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A Gaulish Throwing Stick Discovery in Normandy: Study and Throwing Experimentations

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In 2010 archaeological excavations on the pre-Roman site of Urville Nacqueville, Normandy (France) discovered a shaped unknown wooden implement. This boomerang shaped wooden artefact, dated from 120 to 80 BC, has been found in an enclosure trench of a Gaulish village close to a ritual deposit of whalebones. The careful study of this implement, aside from archaeological and ethnological comparison, shows that it has probably been used more like a bird-hunting throwing stick. To test this hypothesis, experimental crafting and throwing of a replica has been conducted, aiming to get more information about its functionality from the various flying trajectories obtained.

> “The Urville Nacqueville throwing stick reinforced with iron strips is unique in Europe for the second Iron Age period. Its different states reflect the transition between an often used hunting projectile to a prestige item assuming a more symbolic function, increasing its archaeological value.

Archaeological Context

This artefact was excavated from a rural district from an enclosure trench protecting a living area where three circular buildings stood. These buildings were of a British isle style. The stick was in a vertical position against the eastern external wall of this structure (Lefort 2010). The base of the artefact was sitting on a small structure made some time after the main trench was filled. The particular position of the artefact implies that it was placed there on purpose rather than disposed of.

Boomerangs and throwing sticks: How these terms are used in this article

Since its appropriation by Europeans, the term ‘boomerang’ has been used to designate indistinctly all kinds of throwing sticks.

This language inaccuracy, caused by modern popularity of these objects, led many to disregard the existence of a larger and more diversified group of related objects, which actually included a very small percentage of returning projectiles (Hess 1975, 24). We tend nowadays, as we will do in this article, to designate only returning throwing sticks as boomerangs, in respect of their Aboriginal etymology (Thomas 2000).

We will give a general definition of a throwing stick as a piece of wood with a variable curved shape, having two or more shaped blades forming an ordinary angle between them. This wooden piece is thrown by hand in rotation around its centre of gravity.

See **Terminology** below for more

Different uses of throwing sticks

Some throwing sticks are capable of reaching between 150-200 meters in range and can break the legs of a big mammal. The Tamils from Southern India were still using this kind of weapon in the nineteenth century to hunt hare and other mammals as large as deer (Hess 1975, 60). In North America, the Pueblos people used a similar object called a ‘rabbit stick’, which was presumably mainly used to hunt rabbit (Heizer 1942). This weapon was also used in ancient Greece under the designation ‘lagobolon’. It is represented on several statues and vases. The other main use of the throwing stick is bird hunting. Well documented in Australia (Jones 1996), this hunting practice is also represented on tomb paintings showing the daily life of the elite in ancient Egyptian society. The scene is generally showing a marsh where the hunter is on a small papyrus boat and waving his throwing stick, followed by his servants. The hunter is aiming directly at a flock of birds and often hit several birds at the same time (Thomas 1991). In Australia, and on other continents, throwing sticks were also used in conjunction with nets for bird, and even sometimes for big mammal hunting (Hess 1975. p 59). As for bird hunting, returning throwing sticks were mainly thrown over a flock of birds to imitate an attack from a bird of prey, and get the birds down to the ground to trap them with nets. Indeed, these were very light throwing sticks weighting generally less than 200 grams and with small wingspans ranging between 40-50 cm. Returning throwing sticks of this nature tended to be specialized in indirect aerial hunting and specially designed for hunting game. Some uses of throwing sticks for fishing in shallow water are recorded in northwest Australia (Jones 1996).

Presence of throwing sticks in prehistoric Europe

The oldest well-identified throwing stick in the world is dated from 23,000 BP, belonging to the upper Paleolithic period. This object, made of mammoth ivory, was found in the Oblazowa cave in Poland (Valde-Nowak 2000) (Thomas 2000). About the Mesolithic period, an artefact dated from 6000 BP was recovered in peat land of Brabant in Denmark (Thomsen et al. 1902). For the Neolithic period, Egolzwil 4 site in Switzerland delivered three examples of throwing sticks dating from the middle Neolithic (Cortaillod culture: 4500-3500 BC.) (Ramseyer 2000). Another example belonging to the final bronze period was discovered in Möringen, Germany.

In the same period, this throwing weapon was represented on the Nile hunting scene painting in the Nakht Theban tomb in Egypt dating from the XVIII dynasty. However, the most spectacular discovery of throwing sticks was made in the Tutankhamun Egyptian tomb: there were more than twenty of these decorated projectiles made of wood or ivory among the other treasures of the young pharaoh. Experiments with replicas have shown that some of these throwing sticks had returning capability (Thomas 1991).

Two returning throwing sticks found at Elbschottern near Magdebourg (Evers 1994) in Germany and at Velsen in the Netherlands are dated respectively from 800-400 BC and 300 BC and are the only known examples from the Iron Age (Hess 1975). (See Figure 1)

Throwing sticks in ancient texts: The cateia from Virgile and Isidore

The 'cateia' is a throwing weapon quoted by ancient authors in the Eneide of Virgile (*Enéide*, VII, 740 and III, 274), Silius Italicus (*Les Guerres puniques*, III, 274) and Valérius Flacus (*Argonautiques*, VI, 83). Ferguson is the first to recognise a boomerang like weapon in these texts and he made the relation with this Latin name (Ferguson 1838). In these texts the cateia is designed by lexical terms compatible with a throwing stick in a warlike context. This particular term is associated with 'torqueo', a verb that means 'throwing an object in rotation' and with the adjective 'pandus' which means 'curved'. Finally, in his *Etymologies* written during the VII century, Isidore de Séville quotes the cateia as a "Gaulish throwing weapon with some returning capability". In a synthesis of information extracted from these ancient texts, Salomon Reinach is describing this object as a short heavy blunt weapon with a wooden flexible handhold (Reinach et al. 1894, p. 192). Servius (ad Aen, VII, 741) also mentions that the cateia has a maximum length of 1.5 cubit (65-80 cm) to aid maneuverability and that it is thrown very short distances because of its weight, sometimes returning to the thrower.

Another proposal for interpretation of the term 'cateia' is as a throwing axe or javelin. This has proven to be incorrect and has been confused with another javelin like weapon named 'aclys'. The term 'cateia' was probably used at the same time, in a confusing manner similar to the confusion caused between the European and Australian uses of the word 'boomerang'. Indeed, in these texts, several different categories of throwing stick are described in apparent contradiction; sometimes as a heavy war version and other times as a light, returning version. But more importantly this Latin term conveys the fact that throwing sticks were in use during the second Iron Age in Europe and was included in Gaulish war outfit, and that this kind of projectile was enough importantly used to be quoted by several ancient authors.

General Description of the artefact

The stick looks like a curved piece of wood with a 54 cm wingspan and 1 cm thickness. The wood analysis shows it was crafted as a whole from a single branch of an apple tree (Pomoideae sp). The Urville Nacqueville stick was carefully crafted and polished to erase any woodworking traces. Three centred narrow parallel grooves have been carved along both surfaces of the artefact. Five iron strips have been fixed around the extremities, elbow and mid part of each blade. Each of these iron strips overlaps and is fixed with a small nail. At time of discovery, one of these strips had been lost from one blade, but a nail hole attested to its presence. (See Figure 2 and 3)

Detailed features of the artefact

The listed detailed characteristics of the artefact could be found in appendix. The measurement, evaluation and database referencing of these parameters had been developed in a previous work (Bordes 2014). (See Figure 4)

Blades

The actual object width is maximum at the elbow at 5.3 cm. Taking into account the wrench of wood visible on the interior edge of the elbow, the width could have been closer to 5.6 cm to begin with.

The width decreases from the elbow to the extremity of the left blade until 3.8 cm. The same thing is true for the right blade which an extremity width of 4.2 cm. However, 10 cm from the right blade extremity, a sudden shrinkage was probably caused by an impact on this exterior edge. It seems that this part had been reformed to be used as a handle. This reformed handhold helps us to determine the laterality of this object, considering the orientation of the dihedral angle deformation on both blades. Indeed, if this object was used as a throwing stick type projectile these dihedral angles were related to the upper face (extrados) to allow stable flight.

Considering this orientation reference, we will refer to the right blade as the 'attacking blade' and the left blade as the 'following blade'.

Section

The section of the object is symmetrical between the lower face (intrados) and the upper face (extrados), though it varies between a rounded rectangular shape for the left blade, to a biconvex shape for the right blade so the section has been described as a mixed type. The consequence of this difference of blade section is that the biconvex attacking blade is slightly lighter and takes more aerodynamic lift than the left blade with a rectangular rounded airfoil, equivalent to a gravity centre shift. This effect amplifies the different aerodynamics applied between the two blades by the curvature angle (Bordes 2011) and contributes to the aerodynamic lift to give the projectile a curved trajectory like boomerangs. Mixed sections are often encountered among throwing sticks around the world. (See Figure 5)

Dihedral angle deformation

Two highly accentuated dihedral angles create a space of 1.5-2 cm between the blade extremities and the elbow plane. These dihedral angle symmetrical deformations start around 13 cm from the blades' ends and are not the consequence of the artefact's burial. These deformations could not come from a withering process during a neglecting state in the trench at Gaulish time because the object had been buried quickly which explains its excellent conservation. It is relevant to notice that these dihedral angle deformations are localised on the blade at the same position as the iron strips. Consequently we can deduce that they are probably due to metal oxidation in a wet environment, which increases the volume of metal strip, and locally pinch the wood section to induce these deformations. We can deduce that these dihedral angles could have been less accentuated in the past and closer to those we could observe generally on throwing sticks, with some dihedral angles showing gaps smaller than one centimetre. This hypothesis had been confirmed by experimentation.

Height/Wingspan ratio

The height to wingspan ratio is a good indicator of the stability of a throwing stick against the risk of flipping in flight. The closer this value is to 1, the more stable the projectile. If the value is below 0.2, this risk of instability in flight is greatly increased. This ratio measured on the Urville Nacqueville stick is 0.33, which results in a pretty stable projectile in rotation.

Grooves

Three centred longitudinal grooves had been engraved on each side of the artefact with a chisel. They are 1 mm wide and deep and have a space of 1 mm between them. The central groove is slightly deeper. These grooves are only decorative in function.

Extremities

The artefact is made of a single wood branch. The extremity is truncated with rounded angles that are worked and well finished. We can deduce that the object is whole and is not part of a larger broken wooden artefact.

Nail hole of the lost iron strip

A nail hole had been observed on the intrados of the attacking blade. The position of this nail hole is comparable to the fixed position of the iron strip on the other blade. (See Figure 6)

Iron strips

We could observe four oxidised iron strips positioned on the elbow at each extremity and after the middle of the following blade (left blade). These iron strips are meanwhile 2.5 cm wide and around 0.5 mm in thickness and are fixed by small iron nails. A lost fifth iron strip was positioned just after the middle of the attacking blade. Its previous presence is confirmed by the deformation of this blade at this position compared to the other strip fixed on the following blade, and a nail hole had been left by its fixation.

Additionally, to set the corresponding iron strip, the elbow had been reworked to carve a notch that cut into the decorative grooves while the others strips are simply fixed over them. This means that these strips hadn't been fixed on the object all at same time but at different times during the lifespan of the artefact.

Indeed, with the observation of the strip fixing and loss it is possible to distinguish the following steps:

Initial form of the object without any iron strip, decorated with set of grooves without dihedral angle deformations (step 1)

Second step after the fixing of the central elbow iron strip, without dihedral angle deformations (step 2)

The fact that the elbow strip had been fixed in a reworked notch that cut the grooves show this fixing was a repair and was not planned at the beginning on this artefact. Indeed, the elbow is the fragile zone of throwing sticks and breakage very often happens there. The trace of impact and wrenching located inside the elbow reinforce this interpretation (see impact traces).

Third step with five iron strips with increasing dihedral angle deformations (step 3)

To prevent future breakage, the object is reinforced by four others iron strips fixed directly around the blades on the grooves; two at each extremity and two others after the middle of each blade, 13 cm away from extremities. These iron strips are probably reinforcement to prevent breakage, without playing any decorative role because iron material is rarely used for decorative purposes in Gaulish times.

After that the object undergoes some deformation of the blade probably due to humidity and iron oxidation. This phenomenon starts to create two important dihedral angles on each blade. The same upward orientation of these symmetrical angles could indicate that the object was laid on a flat surface during this period. The artefact is probably also underused during this time.

A fourth step with only four iron strips with full dihedral angle deformation (step 4)

Later, the object could have been used once more as a projectile and endured damage which explains the loss of an iron strip on the right (attacking) blade.

Finally, at this step, the artefact is deposited in the trench. The process of oxidation goes on to contribute to the state of the recovered archaeological object.

Impact traces

Careful observation of the Urville Nacqueville object surface reveal some small wood wrenching on the edges which could correspond with some impact damage on this artefact; consequences of its usage as a projectile on ground or against obstacles. (See Figure 7a and 7b)

Apart from the wrenching at n°1 and n°9, the damages around oxidised iron strip hadn't been taken into consideration. Indeed, these wrenching could have been the result of oxidised iron fragments flaking from the strip with wood splinters attached. However, it is important to take note of the broken corner at n°1. The wrenching at n°9 is related to important damage at the elbow which lead to the first central elbow iron strip repair. The wrenching at n°2 seems to have been repaired and the edge reworked decreasing the width of the blade and making a better handle. This major wrenching damage is probably the cause of the loss of the fifth strip.

Smaller wrench damage at n°3 to n°7 is mainly localised on the outer curvature and the supposed attacking edge[5] and could be compared to impact observed on ethnological models of throwing sticks (See Figure 7). Consequently, these impact traces could confirm the way of rotation of the object used as a projectile as well as the awarding of the holding blade. The wood wrenching at n°8 located on the inner curvature and also on the attacking edge of the following blade reinforces the hypothesis that the artefact was used as a projectile. (See Figure 8)

Mass evaluation and mass on surface ratio

A mass evaluation had been done with the accurate drawing of the artefact. If we take into account the fact that the mean airfoil shaping is 16% less in surface compared to a rectangular section, we found a 210 cm^3 volume estimation. Calculating the mass with a mean density for apple tree wood of between 0.657 g/cm^3 and 0.833 g/cm3, we found a mass ranging from 138 g to 175 g for the object without any iron strip (step 1).

Evaluation of iron strip mass

Even if the iron strips are not all identical, the estimation can be calculated by taking a mean width of 2.5 cm and circumference of the blade section. It gives a ballast of 8.5 g per strip using the iron density (7.8) and a mean strip thickness of 0.5 mm. If we suppose all iron strips almost identical, it gives finally a range of 172-209 g object with four strips and a range of 180 - 217 g with five iron strips.

Mass to surface ratio is an important parameter for throwing stick flight. A low mass to surface ratio throwing stick will undergo more aerodynamic lift and if this force is stronger than its weight, it will follow a curved trajectory. Conversely, a throwing stick with a higher mass to surface ratio will have a weight greater than aerodynamic lift force and will follow a straight line trajectory. For the function of an experimental database it was possible to establish a mass to surface limit ratio which could separate different throwing stick classes related to these parameters (Bordes, 2009). For example, the very light throwing stick class corresponds with boomerang like projectiles, having a usual returning trajectory ratio under 0.7 g/cm2. Over this value, another throwing stick class with a ratio between 0.7 and 0.9 g/cm2 has a curved but not strictly returning trajectory.

For the Urville Nacqueville artefact, the calculated mass on surface ratio without iron strips is between 0.55 to 0.7 g/cm2 and 0.69 to 1.03 g/cm2 depending of the number of strips (1-5).

Incidence tuning

No incidence torsion was observed on the archaeological object, but in absence of an accurate plot of this parameter after the discovery, flight experimentation showed that slight incidence torsion tuning could have existed on the artefact Consequently, these impact traces could confirm the way of rotation of the object that allow us to assign it to a right handed throwing stick.

Useful Archaeological and ethnological comparisons

Two archaeological throwing sticks found in Europe could shed light on the Urville Nacqueville stick. First is the boomerang-like throwing stick found in Velsen (The Netherlands) (Hess, 1975), which is a returning projectile. The Velsen boomerang-like projectile belonging to the middle Iron Age period (300 BC) and was discovered less than 600 km away from Urville Nacqueville. (See Figure 9)

The Velsen throwing stick has a 39 cm wingspan giving a 0.35 height to wingspan ratio. Its mean width is 3.5 cm. Its thickness varies from 6 mm from the extremity to 8 mm at the elbow. Its mass is 72 g and its mass to surface ratio was calculated as 0.47g/cm². This object is made of oak tree wood, which is a favourable wood for crafting light throwing sticks and boomerangs. Its shape, rounded with constant width and truncated ends, is similar to the Urville Nacqueville stick. However, its height to wingspan ratio is a bit higher and it is a lighter and finer object compared to the Urville Nacqueville example. Its characteristics therefore belong to the ‘very light throwing stick’ class **(**mass/surface ratio < 0.7 g/cm²) and its conserved positive incidence attacking blade tuning confirms its returning capability and its right-handed laterality.

The second is the Magdebourg returning throwing stick, found at Elbschottern near Magdebourg in Germany, and is another archaeological discovery similar to our studied object. This throwing stick belongs to an older period with a date ranging from 800 to 400 BC. The wood used is ash. Its better-conserved blade has a 22.7 cm length, its thickness is between 0.7 and 1 cm and its width ranges from 7.35 at the elbow to 4.25 - 4.4 cm at the extremity of the blades. Its rendered wingspan is 37 cm giving a height to wingspan ratio of 0.67. From its drawing, it's possible to calculate a surface area of 182.6 cm² and make an estimation that its weight is between 76 and 109 g considering the mean density of ash wood. Finally it's possible to obtain a mass to surface ratio ranging from 0.4 to 0.6 g/cm2 which shows that this projectile belongings to the ‘very light throwing stick’ class and, we predict, has returning capabilities as a boomerang like object.

Indeed, experimentations conducted on the replica showed a returning trajectory and left handed laterality.

Compared with the Urville Nacqueville stick it is a smaller and lighter object. Similar to Australian Aboriginal boomerangs the Magdebourg throwing stick has a widened elbow though the Urville stick has a constant width. Its rectangular airfoil is close to that of our object of study although it has a slightly different attacking blade airfoil with a concave intrados. This feature aims to dramatically increase aerodynamic lift on the attacking blade to accentuate the returning trajectory. This mixed type airfoil is commonly encountered on throwing sticks in Australia and also exists on the Urville Nacqueville artefact. (See Figure 10)

Ethnological comparisons are also rich in information for our study. Indeed, the Urville Nacqueville artefact has common features with the famous American pueblos throwing sticks (Heizer 1942). These specialised throwing sticks were used in rabbit hunting and often have a curved shape, truncated end and rectangular airfoil, but could have an elaborate carved holding. Nevertheless, these rabbit sticks are designed for ground hunting and are generally thicker, larger, and heavier than the Urville Nacqueville stick. This comparison suggests that the Urville Nacqueville artefact would be too fragile for ground game and be more suited to bird hunting.

But the more striking common point between our artefact and South west American throwing sticks is the presence of centered grooves, also appearing in sets of three or four, frequently encountered on the Anazasi Throwing stick which precedes pueblos rabbit sticks (SeeFigure 11).

Indeed, throwing sticks in south west America originate from an ancient central American tradition and were used by Mayan people as fighting sticks and to deflect incoming enemy darts (Heizer 1942). They frequently show a centered set of grooves on both faces similar to those observed on the Urville Nacqueville artefact. These sets of grooves are regularly interrupted by several gaps allowing binding of the stick by sinew or vegetal fibre cord. This system of throwing stick reinforcement could have been used also on the Gaulish artefact, but using iron material, which was the more common new material for Iron Age period. (See Figure 12)

Another ethnological comparison about reinforcement and repair are iron strips used for valari Tamil throwing sticks which could shed light on this particular use of metal on the Urville Nacqueville stick. Indeed, iron strips are used for south Indian throwing sticks called ‘valari’ dating from nineteenth and twentieth century, used for hunting and war. Additionally, valari bonded with iron strips are sometimes no longer thrown, but play a ritual and symbolic role in the temple or are exchanged during weddings.

Some of these throwing sticks have a type of wide iron strip carefully fixed on the extremity of their short following blade, and have around 2.5 cm width close to our Gaulish artefact strips, but are thicker (around 1 mm). This type of strip is planned in the design of the throwing stick, being set in carefully carved notches and welded. (See Figure 13a and 13b)

Another type of iron strip on valari Indian throwing sticks is the repair strip. Some valari show narrower iron strips, with a width of around 8-9 mm and 0.5-1 mm thickness fixed by a small iron ring on the edge, mainly for repair. Indeed, valari with this type of strip are always damaged or have wood splitting. (See Figure 14a and 14b)

A last ethnological comparison could be made between the dimensions and airfoil shaping of our studied archaeological object and light throwing sticks and boomerangs from the Lake Alexandrina region of South Australia. In this region curved light throwing sticks and boomerangs for bird hunting, which have a biconvex airfoil, thickness between 6 and 10 cm, wingspan ranging around 50 cm and truncated blade ends, have been discovered. Their only distinct feature is a widened elbow for more resistance. This point allows us to better understand why the main default of the Urville Nacqueville Gaulish artefact is lacking a widened elbow and why it needed to be repaired by a iron strip in a reworked notch after a breakage. These common feature shared with Aboriginal light bird hunting sticks allow us to favor the bird hunting use if we identify our Gaulish artefact as a throwing stick-like projectile. (See Figure 15)

Arguments for the throwing stick hypothesis

Here is a summary of arguments reinforcing the hypothesis that identifies the Urville Nacqueville Gaulish artefact as a throwing stick.

Its dimensions are compatible with those of a throwing stick

As we see above, if we compare its wingspan, thickness and width with those of ethnological throwing stick examples such as Aboriginal Australian ones, its dimensions fit with the mean values encountered for these projectiles.

A rectangular cross section on the following blade is commonly encountered on American rabbit sticks and the biconvex attacking blade section is the most common airfoil used for throwing sticks around the world. Among Aboriginal Australian throwing sticks, mixed types of airfoil on each blade of the same projectile are frequently observed.

Stable in flight

Its height to wingspan ratio of 0.26 shows that it is a stable projectile in flight without risk of flipping.

Type of wood

The wood used is compatible with and favourable for light throwing stick and boomerang crafting. Apple wood as a medium density and resistant wood is still used today to craft modern boomerangs. Medium density and resistant woods are also used around the world for light throwing sticks such as rabbit sticks of oak wood made by Pueblo Indians in Arizona or Casuarina wood in South Australia.

Sets of grooves are common on throwing sticks

Several types of throwing sticks are partially or totally covered by grooves like the kylie grooved throwing stick crafted in arid central Australia or Anasazi throwing stick in south west America.

Reworked notch and strip fixing strip is used for throwing sticks

Repairs by binding with sinew or vegetal cord strips after carving a notch is commonly encountered among Aboriginal traditional throwing sticks and boomerangs. Anasazi throwing sticks are reinforced by vegetal or sinew strip too, and in a similar pattern by interrupting centred sets of grooves.

Iron strips are found on certain types of throwing sticks for reinforcement and repair

South Indian valari throwing sticks display this feature, as well as some archaeological Egyptian prestige throwing sticks similar to those of the collection found in Tutankhamun’s tomb displaying a gold covering (Thomas et al. 1991). Dimensions and thickness of iron strips found on the Urville Nacqueville Gaulish artefact are comparable to those observed on Indian valari.

Use of such reinforcement and repair on throwing sticks enhances their prestige and could change their primary projectile function to a more symbolic role in ritual and social cultural events.

Experimental replica crafting and throwing

The replica crafting with traditional or even prehistoric hand tools is a deliberate choice aiming to evaluate an object produced by very simple crafting ways and remain aware of the resulting crafting defaults on the throwing stick obtained, that could drastically affect its aerodynamics. Indeed, this information could be missed by using a modern crafting method leading to a more ’perfect’ result.

Indeed, a drawback of the hand crafting method is that it does not lead to an exact replica of the archaeological object (If such a thing exists!), but has the advantage of leaving on the wood surface natural irregularities which are a factor in slowing rotation in flight that could be underestimated with a more perfect surface created by modern crafting (replica in resin for example). Differences between a replica and the archaeological object had been offset by creation of three replicas (A, B, and C) to flank the archaeological artefact characteristics. In this approach, differences are turned in advantage because they are discussed and help to gain a better understanding of the use of the object studied.

Making of the replica A

A first replica was made by Luc Bordes using a plain curved branch of apple wood. The coarse shaping was done with a hand cutting tool (machete) followed by a shaping stage with a flint scraper block. The finishing and polishing stages were undertaken with hand-held sandstone. Grooves were done with a steel chisel without hammer. Dihedral angle deformation was produced by steam and dry heating. This replica, created from an early drawing of the archaeological object, was slightly thinner and lighter than the archaeological artefact. Summary of replica A characteristics can be found in appendix. (See Figure 16a and b)

Flight experimentation without strip (step 1)

The throwing experimentations were done trying with both successive orientations of the object, dihedral deformation extremities pointing upward or downward. The replicated projectile was thrown in different directions relative to the wind.

Extrados/intrados orientation: Orientation of the dihedral deformation

Throwing the object vertically with dihedral angle deformation pointing downward leads to an uncontrollable trajectory turning right at the end because of the gyroscopic precession effect. Throwing it horizontally leads to a straighter trajectory but is difficult to master and subject to flight instability.

As assumed, the trajectory obtained with dihedral angles pointing upward is far more stable, but because of the rotation, the small wingspan and the light weight of the object, the flight is not straight, but rather S-shaped. Nevertheless, this first set of throwing experimentations show that the extrados could be assigned to the side to which dihedral deformations are pointing.

Determining throwing inclination

With this extrados/intrados orientation, different throwing inclinations had been tested from a nearly vertical throwing (typical throwing for boomerangs) to a more horizontal throwing (typical throwing inclination for heavy throwing sticks) passing by different intermediary inclinations of approximately 45°.

Throwing near a horizontal plane worsened the S-shaped trajectory, which renders it even more inaccurate and useless. This result could be planned, as symmetrical light throwing sticks acquire quick rotation and a strong gyroscopic effect that turns the rotation plane inducing a systematic right curved end of trajectory for a right handed projectile (Thomas 1985).

The best trajectory was found for a medium inclination around 45° which delay the gyroscopic rotation plane turning effect and lead to a straighter trajectory, but the object still flies too low and with low accuracy.

Determining projectile twisting, tuning and enhancing its flight by positive incidence tuning on attacking blade

Twisting tuning for throwing sticks and boomerangs is critical. Apart the main positive dihedral deformation, no incidence twisting was noted on the archaeological object. Indeed, they could be altered and difficult to observe on a two thousand year old artefact. This parameter was not measured accurately at the time of discovery, so this allows the proposal of a hypothesis about incidence tuning existence on the Urville Nacqueville stick by experimentation.

The Urville Nacqueville artefact is close to a light throwing stick and Aboriginal boomerang by its mass to surface ratio, which led to similar tuning for its experimentation. For example, positive incidence tuning on the attacking blade is frequently used for Australian Aboriginal boomerangs and the light throwing stick category (Bordes 2011).

Additionally, considering the object thickness, size and weight, it would be not adapted to ground hunting because impacts with the ground and with obstacles would break it. Used as a hunting stick, it would be likely have been used as a bird hunting stick.

The trajectory obtained by using a slight positive incidence tuning, done by heating, are far much satisfactory, showing more diving and distance with a more stable flight in a slight curve (See Figure 17).

The trajectory could be kept low with a vertical throwing allowing people to aim at birds when they take off, or in a higher climbing route by leaning the object at 45°. The end of trajectory initiates a slight return if the object is thrown with a lot of rotation energy, more or less marked, depending of the relative wind.

The maximum distance observed is 35 m for climbing a high trajectory and a reach 45 m for a low trajectory (See Figure 17).

Even if this object does not show a true returning capacity, the observation of the initiation of this effect at the end of its trajectory allows the throwing stick not to get lost and to sweep a larger aimed zone increasing its chance of hitting a fowl.

Another main point is that this flight allows the throwing stick to lean horizontally at the end of its trajectory and fall parallel to the ground with less chance of being broken, which is the main risk of others type of trajectories tested before (without tuning or with a strict vertical throwing). (See Figure 17)

A curving trajectory in standard conditions with a low relative wind happens too far from the thrower to get a chance of a complete return. Indeed, it seems that returning completely wasn't the aim of this throwing stick because along its stages, the artefact had been weighted with an increasing number of iron strip ballasts, decreasing progressively its chance of experiencing a returning flight.

Experiments with addition of ballast equal to iron strip, with presence of both dihedral positive deformations

To make the ballast, 1 mm thick lead was fixed with adhesive tape. This way of temporary fixing was preferable for the throwing experiments, to allow setting and removal as required. Three tests were done with one, four, or five lead ballasts of eight grams each.

With a single eight gram ballast at the elbow, the projectile’s trajectory was a little shortened and higher. This effect is predictable and frequently observed on modern boomerangs weighted at the elbow (the gravity centre is shifted toward the elbow). In this way, the artefact in the second state increases its stability and climbing capability and remains very efficient for bird hunting (trajectory type 3).

With four eight gram lead ballasts, the distance was increased by ten meters, to a maximum between 45 and 55 m. The thickness increase at the strip position tended to slow the projectile rotation, decreasing the aerodynamic lift and gyroscopic precession effect.

Adding three additional lead ballasts dramatically changes the object flight. The projectile does not generate enough aerodynamic lift to counter balance the increased mass, and the inaccurate trajectory is straight and low, describing an S figure because of the clockwise rotating plane due to the gyroscopic effect (trajectory type 1).

Experiments with addition of ballast equal to iron strip, without dihedral positive deformations

If we restart the same kind of experiment with little or no dihedral positive deformations, it possible to throw the replica with full five lead ballast with a better trajectory (trajectory type 2). Indeed without dihedral positive deformations that slow the rotation movement, the projectile recovers faster rotation and superior aerodynamic lift leading to a more stable slightly curved trajectory. (See Figure 18)

Making of Second (B) and third (C) replicas after direct archaeological artefact examination

Two others replicas had been made to flank the archaeological artefact characteristics, specifically thickness and mass. They were made on the same day with slightly different crafting techniques by Luc Bordes and François Blondel. Replica B has been crafted with cabinetwork techniques (wood chisel, file and sandpaper) from a curved plank extracted from the core of an apple tree branch. This replica moves away from the archaeological artefact due to its airfoil, which tended to be flatter on the intrados (almost flat convex airfoil).

Replica C has been made by more simple manual techniques (machete, flint scraping hand tools and grinding stone) from a curved plank extract from the core of an apple tree branch. It has a wingspan little shorter than the original. Central grooved lines have not been included on this replica.

Tests with addition of ballast equivalent to the iron strips, with dihedral positive deformations

For these tests, replica B has been equipped with four eight gram lead ballasts fixed with adhesive tape to simulate the fourth state of the artefact. Replica C is equipped with four steel strips of identical mass to simulate the same state.

These replicas, whose mass was closer to the original artefact, have been thrown the same way as replica A, in the same conditions of wind and under different wind directions. Trajectories obtained are almost straight, low or driven down to the ground, following inaccurate flight in an S-shape (trajectory type 1, Figure 17). In these conditions, replica B's S shaped flights were worst, probably because of its slightly different airfoil and its slightly superior wingspan compared to replica C, decreasing even more its aerodynamic lift and rotation.

The steel strip located at the extremity of replica C's attacking blade appears to make the object uncomfortable to hold, sometimes doing harm (a little cut on the finger), because at the opposite of the central strip set in a notch at the elbow, the mid blade and strips on the extremity are set on the surface of the artefact and are therefore prominent from it.

Another set of tests was tried with all ballasts removed from replica B to simulate the first state of the archaeological object, keeping the incidence tuning neutral. The same useless trajectories were observed.

A third set of tests was attempted on the same replica changing the incidence tuning to positive on the attacking blade as done for replica A. The flight obtained was far improved, being stable and accurate. The object kept its rotation until the end of its trajectory and lay down flat, without risk of breaking. On the other hand, the curvature of the flight is less accentuated or is absent compared to the tests done with the replica A.

Experimentation with replica without dihedral positive deformations

The main observation about Replica B and C is that they do not reach enough rotation speed for efficient flight. This is because of their dihedral positive deformations and increased thickness. Indeed these dihedral positive deformations that were less critical on Replica A tend to have more accentuated negative influence on the flight of thicker replica B and C.

This remark lead us to wonder if these accentuated dihedral positive deformations would have really existed on the functional Gaulish object as a throwing stick and try a last set of tests, removing all dihedral tuning on replica B and C similar to what we did with replica A.

The results are very convincing: replica B and C recover a very correct flight, with a slightly climbing and curved trajectory end. It could be noted that the Replica B flies with less climb and increased range compared with replica C.

In conclusion, it can be said that the three different replicas, even though they do not have an identical flight, show the same general flight behaviour. (See Figure19)

Restitution of the Urville Nacqueville artefact use as a throwing stick

To get an insight of the use of this artefact as a throwing stick, we need to take in consideration all its characteristic and experimental tests results:

Without iron strip, the artefact mass to surface ratio is between 0.52 and 0.66 g/cm^2, which categorises it in the very light throwing stick class ($M/S<0.7$ g/cm2)(Bordes et al. 2014). This is the group where boomerangs type projectiles are found. This means that in the archaeological state one and two, it is not surprising to obtain from the replica a curved trajectory with a proper incidence tuning on the attacking blade.

On the other hand, adding five iron strips brings the ratio of mass/surface to between 0.66 and 0.8 g/cm^2, which changes its classification to light throwing stick category ($0.7<M/S<0.9$ g/cm^2) with no potential of complete return. Indeed, the limit of these two categories is fixed around the value of 0.7 g/cm^2 in my personal experimentations. I observed that it is very difficult to craft and tune returning projectiles in raw wood with traditional crafting techniques with mass to surface ratio over 0.7 g/cm2. In the state three, the object is obviously a projectile with a straight trajectory or following a slight S-shape but with no accentuated curve, its mass winning over its aerodynamic lift in standard relative wind conditions (light breeze of 10-20 km/h).

The low shaped rectangular or biconvex airfoil of the artefact bring less aerodynamic lift than a true plane convex airfoil encountered frequently on the boomerang type projectiles. This confirms that this artefact had been crafted more like a light throwing stick than a playing object designed to return to its thrower, as experimental tests have shown.

Considering the artefact’s mean thickness (between 9 and 10 mm) its reduced dimensions and the medium density of its wood, this projectile would not be very efficient on ground targets and would break easily. This consideration allows us to infer that it has been made to travel by aerial trajectories probably to hit only fowl as a weapon specialised in bird hunting. However two different trajectories are possible; a low flight aiming to intercept birds on take off or a higher flight to hit a flock of flying birds.

Indeed, one of the main advantages of a throwing stick is the potential to bring down several fowl by a single throw, as one impact on a target will not stop the projectile rotation, the throwing stick will go around and hit other targets without too much loss of energy.

The strips, especially the central elbow strip, testify the archaeological artefact had several different states. Their presence shows that the artefact needed reinforcement and has been probably exposed to important strains and shocks.

Another thing to take into account is the additional mass of these strips simulated by the ballast added to experimental replicas tends to increase the range of the artefact used as a projectile. This increasing mass, along the different stages of the artefact’s life, confirm that these modifications were aimed for throwing stick use, designed to hit targets rather than a gaming toy use, modified to accentuate its curved trajectory, like the famous boomerangs.

Nevertheless, this light throwing stick—as it could be classified in its original state without iron strips, or in its second state, with the unique central elbow iron strip, in the very light throwing stick group, close to the precursor of the boomerang. This category of projectiles are capable of accentuated curved flight in strong wind which means that the gaming use of this Gaulish artefact couldn't be totally excluded and may have existed aside the hunting main use.

In the third state, the artefact become less functional as a projectile after the adding of iron strips at both mid blades and blade ends over the decorative grooves. These four strips have been added as reinforcement. Indeed iron material is seldom used as decorative purpose in Gaulish times.

These new iron strips have weighted the artefact so that it was probably no longer used for real hunting, but more likely kept as a prestige item. Iron strips at the blade ends also render the object less comfortable to hold for throwing. Additionally, these final strips are not fixed inside notches that render them a little more prominent from the surface, and they therefore accentuate the rotation braking and make holding the stick uncomfortable.

States four and five with loss of one iron strip and repair shows the difficulty encountered by the Gaulish users with this additional strip weight which lowers the flight towards the ground increasing the risk of breaking the artefact which is not designed to be resistant against solid obstacles. This loss of function as a projectile could have been the reason of its deposition as a votive item in the trench where it was discovered.

Conclusions

The Urville Nacqueville throwing stick reinforced with iron strips is unique in Europe for the second Iron Age period. Its different states reflect the transition between an often used hunting projectile to a prestige item assuming a more symbolic function, increasing its archaeological value.

This throwing stick was probably used as a bird hunting stick and gives evidence of an ancient tradition of making and using light hunting sticks in the north of Europe. This tradition seems to have perpetuated from the first Iron Age. This discovery indicates the great continuity of throwing stick usage in Europe from the Palaeolithic, as evidenced by the ivory throwing stick found at Oblazowa (Walde-Nowac 2000), through the Mesolithic period with wood-like artefacts found in north of Russia, until the Neolithic with the Egolzwil throwing stick found in Switzerland (Ramseyer 2000). Despite of more modern and efficient weapons for hunting, like bows, people continue to use throwing sticks as a reliable weapon for hunting during the Iron Age, and in the Gaulish period, enhancing this primitive projectile by using metal on it.

This hunting weapon was especially adapted to swamp and coastal areas rich with fowl, as showed by the discovery of the Elbchottern boomerang like object along the river Elbe (Evers 1994) and the Velsen boomerang like object (Hess 1975) found on a coastal site in the Netherlands. The Urville Nacqueville throwing stick was also found in a swamp and coastal area, which is a favourable environment for using these weapons for bird hunting considering they often live in large numbers in such environments. This is confirmed by numerous bird remains found in Gaulish layers on the Urville Nacqueville archaeological site.

If we take into account archaeological excavation data from the site of Urville Nacqueville, people were living there around 80 BC in a flourishing town, evidenced by the discovery of several gold coins, which was commercially connected by channel boat crossing to the Dorset region in the British Isles. Moreover, because of the animal bones found in archaeological excavation including many bird remains, we know that hunting activity was practiced on this site and that during the second Iron Age, hunting activity was reserved to the Gaulish elite.

Bird hunting sticks were already obsolete as main weapons at the second Iron Age because these implements were no longer primary hunting weapons since possibly the Neolithic period during which they seem to acquire new symbolic functions. Even so, this discovery shows that its usage has been perpetuated until Gaulish times with increasing symbolic value. Were throwing sticks used at this time like in Ancient Egypt for bird hunting by noble Egyptians in the Nile delta? The evidence collected during this study and experimental test converge toward this conclusion. This prestigious hunting conclusion could explain at the same time the fine crafting of the functional artefact and care for its repair, followed by its conservation as a culturally significant item which led to the votive deposit in the trench where it was found.

Finally, it seems that the north of Europe kept a living tradition of throwing sticks and boomerang use during the second Iron Age, but unlike the Australian continent where these implements were passed through the millennia by Aboriginal people, this tradition has since been forgotten... but now partially recovered!

Keywords weapon
(re)construction
throwing stick

Country France

Appendix

Archaeological artefact characteristics

Typology: Symmetric rounded shape, truncated ends, biconvex/rounded rectangular airfoil
Wingspan: 54 cm
Height: 15 cm
Mean thickness: 10 mm
Airfoil: biconvex/rounded rectangular
Surface: 250 cm^2
Volume : 210 cm^3
calculated mass without strip: 138 - 175 g
calculated mass with four strip: 172 - 209 g
calculated mass with five strip: 180 - 217 g
Mass with four iron strip after conservation treatment: 135 g
Wideness: 3.8 to 5.3 cm
Height/Wingspan: 0:27
Mass/surface ratio without strip: 0.55:0.7 g/cm^2

Mass/surface ratio with strip: 0.69:0.83 g/cm^2
Attacking blade airfoil: biconvex
Following blade airfoil: rounded rectangular
Attacking blade dihedral angle/Following blade dihedral angle +16/+18
Attacking blade incidence angle/Following blade incidence angle 0 / 0

Replica A characteristics

Typology: Symmetric rounded shape, truncated ends, rounded rectangular airfoil
Wingspan: 52 cm
Height: 15 cm
Mean thickness: 8 mm
Airfoil: rounded rectangular
Surface: 236 cm^2
Volume: 158 cm^3
Mass without strip: 135 g
Mass with four strip: 169 g
Wideness 5.3 cm
Height/Wingspan: 0:27
Mass/surface ratio without strip: 0.57 g/cm^2
Mass/surface ratio with four strip: 0.72 g/cm^2
Attacking blade airfoil: rounded rectangular
Following blade airfoil: rounded rectangular
Attacking blade dihedral angle/Following blade dihedral angle +16/+18
Attacking blade incidence angle/Following blade incidence angle 0 / 0

Replica B characteristics

Typology: Symmetric rounded shape, truncated ends, Quasi biconvex/rounded rectangular airfoil
Wingspan: 54 cm
Height: 15 cm
Mean thickness: 10 mm
Airfoil: rounded rectangular
Surface: 244 cm^2
Volume: 216 cm^3
Mass without strip: 165 g
mass with four strip: 199 g
Wideness 5.3 cm

Height/Wingspan: 0:27
Mass/surface ratio without strip: 0.68 g/cm^2
Mass/surface ratio with four strip: 0.83 g/cm^2
Attacking blade airfoil: rounded rectangular
Following blade airfoil: rounded rectangular
Attacking blade dihedral angle/Following blade dihedral angle +16/+18
Attacking blade incidence angle/Following blade incidence angle 0 / 0

Replica C characteristics

Typology: Symmetric rounded shape, truncated ends, Quasi biconvex/rounded rectangular airfoil
Wingspan: 52 cm
Height: 15 cm
Mean thickness: 10 mm
Airfoil: rounded rectangular
Surface: 248 cm^2
Volume : 208 cm^3
Mass without strip: 182 g
Mass with four strip: 199 g
Wideness 5.3 cm
Height/Wingspan: 0:27
Mass/surface ratio without strip: 0.68 g/cm^2
Mass/surface ratio with four strip: 0.73 g/cm^2
Attacking blade airfoil: rounded rectangular -biconvex
Following blade airfoil: rounded rectangular-biconvex
Attacking blade dihedral angle/Following blade dihedral angle +16/+18
Attacking blade incidence angle/Following blade incidence angle 0 / 0

Terminology

Throwing stick

This term is general here and is applied to a tool made of one or several pieces of wood, or less often to others of natural material that are set with an angle between 0 to 180 degrees.These wood pieces are called blades, are shaped, and this object is thrown with rotation in the air, in a rotating plane. Boomerangs are only a particular sub category and are very specialised throwing sticks with a returning trajectory.

Boomerang

My terminology in this article is to identify as boomerangs only objects that have a 180° turning trajectory. In fact many Aboriginal words (ex bargan, boomari) which have given later this artificial name 'boomerang' was originally attached only to the light returning type of implements. Later early colonists and Europeans, confused by the many kinds of sticks, assimilated non-returning heavy throwing sticks under this same appellation. This confusion of terms continues to this day. The classification of throwing sticks and boomerangs is a difficult issue to deal with, and is a subject far beyond the remit of this article.

Extrados/Intrados

The face of a throwing stick that is directed toward the ground or the outside of trajectory during its flight is called intrados or lower face.
The other face, the upper face that could be seen by the thrower is called extrados or upper face. The extrados is more often decorated.

Attacking blade

For two bladed throwing sticks, the two blades are not aerodynamically equivalent. The blade that needs to travel a greater angle before being at the same position of the other one is called the attacking blade. The other is called following blade. The attacking blade travels through a much greater angle of air behind the slipstream of the following blade and gets intrinsically more of aerodynamic lift, all other parameters being the same. This is the blade that is handled in common Australian aboriginal style of throwing, curvature facing the target, but could sometimes not be thrown that way.

Attacking edges

Edge of a pale going directly against the relative wind created by direction of throwing stick rotation. On the contrary of the trailing edge being in its slipstream

Incidence torsion

The incidence is defined by the angle between the table plane and the medium axel passing in the middle of the throwing stick airfoil measured in the blade moving direction (See Figure 20)

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Gallery Image

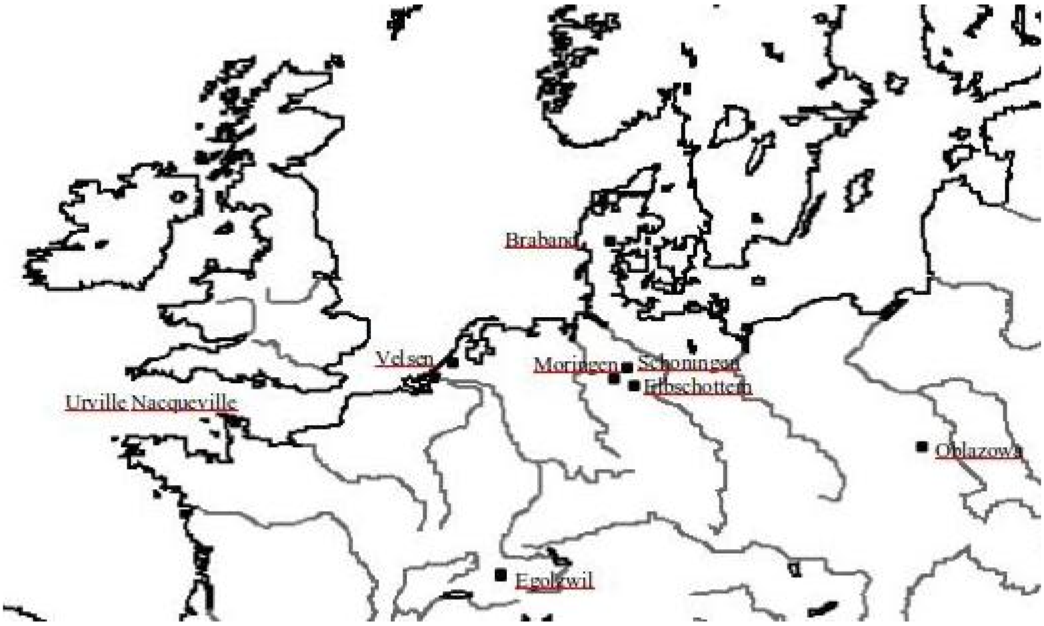

FIG 1. EUROPEAN MAP WITH THE LOCALIZATION OF ARCHAEOLOGICAL SITES WHERE THE DISCUSSED THROWING STICKS WERE DISCOVERED.

FIG 2. PICTURES OF THE ARTEFACT DISCOVERY ALONG THE ENCLOSURE TRENCH (FRANÇOIS BLONDEL)

FIG 3. PICTURES OF THE ARTEFACT DISCOVERY ALONG THE ENCLOSURE TRENCH (FRANÇOIS BLONDEL)

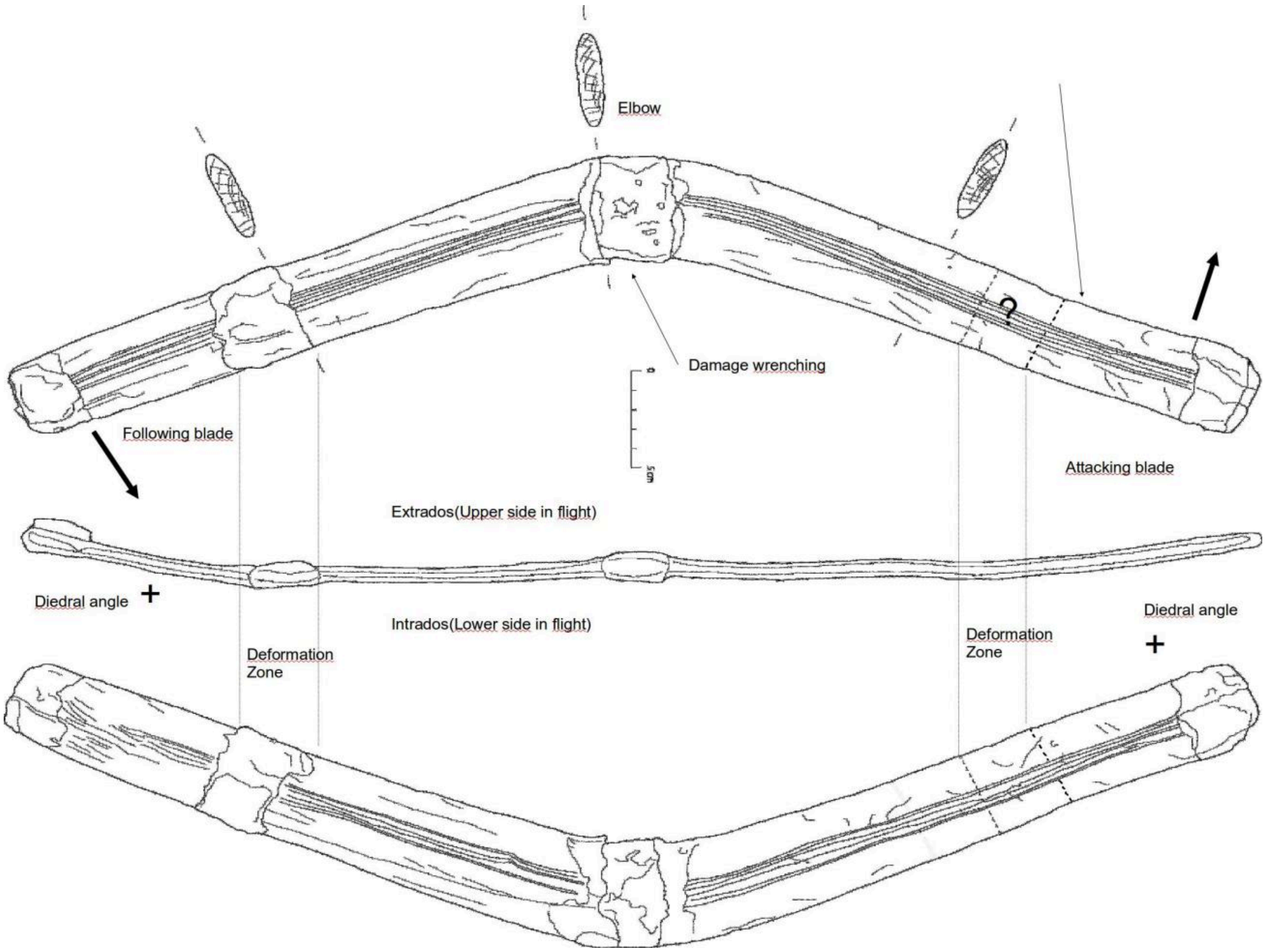

FIG 4. DRAWING AND INTERPRETATION OF THE URVILLE NACQUEVILLE STICK BY FRANÇOIS BLONDEL. WRENCH AND WIDTH REDUCTION OF THE RIGHT BLADE IS INTERPRETED AS A RIGHT HANDED HOLDING. ARROWS INDICATE THE ANTICLOCKWISE DIRECTION OF ROTATION.

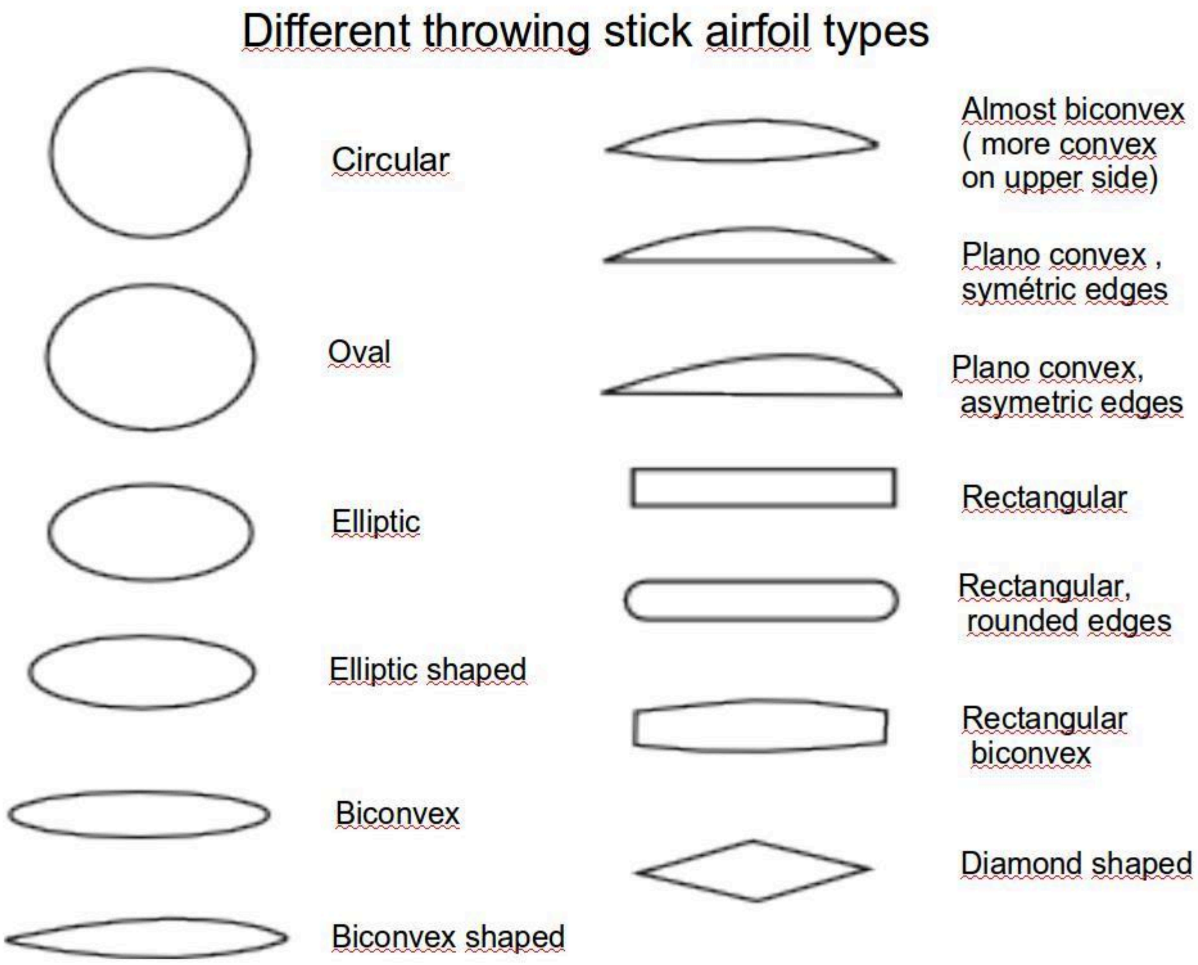

FIG 5. DIFFERENT SECTIONS ENCOUNTERED FOR THROWING STICK AND BOOMERANGS (LUC BORDES)

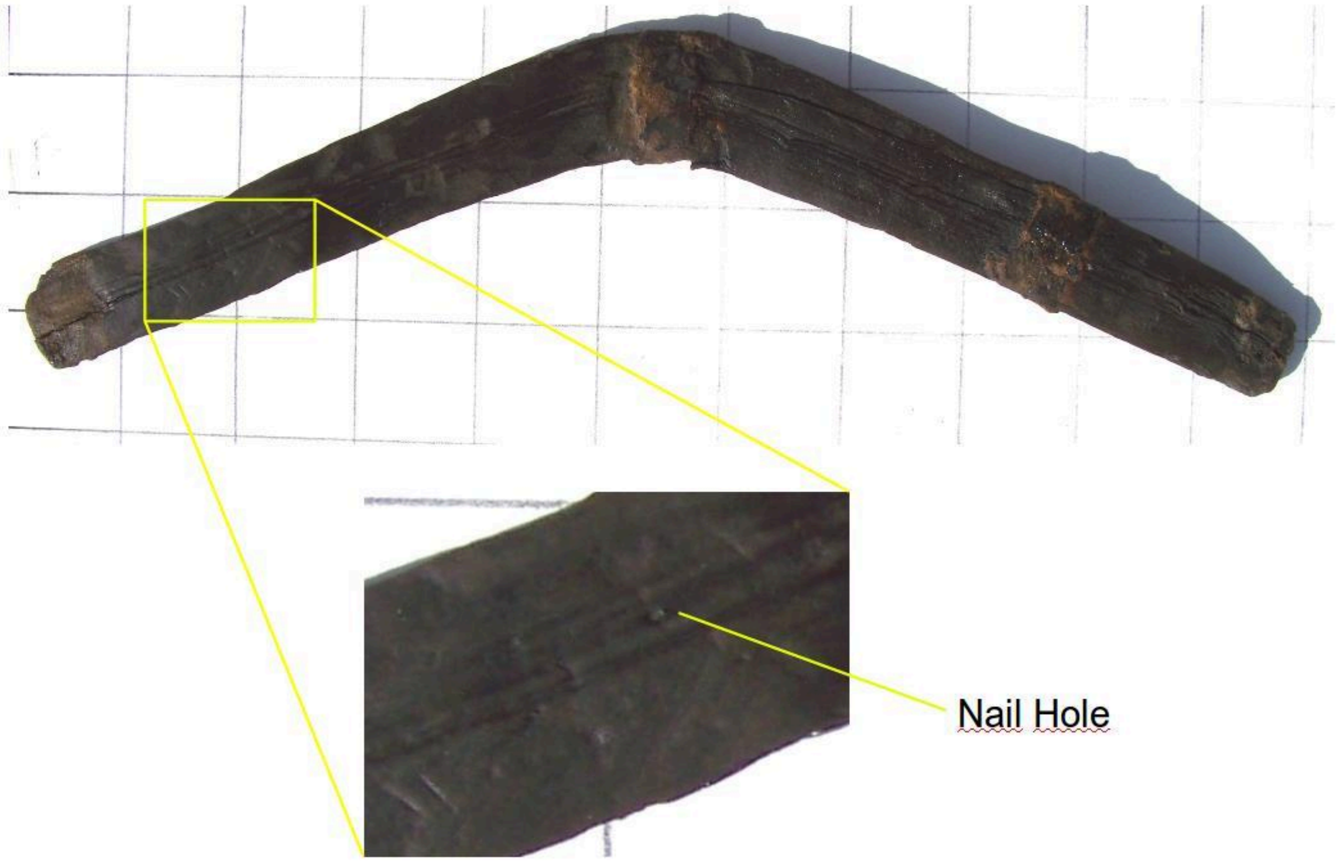

FIG 6. OBSERVATION OF A NAIL HOLE ON THE INTRADOS OF THE ATTACKING BLADE (FRANÇOIS BLONDEL)

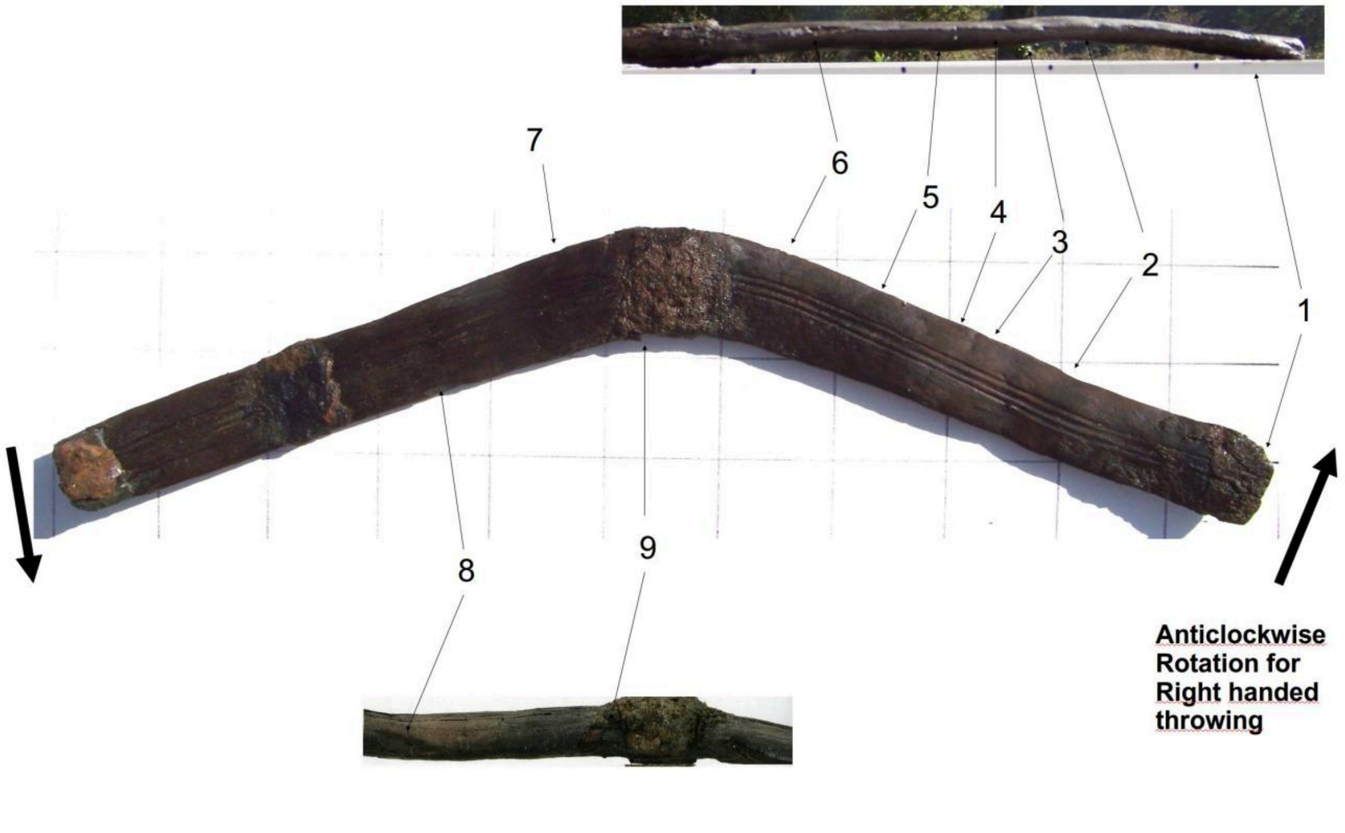

FIG 7A: IMPACT TRACES OBSERVED ON THE EDGES (EXTRADOS VIEW) (FRANÇOIS BLONDEL)

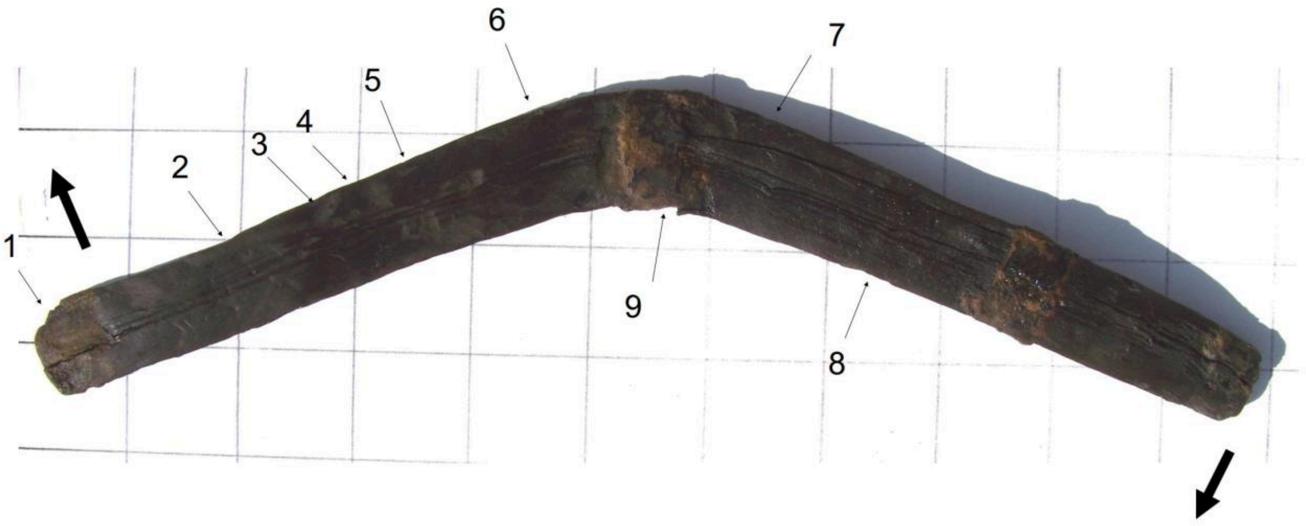

FIG 7B: IMPACT TRACES OBSERVED ON THE EDGES (INTRADOS VIEW) (FRANÇOIS BLONDEL)

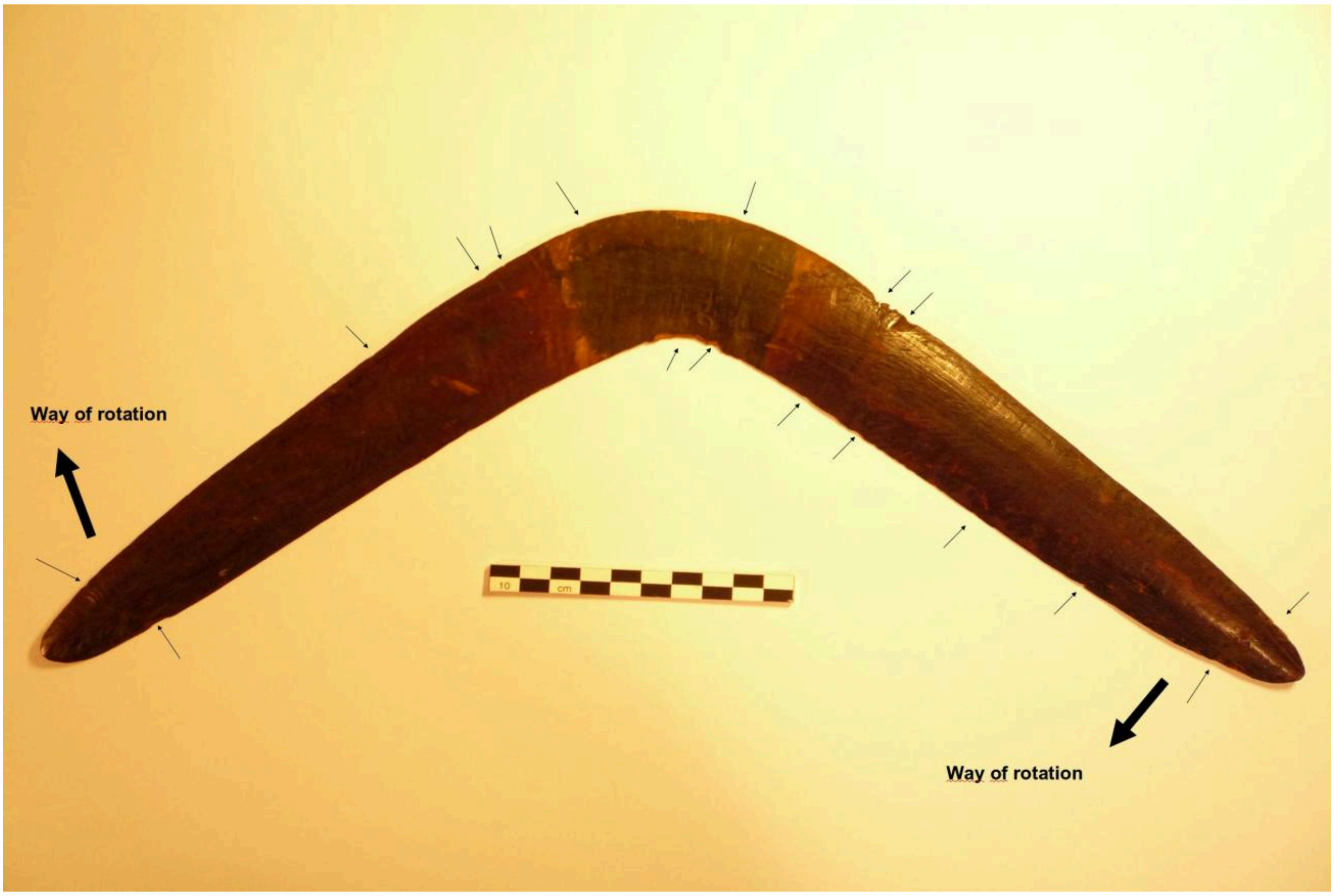

FIG 8. EXAMPLE OF LOCALISATION OF IMPACT DAMAGE ON A LEFT-HANDED SOUTH AUSTRALIAN ABORIGINAL BOOMERANG: IMPACTS ARE IN MAJORITY ON THE OUTER CURVATURE AND ON ATTACKING EDGES (PRIVATE COLLECTION STEPHANE JACOB ART AUSTRALIE)

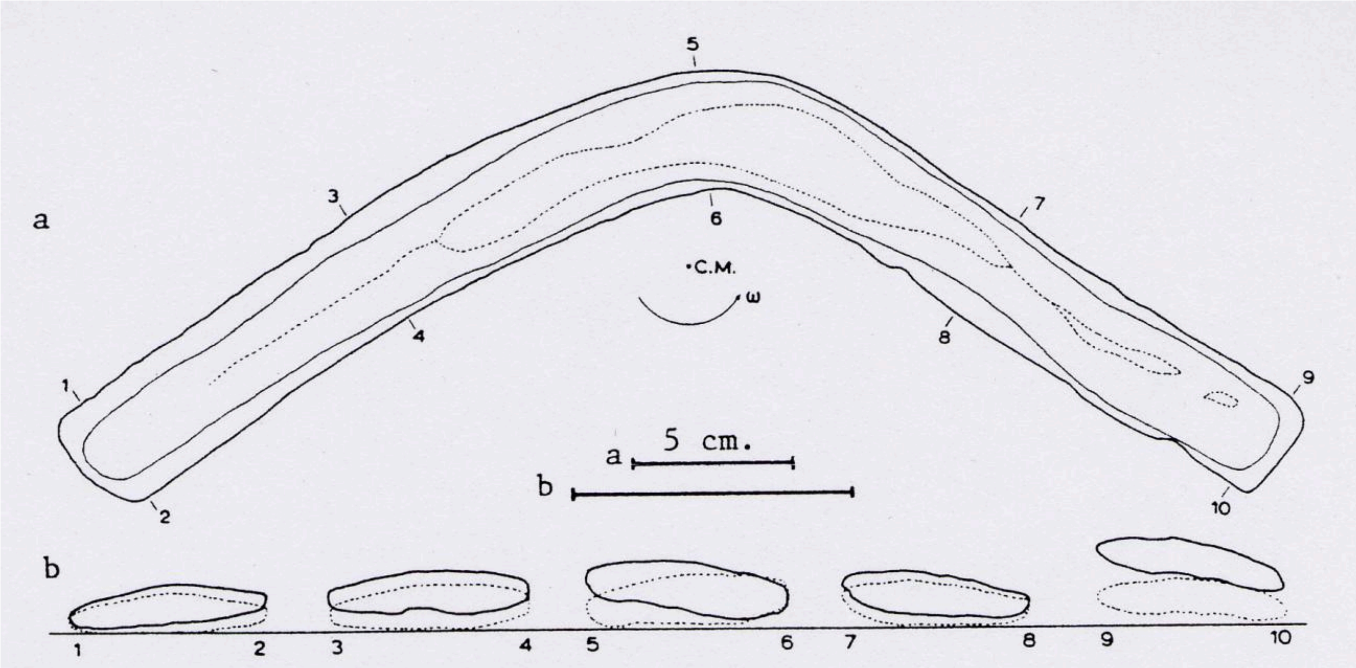

FIG 9. DRAWING OF THE VELSEN BOOMERANG-LIKE THROWING STICK (HESS 1975)

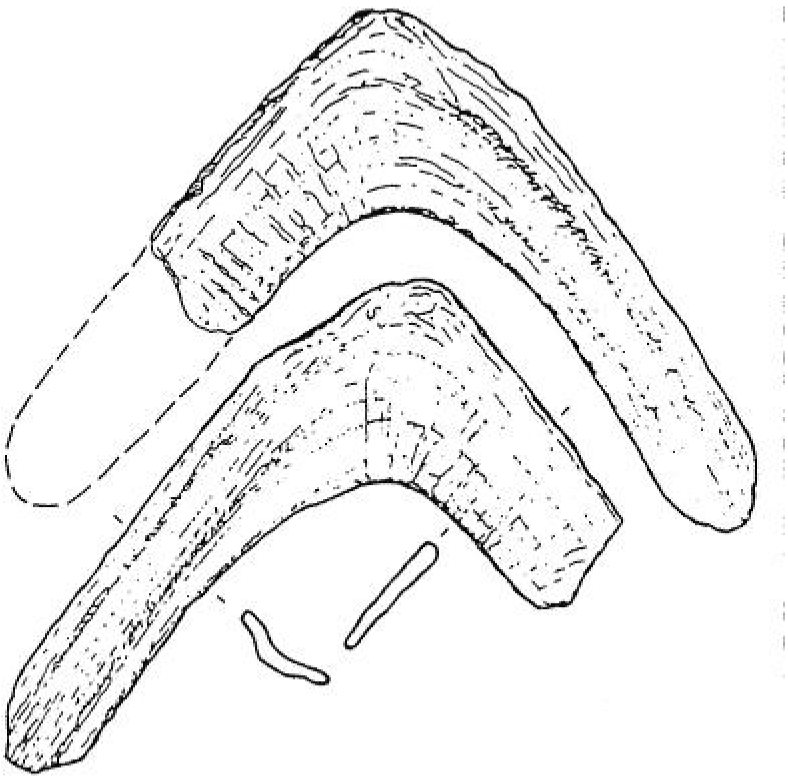

FIG 10. BOOMERANG-LIKE THROWING STICK FOUND AT ELBSCHOTTERN NEAR MAGDEBOURG IN GERMANY. DATED BETWEEN 800 AND 400 BC (EVERS 1994)

FIG 11. EXAMPLE OF AN ARCHAEOLOGICAL PUEBLOS RABBIT STICK DATED FROM 500 BC TO 500 AD GRAND GULCH, UTAH. (NATIONAL MUSEUM OF AMERICAN INDIANS, NEW YORK). NOTE THE GAP BETWEEN SETS OF GROOVES FOR ATTACHING BINDING WHICH REINFORCED THIS THROWING STICK.

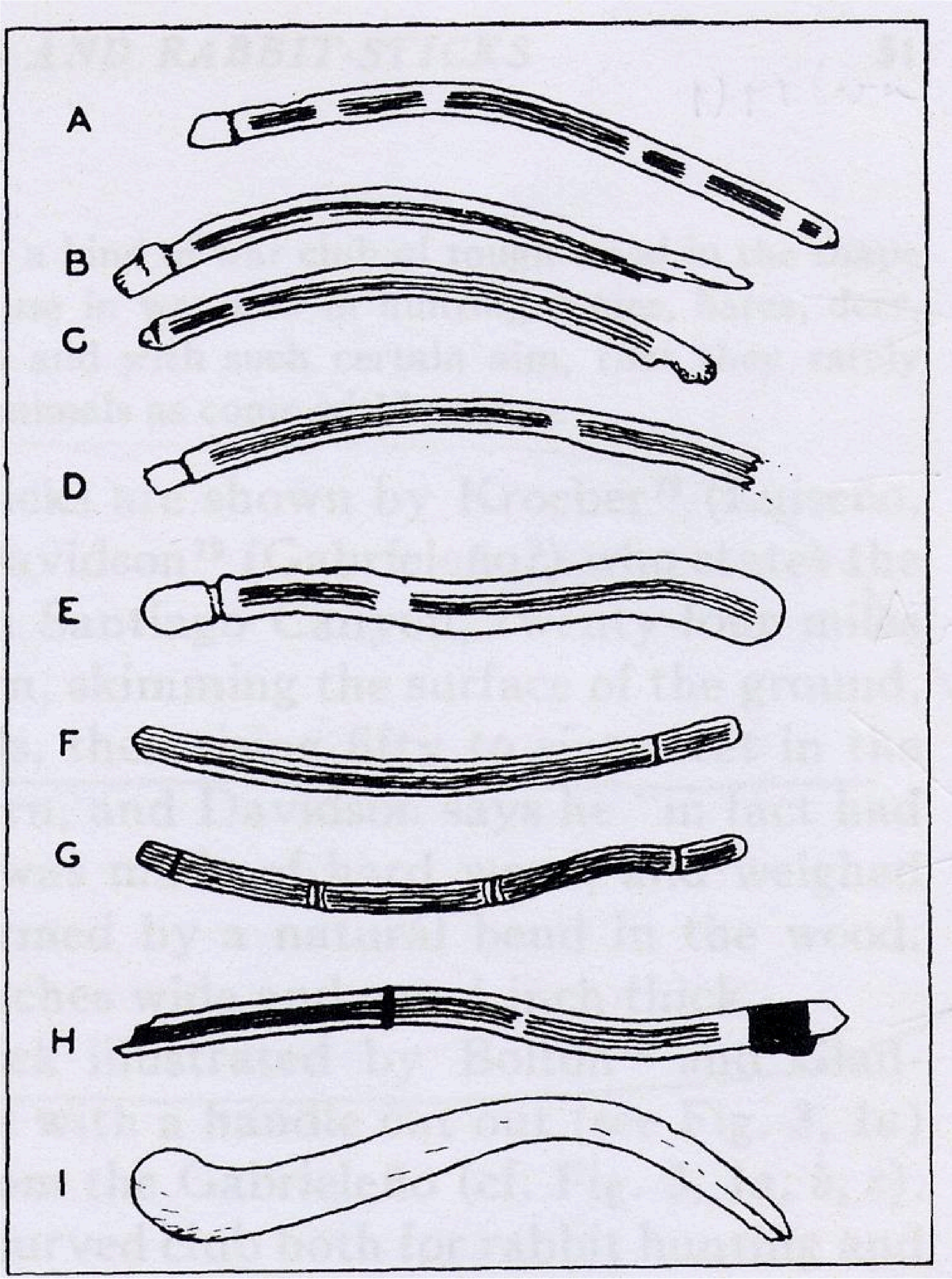

FIG 12. SERIES OF SIMPLE OR DOUBLE CURVATURE GROOVED THROWING STICKS FOUND IN SOUTH WEST OF AMERICA IN TEXAS, NEW MEXICO AND UTAH (HEIZER 1942)

FIG 13A AND 13B. VALARI CAREFULLY FINISHED WITH AN IRON STRIP AT THE END OF THE FOLLOWING BLADE. WIDTH OF STRIP IS 24 MM, THICKNESS 1 MM (PITT RIVERS MUSEUM, OXFORD UK)

FIG 13A AND 13B. VALARI CAREFULLY FINISHED WITH AN IRON STRIP AT THE END OF THE FOLLOWING BLADE. WIDTH OF STRIP IS 24 MM, THICKNESS 1 MM (PITT RIVERS MUSEUM, OXFORD UK)

FIG 14A AND 14B. EXAMPLE OF VALARI SHOWING THE TWO DIFFERENT TYPES OF IRON STRIPS ENCOUNTERED: A WIDE WELDED IRON STRIP AT THE SHORT FOLLOWING BLADE EXTREMITY AND SEVERAL NARROWER REPAIR STRIPS FIXED WITH RINGS (PITT RIVERS MUSEUM, OXFORD UK)

FIG 14A AND 14B. EXAMPLE OF VALARI SHOWING THE TWO DIFFERENT TYPES OF IRON STRIPS ENCOUNTERED: A WIDE WELDED IRON STRIP AT THE SHORT FOLLOWING BLADE EXTREMITY AND SEVERAL NARROWER REPAIR STRIPS FIXED WITH RINGS (PITT RIVERS MUSEUM, OXFORD UK)

FIG 15. EXAMPLE OF AUSTRALIAN ABORIGINAL BIRD HUNTING STICK FROM LAKE ALEXANDRINA REGION (SOUTH AUSTRALIAN MUSEUM). MASS 260 G, WINGSPAN 57 CM. DESPITE ITS APPEARANCE, THIS OBJECT IS NOT A BOOMERANG WITH A RETURNING TRAJECTORY BECAUSE OF HIS WEIGHT, AND CAN BE COMPARED IN TERMS OF PROJECTILE USE WITH THE GAULISH ARTEFACT OF URVILLE NACQUEVILLE.

FIG 16A AND B. REPLICA A WITH DIHEDRAL ANGLE DEFORMATION, EXTRADOS (A) AND INTRADOS (B) VIEWS (LUC BORDES)

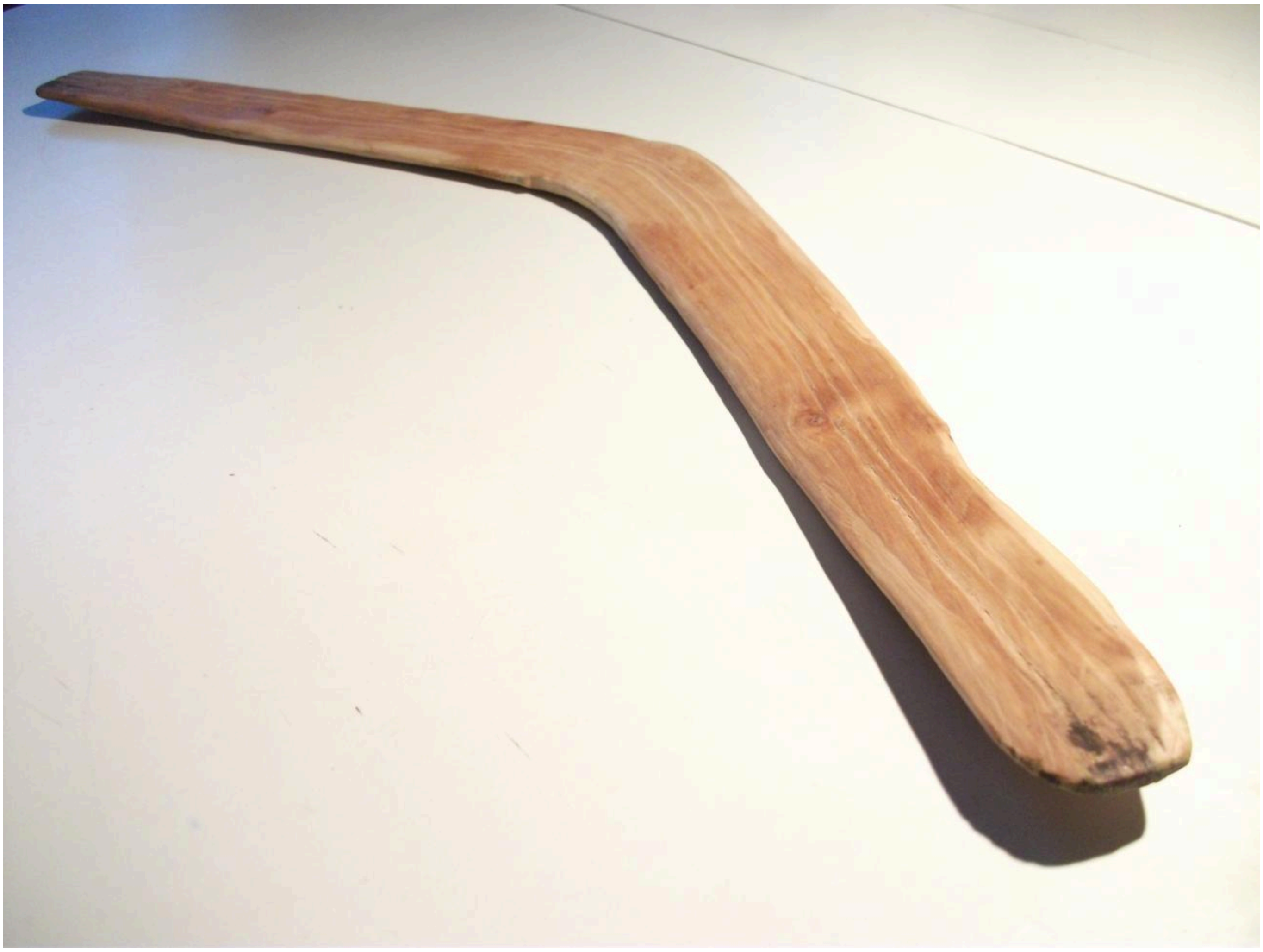

FIG 16A AND B. REPLICA A WITH DIHEDRAL ANGLE DEFORMATION, EXTRADOS (A) AND INTRADOS (B) VIEWS (LUC BORDES)

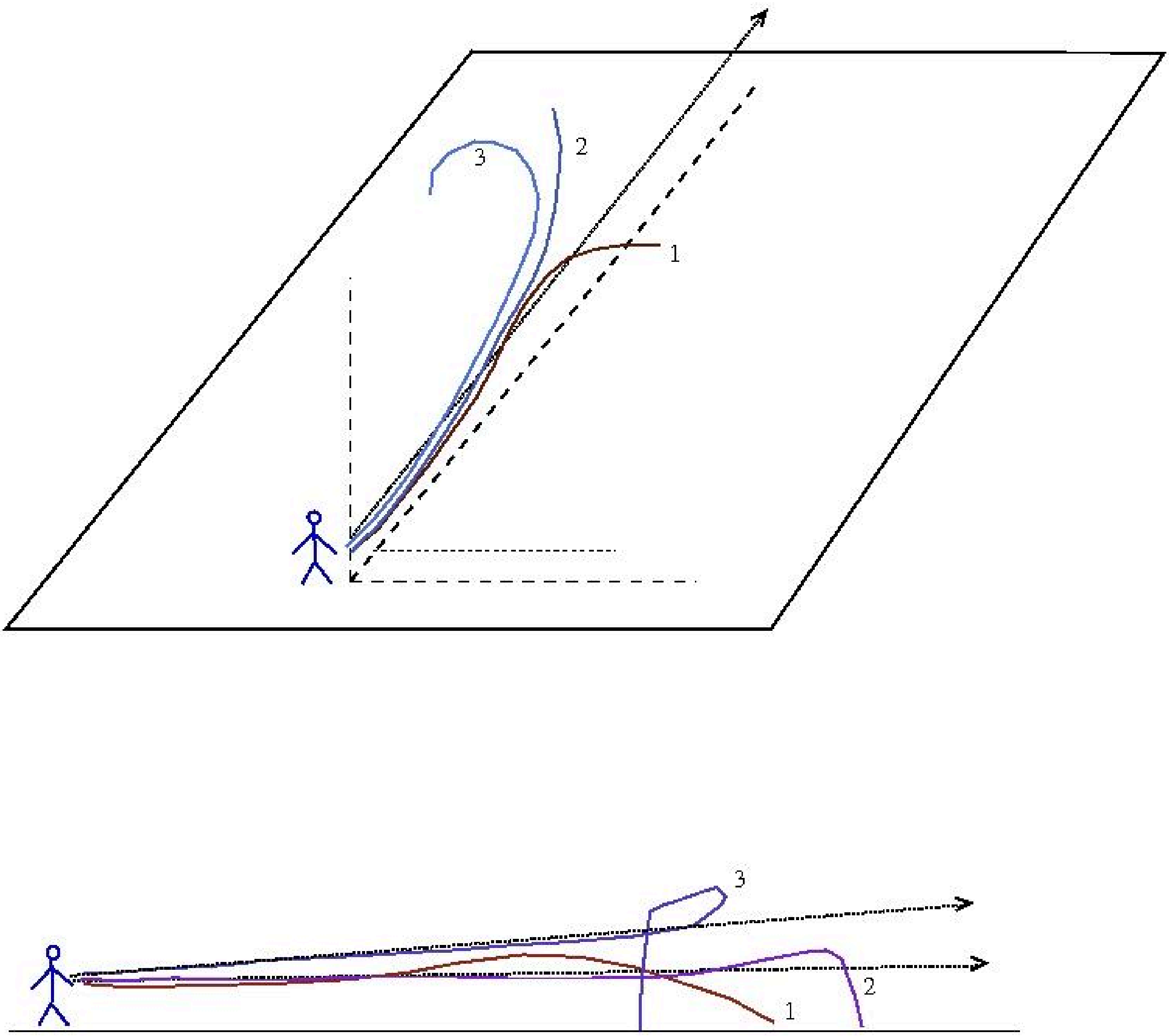

FIG 17. THE DIFFERENT TYPICAL TRAJECTORIES OBSERVED DURING THE TESTS: (1) INACCURATE S SHAPED TRAJECTORY BY THROWING THE OBJECT HORIZONTALLY, WITHOUT INCIDENCE OR DIHEDRAL ANGLE TOWARD THE GROUND: (2) OPTIMAL LOW TRAJECTORY BY THROWING NEAR VERTICAL PLANE: (3) OPTIMAL HIGHER TRAJECTORY BY THROWING WITH A 45° ANGLE FROM THE VERTICAL.

FIG 18. REPLICA WEIGHTED WITH LEAD FIXED BY ADHESIVE TAPE (PREPARED FOR FOUR STRIP TEST)

Replica	Strips	Diédral	Positive Incidence	Type of flight	Object state
A	0	yes	yes	3	1
A	1(elbow)	yes	yes	3	2
A	4	yes	yes	1	4
A	5	yes	yes	1	3
A	0	no	yes	3	1
A	1(elbow)	no	yes	3	2
A	4	no	yes	2	4
A	5	no	yes	2	3
B	4	yes	no	1	4
C	4(steel)	yes	no	1	4
B	0	yes	no	2	1
B	0	yes	yes	2	1
B	0	no	yes	2	1
C	0	no	yes	3	1

FIG 19. SUMMARY OF EXPERIMENTAL TESTS ON REPLICA A, B AND C WITH INDICATION OF THE NUMBER OF STRIPS, DIHEDRAL DEFORMATION, AND POSITIVE INCIDENCE TUNING. THE TYPE OF FLIGHT OBTAINED IS INDICATED ALONG WITH THE CORRESPONDING STATE OBSERVED ON THE ARCHAEOLOGICAL ARTEFACT.

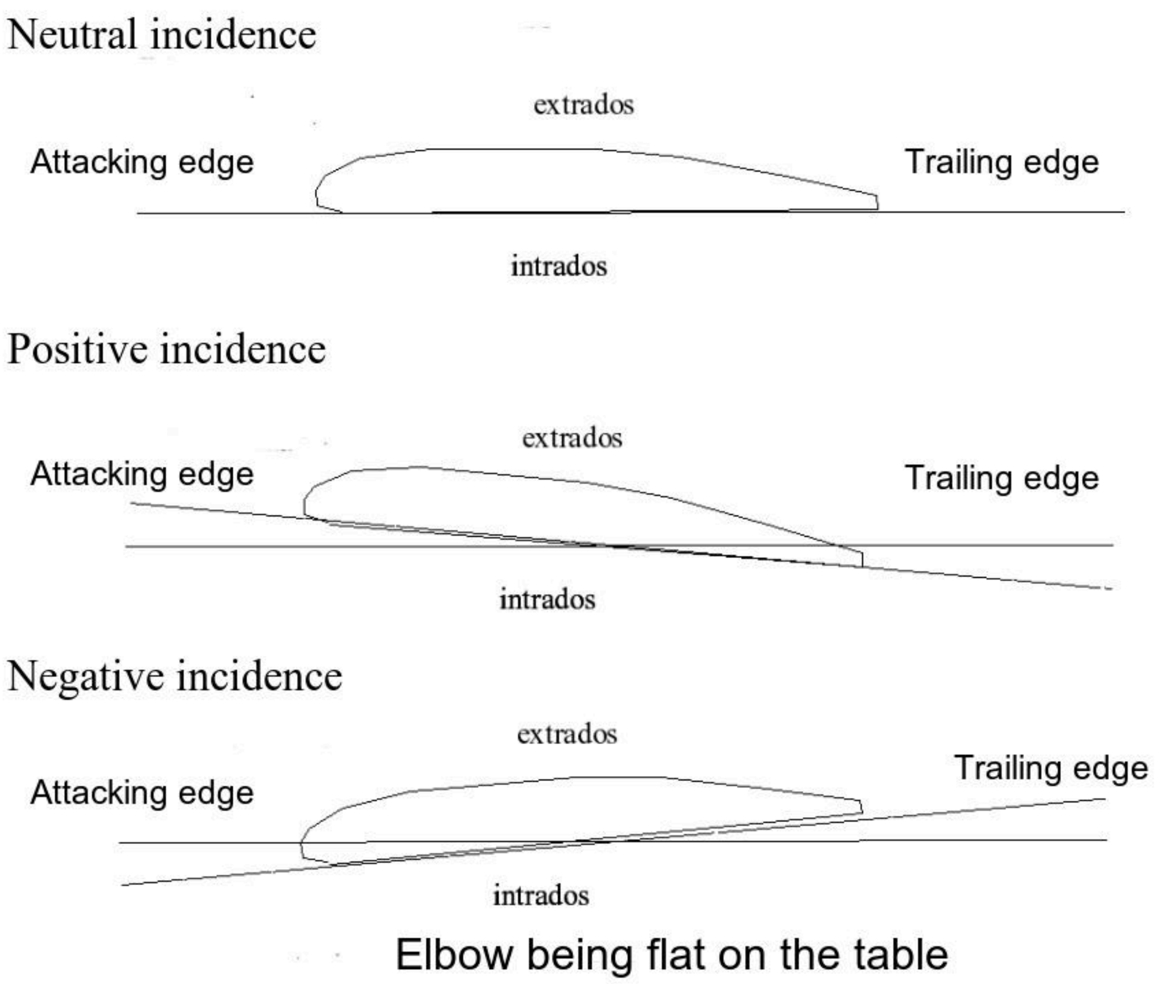

FIG 20. DRAWING SHOWING THREE TYPE OF POSSIBLE INCIDENCE TUNING: NEUTRAL, POSITIVE AND NEGATIVE (LUC BORDES)