A study of traditionnal throwing sticks and boomerang tuning

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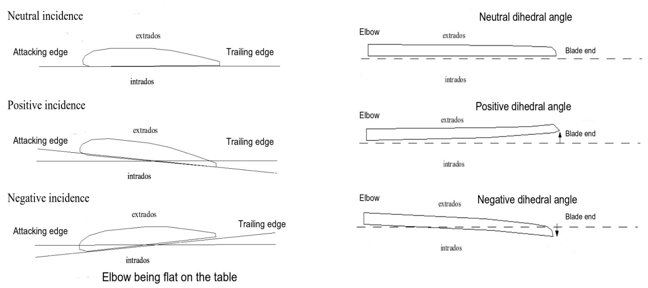
Introduction

The first thing we could see about throwing sticks[1] is their curved shapes. Though, even if their curved shape stabilise their flight by lowering their center of gravity, this seeming parameter isn't the only one to govern their trajectory. Others parameters, like their airfoil cross section, blade wideness, thickness, surface, and mass are also decisive. One another parameter less studied in detail, is the blade twisting of these objects, which allow to tune their flight low over the ground or make them climbing in the air and, in the famous case of boomerangs, are even critical to make them return to the thrower. By studying different ethnologic series, most dated from XIX to XX centuries, i observed different traditions of tuning adapted to different type of throwing stick, and sort out their specialisation basing my opinion on the experience of numerous flying try on experimental throwing sticks.

Two different kind of tuning: incidence and diedra

If one lay down a throwing stick or a boomerang in raw wood with his elbow on a flat surface, he can realize that some his parts aren't in contact with the table plane. One throwing stick is rarely totally flat ! Indeed, the object follow the natural twisting of wood which as raw matter material, could have been submitted to tuning twisting to enhance his flight, or could have be twisted in the drying process, or again by too high variations of wood hygrometry during its conservation.
The incidence is defined by the angle betwen the table plane and the medium axe passing in the middle of the throwing stick airfoil taken in the blade moving direction.



Figures 1a,1b: Incidences and dihedral twisting

The more important thing to remember is that a positive incidence angle increase greatly the aerodynamic lift of one given blade while a negative incidence angle is decreasing it.
This twisting is the basis way of tuning ancient throwing sticks and traditionals Aboriginal boomerangs. People in prehistory and numerous cultures around the world which have produced throwing sticks were aware of these tunning possibilities. They learned how to make the most of them and also to get round their drawback, making evolve their tool to fit their specifics needs.

A dihedral angle is the angle formed by the table plane and the plane passing by the elbow to one of the throwing stick blade end. A positive dihedral angle will give a little more aerodynamic lift than a negative dihedral angle, but this parameter play a lesser role for the objects studied here. Their effects are of growing importance for moderns boomerangs, which are lighter than traditionals ones, compared to their lifting surface.
For that reason, we will concentrate on the incidence angles only in the following study.

Throwing sticks: Between imbalance and balance of aeodynamic lift

A main point to take in account is that the two blades of a throwing stick, which could fly either in straight line or having a curved trajectory, aren't intrinsically equivalent from an aerodynamic point of view. For that reason, as one throwing stick start to be curved, the notion of attacking blade and following blade are necessity to differentiate them(1).

These difference of aerodynamic lift are more significative for throwing sticks having advanced airfoil like biconvex, quasi biconvex and flatconvex ones which give them fast rotation.
They will be less accentuated or negligible for throwing sticks with elliptic or round cross section.

Indeed, if we take for example a straight throwing stick, both blade are totally equivalent because each of them are travelling the same angle of 180° in front of the relative wind generated by rotation movement. Now if we take a curved stick with an opening angle of 150°, we can see that the attacking blade is covering a 210° angle outside the curvature before being at the same position than the other one, and the following blade is covering only an 150° angle inside the curvature. As the aerodynamic lift is depending of the pressure of the air which oppose itself to the angular movement of one given blade, the greater angle its exist in between two given blades, more the following blade will undergo aerodynamic lift for each complete revolution, having more air pressure to face, before the slipstream turbulences of the previous one.
If we give the letter « O »to name the aperture angle of a given stick, the following blade is going to travel this angle but the attacking blade is going to travel an 360°- O angle, and we can consider that in fonction of the aperture of the stick a proportionnal lift ratio between the two blades is applied as below:

Aerodynamic lift on attacking blade =((360-O)/O)*A*lift on following blade

« A » being a constant caracterizing the difference of lift between the two blades which could have different cross section or tuning.
The A constant should be equal to unity if the attacking blade is completely identical to the following blade with same twisting tuning, which is not the common case on raw wood traditional objects.
This very simplified relation means that for an object having an aperture or a curvature of 120° angle with two identical blades having the same tuning, the produced lift on the attacking blade could be twice of the value on the following blade per rotation turn !

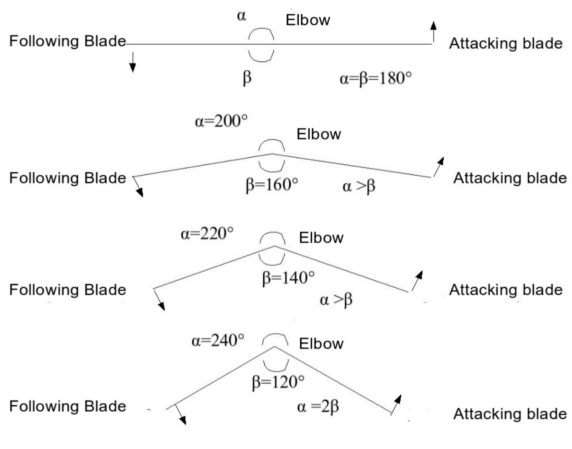


Figure 2: Travelled angles by the attacking and following blades depending of the throwing stick curvature.

For that reason, tuning a positive incidence on the boomerangs attacking blade make them climb far more than the same tuning on the following blade which would give less effect.
Generally speaking, this is exactly the principle of traditionnal Aboriginal boomerangs which are tuned to increase this imbalance of lift positively to the attacking blade. This tuning is confirmed by the ethnological collections measurements, as we going to see in the next section.

On the contrary, the tuning of throwing stick designed for hunting , aiming to have a straight flight, would offset this difference of lift, to decrease volontarily the attacking blade lift by neutral or negatives incidences to recover the balance of lift between the two blades.
This way of seeing the differential tuning between the two blades of a throwing stick get the advantage over more calculatory or many lines of mathematics equations in the way it could have been perceptible by primitive people living thousand years ago, by simple observation and intuitive comparaison of these two distinct blades. Most of all, it render an account of most of two blades throwing stick flight behaviour considering their twisting tuning(2)(3).

To end, we can notice that this lift imbalance effect doesn't exist for multiblade boomerangs like tribladed or four bladed boomerang because angle between any blades is always the same and they are consequently aerodynamically equivalent.

A simple technique of measurement:

The technique of measurement of the twisting is pretty simple: I lay down the throwing stick on a very flat surface, a table or a board, with its intrados against that surface. I press on the object at the elbow and i measure the interval between the midline of the airfoil cross section and the table as showed below:

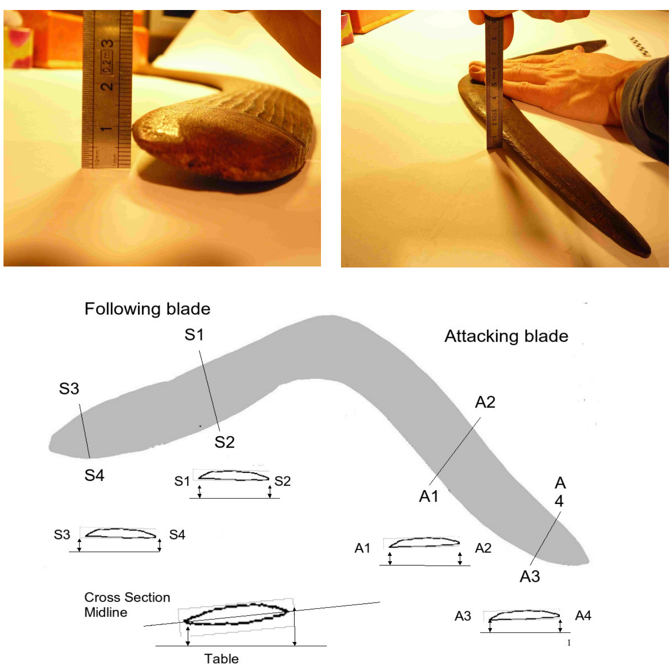


Figure 3a, 3b,3c: Measurement of incidence and dihedral angles.

Positives and negatives incidences values are obtained with this simple calculation:

Incidence angle of the attacking blade: ((A2-A1) + (A4-A3))/2 (Mean of the two incidences noted in middle of the blade and at the end of the blade)

Incidence angle of the following blade: ((S2-S1) +(S4-S3))/2

In the case of when one or both blades have a negative dihedral angle, i need to flip over the object to make the measurement, only one blade at a time on the table, intrados facing me. The values will be taken as negatives, but the incidences are calculated the same way, being calculated always as a relative difference.

In fact the main difficulty is to determine the correct orientation of the throwing stick airfoil, that is to say which face is the extrados or upper face of the object when it is thrown, from the intrados which is the lower face, facing down the ground when flying.
In the case of a plan convexe section or quasi flat convex section, it is the more convex face that will be the extrados, because it is this orientation that give to the throwing stick its best aerodynamic lift according to the Bernouilli law(1)
In the case of biconvex airfoil, we will need more details, for example the state of surface cleaner for the visible extrados face, presence of grooving or more extended decorations often seen on the extrados or impact mark on attacking edge that give the direction of rotation.

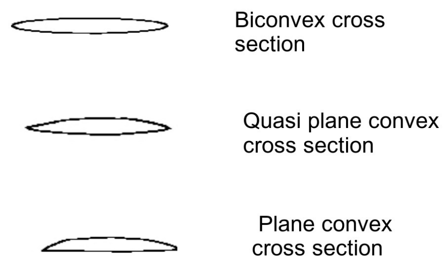


Figure 4: Three main kind of airfoil cross section. the extrados is corresponding to the most convex face.

We need to determine which is the attacking blade from the following blade: This is more easy for asymetric throwing stick because it very often the longer and heavier blade which is the attacking blade. Indeed, adding weight to that blade tend to decrease the lift on this blade and offset it to get back to the balance needed between the two blades of most of non returning throwing sticks as seen in the previous paragraph.
In case of very symetric throwing stick we need to find marks of holding or a obvious and common tuning corresponding to a right handed use. we need to keep in mind that there is no absolute generals rules and, depending of the use, wood used, and trajectory being searching for, « the philosophy » of flight of these projectiles is very different from a specific cultural area to another one . One need to dwell on each new type of objects, taking in account all the others parameters without ignoring any details to a better understanding.

Traditionnals boomerangs: A different tradition of tuning from their modern counterpart

The fact that when the Aboriginal australian boomerang, speaking only about of the returning object here, had been introduced in europe around the beginning of the XX siecle and the raw wood was replaced by modern plywood play a great role in their differences of tuning.
Indeed, plywood has a more regular surface, having two working faces strictly planar and parallèle allow to devellop more sophisticated airfoil cross section with asymetry between attacking and trailing edge, close of the airfoil of our modern planes.
This airfoil evolution allow an increase of aerodynamic lift which add itself to the increase of lift given by the superior state of surface modern materials.
In opposite way, aboriginal boomerangs don't show obvious differences between attacking edge and trailing edge, are heavier

and keep more often an irregular raw wood surface which brake a bit the rotation.
For that Reason, the tuning with incidence angles which is capable to bring much more aerodynamic lift and use the natural twisting of raw wood piece was more easy and preferred by Australian Aborigines.
On the other hand, moderns boomerangs, with enhanced airfoil cross section, lighter, and with a better state of surface aiming for performance , need less this supplementary twisting tuning that sometimes could brake the rotation, if too accentuated.
In fact it's possible to show that a airfoil modification is equivalent to a twisting incidence or dihedral angle tuning, with the difference being on the matter removed, but it's an another story.

Diversity of tuning of aboriginal australian throwing sticks

The twisting incidences angles of each blade of 120 Aboriginals australians throwing sticks, all categories included, belonging to the quai Branly muséeum in Paris have been measured and showed on a graph(see figure 5) . On the abscissa we find the value for attacking blade and on the ordinate the value of the following blade. The objects located on the right upper part have a positive incidence value on each their blades. On the opposite all objects located in the lower left part have two negatives values. The right lower part concerns objects having a positive value on attacking blade and negative value on folllowing blade and vice versa for the upper left part of the same graph.
We can note the great diversity of tuning among these throwing sticks which have differents parameters of mass, surface, airfoil and dimensions.

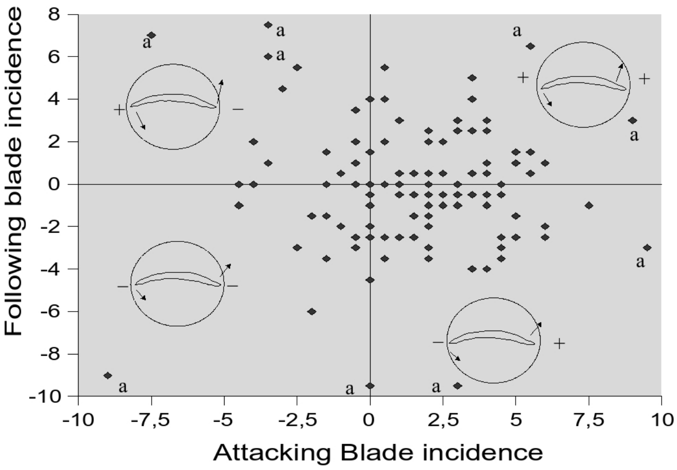


Figure 5: Incidences angle of 120 throwing sticks from the Quai branly museum in Paris . Some objects have the same tuning XY values and the points are overlaid.

A great diversity of tuning adapted with their uses

We can see here the higher frequencies of using positive incidence on attacking blade concerning throwing sticks studied in that collection.

This tuning is often use for light throwing sticks which aim a climbing and turning trajectory.

It is counterbalance by a negative incidence on the following blade for a great number of throwing sticks.
Tuning with negative incidence on the attacking blade are less common and often use to aim toward low hovering trajectory, specializing these throwing sitcks for gound hunting.
Beside these two divergent tendencies, we need to take in account of the others throwing sticks parameters noted during this study(mass, surface, airfoil, dimensions) to properly discuss of these incidences tuning. For that reason, we will be more interested here to decode the tuning mode of more precise serie of throwing sticks belonging to a same crafting tradition or same cultural and geographic area, included in a same or a close catégorie(4)
This kind of graph have another advantage: It's possible to spot quicky throwings sticks with abnormal tuning(noted « a » on the graph) caused by excessive twisting of wood in time. Only about ten objects out of 120 studied are showing such abnormal incidence angles which prevent good flight behaviour because it could provoke throwing stick flip over during operation or could brake dramatically their rotation. This is showing, unlike commonly accepted, that the twisting tuning of ethnological throwing sticks are keeping themselves pretty well with time and could be exploited for their study.

The specific tunning of boomerangs and his variations: Examples of Western australians boomerangs

These boomerangs have a typical flat convex cross section which cleary permit to allocate their extrados and intrados faces. Additionnaly, a positive incidence angle on the attacking blade is necessary for an excess of lift on this blade to get returning flight as it has been confirmed by numerous personnal try on different raw wood boomerangs.

Figure 6a, 6b: Examples of Aboriginal throwing sticks from Western australia. Respectively 60 and 70 cm wingspan.
(Photos Museum of Quai branly, Paris)

Throwings sticks measured here belong to very light throwing sticks class(M/S< 0.7 g/cm2) in fonction of my own classification(4), that mean they are in the boomerang class in term of mass divided by surface, and are actually boomerangs when their tuning is correct.
Most of them have a flat convex airfoil, giving them a lot of aerodynamic lift. I observed a systematic clear positive incidence angle on the attacking blade.
it is necessary to bring excess of lift needed for turning flight and make them return. About the following blade, i could observe three differents options of tuning that appear on the graph as three separate group of values:
The N°1 group having positive tuning on both blade will have superior aerodynamic lift and high trajectory with passive return helped by gravity.
The N°2 group having positive tuning on attacking blade but neutral or slighty negative tuning for the following blade, will have less lift compared to the first group and a lower trajectory, but a longer range.
The N°3 group having compensated negative incidence tuning on following blade which going to a just a low more active trajectory closer to the ground
This parameter isn't conditionning the whole flight by itself. Mass, surface and dimensions are going to influence it too, but the critical incidence tuning is going to give a clear tendancy for objects belonging to a same class.

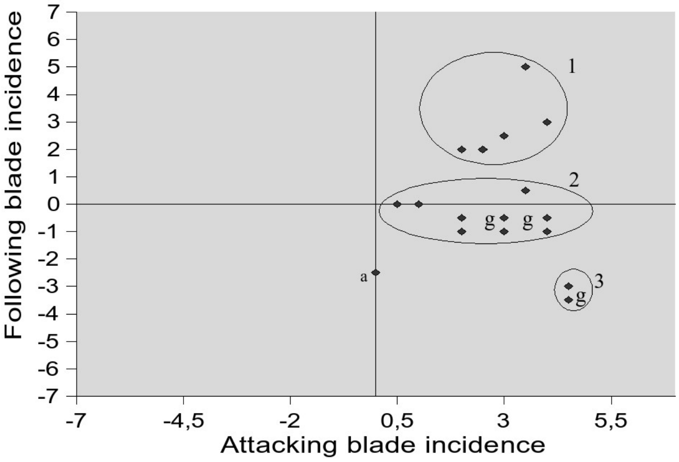


Figure 6c: Incidences of 18 western australian boomerangs. The boomerangs noted « g » are lefty.

Boomerangs from Alexandrina lake area, South australia: an ancient technology

Figure 7a, 7b: Examples of Aboriginal boomerangs from lake Alexandrina region, 57 and 54 cm of wingspan respectively. (Photos South australian museum, Adelaide)

These boomerangs from the Alexandrina lake area are interesting for several reasons: This region where the Murray river go into the southern ocean is rich in freshwater supplies, but also in coastal ressources like those collected from the Coorong huge lagoon by Ngarrendjeri people, for example. This environnement is rich in wood ressources to make boomerangs and throwing sticks, Casuarina trees commonly growing in this region. Large water supplies surely attract many birds who are the main and more easily hunting targets of light throwing sticks at all periods. These factors make the area a land of early devellopement of the boomerang derived from these weapons.
These boomerangs are very differents from the previous ones because they have biconvex airfoils which result from a more ancient technology than the flat convexe airfoil that give more aerodynamic lift to Western australians boomerangs. Nonetheless, they are returning objects beause of their small mass/surface ratio and their blade tuning. Most of them have been crafted in She-Oak wood(Casuarina Stricta) which grows commonly along the coast, and have caracteristic truncated shaped ends.
We can find on these boomerangs a positive incidence on attacking blade, necessary to create more lift on this blade and create a turning trajectory. The other blade is either neutrally tuned or slightly positively tuned(group 1) or negatively tuned (group 2).

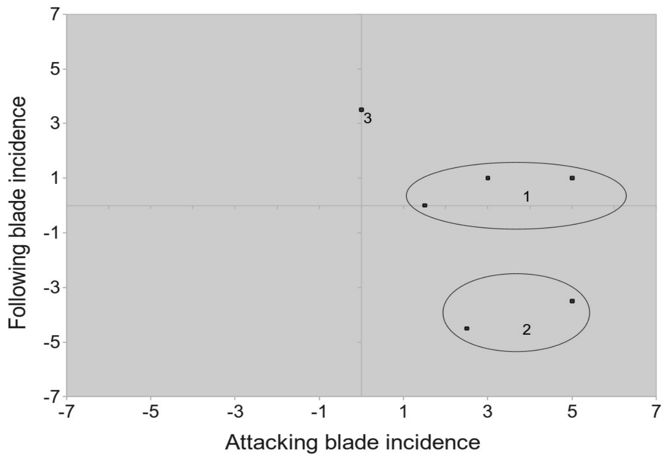


Figure 7c: Incidences of 6 lake Alexandrina region boomerangs

The objet marked 3 having a neutral incidence tuning on his attacking blade which would prevent it to return correctly(the object will travel too much distance and keep a low trajectory)

These twisting tunning are showing that is possible to find some australian Aboriginal boomerangs tuned to have returning trajectory without having systematic flat convex airfoils. This type of biconvexe archaic airfoil show that boomerangs from Alexandrina region could belong to an more ancient tradition, remembering the important discovery of ancient wooden prehistoric Aboriginal boomerang dated from 11 000 BP at Wyrie swamp(near Milicent), just few hundred kilometers away from lake Alexandrina along the southern australian coast.

Some particular light throwing stick from Kimberley

The orientation extrados/intrados for this kind of throwing stick is given by their grooving or by their quasi flat convex airfoil. The Attacking blade is determined with holding mark or a slight asymetry of the object or again with impact mark point out the direction of rotation.
They have a caracteristic V shape, a wide elbow and overall pointed extremities. They can be grooved on both faces and painted with transversal strip of white clay pigment.
It is important to notice that the wide grooving of these sticks looks like the wide and smooth grooving found typically on the hunting sticks of the central desert region, but rarely on objects of boomerang type.
These very curved throwing sticks(90-130 ° of aperture angle) have a wingspan between 50-70 cm, a biconvex or quasi flat convex especially a low mass/surface ratio which set them as light throwing sticks class($0.7 < M/S < 0.9$ g/cm2) or very light ($M/S < 0.7$ g/cm2).

Figure 8a, 8 b: Two examples of V shaped throwing sticks from the Kimberley region. 47 et 57 cm wingspan respectively. (Photos Museum of Quai branly, Paris)

A particular question is asked about these typical throwing sticks from the Kimberley region:

In most of publication, they are presented, at least implicitly, as typical boomerangs of this region. Nevertheless, the measurement of their angles of incidence is surprising and show a tuning that doesn't design very well these objects to have a returning trajectory.
Indeed, the incidence of their attacking and following blade is either neutral or negative(group N°1), which is going to decrease dramatically the aerodynamic lift. If we consider their low mass, small wingspan and accentuated curvature which going to bring a lot of rotation, they are ajusted to a non strictly straight flight but a low hovering « S » shape trajectory.
Consequently we can propose that these three objects are more ajusted for ground hunting, even for fighting if we consider the offensive aspect of the wicked pointed extremities.

A fourth object(N°2) seem to have a more classic compensated tuning, positive attacking blade, but negative for following blade. If we consider its mass and flat convex airfoil, it is directed toward a more climbing and turning trajectory, ,but no return(mass/surface ratio is too high). A perfect birds hunting stick.

This example show that the incidence tuning could also be adapted in fonction of their use, but these kind of throwing stick seem mostly tuned to aim at a target and not accentuate a curved trajectory to make them returning to the thrower. It will be interesting to study others examples of these Kimberley throwing stick to confirm this tuning tendancy.

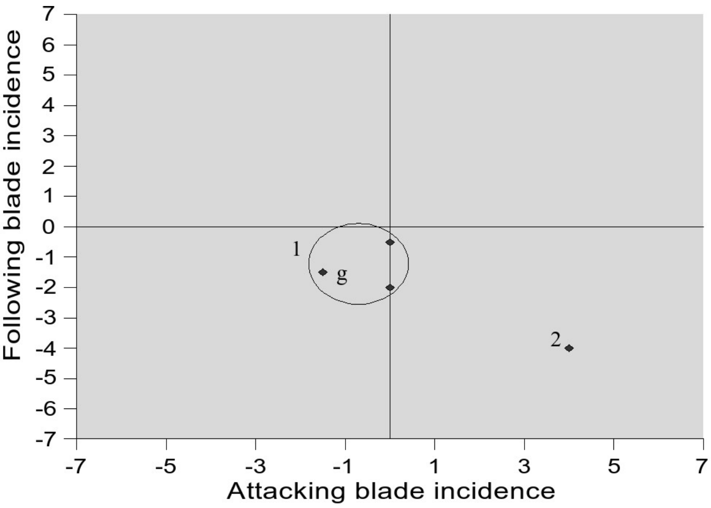


Figure 9a:Noted incidences for the throwing sticks serie of Kimberley (museum quai Branly, Paris)

I had this opportunity, working on another complementary serie of this kind of objects at the South australian museum(fig 9b) which confirms that the majority of these throwing sticks(at least group 1) are found in a similar configuration of twisting, with slightly negative or neutral incidence tuning on attacking blade leading them to be classified in non returning light throwing stick class.
But it is not so simple because some exception exist(objects 2 and 3) which correspond to lighter objets and have positive incidence tuning on attacking blade.
This is showing that the returning gaming trajectory wasn't the primary use of these objects, but Aboriginal who made them knows how to make sometimes lighter examples which could acquire boomerangs tuning and trajectory. Is it to adapt them to bird hunting or to be used by younger hunters ?
Anyway these Kimberley light throwing stick are related to an intermediate step in the evolving technology between hunting stick and gaming boomerangs.

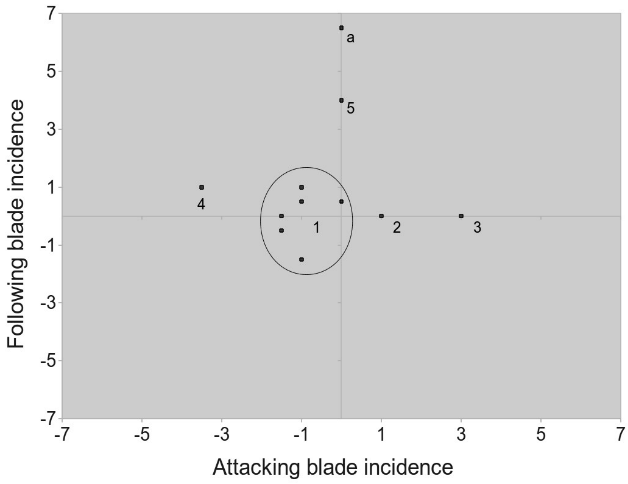


Figure 9b:Noted incidences for the throwing sticks serie of Kimberley (South australian museum, Adelaide)

One remarkable serie decorated with ochre from Mornington island

In the study of this collection, i have also notice another remarkable serie of aboriginal throwing sticks
A very homogenous serie of five objects coming from a same crafing tradition from Mornington island, Queensland.
Having a sligtly waisted asymetric shape and rounded or smoothed square ends, they are especially caracterized by their red ochre decoration on all their surface with several strip of white clay pigment, a wide one at the end of following blade and one or two narrower parallele adjacent strips

These sticks have a engraved distinctive holding mark and decoration which clearly indentify their Attacking blade(the longer blade not decorated with white strips). Their quasi flat convexe cross section and some others details like impact marks achieve the determination of their laterality, all right handed for the examples studied here.

Figure 10a, 10 b: Throwing sticks from Mornington island with two white strips and detail of holding mark.76 cm of wingspan.
(Photos Museum of Quai branly, Paris)

Their belonging to a unique cultural and geographic tradition is reinforced by a same distinctive mark of holding. This could allow to suppose that they were made by the same Aboriginal group or even a same crafter !
Three of these examples of throwing sticks are covered by a layer of ochre which got a patina and have a close tuning(groupe N°1) with a neutral or a slighty negative incidence on both blades
They classified themselves as typical throwing stick with a mass on surface ratio between 0.9 et 1.1 g/cm2 and have a quasi biconvex airfoil. This is ajusting them to ground hunting.

However, Another throwing stick(N°2) is discerned by a far more recent layer of red ochre. This ochre layer hasn't any patina and settle on my gloves during the manipulation, making appear the older layer of ochre with the same patina like the three objects belonging to the group N°1. This object had been decorated a second time but with only one white narrow strip !

This new paint layer was covering the older painted decoration like the three object of the group N°1 having two white strip. The N°2 object present also a different tuning with a clearly more positive incidence on its attacking blade which orient its flight toward a climbing trajectory, if we consider his lower mass on surface ratio, classifiying it among the light throwing sticks category (0.7<M/S<0.9 g/cm2). This stick will be adapted for climbing flight with a slight turn, fitted for birds hunting. Was it tuned at first for this specialisation or his twisting have been tuned again in relation with the renewal of his painting ? Could its fonction or owner has been changed ?

Figure 10c, 10d: Throwing sticks from Mornington island painted a second time with only a white strip and detail of the changed part . 70 cm wingspan.(Photos Museum of Quai branly, Paris)

The fifth object(N°3) is also very interesting:
This is a throwing stick with a lower mass/surface ratio below 0.7 g/cm2 with positive incidence tuning on each blade. Additionnaly it has a flat convex with much more aerodynamic lift. So it transpire that this object has a obvious returning capacity as a boomerang.

Figure 10e: Boomerang from the Mornington island .48cm wingspan. seeing from intrados.

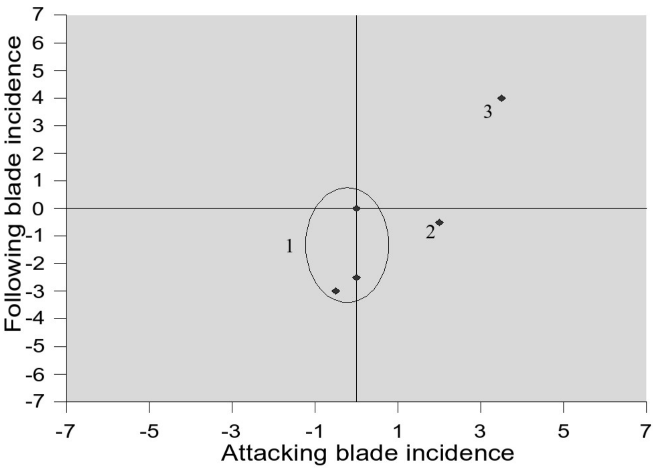


Figure 11: Noted incidences on Mornington throwing sticks

We are here in presence of a serie including three different represented categories of throwing sticks which distinguish them selves by their mass on surface ratio and twisting tuning, being at the same time produced by same cultural group or individual !

A remarkable indian Valari serie

The Valari or Valai Thadi are Tamoul throwing sticks from south india(Tamil Nadou) traditionnally used for hunting (from small game to the size of a red deer) and war.

Figure 12a: Serie of indian Valari. The visible face are corresponding to the intrados. 12b Detail of the holding ball with distinctive mark. 50 cm wingspan.(Photos Museum of Quai branly, Paris)

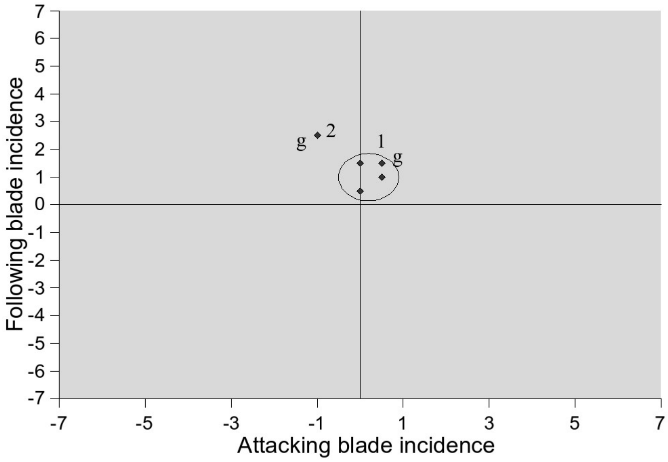


Figure 13: Noted incidences on the Valari serie

The determination of holding blade which is also the attacking blade, is given by the wood ball at its extremity which bear distinctive marks relative to its geographic origin and crafter identity.The upper and lower face(extrados/intrados) make itself obvious in comparing their twisting: Three of these objects was showing exactly same way of tuning in opposition with a fourth one which showed inverse tuning. Statistically, the three objects tuned the same way are right handed and the fourth one probably lefty.

A fifth stick(N°2) has different dimensions and showed different tuning but its flight orientation in term of extrados/intrados has been deduced from the observation of the tuning tradition of those from the group N°1

The four sticks which have a close morphology are showing very close accurate tuning with neutral or a slight positive incidence on the attacking blade and a slight positive incidence on following blade
They are belonging to a same crafting tradition, probably from the same geographic area which is confirmed by the same engraving on the holding ball.
Without taking in account the tuning of these indian throwing sticks, we can infer that they are not returning ones. Indeed the braking effect of the holding ball is too great to obtain a returning flight. Despite this braking effect, Valari have reduced wingspan and biconvex shaped airfoil and could acquire a lot of rotation and consequently superior aerodynamic lift.
In these conditions, their incidence tuning is going to orient them toward long range trajectory, with slight climb and sometime « S » shaped flight.

But if we take in account the breaking effect in rotation of holding ball that going to induce a decreasing of the aerodynamic lift, we could propose a relatively long range straight trajectory that could be fit easily for ground target. Finally they are long range throwing sticks(50-100 meters), keeping probably a lot of rotation in flight, multipurpose and very efficient even in fighting situations.

The case of american Zuni/Hopi rabbitsticks

Figure 14a, Rabbitstick Zuni 14b, 14c, 14d rabbitstick Hopi 50-60 cm wingspan.(Photos Museum of Quai branly, Paris)

These throwing sticks with carved handle, commonly called rabbistick(5)(6) are typical of models used by pueblos indian from Pueblos Hopi et Zuni Arizona tribes, culture which apogee is between 800 et 1600 after JC and whose rabbit hunting tradition has been continued until the XX century.These hunting weapons are called Puskoho or Packeho by the indians of this region.
Five object out of seven object serie are showing a typical red and black decoration made of a red part on the elbow highlighted by black lines and black U shape closing the following blade and juste above the handle painted in red.
Pairs of short parallel black lines are painted in the midlle of each blade from the edge and perpendicular to it.
These pair of short lines would symbolize the rabbit ears and recall the couple of short lines painted on the indians warriors faces. We could note that all four Hopi objects have their double line painted on their attacking edges. So we could state the hypothesis that these painted marks could give a sort of indication of throwing orientation to the thrower and at the same time help to differenciate its tribe owner. Indeed the only stick belonging to Zuni tribe have in a opposite way, his double line on trailing edge.
  Two other objects are non decorated.
The airfoil cross section of all these sticks are rectangular slightly convex, probably to avoid too much aerodynamic lift that would be given by a classical biconvex class section.
That could be explained by the medium density of the wood used, the oak, (density between 0,7 and 0,8 g/cm3), far less dense than accacia used by australian Aborigines (density around 1 g /cm3 or more).
The presence of the handle make obvious the choice of the attacking blade, but on another hand the symetric rectangular convex cross section bring more difficulties to orient their extrados and intrados faces.
However, we expect to find a neutral or negative tuning on the attacking blade to orient their flight toward low hovering trajectory aiming to hit small rabbits.
If we choice this tuning option to determine their orientation and measure their incidences angles, we found majority of them with the same tuning, probably right handed, that confirm statistically their extrados/intrados orientation.

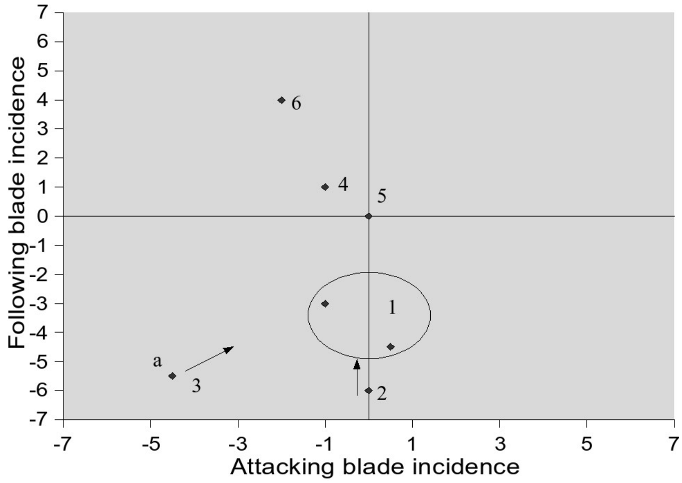


Figure 15: Notes incidences on the Hopi(1,2,4,5,6) et Zuni(3) sticks

The two object n°1 group(picture 14 a et 14 b), the n°2 object , n°3(picture 14 d) et n°4(picture 14 c) are the five decorated ones.
The two object of the N°1 group have either a slight postive or negative incidence on attacking blade but alway a negative incidence on the following blade.
The N°2 object have a dommaged following balde, that make me believe his incidence value could have become abnormal after a shock. However it had initially a lower negative value for this blade and could be closer in term of tuning from the objects of the N°1 group.
In the same manner, the Zuni rabbitstick N°3 which have, in its actual state, too accentuated twist, will flip over during its flight and will have too much rotation braking.
Beside this, his tuning cannot have been inversed with time and that wood twisting probably get accentuted . So we can replace its original both incidences at lower values, which is bringing it more closer to the tuning way of the group N°1.
Its tuning with both negative incidence values on both blade could be also explained by its different cultural belonging, being the only Zuni stick of the serie.

The N°4 object which have the same decoration seem to have a clearly different tuning.
We can observe an almost perfect planeity for the N° 5 object and a very positive incidence tuning on the following blade of the non decorated N°6 object.

We see that the majority of these throwings sticks, considered as right handed, have neutral or negative incidence on attacking blade along with different choice of tuning option on the following blade. The tuning of the throwing sticks studied here are in good agreement with their rabbit hunting specialisation, as small ground targets. But serie containing more object would be necessary to understand fully the different tuning tradition and confirm these first measurements.

Conclusions:

This study bring an insight of the different incidences angles tuning traditions that could have existed for different category of throwing sticks belonging to different cultures. One need to alway recall that others important parameters like mass on surface ratio, the type of airfoil, height on wingspan ratio, dimensions are also necessary to attempt reconstruction of throwing stick flight, adapted with their natural and cultural environnement which orient their specialisation.
This make essential to work on extended serie of object belonging to homogenous cultural group and close related to their aerodynamic classification. In this frame additionnals objects will be needed to confirm these tuning tendancy observed in this study.

It is precisely among these twisting that modifying slightly but adequately the natural worked piece of wood, that we could find the specificity of traditionnal throwing sticks tuning. By this way, these accurate twisting orient what else could be just seen as simple sticks, toward throwing weapons develloping very impressive performance.
Moreover the existence of these twisting tuning in these simple looking objects make them finally appearing as a concentrate of prehistoric aerodynamic technology ! Without the mastering of these twisting tuning learned through millenia surely throwing stick could have stayed as more simple throwing club and the fascinating boomerang wouldn't have been invented !

Notes: About Definitions of terms linked with aerodynamics of boomerang and throwings sticks cited in this article, the reader could additionnaly find numerous works on this subject, particulary books on modern boomerangs giving further explanations on these terms.

Throwing stick and boomerang terminology:

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

2 My terminology in this article is to call 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 attached only to light returning type of implements. Later early colonists 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 that I'm trying to deal with, however it remains a subject being far beyond the point of this article.

3 Attacking wing:
For bipale throwing sticks, the two wings are not aerodynamically equivalent.
The blade which need to travel a greater angle before being at the same position of the other one is called the attacking wing.
The other is called following wing.
The attacking wing travelling through a much more greater angle of air behind the slipstream of the following blade, get intrinsically more of aerodynamic lift, all other parameters being the same.
This is the wing which is handled in common australian aboriginal style of throwing, curvature facing the target, but could be sometimes not.

4 Extrados/Intrados
The face of a throwing stick that is directed toward the ground or the outside of trajectory during the 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.

5 **Attacking edges:**

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

Bibliographie:

1 La magie du boomerang Jacques Thomas

2 Tuning a throwing stick

Primitive Technology I a book of earth skills

3 Making throw sticks behave

Primitive Technology I a book of earth skills

4 Bâtons de jet: des outils préhistoriques méconnus,approche Aérodynamique et expérimentation .Langage de pierre. la restitution du geste en archéologie préhistorique. Colloque Européen 2009 aux Baux de Provence Musée des baux de Provence

5 La chasse collective au lapin chez les Hopi, Oraibi, Arizona ", Paris, Musée de l'Homme : Journal de la Société des Américanistes de Paris, Nouvelle Série 33 : pp. 63-90. 2e éd.1946.

6 Ancient grooved Clubs and Modern Rabbit-Sticks
Robert F. Heizer American Antiquity. Vol. 8,No. 1(Jul., 1942), pp.41-56

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