ESE

GRAIN PACKING IN EARLY STANDARD CAPACITY MEASURES: EVIDENCE FROM THE SCOTTISH DRY CAPACITY STANDARDS

Alan D.C.Simpson

ANNALS OF SCIENCE, 49 (1992), 337–350

Grain Packing in Early Standard Capacity Measures: Evidence from the Scottish Dry Capacity Standards

A. D. C. SIMPSON

History of Science Section, National Museums of Scotland, Chambers Street, Edinburgh EH1 1JF, U.K.

Received 28 November 1991

Summary

The large grain measures used until at least the end of the nineteenth century for controlling the sale of dry goods have precise legal definitions in terms of smaller units of weight or capacity. They are related by experimental procedures which in the modern period have involved water determinations, but it has been appreciated that for medieval measures the medium was grain. A study of the way grain packs in such vessels has enabled the sizes of early Scottish standards to be recovered for the first time and deductions made about their evolution and use, against a background of early English practice.

Contents

1. Introduction: The weight basis of capacity measures

As a class of scientific instrument, the early metrological standard is one of the most difficult to interpret adequately. On a superficial level, a standard may appear to be fully controlled by Statute, yet the function of the standard may be more restricted than the wording of the Statute might suggest. Thus, for example, a linear standard may be used in a context where there is statutory authority for its overall length, but not for its subdivision, which may be less accurately executed.

Equally, the method of applying the standard may involve aspects of practical or traditional usage which are not obvious and are not covered by Statute. An example of this is the 1497 English bushel standard capacity measure of Henry VII which was constructed to contain 9 gallons, rather than the 8 gallons specified in the 1496 Act.[1] The reason for this was that in actual use, the grain was always heaped up in bushel measures: traditionally the heap was one eighth of the quantity contained in the measure itself, so that the quantity dispensed was actually 9 gallons. The 1497 standard is the earliest Exchequer standard to survive; therefore we can appreciate that from at

[1] R. D. Connor, *The Weights and Measures of England* (London, 1987), p. 157.

least this date the physical standard was made oversize, so that when the grain surface was 'struck', or levelled by drawing a lath across the rim, the contents were 9 gallons.

Here we can see that the officials who constructed the standard acknowledged that it was more important to follow the practice of the market place than the letter of the controlling Statute. None the less, in authorizing this size of standard they were attempting to stipulate that the bushels that conformed with it should be used as struck and not heaped measures.

Centralized control over weights and measures was essential because of the monarch's dependence on assessment of customs and rentals for royal revenue. It must be expected, therefore, that the standards reflect the best level of technical competence of their day. However, it was only from about the mid-eighteenth century that legal metrology was characterized by a recognizably modern degree of technical precision. In previous centuries we are faced with traditional usage and technical judgements which are much less accessible. Indeed, it is difficult to approach early artefacts without bringing some inappropriate modern preconceptions of measurement practice to bear on their interpretation.

This is a particular problem in the confused area of the larger capacity measures, whose specific function was to measure dry goods such as grain. These dry measures are normally related by Statute in an apparently exact numerical fashion to smaller liquid measures, such as pints; and yet their purpose is to measure in a very different medium from the water, wine, or ale which is normally dispensed in pints.

In spite of this, by the eighteenth century large capacity standards such as bushels were defined in terms of their water content because this was amenable to the most accurate measurement. The vessel could be considered as being created, or 'raised', from repeated water fills of the smaller measures or from a set number of weighed quantities of water. In practice, it is unlikely that standard measures would be created from scratch in this fashion except when their definition changed in some way.

More normally, standards would be adjusted against existing standards using a direct comparison of the volume of their water contents. The precise level to which these large vessels were filled had to be judged visually against the rim. In the nineteenth century this could be achieved with much greater accuracy than before by using large circular glass plates which were placed over the vessel and could be finely adjusted through a small central hole.

At a rather earlier period, however, the large measures were raised using the specific medium they were designed to measure, namely grain, and the capacity was expressed either in terms of so many fills of the smaller vessel, or as so many pounds weight of grain.

Although we think in terms of the pint as a measure for liquid and the bushel as a dry measure, a gallon can be considered either as a liquid measure or as a fraction of the grain bushel. The 1496 gallon of Henry VII was defined as containing 8 Troy pounds of wheat (each Troy pound containing 12 Troy ounces of 480 grains), and it might be thought of as a dry measure because the surviving 1497 standard actually contains 9 pounds of grain—like the bushel standard it had been constructed to accommodate the traditional heap of one eighth. The result of the enlargement, however, is that a physically larger vessel had been created which could be used for liquids, or as a dry measure and perhaps again heaped.

R. D. Connor in his *Weights and Measures of England* has provided late-thirteenth- and fourteenth-century references to the long-standing convention that rental payments in kind were demanded by the lords of the manor and by the king's officials in heaped measure, and has given an extract from the 1301 Customal of Sandwich, Kent, which identifies the addition as an eighth.[2] The oversized Henry VII measures tell us that the practice was so universal that specially enlarged standards were sanctioned to control the quantity of heaping by incorporating it in the body of a larger measure. It is perhaps not surprising that these too were used heaped in some circumstances, giving rise to a capacity that was enlarged by a further eighth.[3]

A confusing array of English gallon measures, all with complex and disputed origins, persisted until they were eventually superseded in legislation of 1824 by the Imperial gallon of 277·4 cubic inches (abbreviated to $in.^3$), which is about 4·546 litres. The principal gallons were the wine gallon of 231 $in.^3$, the Winchester or corn gallon of 272 $in.^3$ (based on the gallon enlarged from the 239·5 $in.^3$ Henry gallon of 8 Troy pounds of wheat) and the ale gallon of 282 $in.^3$. Robin Connor has proposed that this last gallon was the result of two stages of enlargement, in the process described above, from the earlier 224 $in.^3$ 'Guildhall' gallon (so named because a standard of this size was located in the Guildhall, London, in 1688).[4]

The origins of the 'Guildhall' gallon are unknown but certainly early. It may have been created on a liquid basis as containing 8 Avoirdupois pounds of wine (each of 16 Avoirdupois ounces of 437·5 grains), but Robin Connor has noted that the volume is also that of 8 Tower pounds of wheat (each pound being the weight of 240 coined silver pence, and considered as 12 ounces of 450 grains).[5] Although the use of the weight system exclusive to the moneyers at the Mint, in the Tower of London, may at first sight seem unlikely, this may be the earlier definition.

Indeed, a parallel may be drawn with the twelfth-century Scottish gallon, which was based on the pound used exclusively by officials at the Scottish Mint—a situation that almost certainly reflects the involvement of the Mint officials as the technicians best qualified to perform the measurements needed to establish metrological standards. The weights and measures introduced in Scotland in the twelfth century were based directly on those of England (a consequence of the remarkably close administrative links between the two kingdoms in Norman times), and it is likely that similar responsibilities were assigned to the Mints of both countries. The Scottish Mint pound had its origin in the poise weight for coinage already used in the English Mint, and it shared the same 450-grain ounce although it contained 15 ounces against the Tower pound's 12 ounces.

The 231 $in.^3$ 'wine' gallon is also likely to have been a measure of 8 pounds weight of wine, but based on the medieval mercantile weight, the *libra mercatoria* (of 15 Troy ounces); however it is possible that it had been set earlier at the marginally larger volume of 8 Troy pounds of wheat (239·5 $in.^3$).[6]

This highly confusing situation, of several concurrent gallons, cannot be resolved adequately because we lack sufficient English evidence of measurement practice for the

[2] Ibid., p. 156.

[3] Ibid., p. 157. It is worth noting that the conventional heaping of one-eighth is a modest amount and that a very much larger heap can be constructed. It may be better to think of it as representing a rounded or adequately filled measure, incorporating a tolerated allowance which had its origin as a compensation for spillage and other losses. By practical experiment in 1618, the Scottish firlot measure (of the same proportions as the bushel) was found to be able to support a heap of nearly half its normal contents.

[4] Ibid., pp. 159, 163.

[5] Ibid., p. 158.

[6] Ibid., pp. 158, 159.

early Middle Ages. However, some help may come from the experience in Scotland, where the metrological framework was initially based firmly on that of England, but developed independently.

2. The dual definition of the firlot

Recent collaboration with Robin Connor has led to a reinterpretation of the relevant early Scottish Statutes, and it can now be appreciated that there was a significant difference from English practice in later centuries.[7]

In medieval Scotland the unit of capacity was not the pound of grain, but the volume of grain contained in the pint standard. The volume of the pint was, however, determined on a liquid basis, as containing so many pounds and ounces of water (initially a whole number of pounds of the original Scots Mint system).[8] This in turn allowed the large capacity measures to be defined in terms of their weight of water content. But this was a notional weight, obtained simply by multiplying the known water weight of the pint by the number of pint fills: no actual weighing was performed, and the larger measures were in fact raised from multiples of standard quantities of grain.

The Scottish measure equivalent to the English bushel was the firlot, and it was last defined in a weights and measures Assize in 1618.[9] It has previously been used in two forms, either struck (for wheat) or heaped (for barley). In 1618 it was redefined at two sizes—a smaller wheat firlot containing $21\frac{1}{4}$ pints, and a larger barley firlot (enlarged to accommodate the heap and now to be used as a struck measure) containing 31 pints.[10] These pints were comparatively large vessels with a capacity of about 105 in.^{3}, or about three of our present-day pints. Several early standards survive, and they are invariably heavy single-handled cast bronze vessels bearing shields in relief, with a depth of about 6 inches and a diameter tapering into 4 inches at the aperture (Figure 1).

The 1618 Assize defined these two firlots in terms of the number of pints they contained, but also gave the physical dimensions of the measures. Unfortunately, if the volumes are obtained merely by multiplying up from the known volume of the pint, the firlots should be 2205 in.^{3} and 3215 in.^{3}. Whereas, if they are obtained from the stated dimensions, making suitable allowances for the internal strengthening structures and recognizing some inherent uncertainty arising from rounding errors in the dimensions, the volumes come out as 2110 ± 20 in.^{3} and 3020 ± 25 in.^{3}. **These two sets of figures are clearly not compatible.**

The difficulty was tackled in the 1750s when investigations were carried out in Edinburgh to recover the original sizes of the 1618 firlots (the capacity measures by this time were being created on a different basis). Two impressive standards, which were

[7] This will be discussed in the forthcoming work by R. D. Connor and the present author, *The Weights and Measures of Scotland*, to be published by H.M.S.O. with the National Museums of Scotland.

[8] The twelfth-century Scottish gallon was 12 Mint pounds weight of water (actually a mixture of three specific types of water), and a fourteenth-century source enables us to deduce that it contained 6 pints. This gallon appears to have been defined for a time in a grain determination, mirroring English definitions, which may suggest that the English gallons (which formed the models of the Scottish gallon) were initially defined on a liquid basis also.

[9] *The Acts of the Parliaments of Scotland. IV (1593–1625)*, edited by Thomas Thomson (Edinburgh, 1816), pp. 585–89.

[10] The heap was considered to represent an additional one half of a firlot. In practice however barley was sold in the same fashion as other material, but using the accepted equivalence of three struck firlots to two heaped. The 1618 Commissioners found that the very substantial heap implied by the three-for-two or six-for-four convention could not be accommodated on the firlot standard, and they settled for a barley firlot of 31 pints rather than the $31\frac{7}{8}$ pints that might have been expected.

Figure 1. A standard Scots pint resulting from the work of the 1618 Commission. This is the vessel used in the 1990 experiments on grain packing. National Museums of Scotland. Inv. NMS T1973.135 (Royal Burgh of Linlithgow Collection).

fruits of this work by Alexander Bryce and others, have recently been described.[11] In his manuscript report to the Justices of the Peace for Stirlingshire, who had commissioned these two measures, Bryce pointed out the discrepancies, but was insistent that the dimensions given in the Assize must be in error.

However, the real error was Bryce's: the experiments were carried out according to the more exacting procedures of his own time which automatically assumed the use of water as the measuring medium. In part this was the result of following the convention established by Thomas Everard's 1696 official determination of the water capacity of the English Winchester bushel, although Bryce may also have been misled by the wording of the Assize.[12] However, from the time of Bryce's work the ready assumption has been that water was always the appropriate medium, and any lingering doubts (if they existed) were dispelled in a legal case heard in the Court of Session in the 1780s.

If the experiment is repeated using grain then it can be shown that the apparently irreconcilable volumes come into almost exact coincidence. The procedure can then be applied to other situations where the volumes appear to be inconsistent. In particular the use of grain-based measurement in a complex and widely misinterpreted Assize of 1426 allows the correct relationship between the firlot and the larger boll measure to emerge for the first time.

[11] Allen Simpson, '"Handle with Care": Handling Warnings of Early Scientific Instruments and Two Early Scottish Grain Measures', *Bulletin of the Scientific Instrument Society*, No. 30 (1991), 3–4.

[12] T. Everard, *Stereometry: or the Art of Gauging made easy* (London, 1738), p. 192. For the interpretation of the 1618 Assize, see footnote 39.

3. Measurement in grain

To a first approximation grain does behave like a fluid: it flows, it appears to be incompressible, and if handled in a consistent manner a set quantity or weight will repeatedly and accurately occupy the same volume.[13] However, the individual grains have a finite size, there are spaces between them and their surfaces are rough. At a microscopic level, therefore, the grains behave in a 'sticky' manner and this affects the precise density to which they may be packed.[14] Once the grains have made adequate contact with their neighbours, it is unlikely that they can be condensed much further and they behave like a slightly elastic lattice under vertical compression. However, in the act of pouring grain from one vessel to another, greater energy can be imparted to individual grains by pouring from a greater height, and this leads them to pack in greater proximity to their neighbours and increases the density slightly. The same effect can be achieved by carefully agitating the grain in thin layers as it is laid down in a large vessel.

The consequence is that the method of filling a capacity measure with grain will influence to a small extent the quantity of grain that it contains. The effect is known. A series of experiments was conducted in the early nineteenth century by Adam Anderson, Rector of Perth Academy, on procedures for filling bushel measures with grain. Anderson was concerned with how this would influence the setting of grain prices, and his findings were published as an appendix to the 1834 Report of the Select Committee on the Sale of Corn.[15] Towards the end of the century, weights and measures Inspectors were permitted to check certain trading capacity measures using rape seed. Even though rape has a very small and regular seed, the regulations for its use by Inspectors stipulated very exacting procedures to ensure that the seed was introduced from a set height through a special hopper to control the rate of flow and to prevent the type of density variation that Anderson had reported.[16]

A trial experiment was conducted with Robin Connor in August 1990 using precision Imperial Standards of a bushel and a half-gallon made by R. B. Bate of London in 1824.[17] These vessels are defined as having a capacity ratio of 16:1, but when the bushel was filled using half-gallons of barley grains it was found to accommodate nearly 17 half-gallons. It follows that the anticipated 16 half-gallon fills would generate a volume significantly less (by about 5%) than one bushel. This

[13] Figures quoted later in this paper show that the measured weights of grain contained in a particular volume are consistent to less than 0·5%.

[14] The microscopic 'stickiness' apparently involves some interlocking of fibrous external material, and in this respect it may differ from that between the particles of granular minerals such as sand, which will more readily distribute themselves to pack initially at a maximum density. For the literature on the flow of granular solids see R. T. Balmer, 'The Operation of Sand Clocks and their Medieval Development', *Technology and Culture*, 19 (1978), 615–32. I am grateful to Dr A. A. Mills for this reference.

[15] 'Letter from Dr Anderson to the Hon. G. J. Vernon, Chairman of the Committee on the Sale of Corn, communicating the Result of some Experiments made by him relative to the Condensation of Grain by different modes of Measuring', *Parliamentary Papers*, 1834, VII.517, Appendix 12. Unfortunately this paper was found after our own experiments had been completed and so I was not able to take measurements in the same form as Anderson. In so far as the results of the two sets of experiments can be compared, the range of densities found is very closely similar and there are no significant discrepancies. For Anderson, see K. J. Cameron, *The Schoolmaster-Engineer: Adam Anderson of Perth and St Andrews, c. 1780–1846* (Dundee, 1988).

[16] *Weights and Measures: Inspectors and Inspection: Model Regulations* (London, 1890), number 36. I am grateful to Maurice Stevenson, Hon. Librarian of the Trading Standards Association, for his assistance with this point.

[17] For a detailed study of Bate, including his work on the standards, see Anita McConnell, *R. B. Bate of the Poultry* (Scientific Instrument Society, London, forthcoming).

reduction results purely from the decision to use grain rather than water as the measuring medium. The amount of the reduction matches the disparity in the incompatible volumes of the 1618 firlots and suggests a physical explanation.

It was initially thought that the reduction in volume was the result of a lower packing density of grains at the periphery of the large and small vessels, and a piece of apparatus was constructed to maximize a surface effect.[18] However, no difference in result was apparent after repeated testing, and so it was appreciated that the observed differences in volume arose as a consequence of the way the vessels were filled.

The grain used in this work was kindly supplied by Richard Morrison-Low of Kilmaron Farm, Fife. The preliminary measurements were made with barley from the 1989 crop, but for the more detailed measurements discussed below grain from the 1990 crop was used. It has recently been demonstrated that the length of barley grains, which form the basis of the length measures in both England and Scotland, has remained effectively constant over the centuries.[19] However, the grain used by us was known to be slightly lightweight (the average grain weight was less than one Troy grain of 0·065 g) and this resulted in a marginally reduced grain width: this size could be related to the conventional width of barley grains of the best quality in 1624, and it was concluded that the difference in shape was so slight as to have a negligible effect on our results.[20]

The determinations were made using standard capacity measures of various forms and a very accurate electronic scale with a 16 kg capacity by Mettler. They were carried out in a cool basement room with a fairly stable temperature and low air-flow. The outer coating of barley is highly hygroscopic, so even after a long period of acclimatizing to the local environment, the weight of the grain changed to reflect external atmospheric conditions. During each series of measurements, extending over a period of a few hours, the quantities of grain were weighed at each stage and then checked at the end of the series. As the grain was dispensed in small quantities it had a tendency to dry out further so that it became very slightly lighter with time, although to some extent it reabsorbed moisture when these small quantities were returned to the mass of material. Small corrections had to be computed to compensate for this weight drift.

The situation is complicated, however, by a longer-term reduction in the diameter of individual grains as the interior dries and this results in a slight decrease in volume of a set quantity of grain. This meant that measurements had to be restricted to as short a period as possible because there was only a limited ability to compare volumes as well as weights before and after measurements: the measurements used here were made by

[18] The device took the form of a sturdy and accurately constructed open-topped rectangular box of about 710 × 720 × 460 mm high. This was divided by a fixed vertical panel into two compartments, the larger of which could be subdivided into 11 thin compartments using ten additional removable panels. The fixed divider was placed so that the volume of the smaller of the two compartments was the same as the sum of the volumes of the 11 thin compartments. The total surface area in the larger subdivided compartment was about seven times that in the smaller compartment: this was about three times the ratio of surface areas for the cylindrical measures and it should have accentuated an effect due to lower surface density.

[19] Connor (footnote 1), p. 3.

[20] Alexander Huntar, writing in 1624, provided the maximum width of grains—'4 Cornes of barlie Bier, lying in breadth maketh a finger breadth': A. Huntar, *A Treatise of Weights, Mets and Measures of Scotland* (Edinburgh, 1624), p. 8. With 4 fingers to the palm and 4 palms to the foot, this gives a conventional grain width of 0·19 inch. The grains used had an equivalent width of 0·17 inch, and as expected the weight was reduced as the square of the ratio of these, from 0·065 to 0·052 g

the present author over only three days in September 1990. Fortunately both of these effects are small compared with the principal effect of differing grain packing density.[21]

Clearly the weights given below reflect the water content of the particular batch of grain used. However, our concern here is with dimensionless ratios of weights and of densities, and these are independent of the weight characteristics of individual grain samples.

4. Maximum packing density of grain

Taking first of all the cylindrical Imperial half-gallon measure, which had an aperture of $5\frac{1}{2}$ inches, it was clear that the method of filling made a marked difference to the contents. Simply tipping in grain quickly from a low height and then striking the surface level could give a content of grain with a weight as low as 1515 g, whereas slowly pouring it from a greater height might result in a content of 1650 g.[22] Pressing the grain surface of the full measure reduced the volume occupied only slightly, but pressing regularly after small quantities had been introduced allowed significantly more to be accommodated. The maximum quantity that could be contained was about 1685 g, giving a density of about 0·741 g ml^{-1}.[23] For convenience, lesser densities are expressed in terms of this maximum density.

The bushel was a heavy bronze cylindrical vessel, with an aperture of about $18\frac{1}{2}$ inches. It was placed horizontally on a solid low trolley, about a foot above the ground, and this provided easy and efficient access for filling using a small vessel and for striking. The tipping in of material in measured quantities was generally from a height of about 18 inches, although fine adjustment near the end of the filling was done from a lower height. In a series of trials no significant difference was found in the overall weight between smoothing the grain down after each half-gallon had been added and pouring it in an arc to distribute the material more evenly. The important feature seemed to be that the grain was being added from a height in small quantities, forming relatively thin layers which had the effect of compacting the underlying layers. Striking the grain surface involved wiping off material that was above the level of the rim and was done not with the sharp edge associated with the early nineteenth century, but with a very smooth small diameter roller, typical of earlier practice.

As a check on the maximum grain density found for the half-gallon measure, grain was carefully added to the bushel in layers which were carefully compressed. The weight of the contents was found to be 26 960 g, which is exactly sixteen times the maximum weight held by the half-gallon measure and gives the same maximum grain density.

5. The 1618 capacity standards

The smaller firlot of the 1618 Assize had the same proportions as the Imperial bushel and was only slightly smaller—2110 in.^{3} (34·58 litre) as opposed to 2219 in.^{3}. However there are no surviving firlot standards in metal, and the only authorized

[21] The loss in weight due to evaporation over a period of a day at the time of the experiment was about 100 g in 25 000 g, or under 0·5%. This is an order of magnitude smaller than the difference of about 4·5% in the apparent weight of the bushel's contents due to differing grain packing densities.

[22] The rounded average of five consecutive measurements in the range 1510·9–1517·1 g (a variation of ±0·2%); and similarly the rounded average of five consecutive measurements in the range 1645·2–1656·3 g (a variation of ±0·3%).

[23] The rounded average of five consecutive measurements in the range 1680·1–1690·3 g (a variation of ±0·3%.)

wooden standards are in comparatively poor conditions and too delicate to be used for experimental purposes. The grain capacity of the firlot was therefore found by working exclusively with the bushel and reducing the quantity by the ratio 2110:2219.

The 1618 firlots were raised using Scots pint measures, which have a different form from Bate's Imperial half-gallon. They are much heavier (about 7 kg) and they have a comparatively small aperture of about 4 inches. One of the principal substandards arising from the work of the 1618 Commissioners was used, and this had a measured water capacity of 104·2 in.^{3} (1·708 litre). Filling it to maximum density with grain (a more difficult procedure because of the much narrower aperture) gave a weight of contents of 1265 g, and a density of 0·741 g ml^{-1}, in agreement with the other measurements.[24]

It soon became apparent that some of the potential ways of filling this type of pint vessel could be eliminated. Plunging the pint through a vat of grain would only fill the measure if it broke the grain surface slowly with the rim nearly horizontal: in practice it proved too difficult to rotate the very heavy pint under the grain and bring it out of the vat filled beyond the rim.[25] The aperture was also too small to allow a hand to be inserted easily, and so the grain could not be compressed in the course of filling. It followed therefore that the pint had to be filled by pouring grain into it from another container. It also turned out to be quite difficult to control the rate of flow of grain so that the pint was full enough to be struck but did not overflow in filling: it seemed much more natural to fill it until it was fully heaped and overflowing before striking it.

If the pint was set on a flat surface and grain poured into it from another vessel, the density of grain in the pint would depend to some extent on the height of this vessel above the pint's rim and the speed of pouring. From a practical point of view, it is necessary that most of the grain be directed into the narrow aperture and this sets an effective limit of about 3 inches for the height above the pint's rim. Increasing the time of pouring to overflow from 5 seconds to 8 seconds increased the weight content from 1140 to 1160 g, but it was found to be difficult to pour slowly enough to extend the filling time to 8 seconds consistently.[26] Overall, considering the ease of controlling the fill of the vessel, it was eventually concluded that a capacity of between 1137 and 1147 g would be likely to arise from a fairly straightforward filling technique.

Several attempts at filling the bushel measure from the Scots pint had given consistent capacities, and two careful measurements on the same day gave an average of 25 450 g.[27] Reducing by the proportion of the volumes of the bushel and 1618 firlot (2219 and 2110 in.^{3}) gives the contents of the firlot as 24 200 g. It follows, therefore, that if the pint's capacity was between 1137 and 1147 g the number of pints of grain required to fill the firlot is between 21·28 and 21·10. However, a further small correction must be made because the substandard pint used in this measurement has been adjusted to an

[24] The rounded average of five consecutive measurements in the range 1261·7–1268·3 g (a variation of ±0·3%).

[25] However, by cupping the aperture with one hand consistent results were achieved: ten consecutive measurements in the range 1123·4–1132·4 g (a variation of ±0·4%) gave a rounded average of 1130 g.

[26] The rounded average of ten consecutive measurements in the range 1138·5–1146·7 g (a variation of ±0·4%); similarly the rounded average of ten consecutive measurements in the range 1156·6–1164·4 g (a variation of ±0·3%).

[27] The weights, corrected for drying between the two measurements were 25 370 and 25 520 g, or about 24 450 ± 80 g. Previous measurements had indicated that differences of under ±100 g (0·2%) would be expected.

accepted early eighteenth-century volume (104·2 in.^{3}), whereas the actual experiments performed in 1618 used the original standard, the Stirling Pint of *c.* 1500, which has the slightly smaller volume of 103·7 in.^{3} (1·700 litre).[28] The number of fills of this standard would therefore have been between 21·39 and 21·20. Making allowances also for the uncertainty in the total volume, the number of fills comes to $21{\cdot}3 \pm 0{\cdot}2$.

The 1618 Commissioners found that the firlot in use contained $21\frac{1}{4}$ fills of the pint, and this was the capacity they embodied in the report that formed the basis of the 1618 Assize. This is comfortably in the middle of the range indicated by this recent experiment. It might be argued that this is fortuitous given the assumptions that have been made about measuring techniques, and clearly there are factors which limit the validity of work of this type and require caution in the application of results. However, in this instance the restrictions imposed by the geometry of the pint measure made it clear that the techniques discussed above are intrinsically more likely to have been used. The precise result ($21{\cdot}3 \pm 0{\cdot}2$ fills) is not in itself important, although it is gratifying to find that it matches the 1618 figure. What is more important is that the result was about $21\frac{1}{4}$ fills and not the $20\frac{1}{4}$ fills that would have been the outcome if differential grain packing had not been a factor, that is if water had been used to fill both the pint and the firlot.

If we make the assumption that the firlot of 24 200 g contains exactly $21\frac{1}{4}$ fills of the Stirling pint standard, we can obtain the likely capacity of the standard pint as 1139 g. The maximum capacity of a 104·2 in.^{3} pint has already been found as 1264 g.[29] It follows, therefore, that the equivalent capacity of the 103·7 in.^{3} standard would be 1258 g. So the density typically found in the pint is only 0·670 g ml^{-1}, or 0·905 of the maximum density. In contrast, the density in the filled firlot (34·58 litre) is 0·700 g ml^{-1}, or 0·945 of the maximum density. Thus, as a consequence of the different manner in which the two vessels are filled, the density of material in the firlot is about 4·5% higher than that in the pint.

The 1618 barley firlot of 31 pints had the same aperture as the wheat firlot ($19\frac{1}{6}$ inches), but was $10\frac{1}{2}$ inches deep rather than the $7\frac{1}{3}$ inches of the wheat firlot. Although the pint measure would probably be held at the same height above the rim of each firlot, for the barley measure the grain falls a greater distance and so would be expected to compact to a slightly greater extent. Anderson in 1834 recorded a density variation of 2% in a bushel measure as he increased the height of pouring up to 32 inches. Moreover, it was also apparent from the earlier trials with the half-gallon that each added layer of grain plays a part in compacting the layers immediately beneath it. It follows that the grain density within the measure must be a little lower near its upper surface, particularly as these last layers are added more carefully to complete the filling. The thickness of this lower density zone will be the same for both the wheat firlot and the deeper barley firlot, but because the underlying denser zone in the barley firlot is deeper, the average density in the barley firlot will therefore be slightly higher.

Therefore, for the barley firlot we must use a grain density which is just a little greater than the density of 0·945 which was derived for the wheat firlot.[30] Indeed, using the two volumes recorded earlier for this firlot (31 pints apparently totalling 3215 in.^{3},

[28] These standards and the reasons for slight differences in their volumes will be discussed in the forthcoming *Weights and Measures of Scotland*.

[29] Derived at footnote 24.

[30] Had the density of 0·945 been used for the barley firlot, its volume would have emerged as $3125 \times \frac{0{\cdot}905}{0{\cdot}945}$ = 3080 in.^{3}, which is indeed outside the volume range of 3020 ± 25 in.^{3} obtained from the dimensions.

the 3020 in.^{3} calculated from the dimensions), the average density in the barley firlot comes out as 0·965 of the maximum grain density.[31] This is certainly compatible with the results of the earlier trials, and it can be used as a guide for the densities to be expected in deeper measures such as the boll (of four firlots).

6. The 1426 Assize

We have taken the step of assuming that the densities derived in the specific situation of the 1618 firlots can be applied in other instances.[32] The most demanding test for this proposal is the relationship between the dry capacity measures of a complex and important Assize of 1426.[33] Here the dimensions give a firlot of 1205 ± 40 in.^{3}, whereas the volume generated by water fills would be 1245 in.^{3}. Reducing this by incorporating the grain packing factor derived above, gives a volume of 1192 in.^{3}, which is now compatible with the volume from dimensions. A volume of 1200 in.^{3} has been adopted for the 1426 firlot (Table 1).

From the dimensions of the boll measure of the 1426 Assize, its volume is 5640 ± 120 in.^{3}. Ostensibly the boll is four times the firlot (that is, we would expect it to be 4800 in.^{3}), but as with the English 1497 bushel this volume obtained from the dimensions includes an in-built allowance. Using grain packing, the size of the boll can be calculated separately as individual fills of the pint measure (which until about 1500 was 77·8 in.^{3}, or exactly three-quarters of the volume of the pint in use in 1618), or else as four fills of the firlot plus a stated allowance in pints. Both of these give a boll of about 77 pints. This is larger than the theoretical size of 64 pints given in the Assize, but the difference between the two of about 13 pints (13 ± 2 pints) is a good match for the allowance of about $10\frac{1}{2}$ pints which is also specified in the Assize.[34] There is some

Table 1. The physical sizes derived for the standard liquid and dry measures defined in the Scottish 1618 and 1426 Assizes, together with the sizes of the Imperial measures for comparison.

	Cubic inches	Litres
1618 Assize		
pint	103·7	1·700
wheat firlot ($21\frac{1}{4}$ pints)	2110	34·60
barley firlot (31 pints)	3020	49·50
1426 Assize		
pint	77·8	1·275
firlot (16 pints)	1200	19·65
trading boll (4 firlots + allowance)	5600	91·75
1824 Imperial Standards		
pint	34·7	0·568
bushel	2219	36·36

[31] $3215 \times \frac{0 \cdot 905}{0 \cdot 965} = 3015$ in.^{3}.

[32] The discussion in Sections 6 and 7 will be amplified in the forthcoming *Weights and Measures of Scotland*.

[33] *The Acts of the Parliaments of Scotland. II (1424–1567)*, edited by Thomas Thomson (Edinburgh, 1814), p. 12. We have concluded from an examination of the manuscripts used by Thomson that some dimensions given by him are incorrect: the issue is examined in the forthcoming *Weights and Measures of Scotland*. The calculations here follow the earliest (*c*. 1460) official manuscript version of the Assize.

[34] The allowance is specified in both the old and new units, but the two quantities differ slightly. This is assumed to be a consequence of conducting this rather difficult measurement twice.

inherent uncertainty in the boll's dimensions (which are only given to half an inch), and so these have been reduced slightly to take the small discrepancy in these allowances into account, and the 1426 boll's volume has been set at 5600 in.^{3}. It can also now be appreciated from internal references in the Assize that this was the capacity of the existing boll in current use before the passing of the Assize. This fits our understanding that this piece of legislation was designed to provide a legal descriptive basis for current practice.

7. Progressive enlargement of the measures

With a much improved understanding of the size of the firlot measures it has been possible to develop a plausible mechanism to explain the enlargement of the firlot between the Assizes of 1426 and 1618, and this has now been confirmed against surviving standards and documentary references. What has emerged is a scheme of progressive enhancement at each Assize by regular factors of one-sixteenth and one-eighth that has significant parallels in the English situation.[35] The essential feature of this is that the officials in charge of constructing and issuing local standards automatically increased their size by the accepted factors before distribution to the burghs, so that in practice the legal size of measure was never in use (Figure 2).

From at least the latter half of the sixteenth century, the responsibility for this work rested with the official cooper of the Royal Burgh of Linlithgow, one of the four principal royal burghs which were each entrusted with the guardianship of one of the primary standards. This official was presumably also responsible for a separate series of capacity measures used exclusively at ports (and hence at most royal burghs, since they had the monopoly of overseas trade) which was outside parliament's control and was regulated by the Convention of Royal Burghs. These 'water metts', so-named only because they measured goods that came by water, were like their English equivalents a recognized and set proportion larger than the conventional 'land' measures.[36]

The Linlithgow cooper showed some latitude in interpreting the Acts when satisfying the requirements of the burghs. At the Assize of 1587 the measurements were

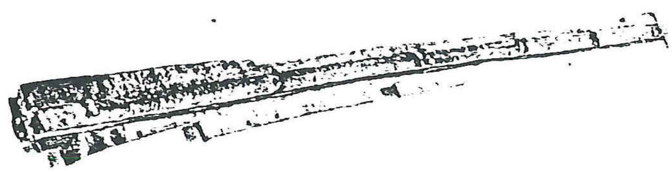

Figure 2. A burgh standard gauge of 1500 for checking the dimensions of dry capacity measures, and constructed to incorporate the official trading allowances. Inverkeithing Museum: Dunfermline District Museums, Inv. DUFDM 1988.281 (photo: National Museums of Scotland).

[35] It should be stressed that a clause in the controlling Statutes stipulated that existing rental agreements and contracts should continue for their duration in terms in the capacities of the old measures, so that neither party should be disadvantaged.

[36] On English water measure, see Connor (footnote 1), p. 178.

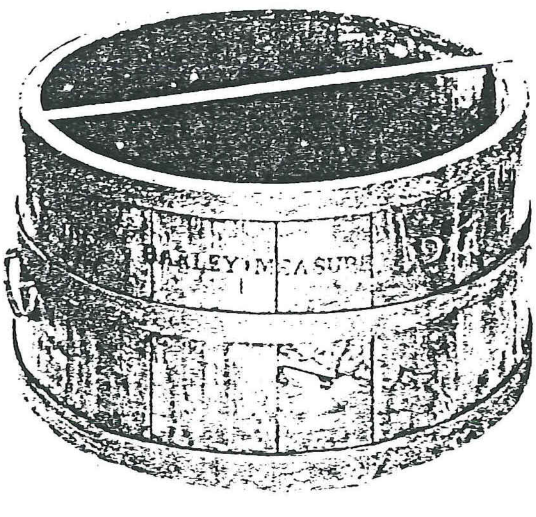

Figure 3. A barley firlot measure with the official brands of Linlithgow. This example was constructed after the move to a water-based standard. North-East Fife District Museums Service, Inv. CUPMS 1984.163 (photo: National Museums of Scotland).

conducted under the control of the Mint in Edinburgh and the specific firlot (this time of $19\frac{1}{16}$ pints) described in the Act is a prototype standard of a new form which has unambiguously been raised using water as the measuring medium—its water-determined volume of 1955 in.^{3} precisely matches the volume of 1940 ± 20 in.^{3} obtained from the dimension.[37] However, the distributing officials apparently remade the firlot on a grain basis to the required $19\frac{1}{16}$ pints plus the allowance of one-eighth, and it was this measure which was later presented to the 1618 Commissioners.[38] This situation was not repeated in the 1618 Assize, where the dimensions given are for a practical grain standard, rather than a theoretical water-based standard.[39] The dimensions are therefore those of the gauges that could be used to construct and adjust local standards. Unfortunately the Commissioners' intentions appear to have been frustrated by the official cooper again making the local standards larger by the traditional proportion.[40]

[37] For complex reasons arising from changes in the weight system, the Assizes of 1563 and 1587 used a pint of 102·5 in.^{3}, of which one standard survives, as do another two which incorporate the additional brewer's allowance of one-sixteenth, bringing them to 108·9 in.^{3}. The 1618 Commissioners returned to use of the 103·7 in.^{3} Stirling pint as the primary standard.

[38] It is indeed possible that the measure presented to the 1618 Commissioners was the standard for the 'water mett' firlot of 1563, which will have become the 'land' firlot standard when all the sizes were revised upwards at the Assize of 1587. It was claimed to be 50 or 60 years old in 1618.

[39] The report of the Commissioners speaks of filling the firlot with water, but the dimensions given are clearly not for a water-based firlot. The reference is presumably a drafting error and relates to the new water determination of the pint's contents which now become the legal basis for the definition of the ounce. At least some measurements were conducted in grain because careful assessments of the size of the maximum heap for barley were made.

[40] The evolution of the capacity standards after 1618 will be discussed in more detail in the forthcoming *Weights and Measures of Scotland*.

In proposing a series of enlargements in the firlot by specific amounts at each significant Assize we can see a difference in metrological practice emerging between the English and Scottish administrations. In England, full advantage was taken of a system of conventional allowances in the use of capacity measures, but although there were frequent protestations about the iniquities of heaping there was little adjustment to basic legal sizes of the measures to compensate for this. By contrast, in Scotland there were several attempts in the sixteenth and early seventeenth centuries to revise the sizes upwards, apparently in the hope of absorbing these allowances. Heaping was not finally outlawed in Britain until the mid-nineteenth century.[41]

Considering the use of grain in raising the early capacity measures has been useful in resolving official details about the standards and has enabled the sizes of succeeding standards to be related in a precise manner. However, the situation became more complex in the century after the 1618 Assize. In particular, new administrative structures were put in place after the Union of the Parliaments in 1707 and this gave rise to fresh official determinations, which were clearly conducted in liquids, of certain measures on which Excise duty was charged.

The English Winchester bushel of 2150 in.^{3} (somewhat smaller than the 1824 Imperial bushel of 2219 in.^{3}) was imposed in Scotland as part of the terms of the Act of Union, and bronze standards of this were distributed to the other burghs by Linlithgow. Just how Linlithgow was adjusting measures at this time is not clear. At least one surviving eighteenth-century standard firlot specifically for dry goods has apparently been made the traditional one-eighth above the 1618 standard, where others with Linlithgow markings have been raised with water, giving an enhanced volume of about 2210 in.^{3}, which represents a rather smaller allowance (Figure 3). The two 1618 standard firlots at Linlithgow may not have survived into the eighteenth century, and by the late eighteenth century measures were certainly being adjusted at Linlithgow solely against the appropriate number of water fills of the pint.

The transition from grain-based to water-based standards was made over an extended period and undoubtedly gave rise to much of the wide variation in capacity measure recorded in the early nineteenth century. However, because the Scottish standards were geographically dispersed, much of this variation was seen as regional, in contrast to the equally intractable problems of variation in the more centralized English measures at the same period. The matter was only to be resolved with the implementation of the unified Imperial system introduced in 1824.

Acknowledgements

This work was undertaken as part of a more extended collaboration with Dr R. D. Connor, University of Manitoba, who has provided constant advice and encouragement. Helpful criticism has been given by D. J. Bryden, A. Fenton, A. A. Mills and A. D. Morrison-Low. Valued practical assistance was provided by R. W. Morrison-Low, and the help of M. Stevenson and V. Thomson is also appreciated. The author is Visiting Fellow at the School of Scottish Studies at the University of Edinburgh, and gratefully acknowledges the support of the School's Director, Professor A. Fenton.

[41] Weights and Measures Act of 1834; Connor (footnote 1), p. 180.