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A SCIENTIFIC ADVENTURE

By Boris Dreyer

TESTING A F.A.N. THEORY

Eighteen months were dedicated to the preparation and construction of the *Fridericiana Alexandrina Navis* (*F.A.N.*, derived from Friedrich-Alexander University Erlangen-Nuremberg – see *AW* XII.4 on the construction). The boat was first watered in March 2018 and christened in May of that year, before leaving on its maiden voyage. It has since been extensively tested, and we present our initial results here.

Producing a highly authentic reconstruction of an Oberstimm-type ship is satisfying, but our real purpose was to rigorously test its capabilities. There are many more tests to do, measuring devices to improve, and parameters to adjust, but the scientific results of the first voyage of a Roman ship from the upper Danube to the Black Sea can now be presented.

Encaustic paint

In the first article, we reported extensively on our considerations for painting the ship. We followed Pliny the Elder's comments on the encaustic method:

> *"... With the same colours the wax used for the burnt-in paintings is mixed. Walls are not painted with it, but warships in general, even cargo ships. ... It is known*

that there were only two types of encaustic painting in the past. ... A third type was added when the warships were first painted, which is done by applying wax, which was melted over a fire before, with a brush; this painting suffers neither from the sun, nor from the sea water, nor from the winds."

– Pliny the Elder, *Natural History* 35.31 and 41

To apply the paint, we heated turpentine and added resin, which dissolved while stirring the mixture. Pigments and beeswax were added next, and the whole stirred to achieve a uniform consistency. The following basic quantities were used: 380 g resin (coarse dammar gum) + 380 g beeswax + 760 g (Portuguese) turpentine (oil) + colour pigments (200 g burgundy or gold ochre, or for green colour 260 g green + 80 g gold ochre).

Result I: Our literary sources Pliny and Philostratus mention three reasons for painting warships: camouflage, representation, and intimidation. It is therefore necessary to find out which paint scheme and paint method guarantee maximum camouflage and effect at the moment of attack. Painting the ship as one of many in a fleet fulfilled an additional purpose. During winter and with expert supervision, soldiers would build or repair some of these boats that they would serve and risk their lives on during the summer months. A specific paint scheme would help the soldier identify with it as his ship and aid in recognition in the chaos of battle. With its stern and prow decorations a ship became a sort of living creature, whose form took on the dynamics of the ship when it moved, enhanced by the eyes painted on the concave bow.

A problem that would never have been recognized this reconstruction is that, contrary to Pliny's claim about the resistance of encaustic paint, ours started to melt under direct sunlight and at ambient temperatures of just over 20°C from the day we launched her. As the originals sailed the Mediterranean as well, something was clearly not satisfactory in our solution.

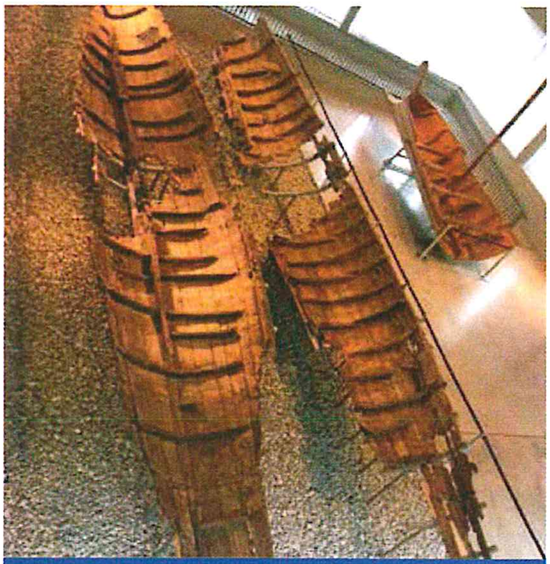
Result II: Temperatures over the summer of 2018 were extreme, which required us to tackle the paint problem. During a longer rest in the Upper Austrian section of the Danube, we had time to effect a solution for the concave bow – most exposed to the sun – which held through the rest of the year and required little repair last winter. We changed the proportions to 237.5 g resin + 475 g turpentine + 142.5 g beeswax and 150 g of each pigment (burgundy or golden ochre, with different proportions and ingredients for other hues and colours). These new ratios allowed for a better coverage that could be applied with a paint roller. The paint hardened and adhered better and has better resistance, as described by Pliny. All in all, the ship looks better!

Rowing tests

During the maiden voyage of 35 km between the university towns of Erlangen and Nuremberg, the FAN's great manoeuvrability came to the fore. We had to to deal with locks and unexpected currents. As we had short oars (410 cm), we were only about 10 m wide, so we easily fit into the floodgates of 12 m width. Learning appropriate manoeuvres appeared easy.

Result III: In ancient times, the waterways in Germania had dangerous currents and were narrow in places. The short oars offer the advantage of manoeuvrability in narrow and small rivers (such as the Breitlach River, where the original was found), while the long oars allow higher speeds (see below).

Further down the Danube, we spent time on Lake Feilenmoos, where we had a total of some 200 guests on board, aged between 12 and 70. Each of them had the opportunity to row aboard the ship.



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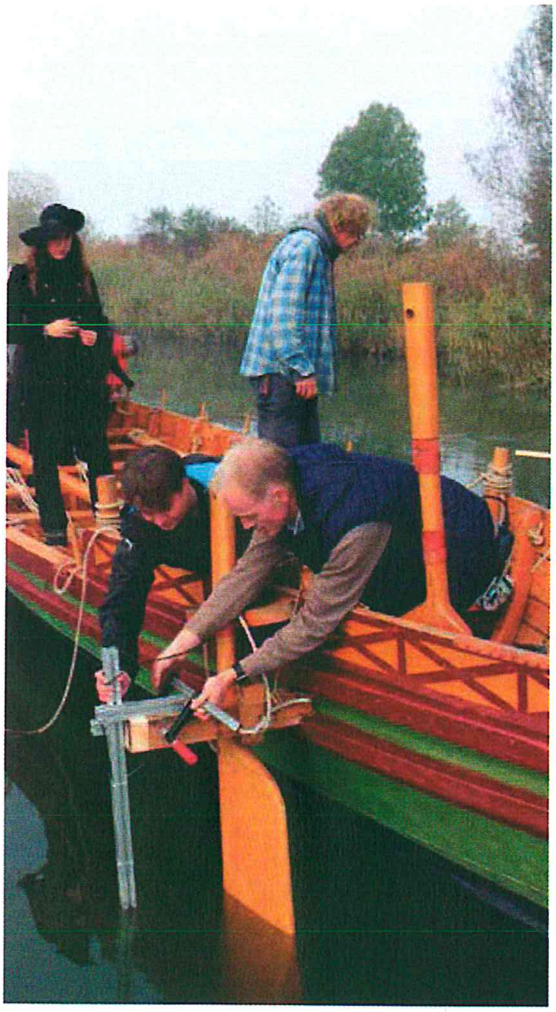

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Result IV: Commands can be learned by untrained crew in a very short time. Both younger and older people can cope with the solid wooden oars, which weigh an average of 15 kg.

At the next station on the Danube, in Ingoldstadt, we had to deal with both rainy weather and a strong current. With six experienced rowers at the prow and stern and twelve inexperienced guests, we warned the crew that they would not return to shore if they did not maintain the correct rowing rhythm. Undoubtedly that focused everyone's mind.

Result V: Even in strong currents (3 m/s) the boat is easy to navigate with inexperienced personnel.

The next day we had to cover the 45 kilometres to Eining, where the wall of the Raetian Limes ended, by noon. We started at 7.45 AM with a crew of twelve, and a ballast of luggage, mast, and yard. There was a strong current with deep water up to the lock at Vohburg. After this, the current was stronger and there were many shallows. By keeping a zigzag course (and enlisting professional help, just in case), we arrived on time.

Result VI: Our short rudder (50 cm below the waterline) proved its worth. Navigating between the shallows with short rudders is possible even in strong currents and with mast taken down.

In Austria we had to cover longer distances with the mast down and stowed. In addition to the helmsman, there were always at least four core crew on board; the rest were guests, though often experienced rowers.

In general, we used tried and tested measuring technology from the field of marine technology, which could certainly be improved for our case. This included instruments for recording the wind direction and speed, the speed of travel relative to the water, and the direction of travel of the bow relative

to north, alongside a GPS receiver to complete the movement vectors relative to the terrestrial reference system. From these motion vectors important information on sailing performance can be derived, such as maximum sailing speeds in different wind conditions.

With the exception of one day, we had to cover 28- to 45-kilometre stretches, which became difficult in the heat (up 40°C), even with hardly any shallows or problematic currents. Hence we developed strategies to optimize rowing performance. Every 30 minutes we took a five-minute break. Rowing in shifts, the even rows could rest every 30 minutes, followed by the odds. Thus a moderate speed was always maintained, and energy was saved. Pulse and rudder stroke were recorded.

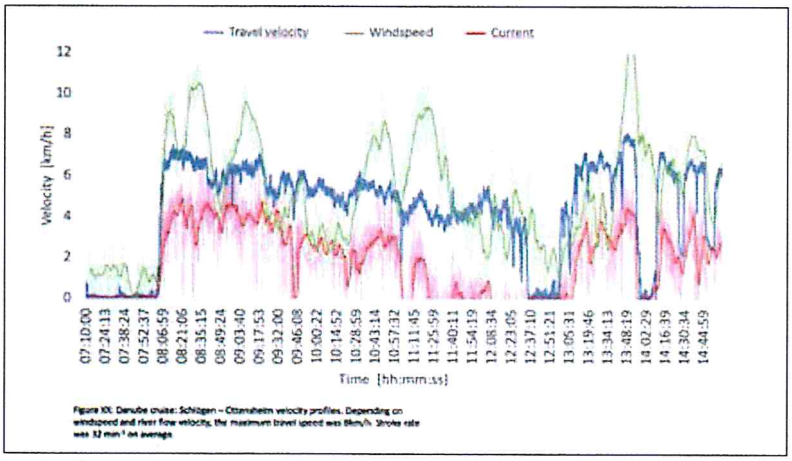
Result VII: Rowing performance can be optimized, with short 410-cm oars and with mast laid down, to an average stroke frequency of slightly over 30, both in shifts and when rowing with the entire team, without having to increase the pulse over a long period.

In the Danube delta we erected the mast and hoisted sails (yard), then sailed manoeuvres with these. Due to its position in the front third of the ship, the exact function and purpose of the mast is not established beyond doubt. It might have been intended for auxiliary sails, yard, or sprit, but a lateen sail is also possible. It is presumed that it was used going upstream to relieve the rowers. On the Danube, even if the course of the river meanders strongly and has a slower current, the wind comes generally from the west, making this only possible and useful under certain conditions. On the lower course of the Danube, however, the wind seasonally also comes from eastern directions.

Result VIII: We were able to use the sail with continuous wind from eastern directions in the last 120 river kilometres west of the mouth of the river upstream.

Tests on the Altmühlsee lake

After the trip to the Black Sea that Summer, we completed manoeuvres and sailing tests in October at the Alt-



Caption this Caption this Caption this Caption this Caption this Caption this Caption this Caption this Caption this Caption this Caption this Caption this mühlsee. In preparation for this, we did supplementary tests with the 1:10 model of the *F.A.N.* in the Erlangen flow channel of the Department of Fluid Mechanics at the beginning of 2017. These tests led to the conclusion that the relatively deep rudders can partially replace the missing keel and give models with concave and round bows stability in the flow.

In order to estimate achievable sailing speeds, the flow resistance of the hull was systematically analysed on two 1:10 models. Speeds theoretically achievable with a full crew at the oars were estimated from these measurements at 4.8 knots at continuous load (18 x 50 W rowing power) and 6.9 knots at peak (18 x 170 W rowing power). Further tests were conducted with concave and round stem, with and without load, and with and without rudder. The applicability of the ITTC procedures to historical ships is subject to certain difficulties, however. The roughness of the wooden planks, for instance, can measurably influence the results. Any such tests should thus be confirmed with the true-scale reconstruction, which is built out of the same type of wood as the original. Advanced flow measurement technology (LDA, PIV) and simulations of turbulent air and water flows, free surfaces, and fluid-structure interaction, which have not yet been carried out with this type of boat, will thus have high relevance for further research.

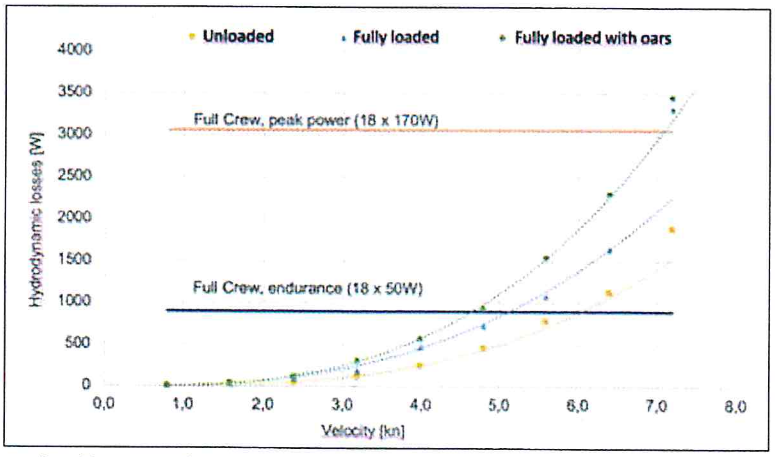
With the historical strop-joints for the oars to the oarlocks made of hemp rope, we'll be able to determine the maximum power and average speed that can be achieved on the main model under oars and without sails.

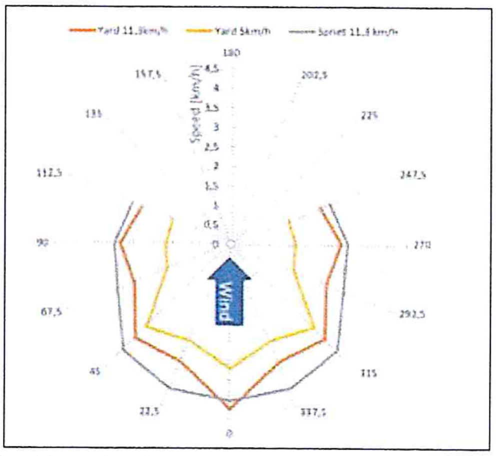
In cooperation with colleagues from Trier and Hamburg, the proven measuring technology was used in the first speed tests of the *F.A.N.* in the canal near Erlangen in July 2018. Next, new test measurements were taken in October in the Altmühlsee with our own measurement technology. These enable an assessment of the performance for historical evaluation.

We tested the long and short oars (long: 470 and 440 cm; short: 410 cm) and long and short rudders (118 cm versus 50 cm) under the same external conditions on two consecutive Fridays, with regard to manoeuvrability and speed. The rowing team consisted of inexperienced students (m/f) from the Faculty of Philosophy and Engineering.

Result IX: The shorter oars are easier for the crew to handle. Manoeuvres are faster. Short and long rudders give almost the same 'grip'; even a single rudder is good enough, but it is even better with the support of the oars of a well-trained team (i.e. after fifteen minutes of training). The long oars allow for higher speeds for a short time. The short oars are therefore more useful for patrol or long-distance operation.

In terms of absolute (speed) values, we are clearly worse than our predecessors. However, for the first time we have also taken the historical (but also individually more flexible) strop-joints to the oarlocks as a basis. This was not done with the aim of breaking short-term speed records. Other factors may have played into this: we had mixed student groups that had not practiced or been trained over a longer period, and their individual potentials were not systematically checked; the operating and testing times were not particularly intensive; and our own measuring equipment could still be further optimized.





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We also evaluated the yard and sprit sails on both test days, after we had improved the original rigging of the sprit by using a new configuration. The different rudders were also tested here.

Result X: Under the working hypothesis of a constant wind for both test days (on the second test day we had considerably more wind) it can be seen that higher speeds can be achieved with the yard sail in all aft winds. It is better to use the sprit in upwind courses, though. Courses with a fixed keel, as on modern sailing boats, were also possible. Clearly, a longer rudder (compared to a shorter one) also contributes to this. Of course, turns in hard wind can be supported by a well-coordinated rowing team (after few manoeuvres these skills are attainable).

We're far from finished with the tests. Going forward, we want to professionalize (and optimize) the parameters (rowing personnel) and the number of alternatives (steering gear, oars, sails) in order to achieve the best possible performance, which will then be used not only on the Franconian lakes but also on the Rhine, Main, and Danube, and on the navigable tributaries – just like 2000 years ago. AW

Boris Dreyer, with thanks to Peter Clement, Joachim Gmehling, Bernhard Gatternig, Susanne Langer, Blandina Mangelkramer, Johannes Nagy, Margit Schedel, Peter Schedel, Josef Schupp, Norbert Thumann, Bernd Wessolowski, Joachim Walther.