Relative Challenges to Oil Recovery from Wrecks: A Comparison of the *USS Mississinewa* and the *SS Jacob Luckenbach*

Introduction

Experience with off loading sunken oil in two significant responses has highlighted some of the wide variability in technical challenges to the retrieval of oil from sunken wrecks. A comparison of the off loading experience with the *USS Mississinewa* in Ulithi Atoll, Federated States of Micronesia and the *SS Jacob Luckenbach* off the San Francisco, California, reflect a continuum of technical challenges in logistic support, dive operations, or oil off loading, as well as other issues. This is of particular interest because both vessels were World War II wrecks.

World War II wrecks comprising the largest group of potentially polluting wrecks are of particular concern because increasing age, increasing corrosion and potential oil volumes. The South Asian-Pacific region has the highest number of wrecked vessels with 34 percent of the known tank vessels, 21 percent of the known non-tank vessels, and 20 percent of the worldwide estimate of oil remaining (maximum estimate of 4,100,000 tones and minimum estimate of 510,000 tones). In terms of tank vessel wreck numbers, the second highest region is the Northwest Pacific, with over 15 percent of the tank vessels and approximately 5 percent of the estimated oil volume remaining. The Northwest Atlantic has roughly the same amount of oil remaining as the South Asian-Pacific with the 22 percent of the non-tank vessel wrecks and 15 percent of the known tank vessels. The Northeast Atlantic, with over 20 percent of the worldwide estimate of oil remaining, is ranked third in the estimated number of non-tank vessels and third in the estimated volume of oil remaining with 17 percent of the worldwide estimates. Thus, the North Atlantic Ocean has 25 percent of the potentially polluting wrecks in the world, and these wrecks are estimated to contain nearly 38 percent of the worldwide oil estimates. (2005 IOSC Issue Paper, Michel, et all).

History and Purpose of Work

USS Mississinewa is a World War II U.S. Navy Fleet oiler that was sunk by a Japanese Kaitensuicide torpedo, which carried a pilot and 1.5 tons of high explosive, on November 20, 1944, at Ulithi Atoll, Yap State, Federated States of Micronesia (FSM) in the western Pacific Ocean. At its sinking, the 553-foot, 24,425-ton vessel had just taken aboard a full load of Navy Special Fuel Oil (NSFO), gasoline and diesel fuel.

In April 2001, sport divers located the wreck of the *USS Mississinewa*. Four months later, in August 2001, a short time after a storm, oil was reported to be leaking from the wreck into the lagoon by recreational divers. The US Navy Supervisor of Salvage and Diving surveyed the vessel and temporary patches were installed and some trapped oil was recovered. In December 2001, a new oil leak was reported and in view of the likely chronic recurrence of the seeping oil, it was recommended that the oil be off loaded as a permanent solution. Between January and March 2003 all safely accessible oil was removed from the vessel. It is estimated that approximately 1.8 million gallons of NSFO and diesel fuel were recovered.

The *SS Jacob Luckenbach* was a C-3 freighter design built in 1944 with a capability to carry 457,000 gallons of ship's fuel. When it sank on July 14, 1953, after a collision with the *SS Hawaiian Pilot*, it was out-bound from San Francisco en-route to South Korea with a load of railroad, automotive, and other materials for the war. The vessel sunk in about 175 feet of water 17 miles southwest of the Golden Gate Bridge, about 10 miles southeast of the Southeast Farallon Island.

Since the mid-1970s mystery spills have repeatedly occurred off the central California coast during late fall and winter months. These "winter mystery spills" occurred during significant coastal storms. While little oil was ever collected on shore or was seen from spotter aircraft, oiled birds would strand along 100 or more miles of the central California coast, with common murres among the most numerous species oiled. Between November 2001 and January 2002, oiled birds, predominantly common murres, were once again discovered on central California beaches and continued to be found almost daily, a much longer time than usual for most oil spills and over a 220 mile expanse of coast. Also, oil collected from these birds continued to have a "fresh" consistency, not "weathered" and tar-like. Air observers noted a sheen in the area southeast of the Southeast Farallon Island, where a few small tar balls had been collected, where satellite imaging captured oil windrows, and where the common murre hind-cast analysis indicated the birds had most likely encountered the oil. Finally, two recreational divers reading newspaper accounts of the search for the mystery oil dove on the wreck of the *SS Jacob Luckenbach*. An oil sample they collected on the surface above the wreck was analyzed and found to match the mystery oil, thereby identifying the *SS Jacob Luckenbach* as the source of the oil. Between May and October 2003, Titan Maritime conducted a vessel assessment and began removal of the available oil with Global Diving & Salvage, Seattle, providing saturation diving services and Crowley Maritime providing the primary work barge and tug services.

War Graves

The issue of war graves has greatly complicated access to and work in many WWII wrecks. Many nations impose sovereign control over such wrecks whether they are in national waters, international waters or the waters of other nations. This right does not extinguish by the passage of time, regardless of when the vessel was lost at sea. In addition to deserving treatment as gravesites, these sunken State craft also may contain objects of a sensitive archeological or historical nature.

Those involved in the *USS Mississinewa* oil removal were acutely aware that the sunken vessel is the war grave for 63 of the ship's complement of 264 persons. All U.S. Navy decisions were made and all operations undertaken against this backdrop. The U.S. Government provided assurances to all concerned local and regional government officials, as well as to survivors' groups, that operations called for no activity in the vicinity of any ship's spaces that would have been manned. Therefore, no human remains would be disturbed. All cargo and bunker tanks were to be accessed directly through the skin of the ship or from within previously emptied tanks.

The *SS Jacob Luckenbach* sank with no loss of life and there were no complications from this perspective in accessing the ship and its cargo.

Wreck Configuration and Oil Location

The wreck configuration and oil location for the two wrecks presented substantial differences in terms of depth, sub-sea conditions, vessel location and access, and oil conditions.

The *USS Mississinewa* rested upside down in 130 feet of water. The 90-foot bow section was separated from the rest of the hull and lay 70 feet forward of it. Although wave height ranged from four to eight feet during the recovery, conditions on the bottom, where dives ranged from 80 to 112 feet, were nearly ideal, with diver visibility in the 70-foot range. Direct vessel access with clear water visibility permitted a relatively straightforward off loading plan. Most importantly, the wreck and surrounding area were safe for removal operations.

The USS Mississinewa's hull was in remarkably good shape, considering that it had been on the seafloor for 59 years. Ship surveys were available for the *USS Ashtabula* class of vessels were helpful in assessing the hull structure and oil loading condition of the wreck and marking the location of tanks and development of a grid system to be established for the location of all work.

The *SS Jacob Luckenbach* presented a different picture. The vessel sustained massive structural damage from its collision and was located in 180 feet deep waters on its side, with part of the hull buried below the sea floor. The wreck was subject to strong currents running through a marine canyon, and in cold water (4°C to 8°C range). The vessel's position and condition were unclear. Careful measurements had to be made and re-checked, due to the heavy marine growth hampering identification of ship structures. In addition, the *SS Jacob Luchenbach* presented difficulties in terms of location and placement of oil tanks to be accessed. Oil was found in multiple locations throughout the vessel with some oil locations not readily reachable from the side of the vessel most accessible to divers.

In addition, when the *SS Jacob Luckenbach* sank, warm bunkers leaked from hull cracks, vents, and compromised bulkheads shortly after the sinking. Oil that did not escape was trapped in cargo space overheads and between decks. As the oil cooled, it solidified into sticky semi-plastic masses in hundreds of frames throughout the ship. When bottom currents changed direction in the late summer and fall each year, the currents would enter the hull and push small amounts of viscous trapped oil out of the ship to the surface or along the bottom later to drift ashore as tar balls. The only oil information initially available was viscosity reports indicating that some of the oil was a low-viscosity "diesel like" product or that the oil was tar-like, with a viscosity of over 300,000 cSt at ocean bottom temperatures. A range of high viscosity oils was found in the tanks. Most of these waxy high-pour point heavy oil products would not easily flow and greatly complicated the recovery operation.

Hull plating samples and hull thickness gauging showed that the hull was in surprisingly good shape, particularly near the fuel tanks. Hull thickness deterioration typically varied from 60% to 5% wastage from the upper to the lower hull plating respectively. However, the condition of tank piping, vent and sounding systems was highly deteriorated. The vent piping was made using electric seam welding and the weld metal used had disappeared from much of the vent piping.

Logistics and Distance

Any oil recovery effort has a logistic support pyramid which must be maintained or the recovery is compromised. Extreme distance complicated logistics in response for the *USS Mississinewa*, as did difficulty in moving equipment from shore to sea and via air and vessel. In contrast the *Jacob Luckenbach* provided opportunity for harbor and pier loading and unloading and proximity to the US coast for shore based equipment and supplies. With the relative proximity of additional equipment and access to shore based operational support, this permitted having less equipment on site and adding to the equipment suit only as it was needed.

For the *USS Mississinewa*, the rescue and salvage ship USS *Salvor* served as the diving support platform. Four other vessels, chartered in Singapore, also played major roles in this mission. Two identical 300’ x 100’ deck barges, *Fels* 20 and *Fels* 21, were towed from Singapore by anchor-handling tugs MV *Seacor Rover* and MV *Jaya Marlin*. While it was felt that one barge would be sufficient a second barge was secured. Given the distance from the support port of Singapore, had a second barge later been required, the project would have been set back – at a considerable day rate – by a 16-day delay while the second barge was towed from Singapore, assuming a barge could even have been located and placed on charter on short notice. In addition, a single laden barge might not have provided adequate freeboard for safe transit of all the deck-loaded equipment in potentially rough seas on the return trip between Ulithi and Singapore. Both barges were required to have space for oil spill response equipment staging, for supporting hot tapping and pumping operations, for berthing (in vans on deck), and for accommodation of two Marine Sanitation Devices (MSDs) and trash handling.

Seacor Rover, the larger of the two tugs, provided hotel services for personnel on scene. The smaller tug, *Jaya Marlin*, remained on station for logistic support and for the return barge transit to Singapore. *Fels* 20 was the primary work platform and was outfitted in Singapore to support all diving, offloading, and support systems that would not fit on *Salvor*’s limited aft deck area, including portable berthing vans for personnel. *Fels* 21 provided temporary storage and transport for all oil removed from *Mississinewa*, with *Fels* 20 providing additional oil storage capacities as required.

Seacor Rover and *Jaya Marlin* were self-contained with respect to storing and processing sanitary wastewater. *Salvor*, stored only 8 to 12 hours’ accumulation of sanitary wastewater before needing to pump and had no wastewater processing capability. Waste was pumped into an onboard, dedicated waste cargo tank on *Fels* 20 and then through portable Marine Sanitation Devices (MSDs) waste processing and discharge of purified water. For solid waste, two standard open-top containers, a small trash compactor and a small barrel burner were used. Solid waste was separated into burnable trash and wet, non-burnable, compactable waste. Solid waste containers were located on *Fels* 20 and the *Jaya Marlin* collected the burnable trash and burned it on the afterdeck in barrels. After compactable trash was compacted, it was stored and ultimately disposed of at facilities in Singapore.

Diving

With diving conditions such as depth, currents, and temperature as disparate as they were between the *USS Mississinewa* and the *SS Jacob Luckenbach*, diving operations were similarly different in complexity.

With the *USS Mississinewa* upside down and with oil containing tanks accessible, working depths were approximately 90 feet, even though the sea bottom was much deeper. This saved about 40 feet of diving depth, consequently reducing decompression times. The *USS Mississinewa* offloading concept of operations involved the use of divers to hot tap into oil cargo and fuel tanks on the vessel's inverted hull and to rig submersible pumps and hoses for pumping oil to a barge on the surface. Generally, decompression times were about 30-45 minutes, following 60-90 minutes of work at 90 feet. Over 90 percent of the dives used surface-supplied air and the remainder used scuba tanks. Surface-supplied air dives were working dives, while scuba dives accomplished photo documentation, maintenance and bottom closeout. Originally, the dive plan called for around-the-clock diving. However, it became clear that the hot tap installation was best accomplished during daylight hours, so most dives took place between 0700 and 1800. This enabled 11- or 12-hour days for divers. Two, three-man dive teams relieving each other for meals.

The *SS Jacob Luckenbach* required the use of saturation diving to address problems which included extended cold-water diving at depths to 165 feet, strong reversing currents, and poor sub-sea visibility. Heavy marine growth over the entire wreck and difficult placement of the wreck presented a complicated picture for access to the oil. In addition, listing to starboard resulted in several starboard tanks being completely inaccessible without massive tunneling. Many of the pumping system components initially mobilized were off-the- shelf items or were quickly fabricated, based on very limited initial information about the wreck. However, the heavy residual oils in the deep tanks and double bottoms proved to be far more viscous than expected and presented substantial pumping difficulty. As a result, the *SS Jacob Luckenbach* off loading plan was developed and modified as new problems were detected.

Saturation diving provided relative safety and efficiency. A two-man, 12-hour saturation schedule was chosen in which divers loaded out the bell with the day's supplies, and descended in the pressurized bell each morning. Divers tended each other, with one diver working in the morning and the other in the afternoon. Each dive lasted 4.5 hours, for a total of approximately 9 hours of working bottom time per day. To achieve the equivalent amount of bottom time using conventional surface diving techniques to the working depth of 165 to 180 feet, approximately 10 dives per day would have been required, along with approximately 50 hours of decompression time in both the water and the deck chamber. This would have required a crew of at least 20 additional people, working 24 hours a day.

However, other complications arose from this saturation diving approach. Decontamination had to take place outside the bell. Divers could not allow any oil to enter their top side habitat or the bell, because the toxicity of any fumes emanating from the oil would be magnified due to bell pressure. Therefore, procedures were developed to avoid direct exposure to oil. If exposed, the diver decontaminated himself outside the bell prior to entry and was inspected and scrubbed down further by his partner as he entered the bell. Whenever the interior of the bell was potentially exposed, the bell was surfaced and thoroughly scrubbed down at night while the divers were sleeping in the habitat. Further, communication became a challenge because divers doing the work were never in face-to-face contact with topside personnel. The proper use of simple new tools or techniques had to be explained in detail. The use of nightly phone conversations to the chamber and drawings and notes passed through an air lock were often necessary to prepare for the next day.

In addition, for surveillance and other purposes the greater depths faced in the *SS Jacob Luchenbach* required the use of remotely operated vessels.

Pumping Operations

Due to differences in water depth, temperature and oil characteristics, substantial differences were found in the *USS Mississinewa* and the *SS Jacob Luckenbach* oil retrieval and pumping operations.

The *USS Mississinewa* applied a conventional hot tap system. The hot tap technique involved a device that employs a flange with a 4-inch pipe nipple and valve bolted or welded to the shell plating of the hull over a tank. With the valve opened, the hot tap machine, with a cutter device (similar to a hole saw) was secured to the valve and the cutter advanced through the valve and against the hull. Using a hydraulic hand drill, the cutter was rotated to cut a 3 1/2-inch hole through the hull. The cutter was then retracted, the valve closed, and the hot tap machine removed and replaced by a hose connected to a submersible pump.

Divers attached hot tap equipment to the high point of each tank, positioned and rigged pumps, hoses, manifolds, and related hardware, and monitored the systems as required during pumping. In two cases, divers were required to cut diver access ports through the *USS Mississinewa*'s shell plating in order to enter and hot tap or investigate internal or otherwise inaccessible tanks. The access ports were then secured by welding steel plates over the openings.

The *USS Mississinewa* divers positioned lightweight, high-capacity submersible pumps on the hull to service several hot tap locations, and connected hoses from the hot taps to the pump and from the pump through a manifold on the bilge keel to the dive platform. An inline booster pump was positioned to boost pressure and flow. A second pumping system, the donut pump, floated on the surface and was connected directly to the hot tap valve through a sufficient length of 4-inch hose. While the donut pump's flow was less than one-half of the primary pumping system, it served effectively for smaller tanks and stripping operations.

In those tanks that were not open to the sea through fractures, a hole was bored below the oil level in the tank to allow water to replace the oil that was removed. Each tank that was confirmed to contain oil was pumped off in this manner. After a series of pumping and settling cycles, when all removable oil had been pumped, the valve was removed from the flange and the hole first was secured with a small, and later a large, dome-shaped cap with a tamper-proof nut in a manner that would prevent future access by sport divers.

The pumping cycle for all tanks included hot tapping, pumping until significant water was discharged with the oil, settling, then repeated cycles of slow pumping (stripping), and settling until a beaker of discharged water revealed no, or barely detectable visible sheen. For some tanks, up to 14 pumping and settling cycles were completed before completion.

Due to the challenge of temperature and oil characteristics , the *SS Jacob Luckenbach* required a heat exchange system to reduce the viscosity of the cold oil. This evolved in two stages.

An initial attempt was made to heat and simultaneously off-load oil from a port deep tank in the stern section. The approach was to use a 3 inch screw pump with a 3 inch discharge hose. The small screw pump had a water inlet and water outlet injection flanges. After the system was attached to the hull using a 6 inch bolted hot tap system, steam was applied to both the pump elbow and to a steam injection point 3 yards below the pump inlet. The idea was to heat the oil in the proximity to the pump while pulling the oil from the hole at a slow pump rate. This would cause oil in the tank to flow into the heated void left behind by pump suction due to hydrostatic head. Steam was provided by boilers on the recovery barge. This worked for only about 4 cubic yards of oil before encountering water.

Later in a second stage evolution, insertion heaters were used successfully to heat the entire tank contents over the course of several days. A system was developed for tank heating with multiple heat exchangers. Heat exchangers were inserted through the hull into the fuel tanks without injecting live steam into the tank, though larger tanks required the use of heat exchangers plus live steam injection nozzles. The steam hoses for these units were linked in series to other heat exchangers, and the exhaust condensate was dumped into the sea. A steam lance was used for local heating, such as directly behind or near the pump.

With ocean bottom temperatures around 6°C and steam temperatures at over 148°C, continuous heat loss into the surrounding ocean occurred from both hoses and tank walls. Tanks were then heated for several days before pumping. Once the oil was heated it was circulated throughout the tank. This was accomplished by pumping warmed oil from the tank via transfer hose through ‘Ts” built into sections of the heat exchangers. The hot oil was then diverted via flexible hose to a long insertion pipe that would push the oil into the middle or corner section of the tank in order to redistribute the heat. Thus warm oil would be pulled from the tank and pushed passed a heat exchanger and back into the tank. This oil circulation process heated parts of the tank space that could not be reached directly with the heat exchangers. In addition, cold seawater entering the void left by removed oil further complicated the heating. This was resolved by pumping to the surface only when all the tank contents could be heated to a high temperature.

Oil temperature was measured at the pump inlet, at the surface and just inside the internal tanks. Internal tank temperature readings were obtained by drilling and tapping holes into the hull and threading temperature gauges into the side of the ship. An average tank temperature 105°F to 130° F was reached before pumping started. Heating took place for a period of hours or days, depending on the tank geometry, until warm pockets of oil could be circulated by the main pump. Oil was pumped to the surface only when temperature probes indicated that the average temperature in the tank was over 115°F with temperatures near the heat exchangers reaching 170°F. The temperature of the oil reaching the receiving station on the recovery barge was usually 90°F to 100°F.

The pumping system used included a special pumping arrangement with annular steam injection. Annular water injection (AWI) is the process of injecting water into either the discharge pipe at the outlet of the pump, or into the suction side of the pump via annular flanges. The small amount of water coats the inside of the transfer hose creating a moving sleeve of water, which displaces the "oil-to-hose wall" friction with a water-to-hose wall friction. Although there is additional friction between the oil and the water the resulting drop in pressure is substantial. The challenge to using AWI is that it requires additional small pumps, small hoses, increased in supply power to operate the pumps, and a portable source of heat energy for the system. The process also adds water to the recovered oil. AWI was used to keep the pump cool during direct steam injection, to keep the inlet warm during oil circulation and to lubricate the discharge hose in order to enhance flow and keep the pressures down. AWI heating water temperatures were approximately 100°F at the surface, with actual water reaching the pump at 70 or 80°F. Without AWI cold oil would clog the pump suction and not allow the forced circulation process to take place.

Although the heating system and methods were ultimately very effective in achieving the oil heating goals, they were extremely inefficient when viewed from an energy supplied vs. energy utilized standpoint.

Conclusion

Recent oil recovery operations from wrecks, including the *USS Mississinewa* and the *SS Jacob Luckenbach*, required facing both human and technical challenges. Ranging from issues of war graves to extreme logistic support, to complex dive operations to the retrieval of extremely heavy oils, each case demands its own unique solutions and prepares us with better tools and techniques for successful future oil recovery efforts. While this is indeed a formidable challenge, the innovative application of both new and old techniques is the key to success. However, responders, divers, and salvors must be prepared to utilize many different techniques to overcome the unknown conditions of the wreck and the oil viscosity.

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