APPLICABILITY OF MILITARY UAS AIRWORTHINESS REGULATIONS TO CIVIL FIXED WING LIGHT UAS IN GERMANY

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Abstract

During the last years Unmanned Aircraft Systems (UAS) have risen within military forces from additional surveillance equipment to an indispensable military instrument. Naturally the interest for a civil usage emerged too. An efficient usage of civil UAS requires the integration into national airspaces, which demands operating and airworthiness regulations for all types of UAS.

Within the range of UAS, light UAS < 150 kg are the broad majority, regarding different designs, variety and manufacturers. It is obvious that there is an intensive necessity for integrating them into national airspaces too. Currently this class of UAS has to be regulated by national airworthiness authorities and there is no harmonized way in treating them with respect to operational and especially airworthiness aspects.

Up to now, the usage of civil UAS in Germany is nearly impossible. If UAS are allowed to fly then only under very prescriptive restrictions. In January 2012, the German Federal Parliament has agreed to change the national Air-Navigation-Act and to include UAS for the first time. However there are not any defined airworthiness regulations for civil UAS < 150 kg in Germany.

This paper seeks to show the applicability of military UAS airworthiness regulations for light UAS to corresponding civil systems. Therefore, a review of different civil airworthiness agencies and their UAS related activities is given. Especially the situation in Germany is reflected. Moreover the paper focuses on UAS airworthiness regulations by NATO and the Bundeswehr in order to provide an insight to military UAS airworthiness regulations.

Furthermore military UAS airworthiness requirements are compared with traditional manned aircraft airworthiness requirements and a perspective to show the applicability of military light UAS airworthiness requirements in accordance to the current EASA UAS policy is presented.

1. INTRODUCTION

With landing of the Euro Hawk in July 2011 at the test site Manching [1], the reality of the usage of UAS[1] in the German Armed Forces (Bundeswehr) has finally arrived in the broad public view in Germany.

The whole Euro Hawk Project was a huge step forward for German Air Force (GAF). In the near future GAF is planning to procure four more systems of Euro Hawk [2]. Not seen by German public, there were massive efforts in the German military airworthiness team of the Bundeswehr Technical and Airworthiness Center for Aircraft to enable this historical transfer flight from the United States to Germany.

But it was not the first UAS of the German Armed Forces. The Bundeswehr, especially, the German Army, has been using UAS since the 1960's [3] and could be seen as a "forerunner" in this field long time before UAS became a notion in the news or, better said, in the civil public world of Germany.

Currently there is an upcoming worldwide market for civil UAS, also in Europe and Germany, in particular for small UAS below 150 kg [4][5]. However, like in the rest of the world, there is an intensive lack of applicable airworthiness regulations for civil UAS and a direct conversion of manned aircraft airworthiness regulations will not be sufficient [6]. It will be especially a tough task to develop adequate airworthiness regulations for light UAS below 150 kg, since the European Aviation Safety Association (EASA) is not responsible for them and leaves this issue to the national airworthiness authorities [7][8].

This paper seeks to show the applicability of military UAS airworthiness regulations to civil UAS. To get a comprehensive overview, a brief history of UAS is given in the next chapters, followed by a review of UAS airworthiness regulations related activities of ICAO, FAA and EASA. A special attention is paid to describing the current situation in Germany. Furthermore airworthiness regulations of NATO and Bundeswehr are reviewed to get an insight into military airworthiness requirements. The last part presents a comparison between traditional manned aircraft airworthiness requirements and military UAS airworthiness requirements and a way to show the applicability of military airworthiness requirements in accordance with EASA's UAS Policy [8].

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1) There are two definitions for UAS: Unmanned Aircraft System and Unmanned Aerial System. Both are used in literature, which can be seen in the following chapters. In this paper these terms are treated synonymously.

2. HISTORICAL BACKGROUND

The history of UAS is much longer than most people would assume. In 1849 the Austrian army used unmanned balloons, carrying bombs to attack Venice [9]. But because of their physical vulnerability to the laws of environment, unmanned armed balloons never became a key figure in armed conflicts. An important step forward towards realizing UAS was made by Nikolai Tesla. He demonstrated the function of wireless controllability and reported a possibility of unmanned armed aircraft in his PhD thesis in 1912 [9][10]. During and after World War I efforts were made to develop unmanned aircrafts as bomb carrying vehicles or as target vehicles by several nations. Well-known examples are the “Kettering Bug” and the “Aerial Torpedo”, both developed in the United States, and the “Queen Bees” of the United Kingdom [10][11]. The “Aerial Torpedo” made the first successful radio controlled flight in 1918 [9][11]. In World War II Germany developed the V-1, the first unmanned vehicle able to fly automatically [11]. Today, in accordance with NATO definition of a UAV, the V-1 would rather be classified as a cruise missile or a guided bomb than a UAV [13]. During the following years and the Korean and Vietnam Wars, the United States developed many new UAS for reconnaissance. To name one in particular, the “Lightning Bug”, which flew over 3400 sorties during the Vietnam War. The “Lightning Bug” was developed after an U-2 incident over former Soviet Union. The US Air Force recognized that for reconnaissance missions it would be better not to endanger a human pilot [9]. Thus, the up to now primary mission profile of UAS was defined: Reconnaissance. Within the 1970’s other countries began to enforce the development of military UAS, too, most of all and with the greatest success Israel [11]. Today the world is facing an almost not ascertainable mass of different UAS. They range in size, weight and appearance from a few grams like the tiny “Nano Hummingbird” [14], to hand launched vehicles, quad copters, tactical UAS that are catapult or rocket launched, to MALE UAS like Predator or Heron TP, up to the 14 tons heavy RQ-4 Global Hawk [15]. German Bundeswehr used an operational UAS for the first time in 1969: CL-89. The usage of UAS within Bundeswehr started in the Artillery divisions, which had the object to determine the targets for the Artillery cannons and to assign the outcome of shootings [3]. Today German forces have, like many other armed forces in the world, different UAS, from hand-launched vehicles like ALADIN and tactical UAS like LUNA and KZO to the MALE and HALE systems Heron and Euro Hawk [16][17].

3. CURRENT SITUATION

Since UAS have risen at the horizon and become state of the art for military forces worldwide, the interest in a commercial use has also emerged [11][18]. In 2007 a market analysis from Frost and Sullivan stated that the commercial UAS market is worth billions of dollars [18]. But today there are still no commercial UAS in the sky. The question that comes in mind is: Why not? The UAS community must face an overcrowded airspace and an overwhelming regulatory framework that has evolved over the years together with manned aviation [11]. With that background, the generic requirement on UAS has to be not less safe than manned aircraft. This demand for safety leads to the need for UAS airworthiness regulations. Besides the arising technical problems like sense-and-avoid, level of autonomy etc., it is one of the biggest issues in integrating UAS into airspace.

There is an extensive lack of general airworthiness regulations for civil UAS. Without an applicable airworthiness regulatory framework there is principally no way to grant a UAS type certification for regular operations within the airspace.

The following paragraphs provide a short recap to current laws and available airworthiness regulations from different airworthiness authorities with a special attention paid to reflecting the situation in Germany.

3.1. Global – ICAO

The International Civil Aviation Organisation (ICAO), founded 1944 during the Chicago Convention, already stated in their charter [19] one article regarding UAS. Respective to the increasing number of UAS today, one could say it was very anticipatory to the future [12]. Article 8 says that:

“Pilotless aircraft

No aircraft capable of being flown without a pilot shall be flown without a pilot over the territory of a contracting State without special authorization by that State and in accordance with the terms of such authorization. Each contracting State undertakes to insure that the flight of such aircraft without a pilot in regions open to civil aircraft shall be so controlled as to obviate danger to civil aircraft.“ [19]

Due to ICAO’s responsibility to ensure airworthiness for all aviation worldwide and the rapidly increasing importance of UAS, they created a UAS Study Group (UASSG) in 2007 with the intention to generate one single point of reference for all UAS related ICAO activities [10][20]. Furthermore this study group has the aim to support the ICAO secretariat in developing standards, procedures and guidance materials. ICAO itself sees its responsibility not in being the focal point in developing technical requirements for UAS but in leading the global harmonization of the afore mentioned points [21]. Moreover, UASSG recognized the fact that there always has to be a human-control of the UAV as the most important element which lead to the fact that they will concentrate their work on “Remotely Piloted Aircraft – RPA” and additionally ICAO states that in consequence only RPAs are able to be integrated into airspace [22][23].

In March 2011, the UASSG issued the Circular 328 Unmanned Aircraft Systems [24]. The circular is not a guidance material, it primarily deems to show ICAO’s perspective and strategy concerning UAS, the fundamental differences between manned and unmanned aviation and wants to encourage the ICAO nations to support the UASSG in developing an ICAO policy. UASSG assumes that developing these documents will take several years [20][22][23].

3.2. United States – FAA

In 1958, the United States Congress passed the Federal Aviation Act, which introduced the Federal Aviation Agency. After creating the Department of Transportation in 1966 the Agency became a sub-organisation of this new department in 1967. The name changed from "Federal Aviation Agency" to "Federal Aviation Administration" [25].

FAA's main responsibility is to ensure civil aviation safety in the United States, including regulation and management of air traffic. The Federal Aviation Act from 1958 allows FAA to establish rules and regulations for aviation in the United States. These Federal Aviation Regulations (FARs) are comprised in title 14 of the Code of Federal Regulations [6][10].

The United States are one of the world's leaders in manufacturing and using military UAS. It is obvious that a huge potential of the market for the usage of civil UAS in the U.S. is not a new idea. This leads to the consequence that more and more manufacturers want to use their UAS on a regular basis in the National Airspace [6][11].

Due to this increasing market and to advance integration of UAS into the National Airspace, FAA has undertaken some significant steps for the certification of civil UAS:

In 1991 a group consisting out of members from FAA, AUVSI[2) and the Air Traffic Control Association, was launched in order to consider issues concerning integration of UAS into NAS. The main work of the group resulted in the development of draft Advisory Circulars concerning UAS maintenance, pilot qualification etc., but these proposals haven't been traced farther by the FAA [26][28].

In 2001 the first version of the "High-Altitude Long-Endurance Unmanned Aerial Vehicles Certification & Regulatory Roadmap" was released by the University of New Mexico [10][28]. This paper had the aim to pave the way for a certification of HALE systems in accordance with FAA regulations and create the basis for a safe, routine airspace usage of these systems within NAS. The HALE certification roadmap project continued in the ACESS5 program driven by the NASA ERAST project until it was closed in 2006 because of monetary issues [28].

In 2005, the FAA Flight Technologies and Procedures Division, AFS-400, issued a memorandum named "AFS-400 UAS Policy 05-01: Unmanned Aircraft Systems Operations in the U.S. National Airspace System – Interim Operational Approval Guidance" [29]. FAA only accepted public UAS as applicants for a Certificate of Authorization (CoA) for the purpose of this guidance. The main criterion that had to be fulfilled in order to get a public CoA was to show that the UAS was airworthy. This had to be proved by the applicant in showing compliance to Military Handbook (MIL-HDBK) 516 "Airworthiness Certification Criteria" or by holding a civil airworthiness certification from FAA or by showing specific information about how the UAS has been proven airworthy in case it doesn't meet one of the first two points [29].

In the same year, FAA started with accepting appliances from non-public civil UAS for a special airworthiness certificate, based on the experimental category out of FAR part 21 [30]. The issuance of a special airworthiness certificate includes all restrictions valid for aircraft of this category in accordance to 14 CFR § 91.319 [31]. Furthermore, the FAA Aircraft Certification Service, AIR-200, issued the first CoA's for UAS the same year.

During February 2006 FAA founded the Unmanned Aircraft Programme Office (UAPO) AIR-160. This office has the aim to focus all UAS activities regarding aviation safety within the FAA [30].

One year later, the former FAA Associate Administrator for Aviation Safety Mr Nick Sabatini issued a notice of policy to point out FAA's position on UAS operating in the NAS [32]. In this notice he substantiated FAA's perception "[…] that no person may operate a UAS in the National Airspace System without specific authority" [32]. This enhances the policy that the only way to operate a civil UAS in the United States is either via CoA or via a special airworthiness certificate.

To handle the small UAS (sUAS), FAA set up an Aviation Rulemaking Committee (ARC) for sUAS consisting of industrial, governmental, academical and FAA members in 2008 [6][33]. Only one year later the group published their "Comprehensive Set of Recommendations for sUAS Regulatory Development" valid for sUAS below 25 kg (55 lbs) to FAA [34]. Currently the FAA is in the process of drafting regulations based on these recommendations [35]. The director of FAA Flight Standards Services, Mr John M. Allen, expected that a Notice of Proposed Rulemaking (NPRM) should be ready for publication in September 2011 and the following final regulation in 2013 [36]. Indeed the NPRM was still not available while this paper was being written.

In March 2008, the UAPO released „Interim Operational Approval Guidance 08-01: Unmanned Aircraft Systems Operations in National Airspace System" [37]. This document replaced the before mentioned guidance 05-01 and represented an update to the initial document due to the soaring emerge of UAS from 2005 to 2008. The guidance now covered also the possibility for a special airworthiness certificate and provided more details in general and specific fields for the operation of UAS, in particular, for flight operations and personal qualification of the operator. The basic principles from the first issue remained.

In addition to the updated Interims Guidance, FAA also released a supplemental policy, Order 8130.34 Airworthiness Certification of Unmanned Aircraft Systems, which described in detail the procedure for the certification of UAS in the experimental category in accordance to FAR 21 [38]. A revised issue of this order was published in 2010 and 2011 [39][40]. The updated order now also contains optionally piloted aircraft [40]. In 2011 FAA established a new UAS ARC, which shall cover all FAA actions for integrating UAS into the NextGen Airspace [41].

Currently, a bill for reformation of the FAA has been presented to the House of Representatives and the Congress of the United States. This law will bring a significant change to the whole UAS community in the United States. Based on text of this bill the Department of Transportation and FAA are requested to enable flying with civil UAS in the U.S. NAS not later than 2015. Due to this FAA shall provide a comprehensive plan, including all related aspects of operation and airworthiness, for a safe integration of UAS into the NAS [42]. In February 2012,

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[2) AUVSI: Association for Unmanned Vehicles International is a non-profit international organization of different members (industry, governmental, academics etc.) for representing and advancing unmanned systems [27].

President Obama signed the bill [43]. First actions by FAA have been to request public opinion for introducing UAS test sites and to publish a list of active UAS CoAs [44][45]. A fast proceed for integrating UAS into NAS by FAA can be expected [45].

3.3. Europe – EASA

In 2002 the European Parliament established the European Aviation Safety Association (EASA) as a single European authority for flight safety and airworthiness within the European community [46][47]. In 2008 the European Parliament put regulation EC 216/2008 [7] in place, which superseded the former regulation and gave EASA more responsibilities in the fields of operations, flight crew licensing and third-country operators [6]. EASA has the legal right to issue mandatory regulations in accordance with the scope of regulation 216/2008. This includes UAS with a MTOW of more than 150 kg, as already described in the introduction [7]. In 2005 EASA issued an Advance Notice of Proposed Amendment (A-NPA) 16-2005: “Policy for Unmanned Aerial Vehicle Certification” [50].

This document based on a report produced by the UAV Task-Force, an initiative from JAA[3)] and EUROCONTROL[4)], was launched in September 2002, shortly after foundation of EASA. This taskforce had the aim to develop European guidelines for UAS with regard to the steadily increasing number of UAS in Europe [48][5)].

The A-NPA marked the first step into direction of an EASA UAS policy. In August 2009, after gathering many comments from the aviation community, the agency released the “EASA Policy Statement: Airworthiness Certification of Unmanned Aircraft Systems (UAS)” [8].

The primary objective of this policy is the protection of people and property on the ground, due to this, the policy demands from any UAS to be not less safe than an equivalent manned aircraft. Furthermore, it doesn’t set up operational restrictions and doesn’t cover the problem of sense-and-avoid for UAS. EASA argues in the policy that sense-and-avoid belongs to ATM and should be regarded outside airworthiness [8][50].

For obtaining a type certificate an applicant has to adapt an applicable airworthiness certification specification from EASA. The policy provides a decision methodology to define the right certification specification. The methodology is based on the kinetic impact energy identified as the most severe danger from a UAS to third parties. Two impact scenarios, for which the impact energy has to be calculated, are defined. It leads to the indication of specifications that have to be used. The applicant needs to make a tailoring of the specifications and to generate a certification basis, including the special conditions that arise from a UAS (e.g. level of autonomy, emergency procedures, command and control link, etc.) [8][50]. Chapter 4.7 provides a more detailed review of this methodology. It’s worth to remark that EASA states that within its policy the usage of [13] as a certification basis could be accepted by the agency[6)].

Although this procedure is not valid for UAS ≤ 150 kg, the methodology can be used to indicate a possible certification specification for UAS of this mass in accordance with [8]. This is shown within chapter 4.7.

A new specific UAS airworthiness code has not yet been generated by EASA for this policy. According to EASA’s rulemaking programme 2012-2015, the process for developing such an airworthiness certification specification is not going to start before 2014 [51].

EASA has recognized the soaring importance and necessity for UAS airworthiness regulations, but the agency doesn’t see this as priority basing on the fact that EASA received only four requests for UAS applications before September 2011 [51][52].

3.4. NATO

Taking into account an increasing number of UAS used within the allied forces of NATO, the organization decided to form an institution to coordinate the UAS activities during the mid 90’s. According to this, one group for each theatre of operation (air, sea and land) has been formed.

In 2006 the three groups were fused together to the “Joint Capabilities Group On Unmanned Aerial Vehicles” (JCGUAV) and put under supervision of the NATO Naval Armaments Group (NNAG)[7)] [53].

NATO also realized that there is a need for UAS airworthiness regulations to ensure a safe usage of them and to enable flying over the national boarders and sharing the benefits of UAS. This led to foundation of the working team NATO Flight In Non Segregated Airspace (FINAS) in 2004, which became a subgroup of JCGUAV [10][54].

In the beginning the group consisted of a staff group and a subgroup out of airworthiness specialists. This subgroup had the task to develop a Standardization Agreement for fixed wing UAS > 150 kg, which should enable a UAS

[3)] JAA: Joint Aviation Authorities. An entity of European Civil Aviation Regulation Authorities established during the 1970’s with the goal to provide common aviation recommendations for Europe. The JAA itself didn't have a legal power like EASA, but in fact, one can say that JAA was the forerunner for EASA. JAA was closed in 2009 with exception to the JAA training organisation [6][47].

[4)] EUROCONTROL: European Organisation for the Safety of Air Navigation. Launched in 1960 with the mission to generate a single European sky and the needed air traffic management for Europe. EUROCONTROL consists of 39 member states and civil and military partners [49].

[5)] [48] also provides a guideline for light UAS ≤ 150 kg. In accordance with [48] a light UAS is classified to be not capable of flying more than 70 kts and doesn’t have an impact energy > 95 kJ. Furthermore light UAS are not allowed to fly above 400 ft above ground level. Due to the intention of this paper to follow a general approach, these limitations will not be used in further considerations. A detailed review of these limitations and the origins are within the scope of an upcoming paper.

[6)] This is only possible if the methodology to choose an airworthiness code doesn’t require another standard in excess than the CS-23 requirements for a single engine aircraft and only if the system safety assessment indicates that values of the policy are reflected within the determined safety targets.

[7)] Superior group to NNAG is the Conference of National Armaments Directors (CNAD). CNAD has the status of a Tasking Authority (TA), which has the responsibility of coordination, validation and managing the development with respect to their standardization tasks together with the NSA. A TA may delegate these tasks to a Delegated Tasking Authority (DTA), which in this case is the NNAG [57][58].

developed in accordance with this STANAG, to fly nearly without restrictions in any NATO member nation [13]. More details on this are given within chapter 4.5.

In 2007 the group issued the first draft of the upcoming STANAG [54]. After three years of intensive discussions, many more draft versions and a two-year-long ratification process within the NATO nations the NATO Standardization Agency (NSA) published the first edition of STANAG 4671: Unmanned Aerial Vehicles Airworthiness Requirements (USAR) on September 3rd, 2009 [13]. One could say it was a historical event for the whole military UAS world or even the whole UAS community. It was the first time that a concrete airworthiness regulation for UAS was issued.

Parallel to the development of STANAG 4671, the staff group recognized that it would be necessary to develop also a STANAG for rotary wing UAS > 150 kg and a STANAG for UAS ≤ 150 kg. After this recognition, two additional subgroups, one for rotary wing UAS > 150 kg and one for light UAS ≤ 150 kg, were launched [10][55].

FIG 1 shows the current structure and hierarchy of NATO JCGUAV and it's subgroups [53].

Like the first subgroup, both new subgroups have been ordered with the same task: To develop a STANAG that enables UAS respective to the mentioned classes flying in non-segregated airspace [55].

At the moment, the Light UAS team has finished the draft of STANAG 4703 [55][56][57] and submitted it to JCGUAV and to the NSA for ratification. It is assumed that the ratification process will take at least one year, so that the official release could be at the end of 2012[8)].

The STANAG 4703 team is already working on edition two. This edition will also contain requirements for small turbine engines. It can be assumed that an airworthiness code for light rotary wing UAS will be developed too, either as part of STANAG 4703 or as a separate STANAG [55].

3.5. Germany

After foundation of EASA, the main airworthiness responsibilities for civil manned aircraft have moved from the national airworthiness authorities of the European Union member states to EASA. Nevertheless, the territorial sovereignty of airspaces and their usage are still regulated by national law [47][59]. In case of Germany this law is the Air-Navigation-Act (Luftverkehrsgesetz). This law is valid for all aircraft and prescribes that only certified aircraft are allowed to participate in German air traffic [47][60].

Currently the usage of any civil UAS in Germany requires a special permit to fly[9)]. But in general, UAS flights are prohibited if the UAS flies beyond line of sight of the operator or if the take-off weight exceeds 25 kg[10)]. It is worth to note that civil UAS are excluded from the mandatory aircraft certification mentioned above[11)]. One could say that this is related to the fact that usage of civil UAS in Germany is prohibited. Another point of view is that the legislative body assumes that type certification is either not necessary or not reachable for civil UAS [47].

Nevertheless the aviation authorities of all 16 German Federal States may issue a permit to fly for a UAS, which deviates from the above mentioned restrictions, if it flies within a restricted airspace or if the operation is not beyond an aerodrome traffic circuit. In addition to these restrictions, the operation of the UAS shall not impose any danger to the public[12)]. This method is very similar to the treatment of UAS by FAA. It is obvious that such a method can't ensure a regular operation of civil UAS in Germany.

Up to 2012, UAS belonged to "other aircraft" [63][13)]. But in in January 2012 German Federal Council and Federal Parliament agreed to include the term "UAS" within the German Air Navigation Act and the related laws for the first time [60][61][62][63][64][65][66].

This change does not imply a general allowance of civil UAS usage and the aforementioned restrictions are still in force. But the concrete naming of UAS in the law is an indicator that the German legislative has become aware of UAS and their increasing importance for aviation and society. A first consequence was the issuance of harmonized regulations of the 16 federal states for issuing a permit to fly for UAS below 25 kg MTOW [67][14)].

The need for type certification of civil UAS is a subsequent consequence that arises due to the changes within the German Air Laws. As expressed in chapter 3.3, EASA is responsible for all UAS that exceed 150 kg MTOW [7]. For all UAS below this MTOW, national airworthiness authorities are responsible for type certification. But as stated before, in the introduction to this chapter, there are not any defined airworthiness regulations for civil UAS ≤ 150 kg in Germany. This fact is leading back to Bundeswehr and allied nations, because they have been using military UAS of this class since decades, as it has been described in chapter 3. To fully understand the context a short return to the paragraphs of the Air-Navigation-Act is necessary.

All military aircraft in Germany fall under the Air-Navigation-Act too, but Bundeswehr, Federal Police and Police are allowed to deviate from the Air-Navigation-Act and its associated laws if it's in the purpose for territorial tasks [47][60][15)]. This doesn't mean that German military aircraft are not type certified. Military Aircraft of the German armed forces are type-certified by Bundeswehr Technical and Airworthiness Center for Aircraft (WTD 61). The certification of all German military aircraft, manned or unmanned, is regulated by the "ZDv 19/1 - Joint Service Regulation 19/1 - Airworthiness Verification And Certification Regulations For Bundeswehr Aircraft And

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[8)] Before promulgation of a STANAG, the promulgation criteria, defined by the TA/DTA, must be met throughout the ratification process. This can be e.g. a majority of ratifying NATO member nations or the non-excess of a defined number of national reservations. A detailed description can be found in [58].

[9)] [61]: §16, passage 1, sub item 7.

[10)] [61]: §15a, passage 3.

[11)] [62]: §1, passage 4.

[12)] [61]: §15a, passage 3.

[13)] [63]: §1, passage 2, sub item 11.

[14)] In fact, [67] defines a very prescriptive set of limitations for a permit to fly for electric powered UAS ≤ 5 kg that are used commercial. If the MTOW is greater than 5 kg and / or non-electric powered a special permit to fly is required as described in [61]. [67] will be examined in an upcoming paper.

[15)] [60]: §30.

Aeronautical Equipment" [68]. In addition to this UAS are regulated by the "LTF 1550-001 - Airworthiness Requirement 1550-001: Special Regulations for Airworthiness Verification of Unmanned Aerial Vehicles in the Bundeswehr" [69]. It is assumed that in the near future the responsible division of WTD 61 is going to implement NATO UAS regulations into their airworthiness regulations [55].

In [70] the question is raised, why the experience of certifying military UAS should not be used for the integration of UAS into the airspace.

The author of the present paper suggests going one step further and to adopt the military airworthiness regulations STANAG 4703 in combination with LTF 1550-001 by the German civil airworthiness authorities to ensure a safe integration of UAS into German National Airspace and also to accelerate the process of defining an airworthiness regulatory framework for civil UAS ≤ 150 kg in Germany.

In the following chapter a brief review of ZDv 19/1, LTF 1550-001, STANAG 4671 and STANAG 4703 is given in order to provide an insight into military UAS airworthiness regulations, followed by a comparison to certification requirements of EASA and FAA.

4. GERMAN MILITARY AND NATO UAS AIRWORTHINESS REGULATIONS SURVEY AND COMPARISON

4.1. UAS Flight Operations and related Hazards

The focus in this chapter is to show the basic principles of the military UAS airworthiness regulations and their requirements and to compare them with civil airworthiness regulations. A review to current rules for flight operation regulations like Visual Flight Rules or Instrument Flight Rules and there implications for UAS would be out of scope for this paper and is not covered.

It seems to be consensus in literature that the most severe dangers related to UAS are the possibility of mid-air collisions and fatalities or damage to property on the ground due to an impact of UAS. Many publications with focus on these hazards are available[16]. In accordance with the scope of this paper, the author decided to exclude specific considerations about these topics.

Considerations about flight operations and UAS related dangers with focus to Germany are going to be covered in a future publication.

4.2. General Remarks

It is important to understand that there are fundamental differences between civil and military airworthiness regulations and policies. In the civil aviation world granting the safety of the people on board is the main objective. To ensure this, a very restrictive airworthiness framework has to be fulfilled by applicants during the type certification process.

In the military aviation world safety in the sense of protecting flight crew and passengers is always the main factor, too. But this objective is often superseded by special military needs, which don't exist in civil aviation. Military forces are naturally interested in achieving their operative goals. For this, a trade-off to safety and reliability is accepted [73]. Due to this reason military aircraft are certified in accordance with special airworthiness regulations defined by the military airworthiness authorities, for example, the German WTD 61.

Though military airworthiness authorities have their own airworthiness regulations and procedures, they are also forced to use the national or international certification regulations. But the military airworthiness authorities are able to certify aircraft that deviate from the civil airworthiness standards for the operational needs [9][68][74].

4.3. ZDv 19/1: Airworthiness Verification And Certification Regulations For Bundeswehr Aircraft And Aeronautical Equipment

As already mentioned in chapter 3.5, ZDv 19/1 [68] is the basic regulation for certification procedures of all Bundeswehr manned and unmanned aircraft and aircraft related parts. Therefore, it has the purpose to define and regulate the deviations from German Air-Navigation-Act regarding specific necessities arising from the military needs of Bundeswehr.

Bundeswehr aircraft are subject to type inspection in order to prove airworthiness and to participate in air traffic, defined by paragraphs 201 of ZDv 19/1, which states:

"201. Bundeswehr aircraft are certified for air traffic if
- the aircraft type and its associated aeronautical equipment has been certified (type certification), and
- after demonstration of aircraft airworthiness." [68]

Following Paragraph 203 clarifies that UAS are not excluded from paragraph 201:

"203. The following shall be verified with regard to airworthiness/system compatibility:
- airworthiness:
- manned aircraft,
- unmanned aircraft in case of missions planned outside of a military training area with associated flight-restricted airspace above; for unmanned aircraft with a takeoff weight of less than 5 kg the Director Airworthiness will decide whether it is subject to verification and certification, […]"[68]

The term "Unmanned Aircraft" may suggest that airworthiness only has to be proven for the airborne vehicle, but ZDv 19/1 [68] defines in Annex 1/3 that airworthiness must be verified for the whole system consisting of UA, Control Station, Control Link and all parts that are necessary for safe operation.

Basing on paragraph 203, one can infer that UAS that apply for a German military type certification are categorized on the intended usage of airspace. This is defined by LTF 1550-001 [69] and described in the following subchapter.

4.4. LTF 1550-001: Special Regulations for Airworthiness Verification of Unmanned Aerial Vehicles in the Bundeswehr

LTF 1550-001 specifies the requirements of ZDv 19/1 for a type certification of a military UAS. WTD 61 issued the first edition in 2002 caused by steadily increasing UAS usage

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[16] For example: [10][71][72].

by Bundeswehr and their allies and due to the fact that at this time no airworthiness regulations or guidance for military UAS in Germany or within NATO existed. In 2007 LTF 1550-001 2nd Edition was published [69].

In chapter 4.3 the categorization of UAS based on the usage was addressed. LTF 1550-001 defines three categories for UAS:

“1.4.1 Category 1

Category 1 unmanned aerial vehicles are operated only within specially designated military training areas or restricted areas with prohibited or flight-restricted airspace above. Flights of manned aircraft through the flight-restricted area are not permitted.“ [69]

It’s worth to note, that Category 1 UAS are not subject of type certification and are not treated as registered aircraft. Furthermore, a Category 1 UAS couldn’t ever be used outside prohibited or flight-restricted areas.

“1.4.2 Category 2

Category 2 unmanned aerial vehicles can take off and land within specially designated military training areas or restricted areas with flight-restricted airspace above. The flight path in between runs through a flight-restricted area or in airspace restricted for general air traffic also outside of military training/test sites.“ [69]

“1.4.3 Category 3

Category 3 unmanned aerial vehicles participate in general air traffic and are operated also outside of flight-restricted areas in airspaces A to G in accordance with the ICAO instrument or visual flight rules.“ [69]

TAB 1 shows the three categories together with their associated operational restrictions.

One interesting point is that there are no limitations within the regulation regarding MTOW of a UAS, but special consideration needs to be given to UAS below 5 kg MTOW. Principally they belong to Category I UAS. But for this very small UAS Director Airworthiness can decide if a certification of airworthiness is needed or an inspection is sufficient.

LTF 1550-001 defines four failure cases: Catastrophic, critical, major and minor. The definitions and the derived failure condition requirements of them are provided in TAB 2 and TAB 3.

Some additional remarks to TAB 2 and the derived requirements of TAB 3:

The basic mandatory requirement for Category 1 and 2 is the “Declaration of Compliance with Designated Operational Area“[69], it means that the UAS will not leave its designated airspace due to technical failure with an acceptable low probability.

For Category 3 UAS, “Non-Compliance with designated Airspace” isn’t explicitly defined. Due to the fact that such an unintended leaving of designated airspace by the UAS may but not necessarily must result in fatalities, this requirement has been classified both as “critical” and “catastrophic” for Category 3.

The required probabilities for catastrophic, critical, major and minor failures are only defined concretely for Category 3. The meaning of these terms is defined in general in section 1.3 of LTF 1550-001.

The mandatory requirement of a flight termination system (FTS) for Category 1 and 2 can be deduced by the necessity to have an ultimate emergency procedure to ensure that the UAS won’t leave its designated airspace.

A field marked with “n/a” indicates that for a requirement and the related category no probability / reliability number is provided and due to that the requirement is not relevant for the category.

Someone could be embarrassed by the fact, that a FTS is required for Category 2 UAS but not for Category 3 UAS. This is based on the fact that Category 2 UAS are limited to special airspace. A FTS can be seen as a “back-up”: if the UAS intends to leave its designated airspace it still could be “stopped” in order to avoid fatalities or damage on the ground17). A UAS certified to Category 3 is not limited to any airspace restriction, so a FTS is not necessary18).

Another more detailed reflection must be given to the probabilities of an uncontrolled crash or flight of Category 2 UAS. The two possible probabilities are based on the kinetic energy of the UAS. In accordance with LTF 1550-001 a UAS with a maximum possible kinetic energy < 50,000 J shall not exceed a probability of $10^{-4}/Fh$ for such an event, or if the maximum possible energy is ≥ 500,000 J it shall not exceed $10^{-5}/Fh$. Between these two energy borders the product resulting from kinetic energy and crash probability has to be less or equal five.

During a type certification process the airworthiness authority can expand the requirements noted in TAB 3.

As already expressed before, LTF 1550-001 was created in order to provide regulatory guidance for military UAS within German Armed Forces to intercept the non-existence of NATO regulations. Now that STANAG 4671 has been ratified by NATO, and that the next two STANAGs for UAS are on the horizon, it is strongly anticipated that UAS division of WTD 61 will issue a new edition of LTF 1550-001 in order to implement the STANAGs, as mentioned in chapter 3.5.

It is expected that the upcoming issue will bring a very significant change to the whole regulation construct of LTF 1550-001. This can be derived from the arising question if the existing UAS categorization can completely be adapted to a regulatory framework based on STANAGs.

4.5. STANAG 4671: Unmanned Aerial Vehicles Airworthiness Requirements (USAR)

STANAG 4671 was officially released on March 3rd 2009 [13]. This was the first time within NATO that a

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17) If an applicant for Category 2 can’t meet all requirements, the authority can allow deviations from the required probabilities if emergency procedures or a FTS are provided and this doesn’t increase danger to third parties. Obviously, this is an inconsistency in the regulation because an emergency system / procedure or a FTS is always required for Category 2 and not only in case the applicant can’t meet the requirements as shown in TAB 2. It is assumed that UAS business segment of WTD 61 will correct this in the new edition of LTF 1550-001.

18) This doesn’t affect emergency systems and procedures, they are still mandatory.

comprehensive set of airworthiness requirements for UAS has been published.

The NATO specialist team for STANAG 4671 created the USAR Code with primary focus on enabling flight of UAS in non-segregated airspace and participating in general air-traffic. It is mutual recognition that a UAS developed in accordance with this airworthiness code and compliant to the related requirements should be allowed to fly in any NATO country, which has ratified STANAG 4671 without an extensive authorization process by the national responsible airworthiness authorities [13]. Furthermore, ratifying nations commit themselves to implement STANAG 4671 within their national regulations.

It needs to be said that STANAG 4671 focuses on technical airworthiness requirements for fixed wing UAS with an MTOW of greater than 150 kg and less than 20.000 kg. It doesn’t cover operational requirements, for example crew licensing, super sonic flight or sense-and-avoid capability. Due to this, restrictions can still be made if an allied nation wants to fly with a UAS in another NATO nation’s airspace, even if the UAS is entirely compliant to STANAG 4671.

In consequence of the fact that a complete assessment and interpretation of the regulation would be too extensive for this paper, the following passages intend to give a short summary on the highlights of STANAG 4671.

Starting point in development of STANAG 4671 was the objective to provide a minimum airworthiness standard for fixed wing UAS > 150 kg MTOW, mirrored in accordance with CS / FAR 23 [75][77] as far as practicable. The intention behind was the demand and desire to gain reliability comparable to manned aircraft. As already mentioned within chapter 3, this is always one general airworthiness requirement for UAS.

Although sense and avoid is not covered, it is also stated within the STANAG, that if ever general requirements for any sense-and-avoid system are defined, such a system will be subject to the airworthiness requirements of STANAG 4671 if it is mounted on a UAS.

STANAG 4671 consists of two books:

- Book 1 provides the primary airworthiness code.
- Book 2 provides the acceptable means of compliance in order to achieve the requirements from Book 1.

The requirements are divided into nine subsections A to I, which all follow the classical CS/FAR structure. The sections A to G are covering the flying vehicle and have been deducted straight from CS-23 [75]. Sections H and I are covering the out-standing characteristics of a UAS: command and control link, communication system and Ground Control Station. Many of these requirements are interconnected. This and the structure of STANAG 4671 are shown in TAB 4, which has been directly taken from [13].

One paragraph and the corresponding AMC have to be named in particular, USAR.1309 Equipment, systems and installations. In a few words, this clause defines the minimum functionality and related failure condition probabilities for the whole UAS. USAR.1309 itself is grouped into six subparagraphs a) to f):

a) General requirements for UAS safety regarding design and function.
b) General requirements for determining UAS safety.
c) Requirements for power supply functionality.
d) Additional paragraph regarding power supply.
e) Requirements for electrical system safety.
f) Explanation that the term “system” within this paragraph is relevant for all UAS subsystems, e.g. hydraulic system, fluid system etc., but not for the powerplant (if it’s a part of a certified engine) and the UAS structure.

Directly related to USAR.1309 is AMC.1309, which has significant importance within the complete regulation due to the fact that it defines the failure conditions and the allowed occurrence probabilities. Furthermore it defines acceptable Development Assurance Levels (DAL) for software. TAB 5 and TAB 6 show the definitions and the accepted probabilities and DALs. As can be seen within TAB 5 the failure definitions of STANAG 4671 are much more detailed than within LTF 1550-001. These definitions have been derived from FAR-23 [77] and the related Advisory Circular for paragraph 23.1309 [79]. Additionally the special needs of UAS have been adapted.

It is important to note that leaving the designated airspace is also defined as a catastrophic condition even though such an event mustn’t result in a fatality. This leads to the fact that some items of a UAS, which within manned aircraft wouldn’t be defined as items that potentially could lead to catastrophic condition, needs to be proven against the AMC for catastrophic, e.g. navigation items.

The required occurrence of failure conditions shown in TAB 6 are the same requirements as for Class I aircraft(19) from FAR-23 [77][79].

Another significant point is the fact that it is mandatory that no single point of catastrophic failure shall lead to a loss of the UAS, stated within AMC.1309. This mandatory requirement has a remarkable influence on the entire UAS design because it forces redundancy on system level.

As already seen within the description of LTF 1550-001, STANAG 4671 also requires emergency procedures or a FTS. Naturally, a UAS built in conformity to this STANAG is intended to fly within general air traffic over populated areas. Due to this an immediate ending of flight should be always the last option because the probability to hit people on the ground is very high.

Presently there are intensive discussions within NATO STANAG 4671 specialist team about a possible change regarding the applicable MTOW of 20.000 kg. The discussion started for reason a question raised about legibility for a MTOW of 20.000 kg but CS / FAR-23, the “base” of STANAG 4671, is limited to 8618 kg [55][80](20).

If a UAS shall provide the same safety to people on the ground than manned aircraft to people on-board, there is no argument to require for a 20 tons UAS less demanding

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(19) In accordance to AC No: 23.1309-1E [79] Class I aircraft are defined as aircraft with less than 6000 lbs (2722 kg) and a single reciprocating engine. CS-23 and FAR-23 differentiate between normal, utility and aerobatic aircraft in combination with the type of engine and seating configuration [75][77].

(20) This MTOW is the upper limit for commuter aircraft by CS-/FAR-23 [75][77].

failure probabilities than for a manned aircraft of 8 tons MTOW, from a purely rational point of view[21)].

If the STANAG 4671 team decides to implement a new MTOW limit, for example at 8618 kg, it could result in one of the following thinkable consequences:

a) A new STANAG for heavy UAS has to be developed, e.g. based on CS-/FAR-25.
b) USAR.1309 has to be reconsidered and exacerbated, e.g. an increased probability for catastrophic failure with 10^{-7} / Fh for a UAS with MTOW greater than the new weight break point or a diversification into different UAS as in CS-/FAR-23.

No matter which of these possibilities will commence, both of them are assumed to take several years of discussion within the group. Furthermore, such changes within the STANAG will always require a new ratification process, which also requires lots of time.

It is obvious that the current STANAG 4671 will see lots of changes in future. The regulation shouldn't be seen as finalized, it should be seen more as a living document that keeps pace with a steady changing UAS world.

4.6. STANAG 4703: Light Unmanned Aircraft Systems Airworthiness Requirements (USAR-LIGHT)

The focus of STANAG 4703 has been logically the same as of STANAG 4671: To enable a UAS flying in non-segregated airspace if it has been developed in accordance with the STANAG. Like STANAG 4671, STANAG 4703 doesn't cover operational aspects like sense-and-avoid [56].

Developing a STANAG for UAS of this class was a huge task as there is nearly an uncountable variety of UAS designs within this spectrum. But often these designs are not developed and built in the ways of classic aviation, hence, it was deemed that a straight traditional approach for an airworthiness code wouldn't be sufficient [5][56].

As it was mentioned before in chapter 4.5, it was decided to point out some of the highlights and specialties of this STANAG and not to provide a complete recapitulation.

Basing on the above mentioned consideration that a traditional approach would not be appropriate, the main objective in creating STANAG 4703 was to provide an airworthiness set which ensures enough safety to the third parties overflown, other airspace users and flexibility to the applicants without being too prescriptive. Due to this the STANAG 4703 team reconsidered a comprehensive set of standards and regulations for creating the single requirements of the regulation[22)].

The basis in developing the mandatory requirements for USAR Light was a "militarized" version of the Essential Requirements for civil aircraft airworthiness taken from Annex I of the (EC) N°216/2008 [7] which was been developed by MAWA[23)].

STANAG 4703 has a complete different layout than STANAG 4671, based on the "hybrid approach" used for creating the regulation[24)]. There are three columns: In the first there are the mandatory "Airworthiness Essential Requirements" (ER). In the second column there are the "Detailed Arguments" (UL), which describe extensively how to fulfil the essential requirements of column one. The last column provides an acceptable means of evidence to the applicant in order to accomplish the requirements of the second column and against the certifying authority [56].

Due to the intention to be "not too prescriptive", the airworthiness requirements of STANAG 4703 are strongly dependent on the intended operational spectrum of the UAS. The basic paragraph for this is UL.0, that states:

"The Applicant must identify the design usage spectrum as the set of all the foreseen operational conditions of the UAV system:
- typical design missions; in-flight operation conditions;
- on-ground operation conditions;
- operational modes (automatic, speed-hold, altitude hold, direct manual, etc.);
- take-off / launch / ramp conditions;
- landing / recovery conditions;
- locations and platforms (e.g. land vehicle, water vessel, aircraft, building, etc.) from which launch, command and control, and recovery operations will be performed (e.g., land, littoral/maritime, air,);
- number of air vehicles to be operated simultaneously;
- transport conditions (define the transportation and storage environment of the UAV system like bag, package, truck or whatever is required);
- operating environmental conditions:
- natural climate (altitude, temperature, pressure, humidity, wind, rainfall rate, lightning, ice, salt fog, fungus, hail, bird strike, sand and dust, etc.);
  - electromagnetic environmental effects (electromagnetic environment among all sub-systems and equipment,
  - electromagnetic effects caused by external environment, electromagnetic interference among more than one UAV systems operated in proximity);
  - lighting conditions (e.g., day, night, dawn, dusk, mixed, etc.);
- identify all the possible mass configurations (minimum and maximum flying weight, empty CG, most forward CG, most rearward CG must be identified).

In all the identified conditions the Applicant must verify to the satisfaction of the Authority the requirements of the following paragraphs." [56]

[21)] For example: AC No: 23.1309-1E [79] requires a probability of $\leq 10^{-9}$ / Fh for single catastrophic failure condition within the commuter class. In [80] a very detailed discussion about the applicable MTOW limits of STANAG 4671 can be found.

[22)] The following source documents are named within STANAG 4703: STANAG 4671, CS-VLA, CS-22, ASTM F2245-06, DEF STAN 00-56 [56].

[23)] MAWA – Military Airworthiness Authorities, is a group formed by the European Defence Agency (EDA) with the aim to develop harmonized European military airworthiness requirements for member states of the European Union. It is important to note that EDA / MAWA don't have the legal power to publish mandatory airworthiness requirements for military aircraft, this responsibility stays within the member nations [81]. One could say that MAWA has the same status as JAA.

[24)] Due to that, a direct comparison from STANAG 4703 to STANAG 4671, or a CS / FAR is accordingly difficult.

As mentioned before, Light Rotary Wing UAS as well as turbine engines aren't covered right now within STANAG 4703. Edition two will cover at least the turbine engine aspect. It is expected that for Light Rotary Wing UAS a STANAG will follow or 4703 will be expanded [55].

It also was recognized that the airworthiness code could be too restrictive for very small and micro UAS. Due to this, a bottom level has been defined at 66 J impact energy. With that, STANAG 4703 is applicable for fixed wing UAS from 66 J impact energy up to a MTOW of 150 kg. This energy criterion has been chosen due to the fact that such impact energy will not lead to a fatality25). Nevertheless, STANAG 4703 contains a guideline for UAS ≤ 66 J impact energy in order to provide a minimum set of airworthiness requirements for this UAS class.

As already stated before, STANAG 4703 doesn't follow a traditional CS structure. In accordance to that there is not a 1309 paragraph as in STANAG 4671 or as in CS-23. But the Essential Airworthiness Requirement 1.3 “Systems and Equipment” and all its related sub-requirements ER.1.3.1 - 5 with corresponding detailed arguments cover the content of a “1309” paragraph.

Particular adherence must be given to Appendix 5 because within that appendix the definitions of failure cases and their related probabilities are made. This is one highlighting point within STANAG 4703. The calculation of the cumulative safety probability requirement (P_{CumCat}), which is the base for calculating the remaining probability requirements, is directly linked to the MTOW of a UAS. Furthermore the determination of the acceptable occurrence of catastrophic failures is calculated by dividing the cumulative safety probability with the maximum possible number of expected catastrophic (N_{ExpCat}) conditions26). This calculation allows a very smooth and non-arbitrary allocation of reliability requirements to an applicant for certification in accordance with STANAG 4703.

By using MTOW as a basic variable for determining the cumulative system safety, the kinetic impact energy of the UAS is inherent used as value.

TAB 7 and TAB 8 provide the definition of the failure cases and the calculation of the related failure probabilities, as well as the related DALs.

STANAG 4703 provides a logarithmic diagram to illustrate the relationship between MTOW and cumulative safety. This diagram is shown in FIG 2.

FIG 2 can easily be expanded to show all failure probabilities in relation to the MTOW for any N_{ExpCat}. To provide an example, this has been done for $N_{ExpCat} = 5$ and $N_{ExpCat} = 10$, shown within FIG 3 and FIG 4.

If the applicant and the certifying authority have agreed on N_{ExpCat}, the required failure probabilities are easy to calculate. But as shown in TAB 8 the failure probabilities are linked to each other. It leads to the fact, that for several N_{ExpCat} the values for P_{CumCat} are equal to another failure probability. This is displayed in TAB 9 and can be seen also within FIG 4.

Another important point within STANAG 4703 is the treatment of single catastrophic failures. ER1.3.3 states the following:

“The UAS, equipment and associated appliances, including the control station, its data links etc., considered separately and in relation to each other, must be designed such that any catastrophic failure condition does not result from a single failure not shown to be extremely improbable. [...]“[56]

This leads to a crucial conclusion: If an applicant shows within verification, that the UAS has some single catastrophic failure conditions, which can lead to a catastrophic failure but have an occurrence probability better or equal than extremely improbable ($P \leq P_{Cat}$), then these single points of failure conditions are allowed.

To gain better understanding for definition and calculation of failure probabilities based on STANAG 4703, a very simple example is made.

An applicant wants to certify a propeller-driven fixed wing UAS of 75 kg with a piston engine and a parachute based FTS. The UAS is designed to land with a landing gear. Furthermore a non-redundant FCS is integrated. The applicant defines following catastrophic failures during the PSSA:

- Failure of FTS: The parachute can't be pulled out and the UAS crashes at maximum glide speed on the ground.
- Structural Failure: The centre wing bulkhead breaks inflight and the UAS enters a non-controllable status.
- Failure of navigation system and command and control link: The UAS can't be controlled and navigate anymore.
- Failure of FCS: The on-board FCS has a malfunction and overrides all commands of the UCS.
- Command and Control Link failure: The UAS transmits wrong or corrupted data about its health status, which cannot be identified by the UCS control systems. These could lead to an uncontrolled landing.

Based on these assumptions N_{ExpCat} is set to five. TAB 10 provides the calculated failure probabilities.

As stated before, it was a very simple example and just had the objective to demonstrate how to calculate failure probabilities in accordance with STANAG 4703. Special considerations, e.g. usage itself, operational area, mitigation measures like pre-defined emergency procedures due to the described mal-functions have not been included into this example. These considerations are essential for a complete type certification based on STANAG 4703.

To conclude this chapter, STANAG 4703 offers a comprehensive set of airworthiness requirements with concurrently flexibility for certification of UAS below 150 kg and especially for very small UAS.

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25) This value was chosen during the developing phase of STANAG 4703 on basis of [82] in which this value is examined amongst others the probability of fatalities due to the impact of a sUAS [55].

26) This number should be determined within a PSSA by the applicant. It has to be approved by the certifying authority. If both, the applicant and the certifying authority, can't agree on a number, alternatively a fixed number of ten can be used [55][56].

4.7. Comparison

In this chapter the regarded failure conditions and their related probabilities of chapter 4 are placed side by side together with traditional manned aircraft airworthiness requirements in order to get a broad overview and a compelling summary.

As mentioned in chapter 4, EASA provides within its UAS Policy [8] a method to indicate appropriate certification specifications in order to create a certification basis for a UAS.

Due to the fact, that this paper seeks to show applicability of STANAG 4703 to civil UAS, a compelling matrix based on [8] is generated in order to compare the different regulations directly to STANAG 4703.

It is recognized, that [8] in principle doesn't fit for UAS ≤ 150 kg. Nevertheless, the provided methodology can be used to achieve the compelling summary of airworthiness requirements mentioned above.

In TAB 11 the four failure conditions "catastrophic", "hazardous", "major" and "minor" and the related failure probabilities or the applicable text passage from every chosen airworthiness regulation are provided.

EASA requires within its policy to calculate the kinetic energy for two failure cases:

"Unpremeditated Descent Scenario - A failure (or a combination of failures) occurs which results in the inability to maintain a safe altitude above the surface. (e.g. loss of power, WAT limits etc).

Loss of control scenario - A failure (or a combination of failures) which results in loss of control and may lead to an impact at high velocity." [8]

For both cases the applicant has to calculate the kinetic energy as follows:

$$(1) \quad E_{Kin} = \frac{(m[kg] \times v[kts]^2)}{10^9}$$

The velocity that has to be used is dependent on each failure case and considered UAS. This is shown in TAB 12. After calculating the energy values[27] for both scenarios, these values have to be compared with FIG 5 and FIG 6. The x-axis values are representative aircraft types, shown within TAB 13.

To get a broad overview and to be not limited on several UAS within the comparison, following limitations and assumptions have been made:

Due to the fact that STANAG 4703 is limited to fixed wing UAS, it has been decided to exclude rotorcraft and airship / balloon UAS within the following examination.

Because of lacking aircraft data, regarding the necessary stall speeds (v_{Stall}), it has been decided to set the upper limit for v_{Stall} equal to the maximum allowed stall speeds within CS-LSA [83], CS-VLA [84], CS-22 [85], CS-23 [75] and the appropriate FARs [77][86][87][88][28]. The derived values of v_{Stall} and MTOW are shown in TAB 14.

A review of current UAS ≤ 150 kg, based on [92] and online available manufacturer data has lead to the perception, that usually the maximum operating speeds of these UAS are not greater than 250 km/h. It doesn't include experimental, demonstrator UAS or target drones / UAS that have the characteristics of a deployable weapon, they haven't been considered. Nevertheless, to get an extensive spread, the upper limit for the maximum operating speed, v_{MO}, has been set to 650 m/s (2340 km/h). The velocities used are summarized within TAB 15.

Based on the above listed Assumptions and on FIG 5 and FIG 6, the regulations that have to be used, can be defined as listed within TAB 16.

The EASA UAS policy covers any type of UAS and connects them to existing manned aircraft airworthiness regulations. As can be seen within FIG 5 and FIG 6, this leads to some crossovers, for example a UAS with a kinetic energy value of 0.0015 could fall either under CS-VLA or the CS-23 Single Engine category.

Due to the fact that UAS ≤ 150 kg are principally not covered within this UAS policy and to keep it simple, the Micro Light / CS-VLA have been summarized into one category and wherever crossover could show up, the upper kinetic energy limit has been set to the more conservative value, which leads to the kinetic energy boundaries shown in TAB 16.

To get a visual categorization, a matrix based on equation (1), TAB 12, TAB 14 and TAB 15 has been generated which visualizes the different applicable airworthiness regulations related to EASA UAS Policy. The derived equations are shown below.

$$(2) \quad \underline{E}_{Kin} = \begin{cases} \underline{E}_{KinS1} = C \cdot \vec{m}_i \cdot \left(1.3 \cdot \vec{v}_{jStall}{}^{T}\right)^2 \\ \underline{E}_{KinS2} = C \cdot \vec{m}_i \cdot \left(1.4 \cdot \vec{v}_{jMO}{}^{T}\right)^2 \end{cases}$$

$$(3) \quad C = \frac{1}{10^9}$$

$$(4) \quad \vec{m}_i = \begin{pmatrix} 0 \\ 0.1 \\ \vdots \\ 149.9 \\ 150 \end{pmatrix} [kg]$$

$$(5) \quad \vec{v}_{jStall} = \begin{pmatrix} 0 \\ 0.1 \\ \vdots \\ 31.3 \\ 31.39 \end{pmatrix} [m/s] = 1{,}9438445 \cdot \begin{pmatrix} 0 \\ 0.1 \\ \vdots \\ 31.3 \\ 31.39 \end{pmatrix} [kts]$$

$$(6) \quad \vec{v}_{jMO} = \begin{pmatrix} 0 \\ 0.1 \\ \vdots \\ 649.9 \\ 650 \end{pmatrix} [m/s] = 1{,}9438445 \cdot \begin{pmatrix} 0 \\ 0.1 \\ \vdots \\ 649.9 \\ 650 \end{pmatrix} [kts]$$

The calculation resulted in $\underline{E}_{KinS1}{}^{[1501\times 314]}$ with 471,314 cells and in $\underline{E}_{KinS2}{}^{[1501\times 6501]}$ matrix with 9,758,001 cells. A

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[27] Note that in accordance to [8] and the related equation (1), the kinetic energy results are Non-SI units and are treated unit-less.

[28] See Footnote 32, 34 and 39.

strong compressed image of both is shown in FIG 7 and FIG 8.

In order to clearly identify the applicable civil airworthiness regulations and to compare it directly to STANAG 4703, an indicator based on TAB 11 and equation (1) to (6) is used within both matrices. The indicator groups the different limits into six areas, displayed in TAB 17, including the 66 J limit of STANAG 4703[29].

FIG 7 shows that for Scenario 1 all calculated energy values are either below the 66 J limit or not covered within [8] or that they are subject to the Micro Light / CS-VLA category.

However, FIG 8 shows that a majority of cells is subject to CS-23 / CS-25. But it is important to note that the velocity breakpoint between Micro Light / CS-VLA category and CS-23 SE category lies at 94,87 m/s or 341,53 km/h. It must be noted that this break point is much higher than usual operating speeds of UAS of this class found within the review as mentioned afore. All velocity and mass break points for both scenarios and the used velocity and speed vector are shown within FIG 7, FIG 8 and TAB 18.

The energy values of both cases have been plotted as logarithmic diagram to provide a better oversight. For every scenario the y-axis is always set as kinetic energy and the x-axis either as MTOW or as velocity.

The logarithmic illustrations in FIG 9 to FIG 12 show that STANAG 4703 is equal or more demanding in terms of failure probabilities over a vast majority area than it is required by EASA for UAS > 150 kg MTOW.

It is only within a very small area that it would be necessary to use CS-23 Single[30] / Twin Engine or CS-25 requirements which require more than STANAG 4703. To cover the CS-23 Single Engine areas, LTF 1550-001 could be used, because as seen in chapter 4.4 and TAB 3, the requirements for category 3 UAS are equal to the requirements of CS-23 Single Engine.

In [93], EASA's methodology was applied to a number of existing UAS, based on existing CS. The conclusion of [93] was, that the methodology of EASA would imply requirements, which are quite impossible to be fulfilled by an applicant.

Using STANAG 4703 for civil UAS could counterbalance this.

5. CONCLUSION AND WAY AHEAD

In the previous chapters, a brief insight into the history of UAS and the current situation of different civil and military agencies and related airworthiness regulations has been provided, especially with focus on military UAS airworthiness regulations of NATO and Bundeswehr.

It has been pointed out that there is an intensive need for civil light UAS airworthiness regulations. Due to this a comparison based on failure conditions between civil manned airworthiness and military UAS airworthiness regulations has been provided. Furthermore a way to show the applicability of military UAS airworthiness regulations in accordance with the current EASA UAS policy has been given.

The future work is going to focus on usage of light UAS in Germany, the related certification and operational safety aspects.

To conclude this paper and to point out the upcoming importance of UAS, a statement of former FAA Associate Administrator for Aviation Safety, Mr Nick Sabatini is quoted.

"The development and use of unmanned aircraft systems (UAS) is the next great step forward in the evolution of aviation."[94]

Mr Sabatini stated it already in 2006. It can be assumed that the usage of UAS will have a heavy influence to airspace usage, airworthiness regulations and the future of aviation in the whole.

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[29] Area I was included in order to provide a complete comparison. One could argue that STANAG 4703 is not mandatory for UAS of this energy value and that these UAS won't cause a fatality. But STANAG 4703 still provides guidance for minimum airworthiness requirements [56] that should be used for this kind of UAS, therefore STANAG 4703 is more demanding.

[30] It is worth to note that the requirements of STANAG 4703 for a 150 kg UAS are the same as of CS-23 Single Engine, if $N_{ExpCat} = 10$. See also TAB 8 and footnote 26. Additionally, it is stated in [8], that if a chosen certification regulation doesn't provide concrete failure probability numbers, the numbers for a class I aircraft, based on [79] should be used. As mentioned above, focus of [8] lies on UAS > 150 kg, it can be assumed that these failure probabilities would be reduced in order to be applicable for light UAS.

ANNEX I. – REFERENCES

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ANNEX II. – NOMENCLATURE, UNITS AND MATHMATICAL SYMBOLS

A-NPA	Advance Notice of Proposed Amendment
AC	Advisory Circular
ALADIN	Abbildende Luftaufklärungsdrohne im Nahbereich
AMC	Acceptable Means of Compliance
ARC	Aviation Rulemaking Committee
ATM	Air Traffic Management
AUVSI	Association for Unmanned Vehicles International
C2	Command and Control
CAS	Calibrated Airspeed
CG	Centre of Gravity
CoA	Certificate of Authorization
ComSystem	Communication System
CS	Certification Specification
DAL	Development Assurance Level
DTA	Delegated Tasking Authority
EASA	European Aviation Safety Association
EDA	European Defence Agency
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FCS	Flight Control System
FINAS	Flight In Non Segregated Airspace
FTS	Flight Termination System
GAF	German Air Force
ICAO	International Civil Aviation Organisation
JAA	Joint Aviation Authorities
JCGUAV	Joint Capabilities Group On Unmanned Aerial Vehicles
KZO	Kleinfluggerät Zielortung
LSA	Light Sport Aircraft
LTF	Lufttüchtigkeitsforderung
LUAS	Light Unmanned Aircraft System
LUNA	Luftgestütze Unbemannte Nahaufklärungsausstattung
MALE	Medium Altitude Long Endurance
MAWA	Military Airworthiness Authorities
MIL-HDBK	Military Handbook
MTOW	Maximum Take Off Weight
NAS	National Airspace
NATO	North Atlantic Treaty Organisation
NNAG	NATO Naval Armaments Group
NPA	Notice of Proposed Amendment
NPRM	Notice of Proposed Rulemaking
NSA	NATO Standardization Assocication
PSSA	Preliminary System Safety Assessment
RPA	Remotely Piloted Aircraft
RTCA	Radio Technical Commission for Aeronautics
STANAG	Standardization Agreement
sUAS	small Unmanned Aircraft System
TA	Tasking Authority
TIP	Type Inspection Program
TIPO	Type Inspection Program Outline
UAV	Unmanned Aircraft Vehicle
UAPO	Unmanned Aircraft Program Office
UAS	Unmanned Aircraft System / Unmanned Aerial System
UASSG	UAS Study Group
UCS	UAV Control Station
USAR	Unmanned Aircraft System Airworthiness Requirement
WAT	Weight, Altitude, Temperature
WTD 61	Wehrtechnische Dienststelle 61 - Bundeswehr Technical and Airworthiness Center for Aircraft (WTD 61)
ZDv	Joint Service Regulation

Fh	Flight hour
ft	Feet
J	Joule
kg	Kilogram
km/h	Kilometers / Hour
kts	Knots
lbs	Pound
m/s	Meters / Second
s	Seccond

E_{Kin}	Kinetic Energy
$\underline{E}_{KinS1}$	Kinetic Energy Value Matrix Scenario 1
$\underline{E}_{KinS2}$	Kinetic Energy Value Matrix Scenario 2
$\vec{m}_i$	Mass vector
N_{ExpCat}	Number of expected catastrophic failures
P_{Cat}	Probability of a catastrophic event
P_{CumCat}	Cumulative probability for a catastrophic event
P_{Haz}	Probability of a hazardous event
P_{Maj}	Probability of a major event
P_{Min}	Probability of a minor event
P_{NE}	Probability of an event that has no effect on safety
v_{MO}	Maximum operating speed
$\vec{v}_{jMO}$	Maximum operating speed vector
v_{Stall}	Stall speed
$\vec{v}_{jStall}$	Stall speed vector

ANNEX III. – TABLES

	Type Certification	*Take off / Landing*	*Flight*
Category 1	no	Special military training areas / restricted areas	above special military training areas / restricted areas in prohibited or flight-restricted airspace
Category 2	yes	Special military training areas / restricted areas	flight-restricted area / airspace restricted for general air traffic, this airspace may be outside special military training areas / restricted areas
Category 3	yes	No Limitations – Participation in General Air Traffic	No Limitations – Participation in General Air Traffic

TAB 1. Comparison between the three UAS categories and the operational restrictions, derived from LTF 1550-001 [69].

Failure	*Definition*
Catastrophic	All failures excluding a safe flight or landing of the aircraft and possibly causing deaths.
Critical	All failures excluding safe flight. The aircraft is no longer able to reach a designated landing/recovery point, the result being a forced premature landing. This type of failure can cause injuries.
Major	All failures resulting in a significant change of the operational status; the mission is aborted; a safe flight and an emergency landing at a designated landing point are still possible.
Minor	All failures resulting in minor changes of the operational status; the mission can be continued; a safe flight and landing are still possible.

TAB 2. Failure definitions of LTF 1550-001 [69].

Requirement	*Category 1*	*Category 2*	*Category 3*
Non-Compliance with designated Airspace	$\leq 10^{-5}$ / Fh	$\leq 10^{-5}$ / Fh	Critical / Catastrophic
Flight Termination System	required	required*	not required
Emergency Systems and Procedures	not required	required*	required
Continuous Monitoring of Flight Path and Aircraft Condition	required	required	required
Uncontrolled Flight or Crash	n/a	$< 10^{-4}$ / Fh $< 10^{-5}$ / Fh***	Catastrophic
Flight Path Tracking Failure / Failure within Data-Transmission	n/a	$< 10^{-3}$ / Fh	Must not lead to Catastrophic
Occurrence of Emergency Procedures**	n/a	$\leq 2 \cdot 10^{-3}$ / Fh	n/a
Catastrophic	n/a	Uncontrolled Crash / Leaving Airspace***	$< 10^{-6}$ / Fh
Critical	not specified	not specified	$< 10^{-5}$ / Fh
Major	not specified	not specified	$< 10^{-4}$ / Fh
Minor	not specified	not specified	$< 10^{-3}$ / Fh
Cumulative Safety	not specified	not specified	$< 10^{-5}$ / Fh

* A FTS or Emergency Systems and Procedures are required.

** Only if the required probabilities for an Uncontrolled Crash and Non-compliance with designate Airspace can't be met by the applicant.

*** Please see remarks to this table within chapter 4.4.

TAB 3. Top-Level Requirements extracted from LTF 1550-001 [69].

		UAV System				
		UAV	*C2*	*ComSystem*	*UCS*	*Other ancillary elements*
General	A	X	X	X	X	X
Flight	B	X				
Structure	C	X				X
Design and Construction	D	X				X
Powerplant	E	X				
Equipment	F	X				
Operating limitations and information	G	X	X	X	X	X
C2 and ComSystem	H		X	X		
UCS	I				X	

TAB 4. Structure of STANAG 4671 and interconnection between its subsections, taken from [13].

Failure	*Definition*
Catastrophic	Failure conditions that result in a worst credible outcome of at least uncontrolled flight (including flight outside of pre-planned or contingency flight profiles/areas) and/or uncontrolled crash, which can potentially result in a fatality. Or Failure conditions which could potentially result in a fatality to UAV crew or ground staff.
Hazardous	Failure conditions that either by themselves or in conjunction with increased crew workload, result in a worst credible outcome of a controlled-trajectory termination or forced landing potentially leading to the loss of the UAV where it can be reasonably expected that a fatality will not occur. Or Failure conditions which could potentially result in serious injury to UAV crew or ground staff.
Major	Failure conditions that either by themselves or in conjunction with increased crew workload, result in a worst credible outcome of an emergency landing of the UAV on a predefined site where it can be reasonably expected that a serious injury will not occur. Or Failure conditions which could potentially result in injury to UAV crew or ground staff.
Minor	Failure conditions that do not significantly reduce UAV System safety and involve UAV crew actions that are well within their capabilities. These conditions may include a slight reduction in safety margins or functional capabilities, and a slight increase in UAV crew workload.
No safety effect	Failure conditions that have no effect on safety.

TAB 5. Failure definitions of STANAG 4671 [13].

Failure	*Probability*		*Definition [1/Fh]*	*DAL*
Cumulative Safety	P_{CumCat}		$< 10^{-5}$	n/a
Catastrophic	P_{Cat}	(extremely improbable)	$< 10^{-6}$	B
Hazardous	P_{Haz}	(extremely remote)	$< 10^{-5}$	C
Major	P_{Maj}	(remote)	$< 10^{-4}$	D
Minor	P_{Min}	(probable)	$< 10^{-3}$	E
No safety effect	P_{NE}	(frequent)	$> 10^{-3}$	E

TAB 6. Failures and related acceptable probabilities and DALs 31), derived from STANAG 4671 [13].

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31) DALs were derived during development of STANAG 4671 from RTCA DO-178B [13]

Failure	*Definition*
Catastrophic	Failure conditions that are expected to result in at least uncontrolled flight (including flight outside of pre-planned or contingency flight profiles/areas) and/or uncontrolled crash. Or Failure conditions which may result in a fatality to UA crew or ground staff.
Hazardous	Failure conditions that either by themselves or in conjunction with increased crew workload, are expected to result in a controlled-trajectory termination or forced landing potentially leading to the loss of the UA where it can be reasonably expected that a fatality will not occur. Or Failure conditions for which it can be reasonably expected that a fatality to UA crew or ground staff will not occur.
Major	Failure conditions that either by themselves or in conjunction with increased crew workload, are expected to result in an emergency landing of the UA on a predefined site where it can be reasonably expected that a serious injury will not occur. Or Failure conditions which could potentially result in injury to UA crew or ground staff.
Minor	Failure conditions that do not significantly reduce UA safety and involve UA crew actions that are well within their capabilities. These conditions may include a slight reduction in safety margins or functional capabilities, and a slight increase in UA crew workload.
No safety effect	Not defined

TAB 7. Failure definitions of STANAG 4703 [56].

Failure	*Probability*		*Definition [1/Fh]*	*DAL*
Cumulative Safety	P_{CumCat}	15 kg ≤ MTOW ≤ 150 kg MTOW < 15 kg	= 0.0015 / MTOW or = 10^{-4}	n/a
Catastrophic	P_{Cat}	(extremely improbable)	$\leq P_{CumCat}/N_{ExpCat}$	B
Hazardous	P_{Haz}	(extremely remote)	$\leq 10 \cdot P_{Cat}$	C
Major	P_{Maj}	(remote)	$\leq 10 \cdot P_{Haz}$	D
Minor	P_{Min}	(probable)	$\leq 10 \cdot P_{Maj}$	D
No safety effect	P_{NE}	(frequent)	$> P_{Min}$	n/a

TAB 8. Failures, related Probabilities and DALs derived from STANAG 4703 [56].

N_{ExpCat}	1	10	100	1000
$P_{CumCat}(N_{ExpCat}) =$	P_{Cat}	P_{Haz}	P_{Maj}	P_{Min}

TAB 9. Equality between P_{CumCat} and the four other failure probabilities for special N_{ExpCat}, derived from STANAG 4703 [56].

Failure		*Definition [1/Fh]*	*DAL*
Cumulative Safety	P_{CumCat}	$= 0.0015/75 = 2 \cdot 10^{-5}$	
Catastrophic	P_{Cat}	$\leq 2 \cdot 10^{-5} / 5 = 4 \cdot 10^{-6}$	B
Hazardous	P_{Haz}	$\leq 10 \cdot 4 \cdot 10^{-6} = 4 \cdot 10^{-5}$	C
Major	P_{Maj}	$\leq 10 \cdot 4 \cdot 10^{-5} = 4 \cdot 10^{-4}$	D
Minor	P_{Min}	$\leq 10 \cdot 4 \cdot 10^{-4} = 4 \cdot 10^{-3}$	D
No safety effect	P_{NE}	$> 4 \cdot 10^{-3}$	n/a

TAB 10. Example for determining the required failure probabilities for a UAS with MTOW = 75 kg and $N_{ExpCat} = 5$, derived from STANAG 4703 [56].

Regulation	*Catastrophic [1/Fh]*	*Hazardous [1/Fh]*	*Major [1/Fh]*	*Minor [1/Fh]*
STANAG 4703 [56]	$P_{Cat} \leq \begin{cases} 10^{-4}/N_{ExpCat} \\ \left(\frac{0.0015}{MTOW \times N_{ExpCat}}\right) \end{cases}$	$P_{Haz} \leq 10 \times P_{Cat}$	$P_{Maj} \leq 10 \times P_{Haz}$	$P_{Min} \leq 10 \times P_{Maj}$
STANAG 4671 [13]	$< 10^{-6}$	$< 10^{-5}$	$< 10^{-4}$	$< 10^{-3}$
LTF 1550-001 [69]	$< 10^{-6}$	$< 10^{-5}$	$< 10^{-4}$	$< 10^{-3}$
CS-LSA [83] 32)	“Instruments and other equipment may not in themselves, or by their effect upon the aircraft, constitute a hazard to safe operation.”33)			
FAA LSA 34)	“The aircraft must be inspected by the FAA and found to be in a condition for safe operation.”35)			
CS-VLA [84]	“The equipment, systems, and installations must be designed to minimise hazards to the aeroplane in the event of a probable malfunction or failure.”			
AC 21.17-3 [86]	“[…] JAR-VLA provides acceptable airworthiness criteria equivalent in safety to those portions of FAR Part 23 determined applicable to VLA […]”36)			
CS-22 [85]	“Instruments and other equipment may not in themselves, or by their effect upon the sailplane, constitute a hazard to safe operation.”37)			
AC 21.17-2A [87]	“[…] the FAA has determined that the criteria of JAR-22 provides an acceptable level of safety […]”38)			
CS-23 / FAR-23 [75][77]				
Class I	$< 10^{-6}$	$< 10^{-5}$	$< 10^{-4}$	$< 10^{-3}$
Class II	$< 10^{-7}$	$< 10^{-6}$	$< 10^{-5}$	$< 10^{-3}$
Class III	$< 10^{-8}$	$< 10^{-7}$	$< 10^{-5}$	$< 10^{-3}$
Class IV	$< 10^{-9}$	$< 10^{-7}$	$< 10^{-5}$	$< 10^{-3}$
CS-25 / FAR-25 [76][78]	$< 10^{-9}$	$< 10^{-7}$	$< 10^{-5}$	$< 10^{-3}$

TAB 11. Comparison of different failure conditions39).

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32) CS-LSA is used as supplementary regulation.

33) [83] § 8.6

34) FAA has not issued a “FAR-LSA” comparable to CS-LSA. FAA treats light sport aircraft either as experimental light sport aircraft under 14 CFR §21.191 or as light sport aircraft in accordance to 14 CFR § 21.190. The FAA definition for a LSA can be found in 14 CFR §1.1. The author decided to use the term “FAA LSA” as a simplification within this passage.

35) [88][87] § 21.190 (iv) (3)

36) [86] § 4.b and please see footnote 39.

37) [85] § CS 22.1301 (b)

38) [87] § 6 a. (2) and please see footnote 39.

39) These regulations have been chosen, because all of them except CS-LSA were used as basis for STANAG 4671 and STANAG 4703. Notice must be given to the fact, that FAA did not issue a direct comparable regulation to CS-VLA [84] and CS-22 [85], but FAA adopted JAR-VLA and JAR-22 in AC 21.17-3 [86] and AC 21.17-2A [87] and treats CS-VLA certified Aircraft as special class aircraft of FAR-23 [89]. The original JARs were transferred roughly into EASA’s CS, which is stated within the explanatory notes of every transferred CS Initial issue. Furthermore, FAA and EASA have a general agreement on acceptance of standards from both authorities [6][90][91].

	Unpremeditated Descent Scenario (Scenario 1)	*Loss of Control Scenario (Scenario 2)*
	v_{S1} [kts]	v_{S2} [kts]
Aeroplanes	$1.3 \times v_{Stall}$ (Landing configuration, MTOW)	$1.4 \times v_{MO}$ (the maximum operating speed, MTOW)
Rotorcraft	Scalar value of the autorotation velocity vector.	Terminal velocity with rotors stationary.
Airships / Balloons	The combination of the terminal velocity resulting from the static heaviness, and the probable wind velocity.	Terminal velocity with the envelope ruptured/deflated to the extent that no lifting medium remains.

TAB 12. Velocities that have to be used for calculating kinetic impact energies in accordance to EASA UAS Policy, taken from [8].

1	Flex wing microlight	8	Midsize Helicopter	15	Light Corporate Jet	22	100 seat airliner
2	3-axis microlight	9	Mid-size Helicopter	16	Large Helicopter	23	Corporate Jet
3	Piston Single-CS-VLA	10	Mid-size Helicopter	17	Large Helicopter	24	Corporate Jet
4	Piston Single 2 seat	11	Piston twin	18	Large Helicopter	25	50 seat airliner
5	Piston Single 4 seat	12	Piston twin	19	Small Twin Turboprop	26	Single-aisle Airliner
6	Large Piston Single	13	Piston twin	20	50 seat Turboprop	27	Wide Body Airliner
7	Helicopter 2 seat	14	Piston twin	21	50 seat Turboprop	28	Wide Body Airliner

TAB 13. Aircraft Types, taken from EASA UAS Policy [8].

Regulation	*MTOW [kg]*	v_{Stall} *[km/h]*	*Remarks*
CS-LSA [83]	600* / 650**	83 (CAS)	Landing configuration with MTOW, most critical center of gravity
FAA LSA[40]	600* / 650**	83	MTOW, most critical center of gravity
CS-VLA / AC 21.17-3 [84][86]	750	83	Landing configuration
CS-22 / AC 21.17-2A [85][87]	750 / 850***		Landing configuration with
		80	- Air brakes retracted - Maximum Weight, water ballast tanks empty
		90	- Air brakes retracted - Maximum Weight with water ballast
		95	- Air brakes fully extended - Maximum Weight with water ballast
CS-23 / FAR 23 [75][77]	5760 / 8618	113	The stall speed has to be determined. This value is for single engine aircraft and Multi Engine Aircraft ≤ 2722 kg MTOW.

* Operations not on water.

** Operations on water.

*** Single engine powered sailplanes

TAB 14. Comparison of allowed stall speeds within different airworthiness regulations.

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[40] Please see footnote 34.

	Scenario 1 (v_{Stall})		*Scenario 2 (v_{MO})*	
	Lower Limit	*Upper Limit*	*Lower Limit*	*Upper Limit*
Velocity [km/h]	0	113	0	2340
Velocity [m/s]	0	31.39	0	650
Velocity [kts]	0	61.02	0	1263.5
Velocity incl. Correction factor [kts]	0	79.32	0	1768.9

TAB 15. Used velocity boundaries for both scenarios.

	Scenario 1		*Scenario 2*	
	Kinetic Energy Value			
Regulation	*Lower Limit*	*Upper Limit*	*Lower Limit*	*Upper Limit*
66 J Limit[41]	≥ 0	< $8.4291 \cdot 10^{-7}$	≥ 0	< $9.7758 \cdot 10^{-7}$
Not determined[42]	≥ 0	< $1.0 \cdot 10^{-4}$	≥ 0	< $1.0 \cdot 10^{-3}$
Micro Light / CS-VLA	≥ $1.0 \cdot 10^{-4}$	< $1.2 \cdot 10^{-3}$	≥ $1.0 \cdot 10^{-3}$	< $1.0 \cdot 10^{-2}$
CS-23 Single Engine	≥ $1.2 \cdot 10^{-3}$	< $1.0 \cdot 10^{-2}$	≥ $1.0 \cdot 10^{-2}$	< 0.1
CS-23 Twin Engine	≥ $1.0 \cdot 10^{-2}$	< $6.0 \cdot 10^{-2}$	≥ 0.1	< 0.3
CS-25	≥ $6.0 \cdot 10^{-2}$		≥ 0.3	

TAB 16. Kinetic energy boundaries and related regulations, derived from [8].

EASA Regulation	*Area*	*Designation*
66 J Limit / Not determined	I	66 J Limit / STANAG 4703 is more demanding.
Not determined	II	STANAG 4703 is more demanding
Micro Light / CS-VLA	III	STANAG 4703 is equal or more demanding
CS-23 Single Engine	IV	STANAG 4703 is equal demanding
CS-23 Twin Engine	V	STANAG 4703 is less demanding
CS-25	VI	STANAG 4703 is even less demanding

TAB 17. Regulation indicator.

Scenario 1			*Scenario 2*		
Area	*MTOW [kg]*	*Velocity [m/s]*	*Area*	*MTOW [kg]*	*Velocity [m/s]*
I / II	0.13	31.39	I / II	0	650
	150	0.93		150	0.93
II / III	15.89	31.39	II / III	0.31	650
	150	10.21		150	30
III / IV	n/a	n/a	III / IV	3.19	650
	n/a	n/a		150	94.87
IV / V	n/a	n/a	IV / V	31.95	650
	n/a	n/a		150	300.03
V / VI	n/a	n/a	V / VI	95.87	650
	n/a	n/a		150	519.66

TAB 18. Weight and velocity breakpoints of both impact scenarios.

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[41] Note: The 66 J limit has been determined by transferring $E_{Kin} = 66\,J = 0.5 \cdot m[kg] \cdot v[m/s]^2$ into the EASA equation for kinetic energy (equation (1)).

[42] Area I and II have both zero as starting point, because they are both not covered within [8]. Please see also footnote 29.

ANNEX IV.– FIGURES

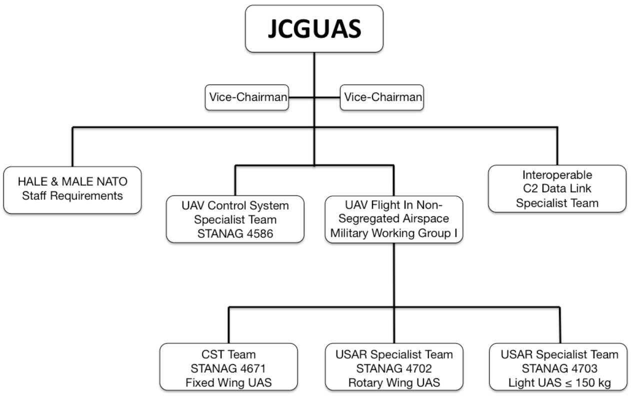

FIG 1. Structure and hierarchically organisation of NATO JCGUAV and FINAS, derived from [53].

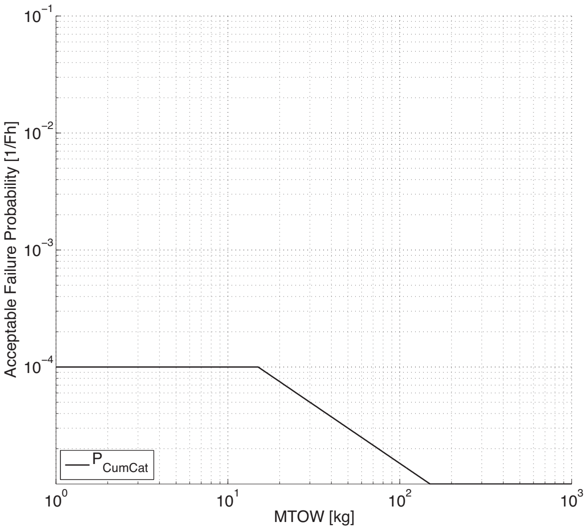

FIG 2. Relationship between Cumulative Safety and MTOW, taken from STANAG 4703 [56].

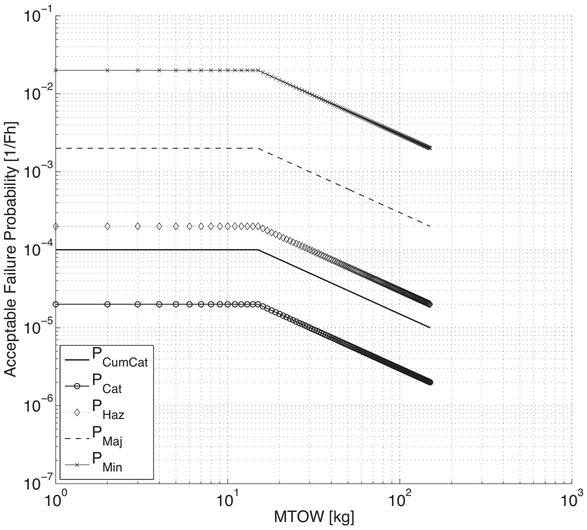

FIG 3. Relationship between Failure Probabilities and MTOW, with $N_{ExpCat} = 5$, derived from STANAG 4703 [56].

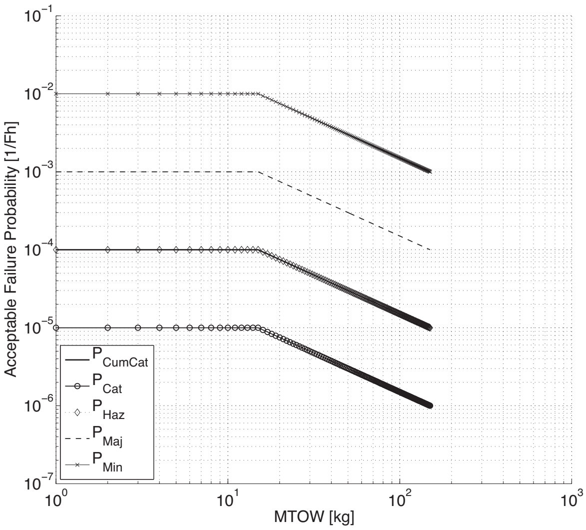

FIG 4. Relationship between Failure Probabilities and MTOW with $N_{ExpCat} = 10$, derived from STANAG 4703 [56].

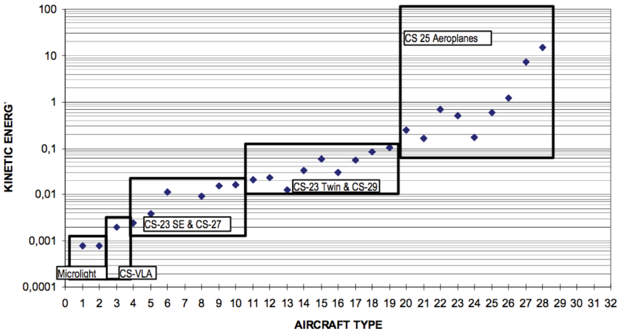

FIG 5. Unpremeditated Descent Scenario, taken from [8].

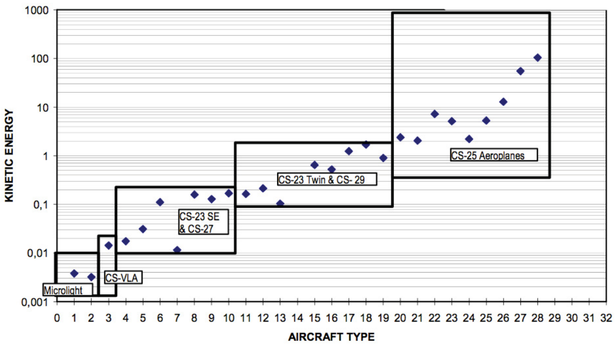

FIG 6. Loss of Control Scenario, taken from [8].

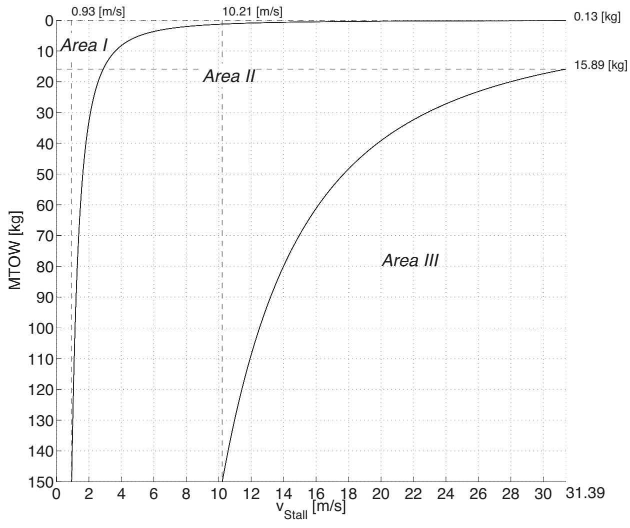

FIG 7. Strong compressed image of $\underline{E}_{KinS1}$.

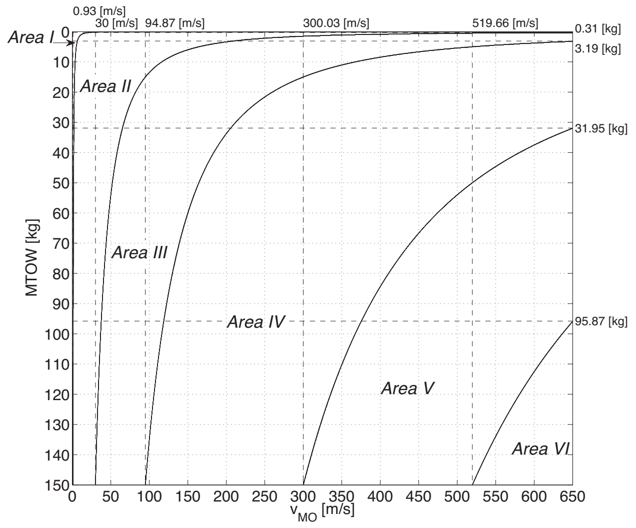

FIG 8. Strong compressed image of $\underline{E}_{KinS2}$.

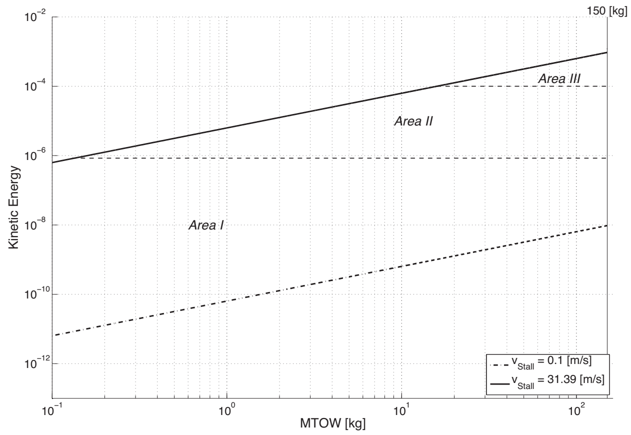

FIG 9. Scenario 1, logarithmic graph MTOW vs. kinetic energy.

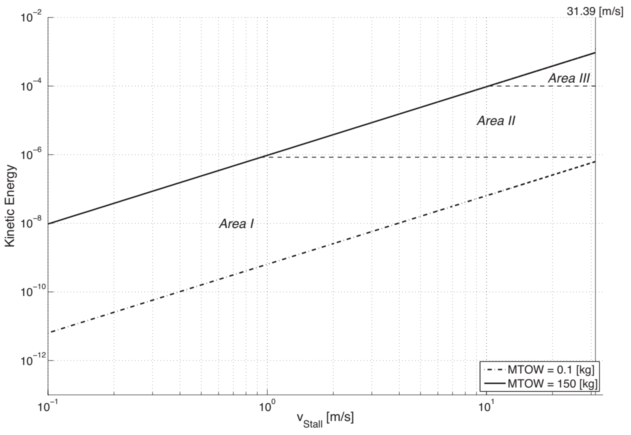

FIG 10. Scenario 1, logarithmic graph v_{Stall} vs. kinetic energy.

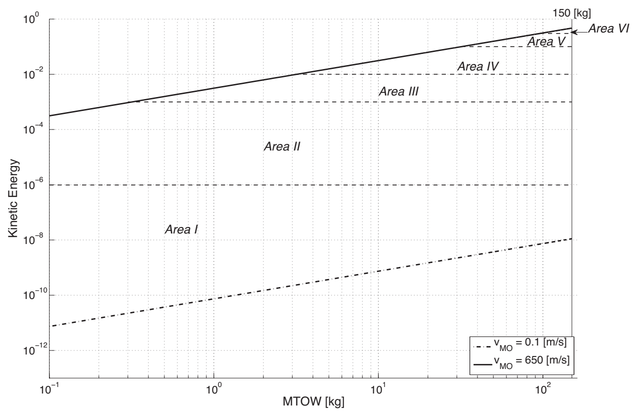

FIG 11. Scenario 2, logarithmic graph MTOW vs. kinetic energy.

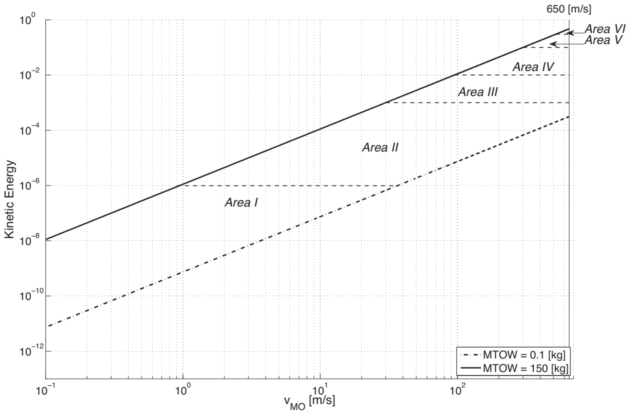

FIG 12. Scenario 2, logarithmic graph v_{MO} vs. kinetic energy.