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Closed-Circuit Rebreathers in the Forensic Study of the *Rouse Simmons* Shipwreck

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Abstract

The Rouse Simmons is a three mast wooden schooner that sank in 165 ffw (50 mfw) in 1912 during a winter storm near the Wisconsin shoreline of Lake Michigan. The wreck is largely intact and was surveyed during two weeks of the summer of 2006. Four dive team members used closed-circuit rebreathers while three team members used technical open-circuit rigs. This allowed a direct comparison of the two technologies under the challenging conditions of deep cold water diving. Water temperature appeared to be the limiting factor in dive time for both rebreather and open-circuit divers. A temporary filling station was set up at the boat dock with oxygen, helium, booster pumps and a limited output air compressor. Expendable supplies for rebreathers (gas and sorb) cost one-half that of the open-circuit rigs but the main benefit was the decreased fill time and simpler logistics of the rebreathers. The rebreathers allowed a very detailed survey of the hull, the rigging and the debris field around the wreck. Preliminary forensic analyses suggest that the Rouse Simmons had steerage and was heading for shelter when it sank. The mizzen mast snapped off just above the deck line and the upper portion was not found. The main mast lies forward and to the port side of the hull and the base appears to be missing. The foremast is intact and lies nearly parallel but on top of the main mast suggesting at least one of these masts fell out of the mast step as the ship went down.

Introduction

Closed-circuit rebreathers (CCR) technology has been used in underwater survey work for many years. By the 17th century Geovanni Borreli and Cornelius Drebbel had proposed and built rebreather technology that permitted man extended investigations in refreshed air environments. Schwann and Fluess, in the mid-1800s built functional personal rebreathers that were used for research, investigations and rescue. Siebe and Dragger developed the technology for commercial and military applications in the late 1800s. Hans and Lotte Haas were known in the early 1900s for their underwater photography and studies using rebreathers. Clandestine applications of CCR by the military expanded their availability through and after WWII (Bozanic, 2002).

By 1964, NASA was using a General Electric CCR in support of the Tektite underwater habitat. This rebreather permitted numerous research scientists extended underwater time studying reef community and structure while working from the habitat. Dr. Fred Parker used this experience with a company called Biomarine that later supplied the US military with rebreathers. The Biomarine CCR influenced many rebreather designs in use today. In the mid 1980s Dr. Bill Stone built a CCR for cave exploration and mapping. Martin Parker of AP Valves in the 1990 brought CCR technology into the civilian market (after the popular Drager semi-closed rebreathers (SCR) proved their limitations) with the Inspiration CCR. Others soon followed. Today, there are dozens of CCR companies and more on the market every year.

To date, many universities do not fully utilize rebreather technology within their scientific diving programs. This may be due to the elevated initial cost, complexity of maintenance and training or the additional hazards of this technology. But when compared to open-circuit diving (OC), the improved diver comfort, options in an emergency and increased efficiency of operations (what we call the footprint) of CCR technology are appealing to many underwater researchers (Gurr, 2002).

In November 1912, the 124 ft (38 m) schooner *Rouse Simmons* departed from Thompson, Michigan, on northern Lake Michigan with a cargo of Christmas trees bound for Chicago (Pennington 2004). The *Rouse Simmons* encountered a fierce November gale, and was last seen flying a distress signal off Kewaunee, Wisconsin. A surf boat from the Two Rivers Life-Saving Station searched several hours for the *Rouse Simmons*, but found no trace of the vessel or its crew. Discovered by recreational divers in 165 ffw (50 mfw) in 1971, the 2006 survey was the first systematic documentation of her wreckage.

The *Rouse Simmons* shipwreck site is located 12 mi (19 km) northeast of Two Rivers, WI, and six miles (10 km) offshore. Project goals were to conduct a Phase II archaeological survey to the level necessary for nomination to the State and National Registers of Historic Places, as well as document any evidence of how and why the *Rouse Simmons* sank.

Methods

Diving: The estimated budget to support an eight person OC team for two weeks was nearly $10,000 for breathing gases alone, therefore, CCR technology was chosen to minimize breathing gas expense and logistics. It was estimated that CCRs would reduce breathing gas costs by half, with the added benefit of improving diver safety and comfort. There was insufficient time to train all staff on CCR, thus providing the opportunity to compare CCR to OC performance while divers completed similar tasks at the same site.

Field work was conducted over two five-day surveys, with one month between each survey. Nine divers volunteered their diving services to the Wisconsin Historical Society (WHS) under the direction of Keith Meverden, Nautical Archaeologist. Five OC divers participated in teams of two and three, depending on their availability. Four CCR divers participated in all dives with one exception at the end of the project. Lake Michigan's surface temperature is near freezing during winter months, but rises during the summer with an upper thermocline between 60-70°F (16-21°C) that can reach to a depth of 30 ft (9 m). Below the uppermost thermocline, the temperature drops to 48-60°F (9-16°C), and can reach a depth of 60 ft (18 m). Below 60 ft in depth the temperature ranges from 38-42°F (3-6°C).

Candidates had to provide medical evaluations, diving credentials and health insurance, attend appropriate training and follow the Wisconsin Historical Society's diving manual (based upon the AAUS model). Several of the staff were newly trained on CCR technology in Florida and took time to gain experience prior to the project. Closed-circuit rebreather and OC staff were required to have at least Normoxic Trimix training. All had experience in shipwreck survey techniques. One member was an accomplished UW photographer, one a former master rigger of sailing vessels, and several were senior diving instructors. Males and females participated as divers. Three CCR models were used during the project: Kiss Classic by Jetsam, Ouroboros by CC Research and Megalodon (APECS 2.0) by Innerspace Systems Corp. All staff provided their own life support equipment except that two Megalodon units were provided by Wakulla Diving Center, Inc. (WDC).

Boats with operators, lodging and food were provided by the WHS. A temporary dive locker and blending station was set up at the dock in Two Rivers, WI. All blending technology (dedicated Haskel booster pumps with controls), and CCR gasses were provided by WDC. All OC gasses and compressors were provided by the WHS.

Divers were organized into OC or CCR teams. Daily briefs prior to departure defined research objectives for each team, which included identification and description of components, measuring and orientation, and photographing for later documentation on a master site plan drawing. Several things helped the team do their work. A photomosaic (Figure 1) was provided to assist in the planning of each dive. Each team was assigned an area of the site to document.

Dive profiles were based upon expected gas supplies and thermal stress. Visibility was very good (Figure 2) and not a factor unless silt was disturbed during the dives. With a bottom temperature of 40°F (4°C), most divers did not stay beyond 30-40 minutes, with maximum bottom times of 44 minutes. Cold water acclimatization was not possible for two divers that traveled from Florida. All divers used argon for dry suit inflation. Deep stops were utilized during decompression, but the majority of decompression was spent in the warmer thermoclines. Including decompression, run times exceeded 60 minutes, and often approached 90 minutes. Surface support was available for entering and exiting the water from small boats.

OC configuration included back-mounted, large-capacity double cylinders using a 23/36 blend. Stages were 30-50 ft^3 aluminum or steel cylinders, one dedicated to 50% nitrox and one dedicated to 100% oxygen.

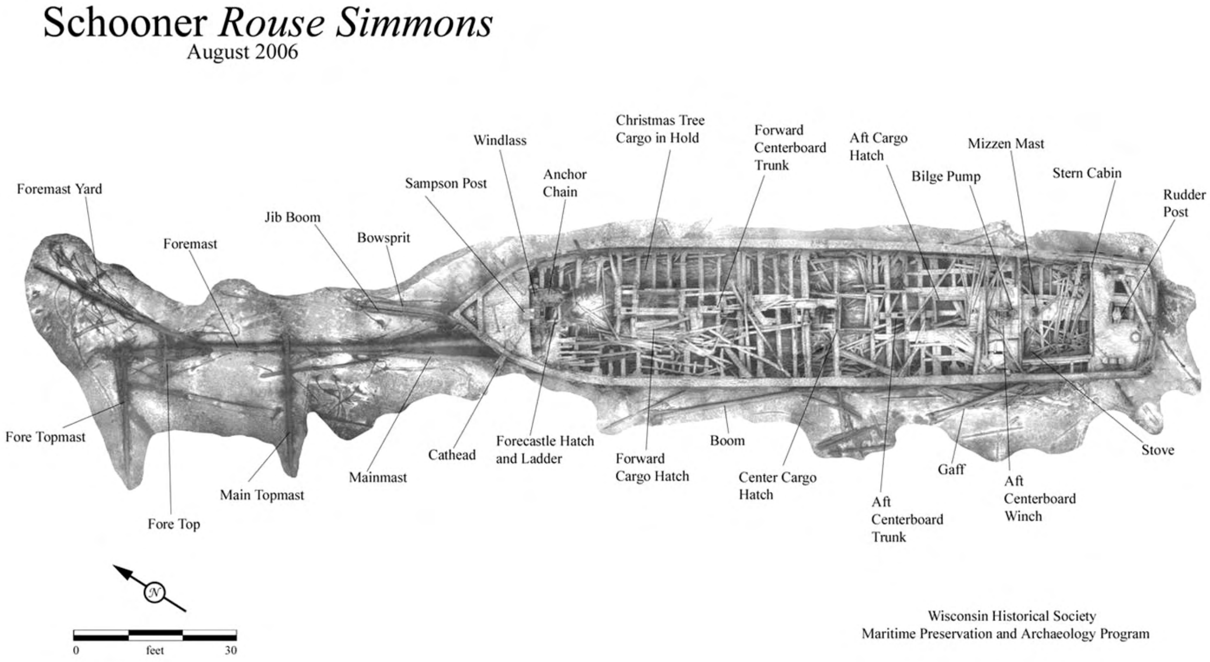

Figure 1. Photomosaic of the *Rouse Simmons* indicating the major features of the wreck

CCR configuration included three liter (20 ft^3) steel RB cylinders (with the exception of the Ouroboros using two liter (13 ft^3) aluminum cylinders), and two 40 ft^3 aluminum stages with bailout gases in case of emergency. The diluent gas on all CCR rigs was 18/36 (18% oxygen/36% helium/46% nitrogen). The bailout stages were 23/36 (23% oxygen/36% helium/43% nitrogen) and 70% nitrox. All participants used VR3 computers and followed the Buhlman decompression algorithm. All divers carried either a redundant VR3 computer or a redundant depth and timing devices and back-up decompression tables.

Each diver conducted one dive per day, after which all cylinders were recharged for the next diving day. CO_2 absorbent canisters were refilled after every dive, regardless of bottom time, with fresh Grace Sodasorb 6-12. Staff archaeologists conducted post-dive debriefings with each dive team member while reviewing the photo mosaic and emerging site drawing.

Survey

The length of the spars near and around the wreck was measured underwater. In some cases the ends were buried in silt and had to be excavated or identified by feel. Circumference and diameter of each spar was measured at key positions and taper of the diameter noted. The ends of each spar were documented by drawings or photographs when possible to help identify the function of the spar, and to determine if it was intact. All measurements were done with a measuring tape, ruler and calipers as needed. Fittings and standing rigging were documented by drawings, measurements and photographs. The relative position of each item to the hull was noted on a site plan based on a mosaic photograph of the site (Figure 1). Spar, fitting and standing rigging components were compared to historic photographs of the intact *Rouse Simmons* (Hirthe and Hirthe 1986; Historical Collections of the Great Lakes, Bowling Green State University).

Figure 2. Two CCR divers descend to the wreck showing the generally good visibility at the site during the survey. The bow of the wreck is clearly visible as is an open-circuit diver to the right of the wreck. (photo by T. Thomsen)

Results

Diving:

Three OC scientists participated on the first week of the project. During the second week one returned and two were replaced with new OC staff. The same four CCR staff participated in both weeks of the survey. The day consisted of briefing, loading, transit to the site, research on the bottom (BT), decompression, return to port, recharging and debriefing, supper, and retire.

Time to support the three OC staff at the blending station averaged a total of 2.5 hours (blending/filling cylinders) per day. The four CCR staff required a total of 30 minutes to complete recharging their two 20 ft^3 cylinders each (base taken from a premix bank, but augmented as required). Bail out cylinders did not require recharging during the project. Canister packing time must be added to the equipment recharging picture. CCR staff repacked at home every day as part of their setup procedures. Each reported taking 30-45 minutes to set up their rigs prior to diving, 10-15 minutes of which is used for canister repacking. Therefore CCR recharging takes 70 minutes total when compared to the OC recharge of 150 minutes (since both must still set up their rigs).

Dive statistics over two one week periods:

<u>OC dives (five divers)</u>
Number of person dives: 25
Average BT: 31 minutes
Average In-water time: 62 minutes
Average gas consumption:
Oxygen 1,300 ft^3 total /3 = 433.3 ft^3 per diver or /25 = 52 ft^3 per dive
Trimix: 3,500 ft^3 total/3 = 1166.7 ft^3 total or /25 = 140 ft^3 per dive
Nitrox: 960 ft^3 total (used in blending 70%)/3 = 320 ft^3 per diver or /25 = 38.7 ft^3/dive

<u>CCR dives (four divers)</u>
Number of person dives: 34
Average BT: 31 minutes
Average In-water time: 91 minutes
Average Sorb consumption: 5.5 pounds/dive
Average gas consumption:
Oxygen: 350 ft^3 total /4 = 87.5 ft^3 per diver or /35 = 10 ft^3 per dive
Diluent: 470 ft^3 total /4 = 117.5 ft^3 per diver or /35 = 13.43 cf per dive
Trimix: 320 ft^3 total /4 = 70 ft^3 per diver (never used – refilled on 2nd wk)
Nitrox: 320 ft^3 total /4 = 70 ft^3 per diver (never used – refilled on 2nd wk)

Cost of the life support materials (not counting fuel, labor, rent, transport much of which was donated or volunteer):

OC gasses: He 2,500 ft^3
O_2 1,300 ft^3
Air 2,500 ft^3
Total cost is \$677.70 /3 = \$225.90 per diver or \$25.10 per day or \$8.37 per dive

CCR gasses: He dil 470 ft^3
O_2 350 ft^3
bail 680 ft^3 (never used)
sorb 193 pounds
Total cost is \$758.20 /4 = \$189.60 per diver or \$21.06 per day or \$5.27 per dive

Survey

The *Rouse Simmons* was a three mast wooden schooner built in 1868 in Milwaukee, Wisconsin and was approximately 160 ft (49 m) in length overall. The hull is unusual in that it was a double centerboard design, but the rigging is typical of ships built for the great lakes trade at the time. The standing rigging was wire rope that had been largely parceled and served, and fastened to the hull with dead-eyes and lanyards attached to metal chain plates. Each of the three masts was made of two spars: the lower mast and the topmast. The lower and top masts were typically connected together in an overlapping fashion known as the doubling. Nearly all the standing rigging and spars were found just forward of the bow of the wreck (Figures 1 and 3). The following is an overview of the survey results.

The bowsprit was broken at the point it protruded from the bow of the ship and was found just forward of the hull. The base of the bowsprit was still within the hull where it fits into the Sampson post below the forecastle deck. The external portion of the bowsprit was still connected to the intact jib boom. Much of the bowsprit and jib boom standing rigging was still attached, composed of chain and wire. The martingale was not found.

The lower foremast was intact but found lying forward of the hull with the base near the port side bow and angled slightly to the starboard with the mast largely parallel to the hull. A top (platform) was found in place on the lower foremast. The fore lower yard was still attached to the lower mast by the metal truss, which was severely bent on one side. The yard was broken at one end and the piece missing. The fore topmast appeared to be intact, its base lying near the top end of the lower mast at a 90^{o} angle. The upper end was buried deeply in the silt and could not be observed. The hardware that connects the topmast to the lower mast (fid and cap) were intact and in place. The lower end of at least some of the wire rope topmast shrouds appeared to be still connected to the futtock shrouds. The futtock shrouds were made of solid round metal stock approximately 1.0 inch (2.54 cm) in diameter and appeared to have turnbuckles forged onto them. They were deformed and bent. The main lower mast was found on the forward port side of the hull, slightly aft and generally parallel to, and underneath the foremast. The base of the main lower mast could be examined only by touch because it is buried in silt appeared to be incomplete. Crosstrees were found and a top (platform) was not present. The main topmast was found lying over both the fore lower mast and the main lower mast. It was completely intact as were the fid and mast cap. Heavy wire standing rigging was found loosely looped around the topmast and appeared to extend under the silt to the underside of the buried main lower mast (Figure 3).

The mizzen lower mast was broken above the deck with the stump in its original location in the mast step. The remainder of the mizzen lower mast was not found, nor was the mizzen topmast. A variety of gaffs, booms and other spars were found on and around the hull. Most appeared to be standard gaffs and booms with wooden jaws as expected on a gaff-rigged schooner. Three smaller spars found on the site were not positively identified.

The *Rouse Simmons's* hull is largely intact and lies on an even keel. With the exception of the port and starboard quarters, all outer hull planking was intact with caulking. Outer hull planks not colonized by zebra and quagga mussels exhibit traces of green and blue paint. The only visible damage to the outer hull was located at the stern. Both port and starboard quarters had several outer hull planks missing immediately forward of the transom (Figure 5). The missing planks were located above the water line. The transom is dislodged on the port side, pushed several inches outward from the hull.

The vessel's stern cabin is no longer extant. Very little weather deck planking remains intact. Much of the cargo hold is visible through the deck beams, filled with silt and stacked evergreen trees. Many of the trees retain their needles. Nearly all deck beams exhibit a salt channel cut lengthwise along their uppermost surface that was used to salt the deck as a preservative. Both fore and aft centerboard trunks are visible on the vessel's centerline, with the centerboards intact within the trunks. A deck winch to raise the aft centerboard remains intact, with a single-acting bilge pump intact aft of the centerboard winch. The fore and main chainplates on the port side have been forcibly pulled toward the stern.

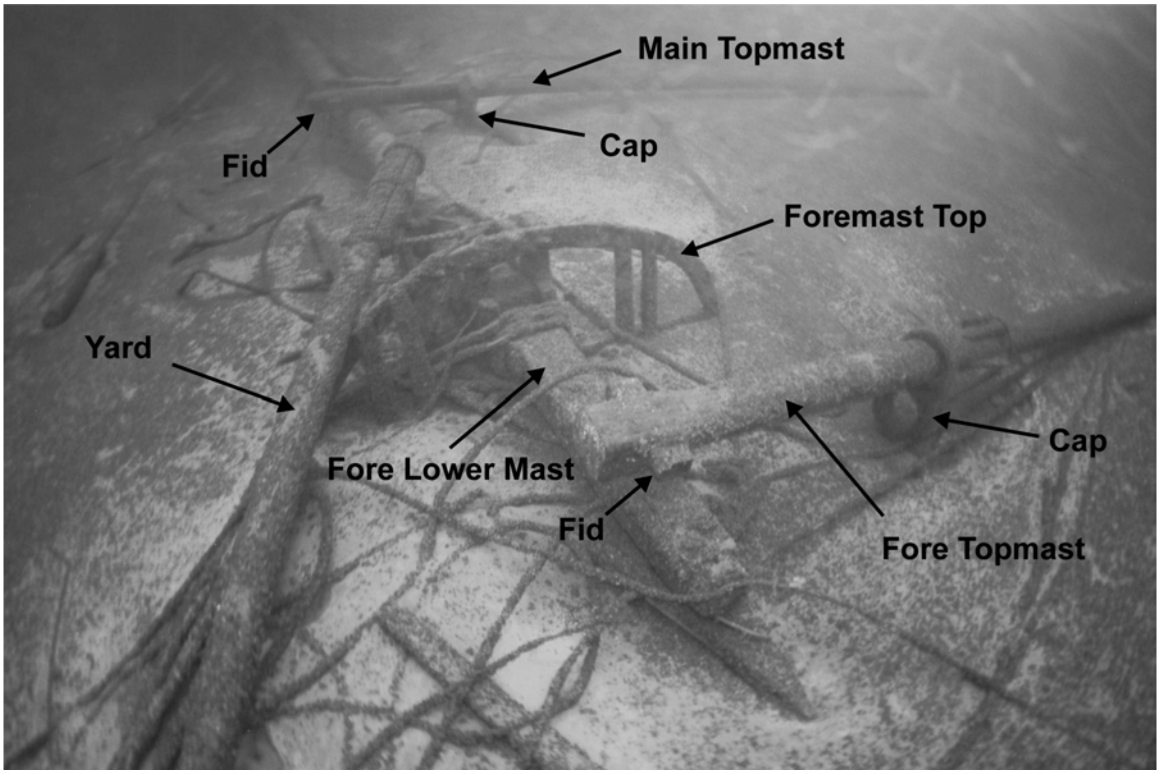

Figure 3. Rigging deposited off the bow (upper left) of the vessel, showing top masts perpendicular to the foremast. The top on the lower foremast can be clearly seen. The main mast is buried below the foremast and cannot be seen in this photo. The main top mast is shown held perpendicular to the foremast in the background. The cap and fid of each topmast can be seen. The diagonal spar in the left foreground is the broken yard used for the Raffee sail. (photo by T. Thomsen)

The weather deck is intact from the forecastle scuttle to the stempost, as well as the windlass and forecastle deck. Both the port and starboard anchor chains have been heaved from the chain locker and are piled on either side of the weather deck aft of the windlass. Both port and starboard anchor chains take four turns around the wooden patent windlass before exiting the hawse pipes.

There is evidence that the port anchor was being prepared for deployment. The four turns of the starboard anchor chain have been loosened around the windlass barrel, gathered, and tied to the strongback that was affixed atop the windlass. The anchor chain has rusted into its tied-up position, and fragments of the fiber line that tied the chain is visible protruding from the chain links. One of the four turns of the port anchor chain is run through an iron Norman Pin that is embedded into the windlass barrel (Figure 4). The Norman Pin (shaped like a large iron staple) was used as a chain stopper prior to modern iron stoppers with a swinging iron gate. Once an anchor was deployed, the Norman Pin was driven into the windlass to lock down the anchor chain, preventing further deployment of chain, and took the strain off the wooden windlass pawl. The Norman Pin is in place at the ready, but has not been driven into windlass to lock down the chain.

The starboard anchor was salvaged by recreational divers, and the severed starboard anchor chain hangs freely from the hawse pipe. The port anchor chain hangs loosely from the bow, is draped over the broken bowsprit on the lakebed, and disappears into the sand forward of the bow. The port anchor's location is unknown, but there is no record of diver salvage. Early underwater footage recorded soon after the vessel's discovery suggests the port anchor chain has not been disturbed, and that the port anchor may have been deployed prior to sinking. A search for the port anchor off the immediate wreck site was not conducted, but will be the focus of 2008 efforts.

Figure 4. The windlass showing the Norman Pin (inverted u-shaped metal in lower left). (photo by T. Thomsen)

Figure 5. The stern of the ship showing damage to the port side of the transom. The stump of the mizzen mast can be seen. (photo by T. Thomsen)

Discussion

Diving

From our data, it appears that the bottom time, or effective time at the research site, for both OC and CCR was virtually the same on this project. Both OC and CCR divers were faced with the same cold water stress that may have normalized this data, and not due to life support efficiency. Two cold water acclimatized CCR divers spent an average of 37 min/dive bottom time across two weeks of the project, while the two non- acclimatized CCR divers spent an average of 24 min/dive of bottom time. All OC divers were cold water acclimatized.

Time at decompression for OC folks was found to be half that for CCR folks. The VR3 does accommodate the more time consuming gradual reduction of trimix possible with the CCR when off-board gas shifting is not followed (as in this case). OC people did perform gas shifts during decompression.

The cost of supporting a CCR dive was found to be 63% that of the OC dive when factoring all consumables used on this project. The cost of delivery was presumed to be equal in both groups and was not factored into these figures. Clearly, if the project had paid a shop to fill cylinders, the cost of labor and overhead would have been much higher. Shop charges are approximately \$0.35$\cdot \mathrm{ft}^{-3}$ for trimix, \$0.25$\cdot \mathrm{ft}^{-3}$ for oxygen and \$0.20$\cdot \mathrm{ft}^{-3}$ for 70% nitrox. With shop prices for fills, the expense for CCR is approximately half that of OC.

CCR is less expensive than OC per dive hour when making helium-based dives. CCR requires much less in-field logistics for gas procurement, fill station time, storage, weight, etc. There is also less danger from out-of-gas emergencies, increased diver comfort with more options when problems do arise. There were no significant differences in efficiency or maintenance between the different rebreather models used on this project. However, the initial cost of CCR is significantly higher than

OC (purchase price and specialized training for CCR technology), and divers can have longer in-water exposures at deeper depths thus with exposure to increased risk.

CCR has definite advantages as a long-term investment, but not necessarily for short term gains (*i.e.*, training divers and purchasing gear for a specific project). However, anywhere that gas procurement is an issue, any CCR disadvantages are outweighed.

We recommend a cost/benefit analysis when considering OC vs. CCR life support technology on a research project. Clearly, for long term investment in UW research, CCR technology will provide better life-support to the science diving community on deeper, longer duration, more arduous exposures. Research requiring minimal noise intrusion, water column mixing, clandestine operations (bubbles) or when gases are limited and/or a small footprint is required, CCR technology will become more beneficial than OC. Availability of gases, functional CCR rigs, trained researchers, and environmental considerations are all cost considerations that should be compared to the cost of OC options.

Selection of the CCR technology, maintenance and repair options and training remain critical to the success of such a venture. The WHS relied upon personal CCR units and the assistance of a training and maintenance facility to insure reliable technology during the project. An institution will need to either provide competent internal monitoring or work closely with external companies to insure CCR reliability.

Rigging and Hull

The wreckage indicates that the rig of the *Rouse Simmons* was essentially as seen in historical photographs and typical of great lakes schooners of the era. The wreck is remarkably intact and the majority of the spars were found and identified. The fore lower mast was positively identified because of the presence of the top, a small platform found in place of spreaders that are normally found on fore and aft rigged masts. The top allows a secure place to work aloft and acts as a spreader and or fairlead for topmast shrouds. A top is characteristic of square rigged masts as well as fore and aft rigged masts that are fitted with a yard. Only the foremast of a schooner would be fitted with a yard. In the *Rouse Simmons* case, the yard served to support the base of a triangular sail known as a Raffee (or Raphe) topsail for sailing down wind (Underhill, 1946). This style of topsail is characteristic of great lakes and coastal schooners but was not in common use elsewhere. One anomaly of the foremast was that the futtock shrouds appeared more modern than those expected on a ship of the *Rouse Simmons* age. The futtock shrouds are solid metal rods that form a connection between the wire rope topmast shrouds above the top or crosstrees and the futtock band located on the lower mast just below the cheeks. Those found on the wreck were of heavier gauge than would be expected and had turnbuckles forged onto them. Normally, futtock shrouds have an eye at each end, the lower eye connects to the futtock band, and the upper end runs through a groove in the spreader or top and terminates in a larger eye or loop forged around a dead-eye. The futtock shroud/turnbuckle arrangement does not appear to be original and is consistent with a report that the *Rouse Simmons* was refitted in 1905 after being partially dismasted. Turnbuckles were not found elsewhere on the wreck and were not in general use on wooden ships of the era. The more modern design we found is consistent with a historical report that the *Rouse Simmons* was partially dismasted in 1905 (Milwaukee Sentinel, 22 Oct 1905) and subsequently refitted.

The main mast was identified because it is nearly the same diameter as the foremast but did not have a top. Instead it was fitted with simple spreader bars which act as a fairlead for topmast shrouds and some backstays. This is typical of fore and aft rigged masts that did not have yards because a secure place to work aloft was not necessary. Historical records show that some great lakes schooners had tops installed on all masts, and although it is common to find a top on the foremast but not the other masts, it is highly unlikely that a top would be installed on the mainmast but not the foremast. Several pieces of evidence allowed the identification of the main topmast. First, both the main lower mast and the main topmast were located aft of their foremast counterparts. Second, a heavy loop of standing rigging, probably a main lower shroud, is loosely wrapped over the topmast and extends under the lower main mast. Third, it appears that a piece of standing rigging from the fore topmast (a topmast shroud) is still connected to one of the futtock shrouds associated with the fore lower mast.

With an intact (and presumable watertight) outer hull at the time of the sinking, the question remains as to why the *Rouse Simmons* sank that November day. It will never be known for certain, but it is possible the missing deck planks played a role in the foundering. Given the intact nature of the hull and the less dynamic environment due to the water depth, the deck planking was expected to be intact as on other wooden vessels in similar Lake Michigan depths. The presence of salt channels on the deck beams suggests the iron deck fasteners may have been compromised by corrosion, allowing the deck planks to dislodge in the storm and allow water entry into the hull.

What happened to the Rouse Simmons?

The standing rigging of a ship is a system integrated with the masts and the hull. Under stress, rigging failures can lead to dismasting and weaknesses in the wooden masts can lead to rigging failures. Wood rot in the masts or corrosion of wire standing rigging are potential weaknesses of a wooden ship of this type. However, it would be unlikely to find evidence of rot or corrosion this long after the wreck. Otherwise, under stress, the failure points are the connections of the standing wire rigging to the chain plates which was accomplished by hemp lanyards threaded through the dead-eyes. Other than the bowsprit/jib boom, we found no evidence of standing rigging still attached to hull chain plate dead eyes by hemp rope, nor did we find standing rigging positioned near hull chain plates. Instead, all of the masts and standing rigging appeared to have been thrown forward of the hull in a relatively small area (Figures 1 and 3).

The mizzen mast broke off above the deck and the upper portion was not found. We found evidence that the main lower mast also broke off above the deck but if so, the base portion has been lost. It is unclear whether the breaking of these masts occurred prior or during the sinking. The fore lower as well as the fore and main topmasts are intact. Because the mounting hardware is still present and undamaged, it appears that these masts fell out of their steps while the ship was sinking. The finding of a broken bowsprit with an intact jib boom is understandable in that it broke where it passed the stem of the ship. The outboard portion of the bowsprit is unlikely to have broken because it is doubled with the jib boom. Because the jib-boom was not broken by the same forces that severed the bowsprit, it is possible that the bowsprit broke before the wreck collided with the bottom of the lake. It is also unusual that the port anchor chain runs atop, rather than below, the bowsprit.

Historic records suggest that the ship sank in the afternoon in temperatures slightly above freezing during gale force winds coming out of the northwest. The position of the port side anchor chain suggests the ship was facing northwest and dragging an anchor. The day of the sinking the winds had come from the southeast and had changed to the northwest during the day, possibly creating large choppy waves. There is no evidence that the ship had significant sail set at the time of the sinking. One scenario consistent with our observations is that the ship foundered as a result of the gale force winds and large choppy seas. The crew may have dropped the anchor in an effort to control the ship. The ship foundered, rolling to port when the bow went under. Wind and water forces wrenched the masts partially aft as evidenced by the distorted chain plates on the wreck. At some point, either on the surface or as the ship sank, the fore and main masts were whipped forward and fell in the relatively small area immediately forward of the wreck as reflected in our survey. As the ship sank, air pressure grew in the stern of the hull, further tilting the bow downward. Air pressure trapped in the stern of the wreck escaped through the transom, partially dislodging the transom and several outer hull planks as evidenced by the transom damage (Figure 5).

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