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[thumb|right|285px|](/wiki/File:Railgun_usnavy_2008.jpg)[Naval Surface Warfare Center](/wiki/Naval_Surface_Warfare_Center) test firing in January 2008[[1]](#cite_note-1) A **railgun** is an electromagnetic projectile launcher based on similar principles to the [homopolar motor](/wiki/Homopolar_motor). A railgun uses a pair of parallel conductors, or rails, along which a sliding [armature](/wiki/Armature_(electrical_engineering)) is accelerated by the electromagnetic effects of a current that flows down one rail, into the armature and then back along the other rail.[[2]](#cite_note-2) Railguns are being researched as a weapon that would use neither explosives nor propellant, but rather rely on electromagnetic forces to achieve a very high [kinetic energy](/wiki/Kinetic_energy) of a [projectile](/wiki/Projectile). While explosive-powered military guns cannot readily achieve a [muzzle velocity](/wiki/Muzzle_velocity) of more than about 2 km/s, railguns can readily exceed 3 km/s, and thus far exceed conventionally delivered munitions in range and destructive force. The absence of explosive propellants or warheads to store and handle, as well as the low cost of projectiles compared to conventional weaponry come as additional advantages.[[3]](#cite_note-3) In addition to military applications, [NASA](/wiki/NASA) has proposed to use a railgun from a high-altitude aircraft to fire a small payload into [orbit](/wiki/Orbit);[[4]](#cite_note-4) however, the extreme [g-forces](/wiki/G-forces) involved would necessarily restrict the usage to only the sturdiest of payloads.

## Contents

* 1 Basics[[edit](/index.php?title=(none)&action=edit&section=1)]
* 2 History[[edit](/index.php?title=(none)&action=edit&section=2)]
  + 2.1 Materials used[[edit](/index.php?title=(none)&action=edit&section=7)]
  + 2.2 Heat dissipation[[edit](/index.php?title=(none)&action=edit&section=8)]
* 3 Applications[[edit](/index.php?title=(none)&action=edit&section=9)]
  + 3.1 Launch or launch assist of spacecraft[[edit](/index.php?title=(none)&action=edit&section=10)]
  + 3.2 Weaponry[[edit](/index.php?title=(none)&action=edit&section=11)]
    - 3.2.1 Tests[[edit](/index.php?title=(none)&action=edit&section=12)]

## Basics[[edit](/index.php?title=(none)&action=edit&section=1)]

[Template:Refimprove section](/wiki/Template:Refimprove_section) [thumb|285px|Schematic diagram of a railgun](/wiki/File:3MpUJGm.jpg) In its simplest (and most commonly used) form, the railgun differs from a traditional electric motor [[5]](#cite_note-5) in that no use is made of additional field windings (or permanent magnets). This basic configuration is formed by a single loop of current and thus requires high currents (e.g. of order one million amperes) to produce sufficient accelerations (and muzzle velocities). A relatively common variant of this configuration is the **augmented railgun** in which the driving current is channelled through additional pairs of parallel conductors, arranged to increase ("augment") the magnetic field experienced by the moving armature.[[6]](#cite_note-6) These arrangements reduce the current required for a given acceleration. In electric motor terminology, augmented railguns are usually [series-wound](/wiki/Series-wound_motor) configurations.

The armature may be an integral part of the projectile, but it may also be configured to accelerate a separate, electrically isolated or non-conducting projectile. Solid, metallic sliding conductors are often the preferred form of railgun armature but "plasma" or "hybrid" armatures can also be used.[[7]](#cite_note-7) A plasma armature is formed by an arc of ionised gas that is used to push a solid, non-conducting payload in a similar manner to the propellant gas pressure in a conventional gun. A hybrid armature uses a pair of "[plasma](/wiki/Plasma_(physics))" contacts to interface a metallic armature to the gun rails. Solid armatures may also "transition" into hybrid armatures, typically after a particular velocity threshold is exceeded.

A railgun requires a pulsed, [direct current](/wiki/Direct_current) [power supply](/wiki/Power_supply).[[8]](#cite_note-8) For potential military applications, railguns are usually of interest because they can achieve much greater muzzle velocities than guns powered by conventional chemical propellants. Increased muzzle velocities can convey the benefits of increased firing ranges while, in terms of target effects, increased terminal velocities can allow the use of [kinetic energy](/wiki/Kinetic_energy) rounds as replacements for [explosive shells](/wiki/Explosive_shell). Therefore, typical military railgun designs aim for muzzle velocities in the range of 2000–3500 m/s with muzzle energies of 5–50 [MJ](/wiki/Megajoule). For comparison, 50MJ is equivalent to the kinetic energy of a [school bus](/wiki/School_bus) weighing 5 metric tons, travelling at 509 km/h (316 mph).[[9]](#cite_note-9) For single loop railguns, these mission requirements require launch currents of a few million [amperes](/wiki/Ampere), so a typical railgun power supply might be designed to deliver a launch current of 5 MA for a few milliseconds. As the magnetic field strengths required for such launches will typically be approximately 10 [tesla](/wiki/Tesla_(unit)), most contemporary railgun designs are effectively "air-cored", i.e. they do not use [ferromagnetic materials](/wiki/Ferromagnetic_materials) such as iron to enhance the magnetic flux.

It may be noted that railgun velocities generally fall within the range of those achievable by two-stage [light-gas guns](/wiki/Light-gas_gun); however, the latter are generally only considered to be suitable for laboratory use while railguns are judged to offer some potential prospects for development as military weapons. Another light gas gun, the Combustion Light Gas Gun in a 155 mm prototype form was projected to achieve 2500 m/s with a 70 caliber barrel. In some [hypervelocity](/wiki/Hypervelocity) research projects, projectiles are "pre-injected" into railguns, to avoid the need for a standing start, and both two-stage light-gas guns and conventional powder guns have been used for this role. In principle, if railgun power supply technology can be developed to provide compact, reliable and lightweight units, then the total system volume and mass needed to accommodate such a power supply and its primary fuel can become less than the required total volume and mass for a mission equivalent quantity of conventional propellants and explosive ammunition. Such a development would then convey a further military advantage in that the elimination of explosives from any military weapons platform will decrease its vulnerability to enemy fire.

## History[[edit](/index.php?title=(none)&action=edit&section=2)]

[thumb|German railgun diagrams](/wiki/File:German_railgun_Bild_1-2.gif)

In 1918, French inventor [Louis Octave Fauchon-Villeplee](/wiki/Louis_Octave_Fauchon-Villeplee) invented an electric cannon which is an early form of railgun. He filed for a US patent on 1 April 1919, which was issued in July 1922 as patent no. 1,421,435 "Electric Apparatus for Propelling Projectiles".[[10]](#cite_note-10) In his device, two parallel [busbars](/wiki/Busbar) are connected by the wings of a projectile, and the whole apparatus surrounded by a magnetic field. By passing current through busbars and projectile, a force is induced which propels the projectile along the bus-bars and into flight.<ref name=hogg>[Template:Cite book](/wiki/Template:Cite_book)</ref>

In 1944, during [World War II](/wiki/World_War_II), Joachim Hänsler of Germany's Ordnance Office proposed the first theoretically viable railgun.[[11]](#cite_note-11) The most common forms of power supplies used in railguns are [capacitors](/wiki/Capacitor) and [compulsators](/wiki/Compulsator) which are slowly charged from other continuous energy sources.

The rails need to withstand enormous repulsive forces during shooting, and these forces will tend to push them apart and away from the projectile. As rail/projectile clearances increase, [arcing](/wiki/Arcing) develops, which causes rapid vaporization and extensive damage to the rail surfaces and the insulator surfaces. This limited some early research railguns to one shot per service interval.

The inductance and resistance of the rails and power supply limit the efficiency of a railgun design. Currently different rail shapes and railgun configurations are being tested, most notably by the [United States Navy](/wiki/United_States_Navy), the [Institute for Advanced Technology at the University of Texas at Austin](/wiki/University_of_Texas_at_Austin#Research), and [BAE Systems](/wiki/BAE_Systems).

### Materials used[[edit](/index.php?title=(none)&action=edit&section=7)]

The rails and projectiles must be built from strong [conductive](/wiki/Conductive) materials; the rails need to survive the violence of an accelerating projectile, and heating due to the large currents and friction involved. Some erroneous work has suggested that the recoil force in railguns can be redirected or eliminated; careful theoretical and experimental analysis reveals that the recoil force acts on the breech closure just as in a chemical firearm.[[18]](#cite_note-18)[[19]](#cite_note-19)[[20]](#cite_note-20)[[21]](#cite_note-21) The rails also repel themselves via a sideways force caused by the rails being pushed by the magnetic field, just as the projectile is. The rails need to survive this without bending and must be very securely mounted. Currently published material suggests that major advances in material science must be made before rails can be developed that allow railguns to fire more than a few full-power shots before replacement of the rails is required.

### Heat dissipation[[edit](/index.php?title=(none)&action=edit&section=8)]

In current designs massive amounts of heat are created by the electricity flowing through the rails, as well as by the [friction](/wiki/Friction) of the projectile leaving the device. The heat created by this friction itself can cause [thermal expansion](/wiki/Thermal_expansion) of the rails and projectile, further increasing the [frictional heat](/wiki/Friction#Energy_of_Friction).[Template:Citation needed](/wiki/Template:Citation_needed) This causes three main problems: melting of equipment, decreased safety of personnel, and detection by enemy forces due to increased [infrared signature](/wiki/Infrared_signature). As briefly discussed above, the stresses involved in firing this sort of device require an extremely heat-resistant material. Otherwise the rails, barrel, and all equipment attached would melt or be irreparably damaged.

In practice the rails are, with most designs of railgun, subject to erosion due to each launch; in addition, projectiles can be subject to some degree of [ablation](/wiki/Ablation), and this can limit railgun life, in some cases severely.[[22]](#cite_note-22)

## Applications[[edit](/index.php?title=(none)&action=edit&section=9)]

Railguns have a number of potential practical applications, primarily for the military. However, there are other theoretical applications currently being researched.

### Launch or launch assist of spacecraft[[edit](/index.php?title=(none)&action=edit&section=10)]

[Template:Main](/wiki/Template:Main) [Template:See also](/wiki/Template:See_also) Electrodynamic assistance to launch rockets has been studied.[[23]](#cite_note-23) Space applications of this technology would likely involve specially formed [electromagnetic coils](/wiki/Electromagnetic_coil) and [superconducting magnets](/wiki/Superconducting_magnet).[[24]](#cite_note-24) [Composite materials](/wiki/Composite_materials) would likely be used for this application.[[25]](#cite_note-25) For space launches from Earth, relatively short acceleration distances (less than a few km) would require very strong acceleration forces, higher than humans can tolerate. Other designs include a longer [helical](/wiki/Helix) (spiral) track, or a large ring design whereby a space vehicle would circle the ring numerous times, gradually gaining speed, before being released into a launch corridor leading skyward.

|  |  |  |
| --- | --- | --- |
| **Parameters of McNab's launcher**[**[26]**](#cite_note-26) | **Value** | **Units** |
| Vehicle Mass | 1000 | kg |
| Muzzle Velocity | 2552 | m/s |
| Muzzle Energy | 35 | GJ |
| Launcher length | 16 | m |
| Maximum acceleration | 19500 | m/s2 |
| Maximum acceleration | 1988 | gn |
| Launch time | 0.43 | s |
| Current density | 6.8 | MA/m |

In 2003, Ian McNab outlined a plan to turn this idea into a realized technology.[[26]](#cite_note-26) Because of strong acceleration, this system would launch only sturdy materials, such as food, water, and – most importantly – fuel. Under ideal circumstances (equator, mountain, heading east) the system would cost $528/kg,[[26]](#cite_note-26) compared with $5,000/kg on the conventional rocket.[[27]](#cite_note-27) The McNab's railgun could make approximately 2000 launches per year, for a total of maximum 500 tons launched per year. Because the launch track would be 1.6 km long, power will be supplied by a distributed network of 100 rotating machines (compulsator) spread along the track. Each machine would have a 3.3-ton carbon fibre rotor spinning at high speeds. A machine can recharge in a matter of hours using 10 MW power. This machine could be supplied by a dedicated generator. The total launch package would weigh almost 1.4 tons. Payload per launch in these conditions is over 400 kg.[[26]](#cite_note-26) There would be a peak operating magnetic field of 5 T—half of this coming from the rails, and the other half from augmenting magnets. This halves the required current through the rails, which reduces the power fourfold.

### Weaponry[[edit](/index.php?title=(none)&action=edit&section=11)]

[thumb|Drawings of electric gun projectiles](/wiki/File:German_railgun_Bild_4.gif)

Railguns are being researched as weapons with [projectiles](/wiki/Projectile) that do not contain explosives or propellants, but are given extremely high velocities: [Template:Convert](/wiki/Template:Convert) (approximately [Mach](/wiki/Mach_number) 7 at sea level) or more. For comparison, the [M16 rifle](/wiki/M16_rifle) has a muzzle speed of [Template:Convert](/wiki/Template:Convert), and the [16"/50 caliber Mark 7 gun](/wiki/16%22/50_caliber_Mark_7_gun) that armed World War II American battleships has a muzzle speed of [Template:Convert](/wiki/Template:Convert)), which because of its much greater mass generated a muzzle energy of 360 MJ and a downrange kinetic impact of energy of over 160 MJ. By firing smaller projectiles at extremely high velocities, railguns can yield kinetic energy impacts equal or superior to the destructive energy of 5" Naval guns, but with much greater range. This decreases ammunition size and weight, allowing more ammunition to be carried and eliminating the hazards of carrying explosives or propellants in a tank or naval weapons platform. Also, by firing at greater velocities, railguns have greater range, less time to target, and at shorter ranges less wind drift, bypassing the physical limitations of conventional firearms: "*the limits of gas expansion prohibit launching an unassisted projectile to velocities greater than about 1.5 km/s and ranges of more than* [*Template:Convert*](/wiki/Template:Convert) *from a practical conventional gun system.*"[[28]](#cite_note-28)Current railgun technologies necessitate a long and heavy barrel, but a railgun's ballistics far outperform conventional cannons of equal barrel lengths. Railguns can also deliver area of effect damage by detonating a bursting charge in the projectile which unleashes a swarm of smaller projectiles over a large area.[[29]](#cite_note-29)[[30]](#cite_note-30) Assuming that the many technical challenges facing fieldable railguns are overcome, including tough ones like railgun projectile guidance and rail endurance, the increased launch velocities of railguns will provide advantages over more conventional guns for a variety of offensive and defensive scenarios. Railguns have the potential to be used against both surface and airborne targets.

The first weaponized railgun planned for production, the [General Atomics](/wiki/General_Atomics) Blitzer system, began full system testing in September 2010. The weapon launches a streamlined discarding sabot round designed by Boeing's Phantom Works at [Template:Convert](/wiki/Template:Convert) (approximately Mach 5) with accelerations exceeding 60,000 [gn](/wiki/G-force).[[31]](#cite_note-31) During one of the tests, the projectile was able to travel an additional [Template:Convert](/wiki/Template:Convert) downrange after penetrating a [Template:Convert](/wiki/Template:Convert) thick steel plate. The company hopes to have an integrated demo of the system by 2016 followed by production by 2019, pending funding. Thus far, the project is self-funded.[[32]](#cite_note-32) In October 2013, General Atomics unveiled a land based version of the Blitzer railgun. A company official claimed the gun could be ready for production in "two to three years".[[33]](#cite_note-33) Railguns are being examined for use as [anti-aircraft](/wiki/Anti-aircraft) weapons to intercept air threats, particularly [anti-ship cruise missiles](/wiki/Anti-ship_missile), in addition to land bombardment. A supersonic [sea-skimming](/wiki/Sea-skimming) anti-ship missile can appear over the horizon 20 miles from a warship, leaving a very short reaction time for a ship to intercept it. Even if conventional defense systems react fast enough, they are expensive and only a limited number of large interceptors can be carried. A railgun projectile can reach several times the speed of sound faster than a missile, because of this, it can hit a target, such as a cruise missile, much faster and farther away from the ship. Projectiles are also cheaper and smaller, allowing for many more to be carried. The speed, cost, and numerical advantages of railgun systems may allow them to replace several different systems in the current layered defense approach.[[34]](#cite_note-34) A railgun projectile without the ability to change course can hit fast-moving missiles at a maximum range of [Template:Convert](/wiki/Template:Convert).[[35]](#cite_note-35) As is the case with the Phalanx CIWS, unguided railgun rounds will require multiple/many shots to bring down maneuvering supersonic anti-ship missiles, with the odds of hitting the missile improving dramatically the closer it gets. The Navy plans for railguns to be able to intercept endo-atmospheric ballistic missiles, stealthy air threats, supersonic missiles, and swarming surface threats; a prototype system for supporting interception tasks is to be ready by 2018, and operational by 2025. This timeframe suggests the weapons are planned to be installed on the Navy's next-generation surface combatants, expected to start construction by 2028.[[36]](#cite_note-36)

#### Tests[[edit](/index.php?title=(none)&action=edit&section=12)]

[thumb|right|150px|Diagram showing the cross-section of a linear motor cannon](/wiki/File:German_railgun_Bild_3.gif) Full-scale models have been built and fired, including a [Template:Convert](/wiki/Template:Convert) bore, 9 [MJ](/wiki/Megajoule) kinetic energy gun developed by the US [DARPA](/wiki/DARPA). Rail and insulator wear problems still need to be solved before railguns can start to replace conventional weapons. Probably the oldest consistently successful system was built by the UK's [Defence Research Agency](/wiki/Defence_Research_Agency) at [Dundrennan Range](/wiki/Dundrennan_Range) in [Kirkcudbright](/wiki/Kirkcudbright), [Scotland](/wiki/Scotland). This system was established in 1993 and has been operated for over 10 years. Using its associated flight range for internal, intermediate, external and terminal [ballistics](/wiki/Ballistics), it achieved several mass and velocity records.[Template:Citation needed](/wiki/Template:Citation_needed)

The [Yugoslavian](/wiki/Yugoslavia) Military Technology Institute developed, within a project named EDO-0, a railgun with 7 kJ kinetic energy, in 1985. In 1987 a successor was created, project EDO-1, that used projectile with a mass of [Template:Convert](/wiki/Template:Convert) and achieved speeds of [Template:Convert](/wiki/Template:Convert), and with a mass of [Template:Convert](/wiki/Template:Convert) reached speeds of [Template:Convert](/wiki/Template:Convert). It used a track length of [Template:Convert](/wiki/Template:Convert). According to those working on it, with other modifications it was able to achieve a speed of [Template:Convert](/wiki/Template:Convert). The aim was to achieve projectile speed of [Template:Convert](/wiki/Template:Convert). At the time, it was considered a military secret.[Template:Citation needed](/wiki/Template:Citation_needed)

China is now one of the major players in electromagnetic launchers; in 2012 it hosted the 16th International Symposium on Electromagnetic Launch Technology (EML 2012) at Beijing.[[37]](#cite_note-37)