How to measure the volume of a wine barrel? From stereometry to the invention of the « épaleur », the rumble of the barrel volume measurement

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Introduction

The use of barrels has been documented for over two thousand years, with the first known mention dating back to Pliny the Elder in 74 AD (Pliny the Elder 74)

The discovery of wood splitting mastery during the Pleistocene era (Leder, D. et al 2024), a crucial step in creating wood pieces for cooperage (Remy 1991, Genty 2021), may suggest an earlier dating. However, barrels were initially made from plant materials (Mille 2020), making preservation challenging as these materials disappear over time (Leder et al. 2024). Today, the rare vestiges found are mainly reused for well linings Marlière (2001). Therefore, it is difficult to precisely date and locate the history of the barrel.

The barrel became widespread in Europe due to the sanitary and reproducibility issues with glass, persisting until the end of the 19th century. The waterskin alters the organoleptic qualities of the contents. The duo of dolium/amphora disappeared in favor of the wooden container. The cooper can set up anywhere, provided the wood supply is viable. In France, this is a reality, particularly thanks to the sustainability of French forests via the Brunoy ordinance (1346), the first known regulation. Others followed, such as Colbert's ordinance (1669), which the former president of the French coopers' federation boasted in 2014 of still benefiting from Fouillé (2014).

Thus, the continued use of the barrel as a container was guaranteed as long as wood supplies were sufficient and no other invention supplanted it.

The Interest of Metrology

For content estimation purposes, knowing the volume of a barrel is essential to know what and how much to buy.

The first developments of metrological systems date back to before our era with the Egyptian royal cubit, used by the Egyptians from the 18th dynasty by a man named Maya (Monnier 2016). Modern metrology, aimed at unifying France with constant measures, led to the National Assembly voting for the meter on March 30, 1791, following a proposal by the Academy of Sciences, and then the metric system four years later, including the meter, are, stere, liter, gram, and franc.

However, while defining common units of measurement facilitates trade, predicting the volume of a barrel is complicated: only the cooper or merchant can afford to weigh the barrel by filling it with water. The end-user, the client, can only weigh the barrel with its contents, empty it, and then fill it with water to the brim. They will thus have the density of the contents and the capacity of the container. This protocol is tedious.

Process problem

Knowing the volume of a barrel is essential for understanding the volume of its contents, as the filling level can easily be observed through the bung hole. Thus, an easy-to-use tool was employed by customs officers to quickly and easily measure the barrel to determine the associated tax: the *velte* (Lavaud 2013), also called a *rod* (in French: *verge*) (Portet 2006) or *jauge* (in French: *jauge*) (Mille et al 2019).

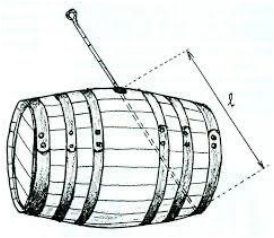

Fig. 1: The velte

In Fig. 1, the velte, a graduated rod, establishes a ratio between the measured diagonal and the total volume of the barrel. However, it is difficult to give a relationship between the diagonal of the velte and the volume of the barrel, as there are many volumetric deformation parameters:

- Number of wooden staves that make up the barrel's shell. This number depends on the quality of the wood upstream;
- Pressure exerted on the hoops by the cooper's driving/mallet or by the hooping machine;
- Humidity and temperature of the storage area.

Nonetheless, mathematicians have been interested in the question, and the first to present his research was Johannes Kepler in 1615 with his reference work *Stereometria doliorum vinarorum*, where he discusses the purchase of wine barrels on the occasion of his second marriage (Kepler 1615, 2018):

After four days the seller came with a measuring rod. With this one and the same rod he indiscriminately and indifferently explored all wine casks without paying regards to the shape, and without ratiocination or calculation. […] Hence when I had learnt that here this use of the diagonal rod has been established by public authority, and that the measurers have been sworn to it, it seemed to be not inconvenient for a new husband to explore, according to geometric laws, a new foundation for the mathematical certainty of this abridged measurement, very necessary for the fortune, and to bring to light its fundamentals, if there should be any.

In addition to Kepler in 1615, there were William Oughtred (1633), Charles Camus (1741), Jean-Philippe Detz (1776), and Jean Taransaud (1976). In 2010, mathematician François Jongmans listed the various geometric incursions into what is now a container for viticultural use and improved the formula, even speaking of *refinement* (Jongmans 2010). Indeed, while the exercise of stereometry is interesting for the theorist, it turns out to be a solitary exercise for the professional, as production disparities legitimize observation rather than prediction. So let's observe.

Emerging Projects

Observing a volume means waiting for it to be real to estimate its capacity afterwards. Thus, in the case of a barrel, several approaches using physical realities could exist: pressure, via Boyle's law (Boyle 1662) and acoustics via Sabine's law (Sabine 1898).

However, these two solutions are not feasible: due to the deformable nature of wood, it is impossible to keep the barrel in place. This is evidenced by Pascal's barrel-breaking experiment which comes from his observations (Pascal 1698).

Patented Realizations

A review of the literature shows that recent developments are more concerned with observation than prediction. Two patents, for example, relate to acquisition devices entering through the barrel hole, and use different capture techniques. Let's take a look at these two patents:

Photogrammetric bung for evaluating the interior volume of a barrel - Patent FR2302608 (Genty 2023)

This first patent (Fig. 2) concerns a support consisting of three cameras (16a, 16b, and 16c) and a light source (4) mounted on a cylinder oscillating through the action of a handle (9) in a helical manner relative to the bung hole (6) via an appropriate groove (7), i.e., the hole of the barrel. The cameras photographically capture the inside of the barrel, and a third-party photogrammetry software allows for a 3D representation of the whole. Finally, two rangefinders equipped with a temperature probe measure the distance between the two ends, the wooden disks, thus providing a reference value which, thanks to the 3D representation, gives a volume. This patent offers the advantage of quality inspection, which is additional information for the cooper and/or the user.

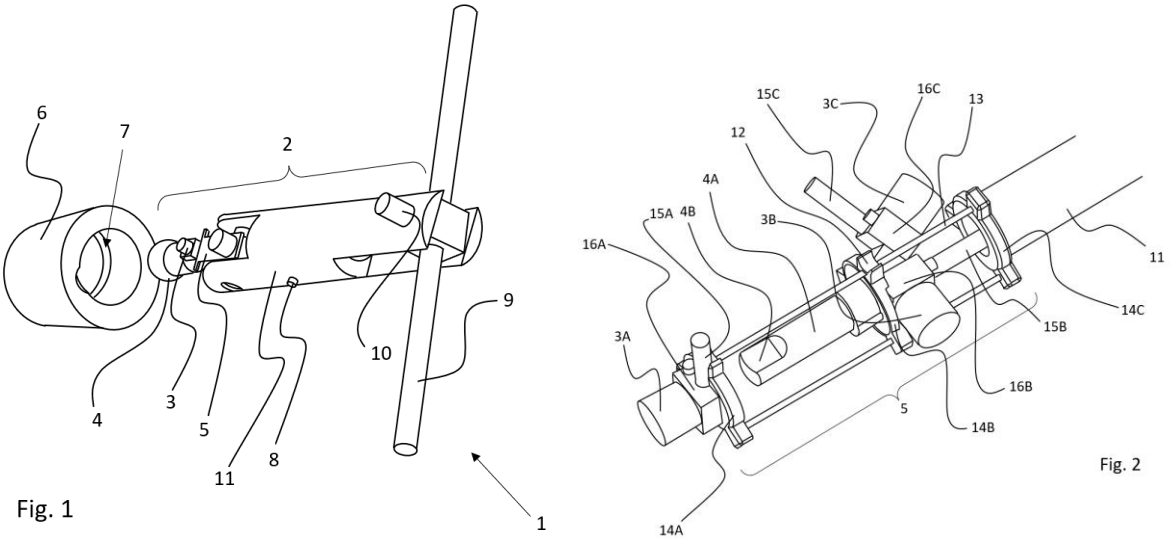

Fig. 2: Views from patent FR2302608

Épaleur - French patent FR2404313 (Genty et al 2024)

This second, more recent patent (Fig. 3) is based on a fixed plane, namely the ground, via a system of wheels (30) and an inertial unit. An infrared camera (17), mounted on a 360° orientation arm (5), takes several points through the combined action of gears and motors (11) to virtually and three-dimensionally reconstruct the barrel (35). This method offers the advantage of providing, correlated with a level sensor, a precise volumetric identification of the content level in the barrel, which would have previously undergone volume measurement.

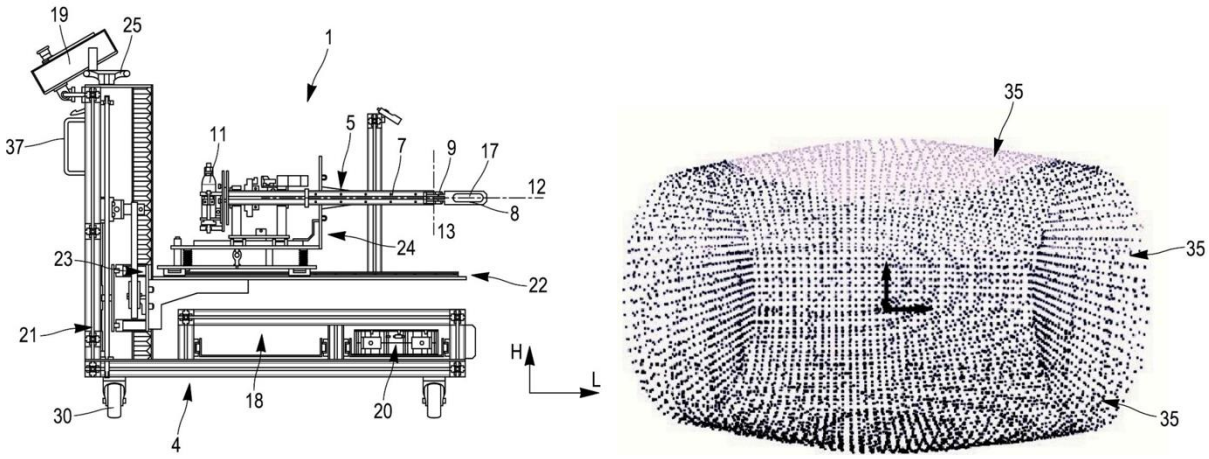

Fig. 3: Views from patent FR2404313

Conclusion

The volumetric measurement of barrels has been the subject of both theoretical and practical considerations for many centuries. Recent industrial developments suggest an imminent technological breakthrough, maintaining the constant principle: it is better to observe than to predict. The miniaturization of acquisition devices makes it possible to envisage other competing systems.

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