Rocket History

Satellite and Space Systems MSc
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A common claim is that the first recorded use of a rocket in battle was by the Chinese in 1232 against the Mongol hordes at Kai Feng Fu.
Rocket Launcher

- A depiction of the "long serpent" rocket launcher from the 11th century book *Wujing Zongyao*.
- The holes in the frame are designed to keep the fire arrows separate.
Konrad Kyeser (1405) depicts Alexander the Great Holding a Rocket

- Rocket technology was first known to Europeans following its use by the Mongols Genghis Khan and Ögedei Khan when they conquered parts of Russia, Eastern, and Central Europe.
- The Mongolians had acquired the Chinese technology by conquest of the northern part of China.
Kazimierz Siemienowicz

- For over two centuries, the work of Polish-Lithuanian Commonwealth nobleman Kazimierz Siemienowicz "Artis Magnae Artilleriae pars prima" ("Great Art of Artillery, the First Part", also known as "The Complete Art of Artillery") - 1650, was used in Europe as a basic artillery manual.

- It contained a large chapter on caliber, construction, production and properties of rockets (for both military and civil purposes), including:
  - multi-stage rockets,
  - batteries of rockets, and
  - rockets with delta wing stabilizers (instead of the common guiding rods ("bottle rockets"),
Lagari Hasan Çelebi Rocket

- Lagari Hasan Çelebi was a legendary Ottoman aviator who, according to an account written by Evliya Çelebi, made a successful manned rocket flight.
- Evliya Çelebi purported that in 1633 Lagari Hasan Çelebi launched in a 7-winged rocket using 50 okka (140 lbs) of gunpowder from Sarayburnu, the point below Topkapı Palace in Istanbul.
William Congreve

- Congreve prepared a new propellant mixture, and developed a rocket motor with a strong iron tube with conical nose.
- This early Congreve rocket weighed about 32 pounds (14.5 kilograms).
- The Royal Arsenal's first demonstration of solid fuel rockets was in 1805.
- The rockets were effectively used during the Napoleonic Wars and the War of 1812.
Konstantin Tsiolkovsky (1857–1935)

- The Tsiolkovsky rocket equation—the principle that governs rocket propulsion—is named in his honor (although it had been discovered previously).
- He also advocated the use of liquid hydrogen and oxygen for propellant, calculating their maximum exhaust velocity.
- His work was essentially unknown outside the Soviet Union.
- Book: The Exploration of Cosmic Space by Means of Reaction Devices

\[ \Delta v = v_e \ln \frac{m_0}{m_1} \]

Where \( v_e = \) exit velocity is fixed by the choice of fuel; \( m_0 = \) initial mass; \( m_1 = \) final mass at burn out;
In 1912 Robert Goddard, inspired from an early age by H.G. Wells, began a serious analysis of rockets, concluding that conventional solid-fuel rockets needed to be improved in three ways.

First, fuel should be burned in a small combustion chamber, instead of building the entire propellant container to withstand the high pressures.

Second, rockets could be arranged in stages.

Finally, the exhaust speed (and thus the efficiency) could be greatly increased to beyond the speed of sound by using a De Laval nozzle.
Robert Goddard

- Robert Goddard and the first liquid-fuelled rocket
- The de Laval nozzle was developed by Swedish inventor Gustaf de Laval in 1888 for use on a steam turbine
V2 Rocket

- In 1943, production of the V-2 rocket began in Germany. It had an operational range of 300 km (190 mi) and carried a 1,000 kg (2,200 lb) warhead, with an amatol explosive charge.
- It normally achieved an operational maximum altitude of around 90 km (56 mi), but could achieve 206 km (128 mi) if launched vertically.
- **Amatol** is a highly explosive material made from a mixture of TNT and ammonium nitrate.
Milestone V2

- Layout of the V2 Rocket
- The vehicle was similar to most modern rockets, with turbopump, inertial guidance and many other features.
Control System

- The V-2 was guided by four external rudders on the tail fins, and four internal graphite vanes at the exit of the motor.

- The LEV-3 guidance system consisted of two free gyroscopes (a horizontal and a vertical) for lateral stabilization, and

- a PIGA (Pendulous Integrating Gyroscopic Accelerometer) accelerometer to control engine cut-off at a specified velocity.
At the end of World War II, competing Russian, British, and US military and scientific crews raced to capture technology and trained personnel from the German rocket program at Peenemünde.

The V-2 evolved into the American Redstone rocket, used in the early space program.
They Worked

- Aftermath of a V-2 bombing at Hughes Mansions, Vallance Road, Whitechapel, London, 27 March 1945
R-7 8K72 "Vostok" permanently displayed at the Moscow Trade Fair

- Independently, in the Soviet Union's space program research continued under the leadership of the chief designer Sergei Korolev.
- With the help of German technicians, the V-2 was duplicated and improved as the R-1, R-2 and R-5 missiles.
- German designs were abandoned in the late 1940s, and the foreign workers were sent home.
- A new series of engines built by Glushko and based on inventions of Aleksei Mihailovich Isaev formed the basis of the first ICBM, the R-7.
- The R-7 launched the first satellite—Sputnik 1, 1958 and later Yuri Gagarin—the first man into space.
In America the manned programmes, Project Mercury, Project Gemini and later the Apollo programme culminated in 1969 with the first manned landing on the moon via the Saturn V, The New York Times had to retract their earlier editorial implying that spaceflight couldn't work.
Space Ship One

- SpaceShipOne for suborbital tourism may show a trend towards greater commercialisation of manned rocketry
Saturn V

- Saturn V is the biggest rocket to have successfully flown.
- The **Saturn V** was an American human-rated expendable rocket used by NASA between 1966 and 1973.
- The three-stage, liquid-fueled launch vehicle was developed to support the Apollo program for human exploration of the Moon, and was later used to launch Skylab.
- Mass: 2,970,000 kg; height: 110.6m, dia: 10.1m
LRO images of the Apollo 12 landing site 6th September 2011
The Viking 5C Rocket Engine. The engine was designed and manufactured by six countries: France, Germany, Spain, Belgium, Sweden and Italy. It was used in first stage of Ariane 4 from 1990 to 2003.
A Trident II missile launched from a Royal Navy Vanguard class ballistic missile submarine.
A Bumper sounding rocket

- Sounding rockets are commonly used to carry instruments that take readings from 50 kilometers (31 mi) to 1,500 kilometers (930 mi) above the surface of the Earth.
- The altitudes between those reachable by weather balloons and satellites
Space Shuttle *Atlantis* during launch phase
Some crewed rockets, notably the Saturn V and Soyuz have launch escape systems.

This is a small, usually solid fuel rocket that is capable of pulling the crewed capsule away from the main vehicle towards safety at a moments notice.
Forces on a rocket in flight, rockets that must travel through the air are usually tall and thin as this shape gives a high ballistic coefficient and minimizes drag losses.
Using a convergent/divergent nozzle gives more force since the exhaust also presses on it as it expands outwards, roughly doubling the total force. Note that the pumps moving the propellant into the combustion chamber must maintain a pressure larger than the combustion chamber -typically of the order of 100 atmospheres.
Due to the supersonic nature of the exhaust jet the exit pressure can be different from the ambient atmospheric pressure.

Nozzles are said to be (top to bottom):
- Underexpanded (above ambient).
- Ambient.
- Overexpanded (below ambient).
- Grossly overexpanded.

If under or overexpanded then loss of efficiency occurs, grossly overexpanded nozzles lose less efficiency, but the exhaust jet is usually unstable.

Rockets become progressively more underexpanded as they gain altitude.

Note that almost all rocket engines are momentarily grossly overexpanded during startup in an atmosphere.
Delta-v's from the Rocket Equation

- A map of approximate Delta-v's around the solar system between Earth and Mars
- The required delta-v can also be calculated for a particular manoeuvre; for example the delta-v to launch from the surface of the Earth to Low earth orbit is about 9.7 km/s
The Tsiolkovsky rocket equation gives a relationship between the mass ratio and the final velocity in multiples of the exhaust speed.

Almost all of a launch vehicle's mass consists of propellant.

Mass ratio is, for any 'burn', the ratio between the rocket's initial mass and the mass after burnout.

Everything else being equal, a high mass ratio is desirable for good performance.
<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Takeoff Mass</th>
<th>Final Mass</th>
<th>Mass ratio</th>
<th>Mass fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ariane 5</strong> (vehicle + payload)</td>
<td>746,000 kg</td>
<td>2,700 kg + 16,000 kg</td>
<td>39.9</td>
<td>0.975</td>
</tr>
<tr>
<td></td>
<td>(~1,645,000 lb)</td>
<td>(~6,000 lb + ~35,300 lb)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Titan 23G</strong> first stage</td>
<td>117,020 kg</td>
<td>4,760 kg</td>
<td>24.6</td>
<td>0.959</td>
</tr>
<tr>
<td></td>
<td>(258,000 lb)</td>
<td>(10,500 lb)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Saturn V</strong></td>
<td>3,038,500 kg</td>
<td>13,300 kg + 118,000 kg</td>
<td>23.1</td>
<td>0.957</td>
</tr>
<tr>
<td></td>
<td>(~6,700,000 lb)</td>
<td>(~29,320 lb + ~260,150 lb)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Space Shuttle</strong> (vehicle + payload)</td>
<td>2,040,000 kg</td>
<td>104,000 kg + 28,800 kg</td>
<td>15.4</td>
<td>0.935</td>
</tr>
<tr>
<td></td>
<td>(~4,500,000 lb)</td>
<td>(~230,000 lb + ~63,500 lb)</td>
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<td></td>
</tr>
<tr>
<td><strong>Saturn 1B</strong> (stage only)</td>
<td>448,648 kg</td>
<td>41,594 kg</td>
<td>10.7</td>
<td>0.907</td>
</tr>
<tr>
<td></td>
<td>(989,100 lb)</td>
<td>(91,700 lb)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Virgin Atlantic GlobalFlyer</strong></td>
<td>10,024.39 kg</td>
<td>1,678.3 kg</td>
<td>6.0</td>
<td>0.83</td>
</tr>
<tr>
<td></td>
<td>(22,100 lb)</td>
<td>(3,700 lb)</td>
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<td></td>
</tr>
<tr>
<td><strong>V-2</strong></td>
<td>13,000 kg (~28,660 lb) (12.8 ton)</td>
<td></td>
<td>3.85</td>
<td>0.74</td>
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<tr>
<td><strong>X-15</strong></td>
<td>15,420 kg</td>
<td>6,620 kg</td>
<td>2.3</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>(34,000 lb)</td>
<td>(14,600 lb)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Concorde</strong></td>
<td>~181,000 kg</td>
<td>2</td>
<td>2</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>(400,000 lb)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Boeing 747</strong></td>
<td>~363,000 kg</td>
<td>2</td>
<td>2</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>(800,000 lb)</td>
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Staging involves dropping off unnecessary parts of the rocket to reduce mass.

Often, the required velocity (delta-v) for a mission is unattainable by any single rocket.

Because the propellant, tankage, structure, guidance, valves and engines and so on, take a particular minimum percentage of take-off mass that is too great for the propellant it carries to achieve that delta-v.
Apollo 6 while dropping the interstage ring
Apollo 11 camera E8

- [https://www.youtube.com/watch?v=DKtVpvzUF1Y](https://www.youtube.com/watch?v=DKtVpvzUF1Y)
- Discovery Launch multiple cameras
- [https://www.youtube.com/watch?v=vFwqZ4qAUkE](https://www.youtube.com/watch?v=vFwqZ4qAUkE)
Mars Rover & Curiosity

- [https://www.youtube.com/watch?v=XRCIzZHpfFtY](https://www.youtube.com/watch?v=XRCIzZHpfFtY)
- Curiosity
- [https://www.youtube.com/watch?v=FZYnIsLNz3c](https://www.youtube.com/watch?v=FZYnIsLNz3c)
Energy Efficiency

- Plot of instantaneous propulsive efficiency (blue) and overall efficiency for a rocket accelerating from rest (red) as percentages of the engine efficiency

![Graph showing efficiency vs. velocity ratio](image)
Sometimes things go wrong

- Space Shuttle Challenger was torn apart 73 seconds after launch after hot gases escaped the SRBs, causing the breakup of the Shuttle stack.
Russian Rocket Technology

- The first launch of A-4 rocket assembled on the basis of components and assemblies of German rocket V-2;
- Missiles systems with ballistic missiles P-1, P-2, P-9, PT-1, PT-2, PT-2P (PT-1, -2 are solid-propellant rockets) were developed and subsequently put into service;
- Strategic missile P5 and tactical missile P-11 were developed;
- The latter was modified for launches from submarines and was indexed as P-11FM;
- Two-stage intercontinental ballistic missiles P-7 and P-9, three-stage Vostok launch vehicle (consisting of P-7 and upper stage Block E as a third stage) for missions to the Moon, and four-stage Molniya launch vehicle for launching payloads to Venus and Mars (consisting of P-7 and upper stages Block I and Block L) were developed;
1950 - the first ballistic missile P-1
1952 - P-2 with detachable warhead
1955 - P-11 for ground forces
1956 - P-5M with a nuclear charge
1958 - P-11M a mobile missile
1959 - P-11FM for submarines
1960 - the first intercontinental ballistic missile P-7
1960 - P-7A
1965 - P-9A
1968 - PT-2 a solid-propellant rocket
1972 - PT-2P
Russian Space Launch Vehicles

- **1957 - 1958** - Launch vehicle - Sputnik - Earth artificial satellites-1, -2, -3
- **1963 - 1976** - Voskhod - manned spacecraft and Zenit SC since 1966 - Soyuz - manned and logistics spacecraft, exploration of the Moon
- **1969 - 1972** - Launch vehicle system N1-L3
- **1987 - 1988** - Reusable space transportation system Energia-Buran
- **1999** - Space launcher system Sea Launch

Sputnik started the space race 4/10/1957
The first domestic liquid-propellant rocket engine with afterburning of generated gas in a combustion chamber allowed it to achieve a specific impulse of up to 340 kgf s/kg in vacuum when using main components.

The engine is attached to a Cardan's suspension with an angle of rotation of up to 3°.
Russian Space Agency Achievements
Summary

- Invention preceded theory by 1000 years
- Theory preceded first successful vehicle (V2) by 50 years
- This is due to serious engineering problems that needed to be solved
- Rockets are unstable and need to be guided
- Rockets are high power devices that push material and components to their limits of stress and temperature
The End