CATAPULT DESIGN HISTORY

Throughout history, humans have applied innovative ideas and designs to devices for throwing weapons. First, the sling was developed to overcome the limitations of the human arm. Next, hunters and soldiers devised the bow and arrow to improve aim and velocity. Eventually, major advances in power and accuracy were achieved with the design of machines called catapults. Early catapults were modeled after the bow and arrow, but quickly evolved into strong, single-armed machines constructed of composite layers of wood, sinew, and horn. This new weapon for attackers unbalanced the advantage once held by defenders during enemy siege (see The Catapult Advantage section below). While the defenders still had the ability to prepare for attack by building large walls, attackers—using catapults—could physically overcome these obstacles. These accurate machines also provided cover fire for troops attempting to breach enemy walls.

From Tension Bow to Torsion Spring

The first catapults were designed under the direction of Dionysius the Elder, ruler of the Greek colony of Syracuse, Sicily in 399 B.C.E. To prepare his city for a long war with Carthage, Dionysius assembled large research and development teams to create products that would give Syracuse strategic advantage in the upcoming war. The teams were made up of specialists who divided their labor into manageable units. Research and development enterprises still use this practice today.

Under Dionysius’s direction, Greek artisans created the gastrophetes, or “belly bow,” modeled after the bow and arrow. To cock the weapon, the archer pulled the stock—the compound beam forming the main axis of the weapon—into his abdomen and pulled back the string with both arms. Using two arms to cock the bow created substantially more power than the traditional hand-bow, for which the archer used only one hand. This tension bow was also larger than the hand-bow and consequently was able to hurl heavier arrows. However, the gastrophetes lacked the ability to throw arrows more than 300 yards and it was incapable of throwing stones.
To address the shortcomings of the gastrophetes, further research led to the development of a new type of bow: the *ballista* (Figure 1). This bow-like device was made of two independent lateral arms connected by a bowstring at the outer ends. Unlike earlier bows, the ballista used the power of torsion to propel stones. Bundles of cord or animal sinew were twisted to energize the bowstring; more twisting created a greater torsion effect and therefore more power. Although similar in form to the gastrophetes, the substitution of torsion for tension made the ballista a more powerful machine.

By the fourth century C.E., the latest projectile-launching device was the one-armed, torsion-driven, sling machine known as the *onager* (Figure 2) or “wild donkey,” named for the bucking action it exhibited under the force of recoil. Unlike the bows used in earlier times, the onager combined both throwing and slinging motions, which extended the weapon’s range. A single arm extended from the torsion bundle and ended in either a cup or a sling, which held the stone. The addition of a sling to the arm of this catapult increased its power by at least a third, and allowed the machine to hurl a missile in a high arc—over potential obstacles—toward a target. Today the onager is the weapon most people associate with the term *catapult*.

**Falling Weight Devices**

By the end of the sixth century, a new stone-projector called the *traction trebuchet* (Figure 3) had appeared in the Mediterranean. The traction trebuchet was a medieval catapult-like device that threw missiles with the force of up to 250 men. Nearly all catapults used at this time
operated by a sudden release of energy; an exception was the medieval counterweight trebuchet. Similar in action to a seesaw or a slingshot, this trebuchet used the energy of a falling counterweight that was suspended from one end of a wooden arm. This propelled a missile that was placed in a sling at the other end of the arm. These machines were simpler to construct, operate, and maintain than those with sinew torsion bundles. Trebuchet were used throughout the Middle Ages and up through the siege of Gibraltar by the French and Spanish fleets in 1779–82.

**Evolution of Catapult Design**

Beginning with the ballista, early catapult engineers combined several design elements to simulate an archer’s motions for consistent and accurate targeting. These included:

- **cams** to transfer rotating motion into sliding motion;
- **claw-and-triggers** to grasp and release the bowstring;
- **dovetail grooves with sliders** to form a moveable joint;
- **flat-link chains** to connect other design elements;
- **pedestals** to provide stability and support;
- **ratchets and pawls** or **winches** to allow incremental accumulation of applied human energy for increased power;
- **stocks** to form the main axis of the weapon;
- **torsion springs** to store the energy used to propel an object; and
- **universal joints** to allow rotation.

A number of design features that made their debut on catapults are still in use today; these include **sliding dovetail surfaces, universal joints, cams, flat-link chains,** and **torsion springs**. Examples of modern uses include:

- **cams** in racecars;
- **flat-link chains** in necklaces and conveyor belts;
- **sliding dovetail surfaces** in woodworking;
- **torsion springs** in garage doors;
- **universal joints** in automobiles and aircraft.

In addition to making significant advancements in military technology, catapult engineers used experimental procedures, derived optimization and scaling formulas, and performed advanced calculations that showed a
level of engineering rationality not achieved again until the time of the Industrial Revolution of the nineteenth century.

**The Catapult Advantage**

Before the development of catapults, the strategic advantage in ancient warfare was held by a defending army, who fought behind walled cities. An attacking army armed with a catapult, however, was no longer at a disadvantage. The ability of the catapult to concentrate hits on a single spot rendered defensive wall battlements and armored siege towers vulnerable, changing forever the equilibrium of politics and society.

Even after the invention of cannons and mortars in the thirteenth century, catapults were still active on the battlefield because they were easy to construct on site and were able to do a great deal of damage with more reliable results than the inconsistent gunpowder of the day. They had the further advantage of positioning flexibility and relative noiselessness.

Today catapults can be seen in medieval re-enactments, engineering contests, and period films such as *Robin Hood*. Movies and television even use catapults to produce dramatic stunts—such as flying livestock in *Monty Python* and an airborne piano in an episode of *Northern Exposure*. 