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Scoping Improvements to 'See And Avoid' for General Aviation (SISA)

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Executive summary

Scoping improvements to 'See and Avoid' for General Aviation

Problem area
In most classes of airspace a pilot flying according to Visual Flight Rules (VFR) is responsible for separation from other traffic. This responsibility is fulfilled by applying the 'See-and-Avoid' (SAA) principle. 'However, several limitations of the 'see-and-avoid' principle have been raised by the General Aviation (GA) community. Unfortunately, there is currently no consolidated information regarding strengths and weaknesses of available solutions to mitigate the limitations of the 'see-and-avoid' principle. In the context of the European Strategic Safety Initiative (ESSI) supported by EASA and its working group addressing General Aviation safety issues (EGAST), this research study to scope the potential improvements regarding 'see-and-avoid' principle was formulated.

Description of work
The work performed in this study includes the following:

- Survey safety issues and initiatives related to SAA;
- Assess different options for augmentation of pilot's visual observation;
- Identify recommendations for harmonization (and standardization).

Results and conclusions
Mid-air collision statistics for General Aviation have been presented and discussed. Data from EASA shows that over the period 2006-2011 there were 82 mid-air collisions involving aircraft with a maximum take-off mass lower than 2250 kg in Europe. On average, there were 16 mid-air collisions in the USA annually from 1991 to 2000. Local initiatives taken in Europe to mitigate the hazards of the see-and-avoid limitations have been identified and discussed. There seems to be consensus that there is currently no solution available that mitigates all the issues related to See and Avoid. Most mid-air collisions occur because the flight crew does not see conflicting aircraft. Options to mitigate SAA limitations include e.g. improvements of the visibility of aircraft, training and education of private pilots to procedures

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Author(s)
L.J.P. Speijker
J.G. Verstraeten
C.G. Kranenburg
P.J. van der Geest

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and visual scanning patterns, and anti-collision devices for GA aircraft.

This study focuses mainly on anti-collision devices. Requirements regarding the potential candidate system solutions to mitigate issues related to the application of See and Avoid have been derived from discussions with stakeholders. Four different types of solutions have been assessed against these requirements:
A. Cooperative and active
B. Cooperative and passive
C. Non-cooperative and active
D. Non-cooperative and passive

It follows that the low cost systems that only detect cooperative traffic (with all their limitations in detecting other traffic), are the most promising to assist GA pilots. Dedicated training and aural warnings are critical to make sure that the pilot is not distracted from his primary See-and-Avoid task for Collision Avoidance. The family of cooperative and active systems (and possibly passive as well) offers a good opportunity for GA pilots to get assistance for their See-And-Avoid task.

This study scopes the potential improvements regarding the use of ‘See and Avoid’ for General Aviation in uncontrolled airspace. Four points emerge:

- The key element of SAA is to look outside for potential traffic. Training and education are considered as the best instruments to optimize this aspect.
- See and Avoid training and education could however be complemented by on-board equipment. Several systems are already widely used and provide help to the pilot to identify other traffic.
- Any on-board equipment to augment the pilot’s visual observations shall be light, low cost, and cooperative (non-cooperative will be too expensive).
- A technical standard developed by the industry needs to be encouraged.

Applicability
The following work could be undertaken to exploit this study:

- To develop a common technical standard for GA generic visual augmentation systems;
- To develop common procedures and requirements for operation of one or more system solutions in uncontrolled airspace. A safety leaflet could support the harmonization of system solutions and procedures.
- Safety monitoring will remain as difficult as today, but with a large equipment of an avoidance system, this may support surveys of situations (e.g. through collecting the number warnings raised and analysing commonalities).

NLR Air Transport Safety Institute

Anthony Fokkerweg 2, 1059 CM Amsterdam,
P.O. Box 90502, 1006 BM Amsterdam, The Netherlands
Telephone +31 88 511 35 00, Fax +31 88 511 32 10, Web site: http://www.nlr-atsi.nl

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Anthony Fokkerweg 2, 1059 CM Amsterdam,
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Telephone +31 88 511 35 00, Fax +31 88 511 32 10, Web site: http://www.nlr-atsi.nl

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Scoping improvements to 'See and Avoid' for General Aviation

L.J.P. Speijker
J.G. Verstraeten
C.G. Kranenburg
P.J. van der Geest

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Summary

In most classes of airspace a pilot flying according to Visual Flight Rules (VFR) is responsible for separation from other traffic. This responsibility is fulfilled by applying the 'see-and-avoid' principle. 'However, several limitations of the 'see-and-avoid' principle have been raised by the General Aviation (GA) community.

The main objectives (and associated methodology/approach) of this study are:
- To survey safety issues and initiatives related to 'See and Avoid';
- To assess options for augmentation of the pilot's visual observation;
- To identify recommendations for harmonization (and standardization).

Options to mitigate SAA limitations include e.g. improvement of the visibility of aircraft, training and education of private pilots in procedures and visual scanning patterns, and anti-collision devices for GA aircraft. This study focuses mainly on anti-collision devices. Requirements regarding the potential candidate system solutions to mitigate issues related to the application of See and Avoid have been derived from discussions with stakeholders. Four different types of solutions have been assessed against these requirements. It is concluded that the family of cooperative and active systems (and possibly passive as well) offer a good opportunity for GA pilots to get assistance for their See-And-Avoid task.

This study scopes the potential improvements regarding the use of 'See and Avoid' for General Aviation in uncontrolled airspace. Four main points emerge:
- The key element of 'See and Avoid' is to look outside for potential traffic. Training and education are the best instruments to optimize this aspect.
- See and Avoid training and education could however be complemented by an on-board device. Several systems are already widely used and provide help to the pilot to detect other traffic.
- Any on-board equipment to augment the pilot's visual observations shall be light, low cost, and cooperative (non-cooperative will be too expensive).
- A technical standard developed by the industry needs to be encouraged.

Recommendations for follow-up standardization and harmonization actions have been identified. EUROCAE could take the initiative to develop a common technical standard for GA generic visual augmentation systems. EGAST may develop common procedures for operation of system solutions in uncontrolled airspace. EASA could e.g. analyse hazards and causal factors related to SAA in more detail.

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Abbreviations

AC	Advisory Circular
ACAS	Airborne Collision Avoidance System
ADS-B	Automatic Dependent Surveillance Broadcast
AMC	Acceptable Means of Compliance
ANSP	Air Navigation Service Provider
ARINC	Aeronautical Radio, INCorporated
ARP	Aerospace Recommended Practice
ATC	Air Traffic Control
ATM	Air Traffic Management
ATS	Air Traffic Services
CAA	Civil Aviation Authority
CCAMS	Centralised SSR Code Assignment and Management System
CDTI	Cockpit Display Traffic Information
CS	Certification Specifications
D&A	Detect and Avoid
EASA	European Aviation Safety Agency
EC	European Commission
ELA	European Light Aircraft
EGAST	European General Aviation Safety Team
EO	Electro Optical
ESSI	European Strategic Safety Initiative
EUROCAE	European Organization for Civil Aviation Equipment
EUROCONTROL	European Organization for the Safety of Air Navigation
FAA	Federal Aviation Administration
FLARM®	Flight Alarm
FOCA	Federal Office of Civil Aviation (in Switzerland)
GA	General Aviation
GPS	Global Positioning System
GNSS	Global Navigation Satellite System
HALE	High Altitude Low Endurance
VFR	Visual Flight Rules
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
IR	InfraRed
LARS	Lower Airspace Radar Service
LAST	Light Aviation SSR Transponder
LIDAR	LIght Detection And Ranging

LADAR	Laser Imaging Detection And Ranging
LPST	Low Power SSR Mode S Transponder
LSA	Light Sport Aircraft
MALE	Medium Altitude Low Endurance
MLAT	Multi-LATeration
MTOM	Maximum Take Off Mass
NAA	National Aviation Authority
NASA	National Aeronautics and Space Administration
ORCAM	Originating Region Code Assignment Method
PCAS	Portable Collision Avoidance System
PSR	Primary Surveillance Radar
SAA	See-And-Avoid
SAE	Society of Automotive Engineers
SARP	Standards and Recommended Practices
SERA	Standardized European Rules of the Air
SSR	Secondary Surveillance Radar
SWP(C)	Size-Weight-Power-consumption(-Cost)
S&A	See-and-Avoid
TAS	Traffic Advisory System
TCAD	Traffic and Collision Alert Device
TCAS	Traffic Collision Avoidance System
TIS-B	Traffic Information Services – Broadcast
TRL	Technology Readiness Level
TSO	Technical Standard Order
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
UAT	Universal Access Technology
VDL	VHF Data Link
VHF	Very High Frequency
VLA	Very Light Aircraft
VLJ	Very Light Jet
VFR	Visual Flight Rules
WAM	Wide Area Multilateration

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1 Introduction

1.1 Background

In most classes of airspace a pilot flying according to Visual Flight Rules (VFR) is responsible for separation from other traffic. This responsibility is fulfilled by applying the 'see-and-avoid' principle, in addition to 'good practices' such as following the circuit patterns closely. 'See-and-avoid' (S&A) is the combination of seeing conflicting air traffic in time, and avoiding the traffic in an appropriate manner, following the rules of the air of ICAO Annex 2 [2]. Application of See and Avoid procedures is important, especially in regions with high traffic density, because collision risk is estimated to increase by the square of the increase in air traffic [36, 37]. However, several limitations of the 'see-and-avoid' principle have been raised by the General Aviation (GA) community [8, 10, 14, 18, and 21].

A failure to see and avoid conflicting traffic can result in a mid-air collision and in the loss of aircraft and life. Today the see-and-avoid issue is mainly addressed through procedures. However, both national and local voluntary initiatives are undertaken to supplement visual observation by electronic means. Examples are the FLARM and PowerFLARM systems for light aircraft, gliders and helicopters and TCAD for General Aviation. Their installation in several aircraft types and extended use in uncontrolled airspace has existed for some time. Spin-offs of the development of Detect and Avoid (D&A) systems for Unmanned Aircraft Systems (UAS) may also introduce new means for augmentation of visual observation. Possible advantages of such systems over human vision are: (1) these systems can scan the airspace continuously, (2) can scan a larger volume of airspace at once, (3) can scan a part of the airspace faster and more efficiently, and (4) can scan the entire airspace (i.e. there are no blind spots). One should realize that the nature of GA introduces constraints to the wide-spread use of electronic augmentation means. The types of aircraft used for GA pose limitations on the power, size, and weight of the systems. The cost of acquisition and installation must be affordable to private pilots. There might be interoperability issues with existing surveillance and airborne collision avoidance standards. In case of a growth in use of augmentation systems a need arises for standardization actions covering operation, safety monitoring, installation and maintenance.

Unfortunately, there is currently no consolidated information regarding strengths and weaknesses of available solutions to mitigate the limitations of the 'see-and-avoid' principle. In the context of the European Strategic Safety Initiative (ESSI) supported by EASA and its working group addressing General Aviation safety issues (EGAST), the proposal to perform a research study to scope the potential improvements regarding 'see-and-avoid' principle was formulated.

1.2 Scope

The scope of the study is restricted to (and focuses on) the following

- General Aviation, excluding Business Aviation (which has ACAS II [48]);
- Flights in uncontrolled airspace;
- VFR flights in daylight conditions;
- Flights in European airspace;
- The 'See' part of the 'See-and-Avoid' process.

1.3 Aims and objectives

The main aims and objectives of this research project are:

- To survey and analyse candidate options for the provision of an augmented traffic situational and collision-risk awareness for VFR Pilots in comparison to visual observation and the limitations of the 'see-and-avoid' principle;
- To survey on-going initiatives undertaken to deploy and operate augmented means of pilots' visual observation in European airspace;
- To identify the required actions to foster harmonization considering the viewpoints of the stakeholders involved;
- To identify a set of comprehensive recommendations for actions by stakeholders considering the different roles and responsibilities of GA stakeholders and the identified issues for coordinated actions in this field. It is noted that there will be no recommendations made to mandate any type of equipment.

1.4 Approach and methodology

The approach and methodology follows three tasks:

Task 1 – Survey of safety issues and initiatives related to 'see-and-avoid'.

The aim is to consolidate and characterize the key operational issues of "see-and-avoid" for GA, namely the commonly hazardous situations encountered, the identified factors contributing to deficiencies in visual observation and the existing mitigations. The analysis of safety issues will build upon existing literature covering mid-air collisions or near-misses in uncontrolled airspace and prevention measures developed over the recent period. With the support of the EGAST, a survey of initiatives taken in the different EASA Member States for the promotion of mitigations to 'see-and-avoid' limitations for GA Pilots, including their lessons-learned, will be performed.

Task 2 – Assess options for augmentation of the pilots' visual observation.
The aim is to assess the potential generic options (from pilots' perspective) for the provision of augmented traffic situational awareness and collision-risk awareness to GA pilots currently available, or in the near-term future, e.g. from developments in the area of UAS sensors. The task encompasses the identification of candidate solutions matching GA needs and constraints and their detailed comparison in term of features, performances and potential limitations, covering e.g. the risk of providing erroneous information or false warnings. In addition the respective requirements regarding installation (e.g. electrical power, size and weight), approval (airworthiness, radio frequency and interferences) and typical cost for acquisition by private pilots will be evaluated.

Task 3 – Recommendations for harmonization.
The task aims to assess the constraints and issues for harmonization of the deployment and operations of one or several generic options addressed in Task 2. The needs for standardization actions covering operation, interoperability, safety monitoring, installation and maintenance will be analysed. In addition the coordination of actions amongst GA stakeholders to support deployment initiatives and exchange of safety-related information will be addressed. The set of recommendations for harmonization actions will be presented together with the related safety benefit(s) as well as the practical steps to be taken and potential constraints/obstacles for their implementation.

1.5 Structure of the document

Section 2 presents the results from the survey of safety issues and initiatives related to 'see-and-avoid'. Section 3 assesses the different candidate solutions for augmentation of a pilots' visual observation against requirements. Section 4 provides recommendations for harmonization actions, together with the safety benefits, steps to be taken, and potential implementation constraints/obstacles. Section 5 contains the overall conclusions and recommendations, and Section 6 the references. Appendix E presents the material and results from a workshop with pilots and stakeholders from the GA community, including EGAST members.

2 Concept, hazards, and mitigations

2.1 Introduction

The concept of see-and-avoid is not specifically mentioned in ICAO regulations. ICAO Annex 2 [2] notes that it is important to exercise vigilance for the purpose of detecting potential collisions. Due to the human nature of the task to see other traffic, no regulations are specifically aimed at regulating the way a pilot is scanning for other traffic. There is an ICAO circular discussing pilot skills needed to make visual look-out more effective [3], and organizations like the European General Aviation Safety Team (EGAST) and the Aircraft Owners and Pilots Association (AOPA) provide good practices on how to scan the airspace for other traffic [4, 5]. The task to avoid other aircraft is regulated by means of right-of-way rules. See-and-avoid can be used to ensure separation from other aircraft, and has to be used to avoid collisions in case separation fails. In some cases, depending on the airspace class and flight rules, ATC will be responsible for separation. The pilot is always responsible for collision avoidance.

This section discusses the regulations and operational concepts and procedures related to see-and-avoid. It also gives an overview of known hazards of the see-and-avoid principle, using existing literature about see- and-avoid safety issues.

2.2 The see-and-avoid concept

In the European Union, the see-and-avoid concept is regulated at high level in Article 3.a.4 of Annex IV of the European Commission (EC) Regulation No. 216/2008 of 20 February 2008 on Common Rules in the field of civil aviation. This article refers to the ICAO Rules of the Air (Annex 2) [2]. This section introduces these regulations and details the operational concept by discussing the main tasks involved in seeing and avoiding conflicting air traffic.

2.2.1 See-and-avoid regulations

ICAO distinguishes three layers of conflict management [6]:

- Strategic conflict management
- Separation provision
- Collision avoidance

Strategic conflict management is achieved by a combination of airspace organization and management, demand- and capacity balancing, and traffic synchronization. Airspace organization and management entails the structuring of airspace in classes to accommodate different types of air activity, the volume of traffic and differing levels of service to best meet the needs of the airspace user. Demand- and capacity balancing allows for the efficient management of the air traffic flow, for example by limiting the number of aircraft in a sector. Traffic synchronization refers to the establishment and maintenance of a safe, orderly and efficient flow of air traffic. In controlled airspace strategic conflict management ensures that the workload of a controller separating aircraft remains at an acceptable level. In uncontrolled airspace strategic conflict management ensures a pilot is capable of providing separation from other aircraft using see-and-avoid.

Depending on the airspace class and the flight rules(IFR or VFR), either the air traffic controller or the pilot is responsible for separation. In case the air traffic controller is responsible there are formal separation minima. In case the pilot is responsible for separation he/she needs to use see-and-avoid. See-and-avoid is the combination of seeing conflicting air traffic in time, and avoiding the traffic in an appropriate manner. An air traffic controller can assist the pilot in his see-and-avoid task by giving traffic information and traffic avoidance advise. This is referred to as “alerted see-and-avoid”. “Unalerted see-and-avoid” on the other hand relies entirely on the ability of the pilot to sight other traffic in time to make evasive manoeuvres. The situation is summarized in Table 1. It should be noted that, although it is not required, flight information services and traffic advisories are in practice often provided at uncontrolled airports. Pilot to pilot communication may also assist pilots in properly executing see-and-avoid tasks.

Table 1: Responsibilities of flight crew and air traffic control per airspace class and flight rules. TA: Traffic Advisory; FIS: Flight Information Services.

Airspace class	*Collision avoidance All flight rules*	*Separation VFR/VFR*	*Separation IFR/VFR*	*Separation IFR/IFR*
A	*Pilot(s)*	-	-	*ATC*
C	*Pilot(s)*	Pilot w/ TA	ATC	*ATC*
D	*Pilot(s)*	Pilot w/ TA	Pilot w/ TA	*ATC*
E	*Pilot(s)*	Pilot w/ TA	Pilot w/ TA	*ATC*
F	*Pilot(s)*	Pilot w/ FIS	Pilot w/ FIS	*Pilot with TA*
G	*Pilot(s)*	Pilot w/ FIS	Pilot w/ FIS	*Pilot with FIS*

Collision avoidance is always the responsibility of the pilot. The pilot can be assisted in his task by on-board systems such as TCAS in the case of commercial aviation and FLARM in the case of General Aviation. ICAO Annex 2 mentions the following regarding collision avoidance [2]:

> *It is important that vigilance for the purpose of detecting potential collisions be exercised on board an aircraft, regardless of the type of flight or the class of airspace in which the aircraft is operating, and while operating on the movement area of an aerodrome.*

ICAO does not specifically mention see and avoid. In FAR part 91, the United States general operating and flight rules, the ICAO regulation is mirrored and a direct reference to see-and-avoid is added [7].

> *When weather conditions permit, regardless of whether an operation is conducted under instrument flight rules or visual flight rules, vigilance shall be maintained by each person operating an aircraft so as to See and Avoid other aircraft.*

The "avoid" part of see-and-avoid is regulated using right-of-way rules, which can be found in ICAO Annex 2 [2].

> *3.2.2 Right-of-way*
> *The aircraft that has the right-of-way shall maintain its heading and speed.*
> *3.2.2.1 An aircraft that is obliged by the following rules to keep out of the way of another shall avoid passing over, under or in front of the other, unless it passes well clear and takes into account the effect of aircraft wake turbulence.*
> *3.2.2.2 Approaching head-on. When two aircraft are approaching head-on or approximately so and there is danger of collision, each shall alter its heading to the right.*
> *3.2.2.3 Converging. When two aircraft are converging at approximately the same level, the aircraft that has the other on its right shall give way, except as follows:*
> *a) power-driven heavier-than-air aircraft shall give way to airships, gliders and balloons;*
> *b) airships shall give way to gliders and balloons;*
> *c) gliders shall give way to balloons;*
> *d) power-driven aircraft shall give way to aircraft which are seen to be towing other aircraft or objects.*
> *3.2.2.4 Overtaking. An overtaking aircraft is an aircraft that approaches another from the rear on a line forming an angle of less than 70 degrees with*

the plane of symmetry of the latter, i.e. is in such a position with reference to the other aircraft that at night it should be unable to see either of the aircraft's left (port) or right (starboard) navigation lights. An aircraft that is being overtaken has the right-of-way and the overtaking aircraft, whether climbing, descending or in horizontal flight, shall keep out of the way of the other aircraft by altering its heading to the right, and no subsequent change in the relative positions of the two aircraft shall absolve the overtaking aircraft from this obligation until it is entirely past and clear.

2.2.2 The See and Avoid operational concept and procedures

The see-and-avoid task of the pilot can be divided into four steps:

1. Detection of objects in the sky;
2. Identification of an object as an aircraft and assessing if there is a conflict;
3. If there is a conflict, determine which evasive manoeuvre is to be executed[1];
4. Execute the evasive manoeuvre.

The first two steps can be considered as the "see" part of see-and-avoid, and the last two steps as the "avoid" part. No information is available regarding the time it takes to detect an object in the sky. A proper scanning technique and knowledge of limitations may improve the chance of a timely detection, but a lot depends on chance, i.e. looking in the right place at the right time.

<u>Step 1: Detection of objects in the sky</u>
To detect objects in the sky the pilot has to look outside the aircraft. To properly fly the aircraft, the pilot also has to look on his instruments. Therefore, his time needs to be divided between looking outside of the aircraft to identify other traffic and looking at his instruments. This division of time is subject of a number of studies. A study conducted by the University of Illinois compared several recommended values for VFR operations, and found that the general guidance that emerges recommends a ratio of outside to inside scanning in a range from 3 to 1 to 5 to 1 [8]. An U.S. study [9] concluded that private pilots on VFR flights spend about 50 per cent of their time scanning outside, hence only a ratio of 1 to 1. ICAO [3] states that generally the external scan will take about three to four times as long as viewing and interpreting the instrument panel, a ratio of 3 to 1 to 4 to 1. EGAST mentions [4] trials that suggest 3 seconds for the instrument check and 20 seconds outside, a ratio of more than 6 to 1.

[1] If there are more conflicts at the same time, it will be necessary to determine priorities first.

When looking outside, the pilot needs to scan the airspace to detect other traffic. It is important to use a proper scanning technique to increase the chances of a timely detection. To be able to detect objects it is necessary to use a sequence of fixated observations, since the eye needs time to focus. A continuous sweep is not sufficient to detect objects. A pilot should feel comfortable with the scanning technique used. ICAO recognizes that there is no technique that is optimized for all pilots [3]. It does state that effective scanning is accomplished by a series of short, regularly-space eye movements that bring successive areas of the sky into the central visual field. Each movement should not exceed 10 degrees and each area should be observed for at least one second to enable detection [3]. Furthermore, a pilot should scan at least 10 degrees above and below the projected flight path of the aircraft. Figure 1 shows two scanning methods that according to ICAO proved to be very effective.

Figure 1: Explanation of two scanning methods [3]

Side-to-side scanning method

Start at the far left of your visual area and make a methodical sweep to the right, pausing very briefly in each block of the viewing area to focus your eyes. At the end of the scan, return to and scan the instrument panel and then repeat the external scan. (See Figure 4.)

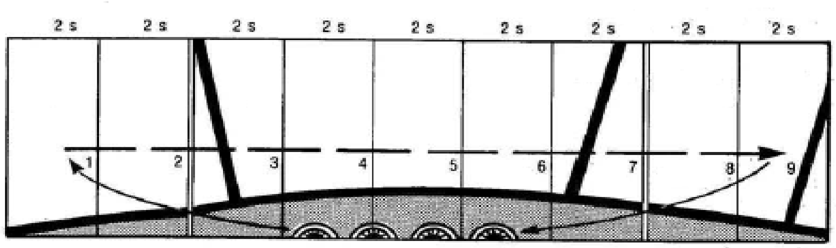

Figure 4. Side-to-side scanning method

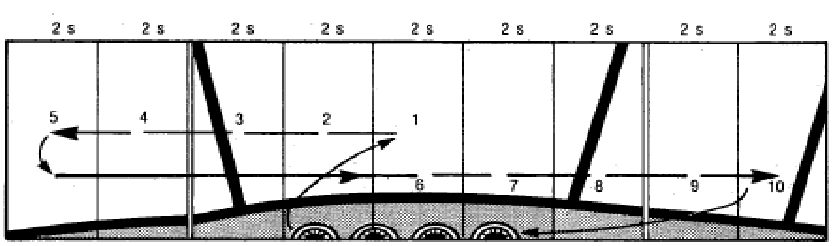

Figure 5. Front-to-side scanning method

Front-to-side scanning method

Start in the centre block of your visual field (centre of front windshield); move to the left, focusing very briefly in each block, then swing quickly back to the centre block after reaching the last block on the left and repeat the performance to the right. Then after scanning the instrument panel, repeat the external scan. (See Figure 5.)

Other actions to aid in scanning that can be performed by the pilot are gentle left and right banks to permit continuous visual scanning of the airspace and momentarily raising of the wing in the direction of the intended turn and look, in case of a high-wing aircraft, and lower the wing in the direction of the intended turn and look, in case of a low-wing aircraft. Furthermore a pilot should make head movements in order to search around vision obstructions in his aircraft, such as doors and window posts. Especially in the traffic pattern, the pilot needs to scan the airspace before initiating a turn to make sure the path is clear and keep a sharp look out for traffic making an improper entry into the circuit.

Step 2: Identification of an object as an aircraft and assessing if there is a conflict
In case an object is detected in the sky it needs to be determined if it is an aircraft and if it is flying a conflicting course. The ability to identify objects as conflicting aircraft is greatly aided by creating a mental picture of the traffic situation. ICAO [3] therefore stipulates that the pilot should be capable to listen selectively to radio transmissions from ground stations and from other aircraft. The pilot can also be aided by on-board collision avoidance systems capable of providing traffic alerts. It is mentioned by most sources on collision avoidance that aircraft with little or no relative motion are hazardous since they are on a collision course. Several systems are available commercially which can provide information to a pilot about the relative position of other aircraft. These systems are the subject of Chapter 3.

Pilots can also increase the visibility of their own aircraft. EGAST advices to use aircraft lights and the landing light in the circuit. On overcast days the use of high intensity strobe lights can be useful. Furthermore it is advised to be equipped with a transponder [4].

Step 3: If there is a conflict, determine which evasive manoeuvre is to be executed
The manoeuvres to be executed for collision avoidance are regulated by the right-of-way rules. An Australian study on see-and-avoid notes, that an incorrect evasive manoeuvre may cause, rather than prevent, a collision. In a head-on encounter for example, a bank may increase the risk of a collision. This is because the ‘collision cross-section’ increases during banking. Therefore evasive action can be unsuccessful or even counterproductive [10].

Collision avoidance leaflets, such as from ICAO [3] and EGAST [4] do not give specific advice on avoidance manoeuvres, the focus is clearly on the detection of conflicting aircraft.

Step 4: Execute the evasive manoeuvre
The last step is the actual execution of the avoidance manoeuvre by the pilot. After the manoeuvre the pilot should immediately continue scanning the airspace for other conflicts.

2.3 Identification of safety issues

This section discusses various safety issues of see-and-avoid. First mid-air collisions accident statistics are discussed, followed by an identification of safety hazards and causal factors. The identification of safety hazards and causal factors is based on the authors engineering judgment, compiled with the Australian Transport Safety Bureau 'Limitations of the See-and-Avoid principle' study [10], the ICAO circular on pilot skills for visual look-out [3], the EGAST safety promotion leaflet about Collision Avoidance [4], information on factors that affect visibility from the World meteorological Organisation [11], ICAO Annex 3 [12] and See-and Avoid work performed for FAA/IVW by NLR-ATSI (and presented to EGAST).

2.3.1 Accident statistics

It has been clear for many years that mid-air collisions can occur in all phases of flight and at all altitudes. Most mid-air collisions occur during day-light hours and in good weather conditions [3, 4]. This is due to the high traffic density in these conditions. This also accounts for the fact that in the United Stated 44% of mid-air collisions occur during the weekend [14]. Because of the concentration of aircraft in the vicinity of aerodromes, also most collisions occurred near aerodromes, specifically when one or both aircraft were turning, descending or climbing. Most aircraft involved in a mid-air collision were flying VFR in uncontrolled airspace [3, 4]. Both experienced and inexperienced pilots are involved in mid-air collisions. A novice pilot may forget to scan the airspace due to inexperience or preoccupation with another task. An experienced pilot may grow complacent and forget to scan [4].

European GA Accident Statistics
Although the probability of a mid-air collision is relatively low, the result is often fatal making the risk of a mid-air collision significant. Table 2 and Table 3 show the European mid-air collision statistics for general aviation for the period 2006-2011; there were 82 mid-air collisions that caused 82 fatalities and 16 serious injuries. The ratio of fatalities to serious injuries clearly shows the severity of mid-air collisions. Most accidents involve aircraft with a maximum take-off mass lower than 2,250 kg.

Table 2: European mid-air collision statistics General Aviation MTOM <2,250 kg (all category aircraft)

	2006	2007	2008	2009	2010	2011	**Total**
Accidents	15	9	10	18	11	13	**76**
Injuries:							
Fatal	14	12	9	18	9	11	**73**
Serious	2	2	4	2	4	1	**15**
Total	**16**	**14**	**13**	**20**	**13**	**12**	**88**

Table 3: European mid-air collision statistics General Aviation MTOM >2,250 kg (Aeroplanes)

	2006	2007	2008	2009	2010	2011	**Total**
Accidents	0	2	1	2	0	1	**6**
Injuries:							
Fatal	0	3	5	1	0	0	**9**
Serious	0	0	0	1	0	0	**1**
Total	**0**	**3**	**5**	**2**	**0**	**0**	**10**

United States GA Accident Statistics

On average, there were 16 mid-air collisions in the US annually from 1991 through 2000. The sky condition was broken or overcast during one-third of the accidents, and clear in two-thirds. Most mid-air collisions occurred during daylight hours, 87% from 8:00 am to 5:59 pm. The fact that most collisions occur in day-time VMC conditions can be attributed to traffic levels. Most MAC occur in day-time on weekends in the warmer months of the year, the times when the airspace is most crowded. In 87% of MACs, at least one aircraft was manoeuvring, and in 70% both were. 77 % involved arrival to, departure from, or flight over an airport, with 60% of the MACs in the traffic pattern [14]. In 2001-2011 mid-air collisions were in the top-ten leading causes of fatal general aviation accidents[2].

2.3.2 Hazards

Accident and accident avoidance scenarios for general aviation aircraft positioned on a collision course in VMC under VFR/VFR may be represented by Event Sequence Diagrams (ESDs) and Fault Trees (FTs). A generic ESD with FTs is shown below. Each ESD consists of a number of specific events:

- One initiating event;
- Several end-events, which are the end state of a sequence of events, and;
- One or more pivotal events (failures of so-called ‘barriers’) with fault trees.

[2] http://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=13672

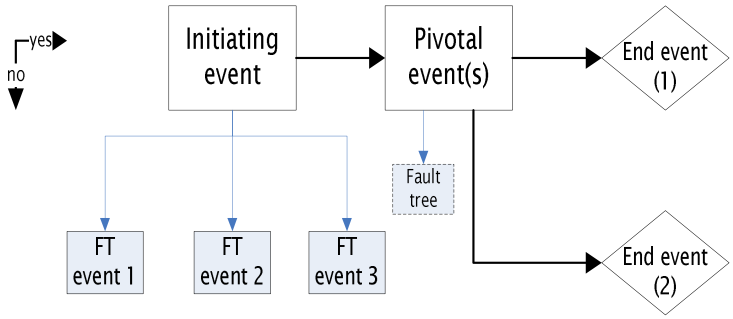

Figure 2: Generic ESD with fault trees

The initiating event is defined as the first event of the accident scenario which commences the series of events leading to the end event, i.e. a collision, a near mid air, or no collision. Accident scenarios end up with collision with other aircraft, and accident avoidance scenarios end up with a near mid air or continued flight.

Figure 3 provides a generic event tree for mid-air collisions. The initiating event considers two aircraft that are on a collision course. The subsequent events show several scenarios how this condition can evolve into a mid-air collision. The dot-lined box shows the event that can be categorized under see-and-avoid. A final barrier sometimes included in comparable models is providence. If all barriers fail providence might prevent a mid-air collision. Since providence cannot be influenced by rules, regulations or procedures, it is not included here.

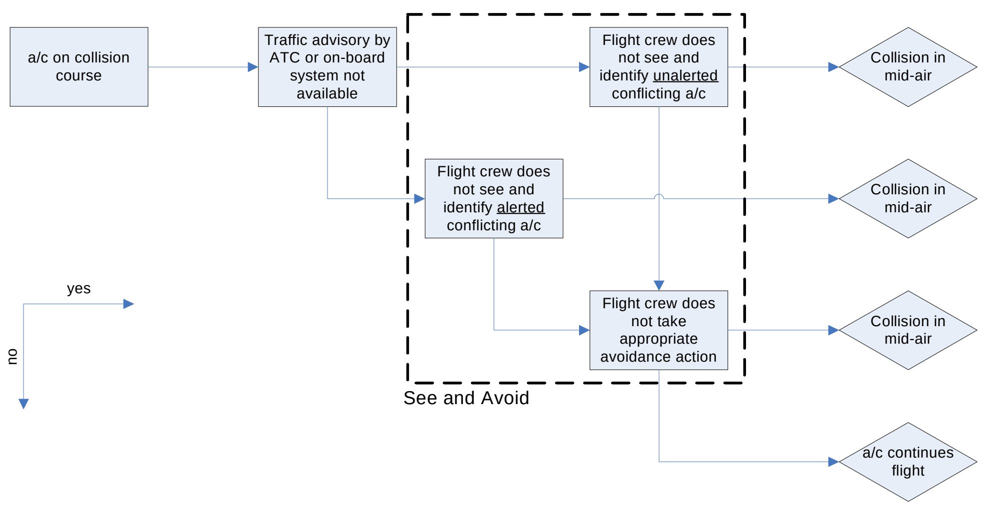

Figure 3: Event tree of mid-air collision. The event traffic advisory by on-board system not available includes unequipped aircraft and failures to detect traffic by the system of an equipped aircraft.

Table 4 provides data on the time required for a pilot to execute an evasive manoeuvre after seeing an object in the sky (based on [16]). Although in reality, the time required may vary between pilots and also depends on other factors, it provides a good indication of the different tasks to be performed. The time it takes to search the sky for objects is not included; it is assumed the pilot is looking towards the target. An Australian ATSB See and Avoid study notes that since individuals differ in their response time, the reaction time for older or less experienced pilots is likely to be larger than average [10].

Table 4: Estimated cumulative time it takes to perform See and Avoid tasks [16].

Task	**Cumulative seconds**
Recognize aircraft	1
Recognize collision	6
Decide on action	10
Muscular reaction	11
Aircraft lag time	13

There are three main hazards leading to a failure to see-and-avoid conflicting traffic. It is noted that the event tree considers one aircraft, for a mid-air collision a failure to see-and-avoid of both crews involved needs to take place. The three hazards, of which the first two are within the scope of this study, are:

1. Flight crew does not see and identify unalerted conflicting aircraft;
2. Flight crew does not see and identify alerted conflicting aircraft;
3. Flight crew does not take appropriate avoidance action.

An important issue to consider is the minimum warning time required for pilots to be able to avoid conflicting traffic in time. The above Table supports setting of requirements for Detect and Avoid systems to support the process.

2.3.3 Causal factors

Several causal factors can be appointed to the two main hazards in the scope of this study. The causal factors are given below and are – together with identified contributing factors – discussed further in appendix B.

HAZARD: Flight crew does not see and identify unalerted conflicting aircraft:

- ATS does not provide traffic advisory;
- On-board system does not provide traffic advisory;
- Conflicting aircraft effectively not visible;
- Pilot does not see visible conflicting aircraft while scanning;
- Pilot does not scan traffic (adequately).

HAZARD: Flight crew does not see and identify alerted conflicting aircraft:

- Conflicting aircraft effectively not visible;
- Flight crew pilot does not see visible conflicting aircraft while scanning;
- Pilot does not scan traffic (adequately)
- Pilot does not use RF to increase situational awareness.

2.4 Survey of initiatives to reduce see-and-avoid hazards

This section discusses initiatives taken to reduce the hazards of see-and-avoid limitations. The term initiative is used loosely and entails activities that study see-and-avoid hazards or contain safety recommendations to mitigate these hazards. Four distinct categories are distinguished:

- European research projects studying see-and-avoid (or related subjects);
- FAA Traffic situation awareness with alerts project
- Safety advice given to pilot communities;
- Accident reports that contain safety recommendations on SAA issues.

2.4.1 European research projects

The table below lists the research projects identified for this study in chronological order. Details on these projects are provided in Appendix C, which contains a one page survey with key issues for each project.

Table 5: European see-and-avoid research projects

Study	Customer	Timeframe
TAGA – Traffic Awareness for General Aviation	German Government	2000 – 2003
BEKLAS – Increased visibility of small aircraft as protection against collisions	German Government	2004
The limitation of the see-and-avoid system	Dutch Ministry of Defense	2004
LAST – Detection and Recognition of Light Aircraft in the Current and Future ATM Environment	EUROCONTROL	2005
Research on cooperative equipment for VFR	FLARM Technology	1998 – 2008
AVAL – ACAS on VLJs and LJs – Assessment of safety Level	EUROCONTROL	2007 – 2009
FAS – Future Airspace Strategy	CAA-UK	2010 – 2011

In 1998, following research, ONERA registered a patent for cooperative equipment dedicated to improve VFR flight safety. This patent has been licensed to Flarm Technology GmbH in 2008 (www.flarm.com). It covers not only collision avoidance, but also additional aspects of aircraft data communication, traffic information display, navigation and 'SOS' distress signals. FLARM is an active and cooperative traffic and collision-warning system for general aviation and recreational flying (see also references [41] and [42]).

Most of these reports share a similar background, namely the aim to address the limitations of the see-and-avoid principle. The LAST study [18] states that although there are widespread opinions on the effectiveness of see-and-avoid in uncontrolled airspace the ability of GA pilots to spot low and fast military aircraft is an issue. The head-on profile of many modern military jets and light aircraft is extremely small and closure rates of aircraft can be phenomenal. This conclusion is also drawn by the study of the limitations of the see-and-avoid system conducted for the Dutch Ministry of Defence [19].

Several solutions to the issues of see-and-avoid are studied. AVAL studies the use of ACAS on very light jets and light jets and concludes that ACAS II equipage seems the most effective option [20, 21]. The study recommends to extend the current European ACAS II mandate to include all civil fixed-wing turbine-engined aircraft with a maximum cruising speed of over 250 knots. LAST safety recommendations on collision devices are more high-level, it states that electronic acquisition could be improved through the widespread carriage of SSR transponders and collision warning systems. The BEKLAS study [22] sees merits in the use of electro-optical solutions because it will work regardless of the equipage of other aircraft. The TAGA study [23] investigates the use of TIS-B to provide aircraft with a cockpit display for traffic information.

No solution is available at this point that will mitigate all issues related to see-and-avoid. According to the AVAL study ACAS II is an effective option for fixed-wing jets, but mandating ACAS II is not feasible for light propeller aircraft. The less expensive TCAS I is not a suitable substitute [20, 21]. The study states, that no evidence was produced on which any safety recommendation for equipping light aircraft with TCAS I can be based. LAST focuses on a possible mandate for SSR transponders, and considers such mandate beneficial. The study does mention some important drawbacks however. TAGA concludes that it is not possible to replace a visual scan of the surrounding airspace by using an on-board traffic display. An electronic traffic display can be used to support the pilot only.

The BEKLAS study recommends several measures to improve situational awareness in General Aviation. Amongst others, these measures are

- Use electrical-optical collision warning systems;
- Equip all aircraft with Mode-S transponders;
- Integrate TIS-B, ADS-B and CDTI using Mode-S Transponders in General Aviation.

2.4.2 FAA Traffic situation awareness with alerts project

In the United States the FAA has started the Traffic Situation Awareness with Alerts (TSAA) Project. The intended function of TSAA is to increase flight crew traffic situation awareness by providing timely alerts of airborne traffic in the vicinity. TSAA is intended to reduce the risk of a near mid-air or mid-air collision by aiding in visual acquisition as part of the flight crew's existing see-and-avoid capability. Aircraft need version 2 ADS-B In.
TSAA provides alerts using voice annunciation to direct attention out the window. In a more advanced TSAA class a Traffic Display will also be available. After receiving the alert, the pilot or flight crew will take the necessary action in accordance with the operational rules in effect at the time; no resolution guidance is provided. The system will work for fixed-wing and helicopter aircraft in controlled and uncontrolled airspace and under both IFR and VFR.

2.4.3 Safety advice

Several institutions and authorities publish documents in which the pilot community is informed on see-and-avoid procedures, and its hazards and mitigations. Some of these documents have been referenced in previous sections discussing the see-and-avoid principles. Table 6 lists the documents considered.

Table 6: documentation on see-and-avoid and collision avoidance safety advice

Title	By	Year
Flight safety info – Eyes open, you are not alone[3]	Büro Flugsicherheit	2002
Flight safety info – See and be seen, avoidance of collisions[4]	Büro Flugsicherheit	2004
Safety Promotion Leaflet – Collision Avoidance	EGAST	2010
SafetySense Leaflet – Collision Avoidance	CAA-UK	2011

[3] In German: flugsicherheitsinfo – Augen auf, du bist nicht allein
[4] In German: flugsicherhetitsinfo – Sehen und gesehen werden. Vermeidung von Zusammenstößen

Both the EGAST leaflet [4] and CAA UK safety leaflet [24] are based on ICAO Circular 213-AN/130 [3]. They both discuss similar issues and present similar solutions. The leaflets offer information on mid-air collision causes, limitations of vision, techniques and procedures of visual scanning, and other operational skills to mitigate the risks of a mid-air collision.
The documents of the German “Büro Flugsicherkeit”, a former part of the Deutscher Aeroclub, are both one-page flyers [25, 26]. The 2002 document points out the need for proper flight preparation, and recommends avoiding crowded airspace. It also mentions the advantage of using radio-communication to increase situational awareness. The 2004 flyer lists the main risk factors of VFR flight and recommends mid-air collision mitigations, such as: proper flight preparation, proper training, and the need to scan the airspace.

2.4.4 Accident reports

Unfortunately mid-air collisions do happen and usually result in fatal accidents. These accidents are often thoroughly investigated by national aircraft Safety Investigation Authorities, although due to a lack of available flight data and cockpit data it is often difficult to arrive at definitive conclusions. Safety recommendations have been drafted by e.g. the UK AAIB, the Swiss Federal Bureau of Civil Aviation (FOCA) and the French Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile (BEA). The safety recommendations from FOCA and the BEA are discussed in reference 51. This section highlights safety recommendations drafted by the AAIB to lower the risk of mid-air collisions. AAIB report 5/2010 [27] contains a safety recommendation and a reference to two earlier safety recommendations related to the electronic conspicuity of gliders and light aircraft. The safety recommendations were directed to the CAA UK. The response of the CAA UK is elaborate and deserves some further discussion here. These safety recommendations are given below.

Safety recommendation 2005-006
It is recommended that the Civil Aviation Authority should initiate further studies into ways of improving the conspicuity of gliders and light aircraft, to include visual and electronic surveillance means, and require the adoption of measures that are likely to be cost-effective in improving conspicuity.

Recommendation 2005-008
It is recommended that the Civil Aviation Authority should promote international co-operation and action to improve the conspicuity of gliders and light aircraft through visual and electronic methods.

Recommendation 2010-041
It is recommended that the Civil Aviation Authority, in light of changing technology and regulation, review their responses to AAIB Safety Recommendation 2005-006 and 2005-008 relating to the electronic conspicuity of gliders and light aircraft.

In response the CAA UK reviewed the issue of electronic conspicuity and concluded that there is no easy solution to the issue for General Aviation. A range of surveillance technologies are in existence or being developed but according to the CAA none provide a complete solution and achieve an appropriate level of interoperability with ATM and its safety nets.

The difficulties involved are related to the overall impact of the benefits, regulatory issues, and cost of solutions. Mandatory transponder carriage does bring benefits by increasing effectiveness of ATS and ACAS, but does not necessarily directly benefit the whole GA community. Solutions such as TIS-B and mandating or encouraging ACAS equipage involve high costs and regulatory burdens. Especially the cost issue can result in hostile reactions from stakeholders. Use of commercially produced, un-certified and un-regulated devices using a non-protected spectrum can bring benefits. The CAA does state that this needs to be treated with caution due to interoperability and liability issues, and fears the devices are not robust enough to be used on a wide spread basis. According to the CAA, ADS-B in/out seems to be the best way forward. It is the only solution that might be suitable for all types of aircraft.

2.5 Mitigations to see-and-avoid limitations

The occasional occurrences of fatal mid-air collisions show that the see-and-avoid principle is flawed. Most mid-air collisions occur because the flight crew does not see the conflicting aircraft. There are several mitigations to this limitation of see-and-avoid. One option is to improve the visibility of aircraft. There is no obvious solution to accomplish this however. From time to time, fluorescent paint has been suggested as a solution to the contrast problem. However, several trials have concluded that fluorescent painted aircraft are not easier to detect than aircraft painted in non-fluorescent colours [10]. There have been frequent suggestions that the fitting of white strobe lights to aircraft can help to prevent collisions in daylight. Unfortunately, the available evidence does not support the use of lights in daylight conditions. The visibility of a light largely depends on the luminance of the background and typical daylight illumination is generally sufficient to overwhelm even powerful strobes [10].

Another possible mitigation is to improve training of private pilots. This could result in pilots who are able to sufficiently scan the airspace but it does not mitigate the hazard of not seeing an aircraft either due to the limitations of the human eye or because the view is obstructed. These limitations can be mitigated by using anti-collision devices on General Aviation aircraft. Both European research studies and accident investigation reports contain safety recommendations to study the use of such devices in General Aviation.

The next chapter will contain a survey of current systems available to aid the pilot in his task to avoid collisions by see-and-avoid. The identified systems will be assessed on parameters relevant for General Aviation such as size, weight and electrical power needed. An important element considered as well is cost, both to purchase and install and maintain such a system. Finally also functional performance will be considered, for example detection range and field of view. It is noted that although this study focuses mainly on anti-collision devices mitigations can be used in combination; e.g. improvement of training and procedures in addition to on-board equipment.

2.6 Summary of results and outcomes

Mid-air collision statistics for General Aviation (for both Europe and United States of America) have been presented and discussed. Data from EASA shows that over the period 2006-2011 there were 82 mid-air collisions involving aircraft with a maximum take-off mass lower than 2250 kg in Europe. On average, there were 16 mid-air collisions in the United States annually from 1991 through 2000.

The see-and-avoid task of the pilot can be divided into four steps:

1. Detection of objects in the sky;
2. Identification of object as an aircraft and assessing if there is a conflict;
3. If there is a conflict, determine which evasive manoeuvre is to be executed;
4. Execute the evasive manoeuvre.

The first two steps can be considered as the “see” part of see-and-avoid (and therefore within scope of SISA), and the last two steps as the “avoid” part. For the first two steps, there are two main hazards leading to a failure to see-and-avoid conflicting traffic. These hazards, with their associated causal factors, are:

1. Flight crew does not see and identify unalerted conflicting aircraft;
    - ATS does not provide traffic advisory;
    - On-board system does not provide traffic advisory;
    - Conflicting aircraft effectively not visible;

- Pilot does not see visible conflicting aircraft while scanning;
- Pilot does not scan traffic (adequately).

2. Flight crew does not see and identify alerted conflicting aircraft;
    - Conflicting aircraft effectively not visible;
    - Pilot does not see visible conflicting aircraft while scanning;
    - Pilot does not scan traffic (adequately)
    - Pilot does not use the radio to increase situational awareness.

Initiatives taken in Europe to reduce the hazards of the see-and-avoid limitations have been identified and discussed. This concerns activities that study see-and-avoid hazards, activities that contain safety recommendations (or even initiate development of solutions) to mitigate these hazards, and accident investigations. There seems to be consensus that there is currently no solution available that mitigates all the issues related to See and Avoid. Most mid-air collisions occur because the flight crew does not see conflicting aircraft. Options to mitigate See and Avoid limitations include e.g. improvements of the visibility of aircraft and training or education of private pilots, and anti-collision devices on GA aircraft.

3 Assessment of candidate solutions

3.1 Introduction

This Section assesses options for augmentation of pilots' visual observation. Limitations are taken into account if relevant for GA owners and GA pilots. The term GA or GA aircraft is used to indicate glider aircraft, powered glider aircraft, ultra-light aircraft, very light aircraft, experimental aircraft and other types of General Aviation aircraft. Note that unpowered aircraft do have right of way under all circumstances.

The classification of the systems is based on the technology that is used for the primary sensor or signal. Discerning characteristics are used to organize the systems in families like active versus passive systems and detection of only independent and dependent cooperative or also non-cooperative traffic. A survey on internet was limited to currently available systems. In the next paragraph the different types that may be of interest are discussed in detail with a general indication of their properties. By introducing a set of requirements in paragraph 3.3 it will become possible to evaluate the properties of the different systems against the requirements and assess the possible candidates in paragraph 3.4.

Every comparison in cost is based on a complete system that is able to assist the pilot with his See-And-Avoid (SAA) task. Every GA system with the required functionality making use of (radio) signals will consist of the following elements:

- one of more antennas (top or top and bottom);
- a central processor unit;
- power supply;
- software for calculations;
- visual and/or aural warnings;
- GPS (or equivalent GNSS) for own position;
- display (optional).

The main components of such systems are meant to provide services like traffic detection, conflict detection, HMI and supporting communications and power. By comparing systems we should distinguish between highly integrated, portable systems with all elements in one box, or modular systems that make efficient use of already installed units, or portable devices for some functions. Important aspects of each system are the software that will predict a possible collision hazard, and the warnings that must attract the attention to the right part of the sky for a visual detection of nearby traffic. Real time evaluation of the performance of the system can only be collected from the experience of GA pilots that have installed such a system. Combined aural and visual alarms are preferred to make sure the pilot receives the warning in all situations. Sometimes one or more examples of the candidate solutions for a system from a manufacturer will be named to illustrate the technology. This is by no means an indication for the selection of a preferred manufacturer.

3.2 Overview of candidate solutions

For the overview of candidate systems first the different technologies will be explained and discussed in general per family. We can distinguish between four families as indicated in the following list:

A. Cooperative and active systems: C-A
   - A1. ACAS (TCAS I and TCAS II)
   - A2. Traffic Advisory Systems (TAS)
   - A3. FLARM / PowerFLARM
   - A4. Radio / LARS
B. Cooperative and passive systems: C-P
   - B1. ADS-B-IN (ModeS-ES, VDL-M4, UAT)
   - B2. Traffic Collision Avoidance Device (TCAD)
   - B3. Transponders (LAST / LPST)
C. Non-cooperative and active systems: NC-A
   - C1. Embedded radar
   - C2. LIDAR / LADAR
D. Non-cooperative and passive systems: NC-P
   - D1. IR camera
   - D2. EO camera (daylight)
   - D3. Acoustic sensors

Cooperative systems can be divided in systems for Independent Cooperative Surveillance and for Dependent Cooperative Surveillance (see Appendix A). The difference will be indicated in the description of the different systems. Currently the only system for Dependent Cooperative Surveillance is ADS-B. Active systems, which use transmissions and their response to detect other traffic, are more reliable for the detection of cooperative traffic in remote areas where no other interrogations are present. In general the power consumption will be higher than for passive systems especially when the range for the interrogation is extended (i.e. for higher cruise speeds). Passive systems use the signals available on a frequency or frequencies to detect the source of a transmission.

3.2.1 Cooperative and active systems

A1. Traffic Collision Avoidance System (TCAS)

The Airborne Collision Avoidance System is the ICAO generic term for systems that are widely known as TCAS (Traffic Collision Avoidance System). For Commercial Aviation or Transport Category aircraft (MTOM over 5700 kg, Number of Passengers > 19) this system is mandatory in all airspace classes. Its function is to provide collision avoidance when separation fails and this can be seen as the last barrier to prevent collision. The system makes use of the communication between the transponders (Mode A/C or Mode S) in both aircraft. TCAS actively scans the vicinity by interrogating of other transponders on the 1030 MHz channel and receiving the replies on the 1090 MHz channel. From these signals the relative distance, altitude and bearing are calculated. In the modern TCAS II version the units communicate and check their Resolution Advisories (RA) when entering the Safety Volume of the other aircraft before presentation the RA to the pilot. The system provides for aural warnings. The integration with the existing systems in the aircraft is expensive. The cost of these certified and reliable systems is high. Also their size, weight and power consumption makes these systems less favourable for small GA aircraft. For GA the worldwide implementation and reliability of the system do not outweigh the negative SWPC (Size-Weight-Power consumption-Cost).

A2. Traffic Advisory Systems (TAS)

Traffic Advisory Systems (TAS) are mainly developed in the USA in accordance with the FAA TSO C147 specifications. Most manufacturers combine the TAS with an ADS-B out transponder to reduce the installation costs. All TAS systems actively interrogate threat aircraft transponders for reply and act as TCAS look-alikes for GA pilots. It provides for ‘real-time’ collision alert with up to a 30-second warning at up to 1200 knots closure speed, which is comparable to TCAS. The TAS processor is provided withthe signal from two antennas on the top and bottom of the aircraft to reduce shadowing and improve tracking. One antenna uses directional technology to get bearing information from the signal itself. The systems tracks up to 50 aircraft, but only the nearest ones are output to a display via an RS-232 or ARINC 429 interface. Even without a display the cost is high.

A3. FLARM / PowerFLARM

FLARM, short for “FLight alARM”, was developed specifically to assist glider pilots flying over the European Alps. Since 2004 it provides for situational awareness and collision warnings by presenting nearby traffic (powered aircraft and gliders), if they are also equipped with a FLARM system which responds to the interrogation. The system is successfully deployed in the Alpine region where gliders use well known mountain routes and no other significant traffic is present. The effectiveness of FLARM is reduced outside mountainous areas where the collision hazard with not-FLARM equipped aircraft and military traffic is more significant. PowerFLARM is specifically developed for powered GA that fly with higher speed. This system inquires the vicinity with a more powerful signal to increase the range for detection in order to provide for more reaction time for the pilot. PowerFLARM comes equipped with a display in the standard configuration. FLARM uses GPS to retrieve its own 3D position (lat, long, alt) and track from a number of recent positions. With a kinetic model the flight path over the next 20 seconds is predicted. For gliders the calculation of the flight path recognizes special conditions like thermalling. The FLARM system broadcasts this information on the local radio channel for FLARM transmissions. The system receives the same information from other FLARM systems within the detection range (typically 2-5 km for FLARM, 10 km for PowerFLARM). The maximum range will depend on the maximum power of the transceiver, and on the efficiency of the antenna installation as well as their position. The risk of simultaneous transmissions from different systems is minimized by a dedicated and patented protocol for FLARM. The FLARM processor compares and checks all received predicted flight trajectories for intersections with its own extended flight path. An alarm is raised when another aircraft poses a potential danger for collision. All information is output in a standard interface format to a display or presented on its own display (PowerFLARM).

A4. Radio / LARS

Because every aircraft is equipped with a radio set this system can be used for exchange of information on the position of other traffic. Not only the communication between pilots can serve this goal, but also a request for information can be transmitted to ATC in that region. A special case for the latter option is LARS (Lower Airspace Radar Service). London Area LARS is a radar-based air traffic information and alerting service available on request for pilots of GA aircraft flying in the busy airspace below or around the London TMA. In the past this service was run from Farnborough as a service from NATS and TAG Farnborough. The service is now extended to many parts of the UK to aircraft flying at low altitude in uncontrolled airspace. The service is cooperative in the way that it reacts to a call from the pilot, although the exact level of service will depend on controller workload and weather condition. At the same time this service is non-cooperative because all traffic that is visible on the radar by ATC in the vicinity of the aircraft will be reported to the GA pilot.

The family of cooperative and passive systems offers opportunities for GA pilots to improve their See-And-Avoid task. The main disadvantage of passive systems is their dependence on “third party Interrogation” of the transponders of nearby traffic. Near airports or in areas with much traffic this will be no problem but in remote areas the system is unreliable for detection of cooperative and (of course) non-cooperative traffic. In general these systems can be small and cheap, because there is only a receiver part involved. Because only cooperative traffic will be visible for other pilots, the installation should be combined with a transponder for Mode A/C or S to assist the pilot(s) of other aircraft with their SAA task.

3.2.2 Cooperative and passive systems

B1. ADS-B-IN (ModeS-ES, VDL-M4, UAT)

Automatic Dependent Surveillance – Broadcast (ADS-B) is a system that transmits the navigation data of an aircraft. This is the only system for Dependent Cooperative Surveillance, where no external system or radar is needed to start the transmissions. The standard transmission rate is once per second, but it can vary for the different types of messages in a transmission. All aircraft in the vicinity that can receive this signal with ADS-B in are able to present the relative 3D-position, speed and identification of the transmitting aircraft on a Cockpit Display for Traffic Information (CDTI). There are a number of technologies that can support ADS-B. The only technology with worldwide implementation is Mode S-Enhanced Surveillance (also presented as 1090ES), which uses the frequency 1090 MHz for their signals. Within the USA the other main system, which is mostly used for GA, is Universal Access Technology (UAT). This system makes use of a frequency outside the VHF range (978 MHz) to have more bandwidth available and is therefore also less vulnerable to frequency congestion and corresponding delays. Additional antennas are needed for this installation. The Swedish CAA developed the VHF Data Link – Mode4 (VDL-M4) for all types of aircraft and this system makes uses of one or two of the channels in the VHF band. With a special protocol that checks on availability of information cells on the frequency before transmitting it is still possible to use this congested communication frequency band for ADS-B messages.

ADS-B is mandatory for Civil Aviation in a number of countries where the radar coverage for SSR is low. In the EU, a mandate exists for ADS-B-OUT. A further example is Australia. Also in Siberia and Alaska ATC uses large numbers of small ground stations and the ADS-B messages from the aircraft for surveillance. In the USA both Mode S-ES and UAT are allowed. In order to get interoperability the ground stations will be equipped for Traffic Information Services-Broadcast

(TIS-B). With this service the ADS-B messages from the aircraft which uses another technology can be presented on the same display as the traffic that uses the same technology as the transmitting aircraft. TIS-B combines all information from ADS-B and transmits the complete traffic picture on both signals. In a number of publications the double equipage of all Transport Category aircraft is promoted to reduce the number of mid-air collision between CA and GA near the airports. In that case UAT becomes the universal technology for GA to view all cooperative, ADS-B equipped traffic. ADS-B can improve the situational awareness in the cockpit.

B2. Traffic Collision Avoidance Device (TCAD)

Traffic Collision Avoidance Device (TCAD) is used for smaller aircraft and has the same function as TCAS but is a passive (and therefore cheaper) system. One example is the Portable Collision Avoidance System (PCAS), which is a trademark of Zaon Flight Systems. The most recent models are the 4th generation since the introduction of PCAS technology in 1999. With this passive receive-only technology on 1090 MHz all transponder equipped aircraft (Mode A/C, Mode S-ES) are detected and with the G4 technology an accurate range, relative altitude and quadrant detection can be integrated in a portable, all-in-one cockpit device.

B3. Transponders (LAST / LPST)

For the surveillance function of ATM the aircraft in controlled airspace are equipped with transponders. These units provide the physical layer for the communication with Secondary Surveillance Radar (SSR). After an interrogation on 1030 MHZ, the units reply on 1090 MHz with the requested information. The same frequencies are used by SSR Mode S ground stations, by ADS-B 1090ES airborne transponders and by ACAS. The navigation information can be derived from the navigation system of the aircraft or by a stand-alone GPS receiver.
The specification for Mode S transponders can be found in the SARPs of ICAO Annex 10.

The family of non-cooperative and active systems offers the best reliability to detect other traffic that can become a collision hazard. The systems are developed for military applications or derived from the new generation of weather radars. Due to their SWPC these systems are not suitable for introduction in GA.

3.2.3 Non-cooperative and active systems

C1. Embedded radar

Military aircraft and MALE or HALE UAV's are in general equipped with radar to detect an enemy that will of course not act as cooperative traffic. The same system can be used to detect all traffic at long range, but only in a small sector. A scanning mechanism is required to get the full Field of view, but the bearing accuracy of radar is low. New radar technology with electronic scanning for the 5th generation fighters are more powerful to improve their range, but also scan a larger volume of air faster. Different wavelengths are applied dependent on the mission of the aircraft or UAV. With the right choice it is possible to detect traffic behind clouds (all weather conditions) and it can be used day or night or to detect targets in the air or on the ground. Countermeasures are developed by designing new aircraft with stealth technology to operate undetected by radar from other aircraft or on the surface.

All these radar systems will not fulfil the requirements for GA equipment. On the contrary, they are heavy, need a lot of power and are very, very expensive to buy and to maintain. Note that state aircraft that operate in civil airspace in peacetime are obliged to comply with all standard regulations for transponder equipage. Also with the assistance of equipment the high speed of fighter aircraft and their small signature makes them hard to detect with SAA.

C2. LIDAR / LADAR

Light Detection and Ranging or Laser Detection and Radar are systems that are comparable in functionality with radar. By using different wavelengths the characteristics for the detection in all weather conditions vary for the different missions that are flown by military aircraft. All these systems will not fulfil the requirements for GA equipment.

The family of non-cooperative and passive systems offers an improvement to the human eye in the detection of other traffic. The reliability depends on the scanning technique and operator training for a single system or the number of sensors and the processing software for multiple sensors. The systems are initially developed for military applications but nowadays the systems are in use for civil applications as well. In the civil world the sensors are mainly used for ground surveillance from the air. Due to their SWPC these systems are less suitable for introduction in GA.

3.2.4 Non-cooperative and passive systems

D1. IR camera

An InfraRed camera is an effective sensor to detect any source of heat that is produced as radiation from combustion or even from compressed air. Unfortunately this sensor is very expensive and should be calibrated to detect small sources of heat against the background of the sunny atmosphere. With the help of a dedicated sensor operator the camera should scan the vicinity with the same pattern as used by a pilot to detect other objects. After detection and locking the zoom function can be used for identification of the traffic. The operation of the system and the Interpretation of the images require a lot of training. With a lock on a target the bearing accuracy is very good, but there is only a rough indication of the range. An IR camera is able to see through haze but cannot see behind clouds. Note that Enhanced Vision Systems (EVS) are available for business aircraft (as landing aid, but not for traffic detection).

D2. EO camera (daylight)

Electro Optical daylight cameras are usually combined with an IR camera in a turret. The turret provides for the scanning of the camera and for stabilization of the images. The Field of view is limited by the location of the camera and sometimes obscured by the wings. In some research projects for UAS an installation with a number of fixed cameras in the nose of a multi-engine aircraft is studied. This prevents the introduction of heavy mechanical constructions for the scanning, but needs a lot of computer power for image processing to combine all pictures in one image and detect foreign objects in the sky.
The limitations of the EO camera are the same as the limitations of the IR camera although the interpretation of the images requires less training. This system cannot fulfil the requirements for GA equipment.

D3. Acoustic sensors

Acoustic sensors are developed to detect other aircraft by their noise. These sensors are still under development and their current TRL is about 6. An acoustics sensor is small and low cost, but they are limited to the detection of powered aircraft. This detection will only work after filtering out the noise of the engine of the carrier aircraft. The spectrum of this noise may vary with the engine speed and a calibration is required for every location of these sensors. With a small array of sensors the direction of the noise can be detected with good accuracy, but the range is hard to determine. For range detection representative data should be available on the source of the sound and the weather condition that influence the noise propagation through the atmosphere.

3.3 Overview of requirements

To assess the candidate solutions the requirements for the analysis must be clear. Because there are no formal requirements known, the following requirements in Table 7 are derived from the discussions with different stakeholders. These requirements will be discussed in detail first.

Table 7: Requirements for GA equipment to reduce collision hazard

Prime		Derived	
1	Addition to 'See-And-Avoid"	1.1	Attract attention when required
		1.2	Training (on ground PC based instruction) available?
2	Cheap	2.1	Price comparable to standard GA equipment
		2.2	Production possible in quantities covering the whole GA market
		2.3	Adaptable to the majority of GA aircraft
3	Easy to install	3.1	Small and light weight
		3.2	Power consumption comparable with Mode S transponders
		3.3	Modular or portable
4	Performance	4.1	Range comparable with human eyes
		4.2	FoR – azimuth: 360 degrees
		4.3	FoR – elevation: +/- 15 degrees
		4.4	Dedicated reserved frequency available
		4.5	Number of tracks detectable
5	Interoperability	5.1	According to a standard for interoperability
		5.2	According to a standard for HMI
		5.3	Options for modules to receive other signals
6	Existing solutions	6.1	Number of systems already in use

Req. 1.1 Attract attention when required

Every pilot flying VFR should spend most of his time on his SAA task. Head down time should be limited to the scanning of his vital flight instruments. Any display that may help to provide situational awareness of the nearby traffic could help in the scanning process of the outside world, but should not attract too much attention. The processing software should help the pilot when separation is lost and there is a collision hazard. The aircraft which causes the hazard (or the first hazard if there a large amount of traffic) should be identified and clearly indicated on a display or through an aural alert. Using both aural and visual warning will help to attract the attention of the pilot to the traffic display to get an indication of the location of the intruder. This will help the See task and hopefully expedite the Avoid task if necessary.

Performance figures on the reliability of the system are only required if the system must be certified. But even voluntary equipage/systems must be checked on the number of false alarms and the number of missed detects of cooperative aircraft. Only user reports can help to get an idea of the number of these events.

Req. 1.2 Training (on ground PC based instruction) available?
New systems with a large amount of options and settings can only be operated safely by experienced pilots. Especially safety related equipment can only be useful for pilots with less experience when there is a possibility for training on the ground. For instance a PC-based instruction on the operation of the equipment, on the presentation on a display and on the limitations of the system will help the pilot to interpret the information quicker in flight. Although not a hard requirement, systems with ground PC based training and instruction facilities are preferred.

Req. 2.1: Price comparable to standard GA equipment
The main hurdle for the introduction of new equipment in GA is cost. The diversity of the GA community makes it even more important to reduce cost as much as possible. The diversity is visible in the following differences: experienced GA pilots versus weekend flyers, expensive fixed wing aircraft versus cheap para gliders, areas with high traffic volumes versus low density areas. A price limit is always arbitrary, but the price of this equipment should be comparable with the price of standard equipment like radio equipment or navigation equipment. It is recommended to make an inquiry within the European GA society (i.e. flying clubs) to find out what is considered affordable.

Also without extensive knowledge of available technologies it is clear that a system will be much cheaper if it has to deal with signals that are already available in the air. These signals are produced by co-operative traffic that is signalling its own position and track. Active detection of not-cooperative aircraft always needs more powerful equipment and that means costs. Note furthermore that if GA aircraft are equipped with transponders, they will be detected by the equipment of other aircraft. Transponders are mandatory in many countries in Europe or will be in the near future.

Req. 2.2 Production possible in quantities covering the whole GA market
The price of equipment is very dependent on the number of items that can be produced and sold. Therefore one of the criteria for the selection will be if it is feasible to produce the system in large quantities not only in Europe but worldwide.

Another feature of a system that is already produced and sold in quantities over 10.000 units (i.e. Commercial-Of-The-Shelf (COTS)) means that a large number of aircraft are equipped with the same system. For systems that rely on replies from the same system, the percentage of cooperative traffic will increase directly with the number of units that are sold and installed.

Req. 2.3 Adaptable to the majority of GA aircraft
The demand for equipment will be higher if it can be used in all types of GA aircraft. The adaptation is not limited to the mechanical and electrical installation but also to the availability of software that is suitable for the environment of the GA pilot. This environment is very different for pilots flying from A to B compared to for instance for glider pilots who want to stay all in the same thermal bubble. The software should be adequate to show the real dangers and reduce the number of false alarms. A family of systems based on the same technology but with the performance adjusted to the speed of the aircraft reduces the price for the core part of the system. Note that FLARM is suited for motor gliders, but may not be suitable for the higher speed GA aircraft.

Req. 3.1 Small and light weight
It is hard to define how small a system should be that can be located at a suitable position in the GA aircraft. A system has to fulfil certain functional requirements. In order to meet those requirements, a certain size will be required. For instance the size of the display is important for the pilot to get the right information in a glance because he/she has to use that information as quick as possible for the ‘See-part’ of the SAA. Also the size of the antennas in combination with their preferred location on the top and the bottom of the aircraft is of importance for their effectiveness. But big antennas on remote locations are less attractive for GA. A modular system can help to find a suitable location for every element although the total volume can be higher than for the integrated system. Because the weight is very important for small GA aircraft it will be an important criterion. About 1 kilogram may be specified as an acceptable maximum weight.

Req.3.2 Power consumption comparable with Mode S transponders
Power is limited in a lot of GA aircraft or even only battery power is available. Because batteries are limited in time, and heavy, the power consumption of the system is an important criterion for selection of an adequate system. An absolute limit for the power consumption is hard to give. A stringent requirement on power consumption (i.e. low) will exclude the detection of non-cooperative traffic.

Req. 3.3 Modular or portable
As discussed by requirement 3.1 the installation will be easier when the system is modular or when the system is highly integrated and becomes portable. It should be noted that the location of a portable system in the aircraft may have a big influence on the performance of the system. It may be necessary to define a test procedure after installation of a portable system to check for minimum performance of the system.

Req. 4.1 Range comparable with human eyes
Dependent on the speed of the GA aircraft the range for detection by the system is important. The range is mainly dependent on the power that is used by the transmitter of the cooperative aircraft, but also on the weather conditions and the location of the antennas with respect to the location of the intruder. In most cases the weather will not be a limiting factor in the conditions that were prevailing in most mid-air collisions: daylight and VMC (for VFR flight). For active systems the power of the interrogation signal may limit the range as well.
An extensive analysis of the minimum required range should be made in the time domain and based on the reaction time of a pilot and the closing speed of both aircraft. Any warning for Collision Avoidance should be at least in the range of the human eye under standard VMC. The current number of 5 km is based on this.

Req. 4.2 FoR – azimuth: 360 degrees

The Field of view for any additional system to the pilot's SAA could be limited to the Field of View requirement from the ICAO Annex. But it will be an important addition for the pilot if all traffic that is in the vicinity can be shown on the display. Therefore an azimuth of 360 degrees is preferred for this equipment. Of course the processing software should define if there is a collision hazard with traffic that is still outside the direct view of the pilot. In case of a collision course the pilot could try to separate from the other traffic by manoeuvring in accordance with the ICAO Rules of the Air.

Req. 4.3 FoR – elevation: +/-15 degrees

The Field of view for any additional system to the pilot's SAA could be limited to the Field of View requirement from the ICAO Annex. The elevation requirement is limited to these values because there is only the need to assist in the 'See task'. If the processing software should detect a collision hazard with traffic that is still outside the direct view of the pilot, the pilot could try to separate from the other traffic by manoeuvring in accordance with the ICAO Rules of the Air. This can be the case when the other cooperative aircraft provides his position and track.
Note: Within the UAS community the collision hazard is based on the definition of a cylindrical self-separation- and anti- collision volume around the aircraft. New system elevation requirements can be derived from the figures for these volumes also.

Req. 4.4 Dedicated reserved frequency available

Because frequency congestion is very hard to predict and the resulting re-transmissions and delays can harm the timely detection of the other traffic, the use of a dedicated aerospace frequency is preferred. Especially in areas with much traffic a reserved frequency is more reliable for the un-interrupted transmission of signals. A worldwide frequency for GA systems to assist the pilot in 'See-And-Avoid' is not available yet, and hard to get in the battle for frequency bandwidth. If regional solutions are available the use of that frequency in that region should be mandated for a specific system to improve the chance of detecting the cooperative traffic.

Req. 4.5 Number of tracks detectable

With longer ranges for detection of aircraft, the number of other aircraft in areas with much traffic will increase significantly. Therefore the number of tracked aircraft and the number of presented aircraft are important to make sure all hazards can be detected in time. Of course the right prioritization of the different tracks and the timely disposal of harmless tracks helps to reduce the required processing power for the extrapolation of all relevant tracks.

Req. 5.1 According to a standard for interoperability
Without a mandate for prescribed equipment or a prescribed standard for communication the interoperability of systems for GA is an issue. Cooperative aircraft that uses a different frequency or a different communication protocol are omitted from the traffic display. Reliability of, and reliance on the system will be improved if more nearby traffic is processed by the system.

Req. 5.2 According to a standard for the Human Machine Interface
A second standard will be the interface between the display and the pilot. Especially the human factors aspect of displaying the information from different systems in an identical manner is important in GA. A lot of GA pilots do not have their own aircraft and may switch regularly between aircraft with different configurations. Presenting warnings and displaying hazardous situations should be uniform in order to expedite the interpretation of the information on the display by the pilot.

Req. 5.3 Options for modules to receive other signals
Interoperability of systems can be provided by optional modules and software that are able to receive and process the information from different protocols. The advantage is that regional differences in equipment of GA can be mitigated by adding the module for the system(s) that are used in that region. For instance the aircraft that are ADS-B equipped can be seen with the appropriate module for the most popular technology in that area like VDL-Mode 4 or UAT. Systems which offer these kind of modules are preferred.

Req. 6.1 Number of systems in use
It may be preferable to use an existing, already widely used, solution instead of developing a new systems solution from scratch. Of course, this will only be feasible if the operational experience with the existing solution is satisfactory and this solution meets the requirements 1 to 5 as listed in Table 7 .

3.4 Assessment of solutions against requirements

Introduction
Before comparing these systems with the requirements, it may be worthwhile to recapture some general observations introduced in Section 2.

Almost one third of the mid-air collisions between VFR-VFR traffic where the flight crew failed to avoid a conflicting aircraft were formation flights. For these accidents it is difficult to ascertain if the crew failed to SAA the other aircraft, due to the close proximity of the aircraft during the flight. Two reasons are stated for the crew not to ‘See’ the conflicting aircraft: First the other aircraft was effectively not visible even if they were scanning the airspace or the flight crew failed to see a visible aircraft because it was not, or inadequately scanning the aircraft. In both cases the assistance of devices that provide for alarms when there is a collision hazard could have reduced the number of mid-air collisions. In Europe, most collisions occur when aircraft join the circuit in uncontrolled airspace near an airport. It is expected that the operation of gliders, when they are thermalling or following identical routes in mountainous areas, may be relatively risky as well. In the broad spectrum of operations with GA aircraft it can be useful to distinguish between recreational, sports- end training flights in remote areas with low density traffic and regular A-to-B flights with light aircraft. In the latter case the operation will involve flight in, below or near a TMA where encounters with Transport Category aircraft (even in controlled airspace) cannot be excluded. It is arguable that the equipment that can assist the GA pilot depends on the primary operations with the GA aircraft. For instance the operation in controlled airspace will mandate the installation of at least a Mode A/C transponder, now or in the near future.

Initial assessment of available technologies

Table 8 presents the result of the initial assessment of technologies for GA pilot assistance in SAA, including the most important advantages and disadvantages.

Table 8: Initial assessment of technologies against requirements

Code	System	Advantages	Disadvantages
A1	ACAS (TCAS I/II)	Worldwide implementation (Transport category)	Expensive to buy (€10.000 - 100.000)
		Reliable	Expensive to maintain
		Reduction of collisions after introduction by a factor 5	Heavy (> 6 kg)
		Pilot acceptance is high	Big box (4 MCU)
		Performance to specifications by certification	High power consumption (> 100 W)
		Very large amounts of units produced	Needs integration with aircraft systems
		Dedicated world-wide frequency	

A2	TAS	Detects all transponder equipped aircraft	Price without display (€10.000 - 20.000)
		Certified to FAA TSO C-147	Weight (total installation > 4.5 kg)
		Large number of tracks	Designed mainly for fixed wing aircraft and helicopters
		Multiple outputs	Mainly used in the USA
		Appreciable amount of units produced	Risk of frequency congestions
A3	FLARM/ PowerFLARM	Moderate price (€ 600 -2000)	Proprietary
		Light weight (< 200 g)	Patented design
		Small (<1 MCU)	GPS dependent for own position
		Low power consumption	Not fully interoperable with 1090 MHz devices
		Easy installation	Recognises Mode-C or Mode-S transponders (optional)
		Detects (Power)FLARM and ADS-B (optional)	No worldwide transmission frequency
		Dedicated frequency	No proof of performance
		Portable version for club/charter operation	
		Large amounts of units produced in Europe	
A4	Radio / LARS	No additional installation required	Dependent on frequency congestion
		No additional service cost	Dependent on ATC availability
		all traffic from ATC radar in vicinity	Dependent on pilots alertness
B1	ADS-B-IN	Performance to specifications (certified)	Very expensive (€10.000 – 25.000)
		Reliable	Needs integration with aircraft systems or ...
		Long range	... GPS dependent for own positions
		1 worldwide technology (1090 ES)	3 different technologies, not interoperable
		Accuracy – integrity is monitored	No assistance for CA
		Dedicated world-wide frequency	NoN alarms
		Very large amounts of units produced worldwide	Risk of frequency congestion

B2	TCAD	Moderate price (€ 500 -1500)	Detects only cooperative traffic
		Light weight (< 500 g)	Needs third party interrogation
		Small (<1 MCU)	Additional system needed for transponder function
		Low power consumption (<10 W)	Risk of frequency congestion
		No installation costs	
		Usable in different GA aircarft	
B3	Transponders	Light weight	No assistance for pilot SAA
	LAST & LPST	Small size	Not compliant with ICAO SARPs power requirement
		Low power consumption with batteries	Health issue for radiated power in 'open' aircraft
		Suitable for unpowered aircraft	Small range of reply
		Ownship is visible after interrogation reply	
		Low installation and maintenance costs	
		Compatible with transponders for commercial aviation	
C1	Embedded radar	Detect all traffic	High price (buy and maintenance)
		Long range	Heavy weight
		All weather / day-night operation	High power consumption
			No CA alarms
C2	LIDAR / LADAR	Detect all traffic	High price (buy and maintenance)
		Long range	Heavy weight
		All weather/day-night operation	High power consumption
		Detection of small objects	No CA alarms
D1	IR camera	Detects traffic through haze	Calibration needed
		Identification with zoom function	Single target detection
		Tracking of target in open skies	High price
		Accurate bearing	High installation costs
			Needs trained operator
			No warnings or alarms
			Limited Field of Regard

D2	EO camera	Identification with zoom function	Single target detection
		Tracking of targets in open skies	High price
		Accurate bearing	High installation costs for turret
			High processing power (multiple sensors)
			Needs operator
			No warnings or alarms
			Limited Field of Regard
D3	Acoustic sensors	Low price	TRL too low
		Multi-sensor applications possible for bearing accuracy	Inaccurate range
		Easy installation	Not reliable
			Low accuracy for range
			Calibration needed

Analysis

For recreational, sports and training flights the cost of the equipment will be the main bottleneck. With the exception of acoustic sensors (D3), most systems that are capable of detecting non-cooperative traffic (families C and D) are too expensive, but also the Size-Weight-Power consumption (SWP) factor does not fit the requirements for GA. Note that limiting the choice to equipment for cooperative traffic includes the need for training and information about the limitation of this equipment. Looking outside for SAA is the primary task for Collision Avoidance, but assistance by equipment with at least aural warnings for a collision hazard can help. Looking head down at a display for situational awareness of traffic can only come second.

In remote areas with no Secondary Surveillance Radar or other systems which interrogate the transponders of cooperative traffic an active system is needed. For areas without radar surveillance the information of ATC will not suffice for aiding in the visual detection of other traffic. Based on price and ease of installation the category A3 will best fit the requirements for GA pilots. However the reliability of these systems with their own frequency and protocol depends on the number of GA aircraft that are equipped with this type. The availability in both modular, and highly integrated, portable systems improves the chance for voluntary installation on different types of GA aircraft.

In areas with SSR or other systems which interrogate the transponders of cooperative traffic a passive system from family B may be sufficient. For detectability reasons a combination with a certified transponder or a transponder of category B3 is required. The ADS-B systems can serve this purpose but are too expensive for GA, especially if they have to serve the SAA function by providing ADS-B in, as well as the installation of an appropriate display. The category B2 will fit the requirements for this environment but also the category A3 when optionally equipped with receivers for the signals on the 1090 MHz radio frequency. Of course the price will be higher and makes the voluntary installation less attractive. For operations in or near a TMA the installation of this equipment is highly recommended to reduce the collision risk.

An alternative solution for interoperability near airports can be the introduction of ground stations that provide FLARM messages of transponder equipped aircraft. Because of the vast increase of received FLARM messages to be processed the performance of the FLARM equipment should be improved for this solution.

Nowadays a lot of small manufacturers like Garrecht Avionik GmbH and EDIATEC GmbH and many others produce systems based on FLARM technology with specific extensions for specific applications, or for a specific operational environment. Because the core of these systems is based on the FLARM technology this helps to get more production and a reduction in the price for the core module. Main differences are in the addition of other receivers, the calculation of the collision hazard and the presentation of the traffic and the hazards. Standardization of simple aural warnings with a back-up text display will help to standardize the information to the pilot for this safety related human factors aspect.

3.5 Summary of results and outcomes

The variety in the types of GA aircraft and their utilization makes it difficult to assess the systems that are fit to assist the pilot with his See-and-Avoid task. Affordability in its most extensive meaning is used as the overall requirement for the introduction of safety systems on a voluntary basis. The requirements are detailed in several elements that can be used to select between the different systems, but also to check if a selected system fulfils the main requirements or not. An important requirement is interoperability, but the need depends on the main operation of the GA aircraft and the area of operation. Near airports the detection of Transport Category aircraft, even in controlled airspace, can be improved with the appropriate equipment.

The different systems are combined in four families:

A. cooperative and active;
B. cooperative and passive;
C. non-cooperative and active, and
D. non-cooperative and passive.

The main characteristics of the different systems are described in detail. It shows that the lower cost systems which only detect cooperative traffic, and with all their limitations in detecting other traffic, are the most promising to assist GA pilots. The family of cooperative and active systems (and possibly passive as well) offers a good opportunity for GA pilots to get assistance for their See-And-Avoid task. The main candidate solutions for the systems in category A3 are FLARM/PowerFLARM (and derivatives) and in category B2 Traffic Collision Avoidance Device (TCAD) systems.

Training in the use of these system solutions, which preferably should be able to provide aural warnings, is critical to make sure that the pilot will not be distracted from his primary See-and-Avoid task for Collision Avoidance.

4 STANDARDIZATION AND HARMONIZATION

4.1 INTRODUCTION

This Section comprises two main elements:

1. Initial assessment of constraints and issues for harmonization of the deployment of generic visual augmentation solutions;
2. Identifying a set of recommendations for harmonization actions.

Firstly, potential constraints and issues have been identified and evaluated through a workshop with EGAST members, GA stakeholders, safety analysts, and system experts. Key issues to convince GA stakeholders of the benefits of introducing the recommended visual augmentation means for GA will be identified. Secondly, the European General Aviation Safety Team (EGAST) will be involved. A set of recommendations for standardization and harmonization actions (covering installation, operation, maintenance, and safety monitoring) have been prepared. Due account will be given to relevant regulatory material from EC and EASA and standardization material from EUROCAE and SAE (e.g. [32]). EGAST may e.g. subsequently decide to develop, with the help of the SISA project team, a safety promotion leaflet to support the introduction of selected candidate solutions.

4.2 INITIAL ASSESSMENT OF CONSTRAINTS AND ISSUES

Any standardization and harmonization effort depends strongly on the support of involved stakeholders. Therefore, a workshop was organized on 22 June 2012 to gather the views of the General Aviation community [49] regarding:

1. Possibilities to deal with practical limitations of see-and-avoid;
2. Needs, wishes and concerns for augmented traffic situational awareness;
3. Generic issues relevant to be addressed

<u>Possibilities to deal with the practical limitations of See and Avoid</u>

Basically, two main opinions were voiced: 1) Equipment is needed, or 2) It is all about training. A summary of the key motivations for either of both opinions is given below:

- It was stated that the limitations of the human eye can only be overcome with equipment to improve the probability to detect traffic. This is because there are situations where a pilot just cannot see other flying aircraft. A supporting detection system would be a potential solution, and can provide the pilot with something to overcome this limitation.

- Concern about a mandatory basis for equipment was raised by the GA community, because of certification issues and installation costs. On the other hand, it was also recognized that if a system solution is not prescribed, little may or will happen. As it is today, it would then remain up to the pilot to decide whether he/she wants to buy and use such a system, leaving it to be a personal risk assessment. It would be an option to show the (safety) benefits to the GA pilots, and leave it to them to decide whether or not to buy a system.
- Concern and drawbacks about the use of additional equipment was raised. It may lead to a situation where too much time is used for looking at equipment instead of scanning the airspace. Pilots may also become dependent on equipment, resulting in over-reliance. This could imply that pilots look out less than required. A system would have to be introduced as a bonus, and therefore it should also be stressed that see-and-avoid is a primary pilot responsibility, requiring sufficient time and concentration to look outside.
- Training and education remain important. There may be some simple tricks and good practices that can be communicated. Two examples are (1) flying below or offset track with another aircraft, and (2) keeping a clean windscreen. Training should be about awareness, vigilance and maybe some “tricks”. Retrain pilots to properly scan the airspace (maintaining skills is essential). However, reaching out to flight schools and their instructors helps, but there is always a substantial number of private pilots that is more difficult to reach. A Leaflet on ‘See and Avoid’ principles is not sufficient, as there is no one solution to improve education and training for it.
- Training is relatively cheap. There are only small costs for extra training, and it helps to raise awareness about see and avoid. It is an option to train pilots to communicate their position to other pilots using RF (but this is impractical in some countries and at times when it is congested).

Needs, wishes and concerns for augmented traffic situational awareness

A summary of the issues brought forward by the workshop participants follows.

- The fact that ADS-B “Out” will be mandatory from January 2015 onwards [45][5], whereas ADS-B “In” will not be mandatory may be a drawback for traffic awareness systems[6].

[5] All aircraft operating IFR/GAT in Europe will have to be compliant with Mode S Elementary Surveillance, whilst aircraft with MTOM greater than 5700kg or maximum cruising True Air Speed

- A mix of different technological solutions may not be favourable. A challenge with on-board systems will be to cope with the diversity and interoperability. Diversity concerns the range of aircraft types and the choice between portable versus built in solutions. Interoperability, especially between General Aviation aircraft, will be an issue. There are already solutions on the market that cannot be ignored, e.g. FLARM.
- There is actually a need for standards for communication/interoperability. Such standards should not prescribe a single solution, but should be simple, open and about communication with transponders and/or systems. It may be useful to create a definition of an open standard.
- There could be a standard for the communication part only, leaving it up to the industry to define a solution. The implementation of raising traffic awareness can be open. On the other hand, the benefit of a standard could be a standardized presentation of traffic and alert (e.g. by voice, aural, visual).
- Costs should be considered in relation to aircraft purchase costs. 1,000 Euro may be acceptable for an owner of a GA fixed wing aircraft, but could be very high for e.g. a paraglider or a powered motor glider.
- Cost recovery mechanisms should be promoted to help convince people to buy these systems. For instance deduced from pilot insurance premiums. It should be recognized that there are different traffic levels; some pilots would feel no need for a traffic alert system. The advantages should be promoted, but a personal risk assessment by the pilot could imply a decision not to buy it, because that person flies in areas with little traffic.
- There is a "field of tension" between interoperability, mandatory equipment/certification, and costs. Making equipment mandatory requires a standard, certification, and costs. The advantages of mandatory equipment are interoperability and standardization. Disadvantages could be overreliance on a system, implying that pilots may look out less, while the system may not "see" everything.
- If systems have to be certified against a certain airworthiness standard, costs of the system may become prohibitive. On the other hand mass production could reduce costs. If FLARM would be taken as a standard (being an already widely proliferated system in GA), considerations would have to be given to the fact that several patents are involved.

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greater than 250kts will have to be compliant with Mode S Enhanced Surveillance and "ADS-B out". The mandate dates are January 2015 for forward fit and December 2017 for retrofit [45].

[6] ADS-B "Out" is the broadcast by aircraft of ADS-B data, whereas ADS-B "In" is the reception by aircraft of FIS-B and TIS-B data and other ADS-B data such as direct communication from nearby aircraft. When referring to mandated equipage, this concerns ADS-B "Out". ADS-B "In" is optional.

Key issues relevant to be addressed
As shown in Section 3, the number of mid-air collisions in General Aviation does not really show any improvement over the last years. The EASA Annual Safety Review 2011 [15] lists mid-air collisions as the third most fatal accident category for EASA Member States registered GA aeroplanes with MTOM above 2250 kg (over period 2002 – 2011) and for gliders below 2250 kg (period 2006 – 2011).

It should be ensured that new systems that support observation of other aircraft are efficient. The costs versus benefits question must be answered very convincingly to potential users to consider acquisition of such equipment. The only realistic solution for a non-mandatory system is to make it very simple, cheap and efficient, such that it will be introduced on a large scale on a voluntary basis.

The role for EASA could be to promote system solutions for augmentation of traffic situational and collision-risk awareness in comparison to visual observation, and to define a common specification, to at least ensure inter-operability.

At the SISA Workshop, it was stated that “if See and Avoid needs to be improved, better training and education should get focus. More attention should be given to human factor aspects and pilot skills. Also attention should be given to the reasons why the outcome is often positive (and not to failures). Systems like FLARM should be considered as a bonus”.

At the SISA Workshop, it was also stated that “there is still a need for better understanding of the problem. A survey among GA pilots should be conducted, not only aiming for a better understanding of the See and Avoid safety issue (incident/accident analysis), but also concerning the price that GA aircraft owners are willing to pay for on-board equipment. It should be investigated how mass production (say 10,000 units) may affect the price”.

It was also stated that “voluntary systems can only work if they are cheap and efficient. There is good experience with voluntary initiatives; for instance from flying clubs in France requiring FLARM to be used by members. It shows the strength of such systems even if they not solve everything. Using Mode-S for FLARM may be too expensive”.

4.3 Standardization issues

Introduction

Standardization may be defined as the process of developing and implementing technical standards, which could be a standard specification, standard test method, standard definition, or standard procedure (something that is understood and accepted widely). Standardization aims to support independence of single suppliers, compatibility, interoperability, safety, repeatability, or quality.

A Minimum Operational Performance Standard (MOPS) may be established for specific equipment in support of its designers, manufacturers, installers and users. A MOPS describes the typical equipment applications and operational goals and establishes the basis for required performance under the standard. Compliance with these standards is usually recommended to assure that the equipment will perform its functions satisfactorily under the foreseen operations. A MOPS may (or may not) find implementation in one or more advisory and/or regulatory documents, including e.g. standards.

Context

European Union civil aviation law defines safety objectives through essential requirements and Implementing Rules (IRs) (binding), whereas detailed implementation aspects are included as Certification Specifications (CS) or Acceptable Means of Compliance (AMC) (non-binding). AMCs illustrate a means to show compliance with the related requirement; it is therefore a way to facilitate certification tasks for the applicant and the National Aviation Authority (NAA). NAAs may decide to issue their own national alternative means of compliance. EASA monitors this process of NAAs authorities through EASA standardization inspections (in accordance with EC regulation No. 736/2006).

EUROCAE is a non-profit European organization, which deals exclusively with aviation standardization (Airborne and Ground Systems and Equipment) and related documents as required for use in the regulation of aviation equipment and systems. As such, EUROCAE develops guidance material that may subsequently be adopted by EASA as an AMC for specific systems or equipment.

Regulations on See-and-Avoid

In the European Union, the see-and-avoid concept is regulated at high level in Article 3.a.4 of Annex IV of the European Commission (EC) Regulation No. 216/2008 of 20 February 2008 on Common Rules in the field of civil aviation (see Section 2.1). This article refers to the ICAO Rules of the Air (Annex 2) [2], which notes that it is important to exercise vigilance for the purpose of detecting potential collisions. See-and-avoid can be used to assure separation from other aircraft, and to avoid collisions in case separation fails. Under VFR, the pilot is responsible for separation, i.e. he/she needs to use “See-and-Avoid” to see conflicting air traffic in time, and avoiding the traffic in an appropriate manner. The “avoid” part of see-and-avoid is further standardized using right-of-way rules, which can also be found in ICAO Annex 2 [2]. Collision avoidance is always the responsibility of the pilot. ICAO Annex 2 [2] does specifically describe collision avoidance manoeuvres, but this is considered out of scope for the SISA project.

In support of the implementation of the Single European Sky (SES) regulations, the EC has asked EUROCONTROL, EASA and other relevant stakeholders to develop a draft Implementing Rule on Standardized European Rules of the Air (SERA) [30, 31]. The Standardize Rules of the Air (SERA), which entered into force at 4th December 2012 (with possible derogation for Member States until December 2014), transpose the ICAO Annex 2, Annex 11 and additional relevant ICAO SARPs into common and standardized European regulatory material. The Draft SERA, Section 3.2, deals with Collision Avoidance. However, as compared to ICAO Annex 2 [2], no specific additional requirements concerning ‘See-and-Avoid’ seem to be foreseen at this stage.

Standardization of system solutions

FLARM systems are currently the most widely used solution in Europe. In fact, the French Gliding Federation has recently decided (in May 2012) to make FLARM (or any compatible equipment) mandatory from 2013 onwards for its member organisations. In Switzerland, the FOCA feedback on Safety Recommendations from the Swiss Aircraft Accident Investigation Bureau (AAIB) relating to FLARM [50] concludes in 2010: “The rapid distribution of such systems only a few months after their introduction was not accomplished through regulatory measures, but rather on a voluntary basis and as a result of the wish on the part of the involved players to contribute towards the reduction of collision risk. FOCA recommends that glider tow planes and helicopters that operate in lower airspace should also use collision warning systems”. This gives FLARM solutions an advantage over other type of solutions.

4.4 Harmonization issues

Harmonization is the process to resolve differences, divergences and the variety of solutions to alleviate ‘See and Avoid’ concerns, by a uniform and common approach across the EASA member states. Such process aims to adjust the differences and inconsistencies among the different solutions (specifications, systems, equipment, and procedures) to make them uniform or mutually compatible. Therefore, the aim would be to agree upon consistent implementation of new systems solutions (and their associated procedures).

Maintaining the existing situation is of course also an option. However, this seems to be not logical, because this implies not addressing the safety concerns that have been expressed to the European General Aviation Safety Team, and not taking advantage of benefits that new system solutions have already shown.
An already identified key constraint for further harmonization (Section 2.2) is the ability of these new system solutions to work together (be interoperable) with existing systems. Small aircraft equipped with a new system solution to mitigate See and Avoid difficulties must operate in an environment where there are other technical systems functioning. The collision avoidance capability of small aircraft must stay interoperable with TCAS already fitted on many existing aircraft.

The family of cooperative and active systems (and possibly passive as well) offers a good opportunity for GA pilots to get assistance for their See-And-Avoid task. The main candidate system solutions in category A3 are FLARM/PowerFLARM (and derivatives) and in category B2 Traffic Collision Avoidance Device systems.

Note that training in the use of these system solutions, which preferably should be able to provide aural warnings, is critical to make sure that the pilot will not be distracted from his primary See-and-Avoid task for Collision Avoidance.
The harmonization process may involve the following:

1. *Standardization of system solutions*. Relevant stakeholders (preferably as part of EUROCAE, ***the*** European civil aviation systems standardization organization) to jointly develop a common technical standard for generic visual augmentation system solutions for small aircraft[7].
2. Provided that it is shown that a system that supports observation of other aircraft is beneficial to safety, installation may be possible in LSA/VLA/ELA1 aeroplanes for day VFR from 2014, without airworthiness approval of EASA or an appropriately approved Design Organization[8].
3. *Operation of system solutions*. EGAST (and EASA) may if needed develop common procedures (and possibly requirements) for operation of one or

[7] Early 2012, FAA has issued a draft TSO for establishing the Minimum Performance Standard for Lower Power Surveillance Equipment [44], with the intention to provide low cost means for aircraft owners to equip their aircraft with a unit to increase safety by making them visible to other aircraft. The TSO addresses aircraft exempted from carrying a transponder or ADS-B (e.g. gliders, balloons).
[8] EASA Working Group MDM.048 is developing Certification Specifications for standard repairs and changes that will not require approval. Phase 1, applicable from early 2014 onwards, will apply e.g. to Light Sport Aircraft (LSA), Very Light Aircraft (VLA), and European Light Aircraft (ELA) 1 [38].

more system solutions in uncontrolled airspace. A safety promotion leaflet could support harmonization of system solutions and procedures.

4. *Maintenance of systems*. Any system solution will have to undergo scheduled maintenance (and updates to e.g. become/stay interoperable). For commercial air transport, such maintenance actions are covered through Part M and need to be performed by a Part 145 certified organization. Note that if airworthiness approval is not required for a system solution, then Part-M is not used.
5. *Safety monitoring* will remain as difficult as today, but with a large equipment of an avoidance system, this may support surveys of situations (e.g. through collecting the number of warnings raised). EASA could then more easily analyse in more detail commonalities of hazards and causal factors related to See and Avoid, develop specific Safety Performance Indicators (SPIs), and then also monitor how these SPIs evolve in Europe.

4.5 Summary of results and outcomes

Over the last years, the number of accidents due to issues with 'See and Avoid' does not decrease. The EASA Annual Safety Review 2011 [15] lists mid-air collisions as the third most fatal accident category for EASA Member States registered GA aeroplanes with MTOM above 2250 kg (over period 2002 – 2011) and for gliders below 2250 kg (period 2006 – 2011). Besides e.g. training and education of private pilots to procedures and scanning patterns, options to mitigate See and Avoid limitations include anti-collision devices on aircraft.

Up to now, the use of anti-collision devices for General Aviation aircraft is promoted on a voluntary basis in Europe. No standardized and harmonized solution exists today. A SAA workshop was organised to identify and assess constraints and issues for harmonization of the deployment of generic visual augmentation solutions. From the discussions and positions expressed by participants of this SAA Workshop, there seems to be a reasonable level of consensus about five points:

- The key element of 'See and Avoid' is to look outside for potential traffic. Training and education are the best instruments to optimise this aspect.
- See and Avoid training and education could however be complemented by on-board equipment. Several systems are already widely used and provide help to the pilot to identify other traffic.
- Any on-board equipment to augment pilot's visual observations shall be light and cheap. Based on current (but incomplete) information, it is expected that any equipment costing more than around 1000 Euro and weighing more than 1 kg will not be acquired voluntarily at large scale within the GA community.

- Due to price constraints, cooperative systems seem the way forward (non-cooperative will likely be too expensive)
- EASA's role is primarily seen as to promote systems and provide encouragement for implementation. EASA must find the right incentives for initiatives.
- A standard developed by the industry, e.g. through EUROCAE, need to be encouraged. This standard will ensure interoperability between systems.

The family of cooperative and active systems (and possibly passive as well) offer a good opportunity for GA pilots to get assistance for their See-And-Avoid task. The main candidate solutions are the cooperative and active systems FLARM/ PowerFLARM (and derivatives) and the cooperative and passive Traffic Collision Avoidance Device (TCAD) systems. Therefore, a technical standard could be based on the current characteristics of these system solutions. If FLARM would be taken as basis for such standard, considerations would have to be given to the several patents that are involved (this may be a disadvantage for standardization). General Aviation pilots should be made aware that a system to increase traffic awareness also has limitations (e.g. it is triggered by other similarly equipped aircraft). It should be investigated what price GA aircraft owners are willing to pay for on-board equipment (and how mass production may affect the price per unit, because voluntary systems will only work if they are cheap and efficient. If a new system solution (equipment) is considered, first a risk assessment has to be performed whether the system really reduces risk, or even may introduce new risks (e.g. overconfidence). This relates to the concept of risk homeostasis, which assumes that everyone has his or her own fixed level of acceptable risk. When the level of risk changes (e.g. because a safety enhancement system is being introduced), there will be a corresponding rise or fall in risk elsewhere to bring the overall risk back to the 'equilibrium'. It could therefore be that GA pilots that have an anti-collision device on-board their aircraft behave less carefully because they will rely more on the guidance and benefits of the anti-collision device. To really understand how this works, more safety research into the safety benefits of introducing new anti-collision equipment for GA pilots would be required.

5 OUTREACH

An adequate outreach to interested parties (both internal and external to EASA) and proper communication of intentions and benefits of this study is important. For this purpose, the objectives and intermediate results have been presented to the EGAST at three subsequent meetings (in March, June, and September 2012). Additionally, a Workshop with GA stakeholders was organized at EASA premises. Further dissemination, e.g. through the EGAST web-site, is foreseen and planned.

The following key benefits evolve from this study:

- Increased understanding of the hazards and causal factors in relation to application of See and Avoid principles in uncontrolled airspace. This is relevant for EASA, EGAST, GA stakeholders, flight schools, and private pilots.
- Requirements for GA equipment to augment traffic situational awareness and collision risk awareness are proposed. This set may feed into (and lead to) an accepted standard. This is important for the manufacturing industry in order to be able to build the right system in an efficient way.
- Harmonization actions are identified. This is important for the aviation community because this may initiate the consistent, uniform and mutually compatible implementation of systems solutions (and their associated procedures) to mitigate hazards in relation to See and Avoid difficulties.
- An overview of initiatives to design, develop, implement and deploy candidate systems solutions to augment pilot's observation means is established. This is important for the research community, e.g. to avoid duplication of work and to proceed in the most practical way forward.

The methodology and approach used is based on three subsequent steps:

1. Survey of safety issues and initiatives related to 'See and Avoid'
2. Assess options for augmentation of pilots' visual observation
3. Recommendations for harmonization (and standardization).

It turned out to be difficult to obtain a complete picture of the possible candidate system solutions types using publicly available material only. This especially applies to potential system solutions available for (and targeted to) the Unmanned Aircraft Systems domain.

6 Conclusions and recommendations

6.1 Conclusions

Mid-air collision statistics for General Aviation (for both Europe and United States of America) have been presented and discussed. Data from EASA shows that over the period 2006-2011 there were 82 mid-air collisions involving aircraft with a maximum take-off mass lower than 2250 kg in Europe. On average, there were 16 mid-air collisions in the United States annually from 1991 through 2000.

Local initiatives taken in Europe to reduce the hazards of the see-and-avoid limitations have been identified and discussed. There seems to be consensus that there is currently no solution available that mitigates all the issues related to See and Avoid. Most mid-air collisions occur because the flight crew does not see conflicting aircraft. Options to mitigate See and Avoid limitations include e.g. improvements of the visibility of aircraft and training or education of private pilots, and anti-collision devices on General Aviation aircraft. Requirements regarding the potential candidate system solutions to mitigate issues related to the application of See and Avoid have been derived from discussions with stakeholders. Four different types of solutions have been assessed against these requirements. The systems are grouped in four families:

A. Cooperative and active;
B. Cooperative and passive;
C. Non-cooperative and active, and
D. Non-cooperative and passive.

It follows that the cheaper systems which only detect cooperative traffic, with all their limitations in detecting other traffic, are most promising to assist GA pilots. Training and aural warnings are critical to make sure that the pilot is not distracted from his primary task for Collision Avoidance. The family of cooperative and active systems (and possibly passive as well) offers a good opportunity for GA pilots to get assistance for their See-And-Avoid task.

This study has scoped the potential improvements regarding the use of ‘See and Avoid’ for General Aviation in uncontrolled airspace. Four main points emerged:

- The key element of ‘See and Avoid’ is to look outside for potential traffic. Training and education are the best instruments to optimize this aspect.

- See and Avoid training and education could however be complemented by on-board equipment. Several systems are already widely used and provide help to the pilot to detect other traffic.
- Any on-board equipment to augment the pilot's visual observations shall be light, cheap, and cooperative (non-cooperative will likely be too expensive).
- A standard developed by the industry, e.g. through EUROCAE, need to be encouraged. This standard will ensure interoperability between systems.

The following key benefits evolve from this study:

- Increased understanding of the hazards and causal factors in relation to application of See and Avoid principles in uncontrolled airspace. This is relevant for EASA, EGAST, GA stakeholders, flight schools, private pilots.
- Requirements for GA equipment to augment traffic situational awareness and collision risk awareness are proposed. This set may feed into (and lead to) an accepted standard. This is important for the manufacturing industry in order to be able to build the right system in an efficient way.
- Harmonization actions are identified. This is important for the aviation community because this may initiate the consistent, uniform and mutually compatible implementation of systems solutions (and their associated procedures) to mitigate hazards in relation to See and Avoid difficulties.
- An overview of initiatives to design, develop, implement and deploy candidate systems solutions to augment pilot's observation means is established. This is important for the research community, e.g. to avoid duplication of work and to proceed in the most practical way forward.

It turned out to be difficult to obtain a complete picture of the possible candidate system solutions types using publicly available material only. This especially applies to potential system solutions available for (and targeted to) the UAS domain. For similar studies, it is an option to also involve EUROCAE for feedback.

6.2 Recommendations

The following actions are recommended to exploit this study further:

- To develop a technical standard for collision warning systems in the field of general aviation. Identified standardisation body here is EUROCAE.
- To develop common procedures and requirements for operation of one or more system solutions in uncontrolled airspace. A safety leaflet could support the harmonization of system solutions and procedures. Identified organisation here is EGAST.
- Safety monitoring will remain as difficult as today, but a large equipage with avoidance systems, this may support surveys of situations (e.g. through

collecting the number of warnings raised and analysing commonalities). EASA and National Aviation Authorities could then more easily analyse in more detail commonalities of hazards and causal factors related to See and Avoid, develop specific Safety Performance Indicators (SPIs), and then also monitor how these SPIs evolve in Europe.

- Training material shall be developed that cover not only the safety benefits for the users but also the limitations and human factor issues such as the potential over-reliance on the equipment.

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Appendix A Terminology

Terminology used is based on the ICAO definitions, as described in ICAO Annex 2 (Rules of the Air), ICAO Doc 9924 (Aeronautical Surveillance Manual), and ICAO Doc 4444 (PANS-ATM). The key terms used are explained in the following.

Aeronautical Surveillance System is defined in ICAO Doc 9924 as a system that: "provides the aircraft position and other related information to ATM and/or airborne users. In most cases, an aeronautical surveillance system provides its user with knowledge of "who" is "where" and "when". Other information provided may include horizontal and vertical speed data, identifying characteristics or intent. The required data and its technical performance parameters are specific to the application that is being used. As a minimum, the aeronautical surveillance system provides position information on aircraft or vehicles at a known time".

The requirements for ATS surveillance systems are contained in the ICAO PANS-ATM (Doc 4444), Chapters 6 and 8. The aeronautical surveillance system defined in ICAO Doc 9924 comprises several elements which will be operated based on the requirements of a specific application. Neither the applications nor the end-users are part of the aeronautical surveillance system. The surveillance service delivered to ground users may be based on a number of techniques:

- **Independent Non-Cooperative Surveillance** (as defined in ICAO 9924). The aircraft position is derived from measurement not using the cooperation of the remote aircraft. An example is a system using PSR, which provides aircraft position but not identity or any other aircraft data.
- **Independent Cooperative Surveillance** (as defined in ICAO 9924). The position is derived from measurements performed by a local surveillance subsystem using aircraft transmissions. Aircraft-derived information (e.g. pressure altitude, aircraft identity) can be provided from those transmissions. Examples: SSR, SSR Mode S and Wide Area Multilateration.
- **Dependent Cooperative Surveillance** (as defined in ICAO 9924). The position is derived on board the aircraft and is provided to the local surveillance subsystem along with possible additional data (e.g. aircraft identity, pressure altitude).

The technologies are categorized as follows:

Technologies	Type	Air traffic surveillance sensor
Non-Cooperative	Independent	• Primary Surveillance Radar (PSR) Multi-Static • Primary Surveillance Radar (MSPSR)
Cooperative	Independent	• Secondary Surveillance Radar (SSR) Mode A/C and Mode-S • Wide Area Multilateration (WAM) system • Multi-LATeration (MLAT) system
	Dependent	• Automatic Dependent Surveillance Broadcast (ADS-B)

Composite Forms of Surveillance are means whereby two or more surveillance techniques are co-located to achieve either benefits in cost (deploying and maintaining at a single site may be cheaper than for a widely distributed set of systems) or which could bring functional benefits through the sharing of surveillance data (e.g. ADS-B collocated with a Mode S ground station could achieve RF efficiencies and improved detection capabilities)

SSR Mode 3/A Code Management Systems provide either a unique SSR Mode 3/A code to IFR/GAT flights operating within a defined volume of airspace, or the Mode S Conspicuity Code (SSR code A1000) to eligible flights operating within Mode S Declared Airspace.

- CCAMS is a SSR Mode 3/A code management system based on a centralised server, located at EUROCONTROL's Network Manager Operations Centre which is linked to the local flight data processing systems of participating ANSPs. CCAMS provides a unique Mode 3/A SSR code to each flight operating within the CCAMS area.
- e-ORCAM is a SSR Mode 3/A code management process which enhances the capabilities of the existing ORCAM to provide:
    - Multiple simultaneous assignments of the same code;
    - Geographical correlation of flights;
    - Directional assignment of codes;
    - Code reporting, and
    - Code retention checking.

Appendix B Causal factors

ATS does not provide traffic advisory

In uncontrolled airspace there are no ATS services available, and clearly no traffic advisory can be provided. If there are ATS services available there are several causes of failure to provide traffic advisories:

- Surveillance system failures: primary and secondary radar, ADS-B;
- Communication system failures, both aircraft and ATS;
- Erroneous communication procedures between ATCo and pilot;
- Erroneous air traffic control procedures (conflict detection, conflict resolution);
- ATCo errors (due to high workload, insufficient training, limited experience, bad safety culture etc.).

On-board system does not provide traffic advisory

The following reasons can be distinguished for a lack of traffic advisories from on-board systems:

- No such system installed;
- System failure;
- Other aircraft transponder not functioning;
- Other aircraft not equipped with transponder.

Conflicting aircraft effectively not visible

In good visibility, pilots can avoid other traffic by exercising the see-and-avoid principle. Application of the see-and-avoid principle by the flight crew will usually only be feasible and reliable in case the weather is according to visual metrological conditions (VMC). However, even in VMC other aircraft may be difficult to see by the flight crew. Influencing factors are described below.

(1) Visibility:

- Visibility is related to the size of the flying object (the smaller, the worse it can be seen);
- Visibility is reduced somewhat by clouds, air pollution and by high humidity. Various weather stations report this as haze (dry) or mist (moist);
- Heavy rain, blizzards and ground blizzards (blowing snow) cause low visibility, such that flight in VMC would not be possible and/or allowed;

- Fog, smoke (e.g. due to forest fires) and sandstorms (e.g. from desert areas) can reduce visibility to near zero, such that flight in VMC would not be possible and/or allowed;
- Sun glare

(2) The limitations of the human eye:

- The field of vision of the human eye of approximately 200 degrees, which reduces with ages and due to fatigue, stress, workload, mental calculation, day dreaming, hypoxia, and adverse thermal conditions. Furthermore, the area in which eyes can actually focus and classify an object is relatively narrow (approximately 10-15 degrees). Although movement can be perceived in the periphery of the eye, it is difficult to identify what is happening there. This often leads to tunnel vision;
- As the eye's threshold for acuity (how large the image of an aircraft needs to be on the retina before it allows identification as an aircraft) is lowest in the centre part of the retina, scanning is required. This takes time. Proper scanning of a 30 degree by 180 degree volume of the sky would require at least 54 seconds. Therefore usually only the middle part is scanned properly. Acuity is reduced by vibration, fatigue or hypoxia;
- The blind spot on the retina. Objects in the blind spot are not seen;
- In empty space (e.g. blue sky) the eye tends to focus at a relatively short distance (e.g. 50 cm). This effect is known as empty field myopia and can reduces the chance of identifying a distant object;
- The eye needs time to focus on an object (accommodation time). This increases with age and due to fatigue;
- Object nearby (e.g. window posts and dirt on the wind screen) can result in the eye being focussed inadvertently on these objects (focal traps), making it difficult to see distant objects;
- The human visual system is particularly attuned to detecting movement but is less effective at detecting stationary objects. Unfortunately, due to the geometry of collision paths, conflicting aircraft will usually appear as stationary object.

(3) The available field of view as affected by:

- Cockpit visibility, which can be reduced by obstructions like window posts, windscreen bugs, sun visors, wings, front seat occupants or the instrument panel;
- Glare directly from a light source (e.g. the sun) or reflected by for example dirt on the wind screen.

(4) The contrast of the traffic with background, which is affected by:

- Aircraft colour and type of background. A dark aircraft will be seen best against a light background, while a light coloured aircraft will be seen best against a dull or dark background;
- Haze or fog. Contrast is reduced when the small particles in haze or fog scatter light;
- Aircraft anti-collision lights. Although there is no evidence that support the use of lights in daylight conditions (see for more information [10]);
- Contour interaction in which the outline of an aircraft interacts with the contours present in the background or neighbouring objects. Contour interaction can be a problem at lower altitudes, where aircraft appear against complex backgrounds.

Pilot does not see visible conflicting aircraft while scanning

Probably the most important factor of a failure to see conflicting aircraft while scanning the airspace is shear providence, not looking at the right spot in the right time. A proper scanning technique as explained in the previous section aids a pilot in detecting other air traffic. Knowing what to look for is even more important. The availability of ATS traffic information is an important factor in the likelihood of identifying another aircraft on a collision course. The availability of ATS traffic information depends on airspace class and flight rules. A search for other traffic in the absence of traffic information, so-called “unalerted see-and-avoid”, is less likely to be successful than a search where traffic information has been provided, so-called “alerted see-and-avoid”. The Australian see-and-avoid study mentions flight trials conducted in the 70s that found that in the absence of a traffic alert, the probability of a pilot sighting an aircraft is generally low until a short time before impact. Traffic alerts were found to increase search effectiveness by a factor of eight [10]. It is noted that a pilot can also become aware of traffic nearby by simply listening to radio contact between ATS and other aircraft.

Even when scanning it takes time to detect and track an aircraft and recognize the collision course. Table 4 indicates that recognizing an object as an aircraft takes only 1 second (note that the times in the table are from the moment an object is spotted in the air). The assessment if there is a conflict takes longer however. According to Table 4 it takes on average 5 seconds. This makes it the longest task in the table. One important characteristic is that an aircraft on a collision course appears stationary in the visual field. Considering the time it takes to recognize a conflicting aircraft if an object is detected it is necessary to identify aircraft far in advance.

Pilot does not scan traffic (adequately)

A pilot may fail to observe an aircraft if not looking outside the cockpit. The time spent looking outside the cockpit is affected by:

- Traffic density and the pilot's assessment of collision risk;
- The time spent by the pilot looking at instrument, this might increase in aircraft equipped with glass cockpits;
- Cockpit workload, which is high in airport traffic patterns where traffic is dense and in terminal areas with ATS which impose tasks. Cockpit workload might also be high while flying with a flight instructor;
- Controlled airspace: if pilots know ATC is responsible for separation they tend to scan less.

Pilot does not use the radio to increase situational awareness

A pilot can use the communication over the radio with ATS, with other aircraft, and with other aircraft with ATS to form a mental picture of outside traffic. The pilot may fail to do so if

- Aircraft is not equipped with radio
- The radio is not functioning
- Pilot is not listening to communications
- ATS other aircraft are not communicating.

Appendix C Survey of initiatives

Project name: ACAS on VLJs and LJs – Assessment of safety Level
Acronym: AVAL
Duration: 2007-2009
Customer: EUROCONTROL
Contractor (including partners): Egis Avia, DSNA, QinetiQ
Problem description / background: ACAS II (TCAS II) reduces the risk of mid-air collisions. Since 2005 ACAS II is mandated for aircraft with a maximum take-off mass of more than 5,700 or a capacity of more than 19 passengers. The question that arises is if there are safety benefits from extending the use of ACAS II to lighter jets, commonly called Very Light Jets (VLJs) and Light Jets (LJs).
Objectives: • Assess the impact of VLJ and LJ operations on the safety benefits delivered by ACAS II in the future European environment • Determine the best approach for ACAS equipage on VLJs and LJs
Description of work: An analysis has been made of the future European ATM environment with VLJs and small LJs. The analysis has been extended with the development of a pre-VLJ and post-VLJ (and small LJs) safety encounter model for the 2008 and 2015 timeframe. The models allowed simulating the future VLJ and small LJ operations with or without ACAS II, and with or without visual acquisition prompted by ACAS I alerts. The safety implications of ACAS equipage by VLJs and small LJs have been evaluated. Finally pros and cons of ACAS equipage by VLJs and small LJs have been formulated.
Main results: • TCAS I equipage is the least preferred option: it might be better not to equip VLJs and small LJs with TCAS I in order to minimize disruption of ATC and ACAS II operations. • ACAS II equipage, at least for mainstream VLJ aircraft seems the most effective option. • It is recommended to extend the current European ACAS II mandate to include all civil fixed-wing turbine-engined aircraft with a maximum cruising speed of over 250 knots. • It is recommended to give proper attention to ACAS II training for pilots of VLJs and small LJs. • It is recommended to demonstrate and quantify the safety benefits of TCAS I, with a focus on the potential impact on the mid-air collision risk reduction delivered by ACAS II. • The study did not produce evidence on which to base any recommendation for equipping VLJs and small LJs with TCAS I.
Documentation: 1. AVAL final report, Safety benefits of ACAS in the future European ATM

environment with Very Light Jets, CND/CoE/CNS/09-142, Edition 1.3, 16 November 2009 2. T. Arino, ACAS on VLJs and LJs – Assessment of safety Level (AVAL), Outcomes of the AVAL study, presentation AVAL/WA7/42/D, version 1.0, 19 November 2009

Project name: Increased visibility of small aircraft as protection against collisions (in German: Bessere Erkennbarkeit kleiner Luftfahrzeuge als Schutz vor Kollisionen)
Acronym: BEKLAS
Duration: finished in 2004
Budget: -
Customer: Bundesministerium für Verkehr, Bau- und Wohnungswesen
Contractor (including partners): ALROUND, IFF TU Braunschweig, Deutsche Akademie für Flug- und Reisemedizin
Problem description / background: The need for this study is related to the central location of Germany in the heart of Europe. North-south and west-east air traffic crosses in German air space. The crowded air space is also structured in a complex manner. Most of the traffic, 95%, consists of light aircraft with a maximum take-off weight of less than 5,700 kg. Clearly hazardous incidents and accidents happen in the airspace. These accidents often involve fatalities. The ground principle to prevent these accidents is see-and-avoid. Currently technical possibilities are studied to reduce the risk of mid-air collisions.
Objectives: • Analyze the current situation of collision avoidance measures in aviation. • Draft recommendations on strategies to further mitigate the risks of a mid-air collision.
Description of work: The following subjects are considered in the study: accident data, human factors, technique and instrument, aircraft operation, possible measures.
Main results: (relevant results only) • The use of electrical-optical systems for small aircraft is promising. These systems are not dependent on the equipage of other aircraft. • There are merits in the integration of TIS-B, ADS-B and CDTI using Mode S transponder in General Aviation.
Documentation: 1. Abschlussbericht, BEKLAS, Erkennbarkeit von Segelflugzeugen und kleinen motorisierten Luftfahrzeugen, L-6/2002-50.0300/2002, May 2004 2. Anhänge zum Abschlussbericht, BEKLAS, Erkennbarkeit von Segelflugzeugen und kleinen motorisierten Luftfahrzeugen, L-6/2002-50.0300/2002, May 2004
Further information: http://www.daec.de/flusi/VermeidungvonZusammenstossen.htm

Project name: Detection and Recognition of Light Aircraft in the Current and Future ATM Environment
Acronym: LAST
Duration: finished in 2005
Customer: EUROCONTROL
Contractor (including partners): Lockheed Martin STASYS Limited
Problem description / background: There are no harmonised European operational requirements concerning the regulation of extended transponder carriage requiring a light aviation SSR transponder. This is due to absence of an agreed operational requirement, differences in airspace management by States and a lack of appropriate airborne equipment. State regulatory need to address how to accommodate the recreational and sporting aviation community with rising commercial air transport activity in a way that utilises the airspace more efficiently whilst maintaining or improving safety. The study was conducted because there is a need to extend transponder carriage by light aircraft in order to support the effectiveness of ACAS, as well as to improve the effectiveness of ATS.
Objectives: Define and quantify the operational problems and hazards for which solutions are needed of transponder carriage requirements for light aviation, both today and in the context of future airspace structures and requirements.
Description of work: A variety of stakeholders, particularly members of the GA community, have been consulted regarding transponder equipage requirements. Procedural, technical and regulatory solutions to address issues and problems involved are identified.
Main results: • The level of risk in Europe varies widely due to issues such as airspace design, GA population and terrain. The types of hazards are generally common to all States; Separation Assurance and ATM Interoperability. The solutions that could reduce many of the risks revolve around segregating conflicting users, improving education, improving 'See-and-Avoid' for VFR flights, and ensuring interoperability between users. • Where the planning levels fail to reduce the risk of light aircraft coming into conflict with other users, the next preventative layer should be to improve the effectiveness of both visual and electronic acquisition techniques to prevent collisions. The 'See-and-Avoid' technique could be enhanced through increased tactical information flow and improved visual conspicuity and acquisition techniques. Electronic acquisition could be improved through the widespread carriage of SSR transponders and collision warning systems. • There are widely differing opinions on the effectiveness of 'See-and-Avoid' in uncontrolled airspace. Some studies have demonstrated that 'See-and-Avoid' is 99% effective in avoiding collisions, whereas others are more concerned about the risks. In particular, the ability of GA pilots to spot low and fast military aircraft is an issue. The head-on profile of many modern military jets and light aircraft is extremely small and closure rates of aircraft can be phenomenal. It is doubted if the 'See-and-Avoid' method in scenarios involving fast jets is effective as the sole means of avoiding collisions. • A Pan-European simulation should be conducted into the effectiveness of the

'See-and-Avoid' method. This simulation should consider the effects of systems such as TIS and ADS-B displays on cockpit distraction and should investigate the use and benefits of oral warnings rather than visual cockpit displays in light aircraft.
Documentation: • Final Report, Study to Address the Detection and Recognition of Light Aircraft in the Current and Future ATM Environment, Issue 1.0, 2 May 2005
Further information: http://www.eurocontrol.int/msa/public/standard_page/General_aviation_VFR.html

Project name: Future Airspace Strategy
Acronym: FAS
Duration: 2010 - 2011
Budget:
Customer: CAA-UK
Contractor (including partners): CAA-UK
Problem description / background: The Future Airspace Strategy (FAS) is a strategic framework that will pull together a complex and diverse set of policy and regulatory issues that will enable judgements to be made that are properly underpinned by cohesive and cogent policy formulation. This will in turn enable air navigation service providers to create an airspace structure that is fit for the future, effective, efficient and ensures that the UK meets any international obligations that are placed upon it. Note that this study has a far wider scope than relevant for our purposes.
Objectives: (Relevant objective only) Establish a future surveillance capability based on a combination of independent ground-based surveillance and airborne derived down-linked data, driven by a combination of performance requirements and new technology.
Description of work: Paper study to develop a future airspace strategy.
Main results: (Relevant results only) Successfully operating a combined ground-based and airborne surveillance capability will require aircraft to equip with technology to a given standard. The mandatory carriage of functioning transponders will be required in identified areas as part of the safety risk mitigations. That may also be an argument for wider carriage if it can be demonstrated that it would successfully reduce collision risk. Some users, in particular within the military and GA community may not be able to comply or create a sufficient business case to justify the necessary investment. In some parts of the GA community ADS-B is already used as a means of reducing collisions with other GA aircraft, but that is not currently compatible with other systems. GA could be a focus for the creation of a cooperative environment and therefore the engagement and support of the GA community is important for this development work. A key principle of this work

should be the willingness to create a co-operative environment in which technology can help to produce a safe airspace.
Documentation: Civil Aviation Authority, Future Airspace Strategy for the United Kingdom 2011 to 2030, 30 June 2011
Further information: http://www.caa.co.uk/default.aspx?pageid=12068

Project name: Traffic Awareness for General Aviation
Acronym: TAGA
Duration: August 2000 – July 2003
Budget: -
Customer: co-funded by the German state Bavaria
Contractor (including partners): Deutsche Flugsicherung (DFS), EuroTelematik, Avionik Straubing
Problem description / background: Evaluation of potential benefits enabled by the use of a traffic presentation onboard of General Aviation aircraft.
Objectives: Finding the answer to the question: does a traffic presentation onboard of a General Aviation aircraft support the pilot in the detection and identification of traffic?
Description of work: Flight trials have been performed studying the detection of traffic, by the use of CDTI, of the same airspeed category and of a higher airspeed category.
Main results: • A significant increase in the overall detection probability had been identified during the flight trials. These improvements were identified at distances greater than 2.5 NM and in positions behind the ownship. • It is not possible to replace the visual scan of the surrounding airspace by the use of a traffic presentation onboard. An electronic traffic presentation can be used to support the pilot only. • Traffic presentation provides significant assistance in the detection and identification of traffic. • An update period of 6 seconds is sufficient for en-route, update periods better than 3 seconds are requested for the approach and departure phase of the flight as well as for the detection of fast moving targets.
Documentation: DFS, TAGA – Traffic Awareness for General Aviation, ASAS Thematic Network Workshop #2, October 2003
Further information:

Project name: The limitation of the see-and-avoid system[9]
Acronym: -
Duration: finished in 2004
Budget: -
Customer: Ministerie van Defensie
Contractor: Koninklijke Luchtmacht (Royal Airforce the Netherlands)
Problem description / background: The see-and-avoid principle is not flawless. Although there have been measures to segregate slow and fast traffic no study has shown what is, and what is not, possible with the see-and-avoid principle. This study shows what is possible using different scan techniques.
Objectives: Quantify visibility of traffic as function of scan technique and assess the influence of speed and visibility conditions.
Description of work: A model is used to quantify the visibility of traffic for several different operational scenarios. By combining the visibility of traffic, collision scenarios and scan techniques a prediction of the probability that an aircraft is seen can be determined.
Main results: • It is possible to quantify the effectiveness of a scan technique. Therefore it is possible to find a good scan technique. A 7 second outboard scan of 0, -20, -40, 0, 20, 40 degrees (with a 20% cockpit scan) gives good results. This scan does not give optimal results however; fast traffic is difficult to see even in excellent visibility conditions. Especially slow General Aviation traffic has difficulties detecting faster aircraft. • The following measures can improve the see-and-avoid system: (1) mandatory use of traffic info, TCAS or AIFF, (2) separation of slow and fast traffic, (3) separation of IFR and VFR traffic, (4) introduction of one-way traffic, and (5) couple visibility requirements with maxium speeds.
Documentation: Lt. Col. H.J. Koolstra, De beperkingen van het see and avoid systeem, Koninklijke Luchtmacht, September 2004
Further information: -

[9] In Dutch: de beperkingen van het see and avoid systeem

EUROPEAN AVIATION SAFETY AGENCY
AGENCE EUROPÉENNE DE LA SÉCURITÉ AÉRIENNE
EUROPÄISCHE AGENTUR FÜR FLUGSICHERHEIT

Postal address
Postfach 101253
50452 Cologne
Germany

Visiting address
Ottoplatz 1
50679 Cologne
Germany

Tel +49_221_89990-000
Fax +49_221_89990-999
Mail info@easa.europa.eu
Web easa.europa.eu