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<b>14. ABSTRACT</b> The established Department of Defense policies regarding the standards that guide designed reliability of medium to large unmanned aircraft (UA) are no longer sufficient to support the trust necessary to employ the technology effectively. Unmanned aircraft technology has reached an evolutionary phase where the policies need to be updated in order to allow for future development. The current standards that govern unmanned aircraft safety and reliability are adequate, but the current policies allow UAS programs the ability to choose to save development cost/schedule by accepting reduced levels of safety and reliability, at the expense of higher life cycle costs resulting from higher attrition rates. The current policies regarding the UAS airworthiness standards that govern unmanned aircraft reliability are insufficient for three reasons. First, low reliability requires UA's to be restricted to airspace that prevents overflight of populated areas. Restricting the airspace that UA's can train in has inhibited the development and employment of the full capabilities of medium to large UA's, negatively affecting the trust in UA's by the operators, supported entities, and adjacent units. Second, a low-reliability aircraft does not make fiscal sense considering the current trend of increasingly costly payloads. Lastly, low reliability creates an unnecessary strain on the personnel and resources of units which operate UA's that are not easily replaced and require investigations after each loss. The level of designed reliability in an aircraft directly affects the degree of trust that can be applied to that aircraft. This paper focuses on the necessity of realigning the policies regarding the standard of reliability for Group 3-5 unmanned aircraft that is sufficient for the level of trust necessary for the missions that the medium and large unmanned aircraft are tasked with.					
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**NAVAL WAR COLLEGE  
Newport, R.I.**

**TRUST BY DESIGN**

by

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**The contents of this paper reflect my own personal views and are not necessarily endorsed by the Naval War College or the Department of the Navy.**

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## ABSTRACT

The established Department of Defense policies regarding the standards that guide designed reliability of medium to large unmanned aircraft (UA) are no longer sufficient to support the trust necessary to employ the technology effectively. Unmanned aircraft technology has reached an evolutionary phase where the policies need to be updated in order to allow for future development. The current standards that govern unmanned aircraft safety and reliability are adequate, but the current policies allow UAS programs the ability to choose to save development cost/schedule by accepting reduced levels of safety and reliability, at the expense of higher life cycle costs resulting from higher attrition rates. The current policies regarding the UAS airworthiness standards that govern unmanned aircraft reliability are insufficient for three reasons. First, low reliability requires UA's to be restricted to airspace that prevents overflight of populated areas. Restricting the airspace that UA's can train in has inhibited the development and employment of the full capabilities of medium to large UA's, negatively affecting the trust in UA's by the operators, supported entities, and adjacent units. Second, a low-reliability aircraft does not make fiscal sense considering the current trend of increasingly costly payloads. Lastly, low reliability creates an unnecessary strain on the personnel and resources of units which operate UA's that are not easily replaced and require investigations after each loss. The level of designed reliability in an aircraft directly affects the degree of trust that can be applied to that aircraft. This paper focuses on the necessity of realigning the policies regarding the standard of reliability for Group 3-5 unmanned aircraft that is sufficient for the level of trust necessary for the missions that the medium and large unmanned aircraft are tasked with.

## **INTRODUCTION**

Reliability is a key building block of trust. Trust in a capability can be accumulated and built upon through demonstration of a capability over time. However, trust in a machine starts with the standards that it is designed and built to. When a technology graduates from the experimental phase and begins to be widely accepted, regulations must be applied to ensure the necessary level of quality and reliability exist to accommodate the further growth of the technology. The specific level of reliability required is dependent on the level of trust that is necessary to effectively and safely employ the technology. The established Department of Defense policies regarding the standards that guide designed reliability of medium to large unmanned aircraft (UA) are no longer sufficient to support the trust necessary to employ the technology effectively.

While the current standards that govern unmanned aircraft safety and reliability are adequate, the current policies allow UAS programs the ability to choose to save development cost/schedule by accepting reduced levels of safety and reliability, at the expense of higher life cycle costs resulting from higher attrition rates. UAS programs need to retain some level of flexibility; however, unless they are forced toward a requirement of greater reliability, the preference for an unmanned system will be toward savings on the cost and schedule. The current policies that govern unmanned aircraft reliability are insufficient for three reasons. First, low reliability requires UA's to be restricted to airspace that prevents overflight of populated areas. Restricting the airspace that UA's can train in has inhibited the development and employment of the full capabilities of medium to large UA's, negatively affecting the trust in UA's by the operators, supported entities, and adjacent units. Second, a low-reliability airframe does not make fiscal sense considering the current trend of increasingly

costly payloads. Lastly, low reliability creates an unnecessary strain on the personnel and resources of units which operate UA's that are not easily replaced and require investigations after each loss.

Certain technologies follow a pattern where they reach a particular level of maturity and obtain a depth of saturation within society or a part of society, where it then becomes necessary to standardize different facets of the technology. The reason for standardization might be to make the technology more cost-effective as components become increasingly complex and expensive, safer for people in the technology's operating environment, or more reliable in the execution of its function. Unmanned aircraft that are used for military purposes represent a technology within a specific functional niche that has reached a level of maturity and advancement where the policies regarding design and development standards that have been used are no longer adequate. Although it is the same basic technology, there are a few specific differences in the development, function, and characteristics between small UA's and the medium to large UA's that require the application of reliability standards between the groups to differ.

Reliability can be defined and analyzed with a variety of different metrics, to include: maintenance man hours per flight hour, individual system or component failure rates, Mean Time Between Failures (MTBF) or the Probability of Loss of Aircraft (PLOA) per flight hour. The level of UAS airworthiness can best be defined and analyzed by looking at the Design Controllable Probability of Loss of Aircraft (PLOAdc) per flight hour or the Probability of Cumulative Catastrophic Failure (Pcumcat). The PLOAdc and Pcumcat for an aircraft give an overview of the overall reliability for that aircraft. The United States Air Force often applies PLOA standards to manned aircraft in order to affect attrition loss rates

(and their associated life cycle costs). Pcumcat was developed in support of NATO UAS airworthiness standards and was derived from manned aircraft civil standards.<sup>1</sup> Pcumcat reflects the acceptable level of safety for a UAS for operations over all population densities. PLOA and Pcumcat, are underlying factors that go into building trust in an aircraft. PLOA and Pcumcat, as applied to aircraft reliability, are underlying factors that go into building trust in an aircraft.

The Department of Defense Handbook for Airworthiness Certification Criteria, MIL-HDBK-516C, indicates that, in order to determine the appropriate level of airworthiness for a UA, “Consideration should be given to the environment in which the UAS will be operated (controlled test range, national airspace, fleet usage, including ship-based applications), to the life expectancy of the system for which it is designed, and to the “expendability” of the UAV.”<sup>2</sup> Furthermore, “To determine the acceptable levels of Vehicle Control Function (VCF) redundancy and reliability, the cost of both UAS and collateral damage on the ground is considered.”<sup>3</sup> The procuring agency is supposed to take all the relevant factors into consideration and determine an acceptable PLOA.<sup>4</sup> In effect, this creates a type of floating level of reliability between UA’s both within the same group and across the different groups.

While providing flexibility to acquisitions and in no small part assisting with the initial proliferation of unmanned systems in the military, this floating standard for reliability

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<sup>1</sup> NATO Standardization Agency . STANAG 4671 - Unmanned Aerial Vehicle Systems Airworthiness Requirements (USAR), September 2009, Brussels

<sup>2</sup> United States, Department of Defense, MIL-HDBK-516C, "DEPARTMENT OF DEFENSE HANDBOOK AIRWORTHINESS CERTIFICATION CRITERIA" (12 December 2014), 1, accessed February 23, 2018, <https://assist.dla.mil>.

<sup>3</sup> United States, Department of Defense, MIL-HDBK-516C, "DEPARTMENT OF DEFENSE HANDBOOK AIRWORTHINESS CERTIFICATION CRITERIA" (12 December 2014), 145, accessed February 23, 2018, <https://assist.dla.mil>.

<sup>4</sup> United States, Department of Defense, MIL-HDBK-516C, "DEPARTMENT OF DEFENSE HANDBOOK AIRWORTHINESS CERTIFICATION CRITERIA" (12 December 2014), 146, accessed February 23, 2018, <https://assist.dla.mil>.

for designing and building different types of unmanned aircraft has caused many of the capabilities of unmanned aircraft to be underemployed and underdeveloped limiting their operational relevance. In addition, as payloads follow the current trend, getting more advanced and expensive, loading them onto unmanned aircraft that may not have been designed to be very reliable, will continue to increase the cost of MISHAPS. Thus, there needs to be a set minimum standard of designed reliability adequate for a minimum and necessary level of trust in unmanned aircraft that the task and investment demand.

## **NATURAL EVOLUTIONARY STEP**

There have been a few distinct and well-known technologies that have followed a similar developmental pattern that can be observed in the evolution of unmanned technology today. In 1885 the first automobile running on gasoline can be visibly recognized as a precursor of today's cars.<sup>5</sup> It took years for the collection of technologies that make up today's cars to mature and evolve to the point which standardization was deemed necessary. From 1885 to today the automobile has changed significantly in form, structure, and functionality while permeating all parts of society. As the automobile progressed through its evolution, it diversified into functional design families to include Sport Utility Vehicles, Pickup Trucks, and even cars specialized for racing. Other more utilitarian uses of automobiles have split off for functions designated or tasks in areas such as construction. There have been many designs that have been integrated into people's everyday lives and yet more designs that failed to catch on and be absorbed into society for one reason or another. As the evolution of the automobile progressed, and the technology was accepted into society,

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<sup>5</sup> Leonid Kogan, Dimitris Papanikolaou, and Noah Stoffman, "Technological Innovation: Winners and Losers," SSRN Electronic Journal, 2012, 1, doi:10.2139/ssrn.2193042.

people and governments eventually saw the need for regulation and standards. A car that exploded when it was rear-ended by another car was a major safety issue and deemed unacceptable. Today, the automobile is regulated and standardized from the design phase through the end of each vehicle's lifetime.

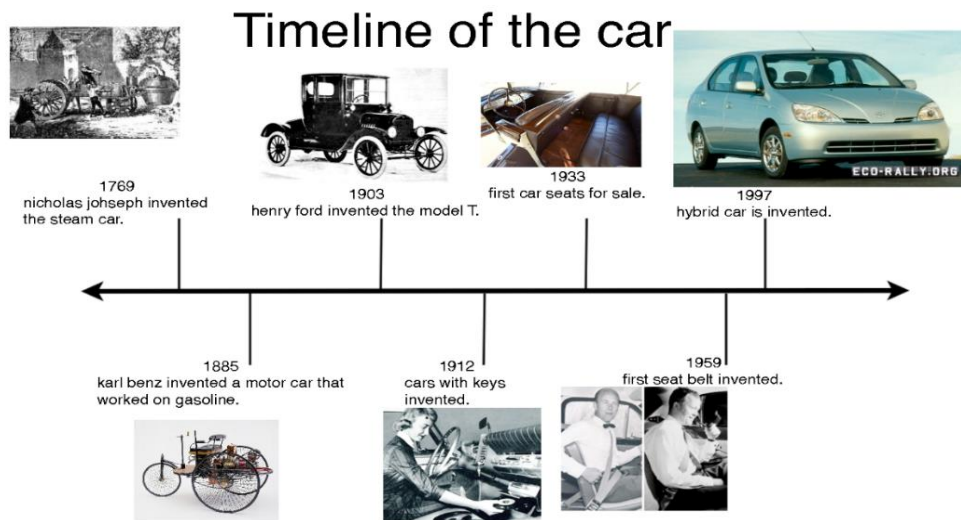


Figure 1/ Timeline of the Car<sup>6</sup>

New and revolutionary technologies are often met with excitement, fear, and sometimes even resistance. The word new in this case is somewhat relative; a technology may not catch on immediately after it is conceived. It may require a certain level of maturity to generate excitement, for people to recognize its potential, and invest in its further development. If a new technology has the potential to be adapted for use by vast swaths of the public, then that excitement can permeate the market with the entrepreneurial spirit taking the technology forward, often in new directions. Developmental variety is important for the maturation and success of a technology as it helps to illuminate the potential of the

<sup>6</sup> "Social studies." Pinterest. November 06, 2013. Accessed February 13, 2018. <https://www.pinterest.co.uk/pin/46795283601865719/>.

technology and weed out the dead ends. The excitement that can permeate a society generated by a technology can often force acceptance and integration of the emerging technology pressuring government and regulatory organizations to adapt. The evolutionary pattern that the automobile followed can be observed in a variety of technologies and now it can be seen occurring with unmanned aircraft technology.

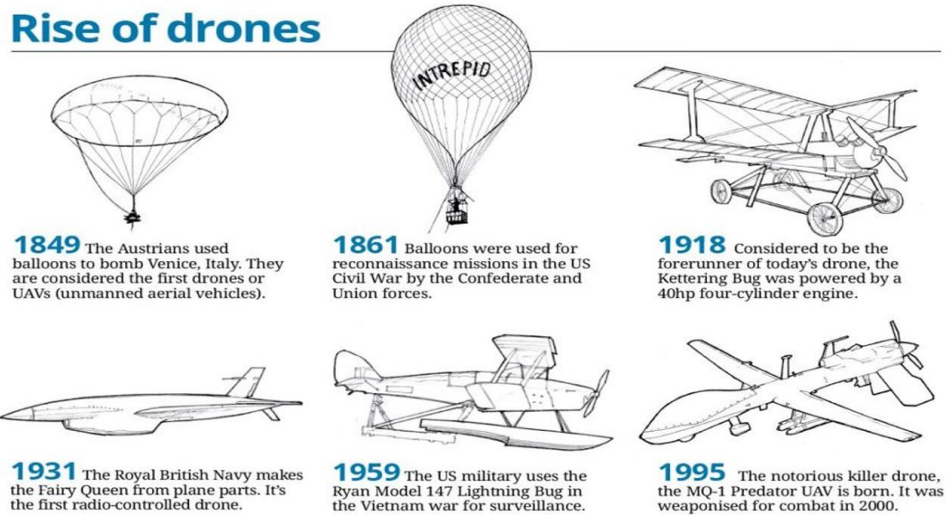


Figure 2/ Snapshot Timeline of Unmanned Aerial Vehicles<sup>7</sup>

Similar to the car industry Unmanned Aircraft have had a long developmental period. For the purpose of this paper the terms Unmanned Aircraft Systems (UAS), Unmanned Aerial Vehicles (UAV), Unmanned Aircraft (UA), Drones, or Remotely Piloted Vehicles (RPV) refers to the actual part of the system that flies in the air and is remotely controlled by an operator vice the aircraft and variety of ground control systems.

One of the first displays of unmanned aerial attack happened when unmanned balloons were used for the purposes of war in 1849 to bomb Venice, Italy.<sup>8</sup> Wars and the

<sup>7</sup> Mohamed Hardi Bin Abdullah, Snapshot Timeline of Unmanned Aerial Vehicles, digital image, SIPMM, November 12, 2017, accessed February 13, 2018, <https://sipmm.edu.sg/autonomous-drones-revolutionizing-conventional-warehousing/>.

<sup>8</sup> Edmund Flagg, Venice: the city of the sea, from the invasion by Napoléon in 1797 to the capitulation to Radetzky, in 1849; *With a Contemporaneous View of the Peninsula*. New-York: C. Scribner. (New-York: C.

states that fight them often play an important role as financial and motivational catalysts for the development of new technologies. This rapid evolution of UA from unmanned balloons to UA's that fit in the palm of your hand, while amazing, is not a new process and should not be feared and fought against but embraced as a natural. The developmental role that the state plays for new technology is typically spurred by a problem which the state generates into a requirement. That requirement is often answered with many different and varied solutions. As seen since the beginning of the Iraq and Afghanistan wars of the early 21<sup>st</sup> century, unmanned systems have blossomed into a variety of designs, capabilities, and potentials. These systems sometimes resemble fixed-wing aircraft and helicopters with all the typical parts. At other times they diverge into quad-copters or even insectile designs that are nearly indistinguishable from living creatures. As was seen with automobiles and other revolutionary technologies there is a natural order, a natural progression as a new technology matures. Unmanned technology has not only pushed the limits of the tools people wield but also people's minds and thought processes as they learn how to classify and integrate this new technology. Unmanned technology, specifically the medium to large UA's, that has been adapted for military use has reached the phase in its development where it requires design reliability standards in order to maintain its value and continue on the developmental path evolving new uses and designs that can be universally trusted.

## **DEVELOPMENTAL DRIVERS BETWEEN GROUPS OF UNMANNED SYSTEMS**

While war and governments have provided a large portion of the seed money for industry to improve, shrink them in size, and reduce the cost of producing unmanned aircraft

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Scribner, 1853), 405.

technologies, governments are not the only stimulus for development. UAS of today play a vital role in military operations while at the same time they have experienced an explosion of popularity and variety within the civilian sector. The degree of proliferation within the private sector is generally dependent on the cost and size of the UA. While still popular with hobbyists, larger UA's have not proliferated the private sector to the same extent as the small UA's. This is likely due to the much larger consumer market catering to people looking for cheap, flashy, and cool toys that don't require large-scale investments. As UA's have developed, they have been sorted into different groups based on weight and capability as seen in Table 1.





UAS Groups	Maximum Weight (lbs) (MGTO)	Normal Operating Altitude (ft)	Speed (kts)	Representative UAS	
Group 1	0 – 20	<1200 AGL	100	Raven (RQ-11), WASP	
Group 2	21 – 55	<3500 AGL	< 250	ScanEagle	
Group 3	< 1320	< FL 180		Shadow (RQ-7B), Tier II / STUAS	
Group 4	>1320		> FL 180	Any Airspeed	Fire Scout (MQ-8B, RQ-8B), Predator (MQ-1A/B), Sky Warrior ERMP (MQ-1C)
Group 5		Reaper (MQ-9A), Global Hawk (RQ-4), BAMS (RQ-4N)			

Table 1/ Unmanned Aircraft Groups 1-5 Descriptions and Requirements<sup>9</sup>

Comparing UA Groups to proliferation in the private sector, the distribution in civil circles decreases as the UA gets larger. Group 1 UA's clearly dominate the civilian markets.

So, what does this have to do with development and reliability? The rate and variety of

<sup>9</sup> United States. Department of Defense, Unmanned Aircraft System Airspace Integration Plan, Version 2.0, March 2011, comp. UAS Task Force Airspace Integration Integrated Product Team (United States. Department of Defense, 2011), D-3, accessed February 13, 2018, <https://www.hsdl.org/?view&did=723337>.

development of UA's rely on the amount of money invested. Smaller UA's are cheaper to build, making them cheaper to buy which allows the reliability to be lower. On the civil side, this math results in larger profits. There is some military benefit to the civilian interest in small UA's. A civilian sector interested and invested in the development of smaller UA's means that the military has a wide variety of cheap UA's to choose from, purchase, and distribute to small units. Because businesses are invested in the development of small UA's, the larger pool of platforms equates to a broader range of capabilities and designs to either purchase "off the shelf" or modify for military usage. The cost to purchase, repair, and replace small UA's is relatively small, which is why the low reliability is not a large concern beyond a general ruggedness that is required when employed by the military in an operational environment.

Expectations with respect to the differences in reliability are important to highlight. UA's designed as small toys, while standardized by mass producing industry, are not typically required to meet a high level of reliability. The understanding is that if a toy breaks, you buy a new one. It is a toy, not a vital or expensive piece of equipment nor is anyone likely to die if it breaks. The sphere of usage for small toys is near the user; if it breaks the chance of injury is low. Therefore, a UA designed as a toy is typically going to be built to a lower level of reliability with reduced quality assurance standards. This difference in reliability between the medium to large UA's and the small UA's is natural and cost-effective, higher reliability equals higher cost. Why would a company purposely reduce their profit margins to create a toy with greater reliability than is expected by the consumer? A general rule has developed that as the size, capabilities, and price of a UA increase, so does the reliability. While this means that a Group 3 UA is probably going to be more reliable than a

Group 1 UA, the reliability for Group 3-5 UA's isn't where it needs to be. Too many Group 3-5 UA's are designed with low reliability because it is cheaper to get the programs started. This results in greater costs down the line, both monetary and non-monetary.

The Unmanned Systems Integrated Roadmap FY2013-2038, released in 2013, states that unmanned systems, "can enhance situational awareness, reduce human workload, improve mission performance, and minimize overall risk to both civilian and military personnel, and all at a reduced cost."<sup>10</sup> While there is a reduced cost compared to manned aircraft, unlike small UA's the larger UA's are not necessarily cheap. An RQ-7 Shadow Group 3 UA may only be a fraction of an F-35; however, it is more than fifty times more expensive than a Group 1 Raven UA. The value of the greater capabilities and higher cost of the Group 3 and above UA's, when compared to Group 1 and 2 UA's, require an increased level of reliability for more expensive and capable UA's. This would increase the initial sticker price of a Group 3-5; however, there will also be a decreased cost in repair and replacement throughout the UA's lifecycle.

In many ways, the larger UA's were developed and built to mimic many of the capabilities of current manned aircraft with some added benefits, such as a reduced risk to personnel. The development of the Groups 3, 4, and 5 categories of unmanned aircraft has not just mimicked some of the capabilities of manned aircraft, but, in some circles, it has also come with some of the same expectations concerning airworthiness, reliability, maintenance requirements, and integration. Differences between manned and unmanned aircraft standards is not necessarily wrong or bad as long as it is understood why those things are important and selectively identify where standards for an unmanned aircraft can and should deviate from a

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<sup>10</sup> Unmanned systems integrated roadmap: FY2013-2038(Washington: Department of Defense, 2014), 20.

manned aircraft. Where aircraft design and reliability might still be important, the lack of a man-in-the-machine may allow certain maintenance procedures to be relaxed in order to ensure a quicker turnaround from landing to takeoff.

UA's are expendable, while the operators may still manage risk, there is typically a higher acceptable level of risk for utilizing a UA vice a manned aircraft. Naval Aviators religiously follow the Naval Air Training and Operating Procedures Standardization (NATOPS) Program; this includes a manual that governs what a pilot can and cannot do as well as telling them what they need to know about their aircraft and its systems to make correct decisions and manage risk. A common saying among Naval Aviators is that "NATOPS was written in blood" referencing the pilots that died learning a lesson about their aircraft and in so doing, added their lessons of what to do and what not to do, so future pilots would not die doing the same thing. Although the loss of life is tragic, the NATOPS program is also in place to help prevent wasting the investment of both money and time to train and build experience in the pilot as well as losing the valuable aircraft the pilot is responsible for. When the man is taken out of the machine, instead of risking the loss of life, now only an asset and its replaceable capabilities are at risk. This allows the UA to be utilized in high-risk situations where it might have otherwise been deemed that risking a person was not worth the risk. If the reward is worth the cost and the UA is lost the UA can be written off, similar to when a weapon is expended.

Simply designing to a higher level of reliability would open doors to advanced training and integration opportunities, as well as provide an opportunity to demonstrate UA capabilities and build trust in those capabilities to both adjacent units and higher echelons of command. The greatest risk to personnel when utilizing UA's is the risk to the people a UA

is sharing the skies with and to the people that might be below it (also referred to as third parties on the ground). When operating in friendly airspace or training in the United States, the risks to people on the ground are often mitigated by restricting the airspace UA's operate in. This airspace restriction limits the utilization of a UA's full capability and prevents UA's from being able to participate in many training and integration opportunities where those capabilities would be validated and tested in tactical situations for the benefit of both the operators those they work with.

While some believe the expendability of UA's is derived from being inexpensive, this not the only factor that makes them expendable. Unlike the Group 1 and some of the Group 2 UA's where they are both inexpensive and expendable, as one starts to look at the Group 3 and above UA's the cost begins to increase, but the expendability doesn't decrease. Increased investment in reliability will likely not increase the overall cost of UA's anywhere near the cost of most manned aircraft the military purchases. Even if reliability is sacrificed and the aircraft itself is still relatively cheap, the payloads/sensors that are loaded on the cheap aircraft are becoming increasingly specialized and costly. The rising cost of losing one of these valuable but expendable assets is anathema for some that say the greatest benefit of UA's, expendability, is being lost. However, it can be argued that even a UA that costs as much as an F-35 is still expendable. If a UA crashes and is destroyed, even an expensive one, the pilot/operator can be available to launch another one to continue the mission. The price, losing a life, skills, and experiences that is risked in a manned aircraft does not need to be paid when a UA is lost. The concept of inexpensive equals expendable needs to be reevaluated regarding UA's. UA's can still be considered expendable regardless of the

reliability or monetary cost because there is no risk to a pilot. When factoring in the cost of a life, a UA can still be defined it as inexpensive.

UAS Groups 1 and 2 are vastly different from Groups 3-5. As a UA gets larger, both the price and capability increase. There is usually a natural and corresponding increase in the reliability moving from Group 1 up to Group 5; however, the reliability for Groups 3-5 is not high enough. People should not resist a higher cost due to increased reliability because UA's are unmanned; expendability is not sacrificed. Increased reliability helps to protect a valuable capability while removing the requirement to put manned aircraft at risk when they don't need to be put at risk. Those that hold the idea that UA's need to be cheap to be expendable as sacrosanct need to shift their focus from expendability being related to the cost of the aircraft. There needs to be a change in understanding that focusses on the idea that utilizing a UA may save the cost of losing the life of a pilot and the millions of dollars invested in their training. With this mindset, it is possible to maintain the concept of UA's remaining expendable, while at the same time investing in enough reliability to be able to trust that it is going to be able to complete the mission over and over again.

## **WHAT IS TRUST IN THE MACHINE?**

As technology develops, one of the key questions that need to be confronted has to do with trust. Trust is a complex concept, but it can be affected by two key factors. The first factor is reliability, while the second part involves the demonstration of the technology's capability. The limit or degree of trust that can be invested in a machine is directly proportionate to the investment in the reliability of the design (i.e., the probability that it

won't fail). The second determinant of trust development is dependent upon whether the design can actually execute the function it was meant to perform.

In order to determine the required degree of trust necessary for a machine to fulfill a given function, a series of three basic questions must be asked and answered:

- What is the importance of the task required of the machine?
- How important is it that the machine is able to complete the task without failure?
- How important and what is the likelihood that the machine is able to complete the task under a designated set of conditions while ensuring that it doesn't do some other thing?

If the combined answer to these question is that it is highly important, then the degree of trust needs to be high. As a technology gets more complex and the things it is designed to do become more multifaceted, answering these three questions becomes not just necessary but essential in determining what the required degree of trust needs to be which dictates the required level of reliability. The importance of the function of a machine has a direct effect on the importance of answering the question, do I trust this machine?

The degree of trust will drive the level of reliability designed into the system which in turn will drive the quality of materials utilized and how precisely the limitations are investigated and defined. This process of building trust in a technology or a machine begins with defining and developing the requirements for what the technology needs to be able to do and what it needs to not do. Those requirements are transformed into a design, to include component limitations and specifications. The required degree of trust for a given technology should drive what limitations and specifications the technology must meet, and the materials used in the technology. If those limitations and specifications don't meet the requirements,

then the trust in the machine will be insufficient. Eventually, a functional machine is put through testing. If the testing is not rigorous enough or the results don't meet the requirements the trust in the machine will be insufficient. The first set of steps in building trust in a machine are critical in setting the limit for how much trust can be invested in a particular machine. If the cost to develop that trust, through the design, development, and testing process, exceeds the value of what the technology will be used for, then a new solution/technology should be found.

The importance of the question of trust is not only dependent on the complexity of the question but on what the defined requirements are and the desired function of the technology. An example of a trust-defining question involving a common military technology might be: How important is it that an infantry rifle is accurate and capable of killing the enemy from a specified distance before the enemy can kill the infantryman while not blowing up in that individual's face? The trust in the infantry rifle needs to be high due to the high value of the job it is meant to do and the thing it is meant not to do. In this case, due to the importance of the function and the degree of trust necessary, the materials, limits, and specifications should meet an extremely low rate of failure. In addition, testing and the quality assurance process for this rifle can be expected to be rigorous to ensure that every rifle meets its requirements.

Once the level of trust necessary for a given technological solution to a given problem is determined and that trust is then translated into the cost of building the machine to a given design standard with the right rigor of testing a cost-benefit needs to occur. The design should be considered in light of three things to determine if the necessary degree of trust is met: the importance of the task required of the technology, safety of friendlies near the technology, and the cost of the technology. There is an acceptable range for each of these

three factors that the design needs to meet for a given machine. These three factors should then be applied to a cost-benefit analysis that determines if the necessary level of trust is appropriate and if the benefit of using the specific technology outweighs the cost. How does the importance of the task the technology is needed for compare to the cost of designing, developing, and testing the technology? If the cost outweighs the benefit, then a new solution or technology must be applied to the task. Trying to force the wrong solution will likely result in an undesirable compromise in order to reduce the cost.

A military Group 3, 4 or 5 UA is typically required to do a variety of missions ranging from conducting Intelligence, Surveillance and Reconnaissance (ISR) to conducting strike missions. The importance of the tasks assigned to a specific T/M/S of UA might vary from day to day, but it is likely that eventually a mission will be assigned that is of high importance. The value of the mission needs to be considered. For example, good intelligence can save lives, while a lack of intelligence can cost lives increasing the importance of being able to trust the UA to accomplish its mission. Excluding targeting the wrong individual, there are two ways that a UA might kill the wrong person: by crashing into another aircraft or crashing into someone on the ground. The importance of not killing friendlies, civilians, or non-combatants is extremely important. The cost of UA's varies greatly, but as new UA's are developed to be modular, accepting different sensors/payloads, those sensors/payloads can sometimes multiply the cost of a single UA. Looking just at the three factors related to the operation of UA's in the context of the components of trust that determine the level of trust necessary: the importance of the task required of the technology, safety of friendlies near the technology, and the cost of the technology, then trust in Group 3-5 UA's needs to be high.

## **UNMANNED AIRCRAFT STANDARDS AND CATEGORIES**

Beginning in the 1990's the US Department of Defense (DOD), eventually joined by the Federal Aviation Administration (FAA), slowly began to identify ways to certify, classify, and regulate UA's. The policies and procedures for UA's have fluctuated between treating unmanned systems as toys with limited capabilities that needed to be completely separate, to treating them as manned aircraft that were still required to operate completely separate from the actual manned aircraft. As the personnel within the US DoD and different governmental organizations have gained the expertise and understanding of how to treat UA's and the comfort and the professionalism of the unmanned operators has grown, the military has begun training toward integrating manned and unmanned aircraft operations. The Group 1 and 2 UA's still rely heavily on airspace separation to ensure safety for manned aircraft while the Groups 3-5 UA's have begun to do a combination of separation and coordination to limit the chance of midair collisions between manned and unmanned aircraft.

Because Groups 3-5 UA's have begun to be integrated and have many similarities in size and capability to manned aircraft, administrative treatment of them concerning rules and regulations has swayed more toward treating the medium to large UA's as manned aircraft than as toys. However, some confusion still exists because of the enormous variance between designs and capabilities of UA's and an inability to compare all UA's directly to manned aircraft. An example of this wide range of differences can be seen in the wide scope of different levels of reliability across the spectrum of UA's where not every UA is allowed to operate over populated areas due to low reliability; however, if a different UA has a high enough reliability, it can operate overhead any population density. This uncertainty in how to accommodate the differences typically results in catch-all statements, such as, "This

instruction may need to be changed or waived to reflect the realities of UAS operations” as stated in OPNAV 3710.7U.<sup>11</sup> This statement, and others like it, have allowed the needed flexibility as the different services stumbled their way through procuring and implementing this new technology. Although this flexibility in UA guidance and rules was initially necessary, it has allowed for a large amount of variance not only in operations but also design requirements and standards that now needs to be more appropriately regulated. As the technology matures, it is becoming too expensive and costly in missed training opportunities to keep the same level of flexibility.

Although there are requirements defined for each UA Type/Model/Series (T/M/S) that the government purchases, the specific level of required reliability and airworthiness can differ between T/M/S’s. There has been no common requirement for unmanned systems to have a specific level of airworthiness. Instead the airworthiness authorities have identified a spectrum of standards that accommodate everything from “toys” to sophisticated Group 5 UAS capable of landing on an aircraft carrier. Unfortunately, this trade-space also provided an out for the acquisition community which chose the least cost, least time, minimum reliability solution to meet the requirements. Even if the materials and components, in reality, have a high level of reliability, the engineering information available and whether there was sufficient and satisfactory testing completed on the UA may limit the trust in a specific T/M/S. Insufficient test data can often be the limiting factor in the category of clearance a UA is eligible to obtain. Table 2 depicts the categories of Interim Flight Clearances (IFC) utilized by NAVAIR to define what airspace a UAS is cleared to operate in and what population density they are allowed to operate over.

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<sup>11</sup> NATOPS General Flight and Operating Instructions: OPNAV instruction 3710.7U (Washington, D.C.: Department of the Navy, Office of the Chief of Naval Operations, 2009), 3-27.

UAS Flight Clearance Category	Intended Usage	Airworthiness Standards & Data	Cumulative Probability of Catastrophic Failure or Probability of Loss of Aircraft*
<b>CAT 1</b>	<ul style="list-style-type: none"> <li>- All Classes of Airspace</li> <li>- All Population Densities</li> </ul>	<ul style="list-style-type: none"> <li>- Airworthiness and safety of flight equivalent to manned</li> <li>- Design engineering review</li> </ul>	≤ 1 UA Loss In 100,000 ft hrs
<b>CAT 2</b>	<ul style="list-style-type: none"> <li>- All Classes of Airspace</li> <li>- Limitations on Flight over Densely Populated and Congested Areas</li> </ul>	<ul style="list-style-type: none"> <li>-Higher PLOA than Manned Aircraft</li> <li>-Tailored Airworthiness Criteria &amp; Standards</li> <li>-Design engineering review</li> </ul>	≤ 1 UAV In 10,000 ft hrs
<b>CAT 3</b>	<ul style="list-style-type: none"> <li>- Over Water or over Sparsely Populated or Unpopulated Areas</li> <li>- Limitations on flight over personnel</li> <li>-Restricted/Warning Areas, Maritime Environment, Combat Zones, International Airspace, Specific Ranges, NAS Class G or COA</li> </ul>	<ul style="list-style-type: none"> <li>Safety of Flight</li> <li>- Risk of Material Loss Accepted, HPOL**</li> <li>-Engineering Review and Risk Assessment</li> <li>- Not designed to accepted engineering standards and/or Insufficient data</li> </ul>	> 1 UAV In 10,000 Ft hrs or Unknown

Table 2/ UAS Flight Clearance Categories<sup>12</sup>

The original concept of an IFC was that it was supposed to be either short in duration, intended to facilitate a specific urgent need, or a new change.<sup>13</sup> The key here is interim, but because “UAS may have a lower level of inherent airworthiness and a higher probability of loss than manned aircraft,” they have been assigned three categories of IFC’s that they can be certified with.<sup>14</sup> There is a wide variance in reliability between UA’s throughout the three IFC Categories. Typically, as the size, capability, and cost decrease, so does the reliability as measured by Probability of Cumulative Catastrophic Failure or Loss of Aircraft (Pcumcat or PLOA) per flight hour. The specific category of IFC assigned to a UA is based on “the engineering design standards, supplied data, and associated system analysis” with the level of

<sup>12</sup> Rich Adams, "UAS Flight Clearance Categories," digital image, March 1, 2017, accessed February 13, 2018.

<sup>13</sup> NAVAIR INSTRUCTION 13034.10F: FLIGHT CLEARANCE POLICY FOR AIR VEHICLES AND AIRCRAFT SYSTEMS (Washington, D.C.: Department of the Navy, Office of the Chief of Naval Operations 2010), 10.

<sup>14</sup> NAVAIR INSTRUCTION 13034.10F: FLIGHT CLEARANCE POLICY FOR AIR VEHICLES AND AIRCRAFT SYSTEMS (Washington, D.C.: Department of the Navy, Office of the Chief of Naval Operations 2010), 6.

data collected and depth of analysis being driven by the type of airspace the UA requirements indicate the UA needs to be able to operate within.<sup>15</sup>

Both manned and unmanned aircraft have been artificially integrated into the below graphic by NAVAIR for comparison. This graphic aptly shows both the wide range in UA reliability as well as the scale of difference in reliability between manned and unmanned aircraft. While some difference in reliability can be expected from design to design, as seen with manned aircraft, the degree of variability in reliability for UA's has covered the spectrum.

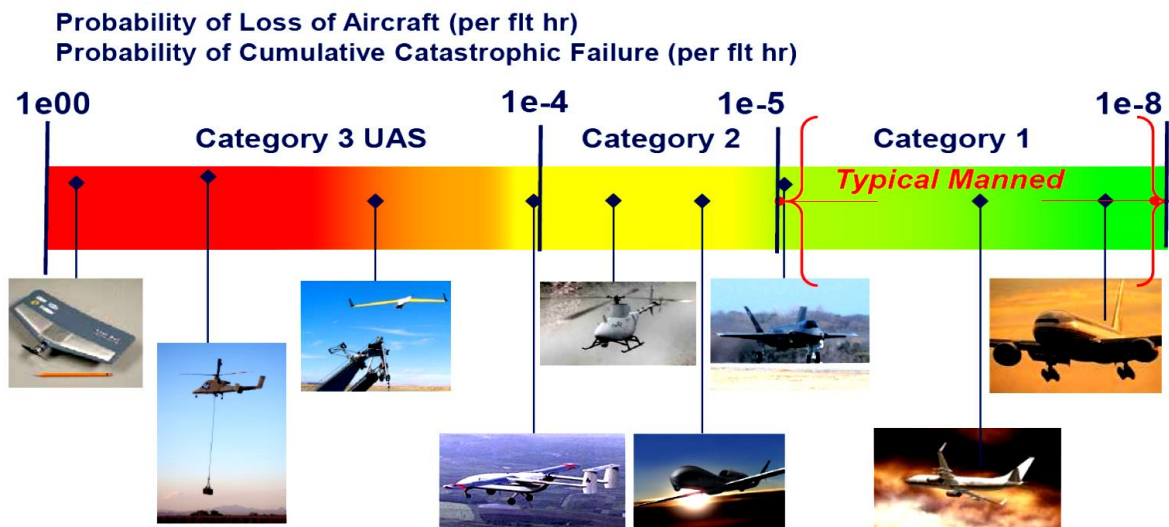


Figure 3/ UAS Airworthiness Spectrum<sup>16</sup>

Pcumcat and PLOA are statistics that measure the reliability of the aircraft as a whole. The reliability of an aircraft is typically a factor of the reliability of individual systems working in concert. If one or more key systems have low reliability with limited or no redundancy, then the aircraft will have a low Pcumcat or PLOA. The minimum Pcumcat for a DOD UA to operate in the US National Airspace (NAS) is “no more than one Catastrophic

<sup>15</sup> NAVAIR INSTRUCTION 13034.10F: FLIGHT CLEARANCE POLICY FOR AIR VEHICLES AND AIRCRAFT SYSTEMS (Washington, D.C.: Department of the Navy, Office of the Chief of Naval Operations 2010), 16.

<sup>16</sup> Rich Adams, "UAS Airworthiness Spectrum," digital image, March 1, 2011, accessed February 13, 2018.

Failure expected in every 100,000 (1e-5) flight hours for UA with a design gross takeoff weight less than or equal to 12,500 lb; and rate of no more than 1 loss of UA per 1,000,000 (1e-6) flight hours for UA with a design gross takeoff weight greater than 12,500 lb.”<sup>17</sup> It should be expected that the smaller/less expensive and easily replaced UA’s are not worth the time, effort, and increased cost to ensure they are reliable enough to warrant a Cat 1 or 2 IFC. However, there are a fair number of UA’s that are Group 3 and above which are treated similarly to manned aircraft and should warrant reliability on par with at least the minimum standards of manned aircraft. As UA technology matures and the ambiguous statements that show a lack understanding of UAS begin to disappear from procedures and policies, it is also time to take another look at reliability for UA’s. This process of review and reassessment is a natural step in the development of any new and revolutionary technology that permeates not just one small group of society but has grown to touch an entire population. The floating reliability requirement is no longer satisfactory for the trust needed by Groups 3, 4, and 5 UA’s.

## **DETRIMENT TO TRUST**

Looking at the current Group 3-5 UA’s and the policies that govern their reliability and forecasting the developmental trends, the level of reliability is falling short of the degree of trust necessary for the important missions they are tasked with and the expectations that are placed on them. A primary selling point for UA’s is their expendability. A common misconception is that to be expendable, a UA must be inexpensive. This forces low reliability and limits the amount of trust that can be invested in a UA. As the technology of UA’s has

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<sup>17</sup> NAVAIR MANUAL M-13034.1: NAVAIR AIRWORTHINESS AND CYBERSAFE PROCESS MANUAL (Washington, D.C.: Department of the Navy, Office of the Chief of Naval Operations 2016), 6-3.

become more advanced, capable, and expensive, the desire for UA's to remain expendable has become a roadblock to the necessity to spend additional money in design, development, and fielding to make them more reliable.

A one million dollar UA with a payload that is designed and built today might have a new sensor designed in two years that costs two million dollars. The total aircraft is now worth three million dollars; however, the part that keeps it in the air is only built with the reliability deemed adequate for a one million dollar aircraft. The PLOA expected of a one million dollar aircraft may have made sense when it was one million dollars. That PLOA no longer makes sense with a three million dollar aircraft and in four years a new payload may make it a four or five million dollar aircraft, especially if they fail at a rate 100 times higher than a manned aircraft. As was seen in the early years of RQ-1 and RQ-4 displayed in Table 3, reliability can improve over time by correcting failures after they happen; however, an early investment in reliability may greatly reduce the number of failures from the start.

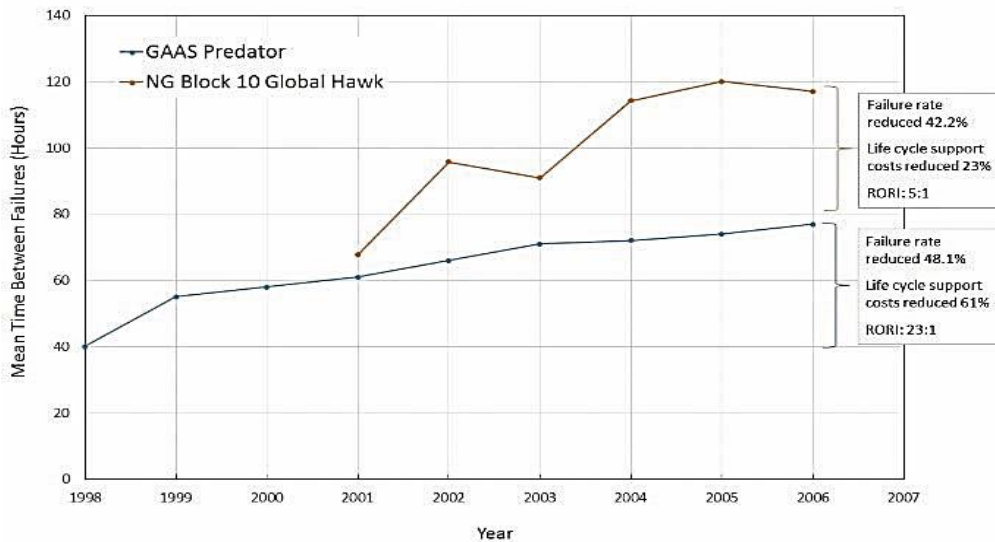


Table 3/ Predator and Global Hawk Reliability Increase Over Time<sup>18</sup>

<sup>18</sup> "Reliability of UAVs and Drones," Reliability of UAVs and Drones | DSIAC, accessed February 06, 2018, <https://www.dsiac.org/resources/journals/dsiac/spring-2017-volume-4-number-2/reliability-uavs-and-drones>.

In addition, the longer it takes to enact a policy change to design requirement with a higher reliability for Group 3-5 UA's the more expensive it will be. The cost to redesign and upgrade the original UA's to a higher PLOA could be just as costly as designing and building a brand new UA. Beyond the drain on fiscal resources, there are secondary and tertiary costs associated with a low-reliability aircraft such as a drain on personnel and negative effects on training.

There is a serious mismatch in the application of resources when the aircraft operated is expensive but unreliable. The least expensive Group 3 UA the Marine Corps owns, RQ-21 Blackjack, is about 1.2 million dollars. If that UA has a one million dollar payload/sensor installed, now losing a single aircraft is a Class A MISHAP requiring an investigation, convening of a MISHAP Board, and a variety of other requirements that sap a squadron's manpower and effectiveness. Between 2016 and 2017 RQ-21 had 18 Class C or greater MISHAPS requiring MISHAP investigations that were found to have been primarily due to system/mechanical issues.<sup>19</sup> The process of the MISHAP investigation and recommendations of corrective measures MISHAP is meant to restore and increase the overall trust in an aircraft; however, a UA that is designed with low reliability will create an endless workload geared toward building trust that was never paid for. In addition, while there is a fairly large number of Group 1 and 2 UA's to replace losses, Group 3, 4, and 5 UA's, due to cost, typically have a much shallower pool of replacements and parts. High non-combat UA loss rates cause a strain on the supply system, which can result in a shortage of assets. A shortage

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<sup>19</sup> Naval Safety Center. Data for UAV and RQ-21 for Class A, B, C, D MISHAPS and Hazards from 2009 to 2018. January 25, 2018. Raw data. FOIA CASE 2018-NSC-150

of assets means that missions may go unfulfilled which can result in a lack of intelligence or missing capabilities for critical operations.

In addition to the cost of aircraft and the cost to personnel, lower reliability has the effect of restricting the airspace where the UA's can operate in order to mitigate the risk to people on the ground. The reliability of the UA directly corresponds to the density of population the UA is allowed to fly and operate over while in the United States. This restriction can also apply to operations within foreign countries, depending on the importance of an operation or training exercise. Restrictions of where UA operators are able to train, negatively impacts squadron readiness. In some cases, an airspace restriction can directly impact the ability of a unit to attain and maintain their Mission Essential Tasks (MET) that they are supposed to be proficient in executing. Airspace restrictions subsequently limit integration with adjacent units, further negatively impacting proficiency as well as the ability for units that operate UA's to demonstrate capabilities of their assets and build trust within the force.

The biggest problem with low UA reliability boils down to trust. The importance of the missions that most Group 3-5 UA's are utilized for requires a high degree of trust which in turn requires a corresponding level of reliability. The system of using a floating standard of reliability for Groups 3-5 UA's does not consistently allow for the high level of trust that this technology demands. The units operating UA's are becoming more degraded by MISHAPS and training restrictions, while a high rate of MISHAPS consumes increasing numbers of personnel and fiscal resources. A change in the current policies must be made that will address these issues that threaten both trust in the technology and future sustainability.

## **A PATH TO TRUST**

Mandating by policy an increased reliability of Groups 3-5 UA's will restore the trust to be effectively employed in the accomplishment of the mission they were envisioned to do. A new Department of Defense-wide policy needs to be set that requires any Group 3-5 UA be designed where the Design Controllable Probability of Loss of Aircraft to be no higher than one failure per 100,000 flight hours, or a Design Controllable Pcumcat of no greater than one loss per 100,000 flight hours for UA with a design gross takeoff weight less than or equal to 12,500 lb; and a Pcumcatdc of no more than 1 loss of UA per 1,000,000 flight hours for UA with a design gross takeoff weight greater than 12,500 lb. All single point of failure and subsystem failure rates need to be in compliance with MIL-HDBK-516C for UAS, allowing for the possibility of unrestricted access to the national airspace. Not only would this policy change allow for future development while accounting for rising costs in payloads and sensors, but it would also help facilitate the employment of the full capabilities of medium to large UA's. This policy shift would also enable the development of greater trust in UA's by the operators, supported entities, and adjacent units.

Although higher reliability will not eliminate MISHAPS nor the requirement to conduct MISHAP investigations, the number and frequency of MISHAPS should be greatly reduced ensuring that the focus of units operating UA's is on conducting their mission and not on constantly trying to figure out why their aircraft fell out of the sky. This minimum standard would also help to pave the way for international partners as well. International working groups, such as Joint Authorities for Rulemaking on Unmanned Systems (JARUS) Working Group 6 and European Organization for Civil Aviation Equipment (EUROCAE)

Working Group 73, consisting of representatives from various European and United States aviation regulatory agencies, have been juggling the concept of what a minimum standard of reliability should be.<sup>20</sup> The United States Department of Defense and the Federal Aviation Administration have been participating in these working groups and have the ability to shape the international policy regarding UA standards ensuring the US DoD UA's will be compliant. Ensuring the US standard matches international standards is important in order to have ease access to operate within international airspace promoting interoperability with allies. The best way to ensure this happens is to prove the validity of the policy through execution and empirical data so that the international community can then adopt and mimic a similar policy concerning minimum UA airworthiness.

This minimum level of reliability would enhance multiple aspects of the development, application, and trust associated with UA's. This level of reliability would meet the requirements for any Group 3-5 UA to obtain a CAT 1 IFC. A CAT 1 IFC would allow UA's to operate in a larger variety of training venues helping to enable the ability for units to achieve their assigned Mission Essential Tasks. Access to additional airspace would also help to facilitate greater levels of integration and participation in exercises both at home and during Theater Security Cooperation Exercises abroad. Greater UAS participation and integration facilitates an incremental increase in trust and confidence in the technology through experience and observation while encouraging the further development and sharing of new Tactics, Techniques, and Procedures. A high degree of designed trust and experiential trust gained through the observation of a reliable capability will result in a more integrated and effective real-world utilization of Unmanned Aircraft in military operations.

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<sup>20</sup> JARUS WG6 – EUROCAE WG73 "1309" CONCILIATION TEAM, JARUS WG6 – EUROCAE WG73 "1309" CONCILIATION TEAM REPORT, PDF, November 2015.

## CONCLUSION

Unmanned Aircraft are now moving into a phase where larger, more capable UA's need a more uniform level of reliability in order to ensure that UA's are safer for the people that are living below them and reducing the various costs associated with needlessly losing a valuable and, in some cases, vital asset. These assets are no longer the emerging technology that was forced through a rushed process to meet an urgent demand signal to save lives in yesterday's battles. It is time to look back and determine the standards that would create the greatest benefit for future development and apply those standards across the board from the design phase through their lifetime just like what happened in the auto industry when the time was right. An article by Richard Whittle talks about the pioneer inventor of the Predator, Abraham E. Karem, who recognized the importance of reliability. "[T]hose who think the secret to the Predator's success was endurance should think again. What he brought to UAVs was a refusal to treat them—as others had—like models or target drones, which aren't built to last, and therefore aren't built to be reliable."<sup>21</sup>

A UA designed to a greater reliability standard means an increased lifespan of each aircraft helping to offset any increased cost due to standardizing a higher level of reliability. Higher reliability would directly translate to reduced stress on the supply chain and increased readiness. The key here is design; UA's that are designed to a higher reliability standard and are not required to receive major post-release overhauls or a series of piecemeal upgrades are more likely to be more holistically functional over their life cycle. The selling point that UA's

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<sup>21</sup> Richard Whittle, "The Man Who Invented the Predator," Air & Space Magazine, March 31, 2013, accessed February 11, 2018, <https://www.airspacemag.com/flight-today/the-man-who-invented-the-predator-3970502/?page=5>.

are expendable is still a valid point, even if the investment in a reliable UA entails a higher cost. If a UA is lost due to a crash or enemy action, there is still no need to launch a mission for the Tactical Recovery of Aircraft and Personnel (TRAP) to rescue a pilot. The sum benefit of increased reliability for Group 3-5 UA's is a substantial increase in trust. Increased reliability will generate trust in the technology by the operators, the units the UA's are working with and supporting, and trust from the innocent populations they need to operate over.

## RECOMMENDATIONS

- A new Department of Defense-wide policy needs to be set that requires any Group 3-5 UA be designed where the Design Controllable Probability of Loss of Aircraft to be no higher than one failure per 100,000 flight hours, or a Design Controllable Pcumcat of no greater than one loss per 100,000 flight hours for UA with a design gross takeoff weight less than or equal to 12,500 lb; and a Pcumcatdc of no more than 1 loss of UA per 1,000,000 flight hours for UA with a design gross takeoff weight greater than 12,500 lb.
- If the policy above is accepted, a waiver would need to be developed that allows UA's that do not and will not ever, need to operate over populated areas to attain an IFC less than a CAT 1. The availability of a waiver does not contradict the requirement for high reliability due to high lifetime costs. However, this would allow for a UA that has no need to operate over populated areas, such as a UA that is designed only to for shipboard and blue water operations, the testing requirements for a CAT 1 IFC are unnecessary.
- In addition to higher reliability to safely operate over people on the ground, full access to the US national airspace is contingent on an effective sense and avoid system in order to ensure safe integration of manned and unmanned aircraft. There are several options currently in development. A study needs to be initiated to determine the most effective and promising option. The best option needs to be invested in and implemented at the soonest opportunity to allow continued development and integration of unmanned aircraft.