SpaceX reusable launch system development program

The SpaceX reusable launch system development program is a privately funded program to develop a set of new technologies for an orbital launch system that may be reused many times in a manner similar to the reusability of aircraft . The company SpaceX is developing the technologies over a number of years to facilitate full and rapid reusability of space launch vehicles . The project 's long @-@ term objectives include returning a launch vehicle first stage to the launch site in minutes and to return a second stage to the launch pad following orbital realignment with the launch site and atmospheric reentry in up to 24 hours . SpaceX 's long term goal is that both stages of their orbital launch vehicle will be designed to allow reuse a few hours after return .

The program was publicly announced in 2011 and the design for returning the rocket to its launchpad using only its own propulsion systems was completed in February 2012 . SpaceX 's active test program began in late 2012 with testing low @-@ altitude , low @-@ speed aspects of the landing technology . High @-@ velocity , high @-@ altitude aspects of the booster atmospheric return technology began testing in late 2013 and continued to late 2015 , when SpaceX first achieved a successful landing and recovery of a first stage .

The reusable launch system technology is under development for the first stages of the Falcon family of rockets . It is particularly well @-@ suited to the Falcon Heavy where the two outer cores separate from the rocket earlier in the flight , and are therefore moving more slowly at stage separation . On flight 20 the speed at separation was close to 6000 km / h and this allowed a return to near the launch site . On flight 22 , going to GTO , the speed was faster between 8000 and 9000 km / h . At faster speeds it is not possible to return the booster to near the launch site and a landing , if attempted , would need to be hundreds of kilometres downrange likely on an autonomous drone ship . The process involves flipping the rocket around , a boostback burn to slow the rocket , a reentry burn , controlling direction to arrive at the landing site and a landing burn .

It is intended that the reusable technology will be extended to both the first and upper stages of the future launch vehicle for the Mars Colonial Transporter and is considered paramount to the plans SpaceX is developing to colonize Mars .

The first controlled vertical splashdown of an orbital rocket stage on the ocean surface was achieved in April 2014 on the ninth flight of a Falcon 9 . Two subsequent flights in January and April 2015 attempted to land the returning first stage on a floating platform . Although both boosters were guided accurately to the target , they did not succeed in landing vertically on the drone ship and were destroyed . A historic vertical landing was finally achieved on December 21 , 2015 , when the first @-@ stage booster of Falcon 9 Flight 20 successfully touched down at Landing Zone 1 , Cape Canaveral . On April 8 , 2016 , Flight 23 achieved the first soft landing on a drone ship in the Atlantic Ocean .

History

The broad outline of the reusable launch system was first publicly described on September 29 , 2011 . SpaceX said it would attempt to develop powered descent and recovery of both Falcon 9 stages ? a fully vertical takeoff , vertical landing (VTVL) rocket . The company produced a computer @-@ animated video depicting a notional view of the first stage returning tail @-@ first for a powered descent and the second stage with a heat shield , reentering head first before rotating for a powered descent . In September 2012 , SpaceX began flight tests on a prototype reusable first stage with the suborbital Grasshopper rocket . Those tests continued into 2014 , including testing of a second and larger prototype vehicle , F9R Dev1 .

News of the Grasshopper test rocket become public earlier in September 2011 , when the US Federal Aviation Administration released a draft Environmental Impact Assessment for the SpaceX Test Site in Texas , and the space media had reported it by September 26 . In May 2012 , SpaceX obtained a set of atmospheric test data for the recovery of the Falcon 9 first stage based on 176 test runs in the NASA Marshall Space Flight Center wind tunnel test facility . The work was contracted for by SpaceX under a reimburseable Space Act Agreement with NASA .

In 2012 , it was noted that for the technology projected for use on a reusable Falcon 9 rocket the first @-@ stage separation would occur at a velocity of approximately 2 @.@ 0 km / s (6 @,@ 500 km / h ; 4 @,@ 100 mph ; Mach 6) rather than the 3 @.@ 4 km / s (11 @,@ 000 km / h ; 7 @,@ 000 mph ; Mach 10) for an expendable Falcon 9 , to provide the residual fuel necessary for the deceleration and turnaround maneuver and the controlled descent and landing .

In November 2012 , CEO Elon Musk announced SpaceX 's plans to build a second , much larger , reusable rocket system , this one to be powered by LOX / methane rather than LOX / RP @-@ 1 used on Falcon 9 and Falcon Heavy . The new system will be " an evolution of SpaceX 's Falcon 9 booster " , and SpaceX reiterated their commitment to develop a breakthrough in vertical landing technology . By the end of 2012 , the demonstration test vehicle , Grasshopper , had made three VTVL test flights ? including a 29 @-@ second hover flight to 40 meters (130 ft) on December 17 , 2012 . In early March 2013 , SpaceX successfully tested Grasshopper for a fourth time when it flew to an altitude of over 80 meters (260 ft) .

In March 2013 , SpaceX announced that it would instrument and equip subsequent Falcon 9 first @-@ stages as controlled descent test vehicles , with plans for over @-@ water propulsively @-@ decelerated simulated landings beginning in 2013 , with the intent to return the vehicle to the launch site for a powered landing ? possibly as early as mid @-@ 2014 . The April 2013 draft Environmental Impact Statement for the proposed SpaceX South Texas Launch Site includes specific accommodations for return of the Falcon 9 first @-@ stage boosters to the launch site . Elon Musk first publicly referred to the reusable Falcon 9 as the Falcon 9 @-@ R in April 2013 .

In September 2013 , SpaceX successfully relit three engines of a spent booster on an orbital launch , and the booster re @-@ entered the atmosphere at hypersonic speed without burning up . With the data collected from the first flight test of a booster @-@ controlled descent from high altitude , coupled with the technological advancements made on the Grasshopper low @-@ altitude landing demonstrator , SpaceX announced it believed it was ready to test a full land @-@ recovery of a booster stage . Based on the positive results from the first high @-@ altitude flight test , SpaceX advanced the expected date of a test from mid @-@ 2014 to early 2015 , with the intention of doing so on the next Space Station cargo resupply flight pending regulatory approvals . That flight took place on April 18 , 2014 .

Musk stated in May 2013 that the goal of the program is to achieve full and rapid reusability of the first stage by 2015 , and to develop full launch vehicle reusability following that as " part of a future design architecture " .

In February 2014 , SpaceX made explicit that the newly defined super @-@ heavy launch vehicle for the Mars Colonial Transporter would also make use of the reusable technology . This is consistent with Musk 's strategic statement in 2012 that " The revolutionary breakthrough will come with rockets that are fully and rapidly reusable . We will never conquer Mars unless we do that . It 'll be too expensive . The American colonies would never have been pioneered if the ships that crossed the ocean hadn 't been reusable . "

Also in May 2014 , SpaceX publicly announced an extensive test program for a related reusable technology : a propulsively @-@ landed space capsule called DragonFly . The tests will be run in Texas at the McGregor Rocket Test Facility in 2014 ? 2015 .

In June 2014 , COO Gwynne Shotwell clarified that all funding for development and testing of the reusable launch system technology development program is private funding from SpaceX , with no contribution by the US government . SpaceX has not publicly disclosed the cost of the development program .

For the first time , SpaceX stated in July 2014 that they are " highly confident of being able to land successfully on a floating launch pad or back at the launch site and refly the rocket with no required refurbishment . "

By late 2014 , SpaceX suspended or abandoned the plan to recover and reuse the Falcon 9 second stage ; the additional mass of the required heat shield , landing gear , and low @-@ powered landing engines would incur too great a performance penalty .

= = Technologies = =

Several new technologies needed to be developed and tested to facilitate successful launch and recovery of both stages of the SpaceX reusable rocket launching system . Following the completion of the third high @-@ altitude controlled @-@ descent test , and the completion of the third low @-@ altitude flight of the second @-@ generation prototype test vehicle (plus eight flights of the first @-@ generation Grasshopper prototype flight test vehicle) , SpaceX indicated that they are now able to consistently " reenter from space at hypersonic velocity , restart main engines twice , deploy landing legs and touch down at near zero velocity . "

The technologies that were developed for this program , some of which are still being refined , include :

restartable ignition system for the first @-@ stage booster Restarts are required at both supersonic velocities in the upper atmosphere ? in order to decelerate the high velocity away from the launch pad and put the booster on a descent trajectory back toward the launch pad ? and at high transonic velocities in the lower atmosphere ? in order to slow the terminal descent and to perform a soft landing .

new attitude control technology ? for the booster stage and second stage ? to bring the descending rocket body through the atmosphere in a manner conducive both to non @-@ destructive return and sufficient aerodynamic control such that the terminal phase of the landing is possible . This includes sufficient roll control authority to keep the rocket from spinning excessively as occurred on the first high @-@ altitude flight test in September 2013 , where the roll rate exceeded the capabilities of the booster attitude control system (ACS) and the fuel in the tanks " centrifuged " to the side of the tank shutting down the single engine involved in the low @-@ altitude deceleration maneuver . The technology needs to handle the transition from the vacuum of space at hypersonic conditions , decelerating to supersonic velocities and passing through transonic buffet , before relighting one of the main @-@ stage engines at terminal velocity .

hypersonic grid fins were added to the booster test vehicle design beginning on the fifth ocean controlled @-@ descent test flight . Arranged in an " X " configuration , the grid fins control the descending rocket 's lift vector once the vehicle has returned to the atmosphere to enable a much more precise landing location .

throttleable rocket engine technology is required to reduce engine thrust because the full thrust of even a single Merlin 1D engine exceeds the weight of the nearly empty booster core .

terminal guidance and landing capability , including a vehicle control system and a control system software algorithm to be able to land a rocket with the thrust @-@ to @-@ weight ratio of the vehicle greater than one , with closed @-@ loop thrust vector and throttle control

navigation sensor suite for precision landing

a large floating landing platform in order to test pinpoint landings prior to receiving permission from the US government to bring returning rocket stages into US airspace over land . In the event , SpaceX built the autonomous spaceport drone ship in 2014 , and conducted an initial flight test and landing attempt in January 2015 .

large @-@ surface @-@ area thermal protection system to absorb the heat load of deceleration of the second stage from orbital velocity to terminal velocity

lightweight , deployable landing gear for the booster stage . In May 2013 , the design was shown to be a nested , telescoping piston on an A @-@ frame . The total span of the four carbon fiber / aluminum extensible landing legs is approximately 18 meters (60 ft) , and weigh less than 2 @,@ 100 kilograms (4 @,@ 600 lb) . Deployment system uses high @-@ pressure Helium as the working fluid . With Flight 25 it was announced that each landing leg contained a " crush core " , to absorb the impact of landing for particularly hard landings .

= = Economics of rocket reuse = =

In order to make the Falcon 9 reusable and return to the launch site , extra propellant and landing gear must be carried on the first stage , requiring around a 30 percent reduction of the maximum payload to orbit in comparison with the expendable Falcon 9 . Reflight of a previously used stage on a subsequent flight is dependent on the condition of the landed stage , and is a technique that has seen little use outside of the Space Shuttle 's reusable solid rocket boosters . In September 2013 , SpaceX said that if all aspects of the test program were successful and if a customer is interested , the first reflight of a Falcon 9 booster stage could happen as early as late 2014 . In December 2015 , following the recovery of the first stage from the 22 December launch , SpaceX projected that the first reflight of a recovered booster would likely occur in 2016 , but that their plan was to not refly the 22 December recovered stage for that purpose . Musk projects that the reflight step of the program will be " straightforward , " because of the multiple full duration firings of the engines that have been done on the ground , and the multiple engine restarts that have already been demonstrated , with no significant degradation seen . Several industry analysts continue to see potential problems that could prevent economic reuse because costs to refurbish and relaunch the stage are not yet demonstrated . Moreover , the economic case for reuse will be highly dependent on launching frequently , and that is simply unknown as of 2015 .

If SpaceX is successful in developing the reusable technology , it is expected to significantly reduce the cost of access to space , and change the increasingly competitive market in space launch services . Michael Belfiore wrote in Foreign Policy in 2013 that , at a published cost of US $ 56 @.@ 5 million per launch to low Earth orbit , " Falcon 9 rockets are already the cheapest in the industry . Reusable Falcon 9s could drop the price by an order of magnitude , sparking more space @-@ based enterprise , which in turn would drop the cost of access to space still further through economies of scale . " Even for military launches , which have a number of contractual requirements for additional launch services to be provided , SpaceX 's price is under US $ 100 million .

Space industry analyst Ajay Kothari has noted that SpaceX reusable technology could do for space transport " what jet engines did for air transportation sixty years ago when people never imagined that more than 500 million passengers would travel by airplanes every year and that the cost could be reduced to the level it is ? all because of passenger volume and reliable reusability . " SpaceX said in January 2014 that if they are successful in developing the reusable technology , launch prices of around US $ 5 to 7 million for a reusable Falcon 9 were possible , and following the successful first stage recovery in December 2015 , Musk said that " the potential cost reduction over the long term is probably in excess of a factor of 100 . "

As of March 2014 launch service providers who compete with SpaceX were not planning to develop similar technology or offer competing reusable launcher options . Neither ILS , which markets launches of the Russian Proton rocket ; Arianespace ; nor SeaLaunch are planning on developing and marketing reusable launch vehicle services . SpaceX was the only competitor that projected a sufficiently elastic market on the demand side to justify the costly development of reusable rocket technology and the expenditure of private capital to develop options for that theoretical market opportunity .

SpaceX pricing and payload specifications published for the non @-@ reusable Falcon 9 v1.1 rocket actually include about 30 percent more performance than the published price list indicates ; the additional performance is reserved for SpaceX to do reusability booster demonstration flight tests while still achieving the specified payloads for customers .

In order to achieve the full economic benefit of the reusable technology , it is necessary that the reuse be both rapid and complete ? without the long and costly refurbishment period or partially reusable design that plagued earlier attempts at reusable launch vehicles . SpaceX has been explicit that the " huge potential to open up space flight " is dependent on achieving both complete and rapid reusability . CEO Musk stated in 2014 that success with the technology development effort could reduce " the cost of spaceflight by a factor of 100 " because the cost of the propellant / oxidizer on the Falcon 9 is only 0 @.@ 3 percent of the total cost of the vehicle .

Separate from the market competition brought about by SpaceX lower launch prices and the potential future of even more radically lower launch prices if the technology can be completed successfully , Aviation Week has said that " SpaceX reusable launch work is an R & D model " ? " The audacity of the concept and speed of the program ? s progress make it an exemplar . ... [the] breakneck pace of development has been almost Apollo @-@ like in its execution ... [even while] success is far from guaranteed . "

On 9 March 2016 SpaceX President Gwynne Shotwell gave a more realistic appraisal of the potential savings of a reused launch now that attempts to reuse the second stage had been abandoned due to cost and weight issues . She said at $ 1m cost of refueling and $ 3m cost of refurbishing a used first stage could potentially allow a launch to be priced as low as $ 40m , a 30 % saving . SpaceX biggest customer SES has said it wants to be the first to ride a reused vehicle , however it wants a launch price of $ 30m or a 50 % saving to offset the risk of pioneering the process .
According to Elon Musk , almost every piece of the Falcon should be reused over 100 times . Heat shields and a few other items should be reused over 10 times before replacement .

= = Technical feasibility = =

Prior to the reusability program 's success in December 2015 , the return of an orbital launch system had never been accomplished . And even after this success , the rapid reuse of a rocket is still yet to be attempted . Developing a reusable rocket is extremely challenging due to the small percentage of a rocket 's mass that can make it to orbit . Typically , a rocket 's payload is only about 3 % of the mass of the rocket which is also roughly the amount of mass in fuel that is required for the vehicle 's re @-@ entry .
Elon Musk said at the beginning of the program that he believed the return , vertical landing and recovery was possible because the SpaceX manufacturing methodologies result in a rocket efficiency exceeding the typical 3 % margin . A SpaceX rocket operating in the reusable configuration has approximately 30 % less payload lift capacity than the same rocket in an expendable configuration .

= = Test program = =

SpaceX is currently testing reusable technologies both for its first @-@ stage booster launch vehicle designs ? with three test vehicles ? and for its new reusable Dragon V2 space capsule ? with a low @-@ altitude test vehicle called DragonFly .
SpaceX has publicly disclosed a multi @-@ element , incremental test program for booster stages that includes four aspects :
low @-@ altitude (less than 760 m / 2 @,@ 500 ft) , low @-@ velocity testing of its single @-@ engine Grasshopper technology @-@ demonstrator at its Texas test site
low @-@ altitude (less than 3 @,@ 000 m / 9 @,@ 800 ft) , low @-@ velocity testing of a much larger , second @-@ generation , three @-@ engine test vehicle called F9R Dev1 . The second generation vehicle includes extensible landing legs and will be tested at the Texas test site
high @-@ altitude , mid @-@ velocity testing was planned but discontinued . It would use F9R Dev2) at a SpaceX leased facility at Spaceport America in New Mexico .
high @-@ altitude (91 km / 300 @,@ 000 ft) , very @-@ high @-@ velocity (approximately 2 @.@ 0 km / s ; 6 @,@ 500 km / h ; 4 @,@ 100 mph ; Mach 6) ballistic reentry , controlled @-@ deceleration and controlled @-@ descent tests of post @-@ mission (spent) Falcon 9 booster stages following a subset of Falcon 9 launches that began in 2013
Eight low @-@ altitude booster flight tests were made by Grasshopper in 2012 and 2013 . The first booster return controlled @-@ descent test from high @-@ altitude was made in September 2013 , with a second test in April , a third test flight in July and a fourth test in September 2014 . All four test flights to date were intended to be over @-@ water , simulated landings . Five low @-@ altitude booster flight tests of F9R Dev1 were flown during April ? August 2014 , before the vehicle self @-@ destructed for safety reasons on the fifth flight .

= = = Flight testing vehicles = = =

Grasshopper is a set of experimental technology @-@ demonstrator , suborbital reusable launch vehicles (RLV) . Two versions of the prototype reusable test vehicles was built , the 106 @-@ foot tall Grasshopper (formerly designated as Grasshopper v1.0) and the 160 @-@ foot tall Falcon 9 Reusable Development Vehicle , or F9R Dev1 ? formerly known as Grasshopper v1.1. Grasshopper was built in 2011 @-@ 2012 for low @-@ altitude , low @-@ velocity hover testing at the SpaceX Rocket Test Facility in McGregor , Texas , that began in September 2012 and concluded in October 2013 after eight test flights . The second prototype vehicle design , F9R Dev1 , was built on the much larger Falcon 9 v1.1 booster stage was used for higher @-@ altitude and higher @-@ velocity flight testing .

The low @-@ altitude , low @-@ speed flights of the first test vehicle ? Grasshopper ? were conducted . F9R Dev1 was also tested at the Texas facility .

= = = = Grasshopper = = = =

Grasshopper , the company 's first VTVL test vehicle , consisted of a Falcon 9 v1.0 first @-@ stage tank , a single Merlin @-@ 1D engine , and four permanently attached steel landing legs . It stood 106 feet (32 m) tall . SpaceX built a 0 @.@ 5 @-@ acre (0 @.@ 20 ha) concrete launch facility at its Rocket Development and Test Facility in McGregor , Texas to support the Grasshopper flight test program . Grasshopper was also known as Grasshopper version 1 @.@ 0 , or Grasshopper v1.0 , prior to 2014 during the time the followon Grasshopper @-@ class test vehicles were being built .

In addition to three test flights in 2012 , five additional tests were successfully flown by the end of October 2013 ? including the fourth test overall in March 2013 ? in which Grasshopper doubled its highest leap to rise to 80 @.@ 1 meters (263 ft) with a 34 @-@ second flight . In the seventh test , in August 2013 , the vehicle flew to 250 meters (820 ft) during a 60 @-@ second flight and executed a 100 @-@ meter (330 ft) lateral maneuver before returning to the pad . Grasshopper made its eighth and final test flight on October 7 , 2013 , flying to 744 meters (2 @,@ 441 ft) (0 @.@ 46 miles) before making its eighth successful landing . The Grasshopper test vehicle is now retired .

= = = = Falcon 9 Reusable Development Vehicle (F9R Dev) = = = =

Beginning in October 2012 , SpaceX discussed development of a second @-@ generation Grasshopper test vehicle , which would have lighter landing legs that fold up on the side of the rocket , a different engine bay , and would be nearly 50 % longer than the first Grasshopper vehicle . In March 2013 , SpaceX announced that the larger Grasshopper @-@ class suborbital flight vehicle would be constructed out of the Falcon 9 v1.1 first @-@ stage tank that was used for qualification testing at the SpaceX Rocket Development and Test Facility in early 2013 . It has been rebuilt as the F9R Dev1 with extensible landing legs .

The second VTVL flight test vehicle ? F9R Dev1 , built on the much longer Falcon 9 v1.1 first @-@ stage tank , and with retractable landing legs ? made its first test flight on April 17 , 2014 . F9R Dev1 was used for low @-@ altitude test flights in the McGregor , Texas area with projected maximum altitude below 3 @,@ 000 meters (10 @,@ 000 ft) . This vehicle self @-@ destructed as a safety measure during a test flight on August 22 , 2014 .

As of April 2014 , a third flight test vehicle ? F9R Dev2 ? was being built and was planned to be flown at the high @-@ altitude test range available at Spaceport America in New Mexico where it was expected to be flown at altitudes up to 91 @,@ 000 meters (300 @,@ 000 ft) -plus .

= = = = DragonFly = = = =

DragonFly is a prototype test article for a propulsively @-@ landed version of the SpaceX Dragon space capsule , a suborbital reusable launch vehicle (RLV) , intended for low @-@ altitude flight testing . It will undergo a test program in Texas at the McGregor Rocket Test Facility , in 2014 ? 2015 .

The DragonFly test vehicle is powered by eight SuperDraco engines , arranged in a redundant pattern to support fault @-@ tolerance in the propulsion system design . SuperDracos utilize a storable propellant mixture of monomethyl hydrazine (MMH) fuel and nitrogen tetroxide oxidizer (NTO) , the same propellants used in the much smaller Draco thrusters used for attitude control and maneuvering on the first @-@ generation Dragon spacecraft . While SuperDraco engines are capable of 73 @,@ 000 newtons (16 @,@ 400 lbf) of thrust , during use on DragonFly flight test vehicle each will be throttled to less than 68 @,@ 170 newtons (15 @,@ 325 lbf) to maintain vehicle stability .

A test flight program of thirty flights has been proposed , including two propulsive assist (parachutes plus thrusters) and two propulsive landing (no parachutes) on flights dropped from a helicopter at an altitude of approximately 3 @,@ 000 meters (10 @,@ 000 ft) . The other 26 test flights are projected to take off from a pad : eight to be propulsive assist hops (landing with parachutes plus thrusters) and 18 to be full propulsive hops , similar to the Grasshopper and F9R Dev booster stage test flights .

The DragonFly test program is not expected to start until after the completion of the F9R Dev1 booster testing at the McGregor facility .

= = = Falcon 9 booster post @-@ mission flight tests = = =

In an arrangement unusual for launch vehicles , some first stages of the SpaceX Falcon 9 v1.1 rockets are being used for propulsive @-@ return controlled @-@ descent flight tests after they complete the boost phase of an orbital flight . These boosters would ordinarily just be discarded in the ocean after setting their payloads on their way . The over @-@ water tests take place in the Pacific and Atlantic oceans south of Vandenberg Air Force Base and east of Cape Canaveral Air Force Station . The first flight test occurred on September 29 , 2013 , after the second stage with the CASSIOPE and nanosat payloads separated from the booster . These descent and simulated landing tests continued over the next two years , with the second flight test taking place on April 18 , 2014 , and four subsequent tests conducted in 2015 .

= = = = Perfecting re @-@ entry and controlled descent = = = =

Following analysis of the flight test data from the first booster @-@ controlled descent in September 2013 , SpaceX announced it had successfully tested a large amount of new technology on the flight , and that coupled with the technology advancements made on the Grasshopper low @-@ altitude landing demonstrator , they were ready to test a full recovery of the booster stage . The first flight test was successful ; SpaceX said it was " able to successfully transition from vacuum through hypersonic , through supersonic , through transonic , and light the engines all the way and control the stage all the way through [the atmosphere] " . Musk said , " the next attempt to recovery [sic] the Falcon 9 first stage will be on the fourth flight of the upgraded rocket . This would be [the] third commercial Dragon cargo flight to ISS . "

This second flight test took place during the April 2014 Dragon flight to the ISS . SpaceX attached landing legs to the first stage , decelerated it over the ocean and attempted a simulated landing over the water , following the ignition of the second stage on the third cargo resupply mission contracted to NASA . The first stage was successfully slowed down enough for a soft landing over the Atlantic Ocean . SpaceX announced in February 2014 the intent to continue the tests to land the first @-@ stage booster in the ocean until precision control from hypersonic all the way through subsonic regimes has been proven . Five additional controlled @-@ descent tests were conducted in the remainder of 2014 through April 2015 , including two attempts to land on a floating landing platform ? a SpaceX @-@ built Autonomous Spaceport Drone Ship ? on the Atlantic Ocean east of the launch site , both of which brought the vehicle to the landing platform , but neither of which resulted in a successful landing .

= = = = First landing success aground = = = =

During the 2015 launch hiatus , SpaceX requested regulatory approval from the FAA to attempt returning their next flight to Cape Canaveral instead of targeting a floating platform in the ocean . The goal was to land the booster vertically at the leased Landing Zone 1 facility ? the former Launch Complex 13 where SpaceX had recently built a large rocket landing pad . The FAA approved the safety plan for the ground landing on 18 December 2015 . The first stage landed successfully on target at 20 : 38 local time on December 21 (01 : 38 UTC on December 22) .

SpaceX does not plan to fly the Falcon 9 Flight 20 first stage again . Rather , the rocket was moved a few miles north to Launch pad 39A , recently refurbished by SpaceX at the adjacent Kennedy Space Center , to conduct a static fire test on 15 January 2016 . This test aimed to assess the health of the recovered booster and the capability of this rocket design to fly repeatedly in the future . The tests delivered good overall results except for one of the outer engines experiencing thrust fluctuations . Elon Musk reported that this may have been due to debris ingestion .

= = = = Near @-@ misses on the oceans = = = =

Falcon 9 Flight 21 launched the Jason @-@ 3 satellite on January 17 , 2016 and attempted to land on the floating platform Just Read the Instructions , located for the first time about 200 miles (320 km) out in the Pacific Ocean . Approximately 9 minutes into the flight , the live video feed from the drone ship went down due to the losing its lock on the uplink satellite . The vehicle landed smoothly onto the vessel but one of the four landing legs failed to lock properly , reportedly due to ice from the heavy pre @-@ launch fog preventing a lockout collet from latching . Consequently the booster fell over shortly after touchdown and was destroyed in a deflagration upon impact with the pad .

Flight 22 was carrying a heavy payload of 5 @,@ 271 kilograms (12 @,@ 000 lb) to geostationary transfer orbit (GTO) . This was heavier than previously advertised maximum lift capacity to GTO being made possible by going slightly subsynchronous . Following delays caused by failure of Flight 19 SpaceX agreed to provide extra thrust to the SES @-@ 9 satellite to take it supersynchronous . As a result of these factors , there was little propellant left to execute a full reentry and landing test with normal margins . Consequently the Falcon 9 first stage followed a ballistic trajectory after separation and re @-@ entered the atmosphere at high velocity , making it less likely to land successfully . The atmospheric re @-@ entry and controlled descent were successful despite the higher aerodynamical constraints on the first stage due to extra speed . However the rocket was moving too fast and was destroyed when it collided with the drone ship . SpaceX collected valuable data on the extended flight envelope required to recover boosters from GTO missions .

= = = = First landings on drone ship = = = =

On April 8 , 2016 , Falcon 9 Flight 23 , the third flight of the full @-@ thrust version , delivered the SpaceX CRS @-@ 8 cargo on its way to the International Space Station while the first stage conducted a boostback and re @-@ entry maneuver over the Atlantic ocean . Nine minutes after liftoff , the booster landed vertically on the drone ship Of Course I Still Love You , 300 km from the Florida coastline , achieving a long @-@ sought @-@ after milestone for the SpaceX reusability development program .

A second successful drone ship landing occurred on May 6 , 2016 , with the next flight which launched JCSAT @-@ 14 to GTO . This second landing at sea was more difficult than the previous one because the booster at separation was traveling about 8 @,@ 350 km / h (5 @,@ 190 mph) compared to 6 @,@ 650 km / h (4 @,@ 130 mph) on the CRS @-@ 8 launch to low Earth orbit . Pursuing their experiments to test the limits of the flight envelope , SpaceX opted for a shorter landing burn with three engines instead of the single @-@ engine burns seen in earlier attempts ; this approach consumes less fuel by leaving the stage in free fall as long as possible and decelerating more sharply , thereby minimizing the amount of energy expended to counter gravity . Elon Musk indicated this first stage may not be flown again instead being used as a life leader for ground tests to confirm others are good .

A third successful landing followed on May 27th , again following deceleration from the high speed required for a GTO launch . The landing crushed a " crush core " in one leg , leading to a notable tilt to the stage as it stood on the drone ship .

= = = = Future tests = = = =

SpaceX aims to return a number of first stages to both land and drone ships in 2016 to clarify the procedures needed to re @-@ use the boosters rapidly . The company hopes to begin offering pre @-@ flown Falcon 9 rocket stages commercially by the end of the year , aiming at relaunching such a stage in the near future . In January 2016 Elon Musk estimated the likelihood of success to 70 percent for all landing attempts in 2016 , hopefully rising to 90 percent in 2017 ; he also cautioned that we should expect " a few more RUDs " (Rapid Unscheduled Disassembly , Musk 's euphemism to denote destruction of the vehicle on impact) .