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HOW ANIMALS RUN

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HOW ANIMALS RUN

Many animals, both predators and prey, have evolved the ability to run two or three times faster than a man can. What are the adaptations that make these impressive performances possible?

by Milton Hildebrand

A man (but not necessarily you or I!) can run 220 yards at the rate of 22.3 miles per hour, and a mile at 15.1 miles per hour. The cheetah, however, can sprint at an estimated 70 miles per hour. And the horse has been known to maintain a speed of 15 miles per hour not just for one mile but for 35 miles.

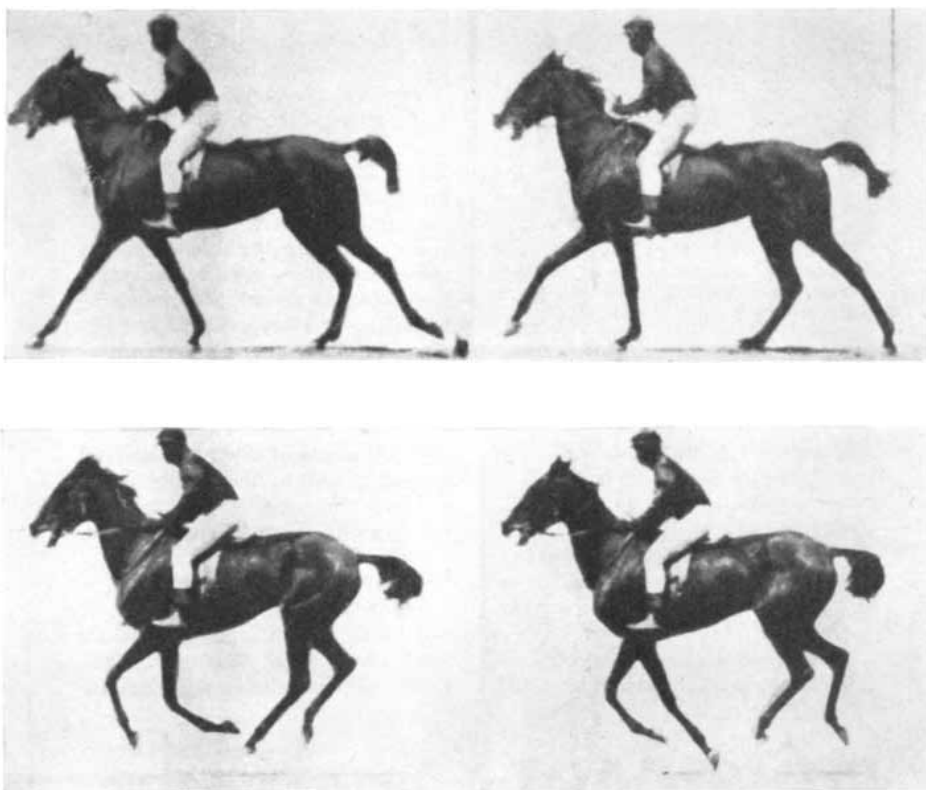
Other animals are capable of spectacular demonstrations of speed and endurance. Jack rabbits have been clocked at 40 miles per hour. The Mongolian ass is reported to have run 16 miles at the impressive rate of 30 miles per hour. Antelopes apparently enjoy running beside a moving vehicle; they have been reliably timed at 60 miles per hour. The camel has been known to travel 115 miles in 12 hours. Nearly all carnivorous mammals are good runners: the whippet can run 34 miles per hour; the coyote, 43 miles per hour; the red fox, 45 miles per hour. One red fox, running before hounds, covered 150 miles in a day and a half. A fox terrier rewarded with candy turned a treadmill at the rate of 5,000 feet per hour for 17 hours.

I have been attracted by such performances as these to undertake an investigation of how the living running-machine works. The subject has not been thoroughly explored. One study was undertaken by the American photographer Eadweard Muybridge in 1872. Working before the motion-picture camera was invented, Muybridge set up a battery of still cameras to make photographs in rapid sequence. His pictures are still standard references. A. Brazier Howell's work on speed in mammals and Sir James Gray's studies on posture and movement are well known to zoologists. Many investigators have added to our knowledge of the anatomy of running vertebrates, but the analysis of function has for the most part been limited to deductions

from skeletons and muscles. The movements of the running animal are so fast and so complex that they cannot be analyzed by the unaided eye.

In my study I have related comparative anatomy to the analysis of motion pictures of animals in action. The method is simple: Successive frames of the motion picture are projected onto tracing paper, where the movements of the parts of the body with respect to one another and to the ground can be ana-

lyzed. The main problem is to get pictures from the side of animals running at top speed over open ground. With an electric camera that exposes 200 frames per second I have succeeded in photographing the movements of a cheetah that had been trained by John Hamlet of Ocala, Fla., to chase a paper bag in an enclosure 65 yards long. However, the animal never demonstrated its top speed, but merely loped along at about 35 miles per hour. I have used the same



STRIDE OF A CANTERING HORSE is shown in these photographs from Eadweard Muybridge's *The Horse in Motion*, published in 1878. The sequence runs right to left across the

camera to make pictures of horses running on race tracks, and I am presently collecting motion-picture sequences of other running animals from commercial and private sources.

All cursorial animals (those that can run far, fast and easily) have evolved from good walkers, and in doing so have gained important selective advantages. They are able to forage over wide areas. A pack of African hunting dogs, for example, can range over 1,500 square miles; the American mountain lion works a circuit some 100 miles long; individual arctic foxes have on occasion wandered 800 miles. Cursorial animals can seek new sources of food and water when their usual supplies fail. The camel moves from oasis to oasis, and in years of drought the big-game animals of Africa travel impressive distances. The mobility of cursorial animals enables them to overcome seasonal variations in climate or in food supply. Some herds of caribou migrate 1,600 miles each year. According to their habit, the predators among the cursorial animals exploit superior speed, relay tactics, relentless endurance or surprise to overtake their prey. The prey species are commonly as

swift as their pursuers, but sometimes they have superior endurance or agility.

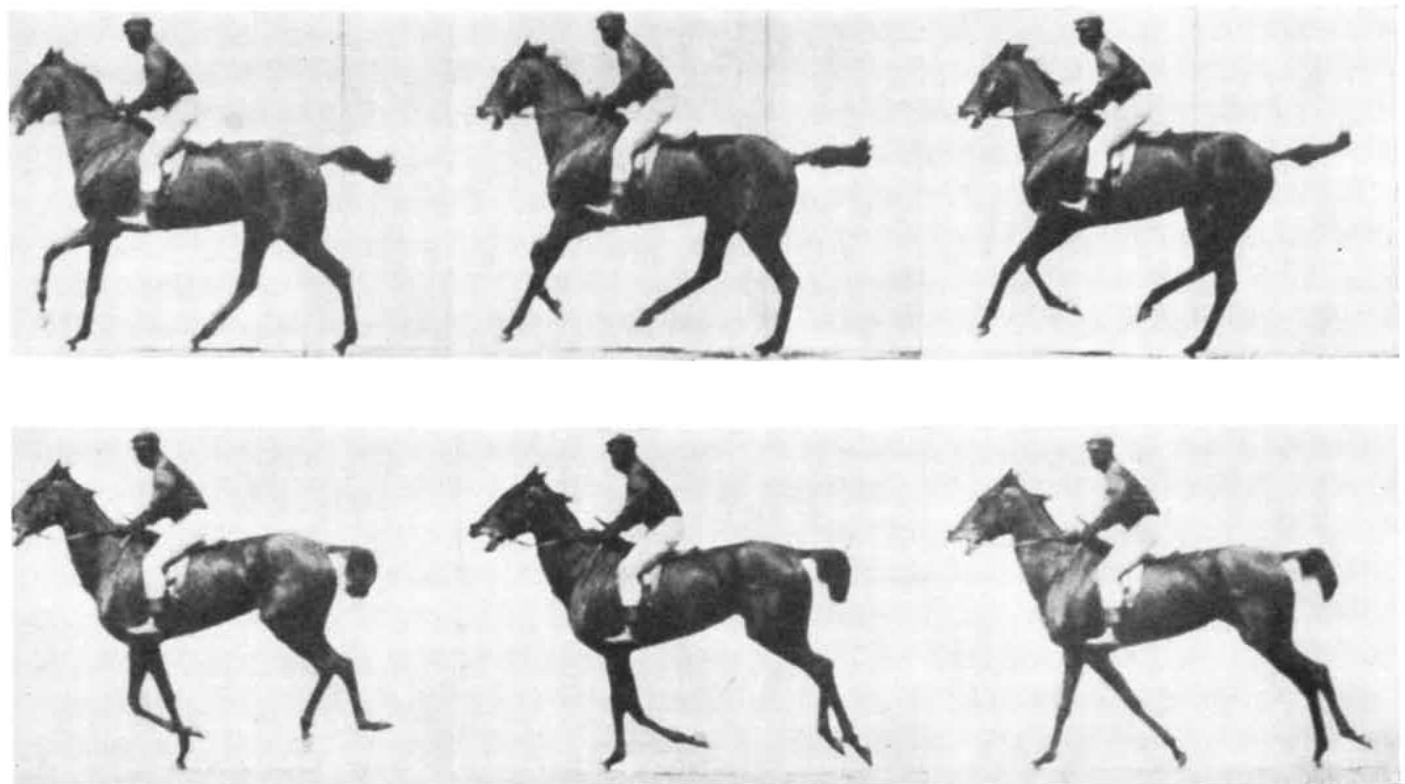
Speed and endurance are the capacities that characterize all cursorial vertebrates. But one could not make a definitive list of the cursorial species without deciding quite arbitrarily how fast is fast and how far is far. Even then the list would be incomplete, because there are reliable data on speed for only a few animals; in most cases authors quote authors who cite the guesses of laymen. Many cursors are extinct. On the basis of fossils, however, we can surmise that many dinosaurs were excellent runners; that some extinct rhinoceroses, having had long and slender legs, were very fast; and that certain extinct South American grazing animals, having evolved a horse-like form, probably had horselike speed.

In order to run, an animal must overcome the inertia of its body and set it into motion; it must overcome the inertia of its legs with every reversal in the direction of their travel; it must compensate for forces of deceleration, including the action of the ground against its descending feet. A full cycle of motion is called a stride. Speed is the product of length of stride times rate of stride. The giraffe achieves a moderate speed with

a long stride and a slow rate of stride; the wart hog matches this speed with a short stride and a rapid rate. High speed requires that long strides be taken at a rapid rate, and endurance requires that speed be sustained with economy of effort.

Although longer legs take longer strides, speed is not increased simply by the enlargement of the animal. A larger animal is likely to have a lower rate of stride. Natural selection produced fast runners by making their legs long in relation to other parts of the body. In cursorial animals the effective length of the leg—the part that contributes to length of stride—is especially enhanced. The segments of the leg that are away from the body (the foot, shank and forearm) are elongated with respect to the segments close to the body (the thigh and upper arm). In this evolutionary lengthening process the bones equivalent to the human palm and instep have become the most elongated.

Man's foot does not contribute to the length of his leg, except when he rises on his toes. The bear, the opossum, the raccoon and most other vertebrates that walk but seldom run have similar plantigrade ("sole-walking") feet. Carnivo-



top row and continues across the bottom row. With these and similar photographs Muybridge settled the controversy of whether

or not a horse "even at the height of his speed [has] all four of his feet . . . simultaneously free from contact with the ground."

rous mammals, birds, running dinosaurs and some extinct hoofed mammals, on the other hand, stand on what corresponds to the ball of the human foot; these animals have digitigrade (“finger-walking”) feet. Other hoofed mammals owe an even further increase in the effective length of their legs to their unguligrade (“hoof-walking”) posture, resembling that of a ballet dancer standing on the tips of her toes. Where foot posture and limb proportions have been modified for the cursorial habit, the increased length and slenderness of the leg is striking [see illustration on page 155].

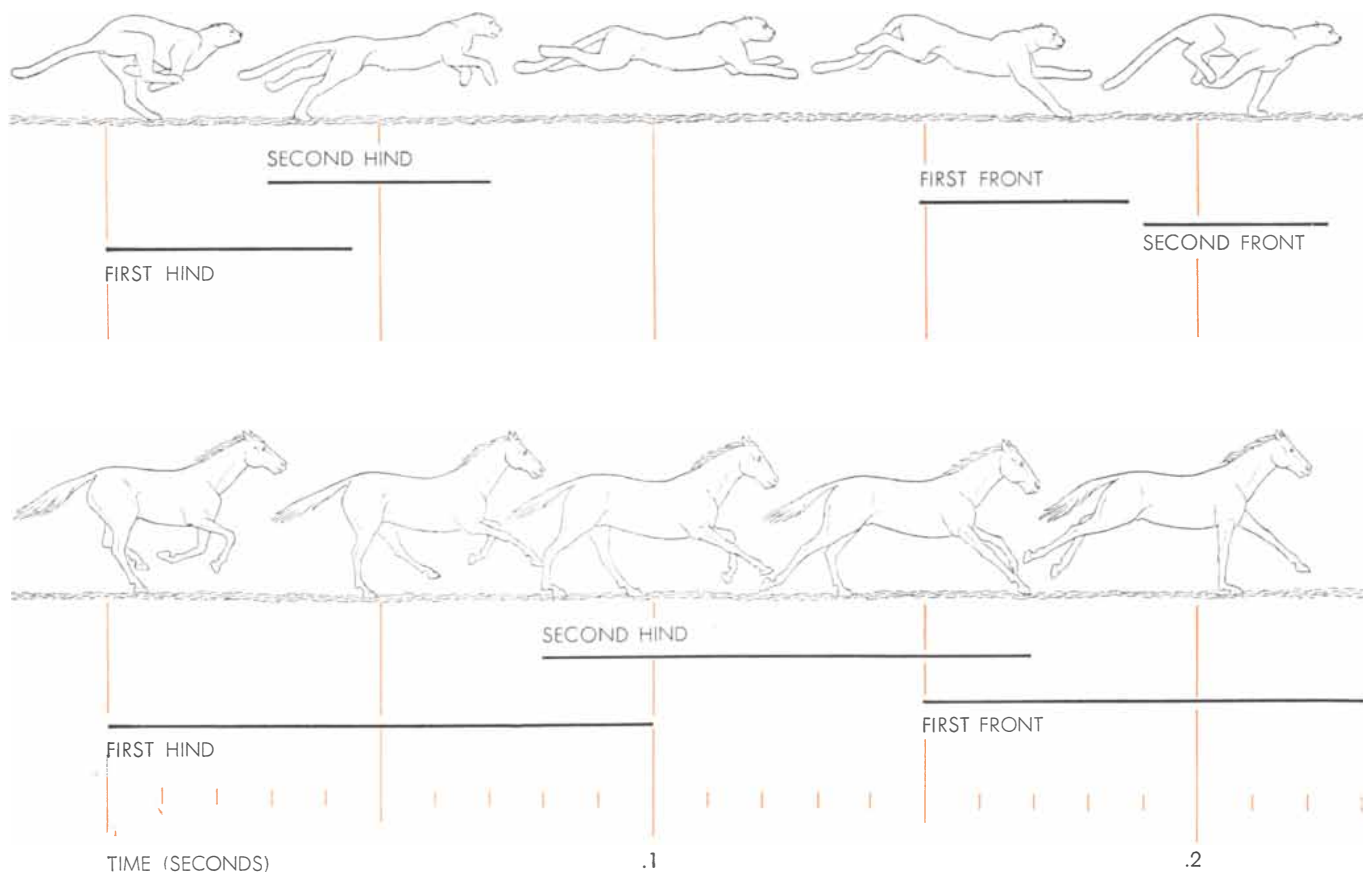
The effective length of the front limb of many runners is also increased by the modification of the structure and function of the shoulder. The shoulder joint of amphibians, reptiles and birds is virtually immobilized by the collarbone, which runs from the breast bone to each shoulder blade, and by a second bone,

the coracoid bone. Because mammals do not have a coracoid bone their shoulder blade has some freedom of movement. In the carnivores this freedom is increased by the reduction of the collarbone to a vestige; in the ungulates the collarbone is eliminated. In both carnivores and ungulates the shoulder blade is oriented so that it lies against the side of a narrow but deep chest rather than against the back of a broad but shallow chest, as it does in man. Thus mounted, the shoulder blade pivots from a point about midway in its length, and the shoulder joint at its lower end is free to move forward and backward with the swing of the leg. The exact motion is exceedingly difficult to ascertain in a running animal, but I have found that it adds about 4.5 inches to the stride of the walking cheetah.

The supple spine of the cat and the dog increases the length of stride of these animals still further. The body of such an animal is several inches longer

when the back is extended than when it is flexed. By extending and flexing its back as its legs swing back and forth the animal adds the increase in its body length to its stride. Timing is important in this maneuver. If the animal were to extend its back while its body was in mid-air, its hindquarters would move backward as its forequarters moved forward, with no net addition to the forward motion of the center of mass of its body. In actuality the running animal extends its back only when its hind feet are pushing against the ground. The cheetah executes this maneuver so adeptly that it could run about six miles per hour without any legs.

With the extra rotation of its hip and shoulder girdles and the measuring-worm action of its back, the legs of the running cursor swing through longer arcs, reaching out farther forward and backward and striking and leaving the ground at a more acute angle than they would if the back were rigid. This clear-



STRIDES OF THE CHEETAH AND THE HORSE in full gallop are contrasted in these illustrations. The sequence and duration of their footfalls, indicated by the horizontal lines under each animal,

relate to the time-scale at bottom, which is calibrated in 10ths of a second. The cheetah has two unsupported periods, which account for about half its stride; the horse has one unsupported period,

ly increases stride length, but it also aggravates a problem. The body of the animal tends to rise when its shoulders and hips pass over its feet, and tends to fall when its feet extend to the front or rear. Carnivores offset this bobbing motion by flexing their ankles and wrists, thus shortening their legs. Ungulates do the same by sharply flexing the fetlock joint at the moment that the body passes over the vertical leg. The cheetah, a long-striding back-flexer, supplements its wrist-flexing by slipping its shoulder blade up its ribs about an inch, and thus achieves a smooth forward motion.

Since running is in actuality a series of jumps, the length of the jump must be reckoned as another important increment in the length of the stride. Hoofed runners have one major unsupported period, or jump, in each stride: when the legs are gathered beneath the body. The galloping carnivore has two major unsupported periods: when the back is flexed, and again when it is extended. In

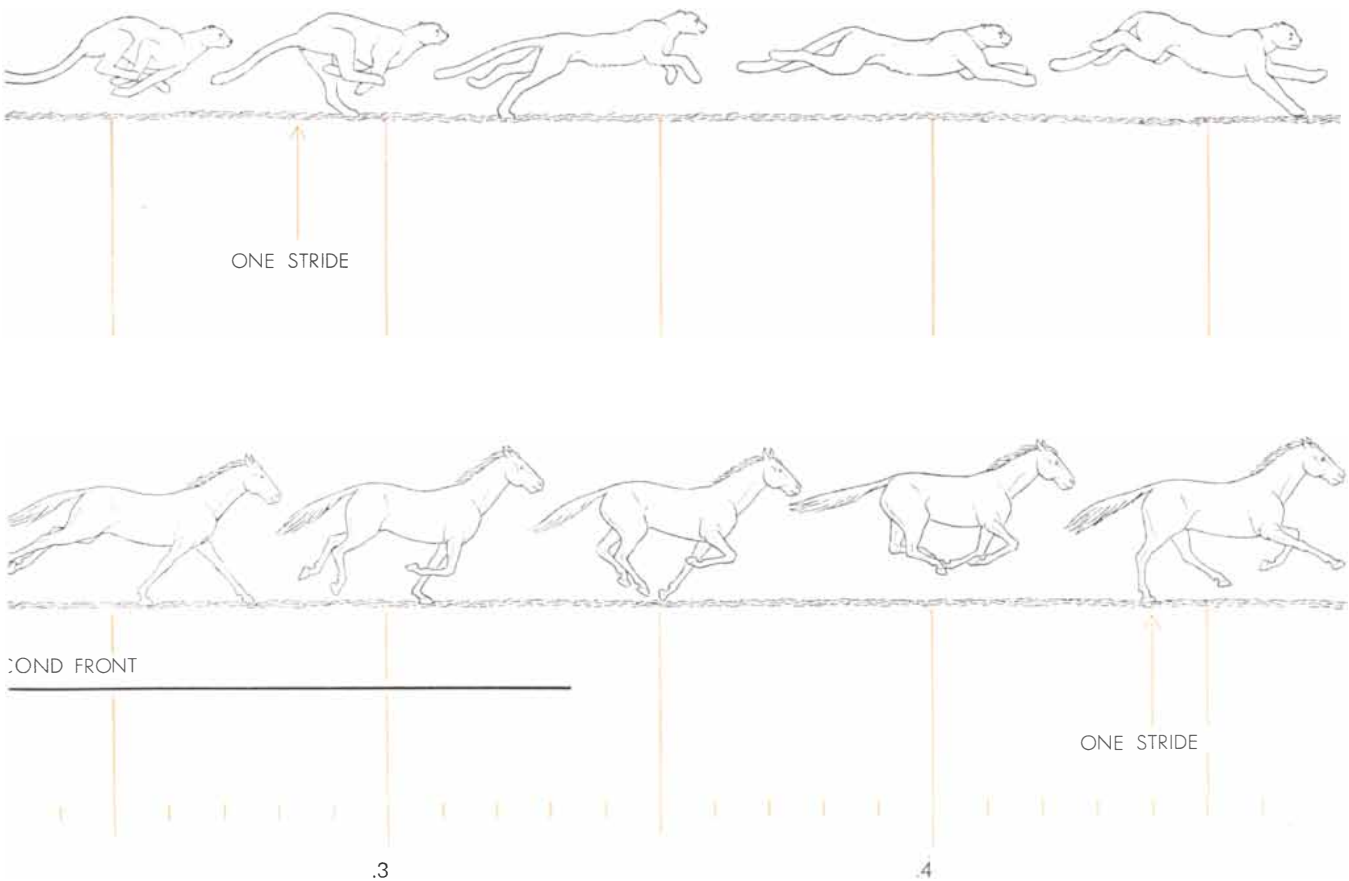
the horse all of these anatomical and functional adaptations combine to produce a 23-foot stride. The cheetah, although smaller, has a stride of the same length.

Fast runners must take their long strides rapidly. The race horse completes about 2.5 strides per second and the cheetah at least 3.5. It is plain that the higher the rate of stride, the faster the runner must contract its muscles. One might infer that cursorial animals as a group would have evolved the ability to contract their muscles faster than other animals. Within limits that is true, but there is a general principle limiting the rate at which a muscle can contract. Assuming a constant load on the muscle fibers, the rate of contraction varies inversely with any of the muscle's linear dimensions; the larger muscle therefore contracts more slowly. That is why an animal with a larger body has a slower rate of stride and so loses the ad-

vantage of its longer length of stride.

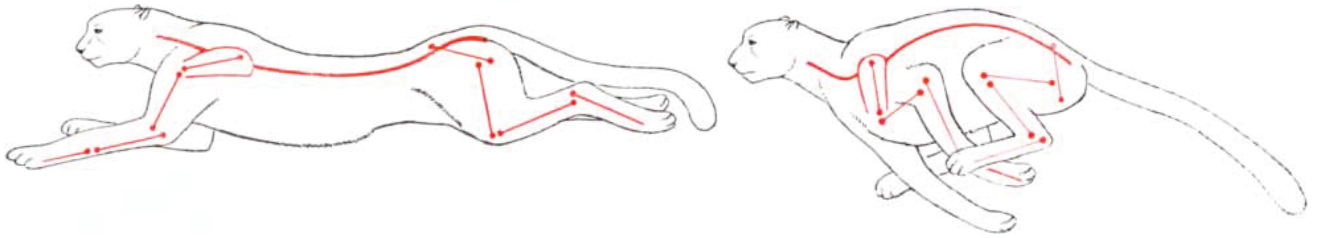
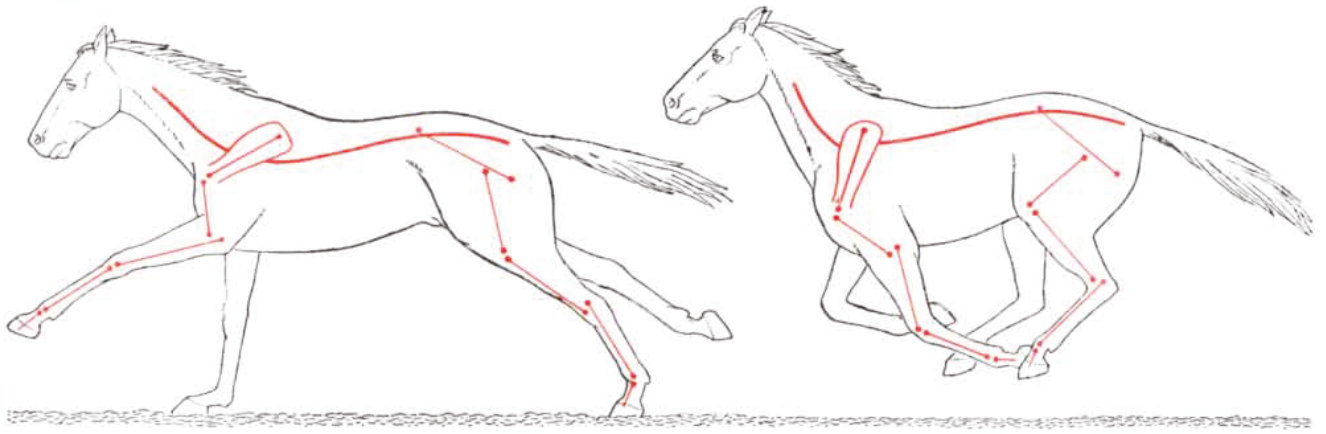
The familiar mechanical principle of gear ratio underlies the fast runner's more effective use of its trim musculature. In the linkage of muscle and bone the gear ratio is equal to the distance between the pivot of the motion (the shoulder joint, for example) and the point at which the motion is applied (the foot) divided by the perpendicular distance between the pivot and the point at which the muscle is attached to the bone. Cursorial animals not only have longer legs; their actuating muscles are also attached to the bone closer to the pivot of motion. Their high-gear muscles, in other words, have short lever-arms, and this increases the gear ratio still further. In comparison, the anatomy of walking animals gives them considerably lower gear-ratios; digging and swimming animals have still lower gear ratios.

But while high gears enable an automobile to reach higher speed, they do



which accounts for about a quarter of its stride. Although both the cheetah and the horse cover about 23 feet per stride, the cheetah attains speeds on the order of 70 miles per hour, to the horse's 43,

because it takes about 3.5 strides to the horse's 2.5. The size of the horse has been reduced disproportionately in these drawings for the sake of uniformity in the stride-lines and time-scale.



SWIVELING SHOULDER BLADES of the horse and the cheetah add several inches to their stride length. The faster cheetah gains a further advantage from the flexibility of the spine, which in addition

to adding the length of its extension to the animal's stride, adds the speed of its extension to the velocity of its travel. Horse's relatively longer leg partially compensates for its rigid spine.



SPRINGING LIGAMENTS in the legs of horses, shown here, and other hoofed runners reduce the need for heavy muscles. Impact of the foot against the ground (*left*) bends the fetlock joint (*mid-*

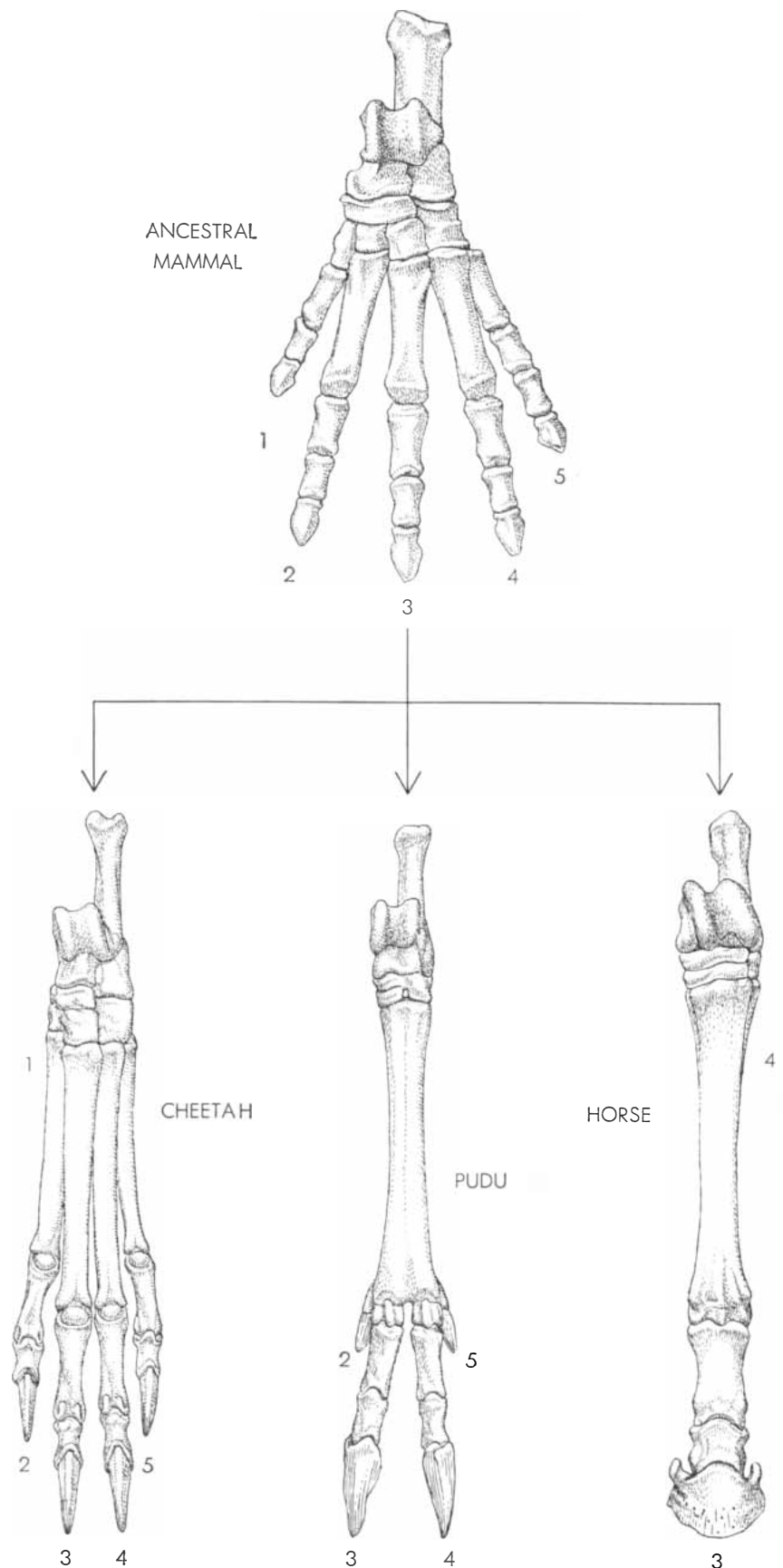
dle) and stretches an elastic ligament (*shown in color*) that snaps back when the foot leaves the ground (*right*). The springing action at once straightens the foot and gives the leg an upward impetus.

so at the expense of power. The cursorial animal pays a similar price, but the exchange is a good one for several reasons. Running animals do not need great power: air does not offer much resistance even when they are moving at top speed. Moreover, as the English investigators J. M. Smith and R. J. G. Savage have noted, the animal retains some relatively low-gear muscles. Probably the runner uses its low-gear muscles for slow motions, and then shifts to its high-gear muscles to increase speed.

Since the speed at which a muscle can contract is limited, the velocity of the action it controls must be correspondingly limited, even though the muscle speed is amplified by an optimum gear-ratio. A larger muscle, or additional muscles, applied to action around the same joint can produce increased power but not greater speed. Several men together can lift a greater weight than one can lift alone, but several equally skilled sprinters cannot run faster together than one of them alone. The speed of a leg can be increased, however, if different muscles simultaneously move different joints of the leg in the same direction. The total motion they produce, which is represented by the motion of the foot, will then be greater than the motion produced by any one muscle working alone. Just as the total speed of a man walking up an escalator is the sum of his own speed plus that of the escalator, so the independent velocities of each segment of the leg combine additively to produce a higher total velocity.

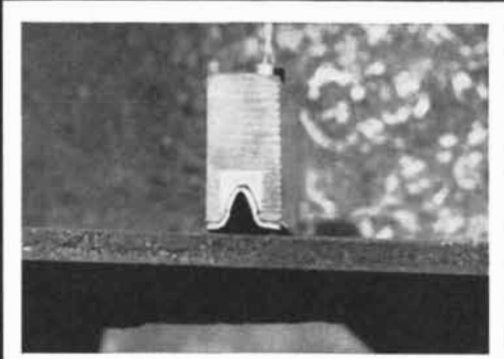
The trick is to move as many joints as possible in the same direction at the same time. The evolution of the cursorial body has produced just this effect. By abandoning the flat-footed plantigrade posture in favor of a digitigrade or unguligrade one, the cursorial leg acquired an extra limb-joint. In effect it gained still another through the altered functioning of the shoulder blade. The flexible back of the cursorial carnivore adds yet another motion to the compound motion of its legs; the back flexes in such a way that the chest and pelvis are always rotating in the direction of the swinging limbs.

The supple spine of the carnivore contributes to stride rate by speeding up the motion of its body as well as of its legs. The spine is flexed when the runner's first hind foot strikes the ground, and by the time its second hind foot leaves the ground the animal has extended its spine and thus lengthened its body. In the brief interval when its hind

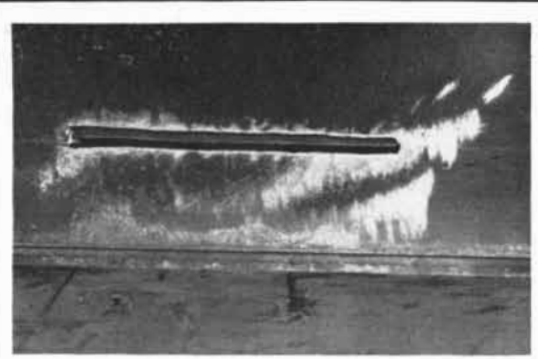


MODERN CURSORIAL FOOT EVOLVED from the broad, five-digit foot of an ancestral mammal (*top*). Lateral digits were lost and metatarsal bones, the longest in the foot, were further elongated. Resultant foot is lighter and longer. Pudu is a deer of the Andes.

A plastic that blasts holes



1. Explosive charge is set in urethane casting.



3. "Line" of fire cuts right through metal plate.



2. Casting directs force of explosion along a sharp line.

in metal

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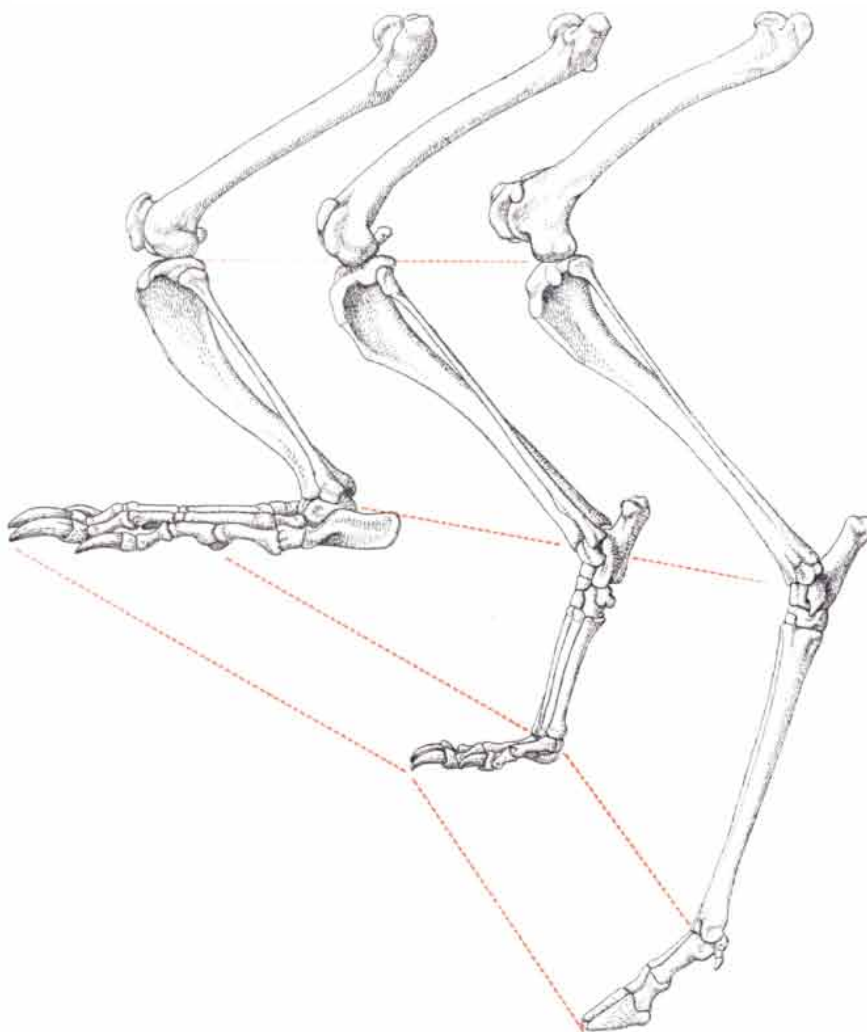
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feet are planted, the forequarters, riding on the extending spine, move farther and faster than the hindquarters. Similarly when the front feet are on the ground, the hindquarters move faster than the forequarters. So although the speed that the driving legs can impart to the forequarters or hindquarters is limited by their rate of oscillation, the body as a whole is able to exceed that limit. In a sense the animal moves faster than it runs. For the cheetah the advantage amounts to about two miles per hour—enough to add the margin of success in a close chase.

In addition to the obvious tasks of propelling the animal's body and supporting its weight, the locomotor mus-

cles must raise the body to compensate for the falling that occurs during the unsupported phases of the stride. The load they must raise is proportional to the mass of the body, which is in turn proportional to the cube of any of its linear dimensions. A twofold increase in body length thus increases weight eightfold. The force that a muscle can exert, on the other hand, increases only as the square of its cross section. Thus against an eightfold increase of load, bigger muscles can bring only a fourfold increase of force. As body size increases, the capacity of the muscles to put the body in forward motion and to cause its legs to oscillate cannot quite keep up with the demands placed upon them. These fac-



ADAPTATION OF THE LEG FOR SPEED is illustrated by the hind-leg bone of the slow badger (*left*), moderately fast dog (*middle*) and highly adapted deer (*right*). The lengthened metatarsus of the latter two has yielded a longer foot and an altered ankle posture that is better suited to running. The thigh bones of all three animals have been drawn to the same scale to show that the leg segments farthest from the body have elongated the most.

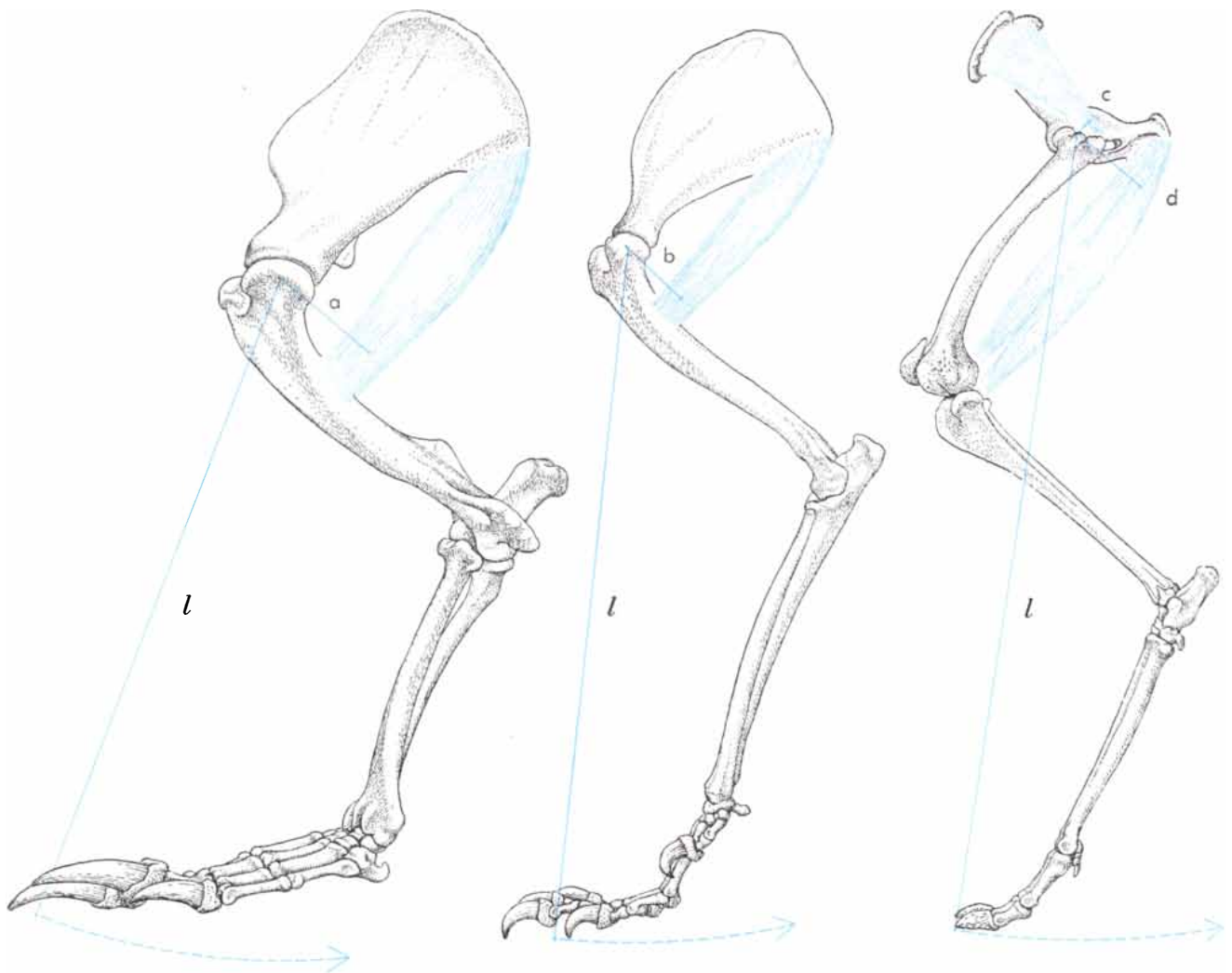
tors in the nature of muscle explain why the largest animals can neither gallop nor jump, why small runners such as rabbits and foxes can travel as fast as race horses without having marked structural adaptations for speed and why the larger cursorial animals must be highly adapted in order to run at all.

If the bigger runners are to have endurance as well as speed, they must have not only those adaptations that increase the length and rate of their stride,

but also adaptations that reduce the load on their locomotor structures and economize the effort of motion. In satisfying this requirement natural selection produced a number of large and fast runners that are able to travel for long distances at somewhat less than their maximum speed. In these animals the mass of the limbs is minimized. The muscles that in other animals draw the limbs toward or away from the midline of the body (the "hand-clapping" muscles in man) are smaller or adapted to moving the legs

in the direction of travel, and the muscles that manipulate the digits or rotate the forearm have disappeared. The ulna in the forearm and the fibula in the shank—bones involved in these former motions—are reduced in size. The ulna is retained at the point where it completes the elbow joint, but elsewhere becomes a sliver fused to its neighbor; the fibula is sometimes represented only by a nubbin of bone at the ankle.

The shape of the cursorial limb embodies another load-reducing principle.



POWER AND SPEED are alternatively achieved in the badger (*left*) and the cheetah (*middle*) by placement of the teres major muscle. In the cheetah the small distance (b) between the muscle insertion and the joint it moves yields a higher rate of oscillation than in the badger, in which the distance (a) is greater. The higher

oscillation rate, coupled with a longer leg (*l*), yields a faster stride. In the vicuña (*right*) the gluteus muscle (c) develops about five times the velocity but only a fifth the force of the larger semimembranosus muscle (d). The animal may use the latter to overcome inertia; the former, for high speed. Legs are not in same scale.

Since the kinetic energy that must be alternately developed and overcome in oscillating the limb is equal to half the mass times the square of its velocity, the load on muscles causing such motions can be reduced not only by reducing the mass of the faster-moving parts of the limb but also by reducing the velocity of the more massive parts. Accordingly the fleshy parts of the limb are those close to the body, where they do not move so far, and hence not so fast, as the more distant segments. The lower segments, having lost the muscles and bones involved in rotation and in digit manipulation, are relatively light.

The rigor of design imposed by natural selection is especially evident in the feet of cursorial animals. The feet of other animals tend to be broad and pliable; the bones corresponding to those of the human palm and instep are rounded in cross section and well separated. In the foot of the cursorial carnivore, on the other hand, these bones are crowded into a compact unit, each bone having a somewhat square cross section. In the ungulates the ratio of strength to weight has been improved still further by reduction of the number of bones in the foot. The ungulates have tended to lose their lateral toes; sometimes the basal elements of the other toes are fused into a single bone. This process gave rise to the cannon bone: the shank of the hoofed mammals [see illustration on page 153]. In compensation for the bracing lost as the bones and muscles of their lower limbs were reduced or eliminated, these animals evolved joints that are modified to function as hinges and allow motion only in the line of travel.

The burden on the muscles of hoofed animals is relieved by an especially elegant mechanism built into the foot. When the hoof of the running animal strikes the ground, the impact bends the fetlock joint and stretches certain long ligaments called the suspensory or springing ligaments [see bottom illustration on page 152]. Because the ligaments are elastic, they snap back as the foot leaves the ground, thereby straightening the joint and giving the leg an upward push. Charles L. Camp of the University of California has found that these built-in pogo-sticks evolved from foot muscles at the time that the animals forsook river valleys for the open plains. The exchange was advantageous, for by means of this and the other adaptations, nature has reconciled the limitations of muscle mechanics with the exacting requirements of speed.

Metals made to run red-hot inside a vacuum

Electronics engineers of 30 years ago had scarcely stopped exulting over the advantages of electron tubes with indirectly heated cathodes before they began to demand improvements.

First they wanted longer tube life. Then they wanted greater uniformity of performance. And later on they wanted such new features as greater resistance to shock and greater ability to endure over-voltage abuse.

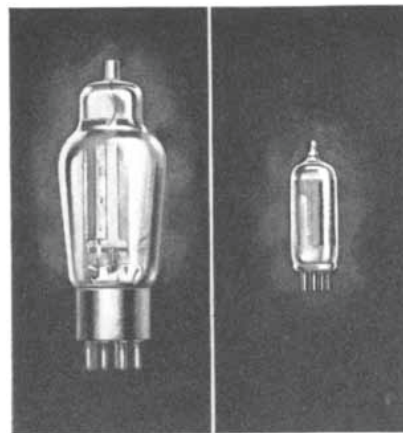
Most of these problems landed on the doorstep of Superior Tube Company. Because from the beginning Superior has been the world's leading independent maker of cathodes for electron tubes. And tube designers knew that the performance of tubes hinged heavily on the cathodes.

To insure uniform performance, Superior developed machines that would consistently turn out these tiny metal parts in the wide variety of needed sizes and shapes to tolerances of less than a thousandth of an inch. Then a rigid quality-control system further insured the dimensional accuracy of the finished product.

The development of cathode alloys took on the character of a trip behind the looking-glass into an area of metallurgy that had never been explored before. Superior Tube engineers led the way.

Early cathodes were made of ordinary commercial Grade A nickel. But impurities shortened cathode life. Superior investigated the performance of high-purity nickel and nickel alloys with varying amounts of desired activating elements. The metallurgy of cathodes, it was discovered, is a delicate balance between alloy composition and operating conditions.

The presence of magnesium or silicon, for example, is desirable in cathodes for certain types of tubes—undesirable in



others. Within the metal itself, certain low-percentage constituents move slowly to the surface, sometimes subliming off and sometimes depositing harmfully on other parts of the tube.

Superior Tube engineers tried substituting aluminum for silicon as an activating element in the nickel alloy. They discovered it provided the needed reduction of the barium oxide on the cathode coating without the interface impedance to which silicon is prone.

When a cathode is at operating temperature, it is red-hot and very close to the melting point of the metal. Hence it normally loses most of its strength. A severe jar or too much expansion could cause distortion. Again Superior engineers searched for improvement. They added tungsten to the alloy and discovered it actually doubled the hot strength of the metal.

The various needs of different types of tubes has resulted in the development of some 10 or more different cathode alloys over the years. But Superior has long recognized the desirability of having fewer alloys, each with greater versatility. In this direction, Superior developed its Cathaloy® series—five alloys capable of covering virtually all needs, besides providing many new benefits. Cathaloy A-31, for example, was found to endure 25% heater overvoltages and still give long life.

Recently Superior introduced cathode alloy X-3012,* which includes tungsten and zirconium to provide a combination of characteristics that makes it applicable in nearly any type of tube.

At Superior, the search for new knowledge about cathodes goes on still. All the knowledge we have is available to those who need it. Feel free to consult with Superior. Write Superior Tube Company, 2502 Germantown Ave., Norristown, Pa.

*U.S. Pat. #2,833,647, Superior Tube Company

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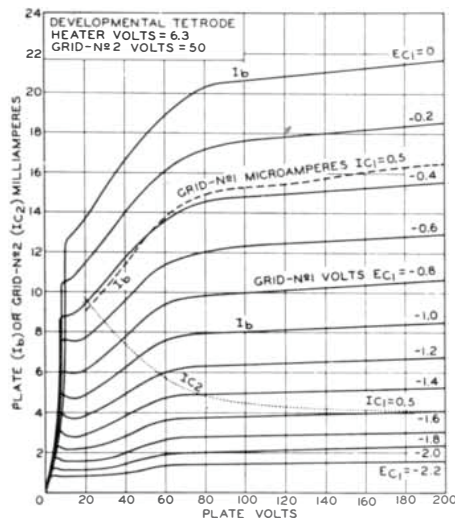
TAKES
ANOTHER
BOLD
STEP
INTO
THE
FUTURE
OF
ELECTRON
TUBES



THE
DEVELOPMENTAL

nuvistor
TETRODE!

Following RCA's announcement of the nuvistor concept and subsequent announcement of the first commercial nuvistor type—the 7586 general-purpose industrial triode—comes news that a nuvistor tetrode is now available to equipment manufacturers on a limited sampling basis. This developmental small-signal tetrode—RCA Dev. No. A-2654—promises to extend the horizons of the nuvistor concept far into the entertainment, industrial, and military electronic fields.



Incorporating all the advantages of nuvistor design, this small-signal general-purpose tetrode is Step 2 of a daring electron-tube-improvement program by RCA. Our developmental work indicates that the nuvistor tetrode will establish new high standards of tube performance for the electronics industry.

Dynamic in Concept

RCA had as its objective in the design of the nuvistor tetrode superior performance in many amplifier applications, particularly at the higher radio frequencies. The new tube is 1/3 the size of conventional rf-amplifier tetrodes, and consumes approximately 1/2 the heater power.

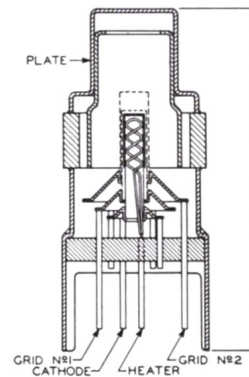
The nuvistor method of construction eliminates or minimizes many of the known causes of tube failure. Use of only ceramics and strong metals provides a structure of extreme ruggedness. Brazing of all connections in a hydrogen atmosphere at extremely high temperatures eliminates structural strain and element distortion. Exhaust and seal-off at very high temperatures minimizes gases and impurities from metal parts.

Opening a New Era: "Nuvistorization"

The nuvistor tetrode shows great promise for mixer, oscillator-mixer, if-amplifier and low-level video-amplifier service.

Application tests in laboratory circuits show that the nuvistor tetrode will give top performance in industrial and military equipment. Out-

standing performance has been obtained in the mixer and if-amplifier stages of such equipment.



**Nuvistor
Developmental
Small
Signal
Tetrode
A-2654**

TYPICAL DATA

ELECTRICAL:

Heater, for Unipotential Cathode:

Voltage (AC or DC)	6.3 ± 10%	volts
Current	0.165	amp

DIRECT INTERELECTRODE CAPACITANCES (approx.):

Grid No. 1 to plate	0.01	μμf
Grid No. 1 to cathode heater, grid No. 2, metal shell and internal shield	6.0	μμf
Plate to cathode, heater, grid No. 2, metal shell and internal shield	1.	μμf
Heater to cathode	1.4	μμf

CHARACTERISTICS, CLASS A₁ AMPLIFIER:

Plate Supply Voltage	125	volts
Grid No. 2 (Screen-Grid) Voltage	50	volts
Cathode Resistor	68	ohms
Plate Resistance (approx.)	0.2	megohm
Transconductance	10,400	μmhos
Plate Current	9.6	ma
Grid—No. 2 Current	2.9	ma
Grid—No. 1 Voltage (approx.) for plate current of 10 μa	-5	volts

MAXIMUM RATINGS, ABSOLUTE-MAXIMUM VALUES:

PLATE VOLTAGE	250 max.	volts
GRID—NO. 2 VOLTAGE	110 max.	volts
GRID—NO. 1 VOLTAGE:		
Negative bias	55 max.	volts
Positive bias value	2 max.	volts
GRID—NO. 2 INPUT	0.2 max.	watt
PLATE DISSIPATION	2.2 max.	watts
GRID—NO. 1 CURRENT	2 max.	ma
CATHODE CURRENT	20 max.	ma
PEAK HEATER-CATHODE VOLTAGE:		
Heater negative with respect to cathode	100 max.	volts
Heater positive with respect to cathode	100 max.	volts

MAXIMUM CIRCUIT VALUES:

Grid—No. 1 Circuit Resistance:		
For cathode-bias operation	1.0 max.	megohm

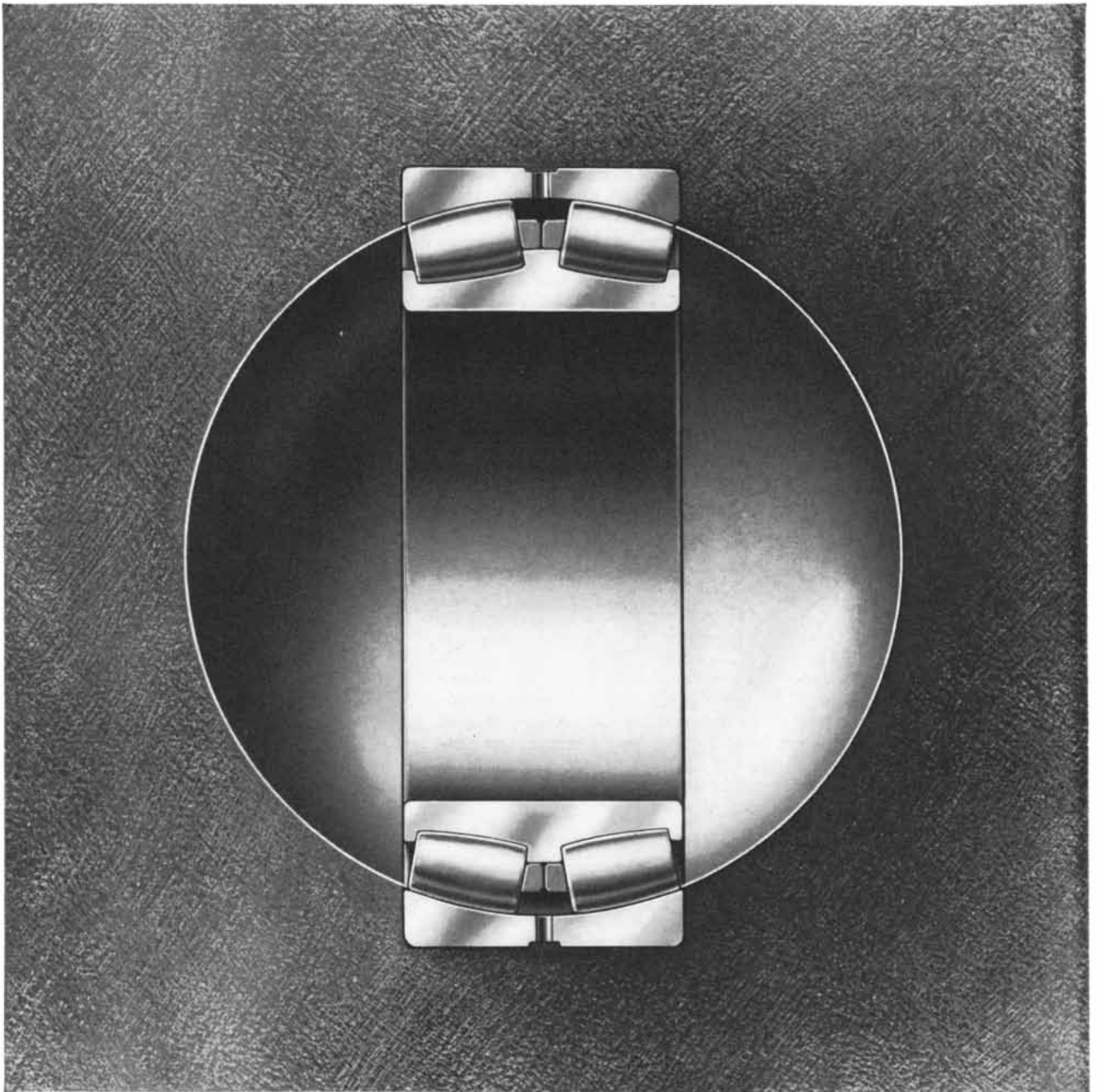
DESIGN ENGINEERS: You will want to evaluate this tetrode for possible use in your equipment designs. For more details on nuvistors and information on how you may obtain samples of the tetrode call your RCA Field Representative at the Field Office nearest you.

Among other nuvistor types in development at RCA is a beam power tube for military, industrial, and entertainment applications. Half the size of its present-day counterpart, the nuvistor beam power tube will have a maximum plate-dissipation rating of 30 watts, and an output of several watts with less than 75 volts on the plate.



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The center guide flange thrust surface and mating roller ends are spherically ground to the same radius. Under load,

the roller seeks positive contact with the center flange. The result is extremely accurate roller guidance, a high degree of geometric stability, minimum friction, and truer rolling motion.

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