

REDUCING THE COST OF SPACE EXPLORATION WITH REUSABLE LAUNCH VEHICLES



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Purpose

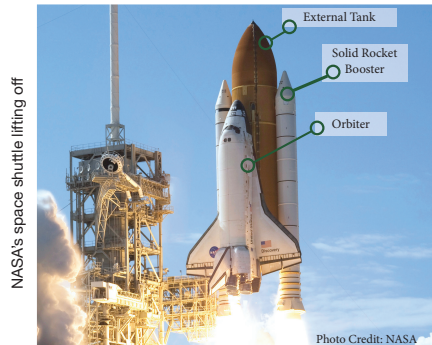
Modern society and scientific discovery relies heavily on communication satellites, microgravity research labs, and space telescopes – all of which require space transportation.

Space launch systems have been in use since the 1950's, however the cost remains extremely high. It costs about \$10,000 USD to launch one pound of payload into low-earth orbit (LEO). Research is going into creating Reusable Launch Vehicles (RLV's) that have the potential to dramatically decrease the cost of space travel and accelerate scientific research and development.

History

Space Shuttle Program (NASA):

- Partially re-usable, manned launch system
- Vertical take-off, horizontal landing
- 133 successful missions
- 6 orbiters built
- \$450M / launch (1)
- ~\$10k / pound to LEO (2)
- Program active from 1981-2011
- Originally designed as a "space-taxi" to deliver payload to low earth orbit. Designed to be rapidly reusable with cost per launch in the \$20M range.
- Repairing hundreds of heat shield tiles and restitching the parachutes after each flight involved specialized labor and took more man-hours than expected.
- The program ended up costing more money than expected. Also considering safety concerns, the program was terminated in 2011.



NASA's RLV Program (1990's):

- Involved bids from three major companies: McDonnell Douglas, Boeing and Lockheed Martin
- Lockheed's X-33 promised to decrease \$10,000 / lb launch price to \$1,000 / lb (3)
- X-33 was a Single-Stage-To-Orbit (SSTO) RLV that used linear aerospike engines
- Douglas created the DC-X, a single stage to orbit (SSTO) RLV that lands vertically. It could potentially be refueled where it landed and launch immediately which would yield fast turn around times.
- Cancelled after technical difficulties and developmental costs



Liquid Fly Back Boosters:

- LFBB were boosters that could potentially replace the two solid rocket boosters on the shuttle.
- They would launch up with the shuttle and after detaching, they would land on a runway similar to an airplane.
- NASA inhouse study (1998) showed that LFBB is technologically viable, no technology breakthroughs are needed and affordable main engine candidates are available. (4)
- LFBB was concluded to reduce annual operations by \$400M USD at 7-8 flights per year.
- Developmental costs were too high so the LFBB never got off the drawing board.

Buran:

- A Russian vehicle analogous to NASA's shuttle
- Launched only once in November 1988

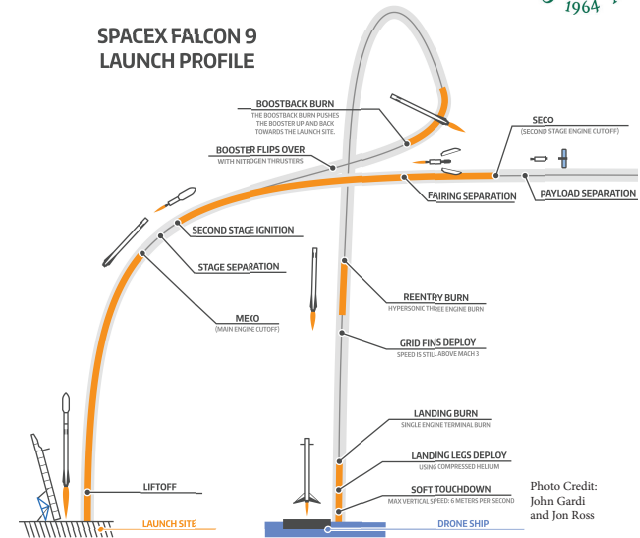
Current Designs

- Space Exploration Technologies (SpaceX) is a private space company that launches satellites, resupplies the International Space Station, and might transport humans to the ISS by 2017.
- Grasshopper program began the reusability testing
- SpaceX plans to reuse the first stage of their Falcon 9 rocket by landing it vertically on a landing pad floating in the Atlantic Ocean. They will slow the first stage in it's decent by reigniting one of the nine engines. It will then land on four legs which are deployed before touchdown.
- Recovering and reusing the first stage will lower the cost of launch since the first stage alone makes up about 3/4 of cost for the Falcon 9 rocket.
- The cost of launch for an expendable Falcon 9 is ~\$61.2M USD. (5)
- Adding enough fuel and equipment to make the Falcon 9 reusable would result in 30% less total payload reaching orbit.
- The reusable Falcon 9-R (reusable model) has already carried DSCOVR to orbit and resupplied the ISS with these weight constraints.



"If one can figure out how to effectively reuse rockets just like airplanes, the cost of access to space will be reduced by as much as a factor of a hundred. A fully reusable vehicle has never been done before. That really is the fundamental breakthrough needed to revolutionize access to space." -Elon Musk, founder of SpaceX

SPACEX FALCON 9 LAUNCH PROFILE



The Falcon 9 rocket, built by Space Exploration Technologies, shows promise for being the first fully reusable rocket. They will start with relanding the first stage, the most expensive part, on a barge in the Atlantic Ocean. The first stage is fitted with grid fins which will help to direct the first stage in it's decent from 50 miles to the landing site. The first stage also has landing legs to support the rocket after it lands vertically.

Conclusion:

Space exploration is very expensive and will remain so until the launch vehicle can be fully reused. NASA's Space Shuttle Program was a partial success but took too much time and money to prepare for another flight. Progress has been made in the private sector with SpaceX's Falcon 9 rocket but as of today, there is no fully reusable launch vehicle available.

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