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Sailing Ma'agan Mikhael II

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Abstract
The Ma'agan Mikhael ship, dated to 400 BC, was built shell-first. Due to its significance, the archaeological find was completely excavated, retrieved from the seabed, conserved, and is now displayed in the Hecht Museum at the University of Haifa. The construction of a sailing replica of the ship took two years (2014–2016), using the techniques of the ancient shipwrights. The replica was launched in December 2016, and since then has made more than 50 sailings along the Israeli coast, which have provided essential information on ancient sailing techniques.

Keywords
Ma'agan Mikhael ship, replica, square sail

Résumé
La réplique de l'épave de Ma'agan Mikhael, datée de 400 avant n.è, a été construit selon la technique « bordé premier ». En raison du caractère exceptionnel de ses vestiges, l'épave a fait l'objet d'une fouille exhaustive avant d'être renflouée et de subir un traitement de conservation en vue de son exposition au sein des collections du musée Hecht de l'Université de Haïfa. La construction d'une réplique aura pris deux ans (2014–2016), en utilisant les techniques des charpentiers de marine de l'Antiquité. La réplique a été lancée en décembre 2016 et a depuis effectué plus de 50 navigations le long des côtes israéliennes, qui ont fourni des informations essentielles sur les techniques de navigation anciennes.

Mots-clés
Ma'agan Mikhael, réplique, voile carrée

1. THE MA'AGAN MIKHAEL SHIP

The Ma'agan Mikhael shipwreck was discovered in 1985, 70 m from the shoreline of Kibbutz Ma'agan Mikhael, which is located 30 km south of Haifa on the Mediterranean coast of Israel. It was found at a depth of 1.5 m, and buried under a 1.5 m-thick layer of sand. Three seasons of underwater excavations were carried out at the site during autumn 1988 and spring and autumn 1989 by the Leon Recanati Institute for Maritime Studies at the University of Haifa, with the late Dr Elisha Linder as project head. Jay Rosloff of Texas A&M University led the excavation team. The surviving timbers, which occupied an area of 11.15 m long, 3.11 m wide and 1.5 m deep, comprised a considerable fraction of the original hull. The existing hull components were the keel, false keel and central stringer, parts of 14 full frames, sections of strakes (12 on the starboard side and 7 on the port side), the mast step, knees in the stem and stern and various internal components. These timbers were of Turkish pine (*Pinus brutia*), except for the tenons, pegs and false keel, which were of oak (*Quercus* sp.) (Kahanov 2003, p. 53-113, 2011, p. 162-163; Kahanov, Pomey 2004, p. 6-13).

The hull had a wineglass-shaped cross-section, and was built by the shell-first method. Starting from the keel and endposts, the hull planks were first joined edge-to-edge by pegged mortise-and-tenon joints creating the outer shell, and the frames were then fastened to the shell by double-clenched copper nails. It also had sewing at the bow and stern, which was a Greek shipbuilding tradition, well attested in both Aegean and Phocaean contexts (Kahanov 2003, p. 113-119; Kahanov, Pomey 2004). In addition to the hull remains, the excavators retrieved 12.5 tons of stone, mostly blue schist with some gabbro (basalt), laid on a bed of dunnage, some 70 items of pottery, a one-armed wooden anchor, a whetstone, several sizes of ropes of various plant fibres, decorative wooden artefacts, food remains, a lead ingot, and a basket of carpenter's tools, which included bow drills, rulers and a square, wooden nails and ready-to-use tenons (Kahanov 2011, p. 162-163).

The ship has been dated to about 400 BC by ^{14}C analysis and the ceramic finds (Artzy, Lyon 2003). After the ship and its contents were completely excavated, the hull was dismantled underwater and the timber sections were retrieved from the seabed and conserved at the laboratory of the Leon Recanati Institute. The hull was reassembled at the University of Haifa, where it is now on display in the Hecht Museum (Votruba 2004; Segal *et al.* 2009; Kahanov 2011, p. 163-167). The late Professor Yaacov Kahanov of the Leon Recanati Institute for Maritime Studies directed the conservation, research and reconstruction of the ship, and initiated and directed the construction of the full-scale sailing replica of the ship.

2. *MA'AGAN MIKHAEL II*: A REPLICA SHIP

A sailing replica of the Ma'agan Mikhael ship was an objective from the moment the ship was discovered and its significance understood. The original inspiration for the project came from the late Dr Elisha Linder, who was succeeded by the late Professor Yaacov Kahanov. The project became viable at the beginning of 2014 with a generous private donation. The replica was constructed at the Israel Nautical College at Akko, and the keel-laying ceremony took place in July 2014. The research objectives were twofold: in-depth research of ancient ship construction by the shell-first method, using mortise-and-tenon joints and sewing; and testing the ship's sailing capabilities while learning about life on board (Ben Zeev *et al.* 2009, p. 1; Kahanov 2011, p. 169).

The archaeological evidence served as the primary source of information. All the components were recorded down to the

smallest detail, such as wood grain, knots, nails, tool marks, holes and the like. The same tree species were used as in the original ship, and timber was supplied by the Jewish National Fund (KKL) from planted forests in Galilee. Planks were cut from straight trunks, and frames were cut from trunks and branches growing naturally in the shapes required to match the curves of individual frames. The builders of the replica used chisels, mallets, hand saws, and measuring, scribing and marking tools similar to those used by the ancient shipwrights. However, where a simple feature, such as the mortise, was repeated, modern electrical tools, such as a band saw, planes, drills and even a mortise-cutting machine, were used.

The builders of the replica followed the shell-first principles and method in an attempt to replicate the archaeological data. The hull planks were manufactured based on the archaeological data and were as similar as possible to the originals. The archaeological information of the planking was only complete up to Strake 3 on both sides. From Strake 4 and upwards, the archaeological information decreased as the remains became shorter and shorter, which forced the builders to make decisions in extrapolating the missing parts. Practically, it was found that above about Strake 6, matching planking to frames gave the best result in replicating the archaeological data. Therefore, floor timbers and futtocks were installed before planking from Strakes 6 and 7 and upward. Thus, up to Strakes 6 and 7, the replica hull was built shell-first, and the floor timbers were shaped to match the installed strakes. From Strakes 6 and 7 the dimensions of the planks were dictated by the frames, as far as they survived, and also by battens corresponding to missing frames and the reconstructed hull lines. The angle of deadrise was constantly checked in order to maintain the symmetry between the two sides of the hull. Mortise-and-tenon joints for fastening planking throughout, and sewing in specific areas, were employed as in the original hull.

No caulking remains were evident in the shipwreck. However, the hull timbers were found to be coated with a mixture of pine resin and esparto wax or beeswax (Glastrup, Padfield, 2004). Therefore, all the hull components of the replica were coated with a mixture of beeswax and pine resin at a 1:1 ratio. Under the waterline, charcoal powder was added to this mixture, giving the underside of the hull its dark colour. In addition, where gaps in the seams were found to be more than 2 mm wide, a traditional caulking material (*Desmostachya bipinnata*) was also used. The hull proved to be practically watertight after allowing the planking to absorb water.

Construction was completed in November 2016. The final dimensions of the replica are 16.6 m overall length, with a beam of 4.3 m over frames. The replica was lowered into the water in the Israel Shipyards dry dock on 16 December 2016, and towed to her temporary mooring at the Kishon Marina in Haifa. The official launching ceremony took place on 17 March 2017, and the ship was named *Ma'agan Mikhael II*. After her arrival at the Kishon in December 2016, the hydrostatic characteristics of the ship were tested, and found to comply with present-day requirements for stability and seaworthiness. This allowed the ship to receive its seaworthiness certificate from the Ministry of Transport, and the replica team to carry out a series of sailings in Haifa Bay and along the Israeli coast. The goal of these sailings was to acquaint the crew with the ship, handling the square sail and quarter rudders, manoeuvring and anchoring (fig. 1a).

3. THE RIGGING SYSTEM OF *MA'AGAN MIKHAEL II*

Apart from the mast step, mast partner beams, and some toggles, no archaeological evidence of the mast, yard, sail or rigging has survived. Thus the mast step was the only surviving timber that could provide a hint of the dimensions of the mast and its location amidships. Two vertical boards, which were fitted into grooves alongside the mast socket, supported the mast. The minimum distance between these boards was 20 cm, which gave an indication of the mast's diameter (Kahanov 2003, p. 99-106). Where the archaeological evidence was missing, iconography (Basch 1987; Ben Zeev *et al*. 2009) and replicas of nearly contemporary ships, such as the *Kyrenia II* (Katzev, Katzev 1989, p. 172-174), *Kyrenia Liberty* and *Jules-Verne 7* and *9* (Pomey 2003, 2017; Pomey, Poveda 2018), were consulted to supplement the missing information. The reconstruction of the ship assumes that she was originally rigged with a single mast carrying a square sail.

The 10.7 m-tall mast is made of cypress (*Cupressus* sp.), tapering from 20 cm diameter at its foot to about 10 cm at the top. It is supported by three shrouds per side, one backstay and one forestay (fig. 1b). A running 'baby' stay is also used when sailing on a close or beam reach. The yard, 11.7 m long, is composed of three overlapping round cross-section pine timbers, connected only by sisal rope lashings. The central piece is 12 cm in diameter and 6.7 m long, while the two side timbers are each 9.5 cm in diameter and 5 m long. It was decided to make the 60 m^2 practice sail of durable synthetic fabric (Dacron) due to the possibility of damaging a natural fabric sail before gaining experience in handling a square sail. It has a sisal (a readily available natural fibre) bolt rope sewn around it to prevent tearing, and five rows of reefing rings. The sail has two sheets and two braces for trimming it to the wind, and ten brails are used for reefing and furling. One halyard and two lifts are led from deck level to the masthead (fig. 1c). A cotton sail has been made for the 2020 sailing season. Once all the elements were complete, several trials were conducted on land in order to study how to raise and step the mast, operate the running rigging and handle the sail. During these trials it was noticed that the heel of the mast shifted towards the bow when the mast was raised. This was prevented by the addition of a 'stopper', which in the original ship apparently was held in place by three small mortises on the mast step (fig. 2). This was an important lesson learned from experience combined with interpretation of the archaeological evidence. After consulting with the project's naval engineer, and due to time constraints, it was decided not to use the two vertical boards alongside the mast socket.

4. SAILING EXPERIMENTS

The major challenge in sailing with a square sail is making way to windward. Experimental sailings were conducted along the Israeli coast from December 2016. The ship is equipped with measuring instruments, including GPS and wind sensors, to record and document all the sailing parameters, and the recorded wind and ship data were used to create and update the polar diagram of the ship.

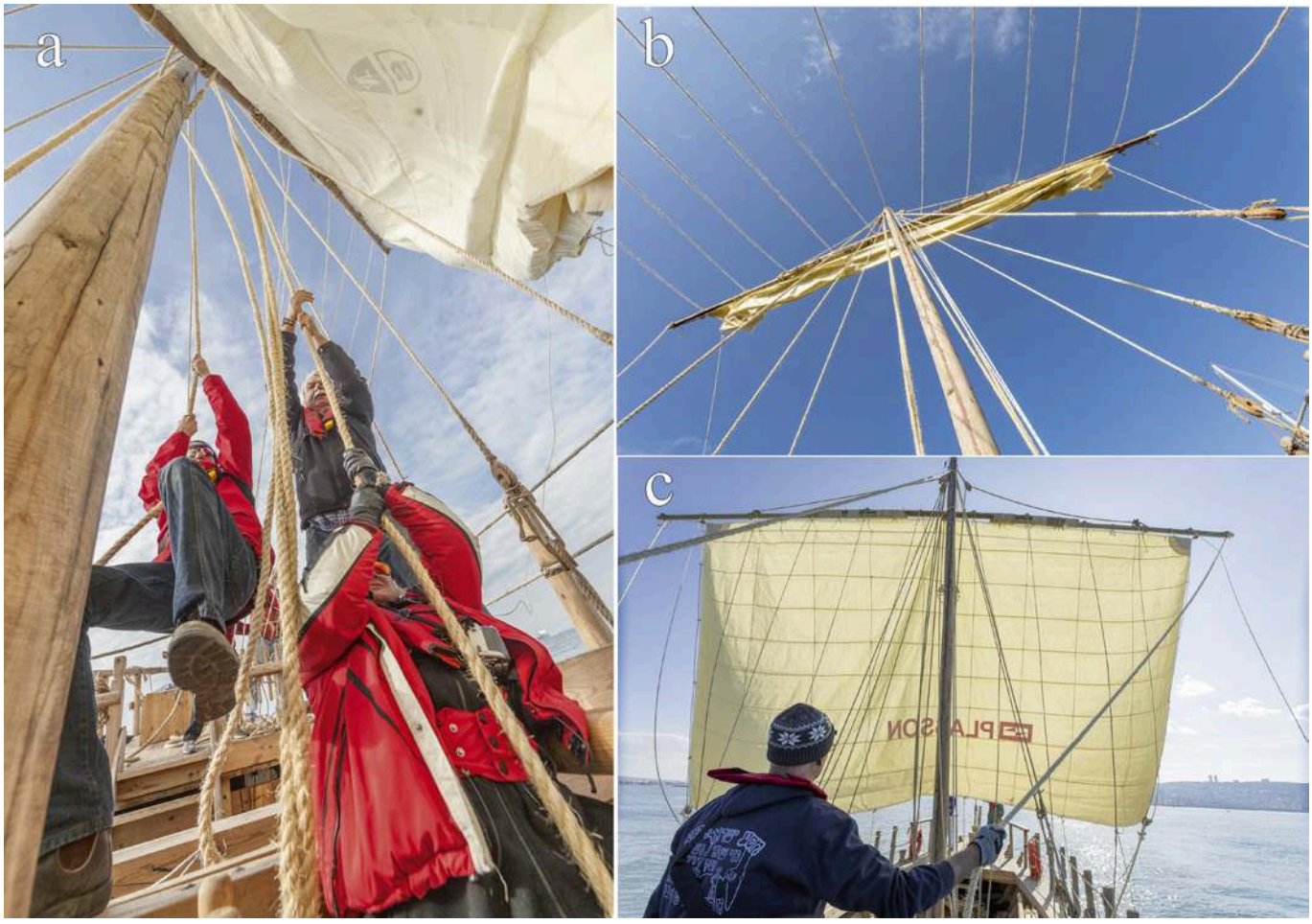

Fig. 1: *The rigging system of* Ma'agan Mikhael II*: a) the crew handling the square sail; b) the mast and rigging; c) the sail and its rigging (photographs E. Efremov)*

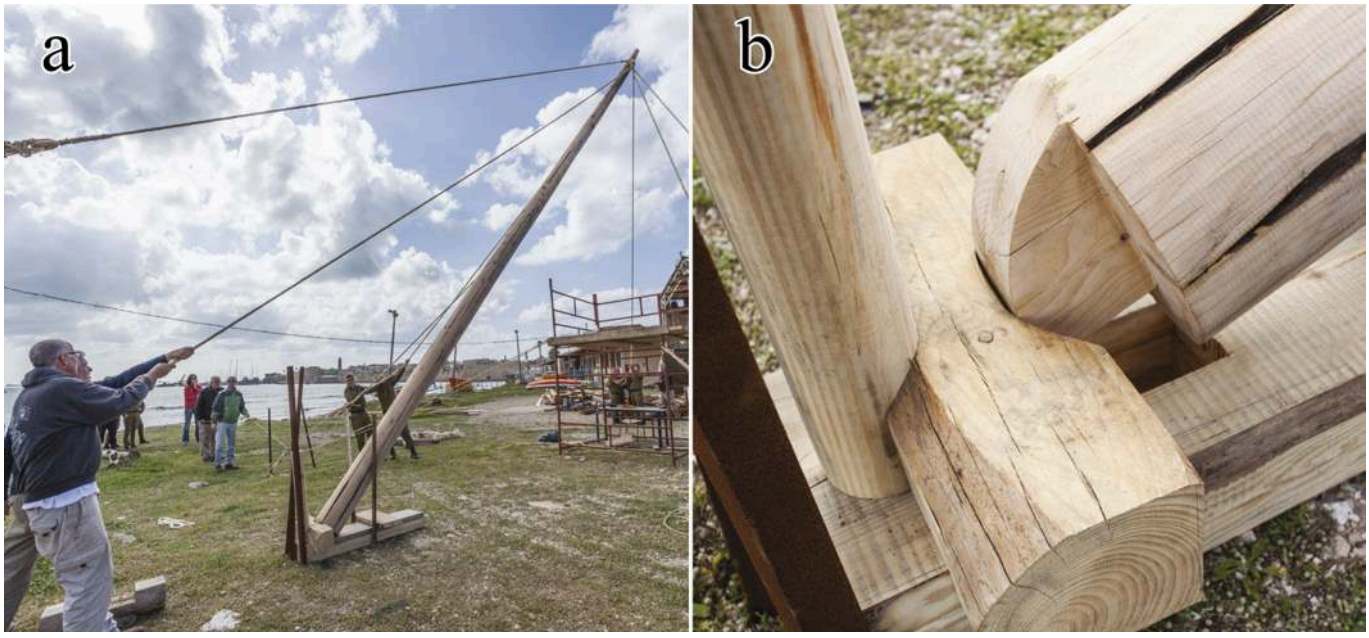

Fig. 2: *The mast: a) trial conducted on land to study how to raise and step the mast; b) the 'stopper' (photographs E. Efremov)*

The first sailings of the ship were conducted in and around Haifa Bay, with the objective of training the crew in the basic tasks of towing the ship and being towed, tying up and securing the ship at the jetty, anchoring and controlling the square rig. The basics of controlling the square rig were learned and practised in the protected bay area with winds less than 10 knots, and with the wind only on broad reaches and runs (fig. 3). From the first sailing the ship was found to have good longitudinal stability, and was easy to sail with a crew of four or five.

In spite of the calm sailing conditions, several rigging failures occurred. One of the quarter rudders broke, and it was decided to replace both by new ones with thicker shafts. The yard also broke on one of the first sailings as a result of incorrect handling. The outer timbers of the yard were replaced, the lashing points were changed, and the braces were attached at different points.

As more experience was gained, we started to sail on beam reaches and close-hauled with the sheet and brace led forward: the sheet fed through a deadeye, which was secured to a stanchion. This enabled tensioning the forward leech of the sail, and improved close-hauled performance. Positioning the yard fore-and-aft for sailing on a beam reach and close-hauled caused the sail to stretch over the forestay. To remedy this, a running 'baby' stay was added, which was tensioned after securing the yard fore-and-aft, and then slackening the forestay to achieve a better sail shape. The ship displayed a strong tendency to gripe, and this was countered by brailing up the aft part of the sail.

After six months of sailing in Haifa Bay, the skills to handle the rig and steer the ship were achieved, and tested on a four-day voyage south to Jaffa and back, a distance of more than 50 nautical miles (NM) each way. The main objective was to examine the possibility of coastal sailing and exploiting the early morning land breeze to advance northward in small hops, until the prevailing north-westerly winds set in about noon. On the first day there was a north-westerly wind of 10-18 knots, and the 52.6 NM to Jaffa were covered at an average speed of 2.8 knots. The return voyage spanned three days: from Jaffa to Herzliya, about 8 NM, at an average speed of 2 knots; from Herzliya to Hadera (22 NM) at an average speed of 3 knots; and from Hadera to Haifa (32.6 NM) at an average speed of 3 knots. Data of all sailings were recorded by a Mareton 100VDR voyage data recorder. This was used to analyse the ship's sailing performance in all the wind conditions encountered. The ship was found to have excellent sailing capabilities, and attained a maximum recorded speed of 5.8 knots while running before a wind of 12 knots.

Fig. 3: *The* Ma'agan Mikhael II *under sail on a broad reach. The two quarter rudders can be seen (photography E. Efremov).*

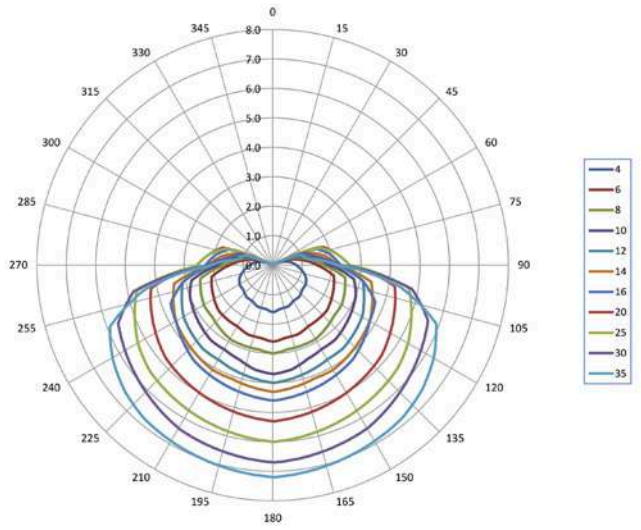

Fig. 4: *The polar diagram of* Ma'agan Mikhael II *(diagram D. Gal)*

During the second year (2018) graduate students, schoolchildren, guests and groups of sailors shared the sailing experiences and deepened their connection to the sea and to heritage vessels. In this year, sailing from Haifa to Ashqelon, a distance of 80 NM each way, including overnight sailing, was preparation for a longer voyage to Cyprus and back planned for 2019.

The ship's polar diagram (fig. 4) shows ship speed of roughly 50% of the wind velocity on a full run, and about 25% of the wind velocity at 80 degrees off the true wind. The polar diagram indicates the Speed Through Water that the ship can achieve at various values of True Wind Speed and True Wind Angle to the ship's heading. Leeway was not included in the polar diagram and it is added to the heading to calculate the Course Made Good. When sailing close to the wind, leeway varied between 10 and 20 degrees.

A sailing model was generated with the assistance of the project's meteorologist, David Gal. This model is based on applying modern meteorological data and the ship's polar diagram to a weather-routing simulator. The model was run concurrently with sailing along the Israeli coast from Haifa to Jaffa and further south to Ashqelon and back, which allowed us to verify the model's accuracy. The sailing model was used to conduct a study on the possible routes and seasons in which a ship such as *Ma'agan Mikhael II* could have made a voyage from the Levant to Greece and back. This is in light of the prevailing north-westerly winds at all seasons of the year. Ten years of gridded wind data at 54 km linear resolution and 6 hours' temporal resolution was used. In all, 40,000 simulated voyages were modelled (Gal, personal communication, 2018).

Several possible sailing routes were examined, and results show the probabilities of a 'good' voyage in every calendar month for each of the routes. The study further examined the synoptic patterns that existed on each potential departure day to try to understand if the ancient Greek sailors would have been able to judge the departure day as a 'good' one. Coastal sailing possibilities were also modelled, using high-resolution gridded data (1 km). The results show the potential of exploiting the morning land breeze to advance some 10-30 NM before the onset of the noon sea breeze or prevailing wind prevented sailing further.

5. CONCLUSIONS

The significance of the Ma'agan Mikhael replica project is in reproducing the conditions of the practical sailing and navigating of an ancient ship. From her first sailing the *Ma'agan Mikhael II* has proven her stability and excellent sailing capabilities, easily carrying 10 to 15 personnel and supplies. The next challenge will be to sail across the eastern Mediterranean from Israel to Cyprus.

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