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Synthesis of AVAL Phase 1 Findings

ACAS on VLJs and LJs – Assessment of safety Level

AVAL Project

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Abstract

The Airborne Collision Avoidance System (ACAS) is a last resort safety net against mid-air and near mid-air collisions between aircraft. In Europe, ACAS has been mandated from 1st January 2005 to all civil turbine engined aircraft over 5,700 kg or seating more than 19 passengers. The carriage and operation of ACAS has demonstrated to reduce the risk of mid-air collision by a factor of 5.

The foreseen introduction of Very Light Jets (VLJ), and other Light Jets (LJ) weighing less than 5,700 kg, which are currently not required to be equipped with ACAS, is raising questions about their integration within the current ATM system.

The first phase of AVAL Project (ACAS on VLJs and LJs – Assessment of safety Level) sought to establish whether equipping these aircraft with ACAS or not, will have an effect on the overall performance of the ACAS safety net.

If VLJs and LJs are not equipped with ACAS, they will not benefit from the additional safety margins provided by this system and will mostly rely on ATC, where this service is provided, and the "see-and-avoid" principle for collision avoidance. However, this benefit needs to be quantified.

This phase of the AVAL study has concluded that the decision about ACAS equipage mandate for VLJs and LJs can only be quantified through an in-depth investigation based on the encounter model approach used in previous ACAS safety studies. The question of extending the current ACAS mandate to VLJs and LJs also carries technical and financial aspects that need to be examined.

Keywords

TCAS	RA	ACAS	VLJ
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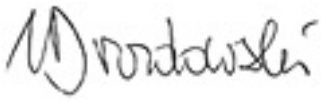
ACAS Operational Expert	 Stanislaw Drozdowski	31 March 2008
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Synthesis of AVAL Phase 1 Findings

ACAS on VLJs and LJs – Assessment of safety Level

AVAL Project

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EXECUTIVE SUMMARY

The Airborne Collision Avoidance System is a last resort safety net that has been introduced to reduce the risk of mid-air collisions. In Europe, ACAS has been mandated from 1st January 2000 for aircraft with a maximum takeoff mass of 15,000 kg or a maximum seating configuration of 30 passengers. In a second phase, this mandate was extended on 1st January 2005 to aircraft over 5,700 kg or seating more than 19 passengers.

The foreseen development of Very Light Jets, and other Light Jets weighing less than 5,700 kg, which are currently not required to be equipped with ACAS II, is raising questions about their integration within the current ATM system, because of their very different performances. As ACAS II is part of the operations in Europe, and an essential element of safety, there is also a need to identify and quantify the effect of VLJs and LJs under 5,700 kg on the performance of the ACAS II safety net.

To this effect, EUROCONTROL has initiated the AVAL project, aiming to perform a comprehensive study to assess the impact of VLJ and LJ operations on the safety benefits delivered by ACAS II in the European environment.

AVAL stands for **A**CAS on **V**LJs and LJs – **A**ssessment of safety **L**evel.

The project comes within the scope of the EUROCONTROL Mode S & ACAS Programme aiming to maximise the safety benefits delivered by ACAS II. The work to be performed in AVAL has been divided in two phases: Phase 1 assessed whether the effect of operations of VLJs and LJs under 5,700 kg on ACAS II performance in the European airspace required further investigation. Phase 2 would be initiated depending on the conclusions of Phase 1 and would consist of a full safety study.

Phase 1 of the AVAL project is now complete. This analysis focused on the key factors that have been demonstrated to affect the safety benefits provided by the operation of ACAS II, i.e. the aircraft operations in the airspace, the level of ACAS II equipage and the pilot behaviour in response to RAs.

Analysing the published performances of VLJs and LJs under 5,700 kg has highlighted three categories of such aircraft with clearly different speed ranges. This argues for the introduction of speed as a determinant for requiring ACAS II carriage. One such category of aircraft is particularly likely to induce difficulties for ATC to handle, as it corresponds to aircraft able to fly in the same airspace as heavier commercial jets, although at 15% to 30% lower speeds. Available sales forecasts indicate this particular category will compose the large majority of the approximately 150,000 additional flights per year that will result from the introduction of VLJs and LJs under 5,700 kg in the European airspace.

If VLJs and LJs under 5,700 kg are not equipped with ACAS II, they will not benefit from the additional safety margins provided by this system and will mostly rely on ATC, where this service is provided, and the “see-and-avoid” principle for collision avoidance. This choice will affect the safety of other aircraft currently equipped with ACAS II. For example, for the second phase of the ACAS II mandate in Europe affecting 10% of the aircraft fleet, studies showed that the risk of collision for the whole airspace would increase by 30% if that portion of the fleet was not equipped with ACAS II.

On the other hand, if ACAS II becomes mandatory on VLJs and LJs, a safety benefit in the airspace is expected. However, this benefit needs to be quantified. It would be affected by the quality of VLJ/LJ pilot response to RAs. Their responses might significantly differ from those observed with current pilots, as many VLJs and LJs could be certified for single pilot operation and will be flown in part by owner-pilots, who might receive considerably less training than professional pilots.

Technical and financial aspects also need to be considered in the decision whether to equip VLJs and LJs under 5,700 kg with ACAS II. Installing additional antennas on a small airframe could lead to interference issues, and consequently affect the feasibility of equipping such aircraft with ACAS II. The costs associated with fitting VLJ aircraft with an ACAS II must be weighed against the safety benefits it would provide.

The full ACAS safety implications of the introduction of VLJs and LJs under 5,700 kg can only be quantified through an in-depth investigation based on the encounter model approach used in previous ACAS safety studies. This requires adapting the various existing models (i.e. for aircraft encounters, pilot responses to RAs and altimetry error) to reflect the typical encounters resulting from the introduction of VLJs and LJs in the European airspace and defining a set of scenarios representative of their operations at a target date. The issue of adapting the current models has been investigated, and the feasibility of using the encounter model approach for the quantification of the safety implications of ACAS II equipage on VLJs and LJs under 5,700 kg has been confirmed.

The carriage and operation of ACAS II by civil aircraft is part of current operations in Europe, and it has been demonstrated to reduce the risk of mid-air collision by a factor of 5. The results of Phase 1 of the AVAL project shows that, whether they are ultimately equipped or not, VLJ aircraft operations will have an effect on the overall performance of the ACAS II safety net. Therefore, to determine fully the safety implications for the performance of the ACAS II safety net it is essential to undertake Phase 2 of the AVAL project

Recommendation. It is recommended to proceed with Phase 2 of the AVAL project. In this second phase, a full safety study will be undertaken. This will be a key element to determine the best approach for the VLJ and LJ aircraft in terms of ACAS II equipage. This full safety study will consist of simulations on a range of operationally realistic scenarios using the established encounter model approach used in the ACAS field to assess:

- The potential consequences on safety is VLJs and LJs under 5,700 kg are not equipped with ACAS II;
- The potential benefits, both for the airspace as a while and for individual aircraft, if VLJs and LJs under 5,700 kg are equipped with ACAS II;
- The use of speed along with maximum takeoff mass as a determinant for requiring ACAS II carriage.

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1. Introduction

1.1. Background and context

1.1.1. The **Airborne Collision Avoidance System (ACAS)**[1] has been introduced in order to reduce the risk of mid-air collisions. It serves as a last resort safety net irrespective of any separation standards.

1.1.2. From 1st January 2000 in the European Civil Aviation Conference (ECAC) area, all civil fixed-wing turbine-engined aircraft having a Maximum Take-Off Mass (MTOM) exceeding 15,000 kg or a maximum approved passenger seating configuration of more than 30 shall be equipped with an ACAS II compliant equipment (i.e. the Traffic alert and Collision Avoidance System (TCAS) II version 7.0). From 1st January 2005, the mandatory carriage of ACAS has been extended to all aeroplanes with a MTOM exceeding 5,700 kg or authorised to carry more than 19 passengers.

1.1.3. It is now required to consider whether safety benefits could be expected from extending the use of ACAS to aircraft belonging to the Very Light Jet (VLJ) category with a MTOM under 4,500 kg and to the Light Jet (LJ) category with a MTOM between 4,500 kg and 5,700 kg. Indeed, the number of VLJ flights is anticipated to rapidly rise particularly in the European Core Area and to potentially impact traffic patterns in Europe.

1.1.4. In that regard, EUROCONTROL has initiated the *Very Light Jets Integration Platform* (VIP) whose main purpose is to ensure the safe and efficient integration of VLJs in the European Air Traffic Management (ATM) environment. The platform has initiated the dialogue around the issues related to such integration, including the potential ACAS requirement for VLJs.

1.2. Study scope and objectives

1.2.1. The objective of the present project is to perform a comprehensive study to assess the impact of VLJ and LJ operations on the safety benefits delivered by ACAS in the European environment, i.e. the AVAL project.

1.2.2. **AVAL** stands for **A**CAS on **V**LJs and LJs – **A**ssessment of safety **L**evel.

1.2.3. The first phase of the AVAL project has now been completed. This phase has evaluated whether the impact of VLJ and LJ operations on ACAS performance requires further investigation. Based on the Phase 1 findings, a decision to proceed or not with the whole AVAL work programme is to be taken.

1.2.4. In its second phase, at this stage scheduled to be completed during 2009, the AVAL project would perform a full safety study and will be key to determine the best approach for the VLJ and LJ aircraft in terms of ACAS equipage.

[1] Two versions of the ACAS standard, ACAS I and ACAS II, have been defined by ICAO. In this document, ACAS refers to ACAS II, as it is the only version which use has been mandated in Europe.

1.2.5. The project comes within the scope of the EUROCONTROL Mode S & ACAS Programme to maximise the safety benefits delivered by ACAS. The study is conducted by Egis Avia (ATM domain, SSS Skill Unit) with the support of DSNA/DTI and QinetiQ in Phase 2 of the project.

1.3. Document overview

1.3.1. The document is organised into five chapters, including this **Chapter 1** on the context, scope and objectives of the AVAL study.

1.3.2. **Chapter 2** provides background information on the safety benefits of ACAS in Europe, the nature of these benefits, how they have been evaluated in previous EUROCONTROL safety studies, as well as the factors that have been demonstrated to most influence the safety benefits delivered by ACAS. This information was the driver for the investigation performed in the AVAL study in terms of VLJ performances, operations and pilot background.

1.3.3. **Chapter 3** summarises available information on VLJs in terms of aircraft characteristics, expected performance and operations. A comparative analysis of VLJ and LJ performance is performed. In terms of operations, elements of information are provided using business jets statistics and some airline views. Finally, in the context of the carriage and operation of ACAS by VLJs and LJs under 5,700 kg that are currently not equipped, the specific issue of the single pilot operation of these aircraft is discussed.

1.3.4. **Chapter 4** discusses the potential impact of VLJs, and other LJs under 5,700 kg, on the performance of ACAS depending in particular on whether or not they are equipped with ACAS.

1.3.5. Finally, **Chapter 5** concludes the document with the main AVAL Phase 1 findings and makes some recommendations for possible future work that would enable a decision on whether to modify the current ACAS mandate applying in the ECAC Member States.

1.3.6. These five chapters are followed by two **Appendices**, respectively providing background data on VLJ and LJ performance, and possible changes to the current safety model in order to represent the introduction of these aircraft in Europe.

2. Safety benefits of ACAS operation in Europe

2.1. The role of ACAS in the ATM system

2.1.1. The International Civil Aviation Organization (ICAO) defines ACAS as "an aircraft system based on secondary surveillance radar (SSR) transponder signals which operates independently of ground-based equipment to provide advice to the pilot on potential conflicting[2] aircraft that are equipped with SSR transponders" (cf. ICAO Annex 2 – Rules of the Air).

2.1.2. ACAS provides two levels of alert to the pilot: Traffic Advisories (TAs) and vertical Resolution Advisories (RAs). The TAs aim to help the pilot in the visual search for the 'intruder' aircraft, whereas the RAs are indications to the pilot of manoeuvres intended to provide separation from all 'threats'; or manoeuvre restrictions intended to maintain existing separation.[3] In the ICAO ACAS Standards And Recommended Practices (SARPs) ([ACAS]), the nominal response to initial RAs is defined as reaching a vertical speed as required by the RA (e.g., 1,500 fpm for a Climb RA) within a delay of 5 seconds and with a vertical acceleration of 0.25 g.

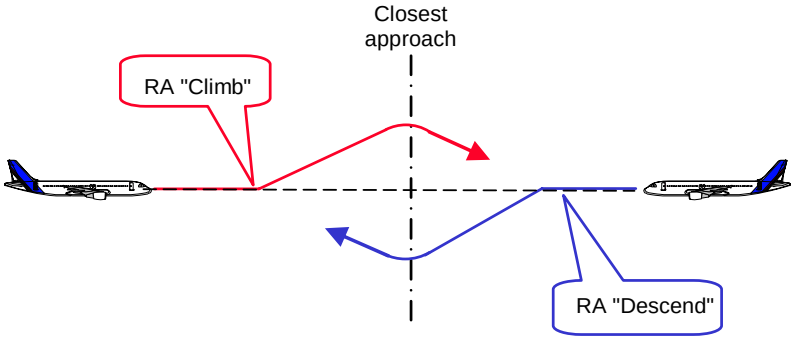

Figure 1: Illustration of a coordinated ACAS resolution

2.1.3. ACAS is not designed, nor intended, to achieve any specific 'Target Level of Safety' (TLS). Instead, the safety benefit deriving from the deployment of ACAS is expressed in terms of reduction in the risk of mid-air collision. This reduction is measured through a 'risk ratio' which compares the risk of a 'Near Mid-Air Collision' (NMAC)[4] both with and without ACAS. Any risk ratio that is less than unity indicates that the deployment of ACAS reduces the risk of collision and thus provides a safety benefit.

$$\text{risk ratio} = \frac{\text{NMAC rate with ACAS}}{\text{NMAC rate without ACAS}}$$

[2] In the context of ACAS, 'conflicting aircraft' is related to a risk of collision and not to the predicted violation of the separation minima applicable in the airspace by the Air Traffic Control (ATC) services.

[3] A guide to the use of ACAS and its functionality can be found in the EUROCONTROL ACAS brochure ([ACA4]).

[4] An NMAC is defined as an encounter during which at some time the horizontal separation of the two aircraft is less than 500 ft and simultaneously the vertical separation of the aircraft is less than 100 ft.

2.1.4. ICAO has defined a set of target 'risk ratios' for different scenarios of aircraft equipage in a theoretical airspace described by a 'safety encounter model' (cf. ICAO SARPs ([ACAS])).

2.1.5. It is recognised that "ACAS can have a significant effect on ATC (Air Traffic Control). Therefore, the performance of ACAS in the ATC environment should be monitored" (cf. ICAO PANS-ATM – Procedures in regard to aircraft equipped with airborne collision avoidance systems (ACAS)).

2.2. The evaluation of ACAS performances in Europe

2.2.1. The framework initiated at ICAO level when defining ACAS minimum performances has been further developed through various ACAS-related projects in Europe. These projects include the 'full-system safety study' completed in the 'ACAS Analysis' (ACASA) project ([ACA1], [ACA2], [ACA3]) performed in support to the mandates for the carriage of ACAS II in Europe, and more recently the 'ACAS Safety Analysis post-RVSM' (ASARP) Project ([ASA]) and the 'Safety Issue Rectification Extension' (SIRE) project ([SIR]).

2.2.2. These projects delivered a comprehensive framework that includes a set of models allowing the replication of the environment in which ACAS is being operated in Europe. These models consist essentially of a 'safety encounter model', models of pilot reaction in response to RAs and a model of altimetry errors applicable in the European airspace. These models are used to determine ACAS safety benefits in operationally realistic scenarios of ACAS equipage and operations.

2.2.3. An essential property of the '*European safety encounter model*' is the level of risk (the NMAC rate) in the absence of ACAS, of 3×10^{-7} NMACs per flight-hour. This underlying NMAC rate is crucial to the determination of the risk that remains when ACAS is being operated.

2.2.4. For typical operations under Instrument Flight Rules (IFR), as observed in the European airspace, ACAS has been demonstrated to provide a risk ratio of 22% ([SIR+1]), i.e. it reduces the risk of mid-air collision by a factor of about five.

2.3. Factors influencing the safety benefits of ACAS

2.3.1. General

2.3.1.1. The ability of ACAS to prevent near mid-air collisions may be affected by several factors including:

- The efficacy of the ACAS logic,
- The environment in which ACAS is being operated,
- The pilot compliance with RAs, and
- The possible interaction between ACAS and other lines of defence against the risk of mid-air collision.

2.3.1.2. In controlled airspace, these other lines of defence notably include clearances and instructions issued by ATC to ensure aircraft separation and even late controller intervention with avoidance instructions (when separation provision has failed). Finally, the principle of "see-and-avoid" applicable to all flights is in no way a substitute for ATC or ACAS.

2.3.2. Encounter characteristics in the airspace

2.3.2.1. Previous safety studies have shown that **ACAS performance is very sensitive to the characteristics of the airspace**. In other words, changes in 'encounter' types that may seem small can have a significant effect on ACAS performance.

2.3.2.2. The 'European safety encounter model' developed in ACASA ([ACA2]), and updated in ASARP ([ASA]) to take into account the effect of Reduced Vertical Separation Minimum (RVSM) operations, reflects the characteristics of close encounters likely to occur in Europe in 2005. The encounters that matters are those in which (at least) two aircraft are on a close encounter course, in which there exists a risk of mid-air collision or in which the response of pilots to RAs can result in a risk of mid-air collision.

2.3.2.3. When envisaging a change in ATM operations as this may be the case with the introduction of VLJs in the European airspace, it is essential that the effect on traffic patterns and close encounters be anticipated so that the impact on the performance of ACAS can be evaluated.

2.3.3. Carriage and operation of ACAS

2.3.3.1. **The level of ACAS equipage in the airspace, as well as the operating mode of ACAS by equipped aircraft, are also key factors that influence the safety benefits delivered by ACAS**. If ACAS is unserviceable, switched off, or in standby-mode, then the aircraft is effectively unequipped. If ACAS is operated in TA-only mode, then it will indirectly provide some limited protection through the ability of TAs to assist in visual acquisition or prompt contact with the controller. Maximum protection will be provided if ACAS is operated in full RA-mode.

2.3.3.2. The transponder equipage of aircraft is also of significance since this has an effect on ACAS surveillance and on the altitude reports that aircraft can provide (and on which the ACAS vertical tracking is based). Mode C equipped aircraft report altitude in 100 ft increments. Mode S equipped aircraft can report altitude either in 100-ft increments or in 25-ft increments. ACAS can use altitude in either reply format, but RAs issued on the basis of the more precise 25-ft altitude quantization will generally be more effective. Similarly, an aircraft can feed its own ACAS with 1-ft, 25-ft or 100-ft quantized altitude, depending on its avionics and transponder.

2.3.3.3. When envisaging a change in the carriage and operation of ACAS, it is essential that the assumptions with regard to ACAS and transponder equipage level be clearly defined.

2.3.4. Pilot behaviour in response to RAs

2.3.4.1. **The pilot behaviour is another key factor for the safety benefits delivered by ACAS** and, in particular, the actual pilot response to the RAs issued by the ACAS logic. Previous studies have demonstrated that the RAs that are generated should be followed, and followed promptly, for best benefits.

2.3.4.2. In the early stages of ACAS implementation in Europe, the ACASA study ([ACA1]) has shown based on the analysis of airborne recorded data that the actual pilot responses to RAs felt into two distinct groups: 'aggressive response' in which pilots achieved a vertical rate in excess of that required by the RA; and 'slow response' in which the delay before a response was initiated was longer than standard, the acceleration was lower than standard, and the vertical rate attained was less than that required by the RA.

2.3.4.3. A few years later, a subsequent analysis of airborne recorded data conducted in the ASARP study ([ASA]) demonstrated that pilot behaviour in response to ACAS had improved. Notably, their responses to corrective RAs were generally very close to the standard response expected by the ACAS logic, although the reactions adopted spanned over a range of reaction times, vertical rates, and vertical accelerations. Figure 2 shows the frequency of these observed responses, combined with the 20% rate of non-response used in the latest ACAS safety studies ([SIR+2]).

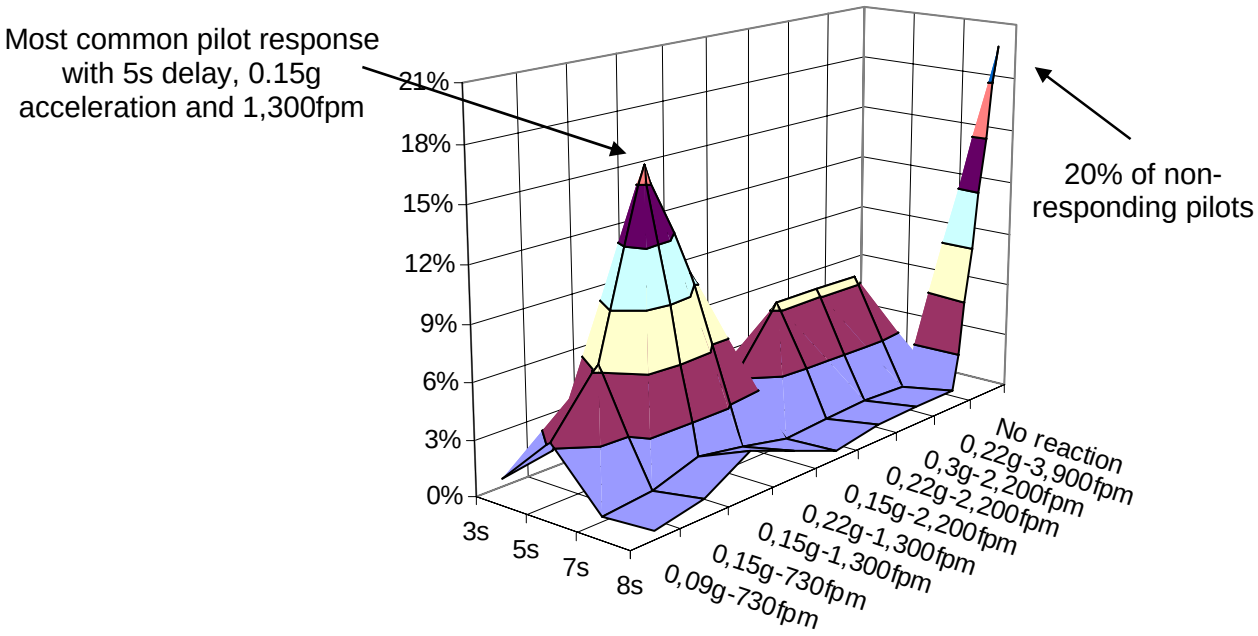

Figure 2: Typical pilot models and associated proportions

2.3.4.4. When envisaging the operation of ACAS by a new population of pilots, it is essential to clearly define the assumptions taken regarding the range of possible pilots' behaviour in response to RAs.

2.3.5. Controller intervention, visual acquisition and altimetry errors

2.3.5.1. In addition to the key influencing factors discussed above, the specific circumstance of a late controller intervention that would result in an instruction incompatible with the sense of a coordinated RA needs to be considered. In this case, one pilot following the controller instruction while the other follows the RA could result in a collision.

2.3.5.2. The possibility of the encounter being influenced by “see-and-avoid” needs also to be considered. The probability of visual acquisition prompted by ACAS should be taken into account, along with the fact that visually acquiring a threat is no guarantee that a collision will be avoided.

2.3.5.3. Finally, for any vertical separation at closest approach diagnosed by ACAS, there is a finite probability that this separation will be negated by altimetry error and that a collision occurs. This probability has to be calculated taking into account altimetry system performances and summed to determine the overall risk in a set of encounters.

3. Introduction of VLJs in the European airspace

3.1. Study objectives

3.1.1. To understand the potential effect of the introduction of VLJs and LJs under 5,700 kg in the European airspace on the safety benefits provided by ACAS, this introduction of new aircraft must be analysed through the perspective of the factors that can influence the performance of ACAS.

3.1.2. Consequently, the environment in which VLJs and LJs under 5,700 kg will likely operate has to be understood, through a review of their performances and of their foreseen operations. Similarly, the pilot response to RAs has a very significant influence on the safety performance of ACAS and it is therefore important to investigate how VLJ/LJ pilots would be likely to react if faced with an RA.

3.1.3. Assessing how VLJs and LJs under 5,700 kg can interact with aircraft currently equipped with ACAS will also enable to determine whether they is an issue from the perspective of ACAS performance.

3.2. Definition of VLJs

3.2.1. There is currently no internationally agreed definition of a VLJ category. However, subject experts are using different definitions. As an illustration, Table 1 extracted from [RCR] shows the definitions used by some organisations such as manufacturers, aviation groups and FAA.

Organisation	Definition used for VLJs
Embraer	Embraer very light jet forecast with air taxi demand. Very light jets are defined as **multi-engine turbojet aircraft weighing 10,000 pounds [4,500 kg] or less**, such as Adams A700, Cessna Citation Mustang, Eclipse 500, and the Embraer Phenom 100.
Honeywell	Honeywell forecast includes **personal jets (aircraft weighing less than 7,500 pounds [3,400 kg] and retailing for under $2.4 million) and several of the new generation low-cost aircraft carried in the very light jet segment**. Aircraft included in the forecast are Adam A700, Beechcraft Premier I, Cessna Citation Mustang, Cessna Citation CJ1, Cessna Citation CJ2, Cirrus, Diamond D-Jet, Eclipse 500, Embraer Phenom 100, HondaJet, and Sino-Swearingen SJ30-2.
Forecast International	Very light jets are defined as **jet aircraft that typically seat up to eight people** with list prices ranging from less than $1 million to approximately $2.85 million. They generally **weigh 10,000 pounds [4,500 kg] or less and are certified for single-pilot operation**. Aircraft included in the forecast are Adam A700, Cessna Citation Mustang, Eclipse 500, and Embraer Phenom 100.
Teal Group	Very light jets are defined as **small jets selling for $1-$4 million**. Aircraft included are Cessna Citation Mustang, Embraer Phenom 100, HondaJet, and potentially one or two other players.
FAA	Very light jets are defined as **jet aircraft weighing 10,000 pounds [4,500 kg] or less, certificated for single pilot operation**, and possessing some advanced avionics. Very light jets entering service soon include Adam A700, Cessna Citation Mustang, Eclipse 500 and Embraer Phenom 100.

Table 1: Definition of VLJs in the literature

3.2.2. Several academic papers have been presented on the subject. According to [AVB], "It seems the industry consensus is forming around the VLJ maxing out at under 10,000 lbs [4,500 kg]. By extension, it then seems, the "light" segment begins at 10,000 lbs [4,500 kg] – something of a change when "light" meant anything under 20,000 lbs [9,000 kg] fairly recently."

3.2.3. According to [BON], "the 10,000 lbs [4,500 kg] threshold between very light and light jets has emerged from an historical perspective, distinguishing two generations of aircraft, with the Cessna CJ1 (10,600 lbs [4,800 kg]), certified in 1992, being the lightest twin turbofan-powered aircraft in the current business jet spectrum. The entry of VLJs expected in 2006 will lower the current business jet spectrum under 10,000 lbs [4,500 kg]."

3.2.4. [BON] also notes that an alternative threshold of 12,500 lbs (5,700 kg) may also be appropriate as it "separates aircraft that are certified under JAR/FAR [Joint Aviation Regulations/Federal Aviation Regulations] Part 23 airworthiness standards for normal, utility, aerobatic and commuter category aircraft from those air transport category aircraft certified under JAR/FAR Part 25."

3.2.5. For the AVAL study, the 5,700 kg threshold is also of particular interest as it determines whether the carriage and operation of ACAS is required or not according to the current ACAS mandate in the ECAC Member States.

3.2.6. On these bases, the definition of VLJs used in the AVAL study is as follows:

VLJs are turbofan-powered aircraft with a maximum takeoff mass not exceeding 4,500 kg (10,000 lbs), certified for single pilot operation and that typically seat from 3 to 8 passengers.

3.2.7. When considering the possibility to extend the use of ACAS beyond the current mandate, **there is therefore a need to consider not only VLJs but also LJs weighing less than 5,700 kg** (12,500 lbs), such as Cessnas CJ1 and CJ2 or Raytheon Premier I.

3.2.8. Figure 3 summarises how aircraft airworthiness regulation and the current ACAS mandate apply depending on aircraft MTOM. JAR/FAR Part 23 contains airworthiness standards for aircraft in the normal, utility, acrobatic, and commuter categories. The MTOM of an airplane in the normal, utility or acrobatic category cannot exceed 5,700 kg. Part 25 contains airworthiness standards for aircraft in the transport category. The majority of aircraft up to 5,700 kg MTOM are type certificated to Part 23 so most aircraft certificated to Part 25 have MTOM greater than 5,700 kg, although there is no lower weight limit.

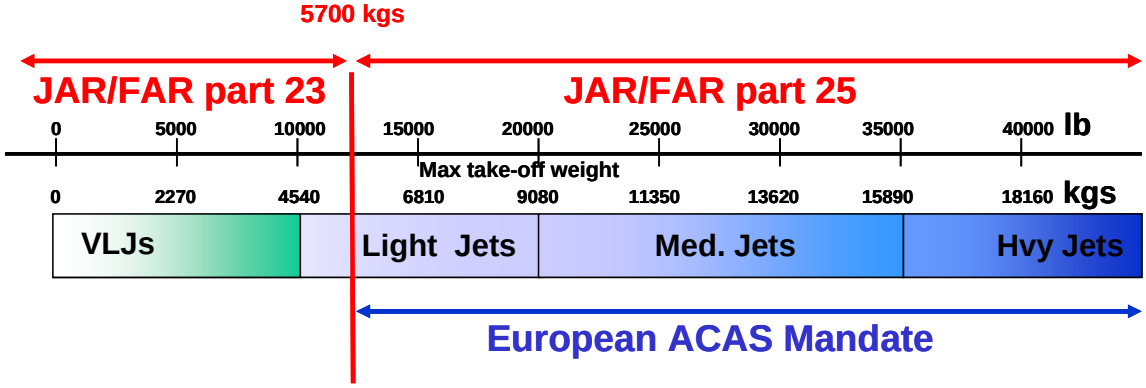

Figure 3: Regulation versus MTOM

3.3. Performances of VLJs and LJs

3.3.1. General

3.3.1.1. One difficulty to deal with when assessing the performances of VLJs is linked to the scarcity of information, as only manufacturer figures are available. With regard to LJs, another source of data is the EUROCONTROL Base of Aircraft Data ([BADA]), but such performance data are not yet available for VLJs.

3.3.1.2. A comparison of the performances between VLJs and LJs is performed hereafter using manufacturer figures, some of which are only projections. These figures are nevertheless the only means of making a fair comparison between LJs and VLJs. To complement the manufacturer views, performances of some LJs are also compared using BADA performance tables.

3.3.2. Comparison of maximum cruise speeds of VLJs and LJs

3.3.2.1. Figure 4 presents ceiling altitude versus speed figures (which are often maximum cruise speeds) as provided by manufacturers ([WEB]), for several VLJs, LJs, turboprops and a few medium jets, for comparison. LJs with a weight below and over 5,700 kg are shown with different colours to differentiate them.

Note: only the names of representative aircraft are indicated. Aircraft names in bold correspond to LJs with a weight below 5,700 kg.

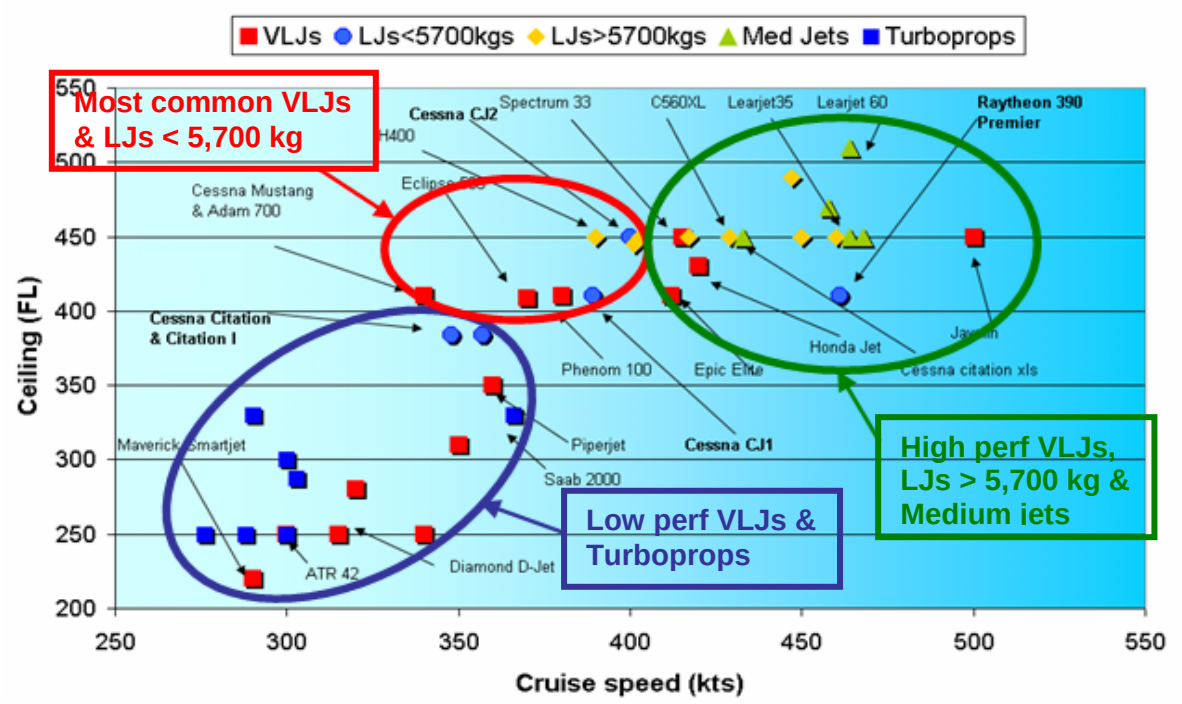

Figure 4: Ceiling versus Cruise speed of VLJs provided by manufacturers

3.3.2.2. VLJs can be gathered into 3 categories:

- The first category (in blue) corresponds to VLJs with a ceiling below Flight Level (FL) 350, and often below FL300, and with cruise speeds below 360 kts. These performances are similar to turboprop aircraft.

- The second category (in green) corresponds to some VLJs with characteristics similar to those of LJs with a weight over 5,700 kg and to medium jets, with a ceiling above FL400 and cruise speeds above 410 kts. These performances are similar to medium jets.
- The third category (in red) includes VLJs with a ceiling above FL400, and with cruise speeds between 340 kts and 380 kts. LJs with a weight below 5,700 kg and this third category of VLJs can be considered as having similar performances. This allows to consider this category of VLJs and LJs under 5,700 kg as a single category of aircraft.

3.3.2.3. **This third category composed of mid-range VLJs is likely to create greater difficulties in traffic handling, as they are slightly slower than LJs and medium jets, while they can fly at similar altitudes**. This category includes the Adam 700, the Eclipse 500, the Embraer Phenom 100 and the Cessna Mustang, for which there are currently orders in Europe, and which are likely to be the most represented. These VLJs are roughly 15% slower than LJs over 5,700 kg.

3.3.3. Comparison of vertical speeds of VLJs and LJs

3.3.3.1. With regard to vertical performances, manufacturer figures could not be found for as many VLJs and LJs over 5,700 kg as for the ceiling and cruise speed performance data. Times to reach a given altitude were collected for 2 VLJs (Eclipse 500 and Cessna Mustang) and 4 LJs (Cessna CJ3, Cessna 560XL, Hawker 400 and Raytheon premier I) ([WEB]).

3.3.3.2. The available data show that, overall, in the time LJs climb to FL350, VLJs climb to FL250. In the time LJs climb to FL450, VLJs climb to FL350. Therefore, one can assess that the vertical performances of VLJs are lower than those of LJs. Between FL350 and FL450, LJs have average vertical rates around 1,000 fpm. VLJs have such vertical rates between FL250 and FL350.

3.3.4. Maximum range of VLJs

3.3.4.1. According to manufacturer figures, the maximum ranges of operation of VLJs are often close to 1,250 NM (or 2,315 km). This corresponds roughly to the distance between Brussels and Moscow, as illustrated below. However, it is likely that the actual range of VLJ operations would be lower than this maximum range of operation.

Figure 5: 1,250 NM circle centred on Brussels

3.3.5. BADA performances of LJs

3.3.5.1. The analysis of BADA performances considered 3 LJs models: 2 LJs with a mass over 5,700 kg (Cessna 560XL, Learjet 35), and the Cessna CJ1 LJ with a mass below 5,700 kg. These models were chosen as they are among the most represented in the European airspace.

3.3.5.2. As shown in Table 2, the BADA performance tables for these 3 aircraft are also valid for other aircraft (as BADA often uses the same performance tables for several aircraft types).

Aircraft shown	Performance equivalent aircraft in BADA	MTOM
Cessna 560 XL (9,071 kg)	Falcon 10 Learjet 24 Beechjet 400	8,755 kg 5,675 kg-5,920 kg 7,303 kg
Learjet 35 (8,300 kg)	Learjet 31 Learjet 25 Learjet 55 Cessna Citation III	7,030 kg 6,805 kg 9,752 kg 9,980 kg
Cessna CJ1 (4,812 kg)	Cessna Citation Bravo Cessna 500 Citation 1 Cessna CJ2 Citation 2-SP Citation 1-SP Mitsubishi MU-300 Diamond Corvette SN601	6,715 kg 5,380 kg 5,585 kg 6,850 kg 5,380 kg 7,361 kg 6,600 kg

Table 2: BADA performances of LJs

3.3.5.3. According to BADA performance tables, there is a significant difference between the 'True Air Speed' (TAS) of LJs with a weight over 5,700 kg and the TAS of lighter LJs. Indeed, the Cessna CJ1 has a TAS that never exceeds 370 kts whereas the TAS of the heavier LJs is well over 400 kts above FL300.

3.3.5.4. The performances of LJs under 5,700 kg are up to 35% lower than those of the heavier models. Above FL300, those performances are 20% lower.

3.3.5.5. With regard to rates of climb, as for TAS, the Cessna CJ1 appears to have lower performances than the heavier LJs in the higher Flight Levels (FLs). **On average, the performances of the smaller LJs are between 15% and 30% lower than those of the heavier models**. At lower altitudes, the difference is even greater and reaches a maximum around FL60.

3.3.6. Conclusion on VLJ/LJ performances

3.3.6.1. **The existence of 3 categories of VLJs, with very different speeds, argues for the introduction of speed as a determinant for requiring ACAS carriage, in addition to the MTOM that is currently used.**

3.4. Sales and growth forecasts of VLJs and LJs under 5,700 kg

3.4.1. Delivery forecast of VLJs

3.4.1.1. Because several forecasts of VLJ deliveries are available from manufacturers and various groups specialised in the aviation market, this section uses several of them to build a complete picture and derive average values for VLJ sales and growth in Europe. These forecasts sometimes use different assumptions with regard to the date for which the forecast is done and the level of traffic growth ([RCR]). The number of forecast deliveries worldwide range from 3,000 to 8,000 depending on the assumptions taken.

3.4.1.2. Figure 6 translates the available figures into sales per year. Sales per year in Europe are also shown, with the rough assumption that they will correspond to 15% of the sales in the world. This figure of 15% is based on [SFO] which states that for Business aviation, the European share will be between 12% and 15%.

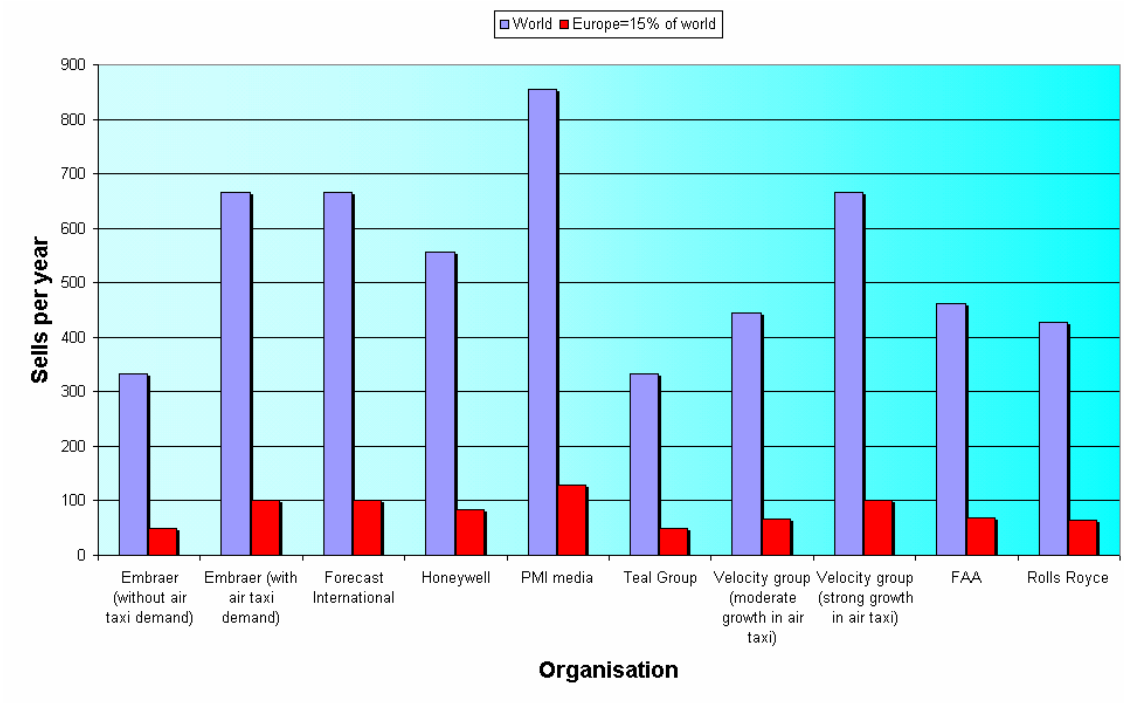

Figure 6: VLJ delivery forecasts – Per year

3.4.1.3. With the assumption that Europe will represent 15% of the sales, the sales in Europe can be estimated to about 80 per year on average, ranging from 50 to 130 per year depending on the forecast source. These sales will primarily originate from the business aviation, where 25% to 33% of the current fleet is expected to be replaced, largely by VLJs, over the next 10 years.

3.4.1.4. Delivery forecasts made in Europe are close to this figure. Based on claims of VLJ sales, there are currently about 230 firm sales of VLJs in Europe, most of which are in 2009 and 2010 ([VIP1]). This can be translated into the figure of about 100 VLJs sold per year. The first orders are for the Eclipse 500, the Cessna Mustang and the Embraer Phenom 100 types.

3.4.1.5. Assuming this sales rate is sustained, about 700 VLJs would be delivered before 2015 in Europe. Assuming VLJs will fly 3 times a day, this gives a rough estimate of an additional 300 extra flights per day each year ([VIP1]).

3.4.1.6. According to Embraer figures ([EMB]), VLJs and LJs deliveries between 2007 and 2016 should be equivalent. Therefore, one can assume a total delivery rate of roughly 200 aircraft per year for VLJs and LJs, assuming a delivery rate of 100 VLJs per year in Europe.

3.4.1.7. **Applying these same assumptions to the different delivery forecasts available leads to a range of 300 to 470 additional flights per day each year made by VLJs and LJs under 5,700 kg.**

3.4.2. Conclusion on growth forecasts

3.4.2.1. **Based on different available forecasts on VLJ sales and business traffic growth, it can be estimated that the introduction of VLJs and LJs under 5,700 kg in the European airspace will result in 110,000 to 170,000 additional flights each year until 2015.**

3.5. Foreseen operations of VLJs and LJs under 5,700 kg in Europe

3.5.1. Foreseen VLJ operations

3.5.1.1. The International Business Aviation Council (IBAC) has classified business aviation operations, which VLJs will be part of, into three main categories ([SFO]):

- Commercial: aircraft flown for business purposes by an operator having a commercial operating certificate. Typically, these are on-demand charters ("air taxis"), fractional operators, but per seat, on demand is also proposed for VLJs.
- Corporate: non-commercial operations with professional crews employed to fly the aircraft.
- Owner-operated: aircraft flown for business purposes by the owner of the aircraft.

Figure 7: Business aviation ([SFO])

3.5.1.2. In addition to these business operations, **VLJs will also be flown for leisure purposes** by owner-pilots or private pilots.

3.5.2. Business aviation network

3.5.2.1. Geographically, the business aviation network is different from the network of scheduled flights. The scheduled network is organised around the capital cities or main population centres, where large carriers have their bases. The top 500 routes for scheduled flights represented some 8,200 movements per day in 2005, which represented 41% of all scheduled traffic ([SFO]).

3.5.2.2. The top 500 business aviation routes represented 500 movements per day in 2005, only 29% of all business traffic. This network concentrates traffic along a London-Rome axis, taking in Paris, Geneva, Cannes and Milan on the way and with more than 50 business movements per day in some areas. There are also a number of more specialised markets: Moscow, the Norwegian Fjords and some island services being obvious examples.

3.5.2.3. Figure 8 shows the top 500 routes for scheduled flights and business aviation. For business aviation, the darker lines (which indicate the busiest routes) have more than one movement/day, the lighter ones are not used every day.

Scheduled flights	Business aviation
	

Figure 8: Top 500 routes for scheduled flights and business aviation in Europe

3.5.2.4. Specific customer demand and difficulties of airport access mean that business aviation often flies to different airports than scheduled flights: Madrid/Torrejon rather than Barajas; Paris/Le Bourget rather than Charles de Gaulle; London/Luton, Farnborough and several others instead of Heathrow or Gatwick. Only two of the busiest ten airports overall have more than 3% of business aviation traffic.

3.5.2.5. Because business airports often share the same Terminal Control Areas (TMAs) as scheduled flight airports, VLJs and LJs under 5,700 kg operating from these airports are expected to interact with scheduled flights in these locations, as well as in the upper airspace.

3.5.3. Requested Flight Levels by business aviation

3.5.3.1. According to [SFO], 28% of business aviation has a Requested Flight Level (RFL) above FL350, where 38% of the other flights have a RFL between FL330 and FL370.

3.5.3.2. There is a second cluster around FL280 and below. Many business aviation trips are short, so it is effective to stay low, below traffic and hence reduce the potential for any en route delays. It also avoids RVSM airspace, which starts at FL290. To enter RVSM airspace, aircraft require specific equipment and approval. It is noticeable that few turboprops ask FLs higher than FL290. At lower altitudes, differences in business aircraft type are evident, with a significant number of piston aircraft with maximum RFLs of FL190-200.

3.5.3.3. Figure 9 shows RFLs versus range flown for business flights. The shading in the background shows the traffic density of non-business aviation aircraft.

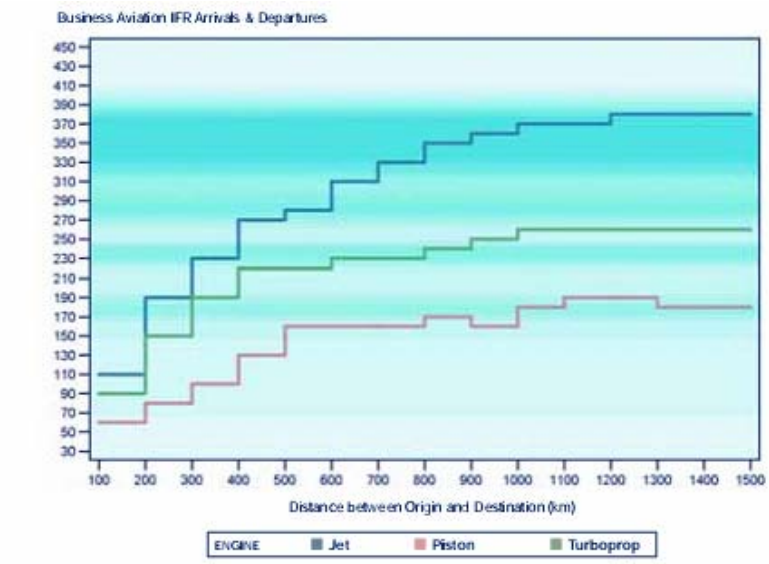

Figure 9: RFL versus range for Business Aviation

3.5.3.4. Figure 9 shows that the longer the flight, the higher the flight level. **For business jet aircraft, only those going farther than 600 km (324 NM) climb in RVSM**.

3.5.4. Current operations of LJs under 5,700 kg in the Core Area

3.5.4.1. In order to further investigate possible operations of VLJs and LJs under 5,700 kg, the flown flight plans recorded in French airspace in 2007 have been analysed. Although no VLJ flight plans have been identified, some were found for LJs, which are anticipated to have performances and operations similar to the most common VLJs. This section describes the operations of these smaller LJs.

3.5.4.2. Among the flight plans that have been collected in 2007, LJs under 5,700 kg represented 0.59% of all flight plans ([WA2]). From a safety perspective, this same category of aircraft was involved in 0.39% of airproxes filed between 2005 and beginning of 2008, and in 0.69% of TCAS events reported over the same time ([WA1]).

3.5.4.3. Figure 10 shows a graph presenting distance versus cruise FL, as indicated in the flown flight plans of LJs under 5,700 kg that have been analysed. Proportions of aircraft flying a given distance and a given FL are colour coded. Blue colours are for low values, while yellow and red colours are for higher values.

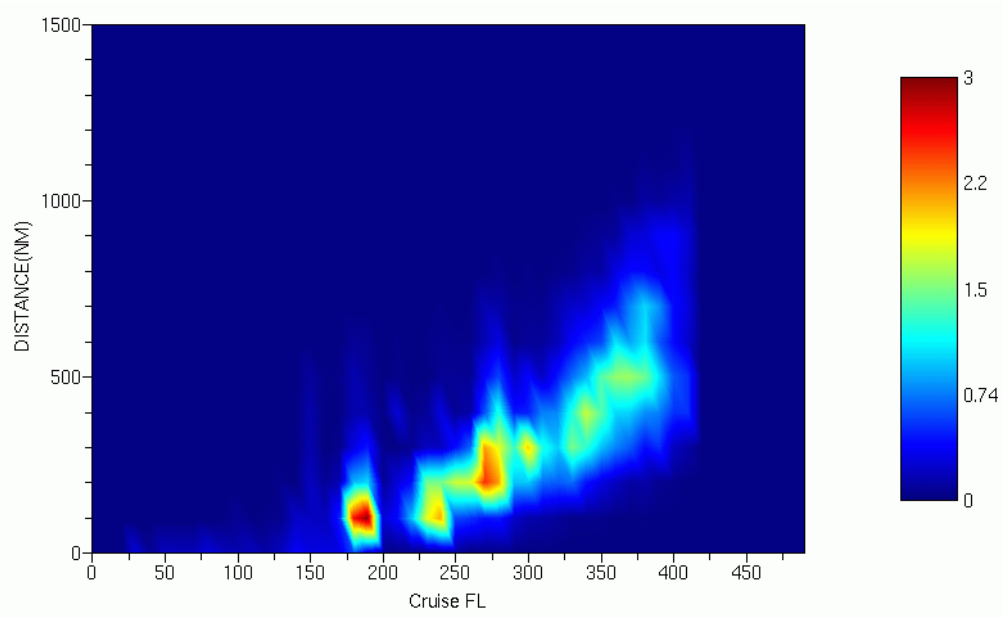

Figure 10: Distance vs. cruise FL graph for LJs under 5,700 kg

3.5.4.4. Three peaks can be noticed in Figure 10, corresponding to three types of operation for LJs under 5,700 kg:

- One below 200 NM and for cruise FLs around FL180. This corresponds to operations close to those of turboprop aircraft;
- One between 100 NM and 300 NM, for cruise FLs around FL270-280, i.e. just below RVSM airspace;
- Another part of these aircraft have cruise FLs between FL330 and FL400, with distances between 200 NM and 700 NM. There is no clear peak such as those around FL180 and FL270, but rather a wide area, shown in light blue and yellow, corresponding to a range of possible distances and FLs.

3.5.4.5. When looking at pairs of departing and arrival cities, LJs under 5,700 kg show operations close to turboprop and piston aircraft. Indeed, they hardly fly twice between the same airports, as the ratio between the number of city pairs they fly between and the total number of flight plans for this aircraft type is close to 30%, whereas it is only a few percent for heavier or faster jets ([WA2]). This 30% figure means that, given airports A and B, an average LJ under 5,700 kg will fly from A to B 3 times in a year. The ratio is similar for pistons and small turboprops, while it increases to 60 for heavy and fast jets, such as the B747.

3.5.4.6. This analysis has also shown that LJs under 5,700 kg fly to some major airports, but also to smaller airports close to the major ones ([WA2]). As a result, they can be considered as flying in the same dense TMAs as heavier jets, which confirms the observations made regarding business aviation in 3.5.2. In addition, although they have slightly lesser performances, these aircraft are able to mix with heavier, and faster, commercial aircraft, including in RVSM airspace

3.5.4.7. Because the VLJs that are expected to be the most common in Europe show performance comparable to LJs under 5,700 kg, this study extrapolates that their operations will also be similar.

3.5.5. Aircraft operators' views on future VLJ operations

3.5.5.1. Several aircraft operators intending to focus on VLJs have already described the type of operations they foresee. These operators notably include Jetbird and ETIRC Aviation.

3.5.5.2. Jetbird plans to operate 100 Embraer Phenom 100 ([JET]). These aircraft will be operated in Europe, mostly between UK, France, Germany, Switzerland and Italy, on the London-Rome axis. Flights will be made point to point, on demand. 90% of the flights will be within the Phenom 100 range.

3.5.5.3. ETIRC Aviation intends to operate 161 Eclipse 500 aircraft. The use will be air limousine, with flights lasting one hour and a half long on average ([ETR]). As shown in Figure 11 , this operator anticipates that the VLJs will likely fly above turboprops and just below commercial jet aircraft ([ETR]).

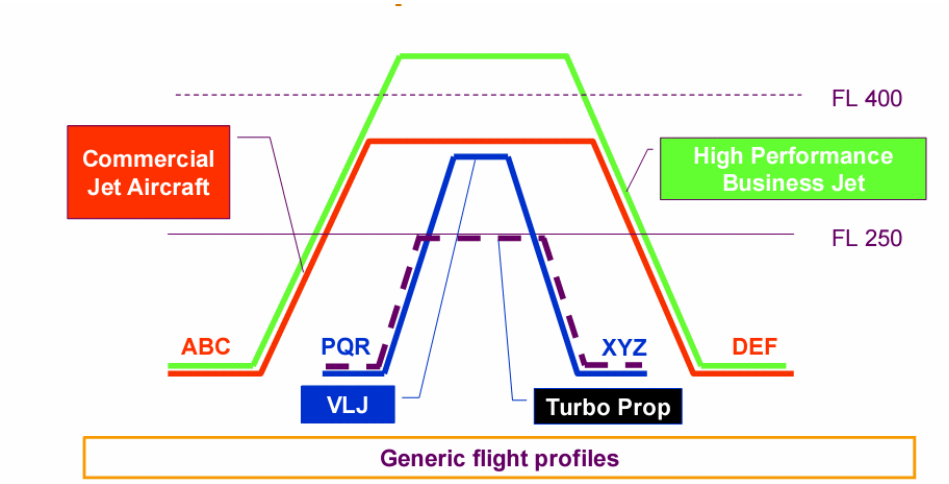

Figure 11: Flight profiles as seen by ETIRC Aviation ([ETR])

3.6. Pilot operation of VLJs and LJs under 5,700 kg

3.6.1. General

3.6.1.1. From the pilot perspective, compared to heavier commercial jets, the main difference of VLJs and LJs under 5,700 kg is their certification for single pilot operation. In addition, the foreseen operation of these aircraft allows two very different types of pilots:

- Professional pilots, who are expected to fly frequently on a given type of aircraft and receive corresponding training, both initial and recurring;
- Private pilots, who will likely have a General Aviation (GA) background and will fly only occasionally on a given type of aircraft, with a more limited initial training and potentially no recurring training.

3.6.1.2. The safety level of GA is generally lower than for commercial aviation, principally because they can operate without ATC but also because of different training standards. Consequently, a concern has arisen regarding the gap in training between the two foreseen types of VLJ/LJ pilots.

3.6.2. Current views on training

3.6.2.1. To address the issue of the gap in training between the two types of potential VLJ/LJ pilots, several options are currently being considered:

- The National Business Aviation Association (NBAA) in the US has issued training guidelines ([NBA]), notably proposing a mentoring programme that seems to have been endorsed by VLJ/LJ stakeholders. The role of a mentor pilot would be to accompany the new VLJ pilot until he acquires the necessary skills and proficiency for safe operation in all flight regimes,
- Manufacturers have associated with training providers to develop specific training programmes for their aircraft in the VLJ segment. These programmes derive from commercial airline programmes as they are based on full-flight simulator sessions and courses on Single pilot Resources Management (SRM), i.e. Crew Resources Management applied to single pilot operation.

3.6.2.2. As an example, Eclipse Aviation has developed a training curriculum for future Eclipse 500 pilots ([CAT]) with United Services, a training-providing subsidiary of United Airlines. This curriculum is grounded on FAA/Industry Training Standards (FITS) and NBAA guidelines. It consists of two main steps, with the first one designed to provide a basics course on jet aircraft and assess the trainee's flight skill. In a second stage, the trainee goes through Eclipse 500 type-rating training, largely based on a highly realistic full-flight simulator, and then flies under a mentor pilot supervision until he has demonstrated a sufficient skill level.

3.6.2.3. The manufacturer programmes, such as the one described above, are perceived as too stringent for owner-pilots, while manufacturers visibly see NBAA guidelines as not sufficient ([BAR]). However, it shows that **manufacturers have taken steps to address the training issue**.

3.6.2.4. **Professional pilots for aircraft operators will thus likely receive significant initial and recurrent training. However, the VLJ market is also targeting owner pilots and it can be assumed that non-professional pilots with close to no exposure to ACAS will fly VLJs**.

3.6.3. Typical Human Factor issues in challenging situations

3.6.3.1. The major challenge associated with single pilot operation of commercial aircraft is to achieve the level of safety and operating efficiency of two-person flight crews. By reviewing the vulnerabilities to errors that can potentially lead to accidents in current two-person crew operations, the effect of transitioning to single pilot operations on the level of safety can be assessed ([WA5]).

3.6.3.2. Table 3 summarises the typical Human Factor (HF) issues in challenging situations and the effect of single operations on the management of such situations, as evaluated in a recent US study ([NASA]). In the context of the AVAL study, what this means with regard to the single pilot operated aircraft faced with an RA is also discussed.

Typical HF issue in challenging situations	Effect of single pilot operation	Effect on single pilot response to RAs
Person-to-person communication breakdown (e.g. improper phraseology, misunderstanding)	Should not be made more significant in single pilot operation	Same likelihood of improper phraseology when reporting RA to ATC[5]
Unacknowledged situational alerts (i.e. a specific and timely alert fails to trigger any crew response)	Should not be made more significant in single pilot operation	Increased likelihood of unnoticed ACAS alerts, as no mitigation exists by a second crew member
Biasing of a decision (i.e. flawed decision-making process due to unrelated factors affecting a decision)	Will carry over in single pilot operation and will be largely the same as in two-pilot operation	Increased likelihood of responding to an RA by going in the wrong direction
Problem solving tunnels (i.e. inordinate amount of time and attention devoted to a given problem detrimental to other possibly urgent tasks)	Will be exacerbated in single pilot operation, as the captain can no longer rely on the first officer to fly the aircraft while addressing a problem	Increased likelihood that the pilot will not respond to ACAS alerts due to lack of resources availability
Critical time-risk relationship in complex, rapidly-evolving situation due to crew workload increase	Would be exacerbated in single pilot operation, as the time-risk factor can go unattended	Increased likelihood that the pilot will respond late, or inappropriately, to the RA
Missing knowledge (i.e. errors of omissions or oversights)	Will be critical in single pilot operation, as no cross-check by other crew member is possible	Increased likelihood that the pilot will miss the RA or respond incorrectly

Table 3: Effect of single pilot operations in challenging situations such as RAs

[5] It is also likely that the single pilot operation of aircraft will results in pilots reporting RAs late to ATC. However, this is caused by a workload issue rather than an HF issue.

3.6.4. Overview of issues related to VLJ/LJ pilot response to RAs

3.6.4.1. Analysis of the pilot-related aspects of equipping VLJs and LJs under 5,700 kg with ACAS highlights two issues regarding the pilot response to RAs ([WA5]). First, most VLJs and LJs under 5,700 kg are likely to be operated by a single pilot, as allowed by their certification, resulting in higher rates of non-response and of late response than observed in current operations.

3.6.4.2. The second issue relates to training, as GA pilots, with close to no experience with ACAS, will transition to VLJs. Although VLJ stakeholders have taken steps to try and bring this population of pilots on par with professional ones through a dedicated initial training, recurring training seems to be unaddressed so far. Consequently, this is also likely to increase the rate of non-standard responses from VLJ pilots if these aircraft would be fitted with ACAS.

3.6.4.3. As a last note, even if ACAS is not mandatory on these aircraft, there will probably be some VLJs and LJ under 5,700 kg equipped with ACAS as it will make pilots feel safer. Consequently, improper RA responses by VLJ and LJ pilots will most likely be observed.

3.7. ACAS issue with VLJs and LJs under 5,700 kg

3.7.1.1. Analysis of the performances of VLJs and LJs enabled to identify three categories of VLJs, one of which corresponding to aircraft able to fly in RVSM airspace, but at 10% to 20% slower speed than heavier commercial jets. Available sales forecasts indicate this category corresponds to the types of VLJs that will be the most frequent in Europe.

3.7.1.2. The current operations of business jets and the foreseen operations of VLJs operators, which are likely to be similar to business aviation, confirm that they will actually mix with heavier aircraft equipped with ACAS, both in upper airspace and in busy TMAs around major cities.

3.7.1.3. Consequently, the introduction of VLJs in the European airspace will have an effect on current operations. As ACAS is a key element of the safety of these operations, the implications of whether to equip VLJs and LJs under 5,700 kg on the safety of the European ATM system must be carefully studied.

4. Potential impact of VLJs and LJs on ACAS performance

4.1. General

4.1.1. As ACAS is part of current operations in Europe and an essential element of their safety, this chapter discusses the issues associated to the possible extension of the European ACAS mandate, or lack thereof, to VLJs and LJs under 5,700 kg. This discussion also provides some elements on the possible use of ground speed as a parameter enabling to discriminate categories of aircraft that would be covered by this mandate.

4.1.2. This section assumes that VLJs and LJs under 5,700 kg will mix with aircraft already equipped with ACAS. However, traffic segregation may also be an option to limit the impact of the lower performances of VLJs on the current ATM system. This segregation could be applied either to the whole airspace or in specific areas, like TMAs. Consequently, this type of assumptions has to be identified before any attempt to quantify the impact of VLJs on ACAS performances in Europe.

4.2. Safety implications when VLJs and LJs are not ACAS equipped

4.2.1. Airspace perspective

4.2.1.1. ACAS has demonstrated to provide additional safety benefits as more aircraft are being equipped. Indeed, the risk reduction provided by ACAS is significantly greater in case of coordinated RAs between two equipped aircraft compared to RAs against unequipped aircraft.

4.2.1.2. **If not ACAS equipped, the operations of VLJs may, therefore, have an impact on the safety benefits delivered by ACAS to large aeroplanes** benefiting from the current ACAS mandate. This may be the case at least in specific locations like TMAs close to the secondary airports targeted by business aviation or the en-route airspace in the European Core Area.

4.2.1.3. To support the decision to extend or not the current ACAS mandate, the cost-benefit of equipping VLJs and LJs below 5,700 kg would need to be further quantified as done in the past ACASA study when assessing the benefit of Phase II of the European ACAS mandate compared to Phase I ([ACA1], [ACA3]).

4.2.1.4. As an illustration, Figure 12 shows the significant benefit that was obtained by fitting ACAS on turboprop and jet aircraft with a MTOM between 5,700 kg and 15,000 kg in the timeframe of 2005. These results showed that the risk ratio would be decreased by a proportion of about 40% as a counter part to the costs induced by fitting ACAS to an additional 10% of the overall fleet. This is to say that having 10% of the fleet not equipped before 1st January 2005 increased the risk ratio by 30%.

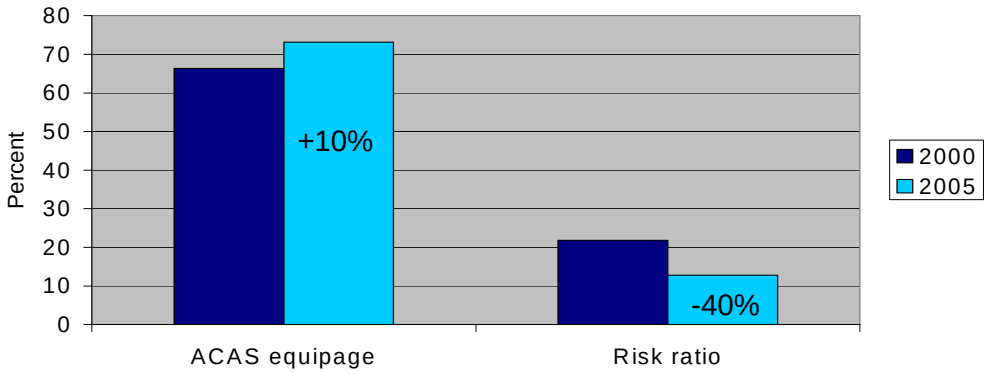

Figure 12: Safety benefits of Phase II of the current ACAS mandate – airspace perspective

4.2.2. Aircraft perspective

4.2.2.1. The carriage and operation of ACAS has demonstrated to provide not only safety benefits to the whole airspace, but also to the own aircraft equipped with ACAS.

4.2.2.2. If not ACAS equipped, VLJs and LJs under 5,700 kg will not benefit from the additional safety margins provided by ACAS. Prevention of collisions will depend on ATC in controlled airspace and on the “see-and-avoid” principle.

4.2.2.3. However, a distinction may have to be made based on the actual operation of VLJs and LJs under 5,700 kg. Indeed, GA-type operation, and other non-commercial owner-pilot use, differs from operation by a commercial operator for business purposes. Another possible distinction could be between flights under IFR and flights under Visual Flight Rules (VFR) since the protection afforded by ATC depends on the type of flights in the airspace.

4.2.2.4. For those VLJs and LJs under 5,700 kg that would be equipped with ACAS, lessons learnt at the time of Phase II of the European ACAS mandate indicate that the safety benefits of ACAS can be very significant.

4.2.2.5. As an illustration, Figure 13 shows the results obtained at that time which highlight that the risk ratio per aircraft class were decreased by a proportion of about 25% for turboprop aircraft weighing between 5,700 kg and 15,000 kg and about 90% for jets in the same weight range when extending the ACAS mandate to aircraft with an MTOM between 5,700 kg and 15,000 kg.

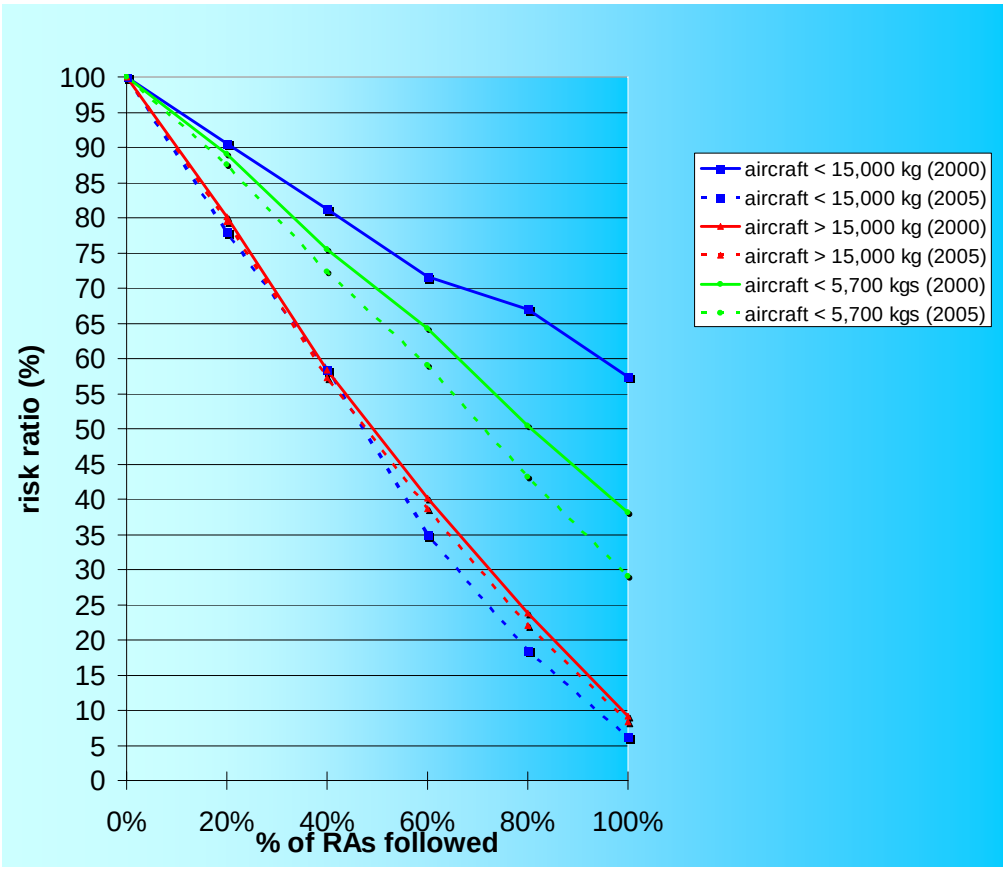

Figure 13: Safety benefits of Phase II of the current ACAS mandate – fleet perspective

4.2.2.6. These results were key to support the decision of extending the European ACAS mandate to smaller aircraft.

4.3. Safety implications when VLJs and LJs are ACAS equipped

4.3.1. Even though ACAS is not intended to achieve any specific 'Target Level of Safety', the risk reduction afforded by the carriage and operation of ACAS by civil aviation is well recognised. Therefore, considering fitting VLJs and LJs with ACAS deserves specific attention.

4.3.2. One of the most significant factors that will need to be considered, if VLJs and LJs under 5,700 kg are to be ACAS equipped, is the actual pilot behaviour in response to RAs. Indeed, **the compliance of pilots with RAs is key to achieve the safety benefits delivered by ACAS**.

4.3.3. The introduction of VLJs/LJs brings two new elements that can affect the pilot response to an RA:

- The single pilot operation of these aircraft (they can also be operated by a two-pilot crew);
- A new population of pilots with different backgrounds: professional pilots (who may have past experience with ACAS or not), but also GA pilots with close to no experience with ACAS.

4.3.4. In the case of a professional pilot with past ACAS experience (i.e., business jet pilots) transitioning to a VLJ/LJ, assumed to be equipped with ACAS, it can be expected that the recurrent training this pilot has received in his former professional context will carry over. The range of responses observed during the most recent airborne data analyses ([ASA]) can therefore be expected from those pilots.

4.3.5. For professional pilots with no or limited ACAS experience, similar behaviours to those observed when ACAS was initially mandated can be anticipated. This means that the slow and aggressive response types identified at that time in initial airborne data analyses ([ACA1]) could correspond to these pilots.

4.3.6. Last, when considering pilots with a GA background, the ACASA slow and aggressive response types can also be expected, because of their lack of experience with ACAS. In addition, the Human Factors analysis also indicates that non-standard manoeuvres should be anticipated, such as responses in the opposite direction or in the horizontal dimension.

4.3.7. In addition to these basic types of response, in cases where a VLJ/LJ would be operated by a single pilot, the Human Factors analysis of such operations (cf. 3.5.5) has indicated that it would increase the probability of non-response, the initial delay between the time of the RA and the start of the manoeuvre and the risk of response in the wrong direction or with a too high vertical rate.

4.3.8. Table 4 summarizes the way the various factors that can influence a VLJ/LJ pilot response to an RA could affect the nature of this response. It assigns a basic type of response depending on the pilot background, with additional effects if the aircraft is flown under single pilot operation.

Pilot background	Basic type of response	Additional effects in case of single pilot operation
Professional, with ACAS experience	As observed in ASARP	- Higher non-response rate - Increased initial delay - Increased risk of opposite response - Increased probability of high vertical rate
Professional, without ACAS experience	As observed in ACASA	
Non-professional	As observed in ACASA, with increased rate of non-response and non-standard manoeuvres	

Table 4: Possible effect of single pilot operations on VLJ/LJ pilot response to RAs

4.4. Options for ACAS equipage

4.4.1. When envisaging a possible modification of the threshold for the ACAS mandate, some consideration needs to be given to the costs associated with the mandatory carriage of ACAS compliant equipment.

4.4.2. Figure 14 shows, for the same aircraft, and assuming a price of between 60,000 and 150,000 US dollars[6] for the TCAS installation (on a new aircraft), the proportion of the aircraft price that the TCAS represents, versus weight.

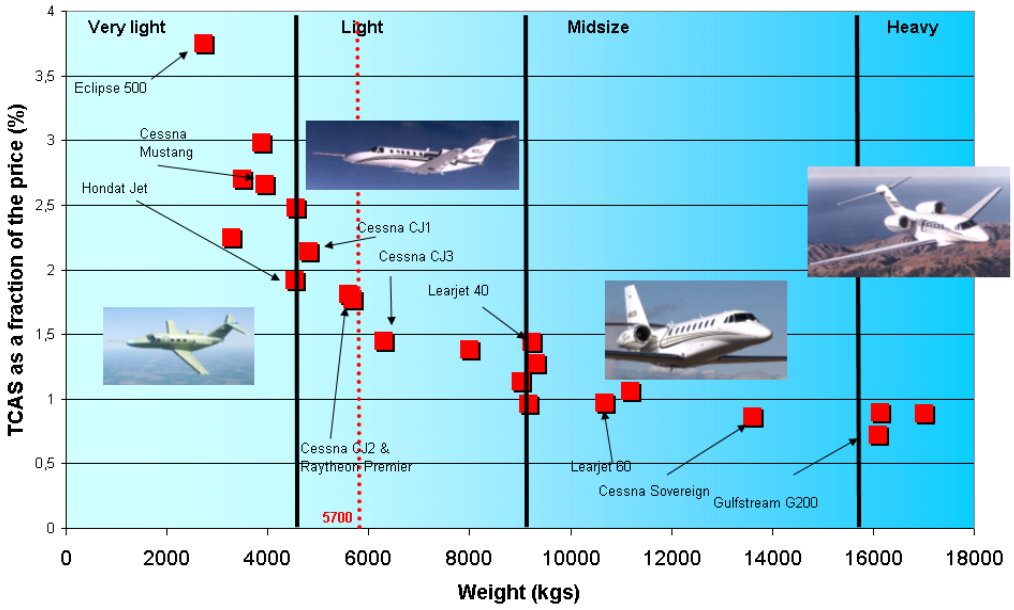

Figure 14: Fraction of the price that TCAS represents for jet aircraft

4.4.3. Figure 14 shows that installing ACAS on aircraft below 5,700 kg represents a small but not negligible part of the price of the aircraft. This is especially true for VLJs, but this proportion is never greater than 3.8% of the price.

4.4.4. **In terms of equipping LJs and VLJs with ACAS, the technical feasibility of equipping VLJs and LJs under 5,700 kg is an area to be looked at** (it is however outside the scope of the AVAL study). In the past, manufacturers have been faced with problem of location and interference issues when equipping small aircraft with several advanced avionics with specific antennas.

[6] Depending on the weight of the aircraft, the heavier the aircraft the higher the price is in this computation.

5. Conclusions and Recommendations

5.1. Main AVAL Phase 1 findings

5.1.1. Phase 1 of the AVAL project was a preliminary investigation of the potential effect of the operations of VLJ and LJ under 5,700 kg on ACAS performance in the European airspace. The analysis focused on the key factors that affect the safety benefits delivered by ACAS, i.e. the aircraft operations in the airspace, the level of ACAS equipage and the pilot behaviour in response to RAs.

5.1.2. Analysing the performances of VLJs and LJs under 5,700 kg has highlighted three categories of such aircraft with clearly different speed ranges. One of these categories is particularly likely to create a compatibility issue with heavier commercial aircraft, as they are able to fly in the same airspace, but at 15% to 30% lower speeds. Sales forecasts indicate this category of VLJs and LJs under 5,700 kg will compose the large majority of the 110,000 to 170,000 additional flights per year that will result from the introduction of VLJs and LJs in the European airspace.

5.1.3. Since the carriage and operation of ACAS has been demonstrated to reduce the risk of collision by a factor of 5 in European airspace, fitting ACAS to VLJs and LJs under 5,700 kg deserves attention. Whether they are equipped with ACAS or not, there is evidence that these new VLJs and LJs under 5,700 kg will have an effect on the overall performance of ACAS as a safety net.

5.1.4. If VLJs and LJs under 5,700 kg are not equipped with ACAS, they will not benefit from the additional safety margins provided by this system. Prevention of collisions will depend on ATC in controlled airspace and on the “see-and-avoid” principle. In addition, this choice will affect the safety of aircraft currently equipped with ACAS. For the second phase of the ACAS mandate in Europe affecting 10% of the aircraft fleet, studies showed that the risk of collision for the whole airspace would increase by 30% if that portion of the fleet was not equipped with ACAS.

5.1.5. The existence of 3 categories of VLJs, with very different speeds, argues for the introduction of speed as a determinant for requiring ACAS carriage, in addition to the MTOM that is currently used.

5.1.6. If ACAS becomes mandatory on VLJs and LJs, a safety benefit in the airspace is expected. However, this benefit needs to be quantified. It would be affected by the quality of VLJ/LJ pilot response to RAs. Their responses might significantly differ from those observed with current pilots, as many VLJs and LJs could be certified for single pilot operation and will be flown in part by owner-pilots, who receive considerably less training than professional pilots.

5.1.7. The question of extending the current ACAS mandate to VLJs and LJs also carries technical and financial aspects. Past experience of TCAS manufacturers shows that there could be problems fitting antennas on a small airframe, which, together with interference issues, could potentially reduce the efficiency of the equipment. The cost of equipping such aircraft with TCAS has been estimated to be no greater than 4% of the aircraft price: this cost has to be balanced against the additional safety benefits provided.

5.2. Recommendations

5.2.1. It is recommended that:

- The implications of VLJ introduction in the European airspace on the performance of ACAS be quantified for VLJs, LJs under 5,700 kg, and other aircraft already equipped with ACAS;
- The use of speed along with maximum takeoff mass is investigated as a determinant for requiring ACAS carriage; and
- Phase 2 of the study proceeds.

6. Proposed Phase 2 work

6.1. Safety effects resulting from equipping VLJs and LJs under 5,700 kg with ACAS can only be quantified by an in-depth investigation using the established encounter model approach. The various models (i.e. for encounters, pilot responses to RA and altimetry error) would have to be adapted to reflect the introduction and operation of such aircraft in the European ATM system.

6.2. The update of the European safety encounter model to include operations of VLJs and LJs under 5,700 kg is twofold:

- The introduction of new aircraft performance classes, possibly based on their typical cruise speeds (cf. 3.3), and
- The determination of the rate and the typical characteristics of encounters involving these aircraft, based on encounters currently observed with aircraft showing similar performances, as well as assumptions related to delivery forecasts and operations for VLJs/LJs (cf. 3.4 and 3.5).

6.3. To assess the benefits of equipping VLJs/LJs with ACAS, there is also a need to introduce specific pilot RA response models for these aircraft, according to the results of the Human Factors study of single pilot operation (cf. 3.5.5).

6.4. **These updated models would then support the investigation of ACAS performance in a set of operational scenarios in terms of level of ACAS equipage at the 2015 target date** (cf. Appendix B for further details on the updates required for the models).

6.5. As ATC scenarios will not be available in the AVAL study timeframe, it implies that Phase 2 will have to define a range of realistic scenarios based on the findings presented in this report. These scenarios will be the basis for a comprehensive sensitivity study of the key factors that influence typical indicators of the safety benefits delivered by ACAS (e.g. logic risk ratios and number of years between collisions in Europe).

7. References

7.1. External documents

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[RCR] 'Report to Congressional Requesters, VERY LIGHT JETS, Several Factors Could Influence Their Effect on the National Airspace System' – United States Government Accountability Office – GAO-07-1001 – August 2007

[SIR] 'SIRE Project Final Report' – EUROCONTROL Mode S & ACAS Programme – SIRE/WP4/58/D, Version 1.1, December 2005

[SIR+1] 'CP115 (LOLO) Evaluation Report' – EUROCONTROL Mode S & ACAS Programme – SIRE+/WP5/40/D, Version 1.0, May 2007

[SIR+2] 'SIRE+ simulation framework' – EUROCONTROL Mode S & ACAS Programme – SIRE+/WP1/03/W, Version 1.1, February 2006

[SFO] 'EUROCONTROL Trends in Air Traffic | volume 1, Getting to the Point: Business Aviation in Europe' – EUROCONTROL Statistics and Forecast Service (STATFOR)

[VIP1] 'VIP – Very Light Jets Integration Platform, First meeting summary' - 16 October 2007'

[WEB] Internet resources, including http://www.airliners.net/, manufacturers websites, and http://www.flug-revue.rotor.com/

7.2. AVAL internal documents

[WA1] 'Performances of VLJs and LJs' – AVAL Project – AVAL/WA1/06, Version 0.1, December 2007

[WA2] 'Operations of VLJs and LJs in European airspace' – AVAL Project – AVAL/WA2/07, Version 0.1, December 2007

[WA5] 'Modelling of single pilot operations' – AVAL Project – AVAL/WA5/08, Version 0.1, December 2007

8. Glossary

ACAS Airborne Collision Avoidance System – a system standardised in the ICAO SARPs that uses transponder replies from other aircraft to warn the pilot of a risk of impending collision.

In this document, ACAS always refers to ACAS II – a system that generates traffic advisories (TAs) and also generates resolution advisories (RAs) in the vertical plane.

ACASA Project ACAS Analysis – a study commissioned by EUROCONTROL in support of the mandate for the carriage of ACAS II in Europe, before implementation of RVSM.

ASARP project ACAS Safety Analysis post-RVSM Project – a study commissioned by EUROCONTROL to investigate the safety of ACAS following the introduction of RVSM in Europe.

Light Jet For the purpose of the study, turbofan-powered aircraft with a maximum takeoff mass between 4,500 kg (10,000 lbs) and 9,000 kg (20,000 lbs).

The industry long ago defined the upper end of the “light” segment at less than 20,000 lbs. However, for the study purpose, there is a need to distinguish between the light jet with a maximum takeoff mass below or above 5,700 kg (12,500 lbs).

RA Resolution Advisory – an ACAS alert providing advice to a pilot on how to modify or regulate his vertical speed to avoid a potential mid-air collision.

Safety encounter model A mathematical model which reproduces the distributions and interdependencies of the parameters characterising risk bearing encounters likely to occur in ATM operations.

The encounters that matters are those in which two aircraft are on a close encounter course and in which there exist a risk of mid-air collision or in which the response of pilots to ACAS RAs can result in a risk of mid-air collision.

TA Traffic Advisory – an ACAS alert warning the pilot of the presence of another aircraft that may become the subject of an RA

TCAS Traffic alert and Collision Avoidance System – an aircraft equipment that is an implementation of an ACAS

Hereafter, TCAS refers to TCAS II, version 7.0 or the future version 7.1 – the equipment that complies with the ICAO SARPs and whose carriage and operation is mandatory for many aircraft in Europe.

Very Light Jet For the purpose of the study, turbofan-powered aircraft with a maximum takeoff mass not exceeding 4,540 kg (10,000 lbs), certified for single pilot operations and that typically seat between 3 to 8 passengers.

VIP Very Light Jet Integration Platform – a EUROCONTROL initiative to ensure a safe and efficient integration of the VLJs in the European ATM environment.

9. Acronyms

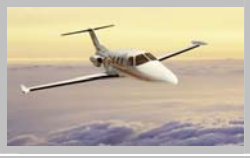
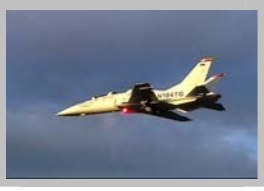
ACAS	Airborne Collision Avoidance System
ACASA	ACAS Analysis
ASARP	ACAS Safety Analysis post-RVSM Project
ATC	Air Traffic Control
ATM	Air Traffic Management
AVAL	ACAS on VLJs and LJs – Assessment of safety Level
BADA	Base of Aircraft Data
CAS	Collision Avoidance System
DSNA	Direction des Services de la Navigation Aérienne
DTI	Direction Technique et de l'Innovation
ECAC	European Civil Aviation Conference
EEC	EUROCONTROL Experimental Centre
EHQ	EUROCONTROL Head Quarters
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FITS	FAA/Industry Training Standard
FL	Flight Level
GA	General Aviation
HF	Human Factors
IBAC	International Business Aviation Council
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
JAR	Joint Aviation Regulations
LJ	Light Jet
MTOM	Maximum Take-Off Mass
NBAA	National Business Aviation Association
NMAC	Near Mid-Air Collision
RA	Resolution Advisory
RFL	Requested Flight Level
RVSM	Reduced Vertical Separation Minima
SARPs	Standards And Recommended Practices
SIR	Safety Issue Rectification
SIRE	SIR Extension

SRM	Single pilot Resources Management
SSR	Secondary Surveillance Radar
SSS	Surveillance Separation & Safety skill unit of Egis Avia
TA	Traffic Advisory
TAS	True Air Speed
TCAS	Traffic Alert and Collision Avoidance System
TLS	Target Level of Safety
TMA	Terminal Control Area
VFR	Visual Flight Rules
VIP	Very Light Jets Integration Platform
VLJ	Very Light Jet
WA	Work Area

10. Appendix A: Background on VLJs and LJs

10.1.1. This appendix provides some examples of VLJs, with information such as weight and ground speed.

VLJs

Aircraft	Manufacturer	Image	ICAO code	Weight	Ceiling	Cruise speed[7]
A700	Adam Aircraft		?	4,250 kg	FL410	340 kts
D-Jet	Diamond Aircraft		?	2,318 kg	FL250	315 kts (long range: 240 kts)
Eclipse 500	Eclipse Aviation		EA50	2,719 kg	FL410	370 kts
Elite	Epic Aircraft		?	3,495 kg	FL410	412 kts
Honda Jet	Honda		?	4,173 kg	FL430	420 kts
Independence	Spectrum		?	3,402 kg	FL450	415 kts
Javelin	Aviation Tech Group		?	3,100 kg	FL450	500 kts

[7] Often high cruise speeds

Mustang	Cessna Aircraft		?	3,847 kg	FL410	340 kts
Phenom 100	Embraer		?	<4,500 kg	FL410	360 kts
Piper Jet	Piper Aircraft		?	<4,500 kg	FL350	360 kts
Smart Jet	Maverick Jets		?	<4,500 kg	FL220	290 kts
Solo Jet	Maverick Jets		?	<4,500 kg	FL310	350 kts
SPn	Grob Aerospace		?	<4,500 kg	FL410	?
Sport Jet	Excel Jet		?	2,200 kg	FL250	375 kts
The-Jet	Cirrus Design		?	<4,500 kg	FL250	300 kts
Victory	Epic Aircraft		?	2,497 kg	FL280	320 kts

LJs

Aircraft	Manufacturer	Image	ICAO code	Weight	Ceiling	Cruise speed[8]
Cessna CJ1	Cessna		C525	4,899 kg	FL410	389 kts
Cessna CJ2	Cessna		C25A	5,585 kg	FL450	357 kts
Cessna Citation I	Cessna		C501	5,380 kg	FL380	357 kts
Cessna Citation	Cessna		C500	4,920 kg	FL380	348 kts
Raytheon Premier I	Raytheon		PRM1	5,670 kg	FL410	461 kts

[8] Often high cruise speeds

11. Appendix B: Update of the European safety encounter model

11.1. Generalities on encounter model-based methodology

11.1.1. A safety encounter model is a model of traffic situations that captures the properties of 'close' encounters[9] as a series of statistical distributions, describing the parameters of a typical encounter and their interdependencies. Usually, the statistical distributions are altitude dependent and are provided for several altitude layers. Among these parameters, one typically finds distributions of parameters such as:

- Altitudes;
- Vertical rates;
- Trajectory type for each aircraft (i.e., level, climbing, levelling-off, etc);
- Aircraft type (heavy jet, small turboprop, etc), often referred to as aircraft classes, used to model realistic aircraft performances;
- Bank angles;
- Angle of approach;
- Etc…

11.1.2. A specification of an encounter model by which the performance of differing ACAS logics can be compared is given in the ICAO ACAS SARPs ([ACAS]). The ICAO encounter model is representative of no particular airspace. It was used as the starting point for the specification of a more sophisticated encounter model representative of European airspace in the ACASA project, and then in the ASARP project which updated the model to introduce RVSM operations. Current European radar data was used to populate the tables and produce an encounter model characteristic of the ECAC airspace at that time and over all altitudes.

11.1.3. This European safety encounter model is built around 3 elements, which are combined to reflect a given scenario in which the safety performance of ACAS is assessed through the simulation of the Collision Avoidance System (CAS) logic:

- A safety encounter model, enabling to generate encounters representative of the geometries observed in actual close encounters (i.e. airproxes or TCAS events). This model is based on a set of aircraft classes, defined by weight and engine type, which are each associated with a given range of performances.
- A pilot response model, characterizing the behaviour of pilots faced with RAs.

[9] The encounters that matters are those in which two aircraft are on a close encounter course (i.e. with a horizontal miss distance of less than the NMAC horizontal threshold) in which there exist a risk of mid-air collision or in which the response of pilots to RAs can result in a risk of mid-air collision.

- An altimetry error model, representing altitude measurement errors by real aircraft systems.

11.1.4. In the context of modelling the introduction of VLJs and LJs under 5,700 kg, the encounter model should be revised to accommodate the anticipated performances of VLJs and LJs (cf. section 3.3), which are currently not taken into account. Similarly, the pilot response model should be adapted to the new populations of pilots that have been foreseen (cf. section 3.5.5). The altimetry error model would not be affected by this introduction.

11.2. Updated aircraft performance classes

11.2.1. The investigation of VLJ and LJ performances in [WA1] has shown that it could be convenient to revise the way classes are defined, by adding a speed component. It is proposed to use the 3 following components in the definition of aircraft classes within the updated European safety encounter model:

- Engine type (piston, turboprop or jet); and
- Maximum take-off mass (above or below 5,700 kg); and
- Maximum cruising true airspeed[10] (slower than 250 kts, between 250 and 350 kts, between 350 and 450 kts, faster than 450 kts).

11.2.2. Combining the values of the above 3 parameters results in 24 potential classes.

11.2.3. Analysis of 2007 French flight plans, airproxes and TCAS events ([WA1], [WA2]) has shown that only 11 of the potential 24 aircraft classes are useful, as some do not correspond to realistic weight and speed combinations. Table 5 shows as greyed cells the classes corresponding to actual aircraft performances.

Maximum cruising true airspeed / Aircraft type & weight		< 250 kts (Very Slow) (1)	250 to 350 kts (Slow) (2)	350 to 450 kts (Fast) (3)	> 450 kts (Very Fast) (4)
Pistons < 5,700 kg	**(A)**	A1	A2	-	-
Turboprops < 5,700 kg	**(B)**	-	B2	B3	-
Turboprops > 5,700 kg	**(C)**	C1	C2	C3	-
Jets < 5,700 kg	**(D)**	*D1*	*D2*	D3	*D4*
Jets > 5,700 kg	**(E)**	-	-	E3	E4
Military jets	**(F)**	-	-	-	F4

Table 5: Proposed aircraft classes

11.2.4. Classes highlighted in grey are those corresponding to current aircraft operations. Classes D1, D2 and D4, indicated in italics in Table 5, will be used to model future VLJs operations, if required.

[10] The rationale for the choice of the boundaries is detailed in [WA1].

11.2.5. In order to validate this choice of aircraft performance classes, Table 6 shows the proportion of these classes in actual operations, based on flight plans flown within French airspace in 2007.

Maximum cruising true airspeed / Aircraft type & weight	< 250 kts (Very Slow) (1)	250 to 350 kts (Slow) (2)	350 to 450 kts (Fast) (3)	> 450 kts (Very Fast) (4)
Pistons < 5,700 kg (A)	0.80	0.58	-	-
Turboprops < 5,700 kg (B)	-	1.30	0.44	-
Turboprops > 5,700 kg (C)	0.03	1.14	4.00	-
Jets < 5,700 kg (D)	-	-	0.59	-
Jets > 5,700 kg (E)			11.06	80.02
Military jets (under FPL) (F)				0.04

Table 6: Proportions of aircraft in each proposed class

11.2.6. In order to update of the European safety encounter model, a revised set of probability tables will be necessary. In particular, it is necessary to know the probability that an aircraft from a given class, among those defined in the preceding section, is involved in an encounter.

11.2.7. To do so, data from close events are used. This is usually done using airprox events. It could also have been done using TCAS events, however this data appears less adequate than airprox events. Indeed, the European safety encounter model table describing the way the aircraft classes are represented versus altitude was built using airprox events.

11.2.8. An analysis of reported airprox and TCAS events which occurred in the French airspace between 2005 and 2008 was performed. This analysis led to the computation of the proportions of each of the aircraft classes defined in the preceding part. General results from this analysis are shown hereafter.

11.2.9. Within the European safety encounter model, altitudes are distributed in a set of five altitude layers. All the characteristics of the European safety encounter model are altitude dependent, and are considered as constant in each altitude layer. They will not be modified by the update of the European safety encounter model.

Layer	1	2	3	4	5
from	1000ft	5000ft	FL135	FL215	FL285
to	5000ft	FL135	FL215	FL285	FL415

Table 7: Altitude layers in European safety model

11.2.10. Analysis of airproxes and TCAS events has shown a major difference between them. Indeed, the altitude distributions are very different. This is shown in Figure 15, which also indicates the current altitude distribution used to describe the European safety encounter model.

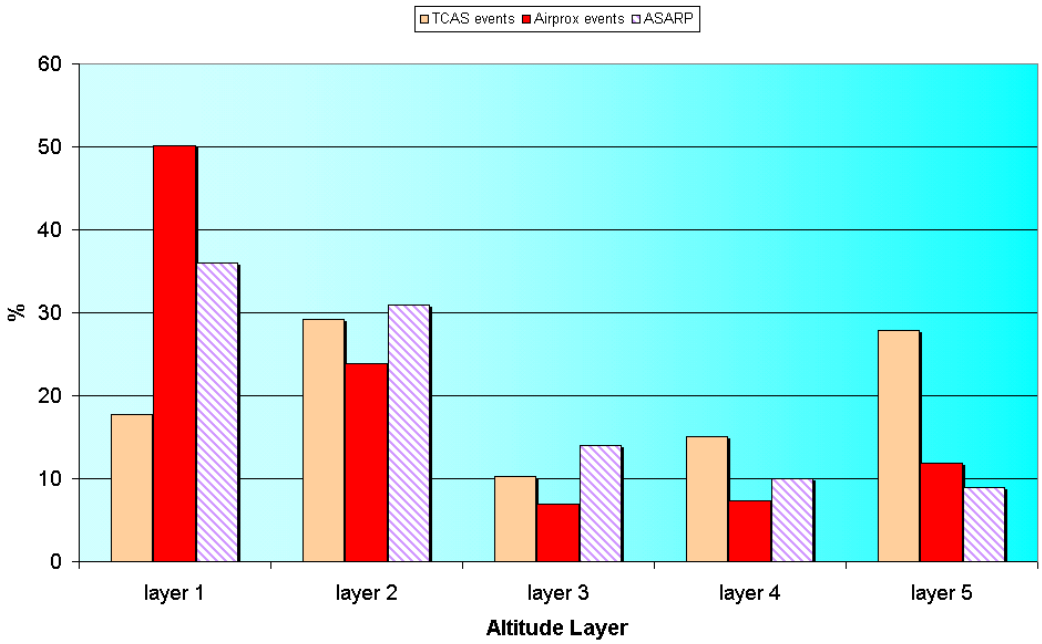


Figure 15: Altitude distributions of airproxes, TCAS events and in current European encounter model

11.2.11. The same trend can be observed in airproxes and in the current encounter model, which is not unexpected, as the altitude distribution for the encounter model is based on airproxes. Both sources of data show a peak in layer 1. However, the distribution of TCAS events is different, with peaks in layers 2 and 5.

11.2.12. It can be concluded from Figure 15 that, depending on the source of data used to populate the table describing the distribution of the encounters versus altitude, the result can be very different. Building an encounter model using of airproxes would results in modelled encounters being mostly generated in the lower layers, while they would be located in the upper layer if the model was built using TCAS events.

11.2.12.1. Probability to be in an airprox or a TCAS event

11.2.12.1.1. Table 8 and Table 9 show the probabilities for each class, on the whole airspace, that an aircraft is involved in an airprox event and then in a TCAS event.

Maximum cruising true airspeed / Aircraft type & weight	< 250 kts (Very Slow) (1)	250 to 350 kts (Slow) (2)	350 to 450 kts (Fast) (3)	> 450 kts (Very Fast) (4)
Pistons < 5,700 kg (A)	21.09	1.76	-	-
Turboprops < 5,700 kg (B)	-	5.66	0.20	-
Turboprops > 5,700 kg (C)	0.00	0.98	6.05	-
Jets < 5,700 kg (D)	-	-	0.39	-
Jets > 5,700 kg (E)	-	-	10.55	41.60
Military jets (F)	-	-	-	11.72

Table 8: Probabilities for reported airprox events

Maximum cruising true airspeed / Aircraft type & weight	< 250 kts (Very Slow) (1)	250 to 350 kts (Slow) (2)	350 to 450 kts (Fast) (3)	> 450 kts (Very Fast) (4)
Pistons < 5,700 kgs (A)	7.10	0.78	0.00	0.00
Turboprops < 5,700 kgs (B)	0.00	1.37	0.44	0.00
Turboprops > 5,700 kgs (C)	0.05	1.67	5.93	0.00
Jets < 5,700 kgs (D)	0.00	0.00	0.69	0.00
Jets > 5,700 kgs (E)	0.00	0.00	13.17	60.53
Military jets (F)	0.00	0.00	0.00	8.28

Table 9: Probabilities for reported TCAS events

11.2.12.1.2. From Table 8 and Table 9, one can notice that 11 aircraft classes have non-nil probabilities. Taking into account a provision for all possible speeds for VLJs (i.e. the four cells on line D), this confirms the need of a total of 14 aircraft classes to also take into account introduction of VLJs and smaller LJs. The distributions of these probabilities by altitude layer are provided in [WA1].

11.3. Models for pilot response to RAs

11.3.1. To represent pilot responses of VLJs and LJs under 5,700 kg in two-pilot operation, the models developed during the former ACASA and ASARP projects are appropriate, as indicated in 4.2.2. The exact probabilities of non-response and non-standard manoeuvres for leisure pilots should be defined in the scenario being investigated.

11.3.2. For single pilot operation, the Human Factors that can affect the RA responses of VLJ and LJs under 5,700 kg pilots have to be quantified in order to define the corresponding pilot models. These effects are quantified relatively to a base value, which depends on the scenario being investigated.

- Non-response rate: the increase caused by the lack of a second crew member can be estimated to 10 percentage points (i.e. 30% if the figure for two-member crews is 20%). Indeed, all types of pilots are now aware of ACAS.
- Opposite responses: commercial airline monitoring has shown they happened in a few percents of cases. This figure would increase by 5 percentage points because of the lack of cross-check by a second crew member and of the probable reduced available time for the manoeuvre.
- Initial delay: it is estimated to 150% of the base value, as the pilot will have to carry all the tasks currently distributed between two crew members.
- High vertical rate: it is anticipated that single pilot operation of VLJs / LJs will increase this rate by 20%. This comes as a result of the later manoeuvres in which the pilot will respond in a stronger manner.

11.3.3. The resulting models for pilots of VLJs and LJs under 5,700 kg are summarised below.

Parameter	Pilot background and response type				
	Professional, with ACAS experience	Professional, no ACAS experience		Non-professional	
		slow	aggressive	slow	aggressive
Initial RA delay	5 to 12 s	15 s	8 s	15 s	8 s
Initial RA target V/S	730 to 3900 fpm	500 fpm	3700 fpm	500 fpm	3700 fpm
Initial RA acceleration	0.09 to 0.3 g	0.1 g	0.25 g	0.1 g	0.25 g
Subsequent RA delay	2.5 s	2.5 s	2.5 s	2.5 s	2.5 s
Strengthening / weakening RA accel.	0.09 to 0.3 g	0.1 g	0.25g	0.1 g	0.25g
Increase / reversal RA acceleration	0.35 g	0.1 g	0.25 g	0.1 g	0.25 g
Increase RA V/S	2500 / 3900 fpm	500 fpm	3700 fpm	500 fpm	3700 fpm
Non-response rate (relative to base rate)	+ 10 percentage point	+ 10 percentage point	+ 10 percentage point	+ 10 percentage point	+ 10 percentage point
Opposite response (relative to base rate)	+ 5 percentage point	+ 5 percentage point	+ 5 percentage point	+ 5 percentage point	+ 5 percentage point
Horizontal manoeuvre	No	No	No	Yes	Yes

Table 10: Pilot models for VLJs/LJs under single pilot operation

11.3.4. Figure 16 below is similar to Figure 2 and provides the distribution of responses for pilots with ACAS experience flying under single pilot operation (i.e. the left column of Table 10), assuming a 30% non-response rate.

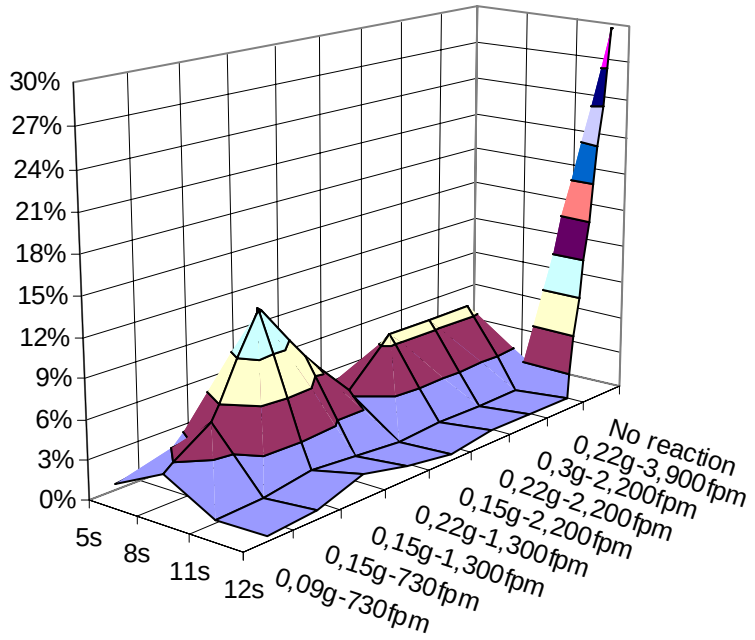


Figure 16: Response model for pilots with ACAS experience flying under single pilot operation

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