Exploring the Safety Concerns of the V-22 Osprey

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The V-22 Osprey, a military aircraft that uses tiltrotor technology, has faced many issues during flight, resulting in crashes destroying equipment and taking the lives of those on board. As a result of the casualties, the military has grounded the Ospreys multiple times to conduct assessments before allowing them back into operation. Despite the issues, no other aircraft can operate with the same performance as the Osprey, resulting in the military struggling to replace them. The Osprey's objective encompasses transporting people, supplies, and equipment long distances for missions and training. Through published articles reporting the findings from the investigations of the V-22 Osprey failures, it is concluded that the faults lie in design, manufacturing, and human error. This paper explores the various safety concerns regarding the gearboxes controlling the nacelles, input quill assembly, stalling, inadequate pilot response, maintenance, and control issues.

Fig 1. MV-22 Osprey [1]

I. Introduction

The V-22 Ospreys are a military aircraft that use modern tiltrotor technology with adjustable nacelles controlled by the pilot, which can rotate 90 degrees from their vertical position. The failure of Operation Eagle Claw showed the military that there was a need for a better-suited aircraft with short and vertical take-off and landing and long, high-speed range performance. Developed by Bell Helicopter and Boeing in the 1980s and '90s, the prototype flight of the Osprey took place in 1989. Testing trials followed over a decade later, in 2000, along with its first grounding due to numerous crashes in testing. Testing was finally completed five years later in 2005, with its first military operation following in 2007. The Marines, Air Force, and Navy each use their own class of Ospreys, MV-22, CV-22, and CMV-22B, specialized for different missions.

The Osprey's mission encompasses transporting people, supplies, and equipment long distances. The MV-22, used by marines, is the basic design of the Osprey having the original components with no special modifications. The Air Force uses CV-22s, which are designed with a second fuel tank and are helpful for special operations that do not have a large landing zone, such as rescue missions. The Navy uses the CMV-22B, which can fly the farthest based on its internal fuel and is also equipped with an aerial refueling probe, giving it the largest range. Despite these slight differences, all V-22 Ospreys share the same modern tiltrotor technology, allowing the Osprey to maneuver as a plane mid-air while in flight and descend as a helicopter after arriving at their landing site. (Figure 1)

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During the nacelle's transitions, the aircraft has no lift and is in free fall for a short period. Although this might sound concerning, it is an expected part of the aircraft's ability to vertically take off and land, giving Ospreys an operational advantage over other aircraft, making it highly versatile and practical. The Osprey may be a powerful aircraft; however, it has faced many incidents during its flights, as shown in Figure 2, which leads to crashes, destroying equipment, and taking the lives of those on board. As a result of the casualties, the military has grounded the Ospreys multiple times to conduct assessments before allowing them back into operation. Justin Katz from Breaking Defense stated that the Air Force reported "catastrophic mechanical failure [and] casual crew decisions" [2] led to a recent deadly V-22 crash. To prevent further accidents, there should be more emphasis on maintenance, controls, and even improving certain design aspects.

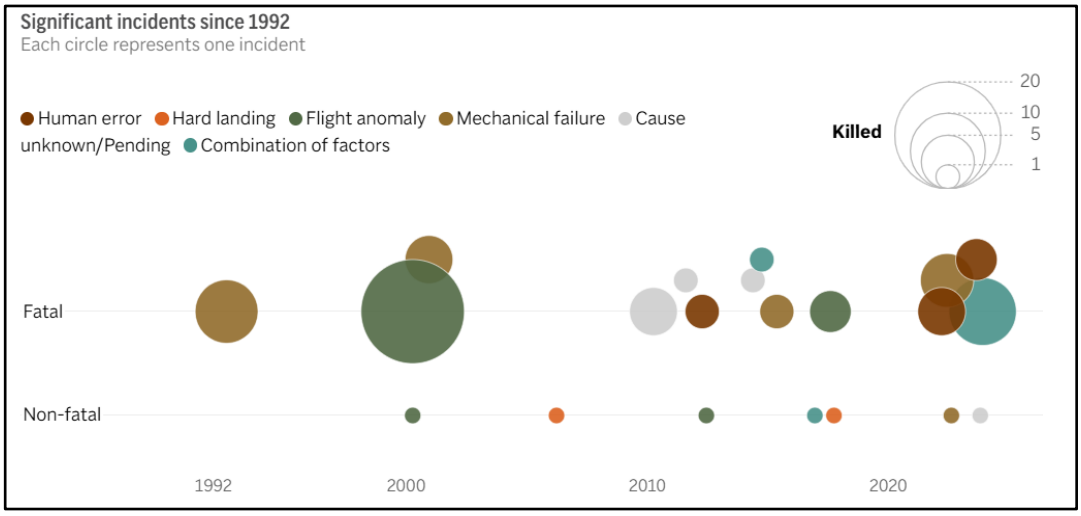

Fig 2: Significant Incidents Since 1992

II. Safety Concerns

Stalling:

The first of many safety concerns is stalling. With the V-22 Ospreys having modern tiltrotor technology, the Osprey itself is more susceptible to vortex ring state. When landing, the Ospreys must turn their nacelles from their horizontal position to a vertical one. During this transition, the Osprey does not produce lift, and for a brief period, the pilot loses vertical forces management. In this condition, there is an increased amount of upward airflow, which results in the propellers' downwash to instead wrap around the tips of their airfoil. Even though the nacelles are rotating, the vortex created by the downwash rotates with the nacelles like a ring.

This is known as a vortex ring state, which, as a result, stalls the Osprey, which then falls out of the sky. Aircraft can recover from a vortex ring state; however, it takes an experienced pilot to recognize it. A vortex ring state is often described as feeling like the aircraft is falling out of the sky. Since the Ospreys already experience a falling out of the sky sensation, it is difficult for pilots to recognize when they are about to stall. The recovery process of the vortex ring state involves descending downward in order to eliminate the vortex and gain lift again. The issue is since the vortex ring state occurs during landing most of the time, the Osprey itself is already close to the ground and losing altitude, which could result in crashing during recovery.

Gearbox Malfunctions:

Gearbox malfunctions are a big issue that causes Ospreys to malfunction. The proprotor gearbox allows the vehicle to take off and land vertically but fly horizontally. There are two gearboxes on a V-22 Osprey, one on each side controlling the nacelles. Often, the gearboxes fail due to a cracked gear or excessive wear. This leads to loss of control of the vehicle, causing accidents. On November 29, 2023, about a half mile off the shore of Yakushima Island, Japan, a US Air Force CV-22B Osprey crashed, killing all eight crew members on board. According to an Air Force investigation, Tara Copp from Associated Press News reported the accident "was caused by cracks in a metal gear" [3] that began to shred, sending debris throughout the gearbox. This caused it to fail and the proprotor to stop operating. This scenario is "similar to those seen on seven previous failures in low-speed planetary pinion gears" [4].

The Osprey landed before the gear failed in all these scenarios, so no fatalities occurred. The gear inside the proprotor was made by the American company Universal Stainless. Over the years, there have been multiple instances where quality control was an issue with Universal Stainless. In 2001, Teledyne Technologies, Incorporated sued the company for "producing defective steel that caused multiple crankshaft failures in general aviation aircraft engines, with over 90% of the crankshafts found to be flawed." [5]

One cause of the gears in the gearboxes breaking is that Universal Stainless was found to have a defect "non-metallic inclusions" [6] in the metal alloy used to manufacture the gears. The non-metallic alloy found in these defects hinders the durability of the gearboxes, which results in the cracks and chips causing the failures. (Fig 3.) According to reports, "given the rate at which those inclusions were making it into the alloy used in the gears, a failure such as the one Gundam 22 experienced was bound to happen." [4] Gearboxes are the only mechanism attaching the nacelles to the body of the V-22 Osprey, resulting in stress added on them. Not only do they have the weight of the nacelles, but they also have the engine and added vibrations. The gears themselves are made from an X-53 steel alloy, which is known for its high strength and toughness against fracture resistance, which is why it is a great material for the gears in the gearbox, considering the high stress they are under. The defect in the metal alloy hinders the strength of the X-53 steel alloy, relating back to Osprey crashes dating back to 2013. The defect in the alloy weakens the strength, which is why the gearboxes result in more failures.

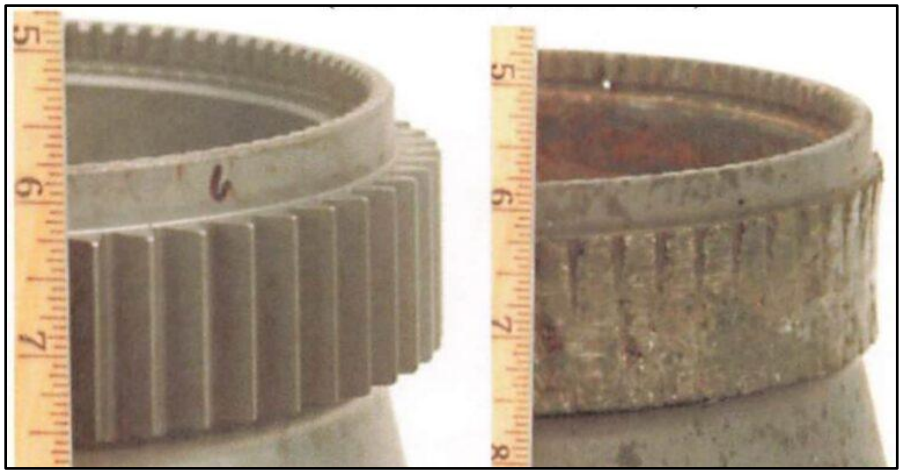

Fig 3. Gears Worn Down from CV-22 Osprey [7]

Input Quill Assembly:

The input quill assembly houses the clutch inside the proprotor gearbox, which transmits power from the engines to the nacelles. (Figure 4A) The input quill rotates the nacelles by engaging and disengaging the clutch smoothly, allowing for a safe transition. (Figure 4B) However, faulty input quill assemblies have been linked to crashes, the most recent in June 2022. When an input quill fails, it is known as a hard clutch engagement (HCE); the HCE, which caused the June 2022 crash, had restricted power from the right motor, causing it to lose power. The Marine Corps released a statement saying, "The dual HCE event and subsequent single engine/ICDS failure created an unrecoverable departure from controlled flight." [8]

This slip results in all the power being directed into one engine, causing the other to fail. The system of the input quill assembly uses sprag clutches limiting rotation to only one direction. The sprag clutches allow one component to rotate freely while applying force to the other component, preventing it from rotating in the opposite direction. When force is applied, all the sprags should catch; however, when the sprags do not catch all at once, the clutch slips, leading to the hard clutch engagement, restricting power, and causing the nacelle failure. Rather than gathering a full understanding of why this happened, a solution was implemented to replace the input quill assembly after a certain number of hours. Office officials claimed this solution "would prevent 99% of future hard clutch engagements." [4] Families of the victims of the June 2022 crash were dissatisfied with this solution, claiming the issue was with the system itself and sued for wrongful death. There have been 19 hard clutch engagement incidents that have been recorded throughout the Ospreys' time in operation. During a meeting in the Congressional office, officials pointed out that there have been no hard clutch engagement occurrences since the new solution was put forth. [4] Ospreys have been grounded twice since the June 2022 incident for hard clutch engagement issues.

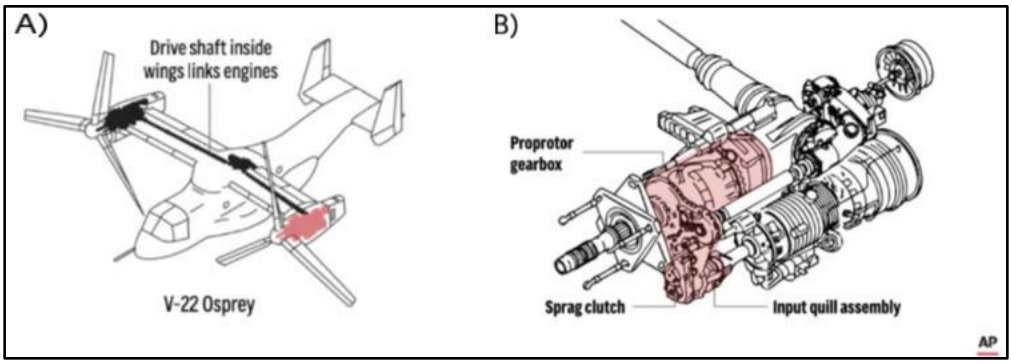

Fig 4. (A) Diagram of Proprotor Gearbox Location & (B) Components [3]

III. Other Minor Concerns

Inadequate pilot response:

Both proprotor gearboxes on an Osprey have three chip detectors. They work by using a magnet to catch small metal shards in the gearbox oil that come off during operation. Once on the magnet, the chip detectors melt the chips using electric currents to prevent complications. If a certain amount of debris is built up, the pilots are notified with a sound and caution light to indicate there have been chips detected in the gearbox. If multiple chip warnings are received, pilots are instructed to land as soon as possible to prevent failures. The accident that occurred on November 29, 2023, involved metal shards chipping off a cracked gear. The shards built up on the chip detectors, and the pilot was notified of a problem; six warnings were given to the pilot, as shown in Figure 5. However, the pilot did not act upon these warnings until the last one, which unfortunately did not give him enough time to conduct an emergency landing. Osprey pilots are supposed to make an emergency landing after the first chip warning, and this protocol was ignored. With better training, this accident could have been avoided. This shows that even experienced pilots need refreshers on what to do in emergencies and protocols enforced and instilled in pilots.

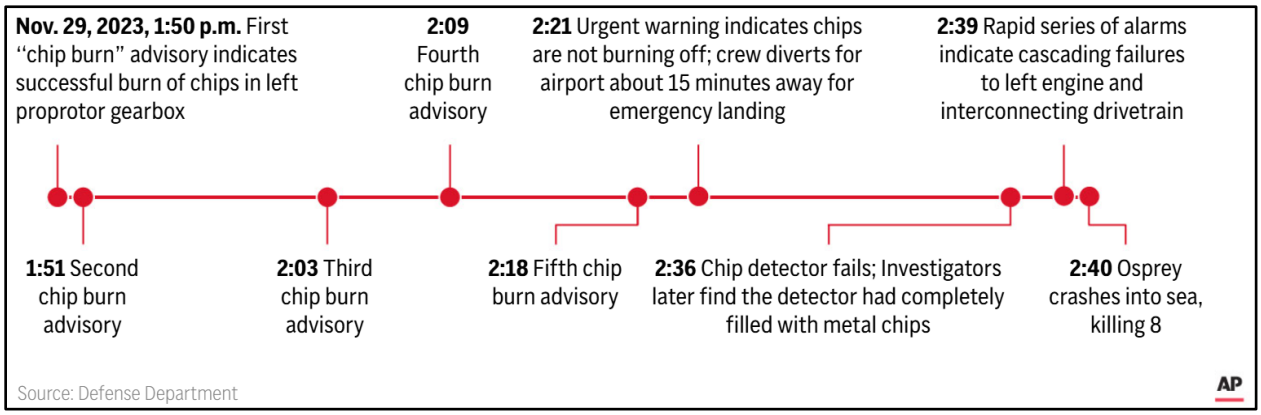

Fig 5. Timeline of the November 2023 Crash [9]

Improper Maintenance:

The purpose of maintenance is to ensure that each aircraft is in working order. The V-22 Osprey is expensive to maintain because of their tiltrotor technology. Operational readiness is a key part of maintenance to ensure that the aircraft are ready to fly when needed; however, the Ospreys have a lower operational readiness than other helicopters. However, these aircraft are on a regular maintenance schedule following other military aircraft. Ospreys get routinely checked based on their flight hours, and each hour threshold requires a different level of maintenance. Ospreys also get routinely checked before each flight to ensure they are in working order.

However, a common maintenance issue is that maintenance starts cutting corners once crews are comfortable working on the same aircraft. Maintenance crews are instructed to follow the maintenance manual exactly as the manual reads. When the manual is ignored, issues occur; for example, a part could be placed incorrectly or a concern

overlooked, such as the gears in the gearboxes. The Osprey has always been difficult to maintain. In 2001, a commander of the V-22 squadron "was relieved of duty after allegations that he instructed his unit to falsify maintenance records to make the Osprey appear more reliable." [10] More focus on maintenance of the V-22 Ospreys needs to occur to ensure that maintenance crews follow the manual exactly how they should with more specifications on the problem areas.

IV. Response To Safety Concerns

Direct Responses:

The United States Department of Defense has acted in response to these safety concerns, mainly focusing on the gearboxes. The V-22 Ospreys have been grounded numerous times after a crash to perform maintenance and follow up with safety precautions. Following the crash of November 2023, the Department of Defense grounded all Ospreys in operation to perform maintenance. Today, the fleet is slowly returning; however, the full fleet is not expected to return to full service until mid-2025 when the head of Naval Air Systems Command is confident there were proper safety solutions put into place.

Flight restrictions are also being placed on the V-22 Ospreys due to their unpredictability. The Naval Air Systems Command implemented fleet-wide protocols to ensure the Ospreys operate safely in all branches. Before an Osprey can fly, the flight hours on each gearbox must be inspected. Due to this inspection, some Ospreys were not cleared to return to flight and additional maintenance will be performed on them. The gearboxes that met the Naval Air Systems required flight-hour minimum were cleared to return to the fleet.

In addition, Osprey pilots are now required to fly within 30 minutes of land, which affects the Osprey's offshore range. Due to the V-22 Osprey not being cleared to go offshore, the C-2A Greyhound was returned from its retirement process to support the Navy's offshore transportation missions. The military is working towards installing new sensors in the V-22 Osprey's gearboxes which will monitor for any failures, predicting when parts need to be replaced. The new sensors will "provide vibration signature data that will allow maintenance to forecast the failure of parts and plan to remove those parts before failure." [11] With proper maintenance, one can predict when a part will fail so the part may be replaced, allowing for safer aircraft operation.

The military is also working towards improving the quality of the steel used in the gearboxes to prevent any chips in the gears resulting in gearbox failures. They plan on using a "more refined Triple-Melt steel" [11] in the gearboxes, hopefully, to minimize chipping during flight. In response to the hard clutch engagements, a new input quill assembly is being designed to reduce or eliminate the hard clutch engagements, while pilots of the current input quill assembly were warned about this potential hazard. [11] The Naval Air Systems Command also inspected the flight hours on each input quill assembly, determining if the Osprey was safe to fly. Following the crash in June 2022, the Marine Corps put a flight data recorder designed to survive crashes to monitor flight data and pinpoint the failures.

V. Compare and Contrast

The V-22 Osprey compared to the CH-47 Chinook:

Entered into service with the US Army in 1962, the Chinook (Figure 6) is $64.75 million per unit and operates solely as a helicopter, which allows it to only travel at a maximum speed of 196 mph. The Osprey, however, is $84 million per vehicle and has a top speed of 315 mph. The CH-47 is a heavy-lift helicopter that is primarily used for transporting substantial force and provision and is relied on by many forces such as the U.S. military, specifically the U.S. Army, Army Reserves, and National Guard, the U.K. Royal Air Force, the Australian Army, and the Canadian Armed Forces. As for holding equipment and troops, the Chinook can carry up to 26,000 pounds internally or 33 troops and 26,000 pounds externally. On the other hand, the Osprey can hold 20,000 pounds of cargo internally or 24 troops, and 15,000 pounds externally with a hook and winch system. The CH 47 Chinook can also travel 400 nautical miles, and the V-22 Osprey can travel 879 nautical miles. The Osprey is used for combat, combat support, and special operations.

Fig 6. CH-47 Chinook [12]

V-22 Osprey Compared to the C-2A Greyhound:

Brought into service for the U.S. Navy in 1966 to replace the Grumman C-1 Trader, the C-2A Greyhound, shown in Figure 7, was announced to take over the role of some operations performed by the V-22 Osprey. This is due to them not being cleared to go offshore currently and facing difficulties in operational areas. In 1973, the original C-2A Greyhounds "were overhauled to extend their operational life… In 1984, a contract was awarded for 39 new C-2A aircraft to replace the earlier airframes. Dubbed the Reprocured C-2A due to its similarity to the original aircraft, the new C-2A includes substantial airframe and avionics system improvements. All the older C-2As were phased out in 1987, and the last of the new models were delivered in 1990." [13] The C-2A Greyhound's top speed is about 395 mph, which is significantly faster than the Osprey's 315 mph. The Greyhound's main purpose is to transport cargo and personnel back and forth between aircraft carriers and can hold up to 10,000 pounds. Although the C-2A Greyhound will not fully replace the Osprey, it is just a temporary replacement until it is fully operational without limits.

Fig 7. Navy C-2A Greyhound (G-123) [14]

V-22 Osprey Compared to the V-280 Valor:

The Bell V-280 Valor (Figure 8) was introduced in 2013 as a long-range vertical lift aircraft and performed its first flight in 2017. The vehicle uses tiltrotor technology and was designed to replace the Sikorsky UH-60 Black Hawk. Estimated at about $43 million, it has a cruise speed of about 322 miles per hour and can transport up to 14 troops. "The tiltrotor aircraft is unique in its functionality, where the engines remain in position while the rotor and drive shafts tilt." The V-280 will complement the V-22 Osprey, as the same unique characteristics are featured in both these aircraft's designs. In December 2022, the V-280 Valor was selected by the U.S. Army as the winner of the Future Long-Range Assault Aircraft Program. Although the aircraft is currently "under production while certification tests are being performed on the prototype," [15] the vehicles "entry into service is expected in 2030." [16]

Fig 8. V-280 Valor [11]

VI. Conclusion

While the V-22 Osprey achieved a cutting-edge advancement in military aviation with its tiltrotor technology, the reoccurring safety issues, particularly issues relating to stalling, gearbox malfunctions, and the input quill assembly concern on the safety of operating this vehicle. These technical issues have led to numerous crashes and fatalities, emphasizing the need for improved pilot responses and better maintenance protocols. Despite these challenges, the United States Military uses the V-22 Osprey frequently due to its unique ability to take off and land vertically, fly horizontally, reach high speeds, and travel long ranges. The U.S. military has been unable to find nor create a replacement for the V-22 Osprey currently, as no other aircraft has the same capabilities as the Osprey and thus would not be suitable for select operations if their qualifications are not nearly the same as the V-22. Overall, the design and mechanics of the V-22 Osprey should be reworked, resulting in a more promising future for the Osprey. An updated design could prevent the Osprey from entering vortex ring state and prevent the hard clutch engagement from the input quill assembly. Better materials should be used for the proprotor gearbox to prevent any chips occurring in the gears, along with more effective pilot training and maintenance protocols being implemented to ensure that any faults do not lie in human negligence.

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