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Vertical takeoff and landing aircraft: Categories, applications, and technology

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Abstract. A Vertical Take-Off and Landing (VTOL) aircraft is an aircraft with the ability to take off and land vertically. The ability of removing the need for a runway allows VTOL aircraft to be used for applications that standard aircraft cannot be used for. These applications include military, firefighting, and transportation applications. For the purposes of this paper, helicopters will be considered to be VTOL aircraft, as they fit the general criteria and are among the first to be widely used. VTOL aircraft can be split into several categories, including hybrid VTOL aircraft, VTOL Unmanned Aerial Vehicles, and electric VTOL aircraft. These categories of VTOL aircraft are compared. Famous VTOL aircrafts like Osprey and Harrier are introduced. The technology behind VTOL aircraft is explained, and the ways in which VTOL aircraft can be made useful are reviewed. In addition, the prospect of VTOL aircraft has been made. This paper may offer a reference for the future works about VTOL.

Keywords: VTOL, Hybrid Aircraft, Helicopter.

1. Introduction

A Vertical Take-Off and Landing (VTOL) aircraft is an aircraft that is capable of taking off and landing vertically. This removes the necessity for the aircraft to use a runway. VTOL aircraft achieves this by using motors to generate lift directly upwards, instead of gradually angling the front of the aircraft upwards. There are different ways to do this. VTOL aircraft has many applications in different fields that traditional fixed-wing aircraft cannot have.

The most well-known type of VTOL aircraft is the helicopter, which uses its rotor blades to generate vertical lift. While it is debated whether or not a helicopter is a VTOL aircraft due to its stark differences, for the purposes of this paper, helicopters will be considered as a kind of VTOL aircraft. One of their first major uses came in World War II, during which helicopters quickly transported soldiers from battlefronts, where there were few runways. The success of VTOL aircraft at this time made large aircraft companies, including McDonnell Douglas, Boeing, and Lockheed Martin, start to manufacture and engineer VTOL aircraft [1]. Noteworthy examples of VTOL aircraft include the V-22 Osprey and the Harrier. Both of them have once served important military applications.

The ability to take off and land vertically serves several applications. However, there is a tradeoff in most cases. VTOL aircraft's flight performance is not strictly superior to fixed-wing aircraft. In this article, related works about VTOL aircraft are reviewed. Several categories of VTOL aircraft, including eVTOL, VTOL Unmanned Aerial Vehicles (UAV), hybrid aircraft, and helicopters, are compared. Then,

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the technology behind VTOL aircraft is explained, and the ways in which VTOL aircraft can be made useful are reviewed. This paper may offer a reference for future works about VTOL.

2. Classification of VTOL Aircraft

VTOL aircraft, unlike standard commercial aircraft, can be designed in many different ways. There are several different categories of VTOL aircraft, which all have their unique advantages and disadvantages. All categories of VTOL are capable of generating forces in the vertical direction, allowing for safe vertical acceleration and deceleration for taking off and landing.

2.1. Electric VTOL Aircraft

Like most vehicles, VTOL aircraft can be electric or non-electric. Electric VTOL (eVTOL) aircraft require less or no fossil fuels, as they rely on batteries for power. Opposed to conventional VTOL aircraft, which are equipped with complex internal combustion machines, eVTOL aircrafts use simpler propulsion units and significantly less energy overall, allowing their motors to generate little noise and pollution [2]. It is possible that in the future, eVTOL aircraft will be used more commonly than conventional VTOL aircraft. However, it must be noted that eVTOL technology is still a relatively new development, implementing it for practical uses will bring out challenges. While eVTOL aircrafts are still not used frequently in the United States, due to the large amount of energy they consume, certifying them for personal use instead of commercial use will be a way to make eVTOL aircrafts more prevalent in the VTOL industry quickly. This means that in the near future, eVTOL aircrafts will likely not be carrying passengers in the same way fixed-wing aircraft do, and will be used for tasks only suited for aircraft capable of taking off and landing vertically instead.

2.2. Hybrid vs. Rotary Wing Aircraft

VTOL aircrafts generally fall into two subcategories based on their ways of generating vertical lift and take-off without the use of a runway: hybrid aircraft, and rotary wing aircraft. Hybrid aircrafts, as the name suggests, are a mix between tiltrotor aircraft and conventional fixed-wing aircraft. This means that after taking off vertically, they are capable of travelling at fast speeds using fixed wings like an airplane. Although most hybrid VTOL aircrafts are either unmanned or remotely controlled, there exist some exceptions [3,4]. A unique example is the V-22 Osprey by Boeing, which is a manned aircraft with the ability to significantly change the angle of its rotors, and thus use the rotors for both vertical and horizontal acceleration. The Harrier also serves similar functions, using a motor and multiple nozzles instead of rotors, and has already been used in combat settings.

Contrastingly, rotary-wing aircraft, or rotorcrafts, use only rotors fixed onto the aircraft to lift off and travel horizontally. The most common example of this kind is the helicopter, which features a large set of blades attached to the top of the helicopter. Throughout history, the helicopter has gone through many design changes. The final product used today has its rotors rotate parallel to the ground during takeoff, and tilt slightly for horizontal travel. Helicopters' precision in landing makes them useful for small landing areas, such as the top of a building. Rotary-wing aircraft are not commonly used for carrying large amounts of weight.

2.3. VTOL UAV's

Due to the unique advantages of being able to take off and land vertically, some VTOL aircrafts have started to become unmanned aerial vehicles. These include variations on the rotorcraft design, including single rotor, tandem rotor, coaxial rotor, and multirotor aircraft, all of which generate lift similar to helicopter. In addition, while technically not aircraft, drones fall under this category, as certain types of drones can take off and land vertically, without someone controlling them inside the drone. These are commonly remote-controlled and can be used for photography and transporting lightweight goods. VTOL UAVs generally lack the precision and power that allow aircraft to carry people, so most are used for other purposes.

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3. Technology of VTOL

There are several ways for VTOL aircraft to take off, but they all generate lift using methods that take advantage of the same basic principles. The most important of these is Bernoulli's Principle, which explains why the pressure of a fluid increases as the speed of the fluid decreases. In essence, the shape of wings or blades generating lift for VTOL aircraft causes the air under the blades or wings to decrease in speed, thus increasing the pressure and generating lift. For helicopters specifically, which have rotor blades that generate lift, the amount of lift being generated is adjusted by changing the angle of attack of the rotor blades. Thus, depending on this angle of attack, the helicopters can either take off vertically, hover in place, or land vertically.

The hybrid aircraft also takes advantage of lift generated under Bernoulli's principle, albeit using different methods. For example, the V-22 Osprey is a tilt-rotor aircraft. It can change between airplane and helicopter mode as a way to use the rotor blades to generate thrust instead of lift. This transitioning mechanism is what powers all hybrid VTOL aircrafts, allowing them to change between two different modes. In fact, most VTOL aircraft system can be divided into two parts: VTOL mode and flight mode [5]. Similar to the V-22 Osprey, the Harrier, developed in the 1960's, can change the direction of its thrust force. Instead of large rotors, the Harrier has a single engine that generates thrust through four nozzles. These nozzles can rotate over 90 degrees and allow the Harrier to take off and land vertically.

Evidently, VTOL aircraft needs something to power them as other vehicles. Usually, airplanes will either have engines that run on a petroleum-based fuel, or electric batteries that can be charged. There have been recent developments in the battery power of VTOL aircraft. NASA has been conducting research on several new types of VTOL aircraft, namely the quadrotor, the side-by-side helicopter, which can all make use of a lithium-ion battery, as well as various types of motors [6]. Ultimately, the type of motor and power-source used by a VTOL aircraft is dependent on what the aircraft will do, how much weight it can carry, and the speed at which it needs to travel.

4. Applications of VTOL

The unique capabilities of VTOL aircraft grant them many useful applications that standard aircrafts lack. Specifically, helicopters can be used as air ambulances to quickly transport accident victims and the ill, and can be used to carry medical personnel to and from the scene of an accident. Fire departments have started to use helicopters to rescue people, and heavy-lift helicopters are also used to move things to the top of buildings, where they can hover long enough for materials to be easily transported [7]. In most of these cases, there is no runway readily available, so helicopters are the only viable option. Helicopters are easier to maneuver, and are in this way better suited for situations requiring a quick response from an aircraft.

VTOL UAVs also continue to be developed. As for VTOL aircraft that are not helicopters, their similar capabilities allow them to perform similar functions. VTOL UAVs can be used for coastal surveillance to protect national borders from illegal immigrants and drugs, as they can still travel easily in remote areas without the infrastructure of airstrips [8]. An example of a VTOL UAV that is considered for military use is the Unmanned Little Bird, developed by Boeing, which has shown promise in being able to qualify for international military use. VTOL UAVs are useful in dangerous situations because they reduce the risk of pilots while controlling the aircraft. Smaller eVTOLs can be used to quickly put out wildfires before they become uncontrollable [2]. These vehicles operate faster and with less resources in the specific situations they are made for, thus making them more efficient than fixed-wing aircraft in these specific cases. In general, VTOL aircraft can be used for many things, except for transporting large amounts of people or cargo.

However, even though VTOL aircraft can be used in a wide variety of ways, they do have their drawbacks. Helicopters used for urban air transport are one of the most critical emission sources, which negatively affects human health [9]. As they cannot carry many people at once, they are less efficient than other aircraft. VTOL aircraft sacrifices power and speed for maneuverability, which is only useful for specific applications. However, in the future, there is much more room for improvement. New designs such as the flapping rotary wing aircraft, which has rotors similar to a helicopter that have the

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added capability of moving up and down, will make VTOL aircraft more fuel-efficient and practical [10]. These new aircraft may be seen as unnecessarily complex, but the advantages offered by new advancements in flapping rotary aircraft are similar to those

5. Conclusion

VTOL aircraft are aircraft capable of taking off and landing strictly vertically, allowing them to begin and end flights without a runway. Specific categories include eVTOLs, VTOL UAVs, hybrid aircrafts, and helicopters. VTOL aircrafts have unique applications, ranging from military uses to firefighting applications. Future research on this subject should keep working to find a solution towards the environmental cost of VTOL aircraft, which may prove to be either unnecessary or impractical. Future development of VTOL aircraft, while helpful for specific situations, can also receive opposition for its rather specific applications. In any case, VTOL aircraft are a unique category of aircraft that function in helpful ways.

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