Autonomous self-landing rocket mounted with co-axial propellers with lidar sensor, avoids hazards and ability to hover in the atmosphere using machine learning.

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Abstract- ***Building a Rocket is expensive, this is enough convincing to develop a reusability system. The reusability system can reduce the production cost for upcoming launches. Pragmatically, we can able to recover the first stage Rocket. The companies like SpaceX and Blue-origin have successfully recovered the rocket by autonomous landing system. This project aims to provide a more sophisticated and efficient design to vertically land rockets using co-axial propellers mounted on top of the rocket, also giving an additional feature to the existing models, which is to hold its position in the atmosphere which helps the rocket to scan the surface using LIDARs and make a decision. Using this information, the rocket can also change the direction accordingly. This technology is very important for surfaces like Mars which are full of clusters. This mechanism can stay put the rocket in the atmosphere and let LIDARs scan the surface and provide sufficient data for autonomous landing. Machine Learning is used to analyze the data and make a convincing approach for safer landing and direction control. Thus, in turn, reduces the risk of damage and inappropriate landing on the surface like Mars and Earth.***

Keywords—co-axial propellers, LIDARs, VTVL.

1.INTRODUCTION

The objective of this paper is to provide a more sophisticated and effective design for an autonomous self-landing rocket using co-axial propellers mounted on top of the rocket to provide an ability to hold its position in the atmosphere, to increase the percentage of effective safely landing and precision landing on a surface like Mars. VTVL is the reusable launch system technology developed for Rockets with vertical take-off and vertical landing capabilities, the technology developed to achieve retro propulsive landing. The thrust must be greater than the weight of the rocket and also it must be vectored and requires some degree of throttling [1].

This subject was in theory for the past few decades, but until 2015, SpaceX successfully recovered the first stage of the Falcon 9 Rocket. The rocket has two main stages. The first stage of the rocket has clustered engines and aluminum-lithium alloy tanks. Excluding the payload which is mounted on top of the second stage, it contains a single engine to drive the payload to the desired orbit in space [2]. After partition, the first stage returns through a reaction-controlled system, RCS uses thruster and reaction control wheels to provide altitude control [3] and RCS is responsible to provide enough torque for rotation, which includes roll, pitch, and yaw.

In this thesis, we use co-axial propellers to provide balance to the rocket with normalized nozzle thruster with the required gimbal angle to change in direction. The co-axial propellers drive the two propellers mounted on a concentric propeller shaft with independent drives and rotating in the opposite direction which results in zero residual torque. This mechanism will add an extra feature to the existing model that is the ability to stay held in the atmosphere and through the feedback, it analyses the best surface to land. And also, to improve the safe precision landing percentage. Thus avoids inappropriate landing on the surface like marks and reduces the loss.

1.2 BRIEF HISTORY

This project was first mentioned in September 2011. Since 2014, SpaceX has intended to develop the technology for reusable Rockets. The long-term objective of this project is to return the first stage of the launch vehicle to a certain landing site, which was later named as "Drone Ship", and to return the second stage of the launch vehicle after orbital realignment after deploying the payload in its orbit and atmospheric re-entry. In December 2015, SpaceX has successfully landed and recovered the first stage of the rocket for the first time[4]. Initially, the recovery of the second stage of the launch vehicle was out of the discussion. As of 2021, SpaceX developed the Starship system, a fully-reusable two-stage launch vehicle.

1.3 PROBLEM DEFINITION

Existing reusable launch systems can't hold their position in the atmosphere, and why is it important to hold a rocket's position in the atmosphere? Holding its position in the atmosphere gives extra time for the rocket to analyze the surface through LIDARs, and with the data received using machine learning the system chooses the most desirable landing site to reduce the risk of failure. For the surface like Mars and point-to-point transfer on Earth, the capability to hold in the atmosphere can increase the percentage of autonomous precision landing and reduce the risk.

2. MODEL

This mechanism comes into play at the time of recovery. Following the separation of the second stage, the rocket propellers back to the earth's surface, slowing down the rocket using parachutes. Co-axial propellers provide enough thrust to lift the rocket with the help of rocket thrusters in the fall. Then the in-build co-axial propeller mechanism comes into action where the co-axial rotor blades open at an angle of 90 degrees to the rocket body. Hereafter, the parachutes will get disconnected. The drive of co-axial propellers starts where the rotor starts rotating. Since to provide support to the co-axial propellers, moveable rocket thrusters will ignite in the fall. A moveable rocket thruster will help to change the direction of flight.

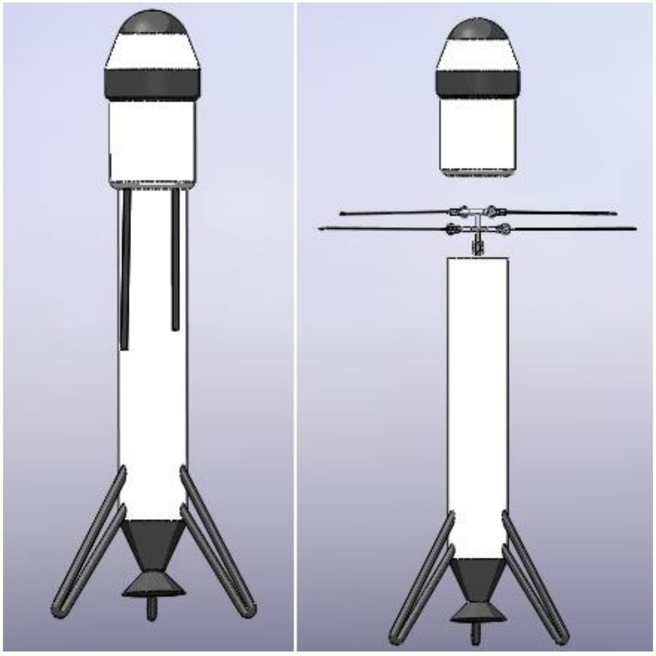

Fig 1. Co-axial propellers mounted on top of launch vehicle

2.1 DRIVE FOR CO-AXIAL PROPELLERS

The co-axial model system inherits stability and quick control. This increases the propulsion efficiency. The co-axial propellers drive the two propellers mounted on a concentric propeller shaft with independent drives and rotating in opposite directions, resulting in zero residual torque. It eradicates the need for using a tail rotor, which consumes about 5-20% of the total power generated [5].

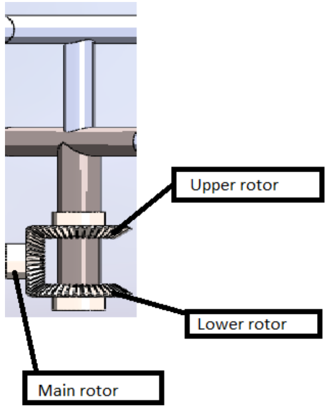

Fig 2. Drive for Co-axial Propeller.

2.1.1 ANALYSIS OF CO-AXIAL ROTOR SYSTEM

The co-axial rotor system is analysed using a momentum theory. More information on this is given by Leishman [6] who worked on various theoretical models. Considering the hovering co-axial case:
Assuming that both rotors provide an equal amount of thrust, 2T, where T = W/2. The effective induced velocity of the rotor system will be

$$(v_i)_e = \sqrt{\frac{2T}{2\rho A}}$$

Thus, the induced power is:

$$(P_i)_{Total} = 2T(v_i)_e = \frac{(2T)^{\frac{3}{2}}}{\sqrt{2\rho A}}$$

Abbreviations:
v_i -Average induced velocity
v_e -Average effective induced velocity
P_i -induced power
T-Rotor Thrust
ρ-Air density (1.225kg/m3at sea level)
A-Rotor disk area.

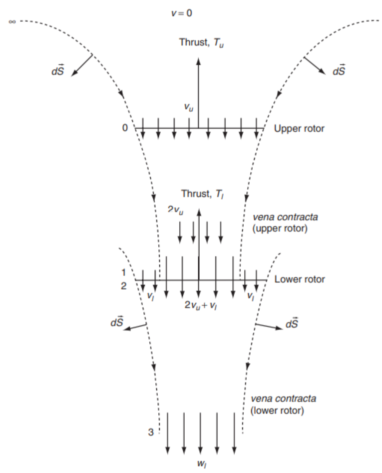

Fig 3. Flow model of co-axial rotor system [6].

2.2 Thrust Vector Control

TVC is the ability of a rocket or other vehicle to manipulate the direction of the thrust from its engine. Pragmatically, the thrust vector of a rocket nozzle, the line of action passes through the vehicle's center of mass that provides the ability to pitch and yaw moments by deflecting the main rocket thrust vector. The direction of the nozzle commands the angle at which thrust is applied that creates a moment about the center of gravity is created [7]. And the nozzle is moved along 3-dimensional with actuators.

2.2.1 Gimbaled Thrust

The deflecting of the Rocket nozzle is done by gimbaling the whole engine i.e moving the entire combustion chamber and outer engine. And the nozzle is attracted to the rocket via a ball joint.[8].

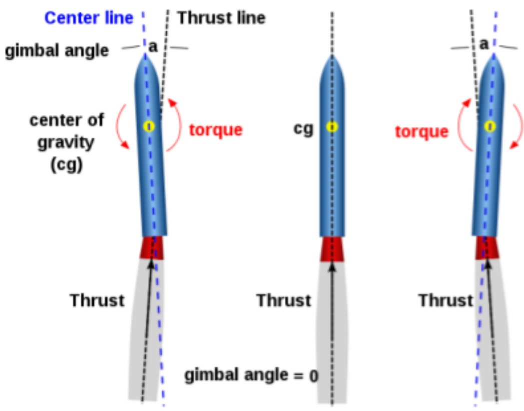

Fig 4. Thrust vector control of a rocket [7]

3. Reinforcement Learning

Reinforcement learning is one of the three basic machine learning concepts, alongside supervised and unsupervised learning. Supervised learning algorithms are trained using labeled input data to classify data or predict outcomes accurately based on previous experience or input-output comes. Unsupervised learning is used to find all kinds of unknown patterns in data. Unsupervised learning algorithm to identify patterns from neither labeled nor classified. On the other hand, a Reinforcement learning algorithm is trained in an environment. RL is also called the science of decision-making. It is about learning the behavior in an environment to obtain maximum reward [9]. This environment is defined as a Markov Decision process [10]. A set of actions are available to choose from at ant state and it involves a policy that takes actions, states that represents where the agent is, and reward which imposes well-defined actions in a state. The value function is used to calculate the reward of a state-action pair.

By following a policy π. The value is defined as the expected return in a state. The value function is derived from the bellman equation, which is the total reward given by taking an action at a particular state. The value function can be defined as [12]

$$v_\pi(s) = E_\pi[G_t|S_t = s] = E_\pi[\sum_{K=0}^{\infty} \gamma^K R_{t+k+1}|S_t = s]$$

The policy π defines which action the agent will take to a given state. $E\pi$ is the random value, R is the reward value at the state at time t, and γ is the discount factor where the value is always between 0 and 1. For spacecraft, the value function is a function of the difference between current and target spacecraft state [13].

3.1 Q-Learning

Q-learning is an off-policy temporal difference (TD) where TD is a phenomenon in RL that predicts the value of a variable based on the value of the input at every time step. Q-learning algorithm is used in the discrete action-space environment. The q value is used to predict future rewards. Q-function is defined in terms of the state and action of the agent. The Q action-value function is defined as [13].

$$Q(S_t, A_t) \leftarrow Q(S_t, A_t) + \propto [R_{t+1} + \gamma max_a Q(S_{t+1}, a) - Q(S_t, A_t)]$$

Q values are stored in the table for every possible state-action pair.

States accesed using binary representation

		States					
		1	2	3	...	n-1	n
Actions	Left	0	0				0
	Right	0.1	0.1	...	...	...	0.1
	Up	0	0		Q(s, a=up)		0
	Down	0	0		Q(s, a=down)		0

Fig 5. Tabular representation of state- action function.[13]

4.Conclusion

This project aims to develop the technology and design to hover capabilities to the Autonomous self-landing rocket. On that note, usage of the co-axial propeller has been considered, which eradicated the residual torque on the body and can generate the thrust required to hover with help of a movable nozzle attracted to the Rocket via a ball joint. Thrust vector control is to be analyzed, where the deflection of the nozzle can change the direction. Since the thrust is applied, a torque about the center of gravity is created. With hover capabilities, the Rocket has more time to scan the surface using LIDARs and make a convincing decision to choose the perfect land site using machine learning. The goal of this project is, to buy more time for the rocket to make proper decisions and choose the safest landing site on the surface like mars especially, increase the efficiency of precision landing, and reduce the hazards by proper decision-making.

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