The dynamic behaviour of the boomerang exemplifies the **Theory of Dynamic Interactions.** The criteria of this theory can be applied to study the flight of the boomerang with a view to better understanding its unusual behaviour.
We will call a boomerang any type of flying object with blades that has been thrown and executes a rotational movement on its own axis of symmetry, which flies through the air or the flight of which it is even possible to guide beforehand, thus managing to get it to return to its point of origin.
These objects can be used as weapons, toys or sports instruments. They are generally made of a sheet of curved wood in such a way that, on being thrown with intrinsic rotation, they can be recovered after having been thrown, given that, if they fly unhindered by any obstacle, they can return to the starting point of their flight path.

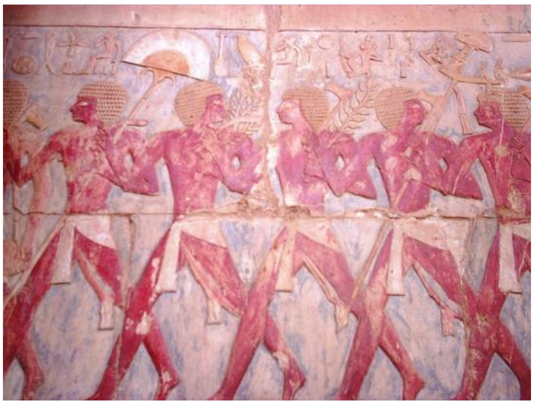
Egyptian boomerang thrower. (The Flight of the Boomerang, page 229)[1]

The behaviour of the boomerang, and even that of the spinning top, has been considered as unique in classical physics. Notwithstanding, we raise the question as to whether or not this behaviour could be generalised in space, in both gravity and zero-gravity environments, and if so, what would the path of a rotating body be with angular velocity and momentum in the direction of one of its rotating axes when subject to external interactions? [1]
Numerous texts have been written to try and explain the flight of the boomerang. Indeed, there are more than a few Internet sites given over to this topic. Nonetheless, we hope to clear up the reason behind its path and for its behaviour in flight, questions which to date, remain unanswered in the context of Classical Mechanics.

HISTORY

The boomerang is an ingenious object known to man for thousands of years. The term comes from the original name used by a tribe from New South Wales (Australia), which was first mentioned in the western world in 1827 by Captain King as “the Port Jackson term” [2]. Notwithstanding, there are other possible antecedents in documents written in 1798 or in December 1804.

Contrary to what a lot of people think, the boomerang is not an invention exclusive to Australia. Remains of boomerangs have been found in Africa and in Europe as well, specifically in 1987 a boomerang was found on an archaeological dig in Poland (Oblazowa). A carved, mammoth tusk, it is reckoned to be some twenty-three thousand years old. Boomerangs have also been found in other places around the world: in India, America, Indonesia, and even on the tomb of Tutankhamun.



Egyptian frieze with throwing sticks

The ancient Egyptians had a similar weapon, as did the Hopi Indians of Arizona and many other peoples. However, the indigenous Australians are the only people in our times that still use this pre-historic instrument that had been consigned to the past by other peoples, a fact which enabled Captain James Cook to record its existence on arriving at Australian shores in 1770. [1]

Detail of a scene from a marsh hunting scene
(British Museum. Detail)

The hunting scene is depicted on the tomb of Nakht (TT 52). The painting displays the customary symmetry of Egyptian art, revealing a studied equilibrium on both sides of the centre. Two practically identical figures, majestic in pose and attitude stand on tiny papyrus boats throwing a boomerang and harpoon, on the left and right respectively. They are accompanied by elegantly attired family members, possibly their wives and daughters, who are holding onto the thrower, by the waist or leg, while they remain stable in the boat.

In these cases, the instrument represented belongs to the class of **throwing sticks**, which were used to stun and, in exceptional cases, kill small animals and proffer blows to enemy infantry during battle.

Traces of artefacts understood to have been like “throwing sticks”, capable of being used as hunting and battle weapons, have also be found at Atapuerca. Notwithstanding, these objects are thought to be pre-date boomerangs that are able to return to the spot from where they have been thrown.

In the light of the foregoing, there seems little doubt that boomerangs have been known to man for thousands of years and in many places around the world. They can be made of different types of materials, as long as they are light weighted and thin, among other characteristics.

WHAT IS A BOOMERANG?

A boomerang is made of two or more blades that must have a certain shape, like aeroplane wings, to be able to glide in the air. A distinction must be made between right and left-handed boomerangs, given that their blades will be rabbeted differently or opposite to each other. A right-handed boomerang will fly anti-clockwise, whereas a left-handed one will fly clockwise. Consequently, the blade shape will be different in each case.

The blades of a boomerang are lift surfaces, just like an aeroplane’s wings.

On moving through the air the shape of the boomerang generates a lift force.

The figure shows different boomerang sections, which vary in accordance with its relative position.

Each blade has a leading edge and trailing edge, the former being the one that first comes into contact with the air. This must be taken into account when making a right- or left-handed boomerang.

The rabbet of the trailing edge angle must be between 1/3 and 1/2 (approximately 25º of the inclination) of the amplitude of the blade, while the leading edge angle must be approximately 45º. The trailing edge rabbet must be gradual from the part that is furthest away from the blade's tip down to the end. The leading edge is practically constant along the whole blade. This is why boomerang blades are lift surfaces, just like the wings of an aeroplane. Their shape generates a lifting force on moving through the air.

The boomerang is thrown with an initial linear velocity and rotation that endows it with intrinsic angular momentum, which it will maintain throughout its path. The boomerang flies on a plane that has centre of mass velocity and is characterised by its closed path.

However, in addition to its intrinsic rotation, the boomerang is also constantly subjected to torque that is non-coaxial with respect to its rotation axis throughout its flight. The weight applied to its centre of mass and the lift force, displaced with respect to the former, constitute a real torque that is constantly acting throughout the flight of the boomerang.[...] The non-coaxial torque causes an inertial reaction, in such a way that the boomerang's initial rotation is maintained throughout its path, except for losses of friction or resistance. ***The action of this torque will be coupled to translational velocity, thus causing its peculiar path.*** [1]

As it travels through the air it maintains its rotation and is initially lifted by the aerodynamic lift effect that is generated by its blades

TRADITIONAL EXPLANATIONS

In the 1960s, Félix Hess carried out an in-depth theoretical and experimental study on the boomerang [3] at the University of Groningen (The Netherlands), which can be taken as the benchmark study in this field.

An article was published in the magazine *Scientific American* (*Investigación y Ciencia* - its Spanish version - in January 2002) by Wolfgang Bürger, also entitled *The Flight of the Boomerang* in which he carried out a dynamic analysis of this instrument. The author proposed that *a boomerang thrown forwards in a vertical position inclines the plane of its blades at the outset and flies in a curve that is approximately on a horizontal plane. According to Hess's observations we saw that the blade plane is always at a tangent to the flight path.*

The rotational momentum of the lift forces of the air is eluded by the boomerang in the same way that a gyroscope does: the plane of its blades rotates at an angular velocity of $\Omega = v/(L\cos(\alpha))$ *around the vertical axis that passes through its barycentre. A boomerang is as much a gyroscope as it is a glider. Its arms are blades that experience a force in its forward and rotational movement through the air. At one and the same time, a rotational momentum acts that wants to tilt the boomerang around the axis of its flight direction; the forward rotating blade experiences a direction wind and a lift force correspondingly greater than the one which is going backwards. As would a gyroscope, the boomerang eludes this rotating momentum by means of a change (precession) of its* *flight plane. The boomerang returns as a result of the movement in its path and gyroscopic precession.*

As would a gyroscope, the boomerang eludes this rotating momentum by means of a change ("precession") of its flight plane. The boomerang returns as a result of the movement in its path and gyroscopic precession [4].

We find this explanation unsatisfactory. It is a common feature of scientific literature to wish to explain the peculiar flight of the boomerang on the basis of a supposed *gyroscopic effect*, or as a result of the *gyroscopic precession* effect. In our opinion these explanations lack a certain precision and do not correspond to a coherent structuring of what is known about dynamics. We do not accept that in order to explain behaviour in physics we have to resort to analogies instead of referring to a logically structured body of knowledge.

In his article, Wolfgang Bürger goes on to acknowledge that there is no definitive, logical answer to explain boomerang behaviour within the realm of classical mechanics:

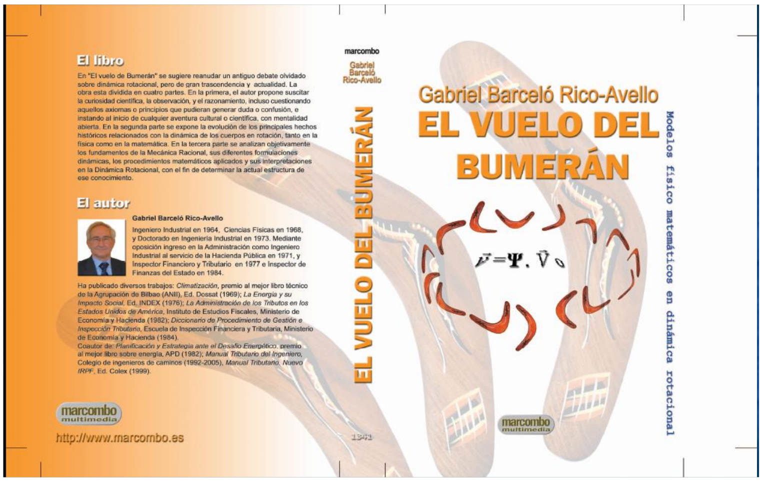
In spite of his insistence, Hess fails to find a conclusive answer to the question of the origin of the tilt until reaching a horizontal position. Boomerang experts and enthusiasts alike who catch boomerangs on their return flight, agree that the blade plane is always inclined towards the horizontal position. Gravity must be the cause of this positioning. Instead of embarking on a downward flight, the boomerang seeks out the horizontal and in doing so increases the upward directed part of its lift force [4].

In our opinion, it is impossible to explain the behaviour of the boomerang within the confines of Classical Mechanics, given that its flight occurs in accordance with non-inertial criteria, which can only be understood by means of the non-inertial laws of rotationally accelerated systems. We believe that the phenomenon ought to be interpreted pursuant to an accelerated systems' rotational dynamics in accordance with the hypotheses put forward in the *Theory of Dynamic Interactions*.

THE BOOMERANG'S PATH

The boomerang, on being thrown, must be endowed with an initial rotation on its axis of symmetry, perpendicular to its plane, but which is maintained on this same axis throughout its flight, as it travels along its orbit, in accordance with a closed path, thus returning to its point of origin.

It must be understood that boomerang dynamics, like that of all the flying objects with intrinsic rotation, are not explained by the laws of classical mechanics, but rather form part of the dynamics of non-inertial systems and, more exactly, that of systems accelerated by rotation, in which the moving object is subject, at one and the same time, to numerous non-coaxial rotations.



Front and back page to the book: The Flight of the Boomerang

Gabriel Barceló states in his book *The Flight of the Boomerang* (*El vuelo del Bumerán*) that after its launch: *The boomerang begins to rise practically vertically and rotate like a disk. It then drops gradually travelling in a circular path, doing a complete turn, without ever ceasing to rotate on itself. It is this peculiar closed path that some experts find more complicated to explain than how a rocket is put into orbit* [1].

In fact, the path of its trajectory will depend on a lot of variables, especially the skill of the thrower and the prevailing wind at the time of the throw.

WHY DOES THE BOOMERANG NOT FALL AND WHY DOES IT RETURN?

Gabriel Barceló's article THE THEORY OF DYNAMIC INTERACTIONS: THE FLIGHT OF THE BOOMERANG [2], published in the *Journal of Applied Mathematics and Physics*, issue 2014, 2, 569-580: http://www.scirp.org/journal/jamp
Paper ID: 10.4236/jamp.2014.27063:
http://dx.doi.org/10.4236/jamp.2014.27063
http://www.scirp.org/journal/PaperInformation.aspx?PaperID=46812#.VSDuHfmsVqU
and the presentation: ***Why Boomerangs fly***;
https://www.dropbox.com/s/ry4v1gij7jk0upk/Bumerang.mp4, provide a detailed description of its dynamic behaviour. A video was also made by the young producer Javier Sánchez-Blanco Boyer, which can be viewed at: https://www.dropbox.com/s/6h8lso3gbexck0j/Bomerang_v3_Mini.mp4?dl=0, where we explain the reason why the boomerang takes the path it does as opposed to any other weighted body, which rises as long as the momentum of the throw lasts and then falls quickly to the ground due to its weight. Its initial flight rises not only due to the momentum received, but also due to the lifting effect of its blades, caused by its peculiar structure.

These construction characteristics are the key to the peculiar flight of the boomerang but fail to explain its closed path; the fact that it can return to its place of origin.

Its characteristic closed path is due to another dynamic phenomenon, which does not occur in bodies thrown without their own rotation, which is why it differs from them: **the reason lies in its peculiar initial rotation,** as is explained in the aforementioned text.

LIFT FORCES

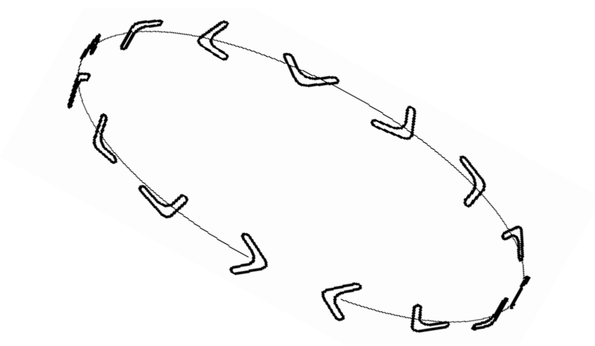
The forces that affect the path of a boomerang that simultaneously translate and rotate around a hypothetical axis external to it are normally studied in treatises. At least the following forces must be taken into account:

- ***Gravity***
- ***Drive***
- ***Rotation***
- ***Lift***
- ***Resistance***

And, especially, the aforementioned force couple made up of the weight and lift forces.

The ***force of gravity*** *is defined by the weight of the flying object, which remains constant throughout its flight path. The* ***drive*** *and* ***rotation*** *forces are provided by the momentum of the throw; they are instantaneous and maintain their respective movements owing to the body's inertia. The lift generated by the blades is proportional to the aerodynamic velocity and the angle of attack.*

The resistance forces consist of the ***structure drag,*** *which is the friction between the air and the boomerang structure, and the* ***induced resistance.*** *The former is a resistance to movement in the air caused by surface friction and the interference of air currents. The structure resistance increases proportionately to the square of the velocity. Induced resistance is caused by the lift and is generated by the displacement of the air from the high pressure area under the blade towards the low pressure area above it.*



Boomerang path

When the high pressure air under the blade swirls around the edge of the low pressure area located above these elements, vortices are created that absorb the kinetic energy. This loss of energy is the induced resistance and it increases as the aerodynamic velocity decreases. This effect becomes more noticeable at low aerodynamic velocities, *where a high angle of attack is needed to generate sufficient lift and balance the weight. Induced resistance varies inversely in proportion to the square of the velocity. The boomerang loses part of its kinetic energy in the form of work in order to overcome the resistances. Therefore, its flight necessarily comes to an end after a space of time.*

Notwithstanding, in addition to analysing the acting forces, the effect of the couples or momenta that can generate these forces must be known, a question we have not seen dealt with in any other text [1].

As it travels through the air it maintains its rotation and is initially lifted by the aerodynamic lift effect that is generated by its blades.

The flight of the boomerang is a clear example of the dynamics of accelerated systems caused by rotation that can be easily explained by the ***Theory of Dynamic Interactions*** and its laws of physics [5]. Nevertheless, this simply structured theory calls for a new idea of rotational mechanics, proposing as it does new inertial hypotheses about matter.

The theory we are proposing is explained in the aforementioned document: THE THEORY OF DYNAMIC INTERACTIONS: THE FLIGHT OF THE BOOMERANG, its dynamic behaviour and peculiar flight.

The aforementioned text and video contain explanations and provides novel, yet scientifically based, answers to the normal questions and answers posed about the boomerang.

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