The Form of the Hunterston Brooch

By ROBERT D. STEVICK

THE BASIC form of the Hunterston Brooch can be constructed by an elementary compass-and-straight-edge method, which this paper will illustrate. Moreover, its form embodies a harmony of disciplined proportion which I believe can be grasped only through the geometrical properties of the form as constructed. This brooch shares principles of design with the Tara Brooch, as well as with manuscript illuminations and sculptured crosses of early Insular Christianity; it even shares its governing ratio with the Tara Brooch.

THE CHALLENGE

The forms of the Hunterston Brooch and the Tara Brooch (Figs. 1 and 2) were difficult to decode in the terms which apply to them in common with the forms of Irish high crosses and the full-page illuminations in the fine Gospels codices of the early Insular tradition.[1] For the brooches there is the special challenge of the canonical shape. Unlike the illuminations enclosed in rectangular frames, and unlike the crosses which by nature are rectangular in form, the brooches employ a circular design without right angles either at the centre or in an enclosing frame. Furthermore, many early high crosses in Ireland have relatively simple forms, which is to say that once the key dimension is recognised and the key ratio identified, it is no arduous task to construct a model that matches the form of the artefact (apart from modifications of it by breakage and erosion). The simplest of these crosses have a shaft with parallel sides. Less simple are the forms with a tapered, or splayed, shaft: their models take more steps to develop, but they seem ordinarily not to depart from the constraints of the key dimensions developed in accordance with the governing ratio. Theoretically, because the dimensions are all linked by a plain scheme of measure and ratio of measure, any dimension can be used as the basis for the derivation of all the others. Practically, only two or three would be suitable as the source for the others — the ring diameter, the overall extension of the cross arms, or the height of the cross. For the ringed crosses, the key dimension is the diameter of the ring in most instances.

The manuscript illuminations — from the Book of Durrow to the Book of Kells — have forms with various degrees of elaboration disposing the key measure

[1] I have described the forms of a majority of the framed crosses and framed evangelist portraits in *The Earliest Irish and English Bookarts: Visual and Poetic Forms before AD 1000* (Philadelphia, 1994). Forms of a number of the early high crosses of Ireland are described in a subsequent series of papers, 'Shapes of early sculptured crosses of Ireland', *Gesta*, 38 (1999), 3–21; 'The shape of the Durrow Cross', *Peritia*, 13 (1999), 142–53; 'The coherent geometry of two Irish high crosses', *Peritia*, 14 (2000), 297–322; and 'High cross design', 221–32 in M. Redknap et al. (eds.), *Pattern and Purpose in Insular Art* (Exeter, 2001).

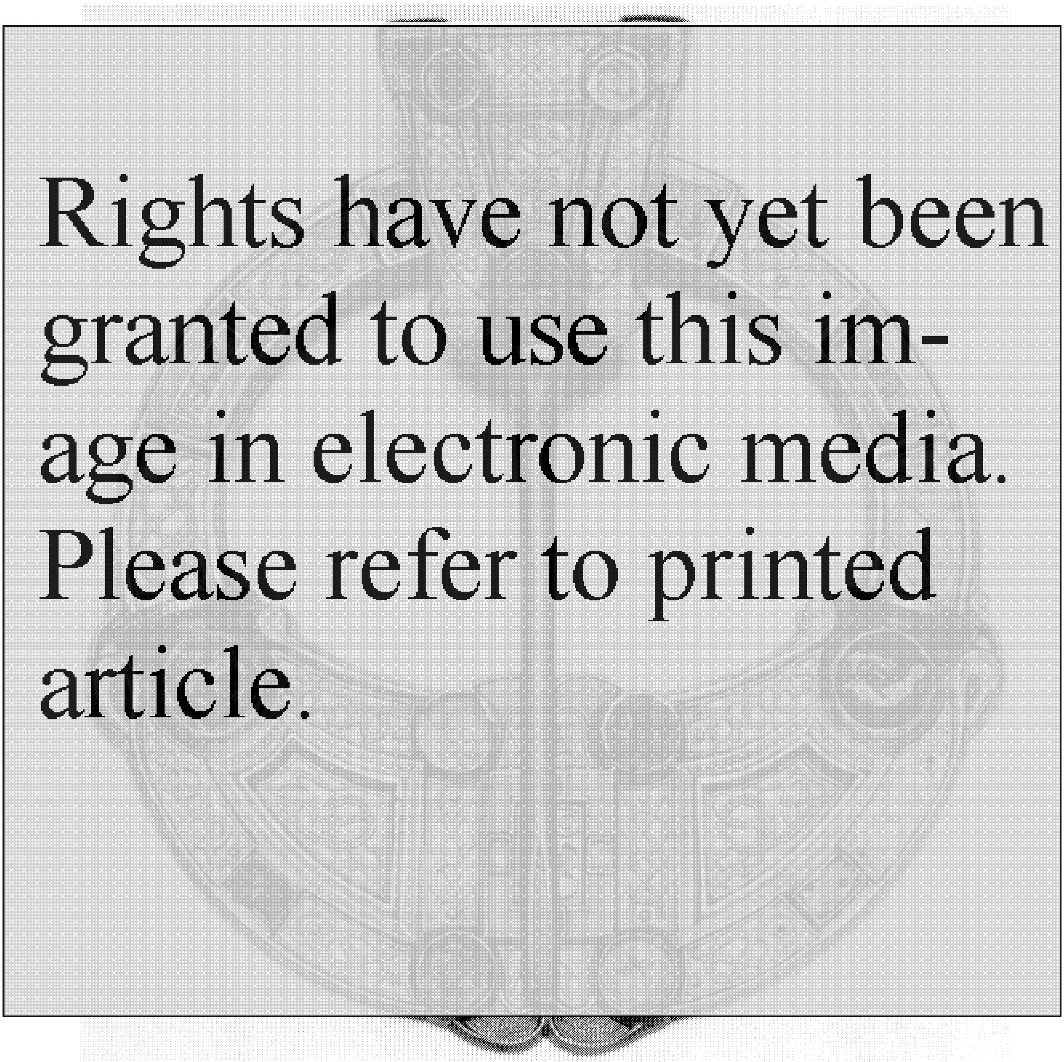
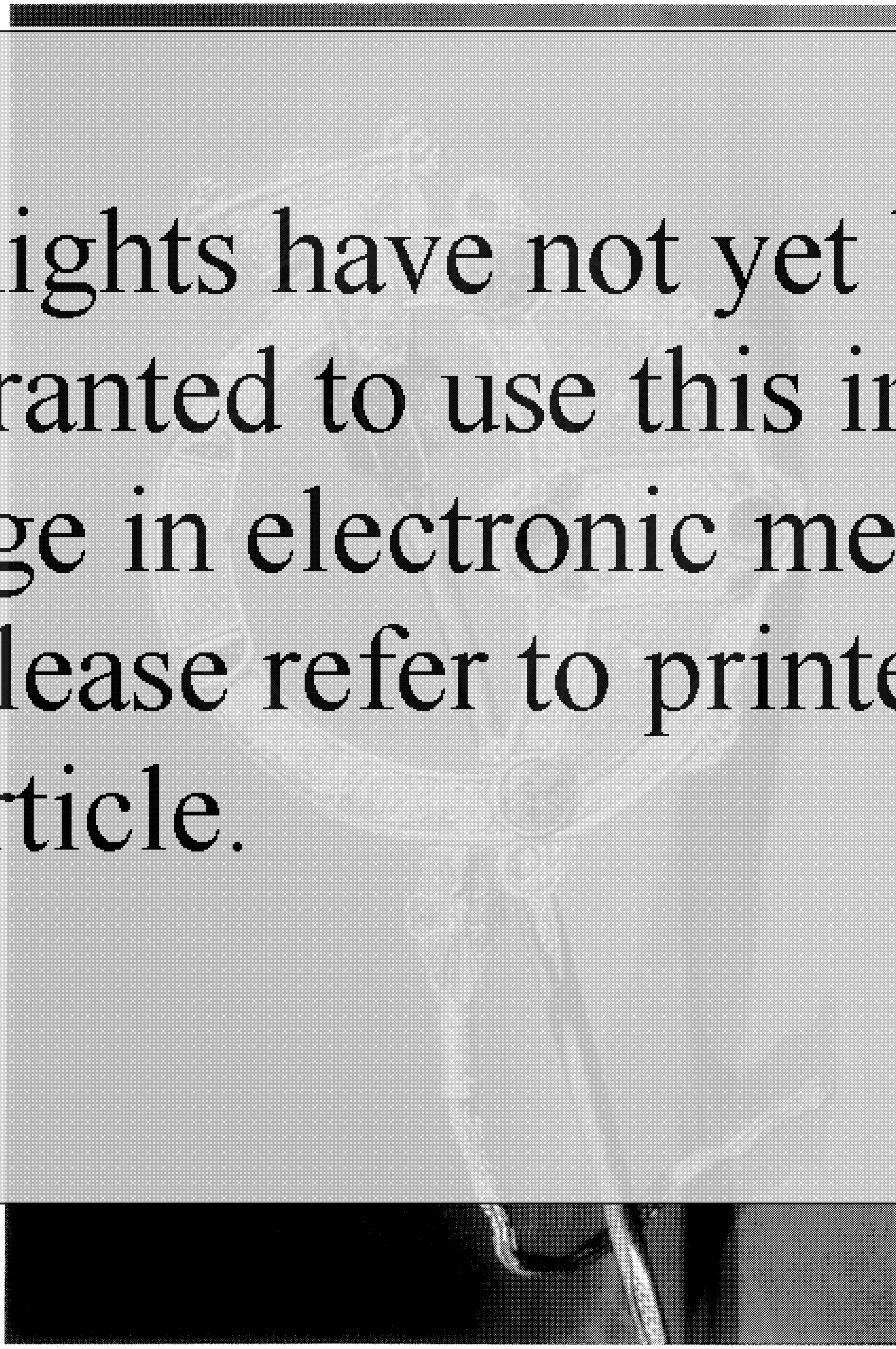


FIG. 1

The Hunterston Brooch, front. © *The Trustees of the National Museums of Scotland.*

and the derivative measures developed from it. The forms developed within rectangular frames can be decoded with a bit of patience, often with help from construction marks visible in the parchment to give clues to the process the artist used in setting out the plan, or to confirm a trial replication of a portion of the whole design. With the full-page illuminations, just as with the stone crosses, it is the coherency of a code that will replicate the whole plan that is the reward of the analyst, as it must have been the pride of the artisan who created it. For all but the earliest of the surviving fine illuminated Gospels texts, the width of the rectangular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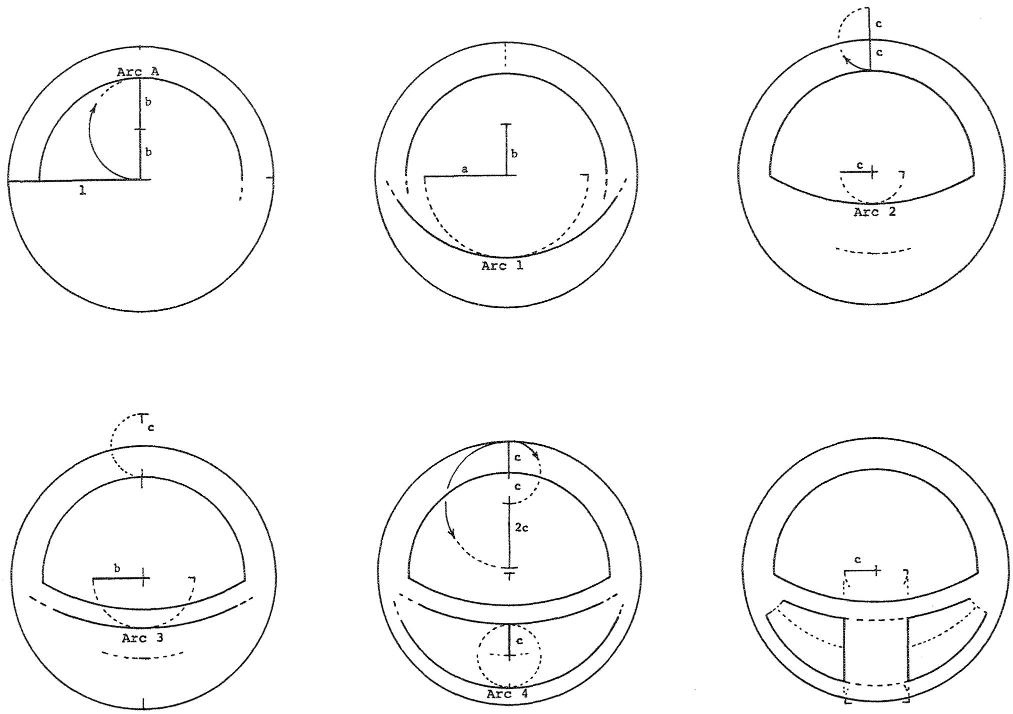

FIG. 3
Form of the Tara Brooch (1). A method of derivation, beginning. *Drawn by the author.*

frame functioned as the key dimension, and its relation to the height of the frame was a direct embodiment of the key ratio.

The form of the Hunterston Brooch was even more challenging to decode than was the form of the Tara Brooch. The main reason is that the given dimension is not obvious. This is because the outline, although generally circular, is not itself a circle; instead, it 'comprises a series of large arcs as well as small projections'.[2] The upper half, the 'hoop', conspicuously curves inward as it approaches the middle of the form. More than that, the inner curve of the hoop turns inward more rapidly than does the outer curve, producing the splay as the hoop joins the terminals. In the lower half, the generally circular pattern is modified by the outer curves turning inward toward the centre as they descend and approach the vertical axis. There are also paired ornamental extrusions from those curves at the sides and the bottom of the form. These matters pose a problem for study of the form: is a circle in fact the basis of the plan? If it is, what is its diameter: the one for a circle that most closely follows the non-circular curves overall? One that fits within the extrusions at the bottom and inside the margin by which the 'cartouche' at the top seems to exceed the curve of the main piece of the hoop? Or one that is inclusive of

[2] R. B. K. Stevenson, 'The Hunterston Brooch and its significance', *Medieval Archaeol.*, 18 (1974), 16–42.

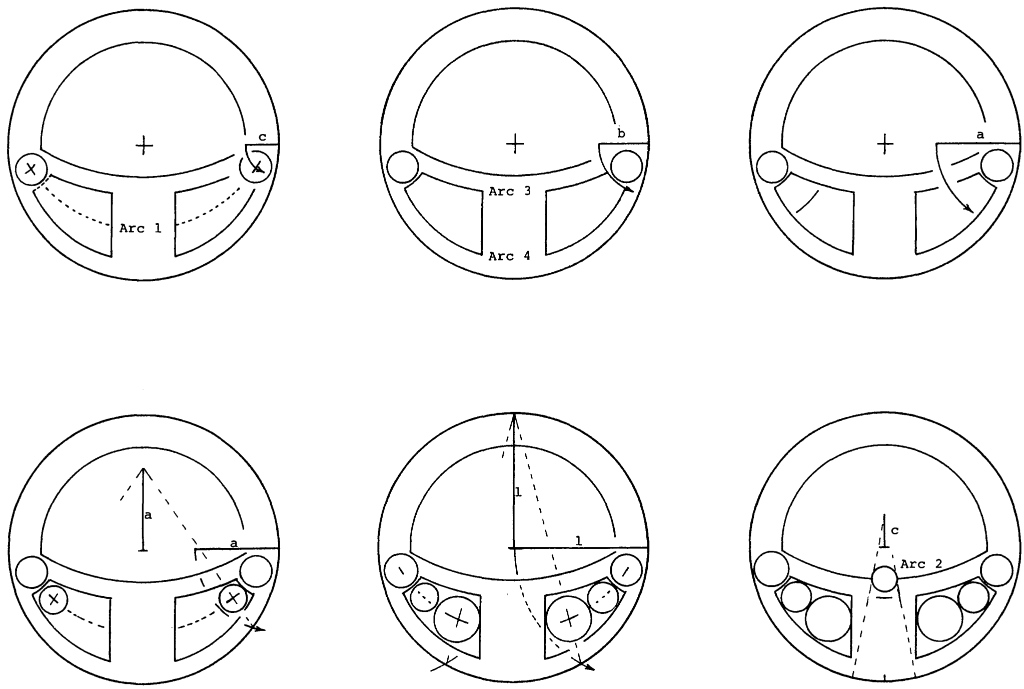

FIG. 4
Form of the Tara Brooch (2). A method of derivation, further. *Drawn by the author.*

these upper and lower parts that may appear to be excessive — apart from the extruded elements on either side at the midline level, the ones by the 'buffers'?

The problem of ascertaining the given dimension continues in the problem of determining the governing ratio (if there is one): how does one determine and apply a ratio when one of its terms is a question mark, so to speak? The Tara Brooch allows one to begin with a circle (even if it is a bit lopsided in one quadrant), so that the overall dimension is readily measurable, and the ratios with inner dimensions are clear from the outset. A set of derivations of its form is given in summary form in Figures 3–4,[3] proceeding from the same source ratios that inform the Hunterston Brooch, constructed as in Figure 5a–b. The Tara Brooch has been referred to as having an 'almost classical simplicity of its general outline',[4] a fully fitting expression of the plainness and the directness of the harmonic relations among its lines and curves. The Hunterston Brooch, though, lacks this plainness and directness of its proportional plan, primarily because of its aberration from a true circle: it strays systematically from that shape without denying it. It is clear nonetheless that the forms of the Hunterston and Tara Brooches share a tradition,

[3] These basic elements of the form of the Tara Brooch are developed in full in R. D. Stevick, 'The form of the Tara Brooch', *J. Royal Soc. Antiq. Ireland*, 128 (1998), 5–16.
[4] A. T. Lucas, *Treasures of Ireland: Irish Pagan and Early Christian Art* (Dublin, 1973), 93.

share a method of creation, share even their governing ratio; but while one has classic simplicity, the other displays baroque embellishment of its underlying form.[5]

I believe it can be shown that the basis of the form of the Hunterston Brooch, like that of the Tara Brooch, is a circle, divided evenly for side-to-side symmetry and divided evenly for balanced asymmetry top-to-bottom. Both originate from drawing diameters of a circle at right angles (as in Fig. 5a). With that beginning it is then a matter of ascertaining the governing ratio among measures of the basic structural lines, and then following through with discovery of practical derivation from the diameters and the ratio for the remaining dimensions of the formal plan. If the form of this piece is like that of the stone crosses and framed illuminations, it will have a given dimension, most likely the diameter of its underlying circle. And if the form is commodular, like the forms of the other works, one measure for the given dimension is the right one, and any others are not. Finding this one measure is where the practical difficulty lay, as explained above. The measure used here is the one that 'computes' with all the others in the same ways that can be observed in the forms of many other early Insular forms: that measure is the diameter of a circle inclusive of the cartouche and the ornaments at the lower edge of the main piece. This is the same measure of the metalwork used by Stevenson to set the diameter of the body of the brooch at 122 mm.[6]

THE METHOD

Here is a step-by-step method that will replicate the basic form of the Hunterston Brooch. Accuracy of this replication was checked not only with fine-line overlays on enlarged photographs, but also by correlation with the meticulous, detailed set of measurements published by Niamh Whitfield.[7] Begin with a circle, draw a horizontal line through its centre as its diameter, and bisect that line with a line perpendicular to it, as in Figure 5a. The initial step is thus to divide a given measure — here, the diameter of the circle — into two equal parts: they are the radii of the circle, whose equal lengths will be designated as 1. This sets the bilateral symmetry. Then set the governing ratio, in this plan the 'extreme and mean ratio', implicit in what is commonly called the golden section of a line. Figure 5b shows one practical method for setting the key ratio within a circle. This method, and others using only compass and straight-edge, require neither postulates nor proofs, needing only accurate drawing skills and thorough understanding of the relative measures. It requires dividing the radial measure first into two equal parts each with length $\frac{1}{2}$ (Fig. 5b, operations 1 and 2 — operations being numbered in parentheses in the figure). And then dividing the radial measure into two unequal parts a and b whose measures embody the golden ratio, φ (Fig. 5b, operation 3), i.e. ${}^{a}/_{b} = \varphi$. By the nature of this ratio 1 and a are also in the same ratio, i.e. ${}^{1}/_{a} = \varphi$, as well as $1 + a$ and 1, i.e. $1 + a : 1 = \varphi$. An alternate method of creating the

[5] N. Whitfield, 'Design and units of measure of the Hunterston Brooch', 295–314 (and plates) in J. Hawkes and S. Mills (eds.), *Northumbria's Golden Age* (Stroud, 1999), notes, p. 211, that 'it is nevertheless simpler in the variety of techniques used and in the range of patterns displayed.'
[6] Stevenson, op. cit. in note 2, 17.
[7] Whitfield, op. cit. in note 5, 302–5, 307–9, and tables 24.1–4.

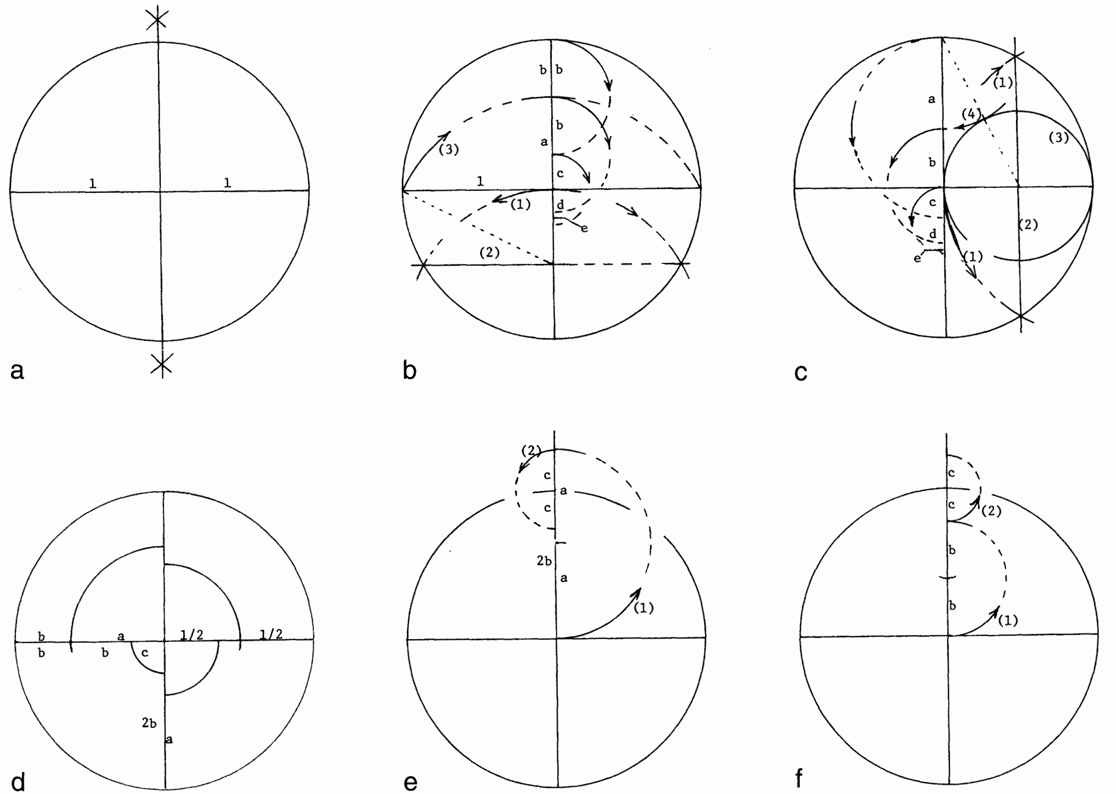

FIG. 5

Golden ratio of radius of circle. a–b. Construction method for a:b = φ. c. Alternate construction method for a:b = φ. d–f. Some relations among 2, 1, a, b, c. *Drawn by the author.*

same divisions into 1, $\frac{1}{2}$, a, b is shown on the right side of Figure 5c (using four operations).

In either derivation, further proportional measures are entailed. These are illustrated on the right side of Figure 5b and on the left side of Figure 5c. One is the measure c, being a – b in simplest derivation. In Figure 5b (top) it is 1 – 2b; in Figure 5c it is 2a – 1; in Figure 5e it is represented again as 2a – 1 and in Figure 5f it is represented again as 1 – 2b. Successive derivative measures are then entailed in similar ways: b – c = d, then c – d = e; see Figure 5b and 5c again. Other interrelations of these measures are illustrated in Figure 5d. Dimensions of the brooch will be expressed throughout this paper in these relative measures 2, 1, a, b, c, d, and e, rather than in numerals representing millimetres (or any other scale of measure). Numerals corresponding to the measures on a constant-unit scale are not transparent representations of that form. Neither do we know the numeral system the designer may have employed (e.g. decimal or duodecimal).

The form of the 'cartouche' is a simple division of the circular segment of the hoop; it can be developed as in Figure 6a–c.

6a From the top of the circle, copy measure c along the centerline (as in Fig. 5e or 5f), and draw an arc (1) concentric with the outer circle, with radius 1 – c. Then plot a straight line parallel to the midline, at the measure 1 above the midline. (The method illustrated uses dividers set at measure 1, i.e. the radius of the circle; the fixed point is set at either end of the midline in turn, and the moving point (2) draws a short arc directly above each end of the midline. Then a straight at a tangent to the tops of those arcs to guide the line (3) drawn at measure 1 above the midline.)

6b On either side of the centre-line, (1) mark the measure $\frac{1}{2}$ along the line just plotted parallel to the midline. Then along the midline, mark points at measure a from the centre of the circle. Run lines (2) from these points, in turn, through the point at measure c below the top along the centre-line: mark the points where they intersect the straight line just plotted in Figure 6a. The result is to mark $^{b}/_{2}$ on either side of the centre-line.

6c The paths of lines from the centre of the circle to the four points just marked (Fig. 6b) set the ends and the internal divisions of the cartouche.

The top lines of the buffers and two further circular arcs can be plotted as shown in Figure 6d–f.

6d The tops of the buffers lie along lines connecting a point at measure c above the centre to points on the midline at measure c from either end of that line.

6e For the inner curve of the lower portion of either terminal, plot a circular arc with radius 1 – d. (The method illustrated for computing d inside the outer circle is to add b + c to c measured from the centre; i.e. 1 – (b + 2c) = d.)

6f Locate and mark a point on the centre-line $\frac{1}{2}$ – c below the centre; the figure illustrates one way to do this ($1 - \frac{1}{2} + c) = \frac{1}{2} - c$). The arc has its centre at measure d from the top, its radius extending to $\frac{1}{2}$ – c below the centre (radius = a + $\frac{1}{2}$).

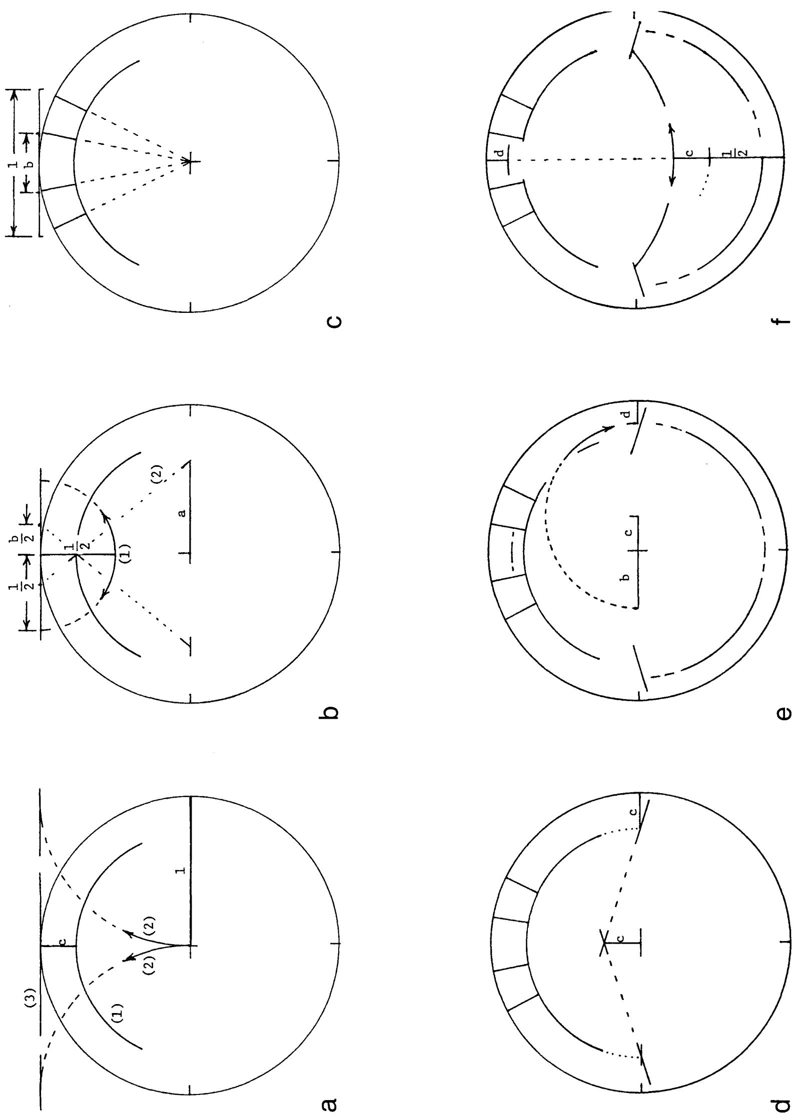

FIG. 6

Form of the Hunterston Brooch (1). a–c. Deriving the form of the 'cartouche'. d. Deriving the top limits of the 'buffers'. e–f. Deriving two arcs of the 'terminals'. *Drawn by the author.*

The layout of the pin proceeds from the same font of proportions. First the head of the pin. With its mainly straight-line outline, it exemplifies plainly the commodular scheme of the total plan; it can be developed as in Figure 7a–d.

7a Plot a straight line parallel to the midline, at the measure 1 + c above the midline. (The method illustrated uses dividers set at 1 + c as it was plotted along the centre-line (Fig. 5b or c); the fixed point is then set at either end of the midline in turn, and the moving point (1) draws a short arc directly above each end of the midline. Then a straight-edge is laid at a tangent to the tops of those arcs to guide the line (2) drawn at 1 + c above the midline.)

7b Measures c and b are then copied and marked along the line just set (in Fig. 7a), on either side of the centre. (Measure d is entailed as b – c)

7c Measure c is marked along the centre-line below as well as above the midline. The lateral lines defining the form of the pin-head are now developed as shown from the measure and points already plotted.

7d Measure b is then copied twice (or measure 2b is copied once) below the top corners of the pin-head to set the lower limit of this piece. Alternatively, measure 2c is copied above the midline at measure c on either side of the centre to set the lower limit of the pin-head.[8]

(Not shown, centres of the pair of circular cells are then plotted from the head's configuration, and drawn with radius 2e.)

The shaft of the pin is broken, making its original length unverifiable. The break occurs 'across a slight swelling, marked by a long tapered compartment filled by a cast rope . . . The pin, however, is beginning to taper away from the middle of the swelling and, if on some later analogies that is taken as the central point of the shaft, the length may be restored to 150 mm.'[9] That measure — an approximation based on comparison with similar artefacts — fits the schematic analysis presented here as well as any measure could. The construction of the plan of the pin-head began (as in Fig. 7a) by setting an extension 1 + c above the centre of the underlying circle, and the head extends beyond that circle by measure c; the loop holding it to the body of the brooch allows some freedom of movement, of course, for practical purposes of attaching the brooch to heavy fabric. The relative measure 1 + c applied to the whole brooch (its diameter) would be 151 mm (rounded to nearest whole number). It is probable, then, that both the pin-shaft and the pin-head dimensions were set by identical relative measures — 1 + c times the radius for the head, 1 + c times the diameter for the length of the pin-shaft. It may be noted, too, that 'the pin seems to have been cast in one with the head'.[10] To set that length in a

[8] The plan constructed here gives the width of the pin-head, and its length, the same dimension (2b); this is at odds with the measures reported by Stevenson, op. cit. in note 2, p. 20, as 45 × 42 mm. Yet drawings on transparent sheets when laid on top of photographs of identical size show a very close, symmetrical, and thorough fit of model and photographs. I think there is no inconsistency here; rather the difference stems from the difference between a plan, or template, and the manufactured piece of metalwork, with its varied and embellished outline (and the effects of wear).

[9] Stevenson, op. cit. in note 2, 21.

[10] Ibid., 20.

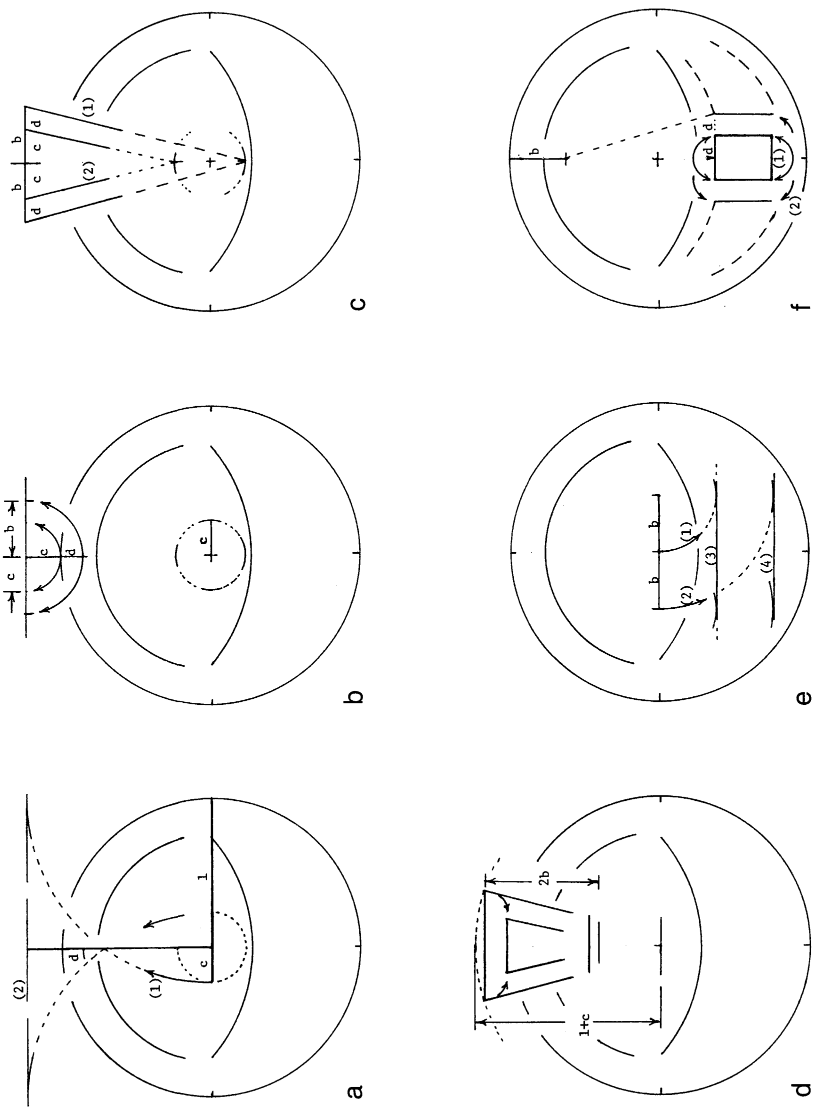

FIG. 7

Form of the Hunterston Brooch (2). a–d. Deriving the shape of the pin-head. e–f. Deriving the extension of the 'gap'.
Drawn by the author.

model is very simple: double the radius of the underlying circle downward from the centre. That produces the measure 2, to be added to the measure 2c from the circle's centre to the lower edge of the pin-head. Thus, the extension for the head above the centre is 2a ($= 1 + c$), the length of the pin-head is 2b, its lower edge being 2c above the centre, and the shaft extends measure 2 below that.

Next, the 'gap', that is, the central portion of the main part of the brooch that corresponds to an actual gap in earlier penannular brooches. Its distinctive shape is emphasised in the parallel vertical lines on either side; the two inner ones join with two parallel horizontal lines to form a rectangle. The layout of this area is illustrated in Figure 7e–f, developed as follows.

7e Plot two straight lines parallel to the midline at the measures b and 2b respectively below the midline. (The method illustrated uses dividers with the fixed point set at measure b from the centre along the midline, on either side of the centre, in turn; the moving point is set at the centre (hence with measure b) and (1) draws a short arc directly below each the fixed point. A similar procedure, this time with dividers' moving point set at measure 2b guides (2) another pair of arcs directly below each fixed point. A straight-edge is then laid at a tangent to the lower sweep of the first pair of arcs to guide a line (3) at b below the midline, and at a tangent to the second pair to guide a line (4) at 2b below the midline.)

7f Measure d is copied and marked along both of these lines on either side of the centre (1); then vertical lines connecting them in pairs form the rectangle at the centre of the 'gap'. Measure d is copied again on either side of the vertical lines just drawn (2) to set the paths of two more vertical lines parallel to them; they outline the 'gap'.[11]

The complex curves of the hoop and the outline of the terminals raise a fundamental question belonging strictly to the domain of the design. This asks essentially whether the curves are plotted in the same terms that give form to the more regular lines and dimensions that have been described up to this point, or whether they were improvised free from the constraints of the commodular design, i.e. whether they were guided essentially 'by eye'. In short, are the curves plotted to the commodular scheme, or were they drawn directly by intuition? The procedure for finding an answer involved plotting various portions or segments of the curves, each by centre, radius, and extent, to find a series of structural lines that approximated the complex curves of the hoop, both inner and outer. Remarkably, the process of convergence of model and artefact resulted from progressive simplification, and above all from progressive submission to a rule governing the ratios in the other parts of the plan. The best approximation was devised after recognising that the convergence of approximations with the actual plan followed steadily from simplifying the terms of construction. The last stage was in the

[11] The pairs of vertical lines just described match the plan of the brooch fairly well; they differ, however, in that the lines are not equally spaced in the artefact — i.e. they are not quite parallel. Their asymmetry is documented with detailed measurements by Whitfield, op. cit. in note 5, p. 304, figs. 24.6A and 24.6B, and table 24.1. Further, Stevenson, op. cit. in note 2, p. 19 and fig. 3, notes that 'three sides' of the rectangular frame at the centre of the gap 'curve very slightly'.

recognition of symmetry and parallels in combining the ratio-measures for setting centres, radii and extensions of the segment arcs.

Figures 8–9 illustrate a method of computing these complex curves. Using only the set of related measures set up initially, it produces approximations that are so close to those of the curves on the artefact as to require no more than light smoothing from one segment to the next.[12] The outer curve of the hoop is plotted first, as illustrated in Figure 8. The measures e and d are marked above the centre along the centre-line. Then from either end of the midline in turn, sketch arcs with radii c, b, a, 2b to intersect the outer circle of the underlying plan. ('Sketch' is used here in the sense of drawing lightly — underdrawing — and not in the sense of freehand drawing.) Draw then the following sequence of arcs:

(1) centre at d above O, from centre-line to end of cartouche;
(2) centre at O, from end of cartouche to intersection with lateral arc b;
(3) centre at e above O, from intersection with lateral arc b to buffer.

The outline of the terminals is plotted in the lower half of Figure 8. Arcs with radii 2b (= 1 − c), centred at either end of the midline, intersect the underlying circle. Above this intersection the outline follows the underlying circle; below, it follows (4) an arc with centre at measure e above the centre of the plan, and linked to the underlying circle at that same intersection. Not only is the approximation for the outer curve of the brooch very close: the same arc extended upward to the midline (shown in dashed lines) accurately sets the limits of the extruded bird's head ornaments at the middle of the brooch.

The inner curve of the hoop is plotted as in Figure 9. The measures e, d, c, b are marked above and below the centre along the centre-line. (Those below are 'minus', e.g. −e) Then draw the following sequence of arcs:

(1) centre at −b, from centre-line to end of cartouche;
(2) centre at −e, from cartouche to intersection with line to lateral arc 2b (or possibly from cartouche to radial line to arc a from top centre-line);
(3) centre at O, between intersections of lines with lateral arcs 2b and a;
(4) centre at +e, between intersections of lines with lateral arcs a and b;
(5) centre at +d, between intersections of lines with lateral arcs b and c;
(6) centre at +c, between intersections of lines with lateral arcs c and buffer.

If the curves of the hoop and terminals were calculated by the same system that produces the other elements of the coherent plan, and in a manner like the one just described, a practical question is how an artisan could reproduce the fairly complex curves in the material models used to embody the form in cast metal. To this question it can be answered first that the multiple steps of calculating those complex curves need not have been performed on the casting model itself. Practically, they could be carried out on separate materials, say, a wafer of wood. When the curves were carefully plotted, ratio by ratio, for this interim model, it

[12] The curves of the hoop plotted here are those of the front of the brooch. A considerable difference between front and back results from the edges not being vertical: according to Stevenson, op. cit. in note 2, 19, 'at the ends of the hoop the front is 14 mm wide, the back 17 mm'.

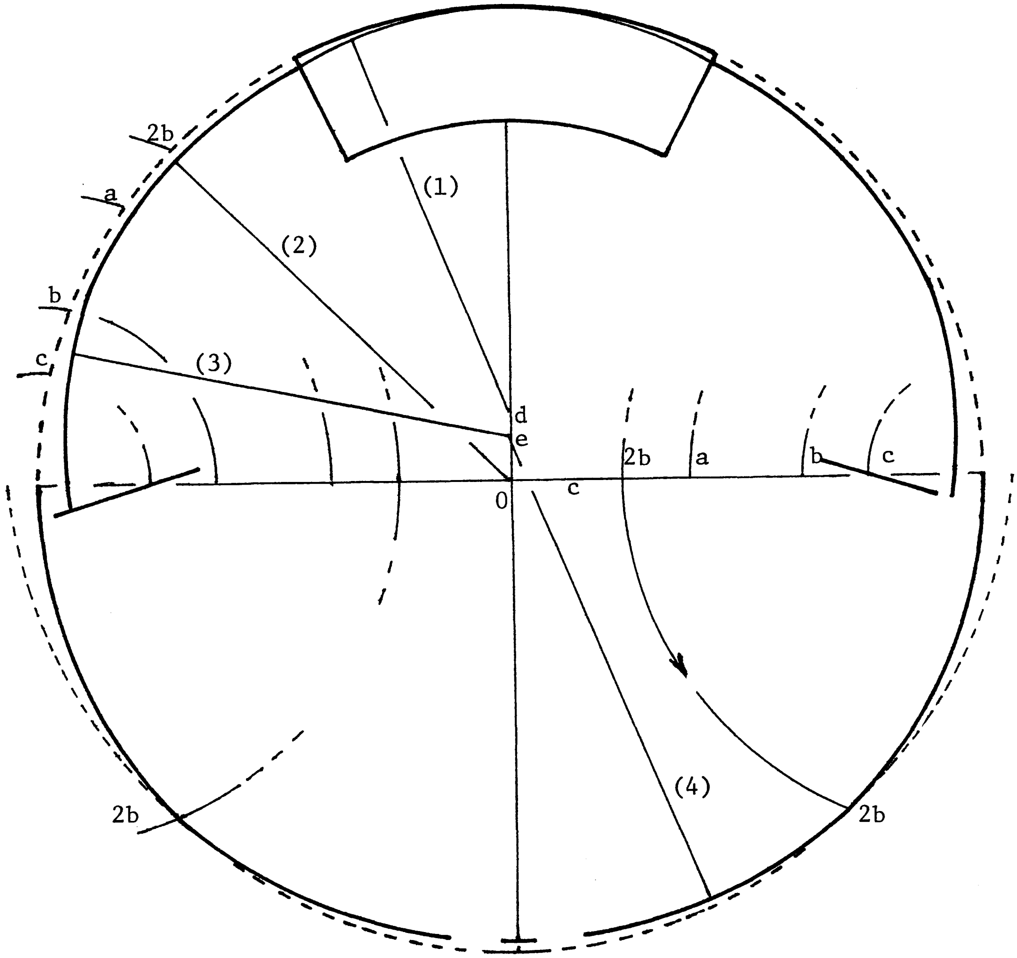

FIG. 8
Form of the Hunterston Brooch (3). Deriving the arcs outlining the brooch. *Drawn by the author.*

could then be cut to shape, smoothing the separate series of arcs into two smooth curves. (The need for smoothing, on the scale represented by the brooch, would be nearly imperceptible.) Then, if needed, that interim model could serve as a pattern for a wax model. A fine scalpel tracing the curves of the first model could cut the pattern for a wax model to be worked further and then used in forming the mould for casting the metal.

There is also a question about the credibility of this reconstruction. It is possible, of course, for any line, or any arc and its centre, to be triangulated with reference to any fixed points that may be at hand, or stipulated. Even the parts of a random design can be triangulated with good approximation, if enough points and measures are invoked. The difference between random or freehand elements of a design — or even a design with subjective (spontaneous, following inspiration of

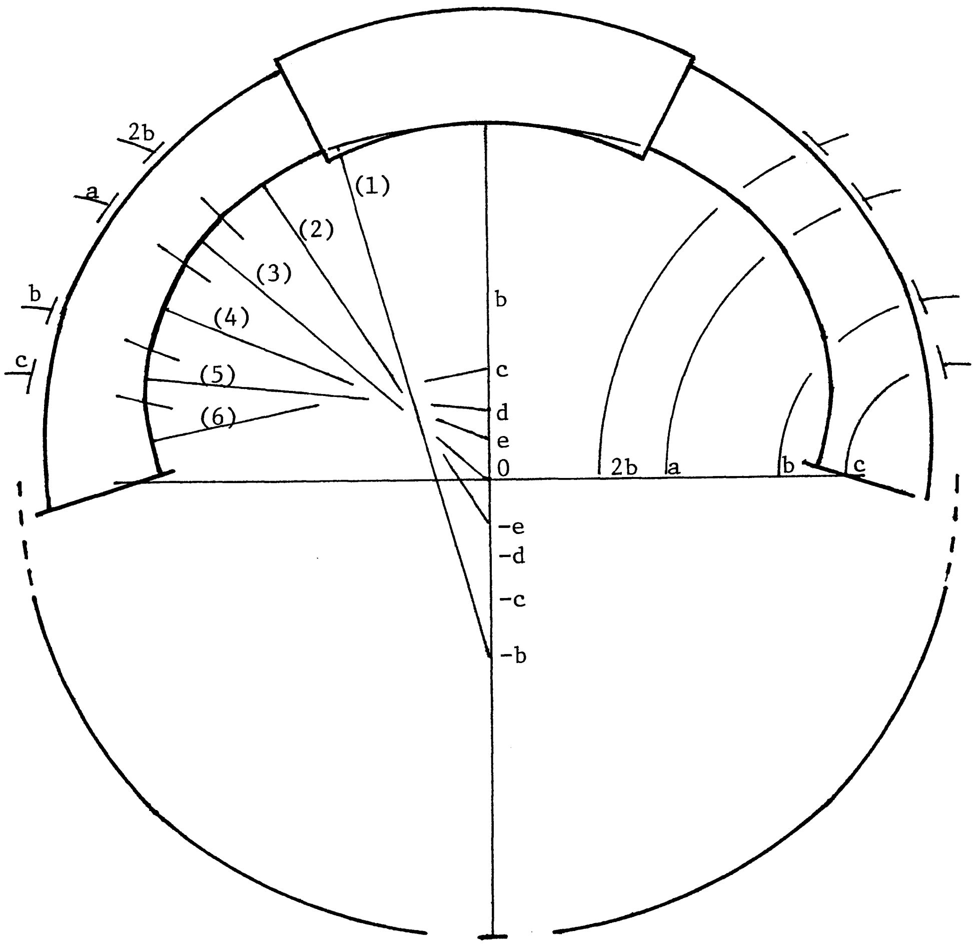

FIG. 9
Form of the Hunterston Brooch (4). Deriving the inner curves of the 'hoop'. *Drawn by the author.*

the moment) placement of any of its parts — and a design of Insular commodular construction is just this: all of the elements in the Insular design interlink one with another throughout the whole form, with minimal repertory of measures, and with all of them related by simple geometrical ratio.

This has been one way to map the primary elements of the form of the Hunterston Brooch. It has for the most part proceeded as a single recipe of operations with simple drafting tools. It must be remembered, nonetheless, that most of the manoeuvres illustrated are not unique in their capacity to plot the structural lines.

DISCUSSION

The method just described for producing the basic form of the Hunterston Brooch constitutes a series of steps in manipulating compass and straight-edge.

TABLE 1
SOME MEASURES IN THE HUNTERSTON BROOCH

FIGURE	FEATURE	MEASURE	RATIO (:1)
Figs. 6–9	Brooch plan, radius diameter	1 (Given) 2 (Given)	1 2
Fig. 6a	Cartouche radius, inner	$1-c$	$1-\frac{1}{\varphi^3}$
Fig. 6a–c	—— width, overall	1*	1
Fig. 6a–c	—— central panel	b*	$\frac{1}{\varphi^2}$
Fig. 6f	Terminals, arc 1, centre	d below top	$\frac{1}{\varphi^4}$
	—— —— radius	$1+\frac{c}{2}$ (or $\frac{1}{2}+a$)	$\varphi-\frac{1}{2}$
Fig. 6e	—— arc 2, centre	0 (centre of plan)	——
	—— —— radius	$1-d$	$1-\frac{1}{\varphi^4}$
Fig. 6d	Buffers, on path of hypotenuse of triangle:	sides c and $1-c$	——
Fig. 7c–d	Pin, head length	$2b$	$\frac{2}{\varphi^2}$
	—— width at top	$2b$**	$\frac{2}{\varphi^2}$
——	Pin, length	$2(1+c)$***	$\frac{4}{\varphi}$
Fig. 7f	'Gap,' width overall	$4d$	$\frac{4}{\varphi^4}$
	—— inner rectangle width	$2d$	$\frac{2}{\varphi^4}$
	—— height	b	$\frac{1}{\varphi^2}$
Figs. 8–9	Brooch outline and Hoop	Sequences of abutting arcs	

*Projected to line at 1 above midline and parallel to it.
**Projected to line at $1+c$ above midline and parallel to it.
***Not verifiable, because part of the piece is missing.

Without those mechanical actions the form cannot be realised accurately. Without understanding of the quantitative relations produced by these actions, furthermore, the harmony of the form cannot be grasped. The topic of this discussion will be therefore the properties of the method of design that produced the form of the Hunterston Brooch and the Tara Brooch, as well as the early high crosses of Ireland, and the best Insular bookarts of Early Christian Ireland and Britain.

A key to discovering those properties of the design method can be illustrated first in terms of its fundamental measures. A few measures are used and re-used, combined and re-combined, within the design: in the step-by-step procedure, reference has been made to only 2, 1, a, b, c, d, e. The key measures are gathered together in Table 1, where they are all expressed again in terms of only those measures. There are no fractions, there are no remainders. For comparison, the

TABLE 2
SOME MEASURES IN THE 'TARA' BROOCH

FEATURE	MEASURE	RATIO (:1)
Brooch radius	1 (Given)	1
diameter	2 (Given)	2
Hoop radius, inner	$2b\,(=1-c)$	$2-\frac{2}{\varphi}=\frac{2}{\varphi^2}$
Arc 1, centre	b above centre	$\frac{1}{\varphi^{+1}}=\frac{1}{\varphi^2}$
radius	$b+a\,(=1)$	1
Arc 2, centre	c above top	$\frac{1}{\varphi}-\frac{1}{\varphi^2}=\frac{1}{\varphi^3}$
radius	$c+1+c$	$\frac{2}{\varphi}+\frac{1}{\varphi^3}=1+\frac{2}{\varphi^3}$
Arc 3, centre	c above top	$\frac{1}{\varphi}-\frac{1}{\varphi^2}$
radius	$c+1+b$	φ
Arc 4, centre	$2(2c)$ below top	$2(\frac{2}{\varphi}-\frac{2}{\varphi^2})=\frac{4}{\varphi^3}$
radius	to $b+c+c$ below centre	$\frac{1}{\varphi}+\frac{1}{\varphi^3}=1-\frac{1}{\varphi^4}$
'Gap,' width	$2c$	$\frac{2}{\varphi^3}$
Pin head, length	$2a$	$\frac{2}{\varphi}$

measures and ratios governing the form of the Tara Brooch are listed in Table 2. The main differences between these designs stem from the tightness of coherency among all the measures among the lines and arcs. The control will be very strict when a plan uses only 2, 1, a, b, c (Tara Brooch); it will be much less strict if it uses 2, 1, a, b, c, d, e, which allows so many more relations and their more complex combinations (Hunterston Brooch).

Further, these measures, with the exception of 2, are joined in a proportional chain. Thus, $\frac{1+a}{1}=\frac{1}{a}=\frac{a}{b}=\frac{b}{c}=\frac{c}{d}=\frac{d}{e}\ldots=\varphi$ (golden ratio). This being the case, it is also the case that a $=\frac{1}{\varphi}$, b $=\frac{1}{\varphi^2}$, c $=\frac{1}{\varphi^3}$, d $=\frac{1}{\varphi^4}$, e $=\frac{1}{\varphi^5}$, and so on. All these measures are thus joined both in their sums and differences, and in the powers of their inverses. The basis of these proportions is the unique and extraordinarily powerful ratio φ. Once the ratios involving 1, 2, and φ have been set by mechanical operations such as the ones illustrated (Fig. 5b, c), they will generate all the measures that are needed to compose the form of the Hunterston Brooch, along with a number of other of the best forms surviving from the early Insular tradition.

It will be clear, then, that iteration is at the heart of the method of design, manifest in not only the dimensions of and among the main components, but also in a single geometrical ratio linking all these dimensions. The design evolves from a full understanding and exploitation of this ratio which controls all the measures and all their relations in the basic form of the brooch.

Iteration of measure is found in at least some of the smaller components of the plan, as well. For example, the diameters of the settings for the two large circular studs on either side of the terminals, measured at their bases, have length 2d. The small circular studs at the lower end of the 'gap' have diameters 2e.[13] It is difficult to know just how far the scheme reaches into the smaller elements and the decorative details. It may well have extended as well to the length of the pin (now broken), as explained above.

A specially interesting instance of iteration together with complementation is employed in the design of the cartouche and the pin-head. The cartouche lateral borders and divisions are along lines radiating from the centre of the brooch (see Fig. 6c); the cartouche lies along the basic circle. The pin-head sides and the parallel cell boundaries complement this plan, lying along lines radiating from c below the centre and c above the centre, respectively (see Fig. 7c); the pin-head extends about equally beyond the outside of the hoop and the concentric inner curve of the hoop, which is at measure c inside the outer curve. Add to this the length of the pin itself (mentioned above) being reconstructed as $1 + c$ the diameter of the main piece, and the extension of the pin-head from the centre being $1 + c$ the radius of the main piece. Another way to formulate the dimensions of the pin-head also shows this pattern of iteration: the top is at measure 2a above the centre of the underlying circle, and the bottom is both 2b below the top, and 2c above the centre. In mechanical terms, of course, the pin and its head move in partial rotation around the hoop, so that in practice, 'above' and 'below' have general reference to the upper and lower halves of the main piece. There is also the practical play allowing the pin slight movement in and out; because the centre of the plan is not physically marked, however, the variation of measure from the centre of the plan is never tested visually and will remain unnoticed. Meanwhile, material dimensions are not altered by the mechanical play.

CONCLUSION

The form of the Hunterston Brooch is another elegant construction in coherent geometry in early Insular metalwork. Of the Tara Brooch it has been said that its creator 'seems to have been gifted with an unerring instinct for proportion whether in mass or line' in producing its 'classical simplicity'.[14] Of the Hunterston Brooch it can be said that the creator of its form understood the rules of commodular design as well as the best designers of Insular artwork, and used that

[13] Besides the match of the model superimposed on a photograph to demonstrate the re-use of these measures, there is the corroboration of the dimensions reported by Whitfield, op. cit. in note 5, table 24.3: the ratios between the millimetre measures of the stud-setting diameters and the radius of the brooch are identical to the ones listed here as 2d and 2e.

[14] Lucas, op. cit. in note 4, 93.

understanding to embellish the form of his brooch with baroque developments.[15] With that difference, it can be said of this brooch, too, that its form employs the same principles of design which generated the plans for the magnificent illuminations in early Insular gospels manuscripts as well as those of the early high crosses of Ireland. Those principles lie in mathematical thinking carried out in constructive geometry (as distinct from number theory and numeral computation). They are independent of any specific scale of measuring, independent of any practical activities such as land surveying or architectural planning, and independent of (though not immune to) any set of symbolic references. The form of the Hunterston Brooch, like that of the Tara Brooch, exemplifies in a superlative way a disciplined handling of proportion to create a harmonious design. It originates in early Insular culture whose richness has not yet been fully told.

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It was in 1995 that Niamh Whitfield drew my attention to the design of the Hunterston Brooch, by asking whether the principles of design I had reported for early Insular manuscript illuminations and vernacular English religious poems might obtain as well for this brooch. I could not provide an answer, because the circular form was unlike any I had analysed up to that time, and especially because the outline of the brooch was not regular — not a circle. Not until six years later, and after decoding the form of the Tara Brooch, was I able to see how the form of the Hunterston Brooch seems to have been laid out; this was some time after publication of Dr Whitfield's paper referred to in this article.[16] Besides initiating the study that led to this paper, Dr Whitfield has also been very generous in providing photographs and measurements made by direct examination of the brooch.

[15] The terms 'classical' and 'baroque' are used here in fairly literal senses, and without covert implications for relative chronology of the two brooches. Stevenson, op. cit. in note 2, p. 35, applies the term 'baroque' to the Tara Brooch, in fact, in reference to its elaboration of decorative details. It is chiefly in terms of technique of the decorative details that he infers, p. 38, the Hunterston Brooch to be 'closest typologically to the prototype' of 'the new decorative style of Celtic brooch and its new pseudo-penannular shape'. In this perspective, the Tara Brooch is 'perhaps the work of a superlative pupil' of an Anglo-Saxon who produced the prototype. In comparisons with other brooches, Stevenson infers, pp. 34–5, that the Hunterston Brooch is very early, because in other pieces 'the complex Germanic outline has been lost in favour of a plain circle'.

[16] Whitfield, op. cit. in note 5.