Design According to Liabilities: ACAS X and the Treatment of ADS-B Position Data

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Abstract— **This paper presents the results of the test application of the Legal Case on ACAS X, the new generation airborne collision avoidance system. The Legal Case is the novel methodology, recently developed by the ALIAS project, to address liability of innovative systems for aviation and ATM. The Legal Case application on ACAS X was conducted in cooperation with EUROCONTROL; IATA, air companies and industries. Results are meant to inform ACAS X's future development.**

Liability allocation; ACAS X; Legal Case methodology; Aviation products liability

I. Introduction

This paper analyses the liability issues of the new generation Collision Avoidance Systems (ACAS X). The legal analysis was carried out by means of the Legal Case, which is a novel methodology to assess the legal risk of innovative aviation technologies. The Legal Case prototype was launched in 2013 as main outcome of the ALIAS I project (Addressing Liability Impact of Automated Systems) and is currently being validated in the framework of ALIAS II, which was funded as follow up activity.

ACAS X was selected as a suitable technology to undergo a test application as part of the validation of the Legal Case methodology. The activity was supported by EUROCONTROL, IATA, aviation industries and air companies, who directly participated in the test application as user group of the Legal Case process. These bodies have most ownership of and responsibility for the deployment stage of the ACAS X technology.

Due to space constraints, the paper only discusses potential liability implications of one specific design choice, namely different options for the treatment of Automatic Dependent Surveillance – Broadcast (ADS-B) aircraft position data. It illustrates how liability considerations can affect design choices and the development process if opportunely taken into account.
The paper is organised as follows:

- section II provides a framework on liability and automation in future aviation scenario.
- section III presents an overview of the Legal Case methodology
- section IV presents the test application of the Legal Case on the ACAS X concept
- section V provides results and recommendations
- section VI addresses final considerations

II. Liabilities and Automation

Human Performance studies on the development of new ATM technologies increasingly conclude with the recommendation to investigate liability issues associated with the use of highly automated systems, as they are likely to constrain the acceptability by the end-users. The reports of validation studies often provide a list of such issues, recommending further investigation, but no action is taken to address them at the validation stage[1].

The increasing automation foreseen for the future ATM [1][2], while augmenting capacity, safety and efficiency, will likely change the tasks of operators, making them more dependent on data and information that someone else, including automated tools, has previously selected or approved as reliable. Such a change would demand for a critical

[1] An example is the recent Human Factors studies on Performance Based Navigation (PBN). The utilisation of the aircraft PBN capability aims at providing more route options, by enabling a route structure design with closer lateral spacing which, while not adversely impacting safety, creates a more efficient use of the available controlled airspace. This is primarily done using Close Route Spacing (CRS). CRS implements closely spaced, pre-defined 2D routes, under the assumptions that: *i)* ATCOs can place a very high degree of reliance on the aircraft capability to consistently navigate to a high degree of accuracy and predictability; *ii)* Flight crews can monitor the actual airborne PBN performance through the On-board Performance Alerting and Monitoring (OPMA) system. The PBN concept foresees a sort of monitoring delegation from ATCOs to crew, thanks to the availability of the OPMA system. The results of the PBN studies recommended to engage more effort in the investigation of the balance of responsibility between ground and airborne side in monitoring the aircraft trajectory during normal operations as well as in case of emergency procedures, such as the undetected degradation of the PBN capabilities (i.e. without an alert from the airborne OPMA system). Liability issues associated to the balance of responsibility between crew and controllers are elements that can constrain the acceptability of this new technology, that otherwise (i.e. from the human factors point of view) would be considered suitable and feasible to implement.

revision on the actual human contribution to the performance of complex socio-technical systems, and consequently, on the criteria for the allocation of liability [3]. Two main questions are considered prominent in this context:

- to what extent the use of new automatic tools may shift liability for accidents from operators to technology, namely from operators to manufacturers, system designers and aviation organizations such as Air Navigation Service Providers, certificatory Agencies, etc;
- whether current liability regimes at both national and international levels are suitable to address failures related to automated technologies, having developed a clear methodological legal framework and tools.

The ALIAS Project is promoting the idea that the ways in which liabilities are attributed and distributed among the stakeholders[2] (and their possible effects in terms of stakeholders' acceptability) have to be properly taken into account during the design process, according to a new approach that we have called "design according to liabilities" [4]. The idea is that addressing liability issues proactively (i.e. earlier in the design process) would be easier, less costly and controversial than at later stages, when the system is deployed.

The design according to liabilities entails not only a change of perspective within the user-centered design methodology, but also a new approach towards liability. Such an approach looks at liability as one of the inherent properties of an ATM system, being it likely to affect stakeholders' acceptability and constrain technological deployment, in the same way as safety and human performance.

III. LEGAL CASE

The Legal Case addresses the legal risks for the different stakeholders involved in the design and implementation process of a certain technology. A legal risk concerns the probability of an unwanted legal outcome (i.e to be ordered to pay damages), as a consequence of uncertain factual circumstances (i.e an accident) and/or uncertain future legal decisions (i.e. the decision taken by a judge). The legal case is meant to detect any issues pertaining to the allocation of liabilities and to address such issues before system's deployment, through convenient technological adaptations or legal arrangements.

A. THE LEGAL CASE PROCESS

As shown in Fig. 1, the Legal Case outlines a 4-stepped process, where each step (rectangles in the diagram) works as input for the subsequent one. After collecting background information on the technology (Step 1), the liability risks for all involved stakeholders are identified (Step 2). Legal measures to mitigate unbalances are then proposed, which undergo stakeholders' acceptability (Step 3). The results of the assessment of the technology are collected in the Legal Case Report (Step 4).

[2] For an analysis of liability relations with regard to automation in aviation, see [5]

Figure 1: The Legal Case process

During Step 3 the legal measures proposed to mitigate the liability risks identified above are presented to the stakeholders and discussed in a structured way. If all the stakeholders agree on the legal measures produced as results of the legal analysis carried out in Steps 2 and 3, the information on liability attribution and measures is included in the concept documentation. This information will be implemented into contractual and other private regulations or into recommendations to public authorities. Otherwise, if a general agreement on the proposed measures cannot be found, the parties will reconsider whether a different legal design should be adopted or whether the allocation of tasks and the operational concepts associated with the technology should also be reviewed. In the latter case, the results of the safety and human-performance cases (if already carried out as it is likely to happen) may also have to be re-examined.

A set of supporting tools –such as tables to evaluate levels of automation and identify tasks and duties, flow diagrams to guide the assessment process, tables and reports– sustain the application process.

IV. LEGAL CASE APPLICATION TO THE ACAS X CONCEPT

In the following we present the results of the Legal Case test application on ACAS X.

The research on the ACAS X technology started in 2008, funded by the US Federal Aviation Administration (FAA), and was carried out in collaborations with the Lincoln Laboratory and the Massachusetts Institute of Technology Computer Science and Artificial Intelligence Laboratory. The new system is based on dynamic programming and - if successful - will ultimately replace the current generation of systems ACAS/TCAS II (Traffic Collision Avoidance System). Dynamic programming allows generation of alerts using an off-line optimisation of utility; ACAS X is expected to address and alleviate technical limitations of the current system, in particular unnecessary advisories, operational limitations, long update cycles and suboptimal surveillance data use. ACAS X is also expected to reduce collision risk, provide increased adaptability to surveillance inputs and flexibility for operations. Importantly, this new concept of operations also enlarges the classes of potential users as it provides for variants that could be deployed for General Aviation and Remotely Piloted Aircraft Systems (RPAS).

Factors that influenced the choice of this technology to undergo Legal Case application included the level of maturity, the likelihood of deployment and the level of automation. ACAS X is a technology at an early stage of maturity. Therefore, the Legal Case application could inform the design from the legal and liability allocation perspective. ACAS X has a high level of automation[6][7]. Moreover, it affects several actors within the ATM system at the same time, in terms of responsibility and hence potentially liability, being situated at an intersection on the one hand between the air navigation providers and airlines, and on the other hand between ATCOs and pilots. In addition, ACAS X has a strong human-machine component. Human factor effects will be relevant to its development and use. Finally, ACAS X has many similarities with TCAS II for which legal analyses could be retrieved from the case law.

A. *The ACAS X operational concept*

Whilst remaining operationally similar to TCAS II, ACAS X presents important functional differences. Both systems work in the collision avoidance layer of ICAO's conflict management system and issue TAs (Traffic Advisories) and RAs (Resolution Advisories) to pilots. The types of alerts foreseen by the ACAS X concept of operations are identical to those issued by TCAS II, but their presence, timing, sequence and efficiency may be different.

ACAS X will differ from the previous generation of ACAS in several respects. First, it can use a wider range of surveillance sources (e.g. transponder interrogations, ADS-B, ADS-R, electro-optical). Secondly, it has a new internal logic TRM (Threat Resolution Module) based on numeric lookup tables. The new collision avoidance logic can be optimised for different surveillance sources, operating environments and operational requirements.

Currently four variants of ACAS X have been envisaged: ACAS X_a, ACAS X_p, ACAS Xo, ACAS Xu.[3] Amongst these variants, ACAS X_a is an active version of ACAS X, which uses active interrogation/reply protocols and Automatic Dependent Surveillance – Broadcast (ADS-B) and is intended to be a direct replacement for TCAS II. ACAS Xo allows compatibility with special operations beyond the scope of ACAS X_a, such as Closely Spaced Parallel Operations; ACAS X_p, will use only passive ADS-B surveillance and is intended for general aviation. Finally, ACAS X_u is customized for Unmanned Airborne Systems (UAS).

In terms of maturity, the overall ACAS X concept has passed the feasibility stage (v2 of the EOCVM concept lifecycle model) [8]and is now at a stage of pre-industrial development and integration (v3). ACAS Xa is the most advanced at v3, while the other variants are less mature. ACAS Xu and ACAS Xo are at a v2 level of maturity, while ACAS Xp is at v1. It is planned for ACAS Xo to be standardised and introduced into service at the same time as ACAS Xa, that is, to be commercially available in the early 2020s. The concept of operation does not foresee ACAS X to be mandatory in the US regulatory framework; while in the European context the question has not been addressed yet. ACAS X is envisioned to be fully backwards compatible and interoperable with current TCAS.

B. *ADS-B Design Choice*

The treatment of unvalidated ADS-B positions by ACAS X emerged as one of the controversial design issues with respect to liability. While the issues concerning ADS-B data are more general than their use for ACAS X, and may be explored in a broader way, nevertheless they have a direct impact on the ACAS X design. In the following, the results of the analysis of the corresponding design options are discussed.

ADS-B data is a satellite based broadcast surveillance technology. ADS-B equipment will be mandated widely by legislation entering into force in 2020 in the United States[4], and in 2017 in the EU. While TCAS II relies on secondary surveillance radar transponder signals, Xa will have active means to collect surveillance data. Xp will rely on "passive" surveillance data, which does not use active interrogation/reply protocols, but only ADS-B surveillance. The ACAS X system's incorporation of new surveillance data sources, such as ADS-B, is one of the key changes foreseen. ADS-B is viewed as an enabler in the change from radar based towards satellite based aircraft location systems.

One of the current controversies is how ACAS X should process (unvalidated) ADS-B tracks. 'Unvalidated' refers to positions which are solely based on ADS-B data, not validated through other surveillance data sources. The design options currently debated are 1) not to show positions based on ADS-B data at all, 2) to display such positions in a distinct way from other positions, without the possibility of generating a TA 3) to display them in a distinct way from other positions, with a warning such as a TA, but no RA 4) to treat them indifferently from other positions and issue TAs and RAs in regular fashion.

From a safety perspective, it was debated in the user group whether ADS-B data is less reliable, and whether this issue can be overcome through certification. Additionally, the risk of spoofing –i.e., of fake ADS-B signals being created– was specifically addressed. In particular, the adoption of additional security measures such as encryption, and the effect of certification on spoof-proofing of ADS-B were discussed[9]. The mere display of ADS-B data (i.e. Options 2 and 3) was questioned from a functional perspective, arguing that the purpose of the ACAS X concept is collision avoidance and not traffic awareness.

[3] In this paper we will use the generic name ACAS X, unless we specifically refer to one of four versions of ACAS X.

[4] 14 CFR Part 91, Federal Rule published in the Federal Register on May 28, 2010.

Lingering behind these opposing arguments is an additional concern, namely that of liability. **What would happen if ACAS X were to issue an advisory based on ADS-B data, which ultimately proves faulty and causes an accident? Who is liable for providing and displaying faulty input data and who is liable for acting upon such data?**

C. The Level of Automation (LOAT) analysis of ADS-B options

The Level Of Automation Taxonomy (LOAT), developed by SESAR 16.5.1[10], is used in the Legal Case to assess the levels of automation introduced by an ATM innovation and to determine the corresponding impacts on the division of tasks between humans and machines. The LOAT table provides criteria for assigning a level of automation to a technology with regard to different cognitive functions (information acquisition, information analysis, decision and action selection and action implementation).

Below you can find the Supporting Table for the LOAT outcomes for the ADS-B design options currently discussed in the ACAS Xa variant. The following analysis was obtained as a result.

Option 1 involves no technical support for positions based on ADS-B only data, therefore all responsibility for collision avoidance lies with the pilot and supporting processes (air traffic control, alternative air traffic awareness tools). Under Options 2 and 3, information acquisition is automated and therefore supported by the technology at a rather high level. The information analysis for unvalidated ADS-B positions on the other hand is only partially taken over by the system. Option 2 arguably requires greater efficacy from the pilot as s/he has to capture the visual display and is not, as in Option 3, aurally alerted by a TA for unvalidated ADS-B traffic.

In Options 1-3, the pilot remains entirely responsible for both decision-making and action implementation. Additionally, the pilot is visually alerted that the positions displayed derive from unvalidated ADS-B sources. The ACAS X system therefore induces the pilot to question the reliability of the data processed in the system. At the same time, the decision-making and execution is left entirely to the pilot. In terms of responsibilities, this places the pilot in a dilemma as the data is presented visually distinct as ‘second class data’. Only in Option 4 does an unvalidated ADS-B position trigger a regular traffic advisory, resulting in automated decision-making and action selection.

This analysis points to an inherent uncertainty: who should be responsible for taking the risk of selecting an action that is based on unvalidated ADS-B data: the technology (Option 4) or the pilot (Option 2-3)? In particular, the results of the LOAT analysis point to human-automation shifts in responsibility with respect to automated decision-making and action selection that deviate from the initial assessment of the ACAS Xa concept and the legacy of TCAS II.

The LOAT analysis identifies shifts in task responsibilities, in particular between technology and humans. Task-responsibilities concern requirements pertaining to the correct performance of a certain task, by humans or technologies, and their violations may lead to liabilities. When the technology is at fault, producers or maintainers may be liable.

V. Stakeholder-based Analysis of Liability Allocation, including recommendations

In the following we briefly summarize the results of the legal analysis. For each stakeholder, first the liabilities for the four design options are presented, then a short statement of the main rationale for such liability is provided, and finally the proposed liability mitigation measures are presented.

A. Pilot/Air carrier liability allocation

Based on the level of automation analysis, there is significant task-responsibility uncertainty with respect to the tasks allocated to the pilot in ADS-B only design options 2 and 3. This was a prime concern expressed in the user group.

In particular, our responsibility analysis shows that under design Options 2-3 the pilot remains entirely responsible for analysis of ADS-B data, and thus for decision-making and action implementation based on that analysis. In legal terms, this may translate in an increased duty of care for the pilot under Options 2-3, because he/she needs to take into account the additional data available and assess its reliability, which may entail a higher legal risk that his/her conduct may be considered negligent. Moreover, the larger responsibility for pilots under Options 2 and 3 may have an impact on air carrier liability.

In fact, under such design options, it may be difficult for the air carrier to provide the proof that the damage was not due to the negligence of its servant (the pilot), a proof which is required for the air carrier liability to be limited, under international law[5]. Figure 2 presents the liability risk for the pilot under the different design options.

Scenario	Pilot liability risk			
ADS-B only	Option 1) Same as TCAS II	Option 2) Medium	Option 3) Medium	Option 4) Low

Figure 2: Liability risk for pilot in ACAS X ADS-B only

	Capped liability	Unlimited liability	
Montreal Damages	113.100 SDR	Negligence	Not sole negligence of other party
3rd party damages (national law)	Strict liability in some EU States	Fault liability (e.g. US)	Strict liability (Some EU States)
3rd party damages (Rome Convention, 1952 Belgium, Italy, Lux, Spain)	Strict liability, depending on weight, ~45000 US $ per injury or 4 mln overall per incident	Intent or omission of agent/servant	

Figure 3: Liability risk for air carrier

[5] Convention for the Unification of Certain Rules for International Carriage by Air - Montreal, 28 May 1999

	Design defect				Warning defect
	Design defect risk	State of the art defence strength a) [if industry standard test, and manufacturers cannot choose options] b) [if industry standard test, and manufacturers can choose options, then depends on industry standard] c) [under the technical advancement test]	Regulatory compliance defence strength For all: Depends on how detailed the standards are written and whether manufacturers have discretion to opt for different ADS-B design options.	Net liability risk for design defects (risk&defence)	Liability
Option 1	Weak-medium	a) Strong b) indeterminate c)weak	Weak-medium	Medium	Low
Option 2	Medium	a) Strong b) indeterminate c)medium-strong	Weak-medium	Medium	High
Option 3	Medium	a) Strong b) indeterminate c)medium-strong	Weak-medium	Medium	High
Option 4	Medium-high	a) Strong b) indeterminate c)medium-strong	Weak-medium	Medium	Low-medium

Figure 4: Liability risk for manufacturer in ACAS X ADS-B only

TABLE I. LOAT OUTCOMES FOR THE ADS-B DESIGN OPTIONS

	Information Acquisition	*Information Analysis*	*Decision & action selection*	*Action implementation*	*R-Impact Analysis*
1. No display of unvalidated ADS-B positions	A0	B0	C0	D0	All responsibility on alternative processes/pilot.
2. Display unvalidated ADS-B positions visually distinct, no advisory	A4	B2	C0	D0	System provides information only, pilot: large responsibility.
3. Display unvalidated ADS-B positions visually distinct, plus traffic advisory	A4	B3	C0	D0	Pilot: responsible for implementation, but has data available to 'second guess' the reliability of data processed in the system.
4. Regular display and advice	A5	B5	C4	D2	Execution left to pilot, all other factors to machine.

Air carrier liability for damages to passengers and baggage should be similar as under current TCAS configuration. Also in case of an accident causing damages on the surface, the liability risk for an air carrier responsible of an aircraft equipped with ACAS X would not be different from liability for an aircraft equipped with TCAS.

Organisational liability will be a residual case of liability for air carriers: it is a kind of fault liability emerging when the harm can be directly related to or caused by business activity. The enterprise is at fault whenever it could have prevented the harm by adopting reasonable precautions, concerning in particular training, provision of adequate documentation, organizational management, and ensuring the overall safety of its activities. According to our analysis, the liability risk for organisational liability seems to be low.

In order to limit the liability risk, measures were proposed that provide evidence that pilots' actions were in line with professional due care. In particular, the task allocation should be enshrined in legally relevant documentation e.g. ACAS manual, PANS-OPS and training requirements should be captured in legally relevant documentation such as Chapter 5 of Doc. 9863 (ACAS Manual) and in the attachments to Doc. 8168 (PANS-OPS). Figure 3 presents the main kinds of liability for air carriers.

B. ATCO/ANSP

The complexity problem for Options 2 and 3 was also identified for the ATCO position, aggravated by the fact that there are gaps in the current procedures for ACAS (in particular concerning training). After an RA, the ATCO ceases to be responsible for separation and may not interfere with the flight path. However, a professional duty could be construed according Paragraph 2.2. of Annex 11 of the Chicago Convention, according to which the ATCO should provide information useful for the "safe and efficient conduct of the flight".

In options 2) and 3) no RA is issued, only a TA and this may result in a higher degree of responsibility for the ATCO confronted with requests for clarification by pilots. Figure 5 presents the liability risk for the ATCO under the different design options.

Scenario	ATCO liability risk			
ADS-B only	Option 1) Same as TCAS	Option 2) Low-Medium	Option 3) Low-Medium	Option 4) Low

Figure 5: Liability risk for ATCO in ACAS X ADS-B only

Procedures must be clarified with respect to the obligations of the ATCO. The proposed liability mitigation measure consists in providing evidence that ATCOs' actions were in line with professional due care. Guidelines for controller actions and training must be enshrined in official documentation. ATCO training requirements regarding ACAS are currently much less well developed than for pilots.

C. *Manufacturer liability*

Manufacturers[6] are primarily liable for production defects, design defects or warning defects. 'Net' liability depends not only on initial liability risk, but also on the strengths of defences that may be applicable (most pertinent are the state of the art defence and the regulatory compliance defence). Figure 4 shows the risk for manufacturer with regard to design defect and warning defect, under the different design options.

Our analysis suggests several measures mitigating design defect risk. In particular, the risk can be addressed by (1) basing the design on scientific studies (specific concerns are the reliability of ADS-B data in general, and the exposure of signals to spoofing); (2) establishing the effects of certification on safety; and (3) exploring safety mechanism designs to limit exposure to ADS-B risks. The manufacturers' liability defences can be strengthened by adopting common industry standards. To strengthen the 'State of the Art defence' common industry standards can be adopted in order to ensure that at least the customary standard of the industry practice can be met.

Another factor that affects liability allocation is the scope of manufacturer discretion allowed by standard. Generally, with less discretion on manufacturers, their liability risk decreases, although compliance with standards and regulations does not necessarily exonerate a producer from liability. Therefore, in order to limit liability of manufacturers, the ADS-B design options ought to be mandated for all manufacturers.

In order to address warning defect risks, it is suggested that manufacturers provide adequate warning information for the technology. The documentation should be designed taking into account in particular the requirements on technology information of ACAS laid down in the Barcelona Court of Appeal Judgment following the Überlingen mid-air collision[7].

Manufacturers can take additional liability allocation measures through contractual clauses concerning: (i) software components (ii) additional services such as installation, maintenance, etc., and (iii) insurance policies. In particular liability for failures of the prewritten ACAS X software component could be contractually severed from the liability of manufacturers. Responsibilities for maintenance, installation and resulting liabilities can be contractually addressed. Insurance clauses may be relevant, in particular it ought to be ensured that 'spoofing' type of incidents are not excluded through specific exclusion clauses.

A final question concerns the liability of standardisation and certification bodies. This is an ill-defined area of tort law, where legal doctrine is still not well developed, giving rise to great uncertainty. However, in general terms, it can be said that a duty of care usually exists, and that standard setters and certification bodies may be liable for breaching such duty of care, by failing to take adequate precautions against foreseeable risks. In case of the ADS-B design options foreseeable risks concern the choice to provide ADS-B only data and to generate TAs and RAs. On the one hand, not providing information or instructions can increase the risk of collision with ADS-B only aircraft, which is considered one of the highest collision risks in the airspace. On the other hand, providing such data and instructions can increase the risk of accidents when the data are false or incorrect, for instance when resulting from spoofing. Therefore, scientific evidence is needed to asses this risks and determine whether the chosen option provides the optimal balance. Figure 6 presents the liability risk for the standard setter under the different design options.

Scenario	Standard setter liability risk (Note: highly indeterminate)			
ADS-B only	Option 1)	Option 2)	Option 3)	Option 4)

Figure 6: Liability risk for standard setter in ACAS X ADS-B only

Concerning the liability mitigation measures for standardization and certification bodies, it is strongly suggested that such bodies assess their respective level of duty of care critically when setting standards and certifications. This implies determining whether (i) ADS-B data is less reliable than other data streams, and (ii) whether the reliability issue can successfully be addressed through certification. This is needed in order to ascertain whether a risk was foreseeable for the standardisation body, and whether the adopted measures will likely be judged by the courts as adequate precautions, on the basis of the available scientific evidence. The suggested measures should provide evidence that the standard setters complied with the duty of care.

Concerning the liability allocation measures, it will be important to consider the impact of how the standard is written on liability, in particular whether manufacturers have discretion; and at which level of detail the standard is written. Generally, less discretion for manufacturers will decrease the liability risk (but not eliminate it).

VI. Results: Application of the Legal Case to ACAS X

From the analysis carried out, it resulted that **the main liabilities are on the air carrier and the** manufacturer. Other liabilities are residual. However, air carrier liability is limited, and unlimited only to the extent that the pilot was negligent.

[6] "Manufacturers" here refers both to Aircraft Manufacturers and Avionics Manufacturers. While the two categories may have different responsibilities with regard to safety, they will be both subject to product liability laws.

[7] Audiencia Provincial (Court of Appeal) of Barcelona, Judgment n.230/2012, published on 8/5/2012.

Consequently, principal liability claims can also be directed towards the manufacturer to obtain higher damages.

Concerning the different design options for ADS-B, the legal analysis shows that under Options 1 and 4, the technology is in charge of all tasks except execution, therefore the manufacturer has generally a higher liability risk, and air carrier (for negligence of the pilot) a lower one. Under Options 2 and 3, the reallocation of tasks is shared between the technology and the pilot, so that liability attribution may be shared as well. The fact that the air carrier (for negligence of the pilot) has a higher liability risk does not necessarily imply that the manufacturer is exonerated, since parallel actions can be brought to courts (see for example the various litigations resulting from the Überlingen accident [11], where multiple actors were held liable, and discussions on the ALIAS Network at network.aliasnetwork.eu).

The level of automation analysis (Step 1.2) [12] showed that the human-machine interaction for ADS-B only design Options 2 and 3 are a deviation from legacy TCAS II, and shift responsibility to the pilot. These human factor and task responsibility issues may translate into product liability for warning defects for the manufacturer, and into pilot liability for negligence (and then consequently into air carrier liability). They may also determine enterprise liabilities upon the concerned organisations for having failed to provide appropriate training. The analysis suggests that the design of the information on the technology should take into account the liability analysis, for example, by providing detailed specifications on procedures to be followed by pilots or manuals accompanying the technology. For the pilot/Air Carrier the task allocation should be enshrined in legally relevant documentation; similarly, training requirements should be captured in legally relevant documentation. The same recommendations can be made for the ATCO/ANSP task allocation and training requirements.

It emerged very clearly from the stakeholder liability distribution assessment (Step 3) that the design for Options 2 and 3 was unacceptable to the pilots because of the complexity of accompanying procedures for both pilots and ATCos.

During the analysis, several technical uncertainties were identified which are due to the low maturity stage of the technology. The risk concerning the reliability of ADS-B data, the risk of spoofing, and the effects of certification on both risks could not be grounded in scientific evidence. Demonstrating that design choices are supported by scientific evidence will strengthen the position of any actor whose liability is to be assessed in front of a court.

For manufacturers, liability mitigation measures lowering the liability risk due to a design defect concretely translate into the need to ground the technology design on scientific studies. Specific concerns here are: (i) the reliability of ADS-B data in general, and (ii) the exposure of ADS-B signals to spoofing. The following measures are suggested: to explore effects of certification on safety, and to explore safety mechanism designs to limit exposure to ADS-B safety. For addressing a warning defect risks, manufacturers should take care to design adequate warning information to accompany the technology.

Furthermore, specific liability mitigation measures may strengthen manufacturers' defences, in particular by adopting common industry standards, as the industry standard may be regarded as the adequate state of the art. Manufacturers must assess the impact of potential discretion and lack thereof left in a given technology standard [13].

Several allocation measures could possibly limit the liability of manufacturers. In particular, allocation can be shifted through contractual clauses. These were identified as particularly relevant for (i) the software component of ACAS X that is developed by an outside software producer (ii) additional services such as installation, maintenance etc. Further, (iii) insurance clauses may be relevant. For example, it should be checked whether incidents caused by spoofing are covered by insurance policies.

In order to limit exposure to subsequent liabilities, it is recommended that decisions taken in particular by standardisation bodies and manufacturers are demonstrably based on scientific studies. ADS-B data issues and in particular spoofing are general issues of aviation technologies, and are therefore beyond the scope of the particular EUROCAE Working Group responsible for the development of ACAS X standards. In this respect, the concern from the standard setter appears to be that (a) there are no scientific studies on the 'spoofing' issue, which is a non-specific issue to ACAS X, (b) the certification does not concern the reliability or spoofing proofness of the ADS-B device, and (c) Safety mechanisms such as encryption for enhancing ADS-B safety were rejected during the design process of ADS-B.

The ADS-B reliability issue can be identified as a challenge for the entire socio-technical system of avionics. The Legal Case process elicited the limitations which the different roles of stakeholders place upon them, as they are constrained by resources, mandates, and functional assignments. The individual actors were therefore unable to address the ADS-B issue sufficiently, making it a typical issue to be addressed by the policy making process.

One of the main outcomes of Step 3 was detecting the tense relationship between certification and liability. Airworthiness circles often presume that when standards are complied with, manufacturers are protected from liability. As the Barcelona Court of Appeal judgment (Überlingen)[8] has recently again demonstrated, manufacturers can be liable even when they comply with all standards. These developments go hand in hand with EASA's limited possibilities to control compliance, moving towards a system of self-certification, which effectively shifts a large part of the liability risk to manufacturers. In the face of these developments, in drafting

[8] Audiencia Provincial (Court of Appeal) of Barcelona, Judgment n.230/2012, published on 8/5/2012. The Court of Appeal's argument on manufacturer's liability has been confirmed by Tribunal Supremo (Supreme Court) of Madrid, Judgment 649/2014, published on 13/01/2015

the standards for ACAS X, with respect to the ADS-B design, the standard setters should take into account the effects in terms of liability risk that result from the level of detail of the standard, and whether they provide a choice for different ADS-B design options for the manufactures.

Stakeholders, standard setters and certifications authorities should consider how standards and certification requirements may affect liabilities. It is true that compliance with certification requirements not always exonerates manufacturers from liability, but compliance can be used as a defence in product liability cases. Producers are assumed not to be liable for design features that are mandated by certification requirement and thus, a detailed certification, by reducing the scope for the producer´s discretion, also reduces the risks of producer´s liability. Moreover, the level of detail of a standard or certification and the relative scope for divergence of the manufacturer may indirectly affect the liability assessment by courts, since the standard or certification may be viewed as evidence of the ‘state of the art’ and be used as a comparator in the assessment of whether a party has acted negligently.

Standardization and certification can be instrumentalized to affect the scope of the parties’ liability and their burden of proof in litigation. In order to mitigate manufacturers’ liability risks, a detailed standard could be written which allows only little or no room for discretion, possibly specifying the kind of information and guidance material that a product must be accompanied by. In turn, this high degree of specification will shield compliant manufacturers to some extent from liability claims based on product design and information defects. Manufacturing defects, i.e. faulty product, will still remain a regular legal risk. In face of the legal uncertainty regarding certification, regulators may introduce a shift in the burden of proof so that when standards are complied with, a design is presumed to be non-defective. Such a presumption would leave open the possibility of the plaintiff to rebut the presumption by proving that nevertheless a design defect existed.

Concerning liability, standard setters and certification bodies themselves currently operate in a legal vacuum. As the analysis carried out through the Legal Case demonstrated, the potential liability is currently unclear, but it is strongly suggested that standard setters assess their respective level of duty of care critically when setting standards. On the one hand standard setters are restrained by resources (e.g. the possibility to conduct studies) and their mandate (e.g. specific technologies may be out of the mandate). On the other hand, manufacturers are restrained in their design options by the applicable standards. Under the current regime, the liability for design choices is to an important extent shifted onto manufacturers. It may be asked whether the currently weak liability of standard setters, provides insufficient incentives for standard setters to write safety-maximising standards. However, an increased liability for standard setters presupposes that they are provided with adequate resources.

Finally, it is to be considered that all ACAS manufacturers are from the US. This is expected to significantly affect the projected liability risk for damages, as in the US damages are often higher that in Europe. The current trend is for losses to become more expensive. In discussions with members of the user group, the relevance of spoofing for insurance underwriters was highlighted and the importance of buyback of exclusionary clauses such as “War, Hijacking and Other Perils Exclusion Clause” (AVN48B) was discussed as a liability displacement measure.

Overall, the potential reduction in insurance premiums depends on documented safety improvements and to some extent on “legal risk” such as case law on ACAS technologies.

CONCLUSIONS

The results of the validation confirm that the Legal Case methodology is generally easy to use and to follow and that it could be successfully introduced in the aviation domain. The use of the Legal Case and its supporting tools (including the LOAT) helped to identify the differences between the different design options in terms of automation and resulting liability risks for all the actors involved. The outcome of the legal analysis carried out with the Legal Case, namely the list of possible legal measures for new aviation systems, was considered relevant and useful by the aviation stakeholders who participated in the validation process. In particular, results of the legal analysis may support standardisation bodies and policy makers (e.g. EUROCAE WG75) in developing a complete insight of the introduction of a new technology, integrating such results with those coming from the safety analysis, the human factor analysis, etc.

The results of the validation will be an input to the consolidation of the Legal Case methodology and to the release a self-standing and ready to use tool at the end of the project.

In the future, the links between the Legal case and other SESAR Cases, in particular the Safety Case, and the Human Performance Case will be developed. Moreover, software tools will be provided, so as to automate part of the Legal Case process and to support a collaborative assessment of liability issues in multi-disciplinary teams.

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