



# TUTANKHAMEN'S TRIBOLOGY

Mechanical  
problems had  
to be solved even  
back in the days of  
wooden chariots and leather  
bindings. **By Robert O. Woods**

**A**n all-too-familiar sight today is that of military vehicles operating in the Middle Eastern deserts. However, long before the tank, the Humvee, or the jeep, wheeled war machines were no novelty in that region. They have appeared there on and off in history for at least 4,000 years.

It can be argued that the wheel was invented in that region. The earliest documented use of wheels exists in the form of pictographs on clay tablets from Uruk. These tablets have been dated to 3000 B.C. They depict primitive carts fitted with what are unmistakably wheels. It did not take long to adapt the wheel to warfare.

External views of wheels are depicted on numerous

historical monuments. We have enough information to make shrewd judgments about their construction. The bearings, although a vital part of the assembly, are still something of a mystery. They do not figure prominently in the drawings, which exist only to record the shapes of the vehicles in which various heroes rode.

Wheeled vehicles first appeared in Mesopotamia around the third millennium B.C. They were originally four-wheel carts drawn by slow-moving animals, typically oxen. Wheels on the earliest vehicles were fixed to the axles rather than rotating independently. The axles themselves were supported in transverse grooves in some kind of chassis, which constituted the bearing.

Much later, elsewhere, simple grooves were supplemented with inverted U-shaped iron retainers. The axles, which must have initially been at least roughly circular in cross section, probably wound up becoming symmetrical after use had knocked the corners off.

Not a great deal is known about ancient bearings be-

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cause until fairly late in their development, the axles and other parts of the assembly were made of wood. Hence very little has survived to study. There are, however, a few preserved examples of wheel parts—most are from chariots. One complete chariot exists in the Museo Archeologico in Florence, Italy. A single wheel, often called “the Egyptian wheel,” is in the Brooklyn Museum of Art. It was discovered near an early pyramid-building site called Dahshur and brought to the United States by a collector in the 19th century.

We owe most of what is known about wheel construction to the Egyptian custom of burying useful articles in royal tombs. Six complete (although dismantled) chariots were retrieved from the tomb of Tutankhamen. Those examples date from around 1000 B.C., by which time the art of chariot building was well evolved. Chariots were then being used both as sporting vehicles and as war machines. The Tutankhamen chariots represent a late stage in an evolution that had begun around 1600 B.C.

The first major battle in which the chariot was a deciding factor came in the 15th century B.C., when the Egyptian Pharaoh Thutmose pulled a brilliant flanking operation and subdued the Canaanites, thereby subjecting an entire geographic region to Egyptian domination.

Egyptians later developed chariot warfare to an exact science. Their tactics are documented in great detail in the description of a battle that took place in the 13th century B.C. between Ramses II and the Hittite king Muwatallish at Kadesh, a site on the Orontes River in modern Syria. The account gives us a mental picture that bears an eerie similarity to aerial views of vehicles advancing in parallel during Desert Storm.

Egyptian tactics involved attacking with chariots in a line abreast, spaced widely enough that a number of foot soldiers could run along between them. Charioteers, usually two per vehicle, would attack the enemy foot soldiers with projectile weapons—arrows and spears—and then would wheel and withdraw, allowing the foot soldiers to cover their retreat and to engage the theoretically demoralized enemy foot.

Those battles were not minor skirmishes, even by the standards of modern warfare. According to contemporary accounts, they involved several thousand chariots and tens of thousands of men. Sheer numbers give us a feeling for the manpower that was available for pyramid building.

A chariot enjoyed the same amount of pampering that is now shown to a fighter plane. Like the fighter plane, the chariot represented a significant investment and, because of the primitive nature of the mechanical details, was probably short-lived and in need of continual care.

**A 1922 photo taken by Harry Burton recorded the discovery of disassembled chariots in an antechamber of Tutankhamen's tomb. In the complete wheel, illustrated above, V shapes met at the hub and created spokes. Fine lines running along each spoke represent the seams where parts joined.**

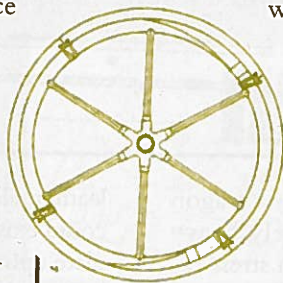
An indication of the amount of workmanship and hence the cost involved in constructing a chariot is illustrated by a modern German team, which has built a replica that took more than 600 hours to complete.

Because of their cost, chariots were status symbols as well as military assets. This was later carried to an extreme during the Iron Age. We are told that the pharaoh and his enemy went into battle—or at least rode to war—in chariots covered with gold leaf.

So essential did chariots become that by the 15th century B.C. the Pharaoh Thutmose III had more than a thousand in his standing war machine. The chariot remained an important military asset until around 1000 B.C., when armed cavalry gradually supplanted it.

Actually, riding on a horse was a fairly late innovation in a Middle Eastern culture accustomed to using horses only as draft animals. Nomadic cultures on the steppes did not have the leisure time or fixed bases needed to build wheeled vehicles. They accordingly developed horseback riding at a relatively early time. This development reached the Middle East so late that it is generally believed the Greek legend of centaurs began when someone first saw a rider and horse descend from the steppes.

Tutankhamen's chariots give us an opportunity to study the details of wheels and axles. The aspect that is most striking to a present-day engineer is that the axles were made of wood and the wheels had wooden journals. The favored materials were elm and birch, which were imported because neither wood was native to Egypt.



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Anyone accustomed to modern practice finds it hard to believe that wood-on-wood could function as a bearing at all. This primitive arrangement was improved in a few cases by the addition of a leather bushing. Lubrication in the form of animal fat or tallow is known to have been used, although the exact composition has not been determined.

The hub, called the nave in archaeological publications, was of exaggerated length. This design was dictated by the bearing fit, which could not have been very good, given the primitive nature of the tools used to make it. Even if the wooden bearings were tight to begin with, they certainly would have worn out of round. The length was thus needed to minimize wobbling of the wheel on the shaft rather than to reduce bearing pressure.

Despite their primitive nature, these wheels were capa-

ble of impressive performance. They operated over rough terrain at the speed of galloping horses.

One of the Tutankhamen axles shows unmistakable signs of lathe turning. This is anomalous, since it is usually thought that the lathe did not come into use in Egypt until the introduction of iron cutting tools. The Iron Age started 400 years after these chariots were built. Early lathes, perhaps those used to produce this axle, were an evolution of the bow drill.

Like the bow drill, the first lathes, called draw lathes, worked by rotating in alternating directions. This back-and-forth motion was produced using a cord wrapped around the workpiece and held in spring tension by a bow made by bending a sapling over the work. The part was rotated manually.

The construction of early wheels depended heavily upon leather's property of shrinking when dried and then setting to a rock-hard consistency. This property was exploited to its limit. Egyptian wheels were made of several pieces, but were "welded" into an apparently solid structure using leather bindings. Portions that in drawings resemble fillets at spoke ends were, in fact, leather thongs.

### Speaking of Spokes

These wheels presented several interesting design problems that were solved with great ingenuity. Unlike a modern bicycle wheel, which depends upon pretensioning slender spokes to such a degree that they never go into compression—even on the side below the axle—a wagon wheel supports its load by putting relatively heavy spokes into compression. This can result in a stress reversal every cycle.

To prevent spokes from working in their sockets, or tenons, during cyclic loading, it is necessary to apply enough hoop tension at the rim to keep the entire assembly in radial compression. In our millennium, this has usually been accomplished by shrinking an iron rim on a wooden assembly. Chariot builders, who did not have this option, relied on the shrinking of leather.

A leather rim on a wheel provided the needed tension, but was subject to wear as it came in contact with the ground. In many cases, a replaceable laced-on "tire" was put over it to protect it.

The second generation of ancient vehicles typically had four-spoke wheels. Solid wheels, which came first, were common until the 15th century B.C. They evolved into four spokes when two crossed timbers were used to connect a crude circular rim. By the time of the chariot, six spokes had become almost universal. Later, around the seventh or eighth century B.C., wheels of eight or even more spokes were occasionally depicted.

The major problem with early spoke wheels was attaching the spokes to the nave. This was solved by making the spokes in the form of vees, where each leg of a vee comprised half of one spoke, and the apex of the vee provided a point at which it could be bound to the nave with wrapped and shrunken leather. The completed assembly looked like a monolithic member, but was, in fact, built up of several pieces. Each spoke consisted of the legs of two adjacent vees, glued together at their longitudinal joint.

In a 1987 issue of the journal *Antiquity*, André W. Sleeswyk argued that the composite spoke assembly could have been used to provide the necessary radial compression. He suggested that the mating surfaces of each pair of spokes might have been separated at their centers during assembly, using spacers that remained between halves until the rim was attached. After the assembly was completed, the spokes could be put into compression by removing the spacers, gluing them, and flattening the bowed shapes by clamping the halves together.

Sleeswyk offered an explanation for curious keyhole-shape openings in the spokes of the wheel in the Brooklyn Museum. Bands strung through them and tensioned with wedges were probably used to force the inboard ends of the spokes against the hub, and to hold the incomplete assembly together while it was being worked on. Today we would probably use a jig.

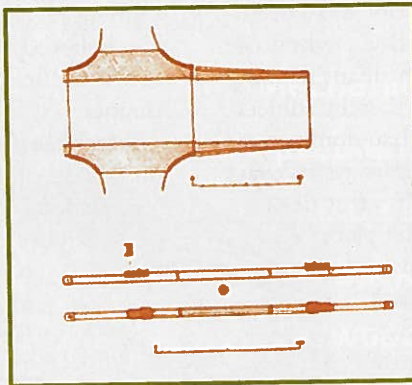
The dependence upon dried leather, along with glued joints, created an assembly that could exist best in a dry climate. It is interesting to speculate upon how long a wheel of this kind would retain its integrity if it were soaked.

During the Exodus, around the 13th or 14th century B.C., crossing the Red Sea compelled the pursuing Egyptians to operate in marshland. The Biblical account states that the wheels fell off the pursuing chariots. The use of dried leather and glues that were probably water-soluble might be an explanation for this.

Some of the linchpins were also made of dried leather. Getting the pins wet might very well cause the wheels to fall off.

The same dry, hot (and dusty) environment that abetted the Pharaoh's rolling stock is the greatest enemy of today's war machines. Ambient desert conditions place stringent demands on engines, transmissions, and suspensions. Bearings in particular must now operate in an isolated world of their own.

Modern wheels turn faster than ancient ones, the power train drives them farther than horses can go, and the wheels seldom fall off—even when wet. But although technology has come a long way since the Exodus, a war wagon will still stand or fall depending upon how intelligently the mechanical problems have been solved. ■



Drawings above show the hub from one of Tutankhamen's wheels and one-piece wooden axles. The favorite woods were elm and birch.