

Autonomous Systems in Aviation: Between Product Liability and Innovation

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Abstract—Increasingly autonomous cyber-physical systems based on self-adaptive software are making their way into the aviation domain. However, the combination of their adaptive learning properties and the safety goals of aviation create unique legal and regulatory challenges for the manufacturers and regulators of such systems alike. This paper argues that some of the fundamental concepts of the product liability regime in the EU and their interpretation deprive manufacturers of autonomous systems of two essential defences: the ‘state of the art’ defence and the regulatory compliance defence. The hesitation in the direction of the overall approach to regulating and certifying autonomous systems in aviation induces legal uncertainty which can only be overcome through surgical legislative intervention. The paper formulates recommendations for amendments in light of the ongoing evaluation and pending review of the Product Liability Directive.

Keywords—Autonomous systems; Self-adaptive software; Aviation product liability; Aviation cyber-physical systems; Aviation safety certification; Product liability directive

I. INTRODUCTION

Software plays a critical role in commercial aviation. Navigation, aircraft control and other functions of flight management systems are now largely automated by software. With pilots’ role becoming mainly supervisory in nature, the trend over the last few decades has been clearly one of steady growth of automation. While automation has undoubtedly improved aviation safety, it has also been a contributing factor to several fatal incidents [1].

The continuous increase in air traffic has called for transformation of the aviation industry. The disruptive power of new technologies, such as increasingly autonomous cyber-physical systems and machine learning, promises to improve the capacity and profitability of air services and contribute to improving safety, security, environmental protection and infrastructure modernisation [2]. However, the “coupling” of cyberspace with the physical world gives rise to significant challenges in terms of reconciling the distinct features of the two environments. Cyberspace, an ideal environment governed by the rules of software code, is opposed to the physical environment of aviation governed by the laws of physics, linear time and stringent safety rules. Connected aircraft and digital

air traffic management (ATM) systems are just beginning to leverage the benefits of this cyber layer. At the same time, increasingly autonomous systems, such as unmanned aircraft systems, relying on self-adaptive software and machine learning, promise cost savings and facilitate new opportunities for air carriers [3], [4].

Against the background of fast-paced developments and growing complexity of software-intensive aviation socio-technical systems [5], regulators and legislators are facing the challenges of the growing divide between technology and regulation. The conservative nature of aviation safety regulation is now confronted with the influx of a wide range of commercial off-the-shelf technologies which cannot be certified using the safety standards for aircraft and ATM systems. Furthermore, existing certification and standardisation processes are based on the assumption that a system’s correct behaviour “must be completely specified and verified prior to operation” [6]. This constitutes a significant barrier to the development of new autonomous systems relying on adaptive software and machine learning algorithms as they are intrinsically self-directed and non-deterministic.

Certification and standardisation also provide the manufacturers of such systems with a certain level of assurance regarding the compliance of their products. More specifically, under product liability law, manufacturers can be held liable for damages to third parties caused by defective products. Until recently, manufacturers’ liability in the aviation industry was considered more the subject of academic debate rather than a practical issue. However, in 2015, the Spanish Supreme Court held liable the manufacturers for product defects of the collision avoidance system (TCAS) installed on board the aircraft involved in the Überlingen mid-air collision accident [7]. A significant precedent “reaffirm[ing] product liability in the aviation domain”, this decision also demonstrates the difficulties in allocating liabilities in socio-technical systems and the role of certification as a determining factor [8].

At EU level, Directive 85/374/EEC on liability for defective products (“Product Liability Directive”) establishes a harmonised strict liability regime which holds the producer liable for damage caused by a defect in their product. The applicability of this directive in the realm of aviation was

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recognised from the very beginning [9]. The general rule is qualified by six exceptions, two of which are particularly important for manufacturers of autonomous systems in aviation. According to Article 7 (d) and (e), a manufacturer may escape liability if they prove that:

- the defect is due to compliance of the product with mandatory regulations issued by the public authorities (known as ‘regulatory compliance defence’); or
- the state of scientific and technical knowledge at the time when they put the product into circulation was not such as to enable the existence of the defect to be discovered (known as ‘development risk’ or ‘state of the art defence’).

This paper argues that these two exceptions can hardly be invoked by manufacturers in the context of increasingly autonomous systems which in turn induces legal uncertainty. More specifically, for manufacturers of hardware and software for the nascent market of commercial unmanned aircraft systems in the EU this might act as a barrier stifling innovation. In light of the ongoing evaluation of the directive, the paper briefly discusses several possible solutions.

The paper is organised as follows:

- section II provides an overview of the specific legal and regulatory challenges of increasingly autonomous adaptive systems;
- section III discusses the central notion of ‘defect’ and the applicability of the notion of ‘state of the art’ to increasingly autonomous adaptive systems.
- section IV focuses on the difficulties in the certification of increasingly autonomous adaptive systems and their impact on the exercising of the regulatory compliance defence;
- section V outlines the impact of these challenges on the developing European market for unmanned aircraft systems;
- section VI looks at the possible solutions to mitigate the legal uncertainty and create enabling conditions for the development of autonomous systems in aviation.

II. AUTOMATION AND AUTONOMY

The terms automation and autonomy are often confused and even used interchangeably. However, while *automated* technologies have been used in aviation for quite some time now, this is not the case for *autonomous* technologies. Automation refers to a system performing its function with little or no human involvement where the system’s performance is limited to its predefined tasks. Unlike automation, autonomy refers to systems which exhibit self-directed behaviour and can dynamically respond and adapt to events which have not been pre-programmed [6].

As future cyber-physical systems in aviation will increasingly rely on autonomous technologies, this will put to the test some established regulatory conventions. From a legal and regulatory perspective, at least two groups of challenges draw attention.

The first challenge is linked to the basic question of when a product is defective, and whether autonomous systems’ learning and adaptive capabilities render the safety expectations test and the manufacturer’s state of the art defence unfit. These problems will be discussed in section III.

The second challenge is related to how certification authorities verify and certify autonomous systems, given predictability and certainty are at the core of the current certification process. Authorities would have to assure the new systems are at least as safe as the existing ones. The US Federal Aviation Administration (FAA) and the European Aviation Safety Agency (EASA) can certainly rely on the ‘special conditions’ for such ‘non-conventional aircraft’, as established in FAR 21, Paragraph 16 and EASA Part 21, Paragraph 21.A.16B, to add safety standards ensuring equivalent level of safety to the one in the airworthiness regulations/certification standards [10]. However, this does not resolve the issue of how acceptability and practicability would be balanced to establish a sufficient level of safety of autonomous systems. The uncertain context and independence of autonomous systems could render existing performance standards inapplicable to them. While some solutions to this problem have already been proposed, their impact on producers’ liability will be discussed in section IV.

III. DEFECTS: BETWEEN CONSUMER EXPECTATIONS AND THE STATE OF THE ART

Under the Product Liability Directive, an injured party can assert a claim against a producer on three conditions: there must be a defect, a damage and a causal relationship between the two.

Article 6 of the Product Liability Directive provides that a product is defective when it does not provide the safety which a person is entitled to expect. It is beyond any doubt that the reasonable safety expectations for an aviation product will be very different from, for example, those for a smartwatch. Furthermore, it should be understood that ‘products’ here in the context of autonomous systems in aviation may include hardware components as well as software applications etc. Thus, the preliminary question of whether an autonomous system is a ‘product’ in the first place must be answered.

The Product Liability Directive defines in Article 2 products as all ‘movables’, even when incorporated in immovables. Considering the software-intensive nature of autonomous systems in aviation, it is reasonable to ask if software fits within this definition. The European Commission’s view is that the directive “applies to software in the same way [as to other movables], moreover, that it applies to handicraft and artistic products” [11]. However, it is uncertain whether the directive applies solely to embedded

software and software available on tangible medium or also to “software as a service” [12]. Legal uncertainty remains high, however, given that to date there has been no case law on whether the Product Liability Directive applies to software, a point also acknowledged by the Commission itself [13]. In any case, as most autonomous aviation systems are likely to be cyber-physical systems operating embedded software, they should fall within the ambit of the definition of a ‘product’.

It was mentioned that for a product to be defective, it must fail to meet a person’s safety expectations. Thus, the notion of ‘defect’ in EU product liability law is not grounded in technical defects but rather in the general public’s expectations of the required degree of safety. In the recent *Boston Scientific* case, the Court of Justice of the EU (“CJEU”) held that “[t]he safety which the public at large is entitled to expect (...) must therefore be assessed by taking into account, *inter alia*, the intended purpose, the objective characteristics and properties of the product in question and the specific requirements of the group of users for whom the product is intended” [14]. In his Opinion, the Advocate General (“AG”) Bot suggested that a product defect “can exist irrespective of any internal fault in the product concerned” and that the “triggering factor does not reside in the product fault, but in the fact that the product does not provide the safety which a person is entitled to expect” [15]. This implies that a product which is technically sound may still be defective if it fails to meet the expectations in terms of safety.

Concurring with the AG Opinion, the court went further and found that even the *potential* lack of safety may give rise to producer’s liability which, in the case’s context of medical devices, stems from “the abnormal potential for damage which those products might cause to the person concerned” (§ 40). Thus, the court ruled that “where it is found that such products belonging to the same group or forming part of the same production series have a *potential defect*, it is possible to classify as defective all the products in that group or series, without there being any need to show that the product in question is defective” (§ 41). While the court did not go as far as AG Bot to highlight the “preventive function” assigned to product liability law (§ 38) [15], it grounded its findings in teleological interpretation of the directive’s objective of fair risk apportionment and the high priority of consumer protection (§ 42, 47).

The decision has been criticised for its “counter-productive effects” in creating liability for potentially defective products and effectively rewriting the directive [16]. Despite some commentators’ opinion that the case has implications only for the medical devices industry, the broad policy objectives upon which the decision is based and the court’s use of broad language suggest otherwise [17]. Furthermore, provided the safety requirements for aviation systems are very high, an analogy to the “abnormal potential for damage” stemming from defects in such products may not be that far-fetched.

The criterion of ‘safety expectations’ merits special attention in the context of autonomous aviation systems.

Autonomous systems are inherently self-adaptive; they control their behaviour in accordance with “context-relevant norms, constraints, or desiderata” [18]. Their objective characteristics come into conflict with the concept of ‘safety expectations’ which is based, *inter alia*, on the expectations at the time when the product was put into circulation and which cannot go beyond that point in time on grounds of subsequent better products (Article 6(1)(b) in relation to Article 6 (2) Product Liability Directive). Thus, it is not clear whether, for the purpose of assessing these expectations, the alteration of an autonomous system’s behaviour or an update/upgrade of its functionality could be considered a *defective* product if it fails to meet the safety expectations or as a *new* product that does not affect them. In addition, the public’s safety expectations are also determined by the presentation of the product (Article 6(1)(a) Product Liability Directive) which means that as well as generally known risks, any risks of which the public has been specifically informed by the manufacturer are also relevant. As a matter of fact, in the case of *Boston Scientific*, the claims were based precisely on alerts made by the manufacturer. Given the broad interpretation of *potential* defects and the likelihood of claims being asserted on the basis of a mere notice, manufacturers are likely to become discouraged to share information with the public where the risk is perceived to be considerably small [16]. This is even more so when it comes to autonomous systems in aviation where the very behaviour of the system coupled with the high safety expectations in the sector may lead to it being considered a product of “abnormal potential for damage”.

The liability for *potential* defects established in *Boston Scientific* raises troubling concerns as it cannot be easily reconciled with the adaptive behaviour of autonomous systems. For example, two autonomous systems may operate in two different contexts changing their behaviour according to different conditions and constraints. If one of them changes its behaviour in a way that does not meet the public’s safety expectations and causes damages, the potential defect liability doctrine would likely automatically render any other instance of the same system operating in a different context defective as well. As a result, this opens the door to an unlimited chain of claims against the manufacturer based on the potential lack of safety of the autonomous system.

Another interesting point could be made with respect to the public’s safety expectations for software-intensive systems in general. It is well-known in the software industry that commercial software is often shipped with flaws and defects and this more or less has been accepted by the public when it comes to standard software packages, such as word processors [19]. In the aviation domain, however, the software assurance process is much more thorough so that it can ensure the product is developed in line with very specific requirements and it does not exhibit any unintended behaviour [6]. Nevertheless, cases such as the Spanish case against the manufacturers of the TCAS involved in the Überlingen accident show that even this software can fail. A reasonable question, then, is how the presence of ‘bugs’, as inherent and

unavoidable ‘features’ of present-day software, impacts the public’s safety expectations. In the English case of *A and Others v National Blood Authority and another*, the court referred to an exchange between Mrs Flesch MEP and the European Commission in June 1980, Viscount Davignon, on behalf of the Commission, stated that “nobody can expect from a product a degree of safety from risks which are, because of its particular nature, inherent in that product and generally known, e.g., the risk of damage to health caused by alcoholic beverages. Such a product is not defective within the meaning of . . . the . . . Directive” [20], [16]. It is interesting to see if manufacturers would employ a similar reasoning to argue that the fact software is never flawless effectively lowers the public’s safety expectations. Furthermore, a related question concerns the extent to which software’s inherent flaws impact producers’ liability for *potential* defects.

The liability for potential defects in *Boston Scientific* operationalises the risk of malfunction to become a defect in the future and not the occurrence of an actual defect [16]. This distinction is critical for manufacturers as it determines whether they may invoke the state of art defence under Article 7 (e) Product Liability Directive. As the public cannot have legitimate expectations of 100% safety, this simply means that if the risk of a product malfunctioning in the future reveals an “abnormal potential for damage”, without any specific indications of current or imminent malfunctioning, the manufacturer may not be able to rely on the state of the art defence.

As construed by the CJEU, the defence refers to the “objective state of scientific and technical knowledge of which the producer is presumed to have been informed” to the extent that this knowledge is “accessible at the time when the product in question was put into circulation” [21]. This means the state of the art must be objectively examined through the lens of the most advanced level of knowledge, regardless of the industrial sector concerned (§ 26). Thus, for a manufacturer to exonerate themselves from liability for potential defects, they must prove that they could not have known about the risk of product malfunctioning in the future, even with the most advanced level of scientific and technical knowledge.

Such an interpretation implies a very high standard for exoneration which is likely to leave manufacturers with no effective defence for the development risks they undertake. This is especially so in the case of autonomous aviation systems, where the learning and adaptation feedback loops may lead to changes in a system’s behaviour that creates new risks that could have been neither known nor foreseen. The problem is further exacerbated by the interaction and exchange of data between autonomous systems which give rise to new and more complex safety risks. Without an objective standard for what an “abnormal potential for damage” constitutes, especially in the case of autonomous systems, the state of the art defence could easily become a thing of the past.

The state of the art is a moving target. In principle, this should mean that for the new risks emerging with the

technology’s continuous development, manufacturers should be covered by the state of the art defence. The far-reaching implications of *Boston Scientific*, however, suggest that the product liability regime in the EU has a “preventive and prophylactic function that goes beyond merely reacting to damage materialization” [17]. While it is true that the court explicitly says that the products “may be”, and not “must be”, considered defective [16], the very possibility that a national court may concur with this reasoning produces legal uncertainty. Consequently, the product liability’s deterrence function may equally end up deterring innovation if applied broadly and indiscriminately.

IV. CERTIFYING AUTONOMY: BETWEEN PRODUCERS’ COMPLIANCE AND STANDARD-SETTERS’ LIABILITY

Standardisation and certification are essential for safety in aviation. It was already mentioned that the current certification standards are rooted in determinism and predictability which means that the correct behaviour of a system must be completely specified and verified prior to operation. However, regulatory authorities are now facing the challenges of introducing commonplace cyber technologies in aviation. This trend not only furthers the state of the art but also renders this traditional mindset largely inapplicable to autonomous systems based on adaptive software and machine learning algorithms, such as the ‘sense and avoid’ algorithms in unmanned aircraft systems.

The need of a new approach to the certification, verification and validation of increasingly autonomous systems in aviation has long been recognised as a critical bottleneck [3]. And while a good amount of research on the certification challenges is already underway, the implications of these challenges for the manufacturers’ liability for defective products has remained largely unexplored.

The link between certification and liability is evident from Article 7(d) Product Liability Directive which establishes the so-called ‘regulatory compliance defence’. A manufacturer can invoke this defence to exonerate themselves from liability if they prove that the defect is “due to *compliance* of the product with *mandatory regulations* issued by the *public authorities*” (emphasis added). Thus, if a manufacturer proves that the defect in their product is the result of their compliance with a mandatory (ie, binding) norm adopted by an authority with regulatory powers, they shall not be liable.

It is generally accepted that this defence has a rather narrow scope and can rarely be invoked successfully [22]. This is so because, first, in most cases legislation establishes minimum standards which provide manufacturers with a wide margin of appreciation and, second, the defect itself must be the result of compliance with the mandatory rule which would rarely be the case.

In a comparative perspective, the regulatory compliance defence in most European countries is of rather limited application.

First, the scope of the term “mandatory regulation” is construed restrictively. For example, in France, Spain, Austria, Germany and the UK compliance with norms establishing minimum legal or regulatory requirements, voluntary standards, private norms and technical standards issued by national or international standardisation organisations are excluded from the scope of the defence. Standards, however, may have a role in determining the public’s legitimate safety expectations in Austria, Spain and Norway. [23] The general stance is that for the “regulations” to be considered “mandatory”, they should be embodied in legal provisions that force the producer to manufacture defective products (Germany, § 1 (2) no 3 ProdHaftG), constitute structural standards of production the cannot be disregarded (Italy, Art. 118 Consumer Code), or cover the design and/or composition of the product (Netherlands, Art. 6:185(1)(d) BW) [23].

Second, the case law dealing with the regulatory compliance defence is scattered and has until recently been of interest mostly to the pharmaceuticals and food industry. Thus, in the case of *Pollard v Tesco Stores*, the English court held that a violation of non-binding British standard is not conclusive proof of defect [24]. At the same time, in the case of *Haribo*, the Cologne Court of Appeal held that while compliance is not an automatic defence, it is a strong evidence that the product is not defective [25]. Broadly speaking, while compliance with standards does not amount to a regulatory compliance defence, it may still act as a *presumption* that the product is compliant [26]. Conversely, non-compliance with standards may be interpreted as failing to meet the legitimate safety expectations of the public.

The recent case of *Überlingen (Manufacturers)* breathed new life into the discussion on product liability in the aviation industry. In the case, the manufacturers of the collision avoidance system, which was installed onboard the two aircraft involved in the Überlingen accident, successfully invoked the defence because of compliance with mandatory requirements imposed by the FAA. The case concerned, *inter alia*, a software update that was available but could not be installed as the standard mandated the use of specific algorithms, ie the standard did not leave any margin of appreciation to the manufacturers. Remarkably, the court applied the Hague Convention on the Law Applicable to Products Liability of 1973 which, based on the principal place of business of the defendants, determined as applicable the law of the US states of Arizona and New Jersey. Nevertheless, authors agree that the essence of the regulatory compliance defence in US law is in line with its embodiment in the Product Liability Directive [8].

The decision in *Überlingen (Manufacturers)* is important in at least two directions: (1) it reinforces the applicability of the regulatory compliance defence to manufacturers in the heavily regulated aviation industry; and (2) brings to the fore the discussion of holding standard-setters and regulators liable for the choices they make in adopting mandatory standards. However, with the advent of autonomous systems, both

‘victories’ may prove to bring only short-lived comfort for the aviation industry.

First, the regulatory compliance defence would be hardly applicable to autonomous systems in the absence of sufficiently precise mandatory regulations. As rightly noted in literature, the current way of drafting standards can at best ‘codify’ the “desire that such systems be reliable” [18]. The certification challenges would likely require an entirely new regulatory approach. Several ways have been proposed in literature [18],[6]:

- a) Employing existing regulatory approaches by limitation of the autonomy’s scope either by (1) placing a human in the loop or (2) making the operational context uniform.
- b) Data-driven multistage approach modelled after the approval process for drugs for medical devices.
- c) Modification of certification standards to enable a more dynamic software structure while keeping the existing safety principles.
- d) Development of new verification approaches where testing is replaced by formal methods.¹
- e) Certification of adaptive functions providing advanced capabilities (eg, recovery from aircraft upset etc.) by treating the system differently based on the time at which it executes (eg, take-off, cruise, landing)
- f) Development of a licensing mechanism for autonomous systems based on the pilot licensing regime which, after demonstration of extensive knowledge and skills, leads to certification.

Nearly all proposed solutions have a bearing on the standardisation and certification process. The solutions in (a) and (c) seemingly involve minimal modifications to the certification process, while those suggested in (b), (e) and (f) will require either major changes or a complete shift of the certification paradigm.

In any case, from a legal point of view, if a certification authority and/or a standardisation body has issued a mandatory regulation which has been complied with by the manufacturer, the regulatory compliance defence will be available. This will not be the case, however, in the testing-based validations in (b) and (f) since their focus would be on the acceptable behaviour of a system which could easily be rendered invalid by a single change to the system [6]. A potential solution to the problem of unanticipated changes is the integration of the approach of machine-driven adaptation with human-driven evolution of the system [28]. It is questionable whether a mandatory regulation for autonomous systems could be precise enough as to

¹ Mathematically based techniques for the specification, development, and verification of software aspects of digital systems which allow automated and exhaustive verification of properties [27].

prescribe specific design choices without leaving any margin of appreciation. Furthermore, any testing-based validation, no matter how comprehensive, could fail to account for the potential of a system learning new behaviour that has not been anticipated during the development. Legally speaking, any such unanticipated change, to the extent it fails to meet the safety expectations of the public, is likely to be treated as a defect. In such cases, even though the manufacturer would have complied with the mandatory regulation of a certification body, their product would still not qualify for the regulatory compliance defence because the defective behaviour would not be the result of compliance with the mandatory regulation and there would be no causal link between the two. This situation raises the reasonable question of whether the certification body could be held liable for its failure to conduct a comprehensive testing-based validation and against what standard its conduct would be judged.

It would be no exaggeration to say that the liability of certification and standardisation bodies is enigmatic. As reported in literature, the cases of standardisation² and certification bodies³ held accountable for adopted mandatory standards are “notoriously rare” [8]. Claims that standard-setters and regulators are “not regularly accountable through legal mechanisms” [8], though, are imprecise. In the case of mandatory standards imposed by a state, the state could be challenged and the rules for liability of public authorities exercising regulatory functions should apply [26]. Admittedly, the situation is more complicated when it comes to the liability of standardisation and certification bodies at EU level.

In the EU, the EC has recognised EUROCAE as the competent body to cooperate with the European Standardisation Organisations (ESOs) in the preparation of European Standards (ENs) and Community Specifications (CS).⁴ EASA has equally recognised EUROCAE for its role in developing aviation safety technical documents. While these standards are considered soft law from a legal perspective, as they set minimum performance requirements, their recognition by certification bodies such as EASA in mandatory regulations essentially transforms them into hard law. In doing so, however, EASA does not become accountable for the choices made in these standards [8].

In principle, as a body of the EU, EASA’s decisions concerning airworthiness and environmental certification, pilot certification, air operation certification etc. may be appealed before a Board of Appeals. Furthermore, actions may be brought before the CJEU for the annulment of acts of EASA which are legally binding on third parties, for failure to act and for damages caused by the agency in the course of its activities.

The case law on the liability of EU institutions suggests that as a general rule liability could be attached only exceptionally,

in cases involving a sufficiently serious breach of a rule of law for the protection of an individual [29]. The court does not seem to distinguish between liability for legislative and liability for administrative measures, focusing instead on the criterion of the degree of discretion enjoyed by the institution [30]. The difficulty here is that the intensity of the judicial review is often described as “peripheral”, especially in cases where the body in question enjoys a wide margin of appreciation [31]. Given the margin of appreciation enjoyed by EASA, one can imagine establishing a manifest breach would be a cumbersome task.

It follows that holding the certification body liable for its failure to conduct a comprehensive testing-based validation of an autonomous adaptive system could be a hard case. While strengthening the accountability of standard-setters and certification bodies for their design choices could be made by legislative amendments, given the maturity of the current system, this is unlikely to happen in the near future. Thus, calls for considering the potential impact of a certain standard on the liability of manufacturers in the drafting process are a welcome ‘soft’ measure that could improve legal certainty [8].

V. AUTONOMY IN THE SKY: UNMANNED AIRCRAFT SYSTEMS

The challenges of liability of manufacturers for ‘defective’ autonomous systems in the aviation industry may not be as remote as some would think. Considering the fast-growing market of unmanned aircraft systems and the ensuing development of new commercial services, these challenges may turn to be just around the corner.

In the recently proposed draft regulation laying down rules for unmanned aircraft operations in the open and specific category, EASA explicitly provides for autonomous operations in the specific category.⁵ ‘Autonomous operation’ is defined as an operation during which an unmanned aircraft operates without the possibility for remote-pilot intervention in the management of the flight. The proposal foresees that aircraft in the specific category, which covers the majority of the commercially viable operations, are organised around the concepts of operational authorisation issued to the operator by a national aviation authority based on a risk assessment process. Thus, in line with EASA’s operation-centric, proportionate, risk- and performance-based approach, in the specific category it is the operator that is responsible for compliance with the technical requirements laid down in the authorisation or the expected standard scenarios. Unlike the specific category, in the open category the manufacturer is responsible for compliance with the technical requirements based on the regime of essential requirements and conformity assessment (CE marking).

As the operator would be the ultimately responsible for the technical requirements of the unmanned aircraft in the specific category, the liability of the manufacturer could only be engaged indirectly. For example, in the acceptable means of

² Eg, the Radio Technical Commission for Aeronautics (RTCA) and the European Organisation for Civil Aviation Equipment (EUROCAE).

³ Eg, FAA and EASA.

⁴ Article 4 (1) (a) Regulation (EC) No 552/2004 on the interoperability of the European Air Traffic Management network.

⁵ Article 2 (1) (d) and UAS.SPEC.10 EASA Notice of Proposed Amendment 2017-05 (A).

compliance⁶ listed in an annex to the proposal, in the case of autonomous operations, the operator should ensure that the UAS complies with the instructions provided by the manufacturer. These instructions would certainly play a role in determining the public's safety expectations. Furthermore, any such 'instructions' may, in their own right, be treated as products for the purposes of product liability.⁷ In this case, provided the acceptable means for compliance and the guidance material are non-binding, the regulatory compliance defence cannot be invoked. Similarly, manufacturers of software and software frameworks could be held liable for defects in the provided software and the accompanying instructions. In light of the issues with the definition of defect and the liability for *potential* defects, discussed in section III above, software companies engaged in the development of software frameworks or applications may face challenging legal uncertainty.

In addition to the open and specific categories, EASA foresees a third category of UAS operations (ie the certified category) which is not subject to regulation by the proposal. This category will require certification of the aircraft and licencing of the flight crew. Examples of such operations include, *inter alia*, large or complex UAS operations over assemblies of people, large or complex UAS operating beyond visual line of sight in high-density airspace, UAS used for transportation of people etc. Thus, potentially, any large-scale UAS operation would fall within the certified category. While EASA is planning to propose first rules for the certified category in the beginning of 2018⁸, it is apparent that the regime will be based largely on the model of manned aviation. Conversely, this means that the challenges of the existing product liability regime, particularly with respect to the regulatory compliance defence, will also persist in the certified category.

VI. RECOMMENDATIONS AND CONCLUSIONS

The digitalisation and increasing autonomy of aviation systems disrupts the traditionally conservative domain of aviation safety and puts to the test the limits of existing product liability rules and certification mechanisms.

While there are no doubts that the Product Liability Directive applies to the aviation domain, reasonable concerns have been raised as to whether its 'strong-arm' power can reach the major aviation technology producers which are currently mostly US-based.⁹ The stated aim of competitiveness

and global leadership of the EU in the development of a "drone ecosystem" [32] is echoed in the regulatory actions of EASA. Furthermore, the rapidly growing number of companies and research organisations from the EU engaged in development of software for unmanned aircraft systems is a strong indicator of the EU's innovative potential in developing autonomous systems for the aviation sector. This delicate balance, however, could be easily distorted by legal uncertainty induced by the fact that the existing product liability regime is arguably unfit for such purposes.

The analysis in the previous sections demonstrates that autonomous systems' learning and adaptive capabilities are a significant challenge for the product liability regime. Most of these issues could only be resolved with legislative intervention. To this effect, the following amendments could be suggested:

- *Software should be included explicitly as a product and the definition should extend to cover both non-embedded software and 'software as a service'.*

This measure is critical for reinforcing the deterrent role of product liability, particularly for entrants that are new in the aviation industry, such as young companies and research organisations developing software for unmanned aircraft systems.

- *Objective standard for measuring the "abnormal potential for damage" must be crafted to restrain the otherwise broad scope of the liability for potential defects and to prevent innovation from stifling.*

In the absence of an objective standard against which the criterion of "abnormal potential for damage" could be measured, the liability for *potential* defects introduced with *Boston Scientific* could have serious repercussions for producers engaged in autonomous systems development. The European legislator should also consider the legal nature of the liability engaged in these cases since the criterion of knowledge on the part of the manufacturer adds a negligence twist to the otherwise strict liability based regime. Furthermore, the regulatory impact of liability based on *potential* defects and *potential* damages should be carefully evaluated as it could have the negative effect of discouraging manufacturers to share information on potential risks, especially when the risks are considered to be minor, out of fear of claims. In the domain of aviation, this could have catastrophic consequences.

- *The state of the art defence must be reassessed in light of the very high standard for exoneration in the case of autonomous systems.*

The learning and adaptation feedback loops in an autonomous system can lead to changes in its behaviour that may create new risks which, by their nature, cannot be known or foreseen. Thus, in light of the liability for *potential* defects, in order to rely on the state of the art defence, a manufacturer must prove he could not have known about the risk of product

⁶ Article 2 (1) (a) of the proposal provides that acceptable means of compliance are non-binding standards which may be used to demonstrate compliance.

⁷ The question of whether information as such falls within the ambit of the Product Liability Directive is subject to discussion in literature. Strong arguments as to why information, especially when 'materialised' on a tangible medium, should be treated as a product could be found in [23].

⁸ Based on the presentation of Yves Morrier of EASA during the UAS Open and Specific Category Workshop hosted by EASA in Cologne on 5th July 2017.

⁹ This was also the case with Honeywell and ACSS in *Überlingen* (Manufacturers).

malfunctioning in the future, even with the most advanced level of scientific and technical knowledge. Provided the leading role of the criterion of ‘safety expectations of the public’ in determining whether a product is defective, the defence may be rendered effectively useless to manufacturers of autonomous systems.

- *The regulatory compliance defence’s role must be reassessed in light of the certification challenges experienced by certification authorities regarding autonomous systems*

If manufacturers cannot rely on the regulatory compliance defence for autonomous systems certified for their ‘proper’ behaviour on the basis of testing-based validation, then the accountability of certification bodies and standard-setters for their design choices and verification and validation mechanisms should be made more explicit.

The highly regulated environment and the paramount importance of safety in aviation have had impact on the liability for defective products which reveals certain specifics compared to other domains. This has led some authors to call for the adoption of a special (possibly international) legal instrument for product liability in aviation [8]. However, given the state of international affairs and the difficulty in promoting a new legal instrument in a field as conservative as aviation, this proposal is unlikely to see the light of day anytime soon.

Even if no international product liability regime for aviation could be agreed in the near future, the aviation industry in the EU has a unique opportunity to participate in the drafting of the new rules of product liability in the EU and to state in a loud voice its concerns and propose solutions to issues which otherwise threaten to suffocate its innovation potential.

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