Ensuring Safety in Human Out of the Loop (HOTL) Uncrewed Aircraft Systems (UAS)

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Abstract

Autonomous systems bring enormous technological potential to a range of industries. They enable capability advantages that were previously seen as impossible. The aviation industry is not immune from this technological change. In recent times there has been a rise in the use of autonomous or Uncrewed Aircraft Systems (UAS). These systems are remotely piloted with some human interaction during flight, known as Human in the loop (HITL) or they are fully autonomous with minimal human interaction during flight, known as Human Out of the Loop (HOTL). This paper will explore some of the methods used to assure safety in a HOTL UAS. Ensuring safety in a HOTL UAS is essential as it reduces the likelihood of accidents and ensures that calculated risk measures are implemented from the preliminary design phase of a UAS. These measures also inform UAS safety programs when identifying potential hazards in UAS design and future operations. Examples of UAS that have implemented some of these measures will be discussed, as well as some of the technological gaps in areas of detection and avoidance of UAS with other aircraft systems. This paper also presents the benefits of HOTL UAS whilst acknowledging the importance of human oversight in exceptional circumstances. An overview of existing and proposed frameworks on the Levels of Autonomy (LoA) for UAS will also be reviewed.

Keywords: UAS, Aviation Safety, Autonomy, Measures.

1 Introduction

The aviation industry is not immune from the rapid modernisation of technological systems. These technological advancements have seen aircraft systems become more intelligent. This has led to a change to conventional aviation rules.

UAS, often operated remotely by stationed operators, exhibit diverse LoA that are tailored to their respective operational contexts. This inherent variability, ranges from nano (10g – 2kg), up to large-scale systems (up to 27 tonnes, with a wingspan up to 40 m), underscores their societal value and applicability.

Industries such as defence, agriculture, transportation, and recreational users are utilising UAS technology which introduce new capabilities for various purposes that were once seen as difficult to carry out. The Australian Defence Force (ADF) operate a range of UAS that carry out various operational objectives. They vary in size and complexity, such as the Black Hornet (32 g - nano), Shadow-200 (208kg - medium) and the MQ-4C Triton (14.6 Tonnes – extra-large). They can perform the same fundamental roles of intelligence, surveillance and reconnaissance actions as a HITL systems activities. Nonetheless, as the evolving complexity and operational environment changes, so too does the role performed by these UAS. Smaller UAS like the black hornet can only operate at short range whereas the larger ones like the MQ-4C Triton can operate longer ranges with greater endurance.

In the civilian and recreational space, UAS also known as drones, are used for a range of applications such as photography, videography, and general drone racing activities. In recent years UAS/drones have started to replace firework displays around the world. They provide a safer alternative to fireworks as they are more cost effective and environmentally friendly. Drone shows are now the highlight at many national gatherings or celebrations. While they are being used for these purposes, they still impose a range of risks to operators, observers, and the surrounding airspace. Aviation safety regulatory bodies and operators have been working to assure that the displays are acceptably safe and reduce the likelihood for accidents to occur. For instance, there was a safety incident that occurred during a drone display for the Women’s FIFA World Cup in Melbourne 2023 where more than 100 of the drones were seen falling into the Yarra River (Hatch, 2023). Whilst there were no human casualties from this incident, the potential consequence of drones falling is not insignificant. Although small UAS pose a lower risk to the public and infrastructure compared to larger UAS, pertinent questions should still be raised for operators, designers, and regulators alike when incidents such as the Women's FIFA World Cup 2023 occur. One such question is "How can safety be upheld in HOTL UAS operations? This fundamental question must be asked because it is difficult for operations of this type to have HITL operations for hundreds of UAS flying in a formation in the airspace.

This paper seeks to address this question by identifying different approaches cited in literature that are used to ensure safety in HOTL UAS platforms. It will assess various methodologies utilised in autonomous systems across different industries that implement comparable levels of autonomy to UAS. Further to this, it will aim to address the benefits of both HOTL and HITL systems, as well as generate a discussion on what acceptably safe HOTL UAS may look like in the future.

2 Defining Autonomy, HOTL and HITL in UAS

Aviation governing and regulatory authorities such as International Civil Aviation Organization (ICAO), Federal Aviation Authority (FAA), and the European Aviation Safety Authority (EASA) have varied definitions of autonomy and autonomous operations in the uncrewed aviation context. They all provide the notion that autonomy is based on the ability for a system to act independently with little to no intervention from a human. Clothier, Williams, and Perez (2013) examined these constructs of autonomy, and provide two models, which are simple and complex autonomy. The simple autonomy model is associated with the dependency or interaction between two entities such as an UAS and an operator. The more the system is independent from the operator, the greater its autonomy, thus changing the degree of independence from the operator or source of influence (Clothier, et al., 2013). Complex autonomy on the other hand, incorporates high-order systems and is more elaborate. Some characteristics of these complex systems include integrated intelligence, advanced situational awareness through machine learning and the ability to adapt to new scenarios. Therefore, UAS that utilise complex systems can (self) execute decisions through their use of multiple sensor suites attached to systems on board. However, designers and operators still need to ensure that in both HOTL and HITL UAS, risks are eliminated So Far As (is) Reasonably Practicable (SFARP) whilst utilising some LoA.

HITL and HOTL definitions can vary depending on the context in which they are used and applied. Similarly, the definitions of ‘human’ and ‘loop’ can vary based on context. However, the fundamental meaning is still the same. HITL is when humans or operators of a system will have oversight and are involved in the use and application of a system (Sydorenko, 2023). The most basic HITL system is the motor vehicle. In these systems the driver has control of the vehicle through steering and control. The driver has influence on the route the vehicle takes and the speed at which the vehicle moves at. Figure 1 below shows a simple illustration of a HOTL and HITL system.

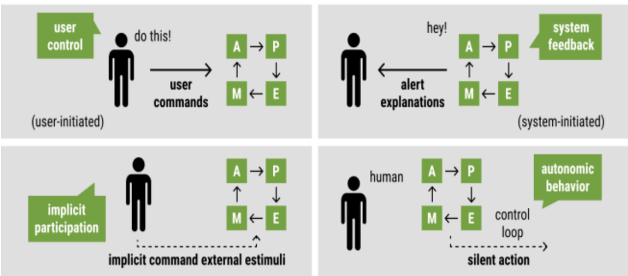

Figure 1: Example HITL and HOTL System (Sydorenko, 2023)

HOTL, on the other hand is when human operators are seen to have no influence on the operation of the systems and these systems are left to make their own decision based on the information they have learnt (Sydorenko, 2023; Zhang & Bareinboim, 2022). An example of a HOTL system is a UAS being tasked with package delivery, which the company Wing is currently utilising. The UAS is loaded up with the package and it carries out the entire task requiring no human input to control its movements. In such an operation the UAS is in control of its own path to the delivery zone. It can manoeuvre through the airspace based on the environment it is encountering and can decide on whether to proceed or not without human intervention. In this scenario the UAS can also detect and avoid other airspace users.

3 Ensuring Safety

Ensuring safety in an aviation operation reduces the likelihood of accidents occurring, whilst also increasing the confidence of the public towards the systems being operated. Thus, it is important that there are rigorous measures in place to ensure adequate safety margins when operating the UAS. Various methods that could be used to ensure safety in HOTL UAS will be explored further in this section.

3.1 Regulatory Compliance

The phrase “Regulations are written in blood” is a proverbial saying that has been used to emphasise the idea that regulations and safety are often considered only after fatal accidents occur. Regulations are important for several reasons, one of which is to ensure that there is consistency across industries. For the UAS industry, this is even more important as most systems are continuing to mature and they vary in the manner they are operated (Zvidza, et al., 2023). In Australia, although the Defence and Civil Aviation Safety Authorities (DASA and CASA respectively) have similar regulations regarding UAS, they also diverge due to the different environments they regulate. Therefore, this changes the level of rigour applied to certifying and operating UAS.

Regulations should not be seen as a hinderance to design or operation however, they should be seen as playing a crucial role in the safe and responsible integration of UAS into the aviation environment. Aviation environments include airspace, tunnels for inspections purposes and any zones that UAS are flown. The need for safer integration of UAS increases as the levels of autonomy becomes more complex. For a HOTL UAS, regulations are vital because they set the restrictions in which these systems can operate. An example of one such restriction is having the UAS fly in a specific aviation environment. The DASA has this restriction on military operated UAS. They mandate a need for a UAS Operating Permit (UASOP) when operating a UAS that is not certified to an airworthiness standard (DASA, 2023). On approval of this permit, the UAS can only operate in the designated airspaces as defined by the UASOP conditions. Further to this, the UAS DASA regulations also ensure that during the design and operation of the UAS there is adequate governance applied to assure safety to the general public and operators.

Regulations have the potential to instil best practice among the regulated community if they are followed. They can provide a structured framework that guides the design and operation of HOTL UAS and assures the safe use of such systems (Malhotra, 2022). If best practice is mandated, it ensures that designers and operators exercise due diligence, and it promotes proper management systems being put in place to support the UAS systems. They also enable regulatory standardisation across the UAS industry. This would make sure that the HOTL UAS are operating consistently with other UAS and airspace users. Regulations can also stipulate specific training that is tailored for UAS pilots/operators. This would enable competent operators to have the required certifications to be able to operate UAS safely.

To date, CASA has already issued regulations relating to a remote pilot licence to operate UAS between 25kg-150kg (CASA, 2023). To aid in training and certifying operators, regulations can also prescribe the use of UAS simulators similar to the way crewed aircraft simulators are used. For autonomous systems this can be achieved by creating digital twins or augmented reality. Digital twins are able to replicate a physical environment in the virtual world (Riordan , et al., 2021). Utilising digital twins would foster rapid prototyping of scenarios, operational environments, possible mission sorties and any risks that might occur. Using these systems to train operators would allow them to mitigate potentially hazardous scenarios before carrying them out in similar environments in the real world.

Reliable regulatory frameworks for UAS, or any other autonomous system is essential for safe operations as it allows these industries to have a reliable growth and consistency. However, it is important to note that while consistency in regulations is crucial, it does not automatically imply safety. The regulations need to be robust, and they need to be followed to ensure that some of the recommended safety measures imposed by them are acted upon. Robust regulatory frameworks should address features of the evolving technological systems like AI.

Furthermore, it is not uncommon for regulations and standards to take a considerable amount of time to undergo substantial changes, often a decade or more. This poses a significant challenge in the face of rapidly evolving technology and AI capabilities. The pace of technological advancement far outstrips the speed at which regulations can be updated. As such, there arises a critical question of how these regulatory frameworks can adapt swiftly enough to keep pace with the changing landscape. This issue calls for innovative approaches and increased agility in the way that regulations are developed, reviewed, and implemented.

3.2 Obstacle Detection and Avoidance

Obstacle detection and avoidance is one of the more complex problems encountered by UAS and other autonomous vehicles. Two common terms used for detection and avoidance for UAS is Sense and Avoid (SAA) or Detect and Avoid (DAA). These both describe the ability for a UAS to identify an obstacle, make a computation on whether the UAS will collide with the obstacle, and where possible and if capable, take evasive manoeuvres to reduce the likelihood of a collision (Opromolla & Fasano, 2021). UAS with SAA systems utilise a range of sensors, image recognition software and artificial intelligence to assist with the SAA functions. The systems are programmed with algorithms that can allow the UAS to learn from its environment and gather data from other sources. This type of system is extremely important in the constantly evolving world of UAS autonomy, especially when operating under a HOTL or in a one-to-many scenario such as a drone display.

When a UAS is operating in airspace it should be identifiable to the operators and other airspace users similarly to how crewed aircraft are identified. A SAA system that is effective will provide users confidence that a HOTL UAS can co-exist within the same airspace as other users whilst reducing the likelihood of incidents and accidents. However, for such a system to work efficiently, there are minimum conditions that should be met by a UAS (shown in Table 1), as presented by Simpson, Brennan & Stoker (2009). However, a more detailed approach can be tailored to meet specific operating roles and environments, depending on the UAS size. It is worth noting that implementing such a system for micro and small UAS is rarely done due to cost, complexity of installation and lack of detectability of the UAS (Al-Kaff, et al., 2017). This concept is also being used in the autonomous ground vehicle industry, as it enables self-driving vehicles to execute tasks safely.

Table 1: SAA Conditions for a UAS (Simpson, et al., 2009)

Function	Collision Avoidance	Separation Provision
Be aware of all traffic in the vicinity	✓	✓
Implement and maintain appropriate separation minima with all other traffic. Have criteria for when to implement traffic warnings (separation provision is potentially about to fail) and resolution warnings (separation has failed and immediate collision avoidance action is required)	✓	✓
Be able to identify traffic that is a collision (or near miss) threat, establish an appropriate avoidance response, taking into account other potential targets, and implement the response if the UAS pilot is unable to do so in time	✓	

However, SAA systems are always used in conjunction with other complex systems to ensure safety. Some of the complex systems include sensor suites that enable autopilot packages to be effective, image recognition software and LiDAR technology. While a few self-driving vehicles are currently employing this technology, the majority of SAA systems are still in the process of development. This is because certain artificial intelligence and machine learning algorithms utilised in this technology presently do not consider the various aspects of human behaviour whilst driving (Gonsalves & Upadhyay, 2021). Also, before these systems are deemed safe enough by the public, regulations and infrastructure needs to be further developed. The UAS industry can learn a lot from how such systems in the automotive industry can be implemented safely in the aviation environment. This will have great benefit to military and commercial systems that require similar technology.

3.3 Real-Time Monitoring and Control

Installing real-time monitoring and control capabilities in a HOTL UAS is essential to operations and carrying out tasks as required. The concept of real-time monitoring and control has long been utilised by crewed aviation platforms. This has provided pilots with situational awareness and has facilitated communication with air traffic control, between aircraft, and other airspace users. In crewed aircraft this has been done by incorporating systems such as Automatic Dependent Surveillance-Broadcast (ADS-B), Traffic Collision Avoidance Systems (TCAS), radar technology and many more systems (Schafer, 2021). The data provided includes the position and the identity of the aircraft to in conjunction to other aircraft and to various ground air traffic control systems (Schafer, 2021; Unmanned Systems Technology, 2023).

Incorporating similar technology to a HOTL UAS would enhance the UASs ability to interact with other airspace users. This means the UAS can then obtain data that will significantly improve its operability and safety in shared airspace. It could also provide the UAS with the ability to optimise its mission, by changing its speed, flight path and altitude based on the information it would be receiving in its current operating environment. In a HOTL UAS scenario this has great potential to improve overall mission success, provide fuel and energy savings and therefore, has the potential to optimise its endurance. This technology has the potential to enable better airspace management and control for UAS and how they integrate with other airspace users.

A reliable real-time monitoring and control system on a HOTL UAS, can increase situational awareness of the UAS, and could reduce overall operational costs as there will be minimal need for human intervention and oversight. Such a system would enhance the autonomy of the UAS, making it possible to operate as a complex autonomous system mentioned in section 2 of this paper with greater flexibility and autonomy with increased safety margins. These types of UAS would have enhanced intelligent systems coupled with machine learning capabilities to be able to collect, process, and react on real-time data. This would have less human involvement in operating the UAS.

3.4 Safety Critical Controls

Safety critical controls play a pivotal role in protecting UAS against potential hazardous states during operation. These controls provide a crucial layer of redundancy, ensuring the UAS retains robustness in the face of challenges such as mid-flight malfunctions, extended loss of communication with ground stations, or operational complexities. By implementing these measures, the systems overall reliability is significantly increased, mitigating anticipated risks to the UAS.

An example of a safety critical control is the "return to home" function, prominently utilised by commercial UAS. This system has the capability to guide the UAS back to its initial launch point should an extended loss of connection with the remote operator occur (Droneblog, 2023). Through its practical application, this control has enabled recreational drone enthusiasts to navigate situations where connection with the UAS is temporarily severed, effectively minimising potential harm to bystanders.

In addition to return to home functions, a further level of safety critical control can be integrated into High-Altitude, Long-Endurance (HALE) UAS systems. This involves the installation of multiple flight control units and specialised software. These controls in allow the UAS to operate autonomously, ensuring a stable flight profile. Some UAS are equipped with integrated autopilot systems, enabling them to navigate through various modes of autonomy. For a HOTL UAS, an autopilot system expands its operational range by optimising flight paths, enabling it to effectively navigate complex environments marked by challenging terrains and obstacles. Moreover, extensions to autopilot functionalities, including flight termination control systems, and return to home features offer an added layer of safety.

Recent reports highlight a concerning surge in incidents involving UAS operating dangerously close to airports and other crucial installations, posing a significant safety threat to all stakeholders (BBC, 2022). While it is explicitly illegal for UAS to operate in close proximity to airports, the incorporation of geofencing as a safety feature drastically diminishes the likelihood of individuals incurring fines from regulatory authorities. Furthermore, it substantially minimises the imminent risk and potential hazards posed to airborne aircraft and vital airport infrastructure.

Geofencing is another safety control that prevents the UAS from flying outside a designated area. However, it is important to clarify that it doesn't align precisely with the concept of redundancy. Geofencing establishes a three-dimensional virtual boundary within a defined geographical area, preventing the UAS from traversing sensitive, restricted, or congested zones (Torens, et al., 2020; Alamouri, et al., 2023). These zones encompass critical areas such as airports, motorways, governmental installations, and military bases. Despite the potential operational constraints associated with geofencing, it grants HOTL UAS the ability to function within controlled parameters, significantly reducing the risk of inadvertent intrusions into restricted zones and potential harm to essential infrastructure (Alamouri, et al., 2023).

The integration of geofencing technology not only assures safer operations for HOTL UAS but also opens avenues for drone-based delivery services. This technology facilitates the establishment of specific operational zones, enabling delivery companies to efficiently deploy HOTL UAS in targeted areas with predefined flight paths. This innovative approach significantly reduces reliance on constant human intervention from ground stations, optimising the delivery process and assuring the safety of operations.

4 Frameworks for LoA

Some regulators[1] have published frameworks and strategic roadmaps to deal with the increasing use of autonomous systems. The Society of Automotive Engineers (SAE) developed a standard SAEJ3016 which describes six levels of automation for a ground vehicle. This standard defines the autonomy in vehicles from level zero (0) (no driving automation) to level five (5) (full driving automation) (Shuttleworth, 2019). As the levels increase from zero to five there is less driver input as the systems tends to become fully autonomous. At each LoA the vehicles reliance on driver input decreases and the complexity of the systems increases. An example of this is used in the Tesla vehicles. This is enabled by the existence of these three packages, autopilot, enhanced autopilot and full self-driving capabilities (Tesla, 2023).

In literature there have been extensive studies to define autonomy for UAS and methods to assess the varied LoA. Clothier, et al., (2013) provided an overview of the diverse frameworks for assessing the LoA for UAS. Clothier, et al., outlines four key differences in some of the frameworks used for LoA. These differences are:

1. Measurements: there are approaches tailored for this determination of LoA:
   a. Aggregation: A single LoA measure is calculated by combining independent properties characterising autonomy, such as guidance, navigation, and control capabilities.
   b. Non-aggregation: This is when LoA is assessed in relation to independent functions or contexts without aggregating them into a single measure.
2. Measurement scales: this details that LoA can be expressed using ordinal, interval, and ratio measurement scales. Most existing frameworks use an ordinal scale, which only allows for comparisons of LoA as greater than, equal to, or less than. Interval scales offer a magnitude of difference, while ratio scales allow for multiplicative comparisons.
3. Number of levels: the number of LoA levels proposed for ordinal scales varies from four to twelve, with limited justification provided in the literature.
4. Component properties: this is frameworks describing LoA using different properties of the Human-Machine System (HMS), such as human/operator control, task allocation, or mission complexity. Variations arise from differences in the concept of autonomy and the context in which frameworks are applied.

Though there are clear differences in the LoA assessed, these measurements provide UAS designers and operators the flexibility to design their systems to meet specific operating contexts for their UAS.

5 Justifying the Need for HOTL Systems and UAS

As autonomous systems become more integrated into society, there is a greater desire for them to be more efficient and less reliant on human intervention in their use. As discussed previously, HOTL systems can enable consistent and reliable services during flight and can be programmed to provide uniform services across the board. Consistent and reliable delivery of services by HOTL systems could assure a higher level of safety and also reduce risks that human might have encountered when carrying dangerous tasks.

For organisations that require greater efficiency, HOTL systems can be scalable to a greater extent, and they can have multiple layers of redundancies incorporated in them. This has the potential to reduce operational costs for systems as less overheads are required to carry out task or oversee operations. It is important to highlight increasing redundancies in the design and production of UAS leads to higher initial capital costs. Nevertheless, this investment in redundancies ultimately yields a safer and dependable system, resulting in reduced operational costs.

As more HOTL systems are developed and integrated into systems and operations, they have the capability to rapidly make decisions based on the vast amounts of data they collect and learn from with the AI and machine learning capabilities most possess. A HOTL system or UAS can be used for various purposes and industries can utilise them for prolonged operations as they have fewer human factors requirements such as the need to take breaks. With less human factors issues, systems like these can provide safer alternatives to operations. However, there is still need for greater research to provide safe and effective HOTL systems. Although there are great benefits of having HOTL systems, there are still some situations when human oversight is required. Humans are always going to be involved in UAS in some way. From the genesis of a design and during the manufacturing process or having oversight and input to them. However, reducing the amount of human input could provide better outputs and operations of UAS. Notwithstanding this, there are ethical considerations involved when operating HOTL systems.

6 Conclusion and Recommendations

The aviation industry is undergoing rapid technological modernisation, and this has seen advancements in the way aircraft systems are designed and operated. UAS provide society with capabilities that were once impossible. They have varied LoA which can be used for a diverse range of activities depending on the context. In the future, the reliance on human involvement in systems will become less common with the existing advancements in artificial intelligence and machine learning. HOTL systems will be the norm in a variety of industries. The aviation industry is one sector that will be using HOTL systems, especially with UAS and with other crewed aircraft functions. Embracing this technology, whilst identifying regulatory gaps and other areas where consistency can be achieved will provide the industry with the necessary tools to assure the safety of HOTL UAS. Regulating and assuring AI will be an ongoing process that requires time and effort due to the integrity of the data being used as there remains hurdles in ensuring the reliability of AI. Implementing redundant

[1] EASA, FAA, and ICAO

systems is just one approach to mitigate unforeseen malfunctions or corrupt data in the technology.

Nonetheless, there is still a need for wider stakeholder engagement and collaboration across the autonomous systems industry. This could be done by setting up advisory bodies and engaging organisations and subject matter experts in working groups. This could lead to greater integration and operability of autonomous systems irrespective of their LoA. Incorporating digital twins and simulators as mentioned in section 3.1 could enhance the operability of efficiency of the HOTL UAS. Operators can learn from the simulated environment before they carry out any missions that require HOTL autonomy. However, further research is required to develop such a system for consistent use across UAS platforms. HOTL UAS systems enable more data collection and analysis, and this can facilitate more robust safety programs, as they can learn about potential incidents before they occur. This will provide the industry with knowledge on how to respond to various situations and what risk levels need to be considered. Coupling all these recommendations and the methods mentioned in section 3 of this paper, HOTL UAS have better efficiency and performance whilst ensuring safety in their operations. a scenario may carry.

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