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Separation Minima Model:

How Changes in Contributing Factors Could Affect Current Standards

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Abstract— **In 1919, the International Commission for Air Navigation (ICAN) was created to develop "General Rules for Air Traffic". In 1926, the US Air Commerce Act was passed calling for implementation of air traffic. Its first basic Separation Minima (SM) was "Do not take off until there is no risk of collision with landing aircraft and until preceding aircraft are clear of the airfield."[1] Since then, many SM standards have been written based upon the technology available at the time and/or expert judgment. Leaps in technology since then require that the SM standards be updated. However, many SM have not been modified to reflect modern technological capabilities. In addition, many regions around the world have set different values for the same operational case or have used different criteria and context descriptions.**

As current traffic demand is expected to double by 2020, one of the ATM system challenges is to safely manage the expected increase of movements. Reducing SM becomes a potential part of achieving this challenge, always keeping in mind that SM reductions increase airspace capacity but should never reduce safety levels.

A useful tool would allow quick comparative analysis to understand what affect changes in contributing factors would have on SM before investing in a Safety Case.

To develop this model RESET, a SESAR aligned project which includes the FAA as a partner, has extracted information from several international regulations (ICAO, FAA, British, Australian, Canadian and Eurocontrol) classifying the descriptions of SM values by phase of flight, operational context, conditions, etc. also identifying aerodynamic factors, human factors, hazards/risks and equipment precision. The valuable results of this research are unprecedented in their contents and for the way in which they are presented. The identified contributing factors were then grouped into budgets and used as variables in the Separation Minima Model.

Keywords-Separation Minima, Model, ATM, Regulations, Safety.

TABLE I. ACRONYMS

Acronym	Meaning
a/c	Aircraft
DOF	Degree of Freedom
ENR	En-Route
FAA	Federal Aviation Administration
ICAO	International Civil Aviation Organization
PoF(s)	Phase of Flight(s)
SM	Separation Minima
SMS	Separation Minima Standard
TMA	Terminal Manoeuvering Area
WV	Wake Vortex
RWY(s)	Runway(s)

I. INTRODUCTION

A. Background

The cornerstones for providing safe Air Traffic Services are the equipment used for Air Traffic Control and information management, the people working in the different parts of the system and the procedures used to manage both the operations and supporting functions. Whereas, equipment and people issues have received considerable R&D attention over the past few years, there has been less attention placed on identifying and understanding the fundamental bases of Air traffic Control (ATC) procedures. In particular, for separation minima, which controllers apply to ensure that aircraft keep a safe distance apart, the evolution has seemingly been a function of what appeared to work operationally and what was deemed to be acceptably safe from the viewpoint of the approving authorities.

It is therefore widely understood that the knowledge underpinning the development and use of such separation minima is tacit. However, in order to evaluate the possibility of adapting separation minima to the changing technological and operational environment of the future, their bases need to be made explicit. To address this issue the research project RESET – Reduction of Separation Minima – conducted a detailed analysis into the origins and bases of current separation standards and has attempted to develop a novel approach to understanding and defining separation minima to eventually answer the question: What potential impact could the technological advancements have on separation minima which were defined decades ago?

B. Objectives

The objective of this research is twofold. The first objective was to create a single source for locating separations minima standards from various regulating bodies. Currently, it is widely recognized that ICAO 4444 contains international regulations on minimum distances for keeping aircraft separated. However, not only are there regional exceptions and local waivers to these regulations, there are many separation standards that are included in other ICAO documents. In addition, a low percentage of these standards make references to their foundations, contributing factors, how they were laid down, or even when. Having all of these standards compiled in one location, and be able to search the associated information by context and categories, would be of great help to researchers and developers of new procedures.

The second objective was to use the information regarding foundations and contributing factors and create a general quantitative separation minima model. This model would be unique as it would not be used as a collision risk predictor, but as a sensitivity analysis tool to analyze how changes in the contributing factors of a separation standard could affect the value of the separation. It would also be unique in that it would be produced using open source tools so other organizations with excellence in a certain area could contribute to the improvement of the model.

Separation minima play a key role in increasing capacity within both NextGen and SESAR. Investigating separation minima reductions is also a long and costly process. Before investing in an entire safety case analysis and risking that the answer would be of minimal operational benefit, using this openly shared tool could help determine which technology could aide most in reducing a separation minima. This would refine the decision making process, thus reducing costs associated with determining which technology to implement first.

II. Separation Minima Standards – What is there now?

The first activity was to collect and search associated documentation to build the repository. These documents are listed in TABLE II.

TABLE II. MAIN DOCUMENTS ANALYSED FOR SMS IDENTIFICATION

Source/Author	Code
ICAO	Docs: 4444, 9476, 9830, 9426, 9574, 9613, 9689, 9643, 7030, 9854, Annex 2, Annex 11.
FAA	Order 7110.65
Civil Aviation Authority	CAP 493
TC Civil Aviation	Standard 821
Civil Aviation Safety Authority	CASR Part 172

In order to classify separation standards from various regulatory bodies, it was essential to agree upon a coherent method of filling in the table. A template, or checklist, following the format of the ICAO 4444[9] document was created. SM information and values regarding PoF, operational conditions and applicable context and constrains were extracted from [9] and other ICAO documents (see from [9] to [13]) as well as from EUROCONTROL and the American (FAA)[14], British (BAA), Canadian and Australian regulations. This information was incorporated into the output table named Separation Minima List and was classified in a way to facilitate the consultation of list. EUROCONTROL regulations were included in order to investigate the future regulatory environment.

The Separation Minima List, located on the RESET website (http://www.reset.aena.es), shows the current status of 622 Separation Minima Standards. It is a self-explanatory table that contains the compiled information about the standards laid down in regulations. Each row represents a Separation Minima Standard. The header column titles correspond to the template checklist and their fields are filled with the corresponding information related to each separation minima case. The column titles are: *Phase of Flights, Operation, Characteristics, Direction / Tracks / Routes, Conditions, Context, Means, Control by, Picture, Separation, Based on, Separation Minima laid down, Reference, and Observations.*

As the Separation Minima cases are organized according to the above mentioned columns, the information can be sorted using a filter tool to find the data needed or compare different standards to identify differences between them. Presenting the results this way also allows the easy introduction of new separation minima regulations and facilitates updating the included information.

III. SMS Foundation Research – What they are based upon?

Once all the SMS were identified, the next step was to identify the foundations that support the Separation Minima Standards Definitions.

The applied methodology followed a five-stage approach, each stage with a specific objective as described below:

- Stage 1. Research the foundations for the current SMS.
- Stage 2. Identification of current SMS foundations strength.
- Stage 3. Research and Identification of the contributing factors to the SMS.
- Stage 4. Selection of the SMS that will be analyzed in more detail.
- Stage 5. Group the SMS to be studied by "thematic areas".

These five stages should conclude in answering the following questions:

Where was the definition of the Separation Minima Standard established?, How was the separation minima standard established? How strong are the foundations? Which factors contribute to the Separation Minima *definition?, Which from the identified SMS are most relevant to be analyzed in more detail?, Do these SMS have some similar characteristics?, Is there a way to study the standards by groups?, Is all the information available needed to analyze each group of Separation Minima Standard?*

The following paragraphs explain how each stage was developed, and give their main conclusions and products.

*1) **Stage 1**. Research the foundations for current SMS.*

The main objective within this stage was to find the current foundations for all the SMS previously identified.

To accomplish that, the SMS Current Status list was used as an input and all the main documents listed in TABLE III were re-distributed in order to start the "investigative process" into the foundation for each SMS, or (by default) any clue or piece of information that could contribute to the understanding of the SMS definition.

TABLE III. DOCUMENTS ANALYSED FOR FOUNDATIONS

Source/Author	Code
ICAO	Docs: 4444, 9476, 9830, 9426, 9574, 9613, 9689, 9643, 7030, 9854, Annex 2, Annex 11.
FAA	Order 7110.65
Civil Aviation Authority	CAP 493
TC Civil Aviation	Standard 821
Civil Aviation Safety Authority	CASR Part 172

The results of this process were documented in the SMS Current Status List in order to maintain the link between each Separation Minima and its Foundations.

*2) **Stage 2**. Identification of current SMS foundations strength.*

This stage aimed to qualify the stage 1 results through a complete "auto evaluation" of the research process. To accomplish this, an indicator called the Foundation Research Assessment (FRA) was created using four possible options: Success, Few Possibilities, Uncertainty, Unaware. These tags, whose definitions are listed in TABLE IV. were used to indicate the knowledge level of the foundations of a certain SMS. Each researcher was asked to check each SMS with one of the options, thereby generating common criterion to evaluate the foundation strength and availability. Statistical results of the Foundation Research Assessment are shown in Figure I.

TABLE IV. FOUNDATION RESEARCH ASSESSMENT, OPTIONS

Success	The foundation was found.
Few Possibilities	The foundation research was carried out, through a lot of effort, looking deeply in a lot of sources, without finding the foundation. In some cases just some clues were recorded.
Uncertainty	Within the effort and time allocated it was not possible to carry out a deeper foundation research.
Unaware	Within the effort and time allocated it was not possible to carry out the foundation research.

The results table hereunder.

Separation Type	(Todas)

..	Phase of Flight				
Foundation Research Assessment	Aerodrome	Arrival (TMA)	Departure (TMA)	En-route	Total general
FEW POSSIBILITIES	80	13	57	156	306
SUCCESS	5	16	14	57	92
UNAWARE	5	1		2	8
UNCERTAINTY	93	19	19	85	216
Total general	**183**	**49**	**90**	**300**	**622**

Figure I. Figure I. Foundation Research assessment, Output

*3) **Stage 3**. Research and Identification of the contributing factors to the SMS.*

To complete this objective, some new columns were added to the table after several discussions, brainstorming, etc. These columns contained the following information:

- *Aerodynamic Effects*. Factors and/or effects that have influence on the separation case.
- *Human Factors*. Factors that have influence on the separation case: controllers, pilots, etc.
- *Hazards/Risk*. Identified the separation minima reduction hazards.
- *Equipment Precision*. Precision of system, equipment or device for applying this separation or on which it is based.
- *Surveillance*. Considerations about surveillance have an influence on the separation application.

Each Separation Minima Standard was analyzed according to this factor list to identify which have an impact on the SMS definition and once identified, it was recorded in the SM Current Status List.

*4) **Stage 4**. Analysis and selection of the SMS to be studied in more detail.*

The main objective of this stage was to identify the most important and/or relevant SMS where reducing its separation could have an important impact on doubling capacity. Criteria to identify the more relevant Separation Minima cases were created. These criteria were established as follows.[1]:

- Standards associated with operations in Europe
- Most commonly used standards.
- Standards based upon the most current technology.
- All PoFs (Airport, TMA Departures, Arrivals, ENR) should be covered.

Inside the Separation Minima List a column called Criteria Check Analysis (CRA) was created with two possible options: YES/NO. This check was performed for each separation minima standard using the listed criteria.

[1] 1st technical meeting minutes, section 4 Definition of Criteria and selection of Standards for Factors Completion, page 4.

In addition, in order to be as effective as possible it was decide not only to analyze the SMS that were considered more relevant to be studied in more detail, but also those that have strong foundations and those whose contributing factors have been identified.

The SMS finally selected to be studied in more detail were those which were:

- marked with a YES in the Criteria Check Analysis (stage 4 input).
- marked with a SUCCESS or a FEW POSSIBILITIES in the Foundation Research Assessment (stage 2 input).
- containing Contributing Factors identified (stage 3 input).

At the end of this stage the initial Separation Minima List of 622 standards was filtered and reduced to 157 standards to be studied in future stages.

5) ***Stage 5.*** *Grouping of the SMS by "thematic area".*

The main objective of this step was to group all the SMS that correspond to the same or very similar cases. To achieve this objective the final customer of this grouping needed to be identified. It was agreed that this work should focus on the *Modeling Phase* therefore this grouping should address the needs of this phase.

As the *Modeling Phase* needed to document and to compile all the mathematical models, simulation models, collision risk models, formulas or equations, etc. that have been used to define the SM Standard, it was agreed to group the SM Standards selected in step 4 by "thematic area".

Two "step by step" grouping methodologies were defined for *Aerodrome* and *TMA/ENR.* as it follows:

TABLE V. GROUPING METHODOLOGY FOR ENR & TMA

Five Steps were defined in this methodology
First Step: PoF Second Step: Type of Control (Radar/Procedural/ADS) Third Step: Type of Separation (Longitudinal/Lateral/Vertical) Fourth Step: Based on (Time/Distance) Fifth Step: - (RNAV/Navigation aids/WV)

TABLE VI. GROUPING METHODOLOGY FOR AERODROME

Seven Steps were defined in this methodology:
First Step: PoF Second Step: Operation (Land/Take off/Interlaced) Third Step: Rwy Configuration (Same/Parallel/Crossing) Fourth Step: Type of Control (Radar/Procedural) Fifth Step: Type of Separation (Longitudinal) Sixth Step: Based on (Time/Distance) Seventh Step: - (WV/Rwy Separation)

At the end of this stage the FILTERED Separation Minima List of 157 standards were grouped and reduced to 21 groups of SMS.

IV. CURRENT STATUS OF SEPARATIONS MINIMA AND THEIR FOUNDATIONS– HOW TO "X-RAY" THEM.

All Separation Minima and Foundation information obtained from this research was integrated into an excel table, which is a Separations Minima Database, freely available on the RESET website.

A. *Phases of Flight (PoF)*

During a flight an a/c goes trough different PoFs which have different hazards and risks and therefore different Separation Minima are applied. RESET research, specifically all the foundation assessment was focused on the flight path. The four phases used in RESET are described in Figure II. Phases of Flight

Each of these PoF and their associated operations are hereunder explained in more detail.

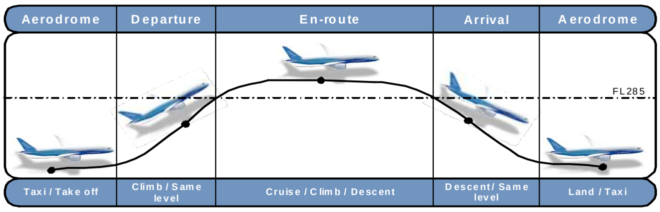

Figure II. Phases of Flight

1) *Aerodrome*

The research carried out in this PoF identified in a total of 183 SMS identified. Under this category, three sub-categories detail the operations included: Taxi, Take off and Land.

2) *TMA/Departure & TMA/Arrival*

This PoF was split into two, one from the initial climb to FL285 (TMA Departures) and the other one from FL285 to the initial approach (TMA Arrival).

The research carried out within this PoF identified a total of 139 SMS, divided in 90 SMS for TMA/Departure and 49 for TMA/Arrival. Under this category sub-categories detail the operations included: Climb, Cruise (same level), Hold and Descent.

3) *En - Route*

ENR PoF (within RESET definition) occurs above FL285 or when cruise altitude has been reached.

The research carried out within this PoF identified a total of 300 SMS. Under this category, four sub-categories detail the operations included: Climb, Cruise (same level), Hold and Descent.

B. *TYPE OF SEPARATION*

1) *Longitudinal Separation*

Around 203 different longitudinal SMS were identified. For the Aerodrome PoF, a/c taxiing operation, a 200-meter separation is applied, considering a taxi speed of 30 kt. No aerodynamic factors are considered, but contributing factors such as Pilot monitoring/situational awareness, Pilot response time, Controller/Pilot communication/coordination, Controller monitoring/situational awareness, the response time of any control function should be less than 0.5 second, Controller display target position error, Accuracy of measured position after processing, Reporting interval, Radar surface. According to [12].

Contribution factors to longitudinal separation are: Atmosphere Parameters (temperature, air density, pressure, thermal stratification, Eddy dissipation rate, wind direction), horizontal and vertical positions and closing angles, vertical path separation at crossing point, speed, airplane weight, dimensions and geometry, pilot monitoring/situational awareness, Controller/Pilot communication, Controller monitoring/situational awareness, Controller workload, Surveillance (Update rate, Controller display target position error, accuracy of measured position after processing, reporting interval.

The main noted hazard associated with longitudinal separations is WV Encounter (WVE) and possible crew/passenger injury, loss of control and/or structural damage.

2) Vertical Separation

Around 37 separate vertical SMS were identified. For the Aerodrome PoF there is no vertical separation. For Departure (TMA), Arrival (TMA) and ENR PoFs, for changing level and cruising maintaining same level operations, the vertical separation minima separation are based on distance and regulations are very standardized and aligned. This is due to this standard is very well documented in ICAO Doc 9536 - Sixth Meeting RGCSP/6 Review of the General Concept of Separation Panel - Volumes 1 and 2, and ICAO 9574 - Appendix A. The value of 300 meters applies for vertical separation below FL 290, between above FL 290 and below FL 410 could applies 300 or 600 meters separation (within designated airspace), and at or above FL 410 the vertical separation is 600 meters.

Among the contributing factors to vertical separation are aerodynamic factors. Apart from maneuver response capabilities, wake vortices are another main contributing factor that may be present due to an a/c climbing or descending. Human factors involved are for instance: Controller confidence, Pilot confidence, Consensus of the users, Pilot monitoring / situational awareness, Pilot response time, Cockpit Resource Management, Crew workload, Controller / Pilot communication / coordination, Controller monitoring / situational awareness, Controller response time, Controller workload, Controller interaction with displays / automation / decision aids, Training / experience.

3) Lateral Separation

Around 64 lateral SMS were identified. For the Aerodrome PoF, different values of separation minima are applied for landing and take-off operations. These operations include: Independent parallel instrument approaches, Dependent parallel instrument approaches, Simultaneous use of parallel rwys, Segregated operations on parallel rwys, Separation between rwys centre line, Successive departures, Simultaneous departures.

For these kind of separation minima, equipment such as ILS and/or MLS are necessary on both rwys, suitable surveillance radar available, and satisfactory two-way radio communication.

V. CONTRIBUTING FACTORS

Once the over 600 separation standards were cataloged, the vast amount were then grouped into 21 scenarios - 11 for the en-route and TMA flight phases and 10 for aerodrome operations (see [22]). The scenarios where then ranked according to their relevance to RESET. Of the 21 scenarios, the following were ranked most significant:

- RADAR – TMA
- Wake Vortex – Aerodrome
- Runway Separation
- RNAV Lateral
- Wake Vortex – En-route

For these 5 scenarios all available documentation was collected and reviewed for mathematical foundations underpinning the separation minima defined in the respective regulations. With the exception of RNAV lateral separations, little or no information was found regarding the models used to define the current standards. However, recent research, namely [15] thru [18], has analyzed the structure of separation minima and attempts to model the influence of some contributing factors. This forms the basis of the RESET separation minima modeling efforts.

Largely following the approach taken in [23], contributing factors were identified for the five selected scenarios and placed within the following groups:

- Aircraft related
- Aircraft positioning
- Surveillance factors
- ATC rules and procedures
- Human factors
- Communications
- Environmental

Contributing factors were collected from documentation as well as expert judgment, which was of particular importance as traceable sources were scarce and contributing factors analysis was to include future operational concepts likely to be implemented in the 2020 timeframe such as airborne separation (ASAS).

VI. SEPARATION MINIMUM COMPONENTS

In recent work, various separation component groupings have been proposed (see [15] and [16]). As the previous step provided the contributing factors for all selected scenarios, these factors could now be easily grouped into a common separation component breakdown as shown in Figure III. Common separation component breakdown.

- Forbidden Zone,
  - Collision Cross Section
  - Dynamic factors
- Surveillance Uncertainty
  - Aircraft Surveillance and Navigation Performance (non-RADAR environment)
  - Ground / Satellite Systems Surveillance
- Intervention Buffer
  - Detection, Communication and Reaction Time
  - Aircraft Performance
  - Human Performance (ATCo and Pilot)
- Wake Turbulence Zone

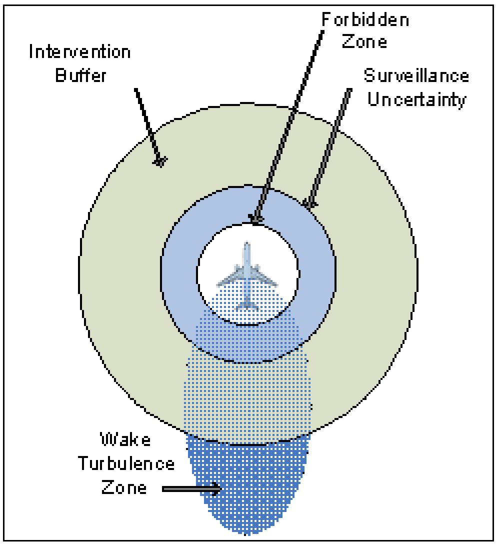

Figure III. Common separation component breakdown

VII. MODELING SEPARATION COMPONENTS

For a first order analysis, it is assumed that all separation components can be linearly superposed with no interrelations. Thus, not considering wake turbulence, the total separation minimum is the addition of the geometrical envelope of the airframe – the *Forbidden Zone* –, all positioning or *Surveillance Uncertainties* and the *Intervention Buffer* needed to detect and avoid a collision.

For simplicity the ***Forbidden Zone*** shall be assumed as a sphere around the aircraft's center of gravity completely encompassing the airframe.

For a classical RADAR-surveyed environment the ***Surveillance Uncertainty*** zone will include factors like accuracy of RADAR sensors, being a function of range, topographical and environmental factors, resolution of displays, mosaic error, refresh rate, integrity of position reporting (missing scans) as well as latency of data acquisition and processing.

In case ADS-B is used for position reporting RADAR parameters are replaced by on-board navigational performance and ADS-B reporting rate.

The ***Intervention Buffer*** comprises the time to detect a potential conflict, to find and communicate a solution to the pilot as well as the time needed to initiate the evasive maneuver and to alter the flight path sufficiently to avoid an imminent collision. As this separation component is expressed in time, its dimension is a function of aircraft speed or closure rate of an aircraft pair. Special attention will be given to this separation component.

The detailed tasks to be carried out by the controller during detection of the separation loss and finding and communicating of the resolution, have been split up into tasks performed by the perceptual, cognitive and motor processors according to [19]. Using the respective processing times, the controller response time, excluding voice communication, can be estimated for the basic case of a separation loss of two aircraft

$$T_{ATCo,noRT} = 7.5[1.4 \sim 18.1] \text{ sec}. \quad (1)$$

The first number in the resultant represents the statistical mode, and the range is represented between the brackets. It has to be noted that the controller reaction time depends on a variety of factors including airspace structure and traffic situation. The multitude of dependencies can lead to large differences in observed reaction times which manifests in the large spread between minimum and maximum of the above value.

The time needed for voice communication with the aircraft is estimated according to [20] to be an average of

$$T_{talk} = 7 \text{ sec}. \quad (2)$$

Assuming that orders are issued to both aircraft involved, in order to expedite resolution of the conflict, the total controller reaction time for this simple case becomes

$$\begin{aligned} T_{ATCo} &= T_{ATCo,noRT} + 2T_{talk} \\ T_{ATCo} &= 21.5[15.4 \sim 32.1] \text{ sec} \end{aligned}. \quad (3); (4)$$

Pilot reaction times are estimated based on statistical analysis of approximately 170 airprox events in [21].

$$T_{P,avg} = 5.7 \text{ sec}, \quad \sigma = 2.3 \text{ sec} \quad (5)$$

The combination of controller reaction time including voice communication with both aircraft and pilot response time, allowing for an additional 3σ over the average value, yields a total response time of

$$T = 34.1[28 \sim 44.7] \text{ sec}. \quad (6)$$

The statistical distribution of the intervention time allows analysis of the results with regard to confidence levels.

To derive the time needed for an evasive maneuver, a 3-DOF simulation of a generic aircraft has been used. Taking into account aircraft limitations such as maximum roll rate and roll angle the envelope of possible horizontal avoidance paths is calculated.

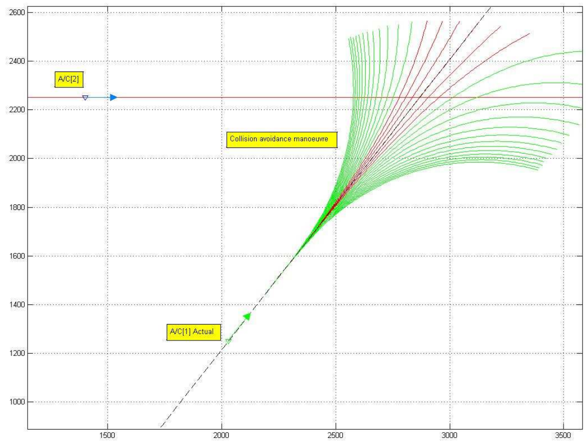

Figure IV. Collision avoidance trajectories

Figure IV. Collision avoidance trajectories, gives an example simulation output with the red trajectories resulting in infringement of the Forbidden Zone and the green flight paths avoiding intrusion.

$$p_{coll} = \frac{n_{coll}}{n_{avoid} + n_{coll}} . \tag{7}$$

For a given encounter scenario, i.e. an intersection angle of the flight paths of the aircraft pair and the respective aircraft speeds, the collision probability for every point along the flight path can be calculated. To construct a worst case scenario it shall be assumed that only one aircraft performs an evasive action; the other aircraft continues on its planned trajectory. Expressing the position along the flight path where the evasive maneuver is initiated in seconds from the moment of collision yields Figure V. Collision probability vs. reaction time (seconds before collision), both a/c at a speed of 100m/sec, 25m forbidden zone radius. Maximum roll rate and angle here are 15deg/sec and 45deg.

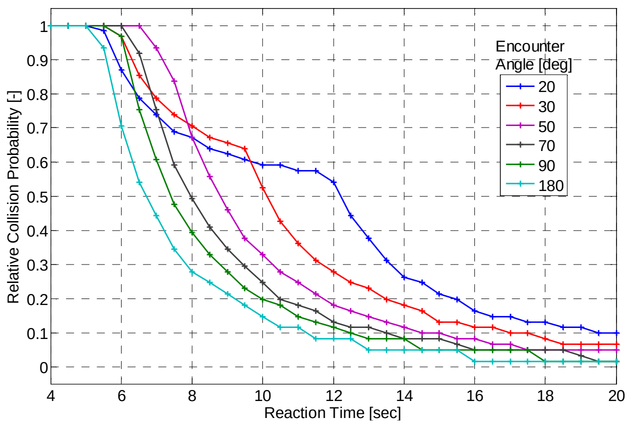

Figure V. Collision probability vs. reaction time (seconds before collision), both a/c at a speed of 100m/sec, 25m forbidden zone radius

Running the calculation along the circumferential of the path intersection of an aircraft pair of which both are flying at a speed of 100m/sec one obtains Figure VI. Iso-lines of constant collision probability around the path intersection. It also gives the example of an aircraft pair with a 43deg encounter angle. For this particular encounter scenario keeping a horizontal separation of at least 1440m would ensure a collision probability of less than 10%.

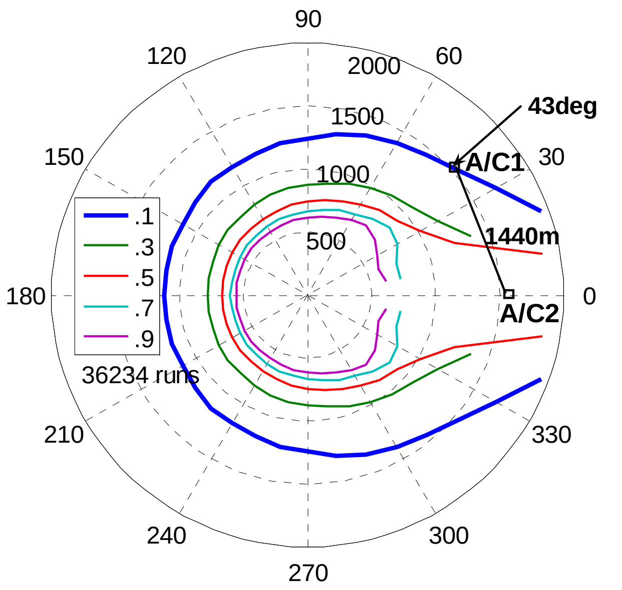

Figure VI. Iso-lines of constant collision probability around the path intersection

To obtain total required horizontal separation the delay time for controller, communication and pilot T has to be translated into a distance using the closure rate for this example (61.44m/sec). It is

$$d_{ATCo,Com,Pilot} = 2{,}095\ m . \tag{8}$$

Thus, the total distance required for successful intervention becomes

$$d = 3{,}535\ m . \tag{9}$$

The ***Wake Turbulence Zone*** is computed based in the UK4 Wake Vortex separation table. Using the weight of the aircrafts the separation defined in this standard is obtained. This value is compared with the separation obtained with the other factors.

A sample tool output for two aircraft travelling on parallel paths is presented in **¡Error! No se encuentra el origen de la referencia.**The separation computed considering forbidden zone, surveillance uncertainty and intervention buffer is plotted for each point along the trajectory. Wake Turbulence separation was not considered in that case and therefore does not show in Figure VII. Forbidden zone, surveillance uncertainty and intervention buffer separation

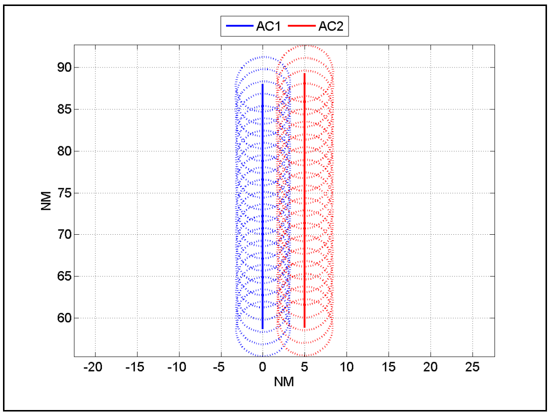

Figure VII. Forbidden zone, surveillance uncertainty and intervention buffer separation

As the Wake Turbulence does not depend on the aircrafts position, it is mainly a longitudinal separation and its actual shape is not known, the WV separation computed is not plotted in the figure but in a different way.

VIII. CONCLUSIONS

Among the 622 compiled SM standards, some differences have been detected between the values applied for the same standards by different regulators. The regulators should agree and study standards in order to improve and standardize SM. For instance, a WV separation minima analysis highlights several differences among regulations. Based on this conclusion, the most restrictive one could be extended to the rest of the states or it could be studied if minima of minima satisfies safety requirements and can therefore be applied to globally reduce separation.

To make sure the studies of which standards are applicable or sensitive to reductions, it is necessary to carry out in depth studies into the foundations and the models and principles upon which were they are based. The foundations analysis defines the background to these rules and enables knowing if it is possible to improve or reduce separations.

Of the 622 international and national separation standards collected and analyzed, foundations were found in only 15% of the cases. In 49% of the cases, even in-depth research researching a lot of information of all available sources, no foundations were found.

This necessitates developing mathematical models to provide a sounds basis for the definition of separation minima standards in the future. Expanding upon previous research, a simple model for calculating separation minima was derived. Statistical input data as well as other model assumptions need to be reviewed. However, preliminary results point in the right direction.

The model, which is currently limited to the horizontal plane, needs to be extended to the vertical dimension. With a more precise, three-dimensional model a large number of calculations should be performed to cover a wide range of encounter geometries and likely speed combinations. The results obtained could then be used as basis for an exemplary air traffic simulation to prove operability of separation minima determined with this dynamical model as well as to provide evidence of a sufficient level of safety.

ACKNOWLEDGEMENTS

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Within this project efforts to research current separation minima status and their foundations were lead by Isdefe with the collaboration of RESET partners and carried out in Work Package 2 (WP2) and WP3.1.

We would like to recognize the valuable contributions to this research carried out by all the RESET partners, especially the ones involved in Reset WP2 and WP3.

DISCLAIMER

Opinions, interpretations, recommendations, and conclusions contained herein are those of the authors and are not necessarily endorsed by the European Commission or other RESET partners.

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