CHAPTER THREE

ATMOSPHERIC RESISTANCE

BULLET AND AIR

Every schoolboy knows that the air impedes a bullet in its flight. Few, however, know what a great impediment it is. Most think such a "caressing" environment as the air—which is something we usually never feel—could not really get in the way of a fast-flying rifle bullet.

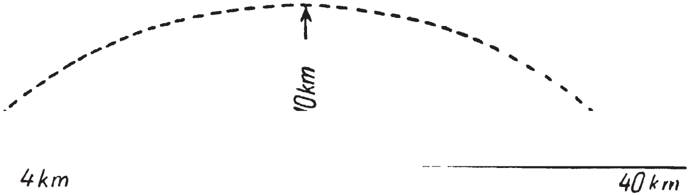

Fig. 28. Flight of a bullet in the air and in a vacuum. The big arc is the trajectory described when there is no atmosphere. The tiny, left-hand arc is the real trajectory

However, one good glance at *Fig. 28* will already make you realise that the air places quite a serious obstacle in the bullet's way. The large curve on the diagram designates the trajectory the bullet would describe were there no air. In this case, after flying out of a rifle tilted at 45°, and with an initial velocity of 620 m/sec, the bullet would describe a vast arc ten kilometres high and fly almost 40 km. But actually our bullet flies only 4 km, describing the tiny arc which is scarcely noticeable side by side with the first one. That is what the resistance of the air, the air drag, does!

BIG BERTHA

The Germans were the first—in 1918, towards the close of the First World War, when French and British aircraft had put a stop to German air raids—to practise long-range artillery bombardment from a distance of 100 kilometres and more.

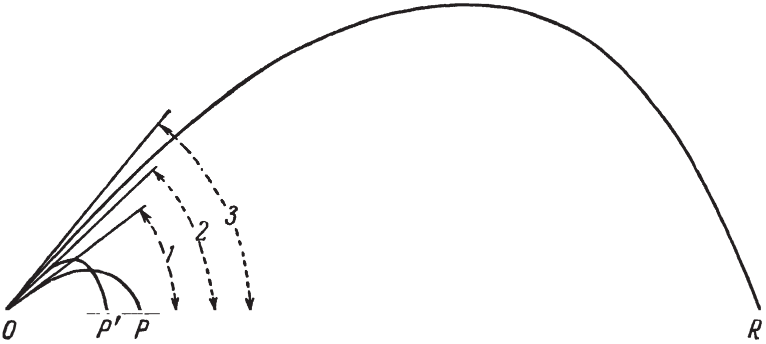

Fig. 29. The range changes when the mouth of a long-distance gun is tilted at different angles. In the case of angle *1*, the projectile strikes *P*, and in the case of angle *2*, *P'*, but in the case of angle *3*, it flies much farther as it goes through the rarefied stratosphere

It was by chance that German gunners hit upon their absolutely novel method for shelling the French capital, which was then at least 110 km away from the front lines. Firing shells from a big cannon tilted up at a wide angle, they unexpectedly discovered that they could make them fly 40 km instead of 20. When a shell is fired steeply upwards with a great initial velocity, it reaches a high-altitude, rarefied atmospheric strata, where the air drag is rather weak. Here it flies for quite a distance, before veering steeply to fall back to earth again. *Fig. 29* illustrates the great difference in trajectory at different angles of the gun barrel. This became the basic principle of the long-range gun that the Germans designed to bombard Paris from 115 km away. Such a gun was made—Big Bertha—and it fired more than 300 shells at Paris throughout the summer of 1918.

It was learned later that Big Bertha consisted of a tremendous steel tube 34 metres long and 1 metre thick. The breech walls were 40 cm thick. The gun itself weighed 750 tons. Its 120 kg shells were one metre long and 21 cm thick. Each charge took 150 kg of gunpowder which developed a pressure of 5,000 atmospheres, ejecting the shell with an initial velocity of 2,000m/sec. Since the angle of elevation was 52°, the shell described a tremendous arc, reaching its highest point way up in the stratosphere 40 km above the ground. It took the shell only 3.5 minutes to reach Paris, 115 km away; two minutes were spent in the stratosphere.

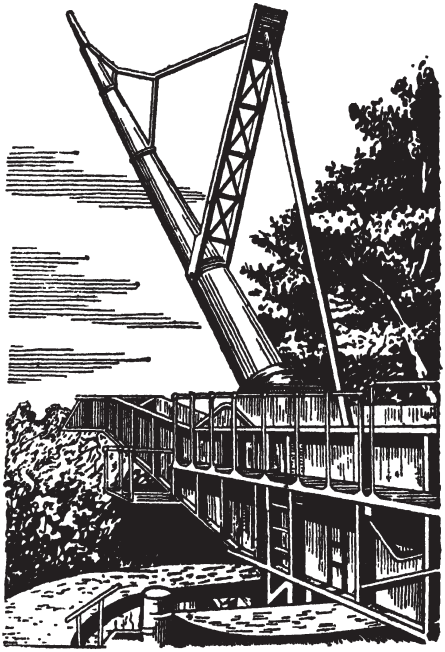

Fig. 30. Big Bertha

Big Bertha was the first long-range gun in history, the progenitor of modern long-range artillery.

Let me note that the greater the initial velocity of a bullet or shell, the more resistance the air puts up, increasing, moreover, in proportion to the square, cube, etc., of the velocity, depending on its amount.

WHY DOES A KITE FLY?

Do you know why a kite soars when pulled forward by the twine? If you do, you will also be able to understand why airplanes fly and maple seeds float. You'll even be able to fathom to some extent the causes of the boomerang's very odd behaviour. Because all these things are related. The very same air which is so great an impediment to a bullet or a shell enables the light maple seed to float and even heavy airliners to fly.

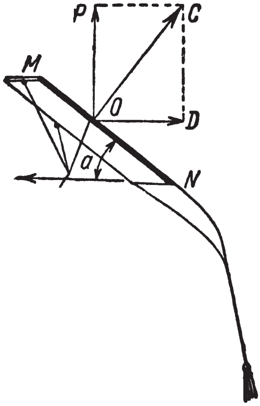

Fig. 31. The forces that make a kite fly

If you don't know why a kite flies, the simple drawing in *Fig. 31* will provide the explanation. Let line *MN* designate the kite's cross-section. When you let the kite go and pull at the cord, the kite, because of its heavy tail, moves at an angle to the ground. Let the kite move from right to left and *a* be the angle at which the plane of the kite is inclined to the horizon. We shall now proceed to examine the forces that act on the kite. The air, of course, should obstruct its movement and exert some pressure on it, designated on *Fig. 31* by the vector *OC*. Since the air always presses perpendicular to the plane, *OC* is at right angles to *MN*. The force *OC* may be resolved into two forces by constructing what is called a *parallelogram of forces*. This gives us the two forces *OD* and *OP*. Of these two, the force *OD* pushes the kite back, thus reducing its initial velocity. The other force, *OP*, pulls the kite up, reducing its weight. When this force is big enough it overcomes the weight of the kite and lifts it. That is why the kite goes *up* when you pull it *forwards*.

The airplane is also a kite really, with the difference that its forward motion, which makes it go up, is imparted not by our pulling at it but by the propeller or jet engine. This is, of course, a very crude explanation. There are other factors that cause an airplane to rise. They are explained in Book Two of *Physics for Entertainment* under the heading "Waves and Whirlwinds".

LIVE GLIDERS

As you see aircraft are not made like birds, as one usually thinks, but rather like flying squirrels or flying fish, which, by the way, employ their flying mechanism not to fly up but merely to take rather big leaps—or what a flier would call "glides". In their case, the force *OP*

(*Fig. 31*) is too small to offset their weight; it merely reduces their weight, enabling them to make very big jumps from some high point (*Fig. 32*). A flying squirrel can jump 20-30 m from the top of one tree to the lower branches of another. In the East Indies and in Ceylon a much larger species of flying squirrel is found. This is the kaguan, a flying lemur, which is about the size of our house cat and which has a wing spread of about half a metre, enabling it to leap some 50 m, despite its great weight. As for the phalangers that inhabit the Sunda Isles and the Philippines, they can jump as far as 70 m.

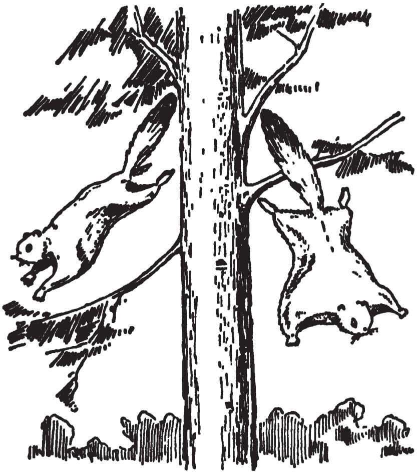

Fig. 32. Flying squirrels jump from 20 to 30 m

BALLOONING SEEDS

Plants also often employ a gliding mechanism to propagate. Many seeds have either a parachuting tuft or hairy appendages (the pappus), as in dandelions, cotton balls, and "goat's beards", or "wings", as in conifers, maples, white birches, elms, lindens, many kinds of umbelliferae, etc.

In Kerner von Marilaum's well-known *Plant Life*, we find the following relevant passage:

"On windless sunny days a host of seeds and fruits are lifted high up by vertical air currents. However, after dusk they usually float down a short cry away. It is important for seeds to fly, not so much to cover a wide area as to inhabit cracks in terraces and cliffs, which they would never reach in any other way. Meanwhile, horizontal air currents may carry these hovering seeds and fruits rather far.

"The seeds of some plants retain their wings and parachutes only while they fly. Thistle seeds quietly float until they encounter an obstacle, when the seed discards its parachute and drops to the ground. That is why we see the thistle so often near walls and fences. But there are other cases, when the seed is attached permanently to its parachute."

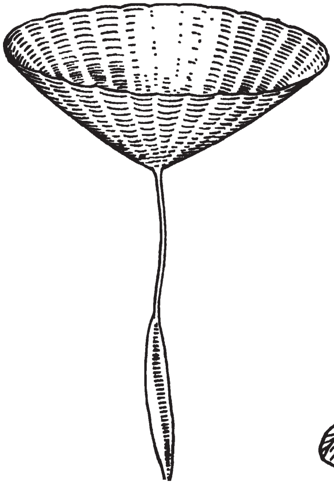

Fig. 33. Fruit of "goat's beard"

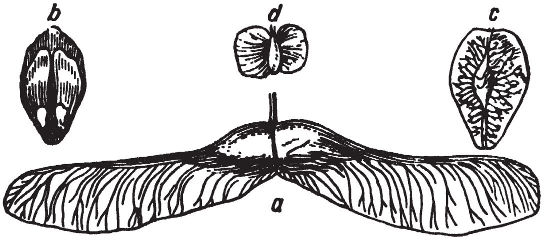

Fig. 34. Winged seeds of *a*) maple, *b*) pine-tree, *c*) elm, and *d*) birch

Figs. 33 and *34* show some seeds and fruits that have a gliding mechanism. As a matter of fact these plant "gliders" beat man-made ones on many points. They can lift a load which may be much greater than their own weight and automatically stabilise it. Thus if the seed of the Indian jasmine should chance to turn over, it will automatically regain its initial position with its convex side bottom-most, but when it meets an obstacle it doesn't capsize and drop like a plummet, but coasts down instead.

DELAYED PARACHUTE JUMPING

This, naturally, brings to mind the brave jumps parachutists sometimes make. They bail out at altitudes of some ten kilometres and pull the ripcord only after plummeting like a stone without opening their parachutes for quite a distance. Many think that in this delayed jump the parachutist falls as if in empty space. If this were really so, the delayed jump would be a much shorter affair, while the near-ground velocity would be tremendous.

However, atmospheric resistance prevents acceleration. The velocity of the falling parachutist during a delayed jump increases only in the first ten seconds, only for the first few hundred metres. Meanwhile atmospheric resistance increases, to finally reach a point where all further acceleration stops and the falling becomes even.

Here is a crude idea of a delayed jump from the angle of mechanics. *Acceleration* continues for only the first 12 seconds or even less, depending on the parachutist's weight. In this period he drops some 400-450 m and works up a velocity of about 50 m/sec. After that he falls uniformly, with the same speed, until he pulls the ripcord. Raindrops fall similarly. The only difference is that the initial period of acceleration for the raindrop is no more than a second. Consequently its near-ground velocity is not so great as in a delayed parachute jump, being between 2 and 7 metres a second, depending on its size. (Read my *Mechanics for Entertainment* for more about raindrop velocity and my *Do You Know Your Physics?* for more about delayed parachute jumping.)

THE BOOMERANG

For long this ingenious weapon, the most perfect technical device primitive man ever invented, had scientists wonderstruck. Indeed. the queer tangled trajectory the boomerang traces (*Fig. 35*) can tease any mind. Nowadays we have an elaborate theory to explain the boomerang; it is no longer a wonder. This theory is too intricate to explain at length. Let me merely note that boomeranging is the combined result of three factors: firstly, the initial throw; secondly, the boomerang's own rotation, and thirdly, atmospheric resistance. The Australian aborigine instinctively knows how to combine all three, deftly changing the boomerang's tilt and direction, and he throws it with a greater or smaller force to obtain the desired result.

You, too, can acquire some knack in boomerang-throwing. To make one for indoors, cut it out of cardboard, in the form shown in *Fig. 36*. Each arm is about 5 cm long and a little less than a centimetre

Fig. 35. Australian aborigine throwing a boomerang. The dotted line shows the trajectory of the boomerang, should it miss its target

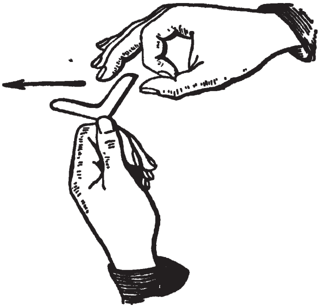

Fig.36. A cardboard boomerang and how to "throw" it

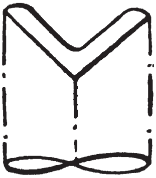

Fig. 37. Another cardboard boomerang (real size)

wide. Press it under the nail of your thumb and flick it forwards and a bit upwards. It will fly some five metres, loop, and return to your feet, provided it doesn't hit anything on the way. You can make a still better boomerang by copying the one given in *Fig. 37*, and also by twisting it to look somewhat like a propeller (as shown at the bottom of *Fig. 37*). After some experience you should be able to make it describe intricate curves and loops before it returns to your feet.

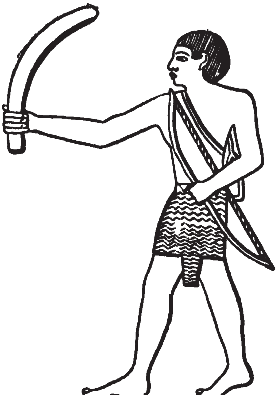

Fig. 38. Ancient Egyptian warrior throwing a boomerang

In conclusion let me note that the boomerang is not at all exclusively an Australian missile as is usually thought. It was employed in India and according to extant murals it was once commonly used by Assyrian warriors (see *Fig. 38*). It was also familiar in ancient Egypt and Nubia. The Australian boomerang's only distinguishing feature is the propeller-like twist that we mentioned, sending it into such a maze of whirls and loops, returning it to the thrower, *should he miss.*