Reusable Rocket

Background

Operational Vehicles

Development

Select Image

Reference Information

A reusable rocket is a vehicle capable of launching into space more than once; this contrasts with an expendable rocket, in which each vehicle is launched once and then discarded.

- No true reusable, operational, orbital launch system has been used; the closest examples are the partially reusable NASA space shuttle (left) and the SpaceX Falcon 9 launch vehicle.
  - The NASA space shuttle reusable parts included the orbiter, its main engines, and the two solid rocket boosters; all were used again after several months of maintenance and refitting.
  - The external tank, which included the fuel and oxidizer tanks as well as the structure, was discarded after each flight.
  - The SpaceX Falcon 9 first stage and Dragon space station cargo vessel have been reused, but the second stage is not reusable.

- SpaceX successfully landed an orbital rocket for the first time when the Falcon 9 first stage landed at Cape Canaveral Air Force Station, FL (right) on December 21, 2015.
  - The Falcon 9 first stage of the space station Commercial Resupply Service Flight 8 (CRS-8) was launched again on April 8, 2016 as part of a Falcon 9 flight carrying a communication satellite and recovered again after landing on the drone ship.
  - On June 3, 2017, CRS-11 was launched becoming the first mission to reuse a Dragon cargo vessel previously flown.
  - The Blue Origin suborbital New Shepard spacecraft rocket booster and capsule have launched and landed, and have been reused, but the capsule has not orbited Earth.
Reusable Rocket Development

Space X

Blue Origin

Concepts
Space X Reusable Rocket Development

The SpaceX reusable launch system development program was a privately funded program that generated a set of new technologies for a reusable rocket.

- The project's long-term objectives included returning a launch vehicle's first stage to the launch site in minutes and evaluate returning a second stage to the launch site following orbital realignment with the site and atmospheric reentry in up to 24 hours.
- The technologies that were being developed for this program, some of which were refined, include:

<table>
<thead>
<tr>
<th>Technology</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Re-startable ignition system</td>
<td>First stage booster restarts are required at both supersonic velocities in the upper atmosphere and at high transonic velocities in the lower atmosphere.</td>
</tr>
<tr>
<td>Throttleable rocket engine</td>
<td>Reduced engine thrust is required because the full thrust of a single SpaceX Merlin engine exceeds the weight of the nearly empty booster core.</td>
</tr>
<tr>
<td>Terminal guidance and landing</td>
<td>Provides capability to be able to land a rocket with closed-loop thrust and throttle control.</td>
</tr>
<tr>
<td>Navigation sensor suite</td>
<td>Navigation sensors are required for precision landing.</td>
</tr>
<tr>
<td>Hypersonic grid fins</td>
<td>Grid fins control the descending rocket's lift once the vehicle has returned to the atmosphere to enable a much more precise landing.</td>
</tr>
<tr>
<td>Large surface area thermal protection</td>
<td>Protection system absorbs the heat load of deceleration of the second stage from orbital velocity to terminal velocity.</td>
</tr>
<tr>
<td>Lightweight, deployable landing gear</td>
<td>Required to make a controlled, soft and safe landing.</td>
</tr>
<tr>
<td>Large floating landing platform</td>
<td>Capability to test pinpoint landings prior to receiving permission from the U.S. government to bring returning rocket stages into U.S. airspace over land.</td>
</tr>
</tbody>
</table>
Space X Reusable Rocket Development

Following the completion of the Grasshopper testing program in 2013, SpaceX conducted a series of tests in 2014 using the F9R development test vehicle (right).

- The F9R test vehicle is a Falcon 9 first stage with landing legs designed to test the precision landing techniques needed to return a rocket to Earth intact.
- On June 17, 2014, the F9R successfully launched, hovered at an altitude of 3,281 ft, and landed.
  - This flight was the first test of steerable grid fins that provide control of the rocket during the fly back.
  - Select [https://www.youtube.com/watch?v=DgLBIdVg3EM](https://www.youtube.com/watch?v=DgLBIdVg3EM) to view the F9R June 17, 2014 flight.
- All Grasshopper and F9R test vehicle flights were from the SpaceX McGregor, TX test facility.

Credit: SpaceX

SpaceX’s reusability testing began with the Grasshopper program.

- Grasshopper (left) was a 10-story Vertical Takeoff Vertical Landing vehicle consisting of a Falcon 9 first stage, a single Merlin 1D engine, four steel landing legs with hydraulic dampers, and a steel support structure.
- In 2013, Grasshopper completed a series of eight flight tests with one flight reaching 2,441 ft high and then successfully landing.
  - Select [https://www.youtube.com/watch?v=9ZDkItO-0a4](https://www.youtube.com/watch?v=9ZDkItO-0a4) to view the Grasshopper flight that reached 2,441 ft.

Credit: SpaceX
Space X Reusable Rocket Development

The Falcon 9 ocean booster landing tests were a series of controlled-descent flight tests beginning in September 2013 and ending with the fourth flight in September 21, 2014.
- The tests attempted controlled-descent reentry into the Earth’s atmosphere after the Falcon 9 rocket’s first stages completed the boost phase of an orbital flight.
- The tests concluded with an attempt at softly landing the first stage of the rocket in the Atlantic Ocean.
- On April, 18, 2014, the Falcon 9 launched the Cargo Resupply mission three (CRS-3) to the International Space Station (left).
- The first-stage was used after the orbital flight for the booster descent and landing flight test.
- The CRS-3 booster became the first successful controlled ocean soft touchdown of a liquid-rocket-engine orbital booster.

- On July 14, 2014, following the successful launch of six ORBCOMM satellites, the Falcon 9 rocket’s first stage reentered the Earth’s atmosphere and soft landed in the ocean.
- The ORBCOMM satellites are commercial telecommunications satellites built by Sierra Nevada Corporation.
- Select https://www.youtube.com/watch?v=ullu7szab5l to see the decent flight test of the first stage back to earth as filmed by a chase plane.
Space X Reusable Falcon 9 Development

The Falcon 9 reusable rocket and Dragon cargo capsule is shown undergoing preparations in Florida (left) in advance of the Cargo Resupply-6 (CRS-6) launch to the International Space Station.

- After the separation of the second stage, SpaceX conducted a flight test attempting to return the first stage through the atmosphere and land it on a 300 ft by 160 ft floating platform.
  - Two of the four first stage landing legs can be seen stowed on the right end of the first stage.

The Falcon 9 rocket carrying the CRS-6 Dragon spacecraft launched on April 14, 2015 (right).

- The booster had a variety of technologies incorporated for the post-mission test including grid fins and landing legs.
  - The hypersonic grid fins control the descending booster's lift enabling a much more precise landing.
- The first stage landed on the platform; however, it came down with too much lateral velocity, tipped over, and was destroyed.
  - This would have been the first time a rocket booster landed.
- The bipropellant valve was stuck; therefore, the control system could not react rapidly enough for a successful landing.
- This was the second attempt to land the booster on a floating platform after an earlier test in January 10, 2015 was not successful.
- Select https://www.youtube.com/watch?v=BhMSzC1crr0 to view the CRS-6 test attempting to land the Falcon 9 booster.
The Falcon 9 Flight 20 first stage is shown (left) moments before successfully landing December 21, 2015 at Cape Canaveral Air Force Station, FL on Landing Zone 1.

- This marks the first time an orbital spaceflight has landed a rocket stage.
- The Flight 20 second stage succeeded in orbiting 11 Orbcomm Generation 2 satellites.

Select [https://www.youtube.com/watch?v=ZCBE8ocOkAQ](https://www.youtube.com/watch?v=ZCBE8ocOkAQ) to view the landing.

The first stage of the Falcon 9 rocket sits on the pad (right) after successfully returning to Cape Canaveral under powered flight and landing vertically.

On January 15, 2016, SpaceX conducted a static fire test on the recovered booster.

- SpaceX reported that the test was good overall, but one of the outer engines showed thrust fluctuations that may have been due to debris ingestion.
- Since January 2017, SpaceX has stopped referring to landing attempts as “experimental” in their press releases, indicating that they are now considered a routine procedure.
Blue Origin is an American privately funded aerospace manufacturer organized by Amazon.com founder Jeff Bezos.  
- The company is developing a variety of technologies, with a focus on rocket-powered vertical takeoff and vertical landing vehicles for access to suborbital and orbital space.  
- Charon (left) was Blue Origin's first flight test vehicle and it was powered by 4 vertically mounted Rolls-Royce Viper Mk. 301 jet engines, rather than rockets, that also controlled direction of travel.  
  - The low-altitude vehicle was developed to test autonomous guidance and control technologies, and the processes that the company would use to develop its later rockets.  
  - Charon successfully flew at Moses Lake, WA on March 5, 2005 flying to an altitude of 316 ft before returning for a controlled landing near the liftoff site.  
  - Select https://www.youtube.com/watch?v=iQNhdYxgLvU to see a Charon test flight.  
- The New Shepard spacecraft is a vertical takeoff and vertical landing vehicle designed by Blue Origin to take a small number of astronauts on a suborbital journey into space.  
- Goddard is the first development vehicle in the New Shepard program.  
  -- It is a precursor, subscale demonstrator, vehicle to the New Shepard suborbital passenger capsule vehicle with a “pusher” propulsion system.  
  -- On November 13, 2006, Goddard was launched (right) from its launch site 25 miles north of Van Horn, TX to a height of 285 ft and landed.  
  - - Select https://www.youtube.com/watch?v=kGWk_rfq_bM to see the test.
Blue Origin New Shepard Development

Blue Origin’s New Shepard spacecraft is a two-stage suborbital vehicle with a booster, or propulsion module (PM), and crew capsule.

- On May 6, 2011, the New Shepard propulsion module, called PM2, did a successful “short hop mission” development test with the crew capsule replaced by a round fairing.
  - Select https://www.youtube.com/watch?v=NANePoo_p30 to see the May 6, 2011 PM2 test.
- On 24 August 24, 2011, the PM2 was launched again (left) flying through Mach 1.2 at 8.5 miles just before the thrust termination system activated, resulting in the loss of the vehicle.

In 2010, Blue Origin was selected by NASA for the Commercial Crew Development Program that included advancing the crew capsule pusher launch abort system.

- On October 19, 2012, Blue Origin conducted a successful crew capsule pad escape test (right) at its West Texas launch site.
  - The reusable pusher escape system was developed to allow crew escape in the event of an emergency on ascent of the suborbital New Shepard spacecraft.
  - During the test, a full-scale suborbital crew capsule was launched from a launch vehicle simulator after firing the capsule’s pusher escape motor.
    -- The crew capsule traveled to an altitude of 2,307 ft under active thrust control before descending safely by parachute to a soft landing 1,630 ft downrange.
- Select https://www.youtube.com/watch?v=Zv74775GFqs to see the crew capsule pad escape test.
The uncrewed suborbital flight tests of the Blue Origin New Shepard spacecraft were launched vertically from its West Texas launch site and then powered flights were performed.

- The booster’s momentum continued to carry it upward in unpowered flight.
- The capsule was released from the booster, descended and then parachuted to a landing.
- After reaching apogee the booster performed a descent and restarted its main engines before vertical landing near its launch site.
Blue Origin New Shepard Development

The New Shepard spacecraft is a fully reusable suborbital spacecraft with the booster flying itself to a vertical, rocket-powered landing after separation from the crew capsule.

- The crew capsule provides about 4 minutes of microgravity to its 3 passengers and experimental payloads.
- On April 29, 2015, Blue Origin flew the first autonomous mode developmental test flight of the New Shepard space vehicle (left).
  - The launch site is 25 miles north of Van Horn, TX.
  - The 110,000 lbs thrust liquid hydrogen, liquid oxygen BE-3 engine powered the vehicle through Mach 3 to its planned test altitude of 58 miles.

- Flight testing the New Shepard also allows Blue Origin to build time on the BE-3 that it plans to upgrade as a commercial product, designated BE-3U, for upper stage use.

- While the development test was deemed a success and the capsule was recovered by a parachute landing (right), the booster stage landing failed because hydraulic pressure was lost during the descent.
- Blue Origin has been developing an improved hydraulic system and plans to resume the development tests soon.

- Select https://www.youtube.com/watch?v=rEdk-XNoZpA to see the test flight of the New Shepard spacecraft on April 29, 2015.
- United Launch Alliance has partnered with Blue Origin to develop the BE-4 for both companies’ next generation launch vehicles.
- The BE-4 uses liquefied natural gas and liquid oxygen.
- Full engine testing to continue after May 13, 2017 powerpack loss.
On November 23, 2015, a Blue Origin suborbital rocket booster launched and descended to a pinpoint propulsive touchdown on a landing pad at its West Texas launch site in Van Horn, TX.

- After the booster separated from the crew capsule, eight drag brakes reduced its terminal speed to 387 miles per hour (mph).
- Fins on the outside of the booster steered it through 119 mph high-altitude crosswinds to a location precisely aligned with and 5,000 ft above the landing pad.
- The BE-3 engine re-ignited slowing the booster as the landing gear deployed and the vehicle descended the last 100 ft at 4.4 mph to touch down on the pad.

- The suborbital crew capsule separated from the booster achieving a maximum altitude of 62 miles and a speed of Mach 3.72 or about 2,854 mph, and then landed safely, guided down by parachutes.
- On October 5, 2016, New Shepard performed an in-flight test of the capsule’s escape system, designed to quickly propel the crew capsule to safety if a problem is detected with the booster.
- On January 22, 2016, the same Blue Origin suborbital booster that flew November 23, 2015, was launched (above) and then landed vertically (right) demonstrating reuse.

- Select https://www.youtube.com/watch?v=74tyedGkoUc to see the booster test landing on November 23, 2015 and the New Shepard spacecraft test flight on January 22, 2016.
The New Glenn is a privately funded orbital launch vehicle in development by Blue Origin and expected to make its initial test launch prior to 2020 from Launch Complex 36, Cape Canaveral, FL.

- New Glenn is a 23 ft diameter two-stage orbital launch vehicle with an optional third stage and a reusable first stage (left).
- The planned payload capacity is 13 metric tons to geostationary transfer orbit and 45 metric tons to low Earth orbit.
- New Glenn will also be available for space tourism flights.
- The first stage will be powered by seven BE-4 methane/oxygen engines producing 3.8 million lbs of liftoff thrust; it is designed and manufactured by Blue Origin.
-- The first stage is designed to be reusable for up to 100 missions, and will land vertically, a technology previously developed by Blue Origin for the New Shepard.

- The second stage will share the same diameter as the first and use a single BE-4 and share the same propellant but be expendable.
- The optional third stage will use a single BE-3U with hydrogen/oxygen as propellant and be expendable.

- Select https://www.youtube.com/watch?v=1d2vS6j9nSw to see an animation of the 270 ft long New Glenn 2-Stage launch vehicle (right).
The Adeline (left), Advanced Expendable Launcher with Innovative Engine Economy, is a reusable rocket winged module concept by Airbus Defense and Space.

- The first-stage engine, avionics, and propulsion bay will be packaged in a winged module and fly back to Earth after launch using drone technology (below).
- The vehicle would then be refurbished and fly another mission.
- Airbus believes it could recover 20-30% of the cost of a flight at an added weight penalty cost of perhaps 10%.

See https://www.youtube.com/watch?v=tV29pEvZvZw for the Adeline reusable rocket concept flight animation.

- The concept has been undergoing testing since 2010 with simulations and a scale-model version for landing tests.
- Adeline can be used in the future evolution of Ariane 6.
- In February 2017, the European Space Agency’s (ESA) prime contractor for the Ariane 6, Airbus Safran Launchers (ASL), stated that the European market does not ensure enough launches to make reusability a profitable pursuit.
- However, ESA leaders have agreed to make an ASL liquid oxygen and methane fueled reusable engine called “Prometheus.” - It is a separate project that could be combined with Adeline.
In June 2015, Airbus revealed its plans to develop rocket engines that fly back to a runway and a reusable upper stage that acts as a space tug.
- The technology could support huge satellite constellations that require a dramatic increase in the number of launches per year.
- Airbus wants the technology to be up and running by 2025.
- The chart shows an Airbus reusable Adeline rocket system proposed for the two-stage Ariane 6 rocket.

- The tug would be left in orbit by an Ariane 6 and would be used several times to take payloads in low Earth orbit to a higher orbit; whereas, the Adeline engine module would land.
- Each time the tug is used, an Ariane 6 second stage would rendezvous to deliver the payload and provide gaseous fuel resupply.
- Airbus also suggests that other rockets, not just Ariane 6, could use the tug.
- Once the tug's operational life comes to an end, it can be sent on a remote exploration mission.
- The space tug concept is propelled by electric propulsion and never returns to Earth.
- The electric propulsion requires relatively long periods of time to accelerate a spacecraft to high speeds compared to traditional chemical propulsion.
The Indian Space Research Organization (ISRO) has undertaken development of a Reusable Launch Vehicle-Technology Demonstrator (RLV-TD).

- ISRO’s goal for the RLV-TD is a single stage to orbit (SSTO) reusable vehicle.
- SSTO studies conclude that the current levels of propulsion and materials technologies limit the vehicle to a two stage to orbit (TSTO) configuration, shown above.
- The autonomous TSTO fully reusable vehicle will be composed of a lower and upper stage.
- A series of technology demonstration missions have been conceived and some started.
On May 23, 2016, the Indian Space Research Organization (ISRO) successfully tested a scaled-down unmanned version of the Reusable Launch Vehicle-Technology Demonstrator (RLV-TD), shown on the left.

- The test validated the RLV-TD critical technologies such as autonomous navigation, guidance & control, reusable thermal protection system and re-entry mission management.
- The vehicle consisted of a winged space plane atop a single stage, solid fuel booster.
- The rocket booster was expendable while the RLV-TD space plane flew back to Earth and landed like a normal airplane after the mission.

-- During the test, the RLV-TD glided down to the defined landing spot over the Bay of Bengal and then landed in the sea.

-- The 23 ft long prototype RLV-TD weighed about 3,400 lbs and flew to peak altitude of 40.4 miles.

- The rocket booster carrying RLV-TD was launched (right) from Satish Dhawan Space Center, Sriharikota in southeastern India.
- In July 2017, ISRO sources stated that another RLV-TD prototype test is being planned to occur in about one year.
- The plan is to launch the RLV-TD from Sriharikota and land it on an undisclosed Air Force airfield in the eastern sector of India.

-- This plan has not been finalized.
Japanese Reusable Rocket Concept

The Japanese Space Agency (JAXA) proposes to develop a reusable high altitude rocket based on the technologies demonstrated in the Reusable Vehicle Testing (RVT) project (left).

- RVT included a series of experimental vehicles to test repeated flights of a reusable rocket and were conducted from 1998 until 2003.
- The design of the experimental vehicles addressed technical challenges for future RVTs such as flight on demand, quick turnaround, higher performance, lightweight structures and materials.
- The project involved ground and flights tests with the flight testing conducted at the Institute of Space and Astronautical Science (ISAS) Noshiro Rocket Testing Center in the northern part of Japan’s main island.

- Select https://www.youtube.com/watch?v=Ogm5w6RxS3A to see a flight test.

- The reusable sounding rocket operational concept (right) launches vertically using main engine thrust, similar to a conventional rocket, and cuts off during the ascent phase.
- It then flies a ballistic trajectory up to the summit altitude.
- After the vehicle enters the atmosphere, it is aerodynamically decelerated and lands vertically returning to the launch site.
- During the landing phase, the vehicle will be decelerated by the main engine thrust for a soft-landing.
- JAXA stated in October 2003 that the present study was just a starting point and there will be a long time period before a future operational vehicle is ready for flight.
Other reusable rocket booster concepts include:

<table>
<thead>
<tr>
<th>Company or Agency (Country)</th>
<th>Launch Vehicle</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>Unavailable</td>
<td>As of March 2017, China is working on a project to recover rocket boosters using a set of multiple parachutes stored in the first stage of the rocket, which is released from the rest of the craft before it burns its way through the Earth's atmosphere. An air bag inflates under the discarded part of the rocket cushioning the impact when it hits the ground. However, China has not officially ruled out vertical landing technology to recover rockets. A final decision will be made before 2020.</td>
</tr>
<tr>
<td>NPO Energomash (Russia)</td>
<td>Angara Launch Vehicle</td>
<td>In November 2014, NPO Energomash proposed housing its RD-191 engine in a capsule attached to the bottom of Russia's Angara booster. The RD-191 is fueled by kerosene and liquid oxygen. After the engine has exhausted its fuel, the capsule will detach and fall back to Earth, protected by a heat shield. A parachute deploys when the capsule hits the atmosphere and the engine lands safely using either a special airbag or small rockets to slow its descent.</td>
</tr>
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</table>
Other reusable rocket booster concepts include (Continued):

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</thead>
<tbody>
<tr>
<td>Russian Federal Space Agency</td>
<td>Unavailable</td>
<td>As of October 2012, the first flight of a reusable Russian rocket booster could occur by 2020. The fly-back booster, called the Re-entry Rocket Module (RRM), is part of a larger project that plans to develop a partially reusable rocket called the Reusable Integrated Launch Vehicle (RILV). The RRM would be the first stage of the RILV. The RRM would have four liquid-propellant rocket engines. After separation, the RRM cruises back to its launch site autonomously, using a wing, along with air-breathing jet engines located in its nose.</td>
</tr>
<tr>
<td>United Launch Alliance (United States)</td>
<td>Vulcan Launch Vehicle</td>
<td>United Launch Alliance (ULA) announced plans in April 2015 to retire the Delta 4 rocket by the end of 2020, and stop launching the Atlas 5 booster sometime in the 2020s, replacing the rockets with the Vulcan launch system. Plans also include phasing in reuse by developing the capability to return the two reusable booster main engines. According to ULA, the engines represent 65% of the booster cost. The bottom of the rocket disengages after completing its powered flight, decelerates with a hypersonic heatshield in the upper atmosphere and parachutes down to be intercepted by a waiting helicopter for capture.</td>
</tr>
</tbody>
</table>
SpaceX Commercial Resupply Service Flight 11, CRS-11, was launched successfully (left) on June 3, 2017 by a Falcon 9 launch vehicle.

- It was the second CRS mission to be launched from historic Kennedy Launch Complex 39 Pad A, FL.
- This was the 100th launch from this pad that included Apollo flights, the unmanned Skylab space station, space shuttle flights and now SpaceX launches.
- The spacecraft was also the first to reuse a Dragon cargo vessel that was previously flown on the SpaceX CRS-4 mission.

The Falcon 9 first stage landed successfully (right) on Landing Zone 1, a facility at Cape Canaveral Air Force Station, FL, making it the fifth successful touch down on land and the 11th overall.

- Dragon carried about 6,000 lbs of supplies to the International Space Station (ISS) in support of the crew members.
- The spacecraft was attached to the ISS for over 27 days and then released.
- After Dragon jettisoned its cargo trunk and re-entered the atmosphere, it splashed down in the Pacific Ocean off Baja, CA returning scientific experiments from the ISS.
- Select [https://www.youtube.com/watch?v=YKJEemoGhJro](https://www.youtube.com/watch?v=YKJEemoGhJro) to view the SpaceX CRS-11 launch and first stage booster landing.
SpaceX Rocket Launches X-37B OTV

A SpaceX Falcon 9 launched the United States Air Force X-37B Orbital Test Vehicle (OTV) on September 7, 2017 from Launch Complex 39A (left) at Kennedy Space Center (KSC), FL.

- The Boeing X-37B is a reusable un-crewed spacecraft boosted into space by a launch vehicle then re-enters Earth’s atmosphere and lands as a spaceplane at KSC.
- The X-37B is operated by the United States Air Force for orbital spaceflight missions intended to demonstrate reusable space technologies; most activities are secret.
- The spacecraft is over 29 ft in length and weighs about 11,000 lbs.

- The Falcon 9 launch was the fifth X-37B mission launched.
- The X-37B is shown in its payload fairing (right) prior to a launch on an Atlas V rocket in April 2010.

- After about 2.5 minutes into the flight, the Falcon 9's two stages separated while the second stage continued boosting the X-37B to orbit and the first stage maneuvered back to Earth, eventually completing a vertical touchdown at Landing Zone 1 at Cape Canaveral Air Force Station, FL.

- SpaceX intends to inspect, refurbish and reuse the first stage on a future launch.

- The company has now recovered one of its Falcon 9 boosters intact 16 times over the last two years; a capability that will reduce the cost of SpaceX’s launches.
Space X Falcon Heavy Launch Vehicle

The Falcon Heavy rocket (left) has three boosters capable of landing safely on Earth after they detach from the spacecraft.
- The launch vehicle will have the ability to lift over 117,000 lbs (53 metric tons) into orbit.
- The first stage is comprised of three cores, or boosters, with a total of 27 Merlin engines, generating about 4 million lbs of thrust at liftoff.
- The second stage with one Merlin engine can place payloads into a variety of orbits including low Earth, geosynchronous transfer orbit and geosynchronous orbit.
- The first demonstration flight is planned for November 2017.
- Select [https://www.youtube.com/watch?v=4Ca6x4QbpoM](https://www.youtube.com/watch?v=4Ca6x4QbpoM) to view the Falcon Heavy flight animation.

- After the two side boosters are released, the center core engine continues to burn for a few seconds safely controlling their trajectory away from the center core.
- Four extendable landing legs deploy as the side boosters turn back to Earth, landing each booster softly on the ground (right).
- The center core will continue to fire until stage separation; its four landing legs will then deploy allowing it to land softly on Earth.
- Small grid fins deploy near the top of the three boosters after separation to control their descent through the atmosphere as well as during landing.
Blue Origin Plans Sub-Orbital Tests, Frank Morring, Jr; Aviation Week and Space Technology; April 13-26, 2015; Volume 177, Number 7, page 33 - the New Shepard spacecraft testing is discussed.

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SpaceX F9R Test Flight
https://www.youtube.com/watch?v=DgLBIdVq3EM

SpaceX Cargo Resupply-3
https://www.youtube.com/watch?v=ullu7szab5l

SpaceX Cargo Resupply-6 Mission Booster Test Flight
https://www.youtube.com/watch?v=BhMSzC1cr0

SpaceX Flight 20 Mission Booster Test Flight
https://www.youtube.com/watch?v=ZCBE8ocOkAQ

Blue Origin Charon Test Flight
https://www.youtube.com/watch?v=iQNhdyxqLvU

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Blue Origin PM2 Test Flight
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Blue Origin Crew Capsule Escape Test
https://www.youtube.com/watch?v=Zv74775GFqs

Blue Origin New Shepard Test Flight
https://www.youtube.com/watch?v=rEdk-XNoZpA
Videos and Animations (Continued):

Blue Origin New Shepard Test Flight Launch, Land & Repeat
https://www.youtube.com/watch?v=74tyedGkoUc

Airbus Adeline Reusable Rocket Concept Flight
https://www.youtube.com/watch?v=tV29pEvZvZw

Japanese Space Agency Reusable Vehicle Testing Project
https://www.youtube.com/watch?v=Ogm5w6RxS3A

Space X Falcon Heavy Flight
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