Verticle Landing Rockets

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ABSTRACT

The concept of Vertical landing Rockets was developed to achieve re-usability of the rocket in order to decrease cost and time of Rocket launching . Successful attempts of vertical landing rockets have been attempted by SpaceX and Blue origin with the motivation of reduction of manufacturing and research costs, these have led the path for the re-usability of rocket engines and autonomous recovery of rockets. This paper will discuss the challenges to meet the precision landing of rockets on earth and other planets and also factors required to extend this technology to implement it in future space tourism.

1 History

The history of Vertical landing rockets dates back to 1961 where this concept was demonstrated by Bell Rocket belt i.e a rocket pack. An individual was equipped with a low power rocket propulsion device that allowed him to safely travel over small distances[1]. This gave birth to the concept of Vertical Landing of Rockets. Apollo lunar module was a 1960's two-staged Vertical take-off and vertical landing (VTVL) vehicle for landing and take-off from the moon. In 1990's Mc Donnell Douglas "Delta clipper" demonstrated the Vertical Take-Off and Landing capabilities of a scaled rocket[2] . In successive years Blue Origin developed on this concept to build a VTVL suborbital reusable launch vehicle named "New Shepard" which had its first ever successful test flight on November 23rd,2015[3]. The greatest breakthrough was when SpaceX "Falcon 9" made it's first successful landing on their autonomous drone ship on March 30th 2017[4]. Subsequently other space agencies around the world are developing their own concepts of VTVL such as ISRO's 'Admire' rocket. The challenges faced in achieving this is discussed in the next section.

2 Theory

Every Heavy Launch Rocket will have multiple stages in its functioning. The VTVL concept concentrates more on the first stage, where they want to retract the first stage of the rocket rather than drowning it in the sea. This not only saves a lot of investment in manufacturing, it also builds a reusable system which reduces time and human effort. The vertical landing of a rocket weighing almost 500,000 kg from an altitude of roughly 70 km descending at a speed of nearly 8000 km/h on a landing path of just 50m wide requires the highest grade of engineering brilliance. A typical trajectory of the VTVL rocket is shown in the figure 1.The requirements to achieve a safe vertical landing is discussed below:

1) Thrust vector control: The control of the descending rockets are achieved by the Gimbled nozzles and Grid fins. The Gimbled nozzles are gimbled in particular angles to orient the rockets to its landing path[3]. Gimbled nozzles are used in thin atmospheres where other aerodynamics surfaces are ineffective. It helps in decelerating the rocket during its re-entry or descent into the atmosphere.

2) Cold gas thrusters: The rockets are employed with nitrogen cold gas thrusters that are mounted towards the top of the first stage. They are critical in performing the flip maneuver which orients the rocket towards it's landing path[4].

3) Re-ignitable engines: Since VTVL rockets have a complex re-entry trajectory, it is required that the engine is ignited several times. Due to this companies are using Re-Ignitable liquid propellant rocket engines. They are designed to re ignite in the upper atmosphere at supersonic speeds as well as in the lower atmosphere at transonic speeds[4]. In case of Falcon 9, Spacex uses Merlin engines which are powered by burning Liquid Oxygen(LOX) and rocket-grade kerosene (RP-1) propellants. Whereas the New Shepard of Blue Origin employs BE-3 bi-propellant rocket engine burning liquid hydrogen and liquid oxygen.

4) Inertial navigation and global positioning system: The rockets are equipped with INS which uses several sensors to measure the position, orientation and velocity of the vehicle, whereas the GPS is used to measure the geolocation. The on board computers takes inputs from these systems and if there is any deviation in the flight path then it instructs the rocket to adjust its position using the grid fins or the thrusters[4].In case of landing on other planets the Gps doesn't come of any use, so the telemetry from earth stations should guide the rocket or the space craft to land on the desired area. However as the distance from earth to the destination increase there will be delays and accuracy of the landing will decrease, there might be communication loss for a while if the signals are out of reach or due to eclipse between the earth, extra-terrestrial object and the spacecraft. The possible solution would be to use visual based navigation[3]. The orbiter can take images once in orbit and the same image can be fed to the lander where it can compare the image it sees with the reference image and develops a flight path to land, this also increase accuracy of landing.

5) Deployable landing gear: The rockets are equipped with light weight landing legs which are made up of carbon fiber and aluminium. They are deployed right before touch down using high pressured helium and consist of impact attenuators in case of hard landings[3].

6) Deployable grid fins: Titanium grid fins are mounted at the first stage of the rocket and are deployed during the decent of the rocket into lower atmosphere. The fins are aerodynamics control surfaces that are used for precise control of rockets position and orientation prior to landing. They alone are responsible for the precise landing that is achieved during vertical landing[3][5].

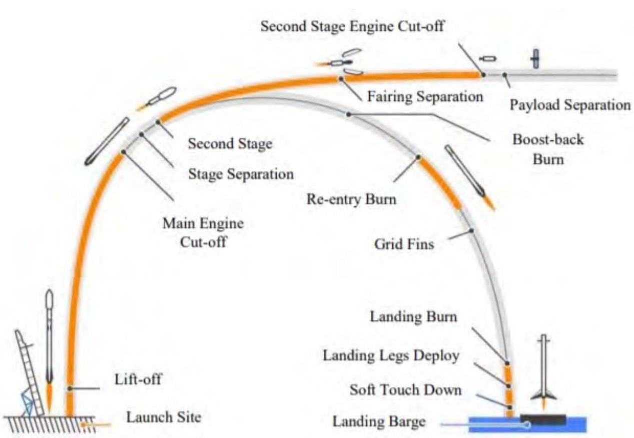

Fig. 1 SpaceX Falcon 9 launch profile [3]

3 Conclusion

The technology required to successfully achieve retro-propulsive landings or vertical landing are, the thrust vectoring (gimbaled nozzle), guidance which is capable of calculating the position and altitude of the vehicle, engines that can re-ignite at different conditions, RCS (Reaction control system) to keep the vehicle at the correct angle, additionally grid fins are used for attitude control during landing.

The additional weight of fuel, larger tank, landing legs, and their deployment mechanisms will usually reduces the payload capacity. The main benefit of the technology is seen in the potential for substantial reductions in space flight costs as a result of being able to reuse rockets after successful vertical landings. In order to enhance the precise landing of rockets on other planets, terrene mapping can be implemented. The GPS based navigation doesn't work on other planets, hence a visual-based navigation system is required which maps the terrene and compares it to the previously taken image to reach the landing site [4].

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