averaged 1290 N (293 lb_f) and ranged between 1030 N (235 lb_f) and 1830 N (416 lb_f).

Figure 22 - Photo of SWEPI boom during first hour of flame exposure.

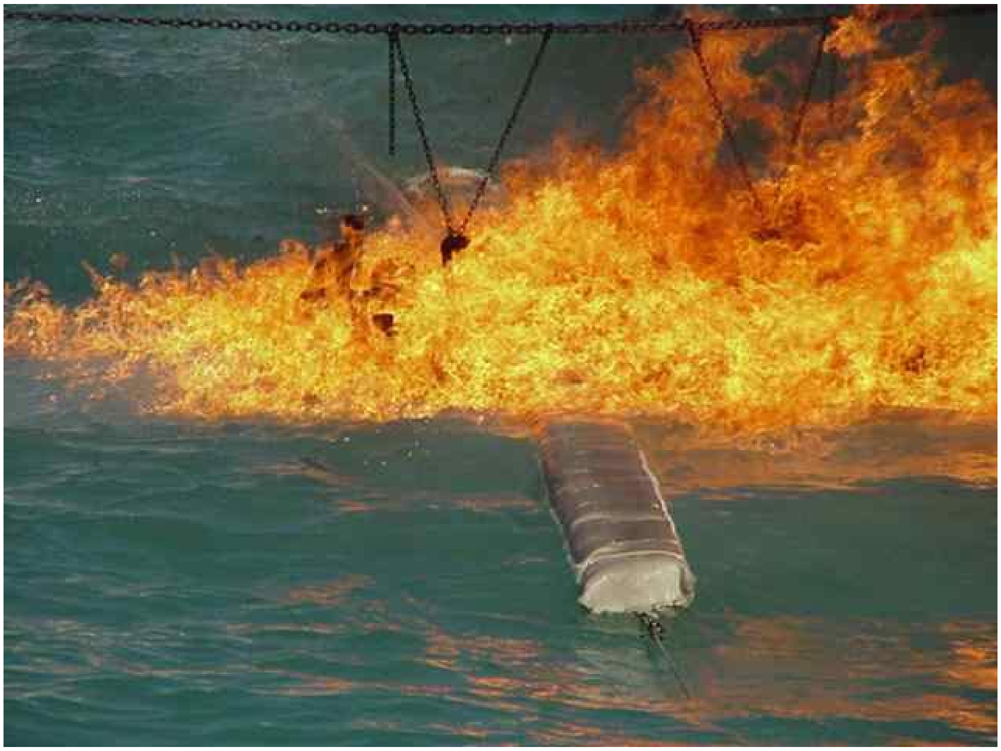


Figure 23 - Close-up of SWEPI boom during first hour of flame exposure.

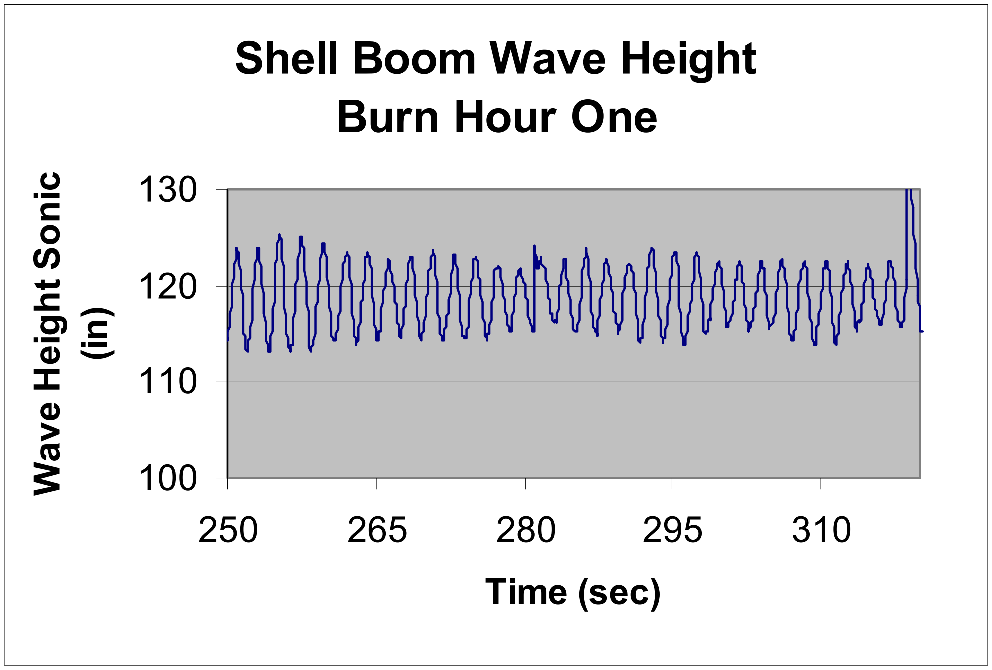


Figure 24 - Wave height record from first hour burn.

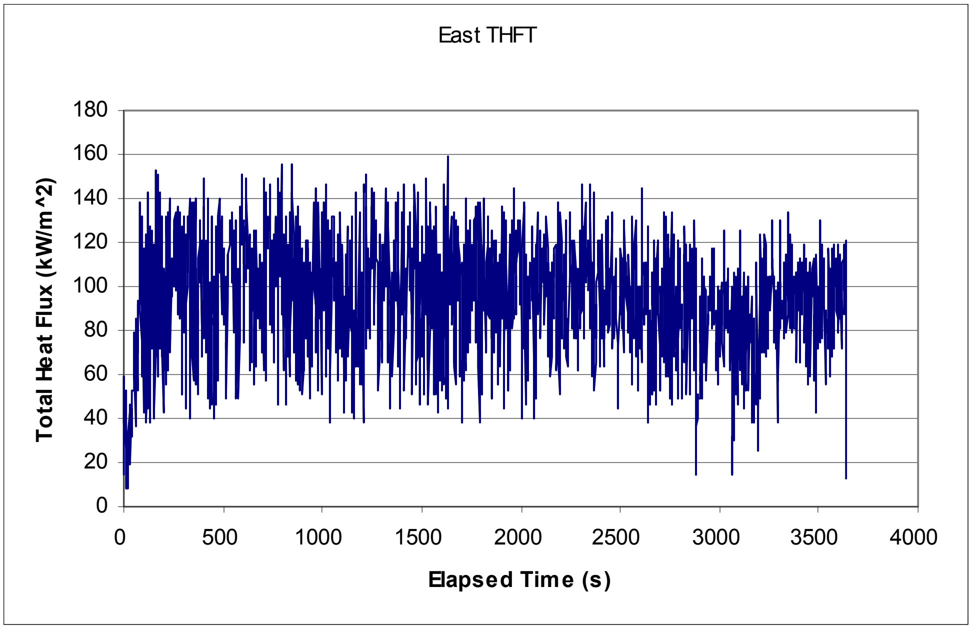


Figure 25 - East THFT

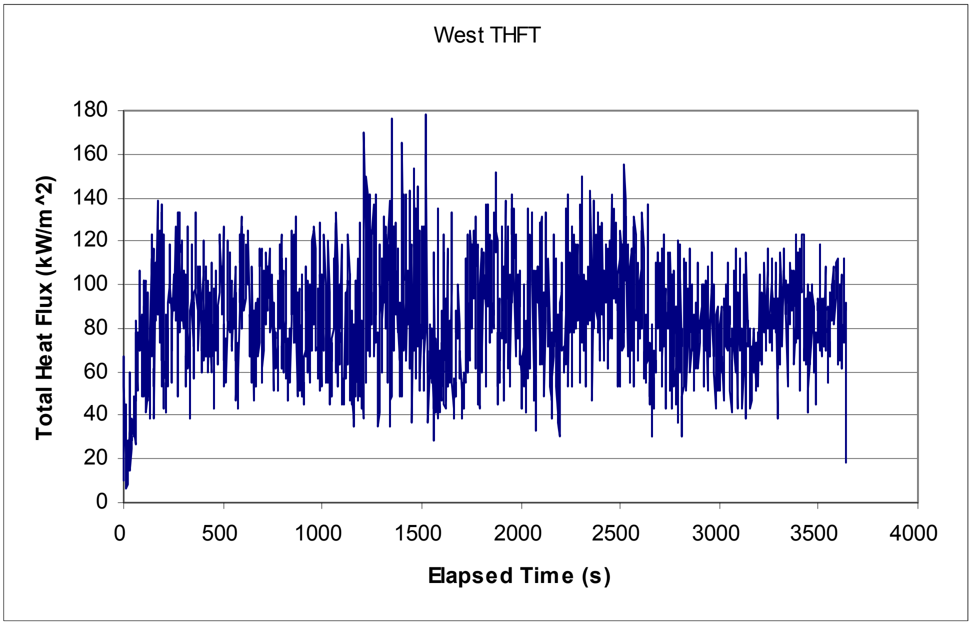


Figure 26 - West THFT

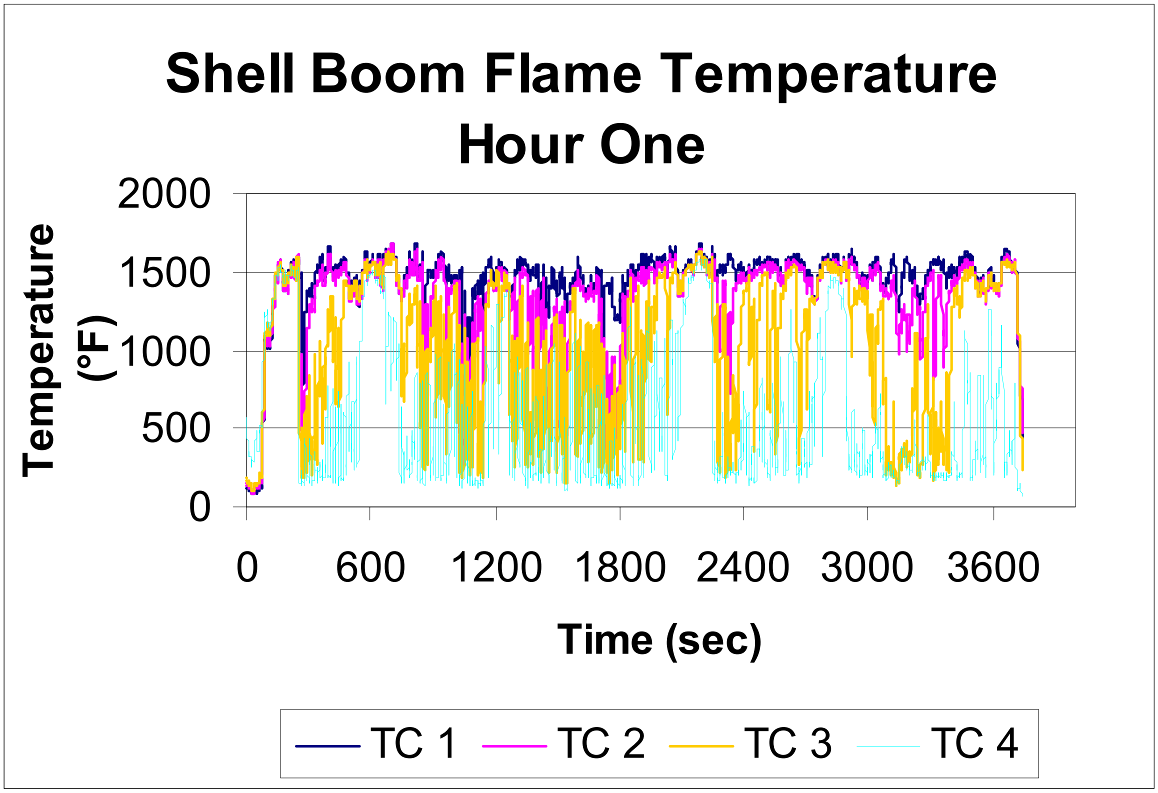


Figure 27 - Flame temperatures.

4.2.2 First Hour Cool-down

After the first hour of flame exposure, the propane flow was shut off and the SWEPI boom was allowed to cool down in waves for one hour. During this period the waves remained the same, and the boom tension cycled between 1030 N (235 lb_f) and 1830 N (416 lb_f).

After the one-hour cool-down, the boom was inspected. Figures 28 and 29 show the condition of the boom. There was some staining of the refractory material with soot and some evidence of the beginning of abrasion cracking caused by flexure between flotation units, but the boom was judged to be in good, serviceable condition.

4.2.3 Second Hour Burn

Figure 30 shows the propane flow measured for this test. The propane valves for the second burn test were initially set at ⅜-open; however, the flames appeared lower than expected, and after about 4 minutes the propane valves were opened to ½. This caused the safety valve on one tanker to activate and the flow of propane ceased. It turned out that the second tanker's safety valve had actuated before the test, and propane was flowing only from one tanker for the first four minutes of the test (at about 15 kg/min [33 lb/min]). A propane hose was used to connect the two tanker's vapor spaces, the safety valves were reset, and the test was restarted. Again, the valves were set at slightly less than ⅜-open; however, the flames continued to appear lower than expected (the recorded flow was only 12 kg/min [27 lb/min]), and after about 15 minutes the propane valves were opened to ½.. A steady 23 kg/min (50 lb/min) propane flow was recorded after this. At the end of this test, the propane valves were further opened, to explore the propane flows that could be achieved with the system. At ⅝-open a flow of 27 kg/min (59 lb/min) was recorded; at ¾-open a flow of 29 kg/min (64 lb/min) was logged; while at full-open a flow of 30 kg/min (67 lb/min) was registered.

Figures 31 and 32 show the total heat fluxes recorded during the first hour of burning. The lower heat flux associated with the restricted flow of propane is apparent. The heat fluxes measured on the

east side of the boom were higher than on the west side because the wind was blowing from the west-north-west at 19 km/hr (12 mph). Figure 33 gives the flame temperatures recorded at the instrument stalk. It is apparent that the lower two thermocouples were influenced by the waves: the lowest (TC 4) was apparently periodically submerged by wave crests. The "cold zone" at the bottom of the fire (where the combustion reaction has not yet proceeded fully) was seemingly also moved up and down by the waves, as evidenced by the dips in the flame temperatures for the other, lower thermocouples. The influence of the periods of low propane flow on the flame temperatures are also apparent. The temperature recorded by the highest thermocouple (TC1) at the steady flow of 23 kg (50 lb) of propane per minute was on the order of 815°C (1500°F), as expected.

The tension on the boom had been re-set to 1100 N (250 lb_f) prior to the second hour burn test; during the test it averaged 1280 N (290 lb_f) and ranged between 970 N (221 lb_f) and 1720 N (392 lb_f).

Figure 28 - SWEPI boom after first cool-down.

Figure 29 - Close-up of SWEPI boom after first cool-down.

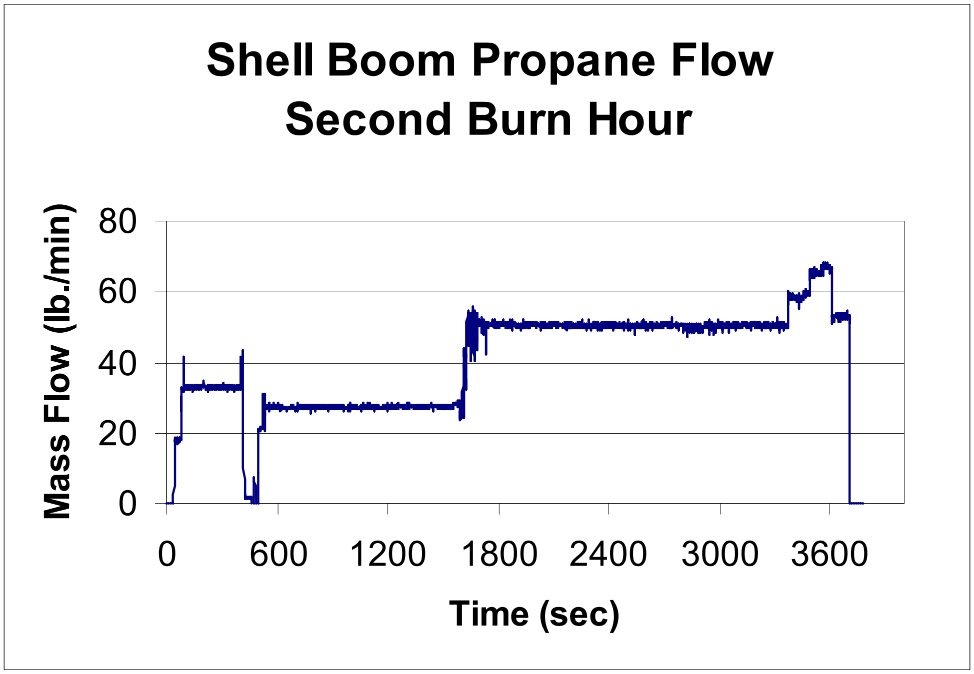


Figure 30 - Propane flow measured during second burn hour.

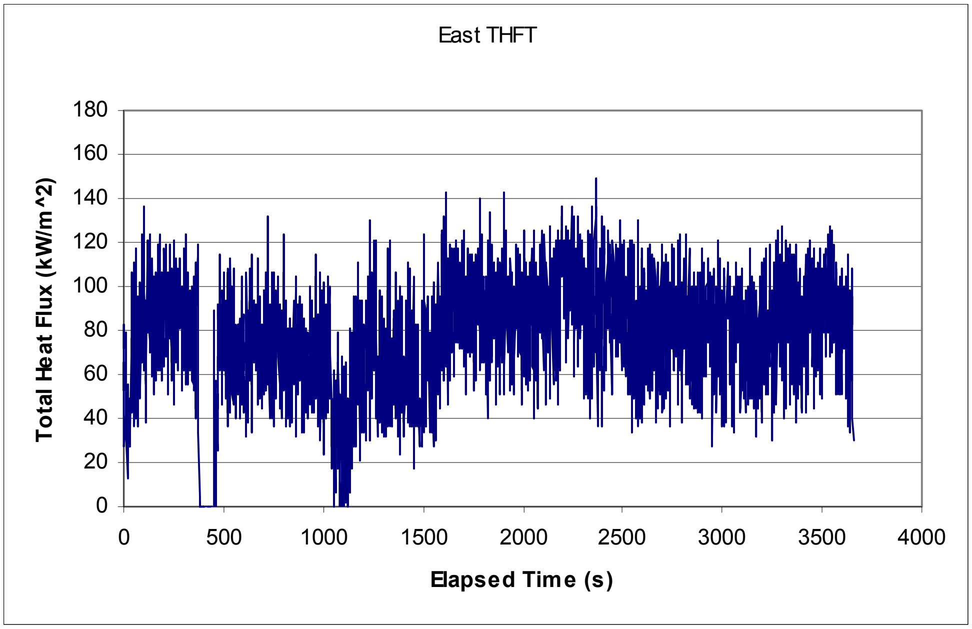


Figure 31 - East THFT

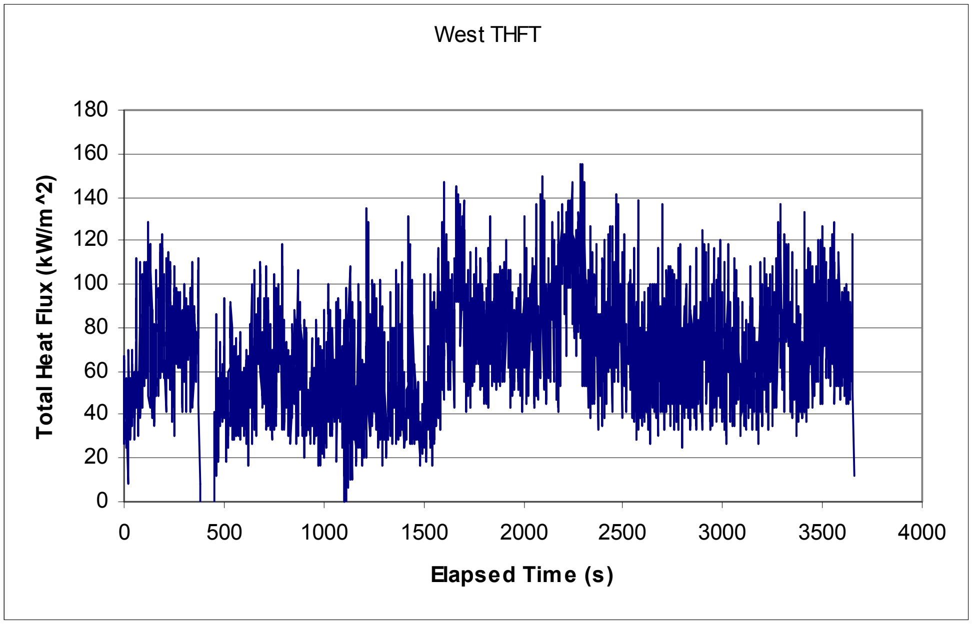


Figure 32 - West THFT

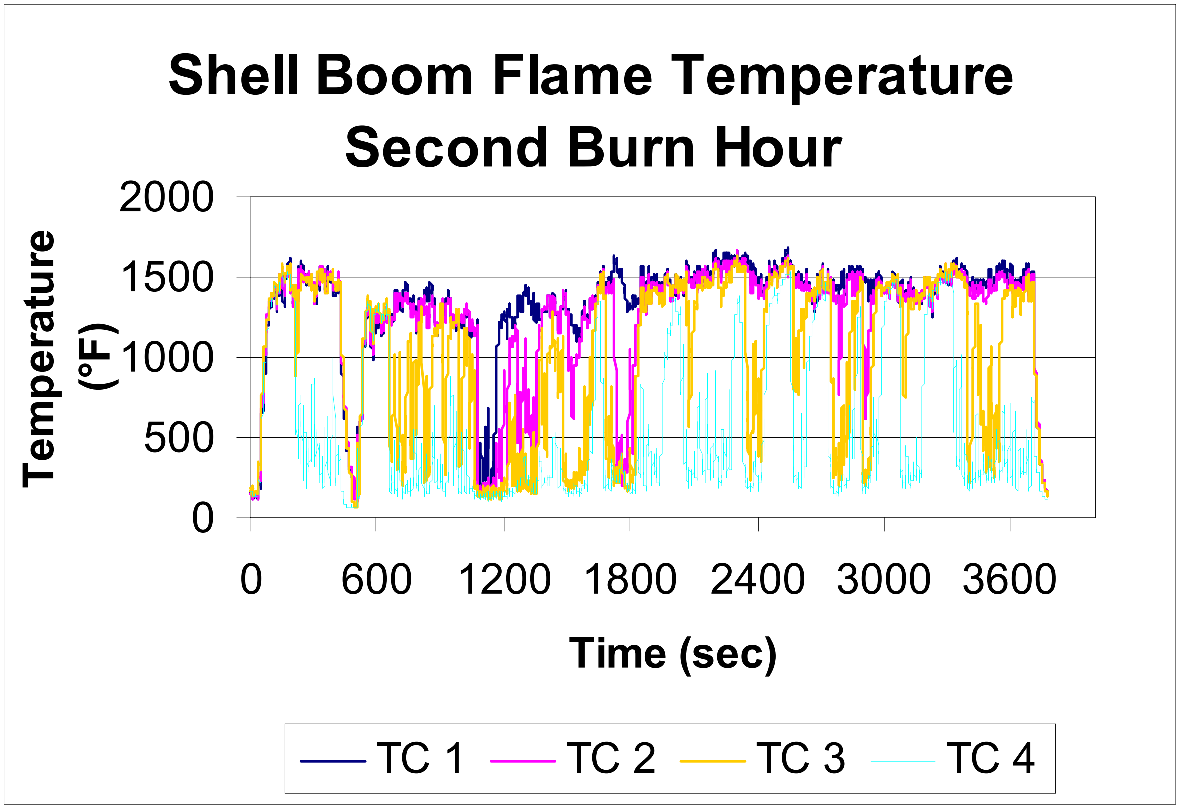


Figure 33 - Flame temperatures during second burn hour.

4.2.4 Second Hour Cool-down

After the second hour of flame exposure, the propane flow was shut off and the SWEPI boom was allowed to cool down in waves for one hour. During this period the waves remained the same, and the boom tension cycled between 1030 N (235 lb_f) and 1680 N (381 lb_f).

After the one-hour cool-down, the boom was inspected. Figures 34 and 35 show the condition of the boom. There was still some staining of the refractory material with soot apparent and some evidence of abrasion cracking caused by flexure between flotation units, but the boom was judged to still be in good, serviceable condition.

4.2.5 Third Hour Burn

The propane valves for this burn were set at ½-open and a steady 22 kg/min (49 lb/min) propane flow was recorded, after the initial adjustments. Figures 36 and 37 show the total heat fluxes recorded during the first hour of burning. The heat fluxes measured on the both side of the boom were almost equal, since the wind speed had died down to only 6 km/hr (4 mph). Figure 38 gives the flame temperatures recorded at the instrument stalk. It is apparent that the lower two thermocouples were influenced by the waves: the lowest (TC 4) was apparently periodically submerged by wave crests. The “cold zone” at the bottom of the fire (where the combustion reaction has not yet proceeded fully) was seemingly also moved up and down by the waves, as evidenced by the dips in the flame temperatures for the other, lower thermocouples. The temperature recorded by the highest thermocouple (TC1) was on the order of 815°C (1500°F), as expected.

The tension on the boom was set to 1100 N (250 lb_f) prior to the test; during the test it averaged 1280 N (290 lb_f) and ranged between 1010 N (230 lb_f) and 1810 N (411 lb_f).

At the end of the third burn hour, the boom was inspected closely for damage. Figures 39 and 40 show the condition of the boom at that time. With the exception of some loss of refractory fabric in a few small locations on the top of the boom, it appeared to be perfectly serviceable.

Figure 34 - SWEPI boom after second hour cool-down.

Figure 35 – Close-up of SWEPI burn during second hour cool-down.

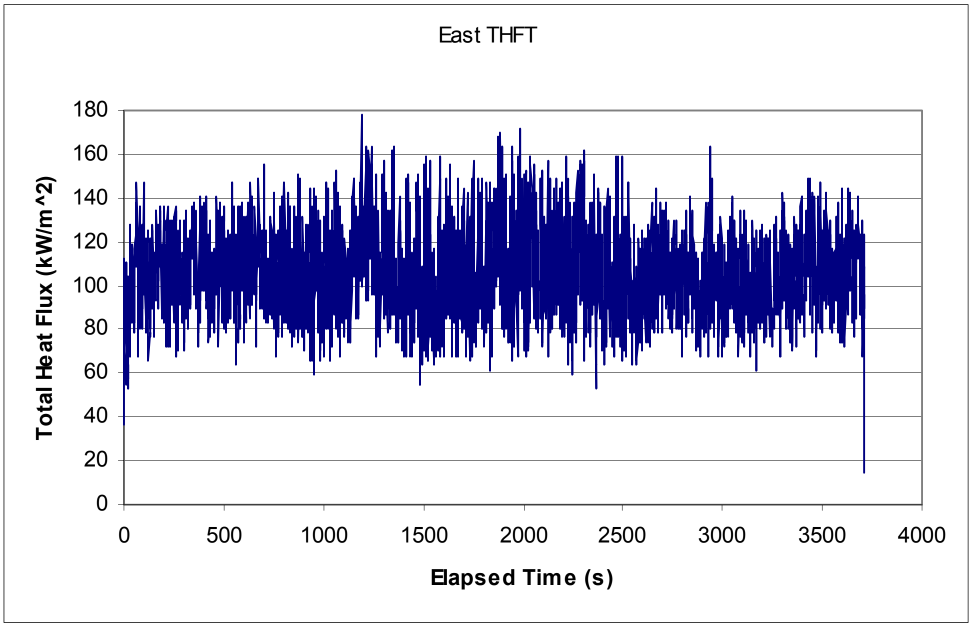


Figure 36 - East THFT

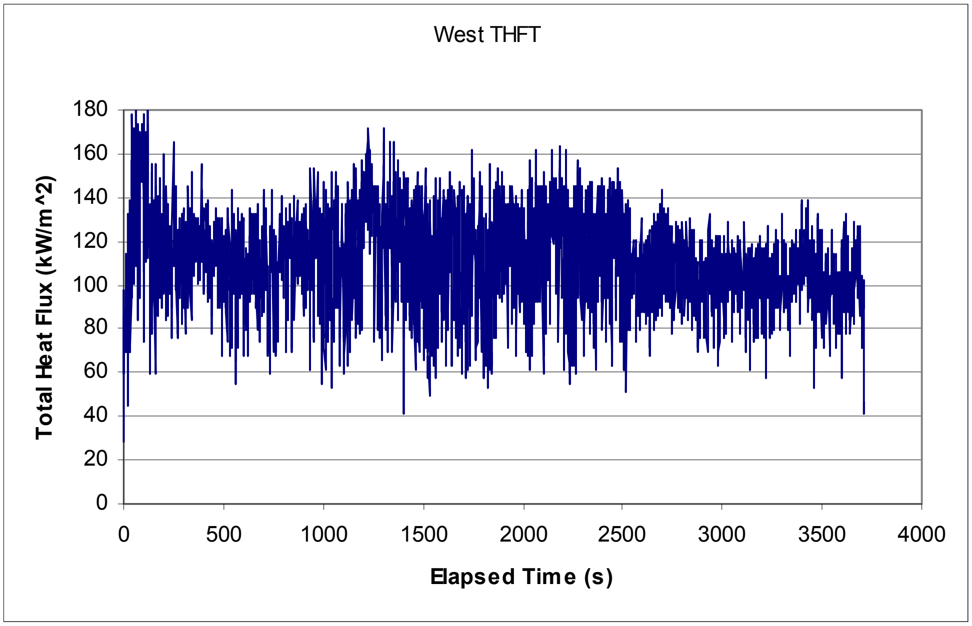


Figure 37 - West THFT

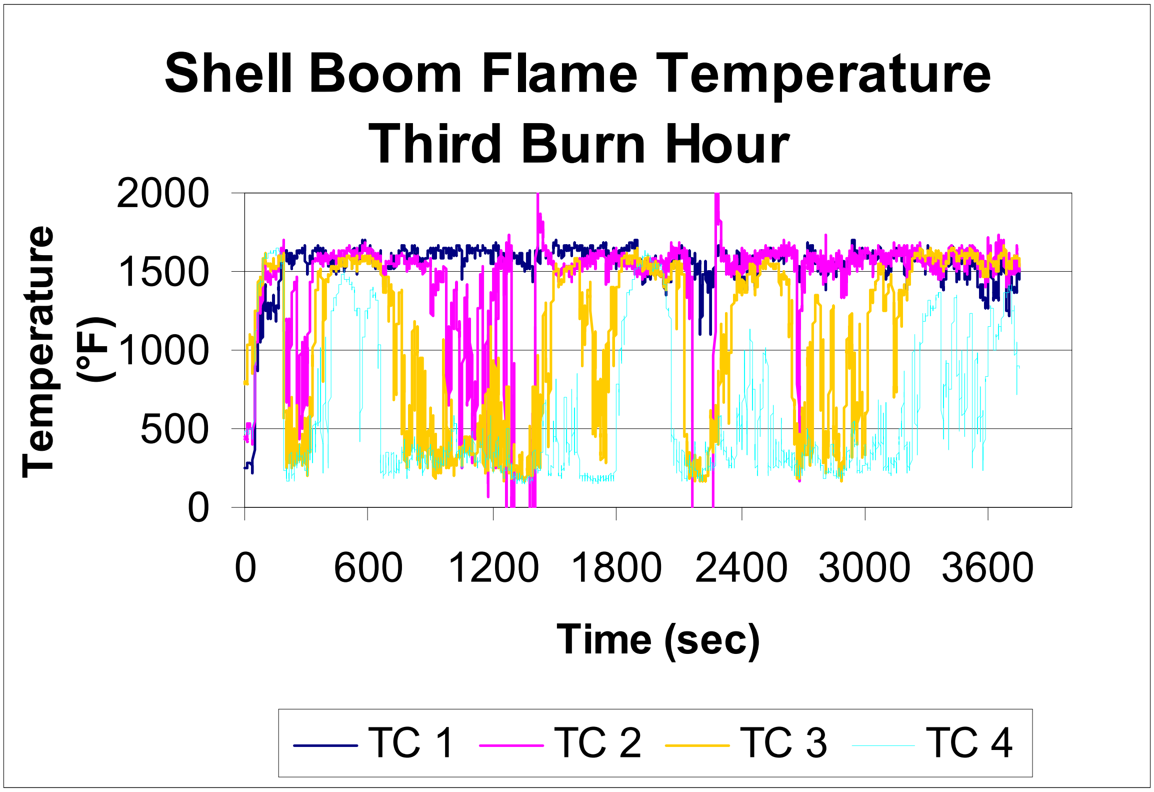


Figure 38 - Flame temperatures.

Figure 39 - SWEPI boom at end of burn tests.

Figure 40 - SWEPI burn close-up at end of burn tests.

Figure 41 - SWEPI boom static oil containment test.

4.3 Post-burn Wave Stress Test

As the boom had survived the three-hour burn test portion of the protocol, it was subjected to a post-burn wave stress test. For this test the wave beaches were lowered to generate harbor chop conditions. The wave heights ranged from approximately 0.2 m (7.5 in) to 0.5 m (20.5 in) with an average period of about 2.1 seconds.

The tension in the SWEPI boom in the first 60 minutes averaged 1400 N (319 lb_f) with a minimum of 930 N (211 lb_f), a maximum of 1980 N (450 lb_f) and a standard deviation of 220 N (49 lb_f). In the last 40 minutes of the test the tension averaged 1430 N (324 lb_f) with a minimum of 930 N (211 lb_f), a maximum of 2280 N (519 lb_f) and a standard deviation of 200 N (45 lb_f).

Inspection of the boom after the test showed no additional visible damage to the exterior components.

4.4 Static Thick Oil Containment Test

On October 26, the SWEPI fire boom test section was connected in a circle and placed in the north end of the tank. Measured volumes of a mixture of diesel and JP-5 were added to the inside of the boom circle to determine it's ability to contain thick, low-viscosity oil slicks (Figure 41). The viscosity of the mixture at the tank water temperature (60°F) was 10 mPas (cP). The boom failed, by drainage, after approximately 56 mm (2.2 in) of the oil had been added. It was clear that this was the operational, calm-water draft of the Shell boom. There was no visually detectable leakage of the oil through the boom fabric prior to the drainage failure.

5. Oil Stop, Inc. Auto Boom Fire Model Results

The processed data summaries and field notes may be found in Appendix D.

5.1 Pre-burn Wave Stress Test

Figures 42 and 43 show the Oil Stop fire boom in place over the bubbler frame during the two-hour pre-burn wave stress test on the afternoon of October 23, 2000. It is clear that the boom was considerably flexed in the harbor chop waves. The boom responded well to the waves and was never overtopped. The wave heights ranged from 0.2 m (8 in) to 0.5 m (21 in) with an average period of 2.1 seconds.

The Oil Stop boom was pre-tensioned to 1140 N (259 lb_f) prior to the test. The tension in the boom in the first 55 minutes averaged 1160 N (264 lb_f) with a minimum of 560 N (128 lb_f), a maximum of 2100 (471 lb_f) and a standard deviation of 220 N (51 lb_f). In the last 50 minutes of the test the tension averaged 1130 N (256 lb_f) with a minimum of 480 N (108 lb_f), a maximum of 2780 N (631 lb_f) and a standard deviation of 250 N (56 lb_f).

Inspection of the boom the morning after the test (Figure 44) showed that the outer screen had creased in many places along the top of the boom (Figure 45), presumably as a result of flexing of the boom in waves. At the fold of a few of these creases the stainless steel mesh had cracked, with the largest crack being only a few cm (approximately 1 in) long. It should be noted that subsequent versions of this boom incorporate material changes that are reported to deal with this problem.

5.2 Burn Test

5.2.1 First Hour Burn

Figures 46 and 47 show the first hour of burn tests with the Oil Stop boom. Note that the boom is not centered in the flame. This was done in an attempt to avoid propane bubbles entering an air chamber valve access slit in the skirt at the center of the test section. For these tests the wave beaches were raised, to produce regular waves. The wave heights varied between 0.15 m (6 in) and 0.29 m (11.5 in). The average wave period was approximately 2.4 seconds. This equates to a wave lengths between 3.75 m (12 ft) and 5.2 m (17 ft). The boom followed the waves well.

The propane valves for this burn were set at ½-open and a steady 26 kg/min (58 lb/min) propane flow was recorded, after the initial adjustments (Figure 48). It was observed that the water entrained by the propane bubbles pushed on the skirt of the boom, forcing it over to rest against the air standpipe floats on the east side of the frame. After several attempted adjustments of the frame the propane was shut down, the frame was adjusted and the tension on the boom increased to 2200 N (500 lb_f). The flames were then re-started with a steady flow of 25 kg/min (54 lb/min).

Figure 42 - Oil Stop Auto Boom during Pre-burn Wave Stress test.

Figure 43 - Oil Stop Auto Boom during Pre-burn Wave Stress test.

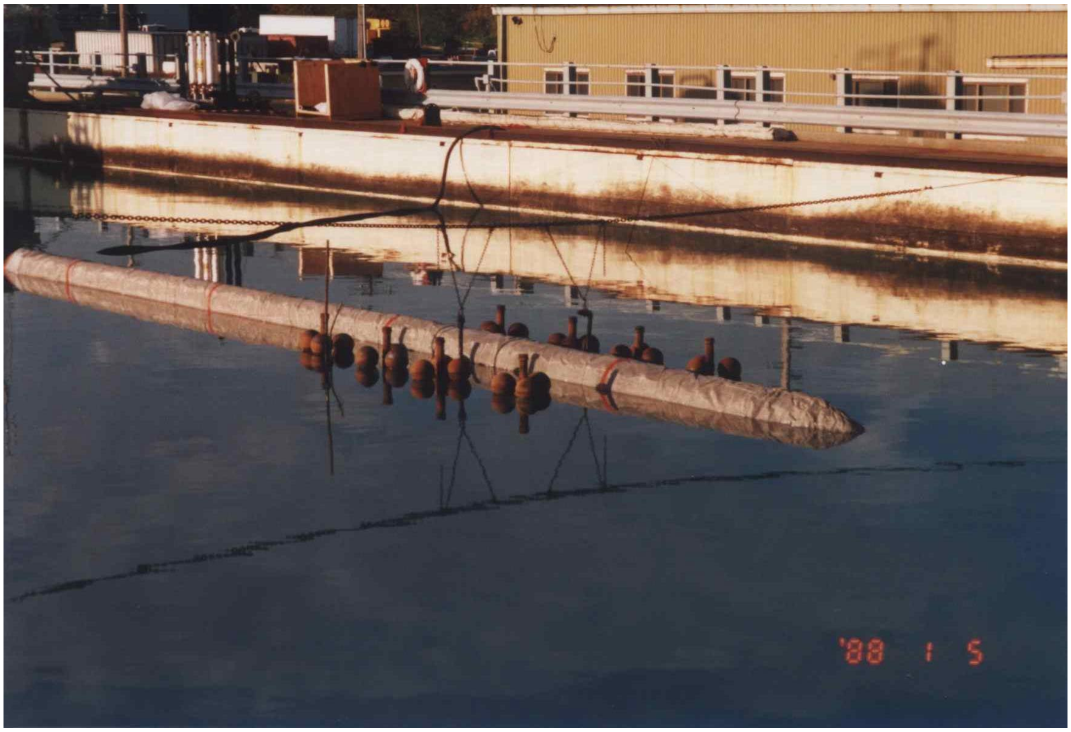


Figure 44 - Oil Stop Auto Boom after Pre-burn Wave Stress test.

Figure 45 – Close-up of Oil Stop Auto Boom after Pre-burn Wave Stress test.

Figure 46 - Photo of Oil Stop boom during first hour of flame exposure.

Figure 47 - Close-up of Oil Stop boom during first hour of flame exposure.

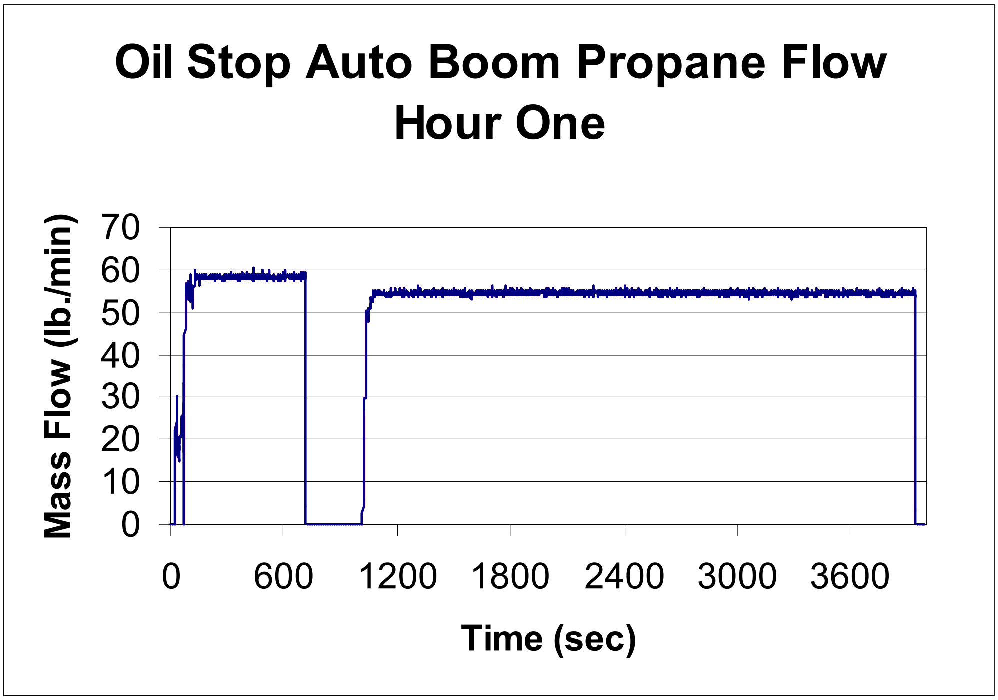


Figure 48 - Propane flow record from first hour burn.

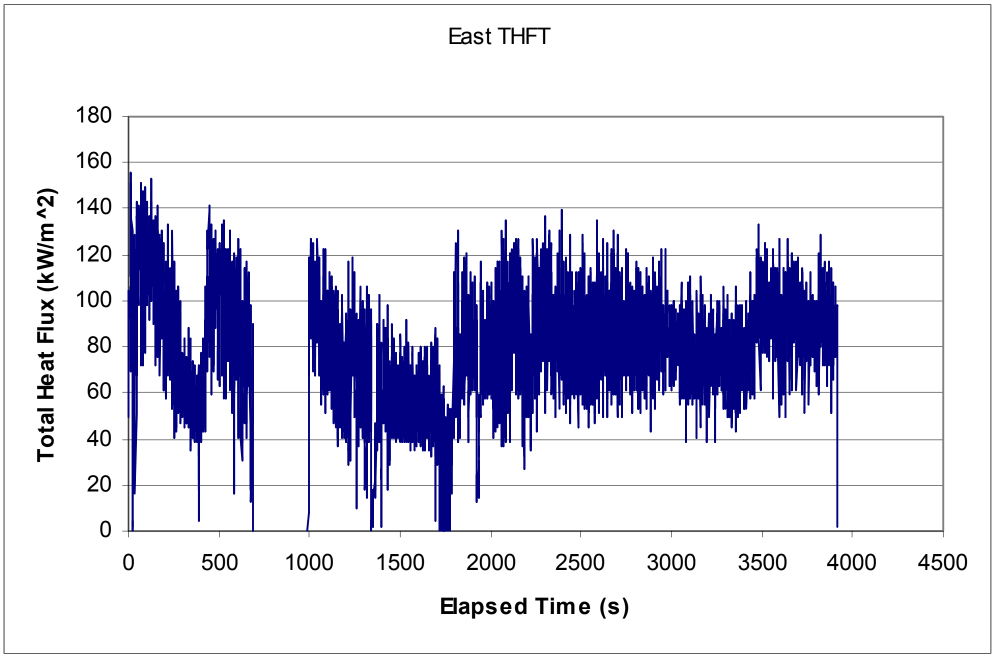


Figure 49 - East THFT

Figures 49 and 50 show the total heat fluxes recorded during the first hour of burning. Several times during this burn tests, the THFTs were lowered below the tops of the waves by the stretching of the suspension chain. This reinforces the need for the THFT support mechanism to be modified to incorporate a constant-tension system. The heat fluxes measured on the west side of the boom were slightly higher than on the west side. The wind was blowing lightly from the south-west at 8 km/hr (5 mph). Figure 51 gives the flame temperatures recorded at the instrument stalk. It is apparent that the lower two thermocouples were influenced by the waves: the lowest (TC 4) was apparently periodically submerged by wave crests. The "cold zone" at the bottom of the fire (where the combustion reaction has not yet proceeded fully) was seemingly also moved up and down by the waves, as evidenced by the dips in the flame temperatures for TC3. The data from TC2 should be treated with suspicion; the excursions to 1400+°C (2500+°F) and below 0° indicate that this thermocouple was beginning to fail. The temperature recorded by the highest thermocouple (TC1) was on the order of 815°C (1500°F), as expected.

The tension on the boom was set to 1100 N (250 lb_f) prior to the test, then increased to 2200 N (500 lb_f) in an attempt to center the boom over the bubbler frame. During the test the tension on the boom averaged 2320 N (528 lb_f) and ranged between 1980 N (450 lb_f) and 2600 N (592 lb_f).

On completion of the first burn hour, the boom was inspected. Numerous cracks in the outer steel mesh were noted (Figures 52 and 53) and it was observed that the underlying refractory felt mat was beginning to degrade. It had been necessary during the burn test to increase the air blower rate in order to keep the boom inflated.

5.2.2 First Hour Cool-down

After the first hour of flame exposure, the propane flow was shut off and the Oil Stop boom was allowed to cool down in waves for one hour. During this period the waves remained the same, and the boom tension cycled between 2090 N (475 lb_f) and 3010 N (685 lb_f).

It had been necessary several times during the cool-down test to increase the air blower rate in order to keep the boom afloat. After the one-hour cool-down, the boom was inspected. No significant further degradation was noted in the section exposed to flames; however, it was observed that, at the north end of the boom, a bolt attaching the connector to the fabric layers had pulled out, causing an air leak. This was inspected, but deemed not crucial to the continued operation of the boom. It should be noted that, in more recent versions of this boom, the fabric used to make the air chambers has been changed to an unreinforced film. The coated glass fabric used in the boom model tested had been identified as susceptible to excessive wear where repeated flexing occurred. As well, the new film is much less likely to allow the bolt holes at the connectors to wallow.

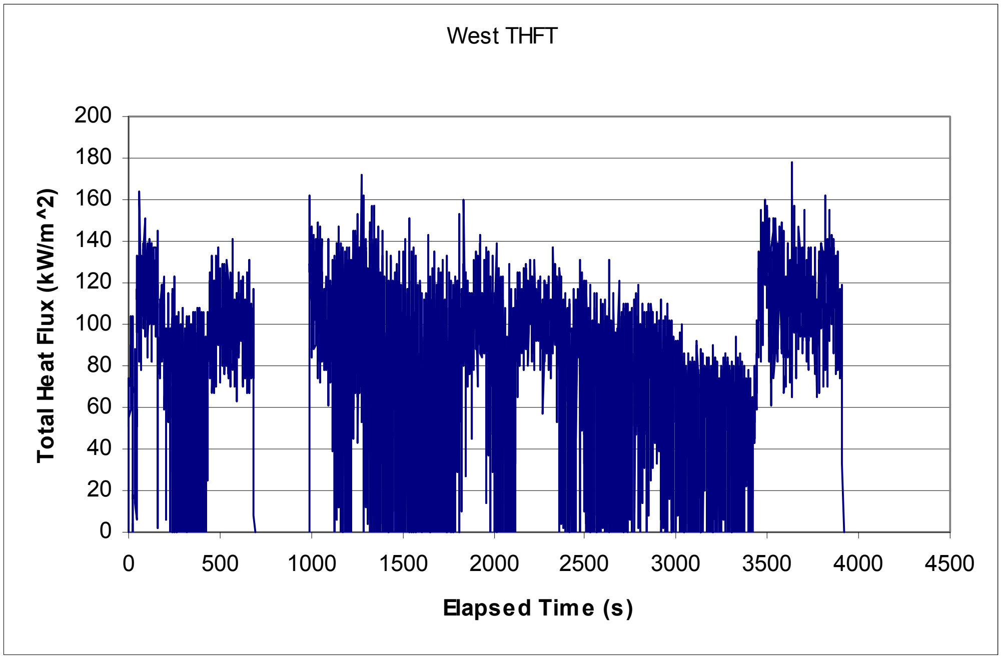


Figure 50 - West THFT

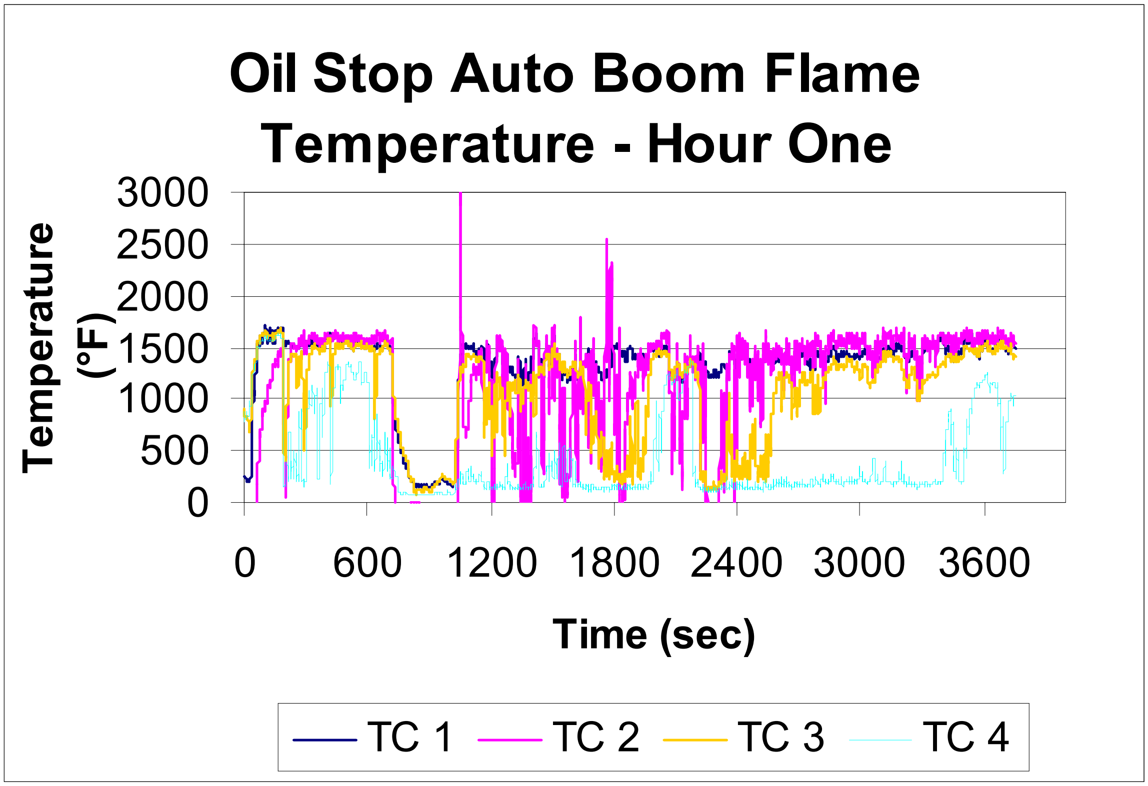


Figure 51 - Flame temperatures.

Figure 52 - Oil Stop boom after first burn.

Figure 53 - Close-up of Oil Stop boom after first burn.

5.2.3 Second Hour Burn

After initial adjustments, the propane flow for the second burn with the Oil Stop boom was recorded at a steady 25 kg/min (56 lb/min). Figures 54 and 55 show the total heat fluxes recorded during the second hour of burning. The heat fluxes measured on the east side of the boom were lower than on the west side because the east THFT had inadvertently rotated and was now looking south towards the 13 km/hr (8 mph) wind from the south-south-west.

Figure 56 gives the flame temperatures recorded at the instrument stalk. The temperature recorded by the highest thermocouple (TC1) at the steady flow of 25 kg (56 lb) of propane per minute was on the order of 815°C (1500°F), as expected. The readings from TC2 should be discounted.

The tension on the boom had been re-set to 2020 N (460 lb_f) prior to the second hour burn test; during the test it averaged 1690 N (385 lb_f) and ranged between 820 N (187 lb_f) and 3120 N (709 lb_f).

Three minutes into the burn test, it was noted that the north end of the boom was sagging, and the air blower was increased to its maximum setting. Fourteen minutes after the start of the burn the north end of the boom was being continuously over washed by waves (Figure 57). After 24 minutes of exposure to flames, the north end of the boom sank and the test was terminated. The total exposure to flames up to the failure point was 1 hour and 24 minutes.

Inspection of the boom revealed that there was a large hole in the top of the boom at the south end of the bubbler (Figure 58). Too much air was escaping from this hole to maintain flotation in the portion of the boom north of the hole (Figure 59). The boom was subsequently removed from the tank and layed out on the deck for inspection. Figure 60 shows the damage to the exterior of the boom and Figure 61 shows the damage to the underlying felt layer, with the stainless steel mesh outer cover peeled back. Figure 62 shows a close up to the damage to the felt layer, and Figure 63 shows a close up of similar damage at another point on the boom. It was apparent that the combination of heat from the flames and loss of insulation to abrasion from flexing in waves had allowed enough heat to penetrate to the coated glass fabric forming the wall of the flotation chamber, causing it to melt.

According to the manufacturer, the version of the Auto Boom Fire Model that is currently produced incorporates several modifications to the version tested:

- The stainless steel mesh is now laminated to a polyurethane-coated polyester fabric to make the screen more durable prior to exposure to fire, and to make it safer to handle.
- The fabric used to make the air chambers has been changed to an unreinforced film. The coated glass fabric was susceptible to excessive wear where repeated flexing occurred. As well, the new film is much less likely to allow the bolt holes at the connectors to wallow.
- The material in which the refractory mat is wrapped was changed to a vinyl-coated polyester fabric for greater protection and stability than the original polyethylene film.

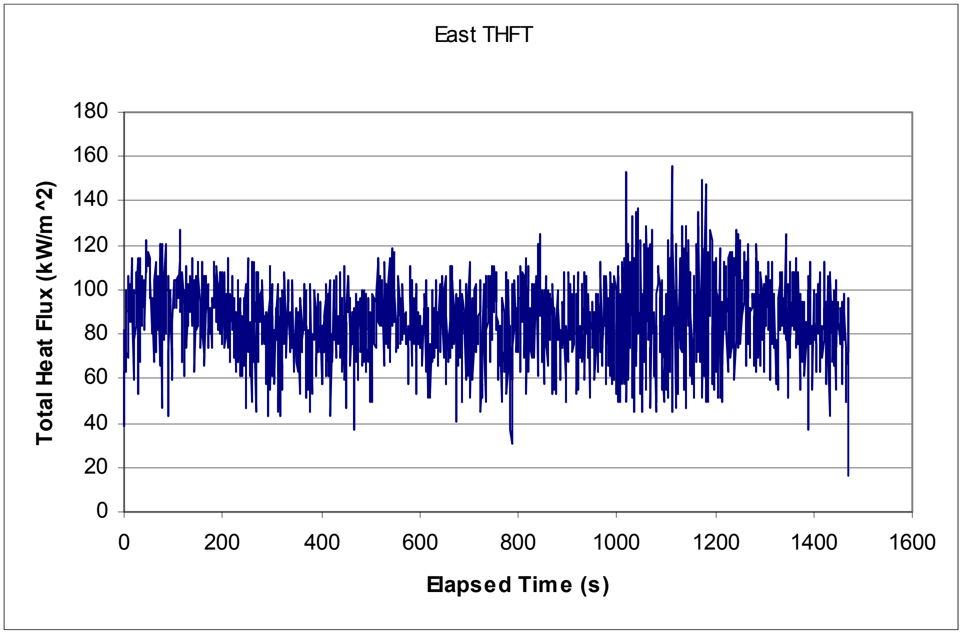


Figure 54 - East THFT

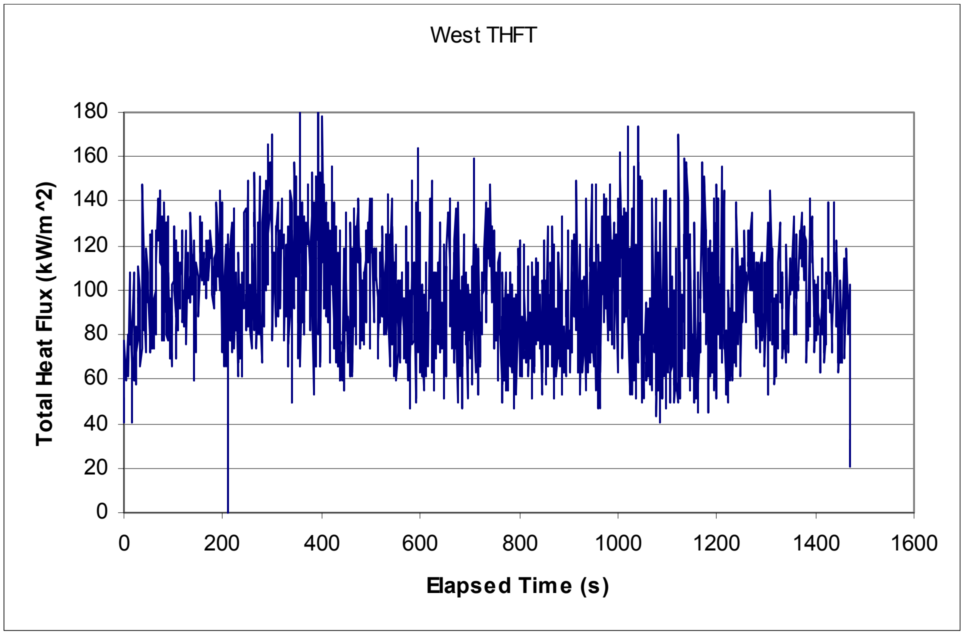


Figure 55 - West THFT

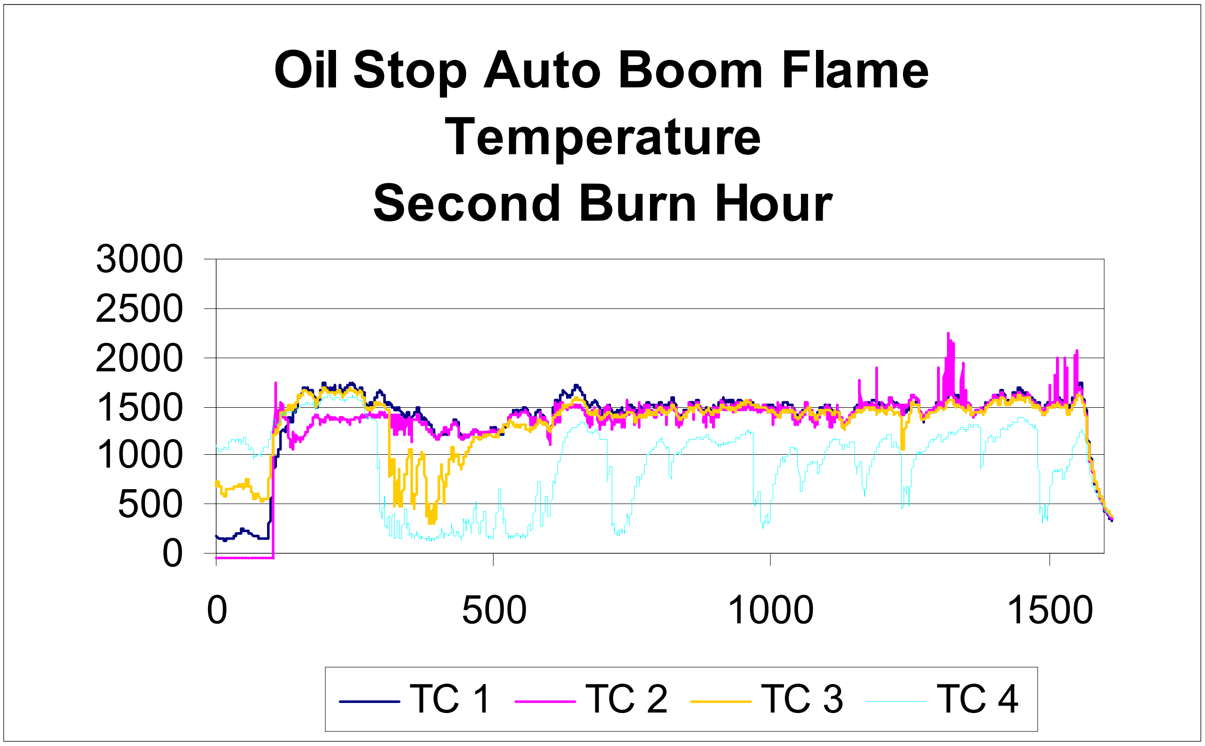


Figure 56 - Flame temperatures.

Figure 57 - North end of boom over washed by waves.

Figure 58 - Location of large hole in boom.

Figure 59 - Close-up of large hole.

Figure 60 - Boom on deck showing exterior damage.

Figure 61 - Boom on deck showing damage to felt layer with stainless steel mesh peeled back.

Figure 62 - Close-up of damage to felt layer with stainless steel mesh removed.

Figure 63 - Close-up of similar damage at another location on boom.

6. Oil Stop, Inc. Water-cooled Fire Blanket Minimum Flow Test

The final test of the project involved exposing a short length of Oil Stop, Inc. water-cooled blanket covering a single flotation section (Figure 64) to the air-enhanced propane fire and slowly reducing the water flow to the blanket, until the floatation unit failed. The tests were run in calm conditions. Figure 65 shows the blanket/floatation unit completely immersed in the flames.

Figure 66 shows the propane flow rate recorded for this test and Figure 67 gives the flame temperatures measured at the instrument stalk (note that the data from TC2 should be discounted). The test involved exposing the test section to three fires of approximately 15 minutes duration, each with a lower flow rate of water being supplied to the blanket covering the flotation section. Figures 68 through 73 give the heat fluxes recorded during the burns. The east THFT had rotated and was pointing almost due south, into the 8 km/hr (5 mph) wind from the south-south west. After each fire stabilized, the east THFT could be seen above the flames. It is also possible that, for the second and third burns, the east THFT was being hit by a spray of water from a leaking cooling hose on the blanket. The heat fluxes recorded with the west THFT show averages in the 100 kW/m^2 range with peaks in the 100 to 150 kW/m^2 range for each of the short-duration burns.

The cooling water flow rate for the first burn was 100 L/min (26.4 gpm). The water flow rate for the second burn was measured in the range of 25 to 31 L/min (6.6 to 8.3 gpm). The water flow for the third, and final burn during which the boom failed, was measured at 16.3 L/min (4.3 gpm).

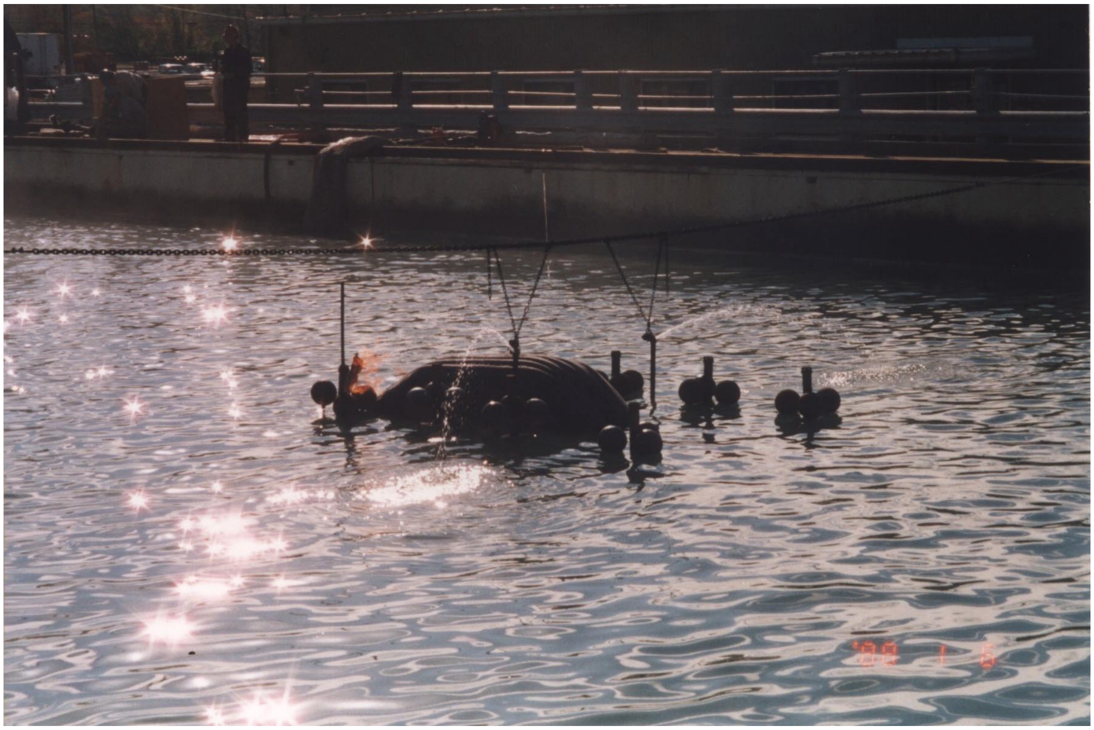

'88 1 6

Figure 64 - Oil Stop, Inc. blanket over single flotation section.


'88 1 6

Figure 65 - Oil Stop, Inc. single unit immersed in flames.

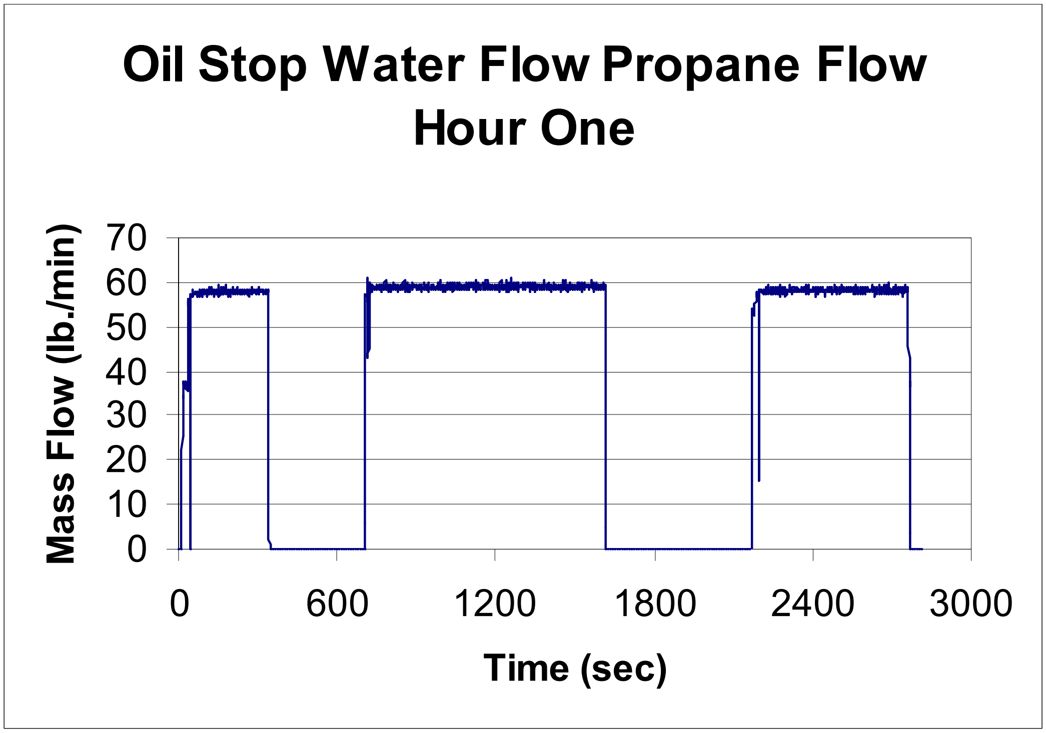


Figure 66 - Propane flow for Oil Stop water flow test.

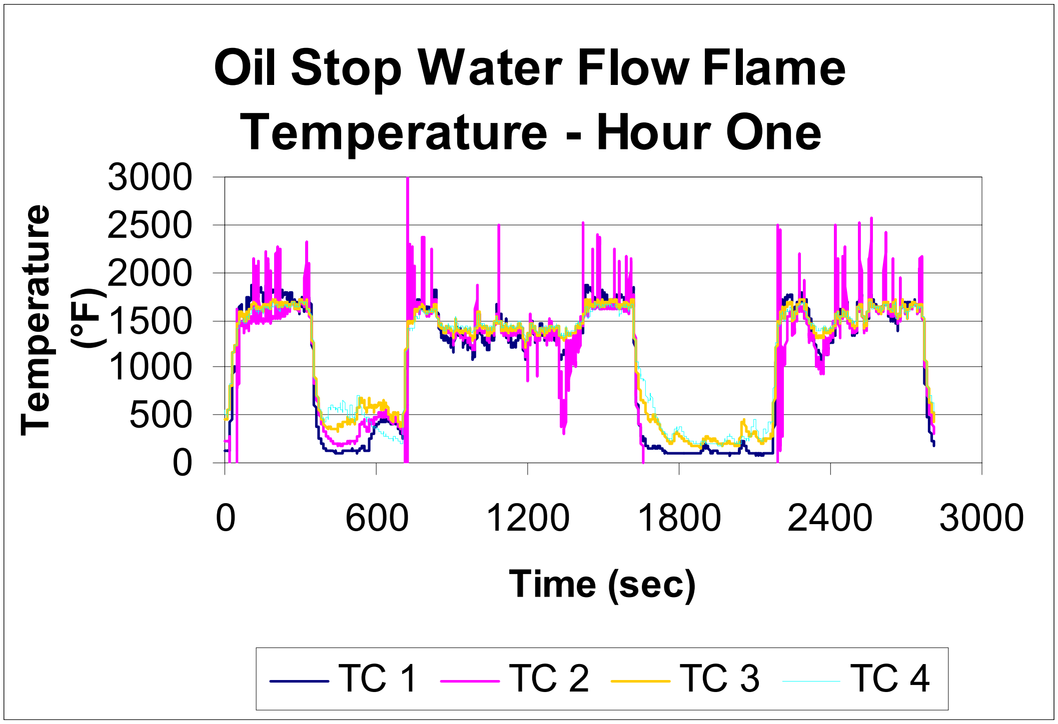
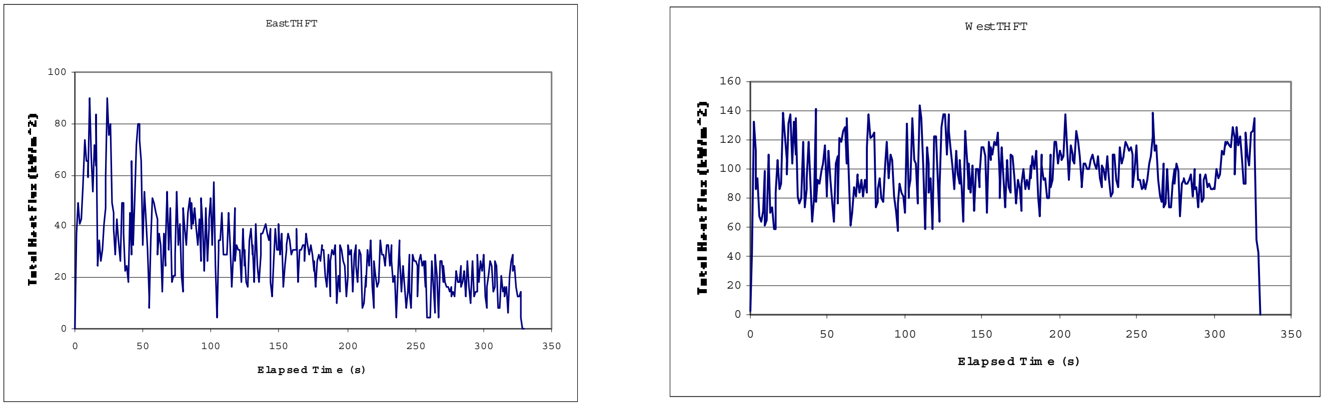
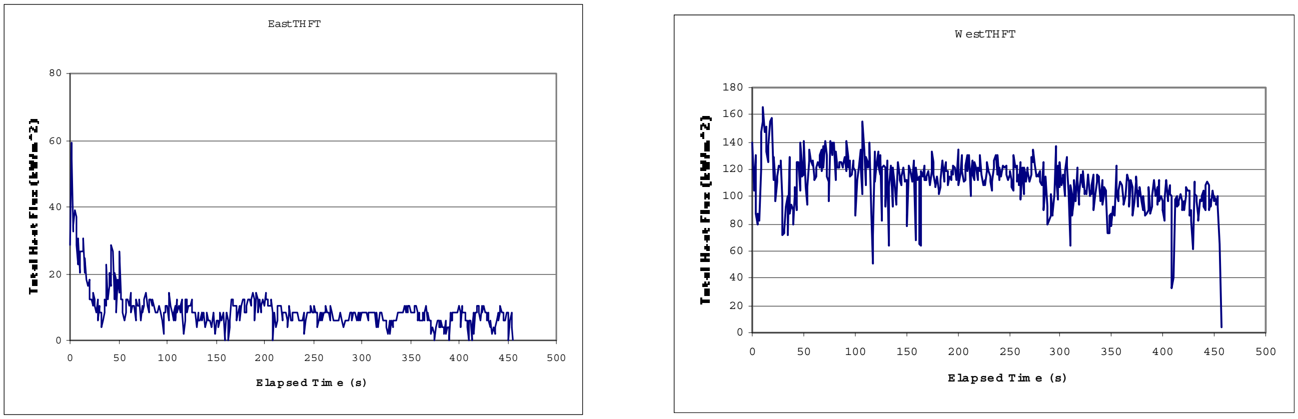


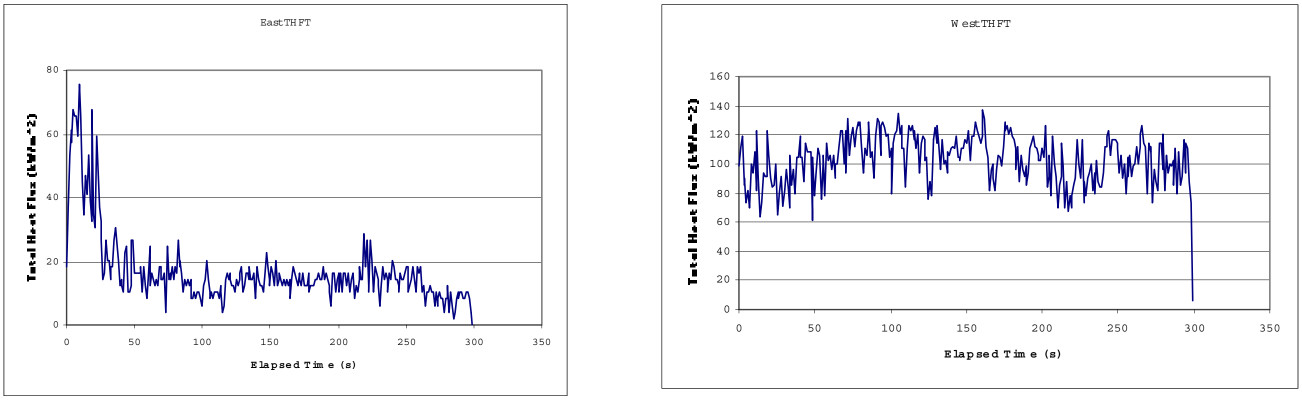
Figure 67 - Flame temperatures for Oil Stop water flow test.



First Burn



Second Burn



Third Burn

Figure 68 - Heat fluxes for Oil Stop water flow test.

7. Conclusions and Recommendations

7.1 Conclusions

1. The SWEPI fire boom for broken ice conditions passed the test protocol; however, its performance in the fire test was probably greatly influenced by its being frequently over-washed by waves. Such waves would not likely be present in its intended operating environment (among broken ice). The boom was able to contain approximately 56 mm (2.2 in) of low-viscosity oil after the wave stress and fire tests. It was clear that this was the operational, calm-water draft of the boom.

2. The version of the Oil Stop, Inc. Auto Boom Fire Model tested was an older model. After two hours exposure to waves prior to the fire tests, it was exhibiting some cracking of the outer stainless steel mesh cover. It failed, by melting of the pressurized air-inflated flotation chamber membrane, after 1 hour and 24 minutes exposure to flames. The version of the Auto Boom Fire Model that is produced now incorporates several modifications:

- The stainless steel mesh is now laminated to a polyurethane-coated polyester fabric to make the screen more durable prior to exposure to fire, and to make it safer to handle.
- The fabric used to make the air chambers has been changed to an unreinforced film. The coated glass fabric was susceptible to excessive wear where repeated flexing occurred. As well, the new film is much less likely to allow the bolt holes at the connectors to wallow.
- The material in which the refractory mat is wrapped was changed to a vinyl-coated polyester fabric for greater protection and stability than the original polyethylene film.

3. The Oil Stop water-cooled blanket section failed in the flames when the cooling water flow was reduced to 16.3 L/min (4.3 gpm).

7.2 Recommendations

1. The bubbler frame should be modified to include guide posts extending out from each end, and up through the water surface, to prevent skirted booms from being pushed sideways by the underwater plume to contact the air standpipe floats.

2. The system for suspending the THFTs in the flames should be modified to incorporate a constant-tension system to prevent their sagging as the support chain heats and expands.

3. A remote-controlled ignitor system should be developed.

4. The newest version of the Oil Stop, Inc. Auto Boom Fire Model should be subjected to the test protocol to determine if the modifications have improved its durability.

8. References

Lafferiere, R. “Report of the burning operations panel”, in *In Situ Burning of Oil Spills, Workshop Proceedings,* Walton, W.D. and Jason, N.H. eds., National Institute of Standards and Technology, Gaithersburg, MD, pp. 7-15, 1998

McCourt, J., I. Buist, B. Pratte, W. Jamieson and J. Mullin, “Testing fire resistant boom in waves and flames”, in *Proceedings of the Twentieth Arctic and Marine Oilspill Program (AMOP) Technical Seminar*, Environment Canada, Ottawa, ON, pp. 1997.

McCourt, J., I. Buist, J. Mullin, B. Pratte and W. Jamieson, “Continued development of a test for fire booms in waves and flames”, in *Proceedings of the Twenty-First Arctic and Marine Oilspill Program (AMOP) Technical Seminar*, Environment Canada, Ottawa, ON, pp. 505-528, 1998.

McCourt, J., I. Buist, W. Schmidt, D. Devitis, B. Urban, and J. Mullin. “Ohmsett’s Propane-fuelled Test System for Fire-Resistant Boom”*, Proceedings of the Twenty-Second Arctic and Marine Oilspill Program (AMOP) Technical Seminar*, Environment Canada, Ottawa, ON, 1999.

SL Ross Environmental Research Ltd. and MAR, Inc., 2000, Data report on U.S. Navy fire blanket tests at Ohmsett. Draft report to PCCI, Herndon, VA

Stahovec, J.G., R.W. Urban and K.V. Wheelock. 1999. Water-cooled, fire boom blanket, test and evaluation for system prototype development. Proceedings of the 22nd AMOP Technical Seminar. Calgary, AB June 2-4, 1999. Environment Canada. Ottawa. pp 599-611.

Walton, W.D., W.H. Twilley, J.V. Mullin and R.R. Hiltabrand, “Evaluating a Protocol for Testing Fire-resistant Oil Spill Containment Boom”, in *Proceedings of the Twenty-First Arctic and Marine Oilspill Program (AMOP) Technical Seminar*, Environment Canada, Ottawa, ON, pp. 651-672, 1998.

Walton, W.D., W.H. Twilley, N.P. Bryner, L. DeLauter,R.R. Hiltabrand and J.V. Mullin, “Second Phase Evaluation of a Protocol for Testing Fire-resistant Oil Spill Containment Boom”, in *Proceedings of the Twenty-Second Arctic and Marine Oilspill Program (AMOP) Technical Seminar*, Environment Canada, Ottawa, ON, pp. 447-466, 1999.

Appendix A - Test Plan

Appendix B - Instrument Calibration Data

Appendix C - Boom Descriptions

Appendix D - Data and Field Notes