MODELLING AND ESTIMATION OF SEPARATION CRITERIA FOR AIRBORNE TIME-BASED SPACING OPERATION

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Abstract

Airborne Spacing procedures are amongst the several ATM innovations that aim to delegate part of the aircraft separation responsibility to the flight crew. In particular, airborne time-based spacing (TBS) has been developed and tested with success in many experiments in the recent years. However, there is still little knowledge about hazardous events probabilities in this application, such as the ones related with separation loss.

This paper presents a study formulating the risk evaluation problem as the estimation of the probability of occurring separation loss events for a large scale stochastic hybrid system. The large size of the system state space poses challenges to the Monte Carlo simulation of these rare events. This paper applies a recently developed novel method for speeding up rare event Monte Carlo simulations to the TBS concept of operations.

1. Introduction

This paper presents initial safety results obtained through modeling and simulation of the airborne Time-Based Spacing (TBS) operation that has been developed by Hoffman et al. [1]. The main aim of this paper is to gain insight on how safety depends of the minimum spacing criterion used within such operation, and which main factors contribute to the safety risk.

In current ATM, flight crews are in charge of a safe and efficient control and navigation of their individual aircraft, and air traffic controllers are responsible for maintaining separation between aircraft. Only when this does not work well, flight crew receive separation support from the Airborne Collision Avoidance System (ACAS). A new allocation of tasks between air traffic controller and flight crew is envisaged as a possible option to improve ATM. It relies on a set of applications enabled by ASAS (Airborne Separation Assistance System), one of which is ASAS-TBS [1], [2], which transfers part of the responsibility in maintaining separation to the flight crew.

This different task allocation is expected to increase controller availability, which could lead to improved safety, enable better quality of service and more capacity (depending on airspace constraints). Also, it is expected that flight crews would gain in situation awareness and anticipation by taking an active part in the management of their situation with respect to a designated aircraft [3; 4].

Although efficiency and capacity are often the main reasons of the evolution in Air Traffic Management (ATM), safety is recognized as a key characteristic when designing advanced ATM concepts [5]. ATM design teams try to obtain improvements in capacity and efficiency, through the exploitation of new technologies, procedures changes, introduction of new procedures, etc. However, the target safety level is intended to be "equal or better" as compared to the current practice. Quantitative risk analysis tries to put the several ATM applications in a continuous risk scale, enabling objective comparison and definition of minimum acceptable levels.

The quantitative risk analysis methodology chosen for this study is TOPAZ (Traffic Organization and Perturbation AnalyZer) [6], which has shown to work well in several previous risk assessment studies of novel ATM operations [7, 8]. This study considers separation loss events such as Short Term Conflict, Infringement of Separation Minima, Near Mid-Air Collision and Mid-Air Collision, but does not address the problems related with wake turbulence encounter.

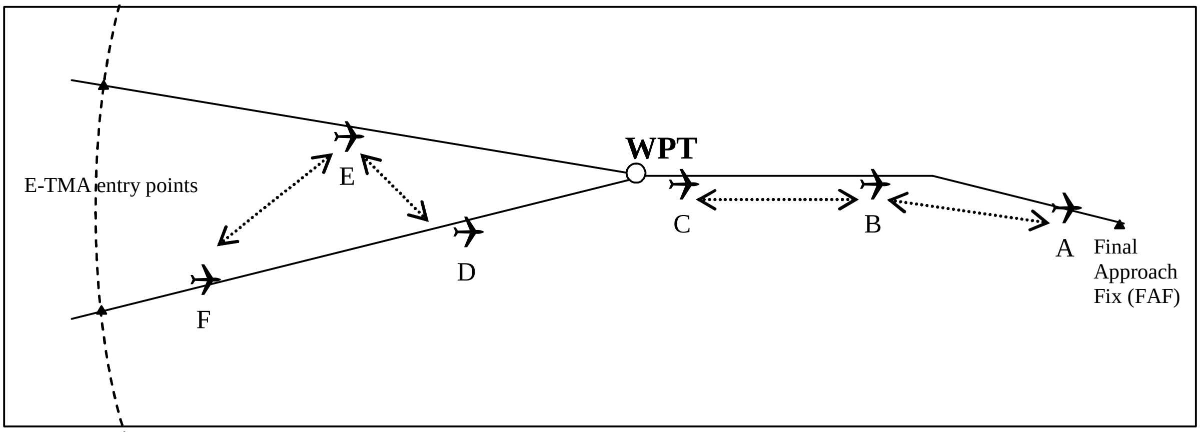

Figure 1: Airborne Spacing operational example.

2. Airborne TBS Operation

The Time-Based Spacing (TBS) procedure in this report focuses on the airspace before the final approach [3]. It is assumed that TBS procedure may start between the Extended-TMA entry point (assumed here to be 60 nautical miles from the airport, after the top of descent) and the Final Approach Fix (FAF). In this phase of the flight, as in other phases, the flight crew must be aware of the surrounding traffic through the ASAS traffic synthesis provided in the Cockpit Display of Traffic Information (CDTI). It is also assumed that ASAS system will be working in Airborne Spacing mode (that is one of the available modes), and the conflict detection is a task of the ATCo.

To illustrate how it works, the following example of [9] is shown in **Figure 1**. In this example, the controller builds the sequence of aircraft early in the sector by assigning a target aircraft to each aircraft in the sequence (i.e. E is a target for F, D is a target for E, etc). Sequencing and merging instructions are then given to ensure the appropriate spacing is achieved by the merging waypoint. Having built the sequence, and having given the aircraft instructions to maintain the sequence (by maintaining the spacing), the controller must now monitor the aircraft for compliance, as C spaces itself from its target B, and B spaces itself from its target A.

The TBS operation involves two steps. In a first step, an ATCo instructs the flight crew to select a neighboring aircraft as a target on the CDTI [4]. Aware of the required target, the flight crew must identify and select it in the ASAS system, and report the target identification to the ATCo. In case the flight crew finds that the target is not in a convenient position, or that the selection of the target might lead to an inconsistent flight execution, or even that they cannot find the target in the CDTI, then they ask the ATCo for clarification. In such case, the procedure may be delayed or aborted.

In the second step, after the target identification read-back of the target identification instruction, ATCo instructs flight crew with one of the following options, depending on the trajectories of the flights involved:

(a) **Merge behind** - the flight crew is instructed to merge the own flight trajectory behind the trajectory of the target aircraft, in a chosen waypoint, maintaining at a given time spacing to the target aircraft. This is the case when the aircraft involved are executing converging approach routes, like aircraft D and E in **Figure 1**.

(b) **Remain behind** - the flight crew is instructed to achieve and maintain a given time spacing behind the trajectory of the target, in a chosen waypoint, maintaining at this point a given time spacing to the target aircraft. This third option is applied when the own aircraft is already flying on the same trajectory of the target aircraft, like aircraft B and C in **Figure 1**.

After selecting one of the options (a) or (b), the flight crew of the follower aircraft will monitor the evolution of the spacing to check if it tends to the desired spacing. Normally, the speed adjustments of the follower aircraft are done automatically, since the aircraft are equipped with the ASAS speed director, which automatically inputs the ASAS suggested speed in the Autopilot System. As an exception, in case of doing training or existing some equipment failure, the flight crew may have to manually apply speed adjustments suggested by the ASAS system.

The aircraft which is applying TBS is denominated the "follower" aircraft, in order to distinguish from the "target" aircraft, which is supposed to land in the same airport as the follower aircraft, but earlier. While monitoring the TBS procedure, flight crew will monitor the execution of the flight plan in line with RNP-1 (Required Navigation Performance Level 1) performance.

The Air Traffic Controller will have graphical system tools for aiding the task of mounting and monitoring chains of airborne spacing aircraft. It is assumed that the ATCo gives traditional speed instructions to a follower aircraft when judged necessary. When however speed difference is such significant that minimum separation tends to become infringed, then the ATCo instructs the follower aircraft to turn away from the trail.

The TBS procedure may normally finish after passing the Final Approach Fix, or eventually be interrupted, due to some failure in the ASAS system, or to some hazard detected by the flight crew or the ATCo. In cases of abnormal termination, the ATCo will execute conventional procedures for separating and sequencing aircraft. In this paper, only one single flow of arriving aircraft will be considered, with no other surrounding traffic.

3. Development of a Monte Carlo simulation model

In order to obtain probabilities of hazardous events per flight hour in a simulated scenario, it is necessary to develop an appropriate mathematical model of the operation considered. Hence, a stochastic model is built that describes this accident risk under the influence of human behavior, technical systems behavior, communications environment, flight procedures, etc. In the context of the TOPAZ methodology, such a model has the form of a Stochastically and Dynamically Colored Petri Net (SDCPN) [10]. This model is a stochastic hybrid system, which enables to evaluate the collision risk by means of Monte Carlo simulation. In this type of simulation, each sample draw is a SDCPN execution that represents a simulated air traffic scenario. Because straightforward Monte Carlo simulation would be far too much time-consuming, we make use of importance sampling based acceleration methods that have recently been developed [11, 10].

For the ASAS TBS operation considered, a complete SDCPN model has been developed, and was presented in [12]. The development of the SDCPN model used a compositional specification approach. First the relevant agents that play a role in the operation were identified. Next, each agent was modeled through a collection of agent specific Local Petri Nets (LPNs), where each LPN is a Petri net describing an agent specific process. Finally, the connections between LPNs within the same agent and between LPNs of different agents are specified, using a hierarchical specification approach.

SDCPN's are very adequate to mathematically model ATM applications. The use of continuous variables called colors, in the SDCPN, enables the use of differential equations, as for example the aircraft physical behavior and control law presented ahead in the text. However, because of the complexity of the model, the formalism of SDCPN is extended to allow hierarchical grouping of its basic elements in LPNs and then, in a higher abstraction layer, grouping LPNs in Agents.

Agents

An agent is defined as an entity that maintains some kind of situation awareness and may play a role in the operation considered. For this particular application, in order to assess the accident risk, the following agents are adopted in the SDCPN model of the TBS operation [12]:

- Aircraft;
- Aircraft Guidance, Navigation and Control Systems (GNC), including Guidance Systems, Own Positioning System, and Communication Systems;
- ASAS System;
- Pilot Flying (PF);
- Pilot Not Flying (PNF);
- Air Traffic Services (ATS) System, including Ground Radio Telecommunication, Navigation Systems Global / GNSS (Global Navigation Satellite System), and ATS Surveillance System;
- Tactical Air Traffic Controller (ATCo).

A high level representation of the relations between agents is shown for two aircraft in **Figure 2**. Each of the agents present in Figure 2 is internally composed by LPNs, as explained in [12].

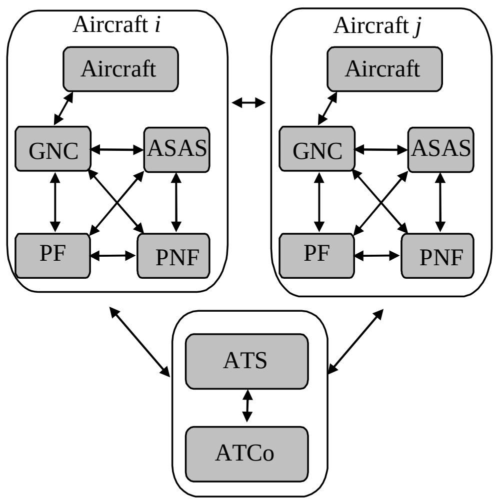

Figure 2: Multiple agents and their relations.

Typically per agent, LPNs are used to represent various hazardous situations in the system state, such as radio failure, ADS-B failure, engine failure, noise in the aircraft instrumentation, failure in the ATC systems, etc.

Aircraft Guidance Behaviour LPN

Amongst the many LPNs in the model, the LPN that describes the aircraft physical dynamics is one of the most important ones. It serves to model the aircraft equations of motion, following the model described by Van der Geest [13]. In this model, the basic aircraft dynamics is described by a differential equation system with the following variables:

- $y \in \mathbb{R}^6$ $[y_1, y_2, y_3]^T$ and is the aircraft 3-D position, y_4 is the aircraft true airspeed, y_5 is the heading angle and y_6 is the vertical path angle;
- $u \in \mathbb{R}^3$ is the control input vector, with u1 being the engine thrust, u_2 the angle of attack and u_3 the bank angle; these variables are evaluated using the control laws described in [13];
- $w \in \mathbb{R}^3$ is the wind vector;
- m is the aircraft mass, g is the gravity acceleration;
- $D : \mathbb{R}^3 \mapsto \mathbb{R}$ is the aircraft drag function;
- $L : \mathbb{R}^3 \mapsto \mathbb{R}$ is the aircraft lift function.

  And the aircraft equations of motion are:

$$\dot{y} = \begin{bmatrix} y_4 \cos(y_5)\cos(y_6) + w_1 \\ y_4 \sin(y_5)\cos(y_6) + w_2 \\ y_4 \sin(y_6) + w_3 \\ \dfrac{u_1 \cos(u_2) - D(u_2, y_4, y_3)}{m} - g\sin(y_6) \\ \dfrac{g}{y_4}\tan(u_3) \\ \dfrac{L(u_2, y_4, y_3) + u_1 \sin(u_2)}{m y_4}\cos(u_3) - \dfrac{g}{y_4}\cos(y_6) \end{bmatrix}$$

LPNs of Human Operators

The Pilot Flying, the Pilot Not-Flying and the ATCo are the most complex agents in the model. The Petri Net model of the Pilot Flying Agent has been developed, and the resulting LPNs mathematically represent a pattern of stages for the human operator task execution. These stages are:

(T1) *Monitoring*: stage where the pilot gathers and integrates information about the current goal. For example, this stage may consist in reading the altimeter or the speed indicator.

(T2) *Monitoring and Decision*: in this stage, using information provided by the instrumentation systems and, possibly, by other human operators, and based in his situational awareness, the pilot makes decisions about: (a) If he needs to query some other human operator and, if it is, what is the query to be done; (b) If a particular action is required and, in case it is, what are the parameter values for its concrete application.

(T3) *Coordination*: stage where the pilot coordinates with other human operators, communicating, questioning and answering, and checking the consistence of his decisions.

(T4) *Execution*: stage where the pilot is effectively operating the aircraft control, activating functions by means of the aircraft control devices.

(T5) *Execution Monitoring*: stage on which the pilot observes the events resulting from the executed action.

(T6) *Monitoring and Goal Prioritization*: stage in which the pilot gathers information and decides which of his goals most require attention in the following instant.

The LPNs of the human operators also include a simple LPN version of the contextual control mode model of Hollnagel [14]. When the human operator has a nominal number of tasks to perform, a token stays in Tactical mode, implying that the human operator performance is nominal. When the number of tasks overload the human operator then the token switches to Opportunistic mode, under which task duration decreases (say factor 2) and error probability increases (say factor 10).

Model parameterization, verification and validation

The SDCPN model was coded in Java programming language, and therefore this computer code generated the scenarios for Monte Carlo simulation. The compositionally specified SDCPN model enables a systematic implementation, verification and validation of the resulting Monte Carlo simulator. This is done through the following systematic steps:

- Software code testing, involving random number generation, statistical distributions, common functions, each LPN implementation, each agent implementation, interactions between all agents, and full MC simulation;

- Numerical approximation testing. This is needed to identify maximally allowable numerical integration step and minimally required number of particular MC simulations;

- Parameterization. This is done through a search for literature and statistical sources, and complemented by expert interviews. The fusion of these different pieces of information is accomplished following a Bayesian approach;

- Initial model validation through studying MC simulator behavior and sensitivities to parameter changes under dedicated scenarios;
- Overall validation, which is directed to the evaluation of differences between model and reality and what effect these differences have at the assessed risk level.

In this study the last step is not yet been addressed. Hence it remains to be evaluated how the simulation model differs from the true operation and how these differences impact the assessed risk level. Hence all findings apply to the simulation model only, and may not yet be fully extrapolated to the true operation.

4. Monte Carlo simulation

The probabilities of aircraft separation loss events are estimated over the SDCPN model, using Monte Carlo simulation that is accelerated through using a suitable type of importance sampling. This section explains the principles of Monte Carlo method and how it was optimized to allow its use in a reasonable computing time.

Monte Carlo simulation

The basic idea of Monte Carlo simulation is quite straightforward. It consists in randomly drawing a great number of samples from a sampling space, use each of them as a random input to the simulation model which results into as many random simulated cases, and to count how many of these simulated cases fall in a particular set. The fraction of the random samples for which the simulated cases fall into that set is an estimate of the probability of reaching that set by the simulation model. In the particular case of estimating the collision probability per a single ASAS TBS operation, define N_s as the number of sample simulated operations, and c_i the collision indicator for the sample *i*, i.e.:

$$c_i = \begin{cases} 0 & \text{if sample } i \text{ does not collide} \\ 1 & \text{if sample } i \text{ collides} \end{cases}$$

If all sampled operations have the same weight, Then the estimated probability of collision *p* is

$$p = \frac{1}{N_s} \sum_{i=1}^{N_s} c_i$$

Following this idea, if *p* is expected to be as low as 10exp-9, for example, then the number of simulated samples necessary for the Monte Carlo returning a valid result, i.e., a non-zero result, would be expected to be of order of 10exp9. Assuming that each simulation sample takes half a second to be executed, due to the large state space (several LPNs, hundreds of variables), the number of hours necessary to calculate *p* would be in the order of 2.8×10exp5, or equivalently more than 15 years. Therefore, appropriate optimization techniques have to be used to speed up Monte Carlo simulations many orders in magnitude.

Monte Carlo Speed Up

The technique we use for the speed up the Monte Carlo simulation is the Interacting Particle System (IPS) approach of [11], which has been adapted by [10] to the problem of collision risk estimation in an SDCPN model of an air traffic operation.

The IPS takes benefit of the fact that the probability that an aircraft loses separation in the interval $[t, T_{\max}]$ is higher for aircraft that already have smaller separation distance at (present) time *t*. A filter selects the simulated cases with smaller distances between aircraft and stops them. These simulated cases are randomly replicated, and then used as initial conditions for the follow-up of the Monte Carlo simulation, where each evolves independently of the others until reaching the next (smaller) separation level. This process is repeated, until the separation level between the aircraft is such small that this equals a collision event. This sequential Monte Carlo simulation and selection (filtering) process of IPS is depicted in **Figure 3.** The initial position of the simulated case is shown as a black circle, and within this the number of replicated cases that start from that position is shown. Following the IPS theory [11] and the mathematical properties of an SDCPN model [10], for any separation level the probability of reaching that level is the product of reaching successively all the outer separation levels.

The use of IPS for ASAS situations [10] allows drastically reducing the computing time of collision probability and the conditioning separation loss events. For the ASAS TBS operation, the IPS makes use of 11 separation levels, and one IPS run consists of 50 thousand simulated cases of a leader and a follower aircraft. With the software written in Java, and running in the Java Virtual Machine, it takes around 5.5 hours in an Intel Xeon 64 bits, 3 GHz dual processor machine, with a memory load of 2.7 GB. Each of the dual processors ran 25 thousand simulated cases. In order to estimate and improve the acuracy of the estimated probabilities, ten IPS runs have been conducted for each scenario, i.e. asking 55 hours per scenario.

Separation Events Considered

The following separation events are explicitly counted in the Monte Carlo simulation:

- **Short Term Conflict (STC)**: This is defined as the event that for an aircraft pair, the 2.5 minutes ahead predicted position difference falls below 4.5 nmi horizontally and 900 feet vertically.
- **Minimum Separation Infringement (MSI)**: This is defined as the event that the position difference of an aircraft pair falls below 4.5 nmi horizontally and 900 feet vertically.
- **Near Mid-Air Collision (NMAC)**: This is defined as the event that the position difference of an aircraft pair falls below 1.25 nmi horizontally and 500 feet vertically.
- **Mid-Air Collision (MAC)**: This is defined as the event that the aircraft centers difference falls within a cylinder that represents the combined aircraft size. The cylinder used here has radius 0.054 nmi and height 131 feet.

Separation Event Probabilities

The results of running Monte Carlo simulations (using the IPS speed-up) are shown in **Figure 4**, for three values (30 s, 45 s and 60 s) of nominal spacing between leader and follower aircraft. For each value the estimated probabilities of STC, MSI, NMAC and MAC are shown.

In **Figure 5**, the MAC probabilities are compared with ICAO's Target Level of Safety (TLS), which is 5x10exp-9 risk of collision per flight hour in each of the three possible directions, and when ACAS is not taken into account [15]. These results show that for the simulation model of the ASAS TBS application [13], an initial spacing period of 45 s or greater leads to compliance with half the current TLS in longitudinal direction (because each aircraft can collide with its leader and with its follower it is appropriate to compare against half of this TLS value).

The MSI probabilities in Figure 4 also show that for a nominal spacing of 45 seconds or less there is almost a 100% chance that ATC is instructing the follower aircraft to maneuver out of the trail. For nominal spacing value of 60 seconds this chance goes down to about 0.1 % chance per 12 minutes. Hence of the three nominal spacing values considered, 60 seconds is the only one that is both sufficiently safe and operational effective.

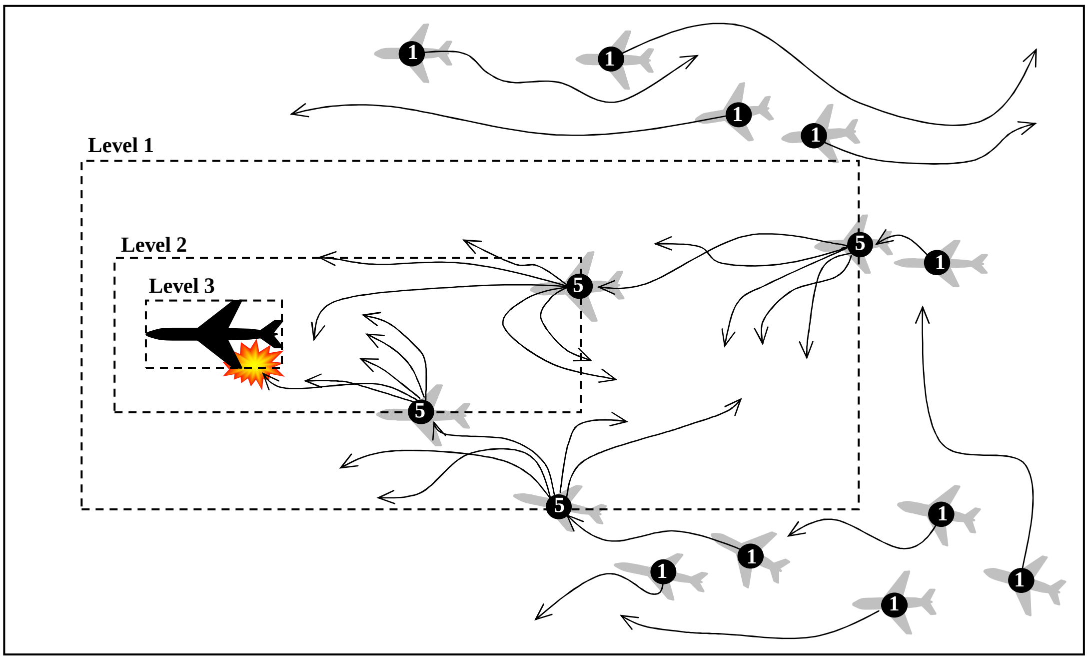

Fig. 3: Example of three levels of selecting simulated cases (showing relative aircraft positions along time).

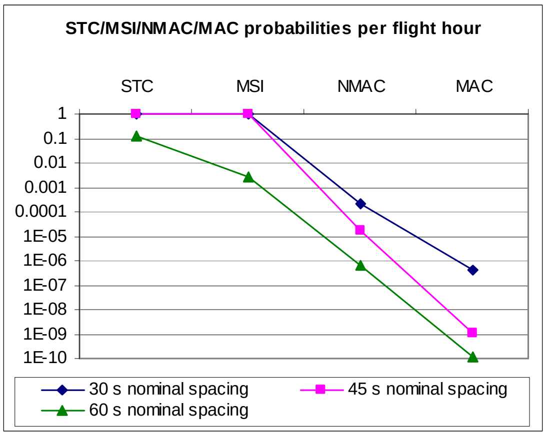

Figure 4: Event probabilities per flighthour for different values of nominal spacing.

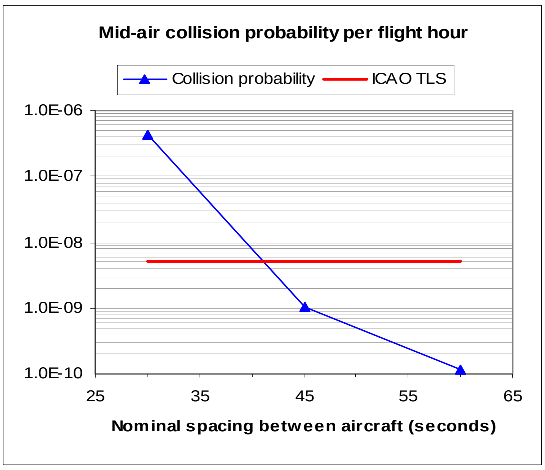

Figure 5: Mid-Air Collision probabilities compared with the ICAO TLS.

5. Analysis of Mid-Air Collisions

Data was gathered from 20 thousand simulated cases which ended in a MAC under nominal spacing of 45 s. This allows us to investigate the factors that contribute to the occurrence of such a MAC event.

Firstly we analyze backwards in time what the initial speed (TAS) difference was for these simulations ending with a MAC. The initial speed of the leader aircraft has the default distribution defined in the model: mean of 310 kt and standard deviation of 7 kt, as shown in **Figure 6.a**. However, the follower aircraft present higher initial speed values, as is shown in **Figure 6.c**. The resulting distribution for the speed difference between leader and follower aircraft is shown in **Figure 6.e**. A mean value of 21.2 kt was found for the initial speed difference for a colliding aircraft pair.

Next, we analyze the final speed of a colliding aircraft pair. For the leader (**Figure 6.b**), we find two zones of concentration, one around 285 kt and another one around 225 kt. These speeds correspond to two different altitudes: 285 kt to FL 95, which is the mean altitude for aircraft entering in the scenario, and 225 kt to FL 75, which is the next altitude instructed by the ATCo. On the other hand, there is a high density of followers at 350 kt (**Figure 6.d**), and the final closure rate has very high concentration around the mean value of 54.7 kt (**Figure 6.f**). The final follower speed values are quite far from the nominal speed, are much higher than the mean initial speed, and may have become this high due to the following factors:

- A drifting error existing in the aircraft sensors of airspeed and altitude;
- A peak in the speed caused by starting a descent;
- ASAS spacing failures (including ADS-B).

These factors may trigger the following scenarios:

- The sensoring error in the aircraft control feedback loop cause the aircraft to accelerate without this being perceived by the pilot;
- The speed peak in a descent may be amplified by the sensoring errors;
- Starting the ASAS spacing with big speed differences (for example, more than 15 kt), ASAS tries to make the follower aircraft catch up from a smaller speed to a higher speed. This compensation causes a strong acceleration in the follower and, at some moment, the ASAS fails, leaving the follower aircraft with a dangerously high speed.

- The sensor error in the leader aircraft propagates through ADS-B to the follower aircraft, which sees the leader with a higher speed, and thus ASAS spacing makes the follower to go with a dangerously higher speed

Working of ASAS for Close Encounters

For the simulations where an STC event occurred, the percentage of follower aircraft that respectively received, initiated or completed an ASAS Spacing instruction prior to MSI, NMAC and MAC, has been evaluated. From these results shown in **Figure 7,** it becomes clear that most aircraft that reached NMAC or MAC didn't receive ASAS instruction before getting to this NMAC or MAC.

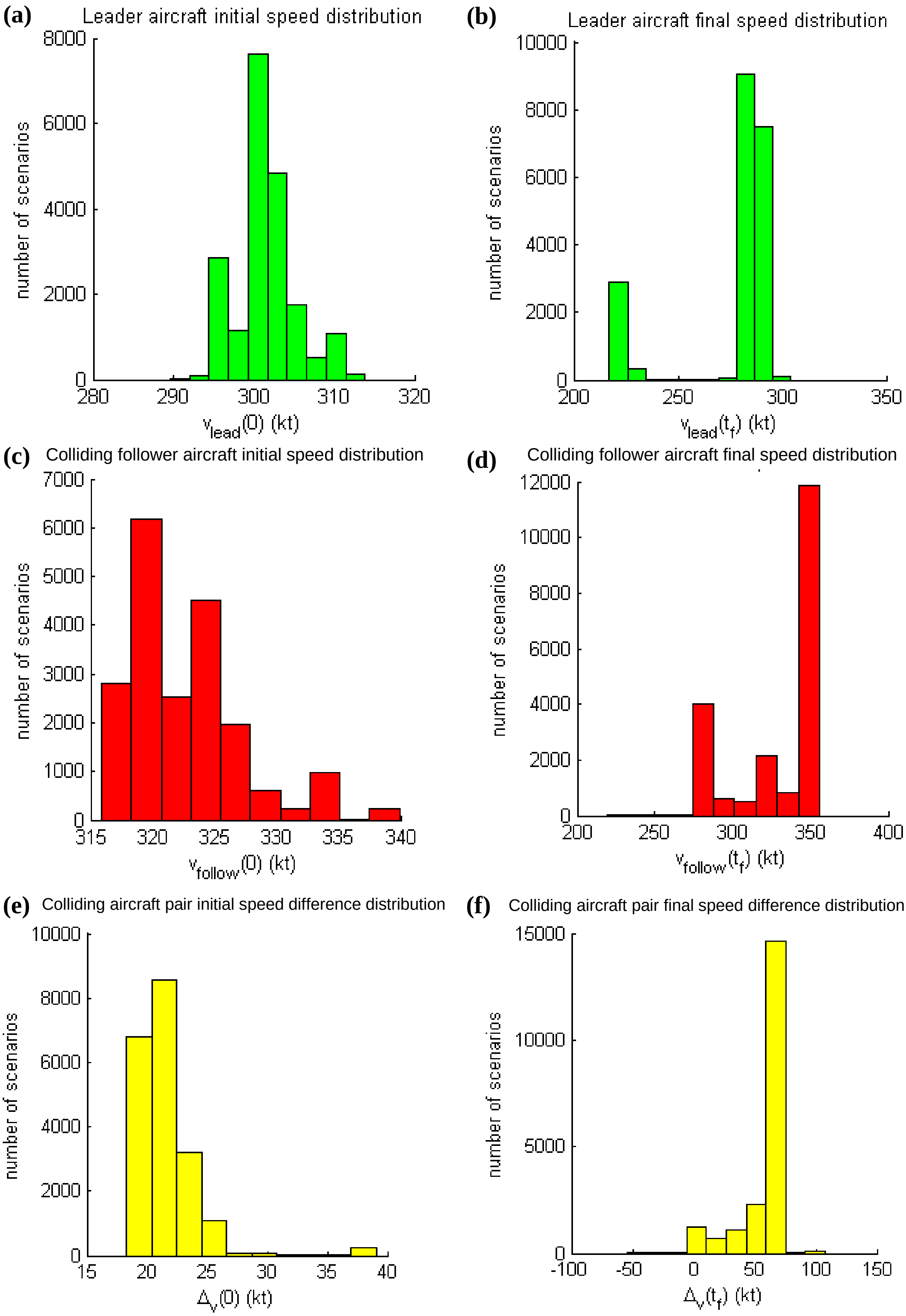

Figure 6: Colliding aircraft pair initial and final speed differences for nominal spacing of 45 s.

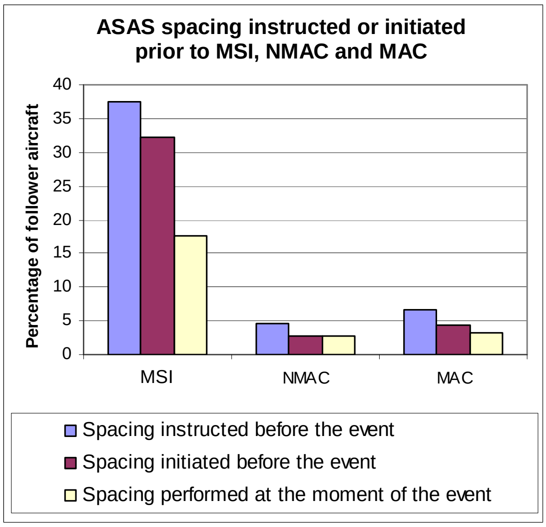

Figure 7: Percentage of follower aircraft that received ASAS Spacing instruction prior to MSI, NMAC and MAC events.

Conflict Detection and Resolution

Given the situation that the follower aircraft has a significantly higher speed and is closing in on the leader aircraft, the ATCo will normally detect conflict and instructs a horizontal turn. **Figure 8** shows that aircraft which reached NMAC or MAC events already had initiated such conflict resolution maneuver. In these cases the maneuver typically was initiated too late. Figure 8 also shows that pilot delay played a minor role in the late initiation. Hence, it can be concluded that the ATCo maneuvering instruction typically came too late.

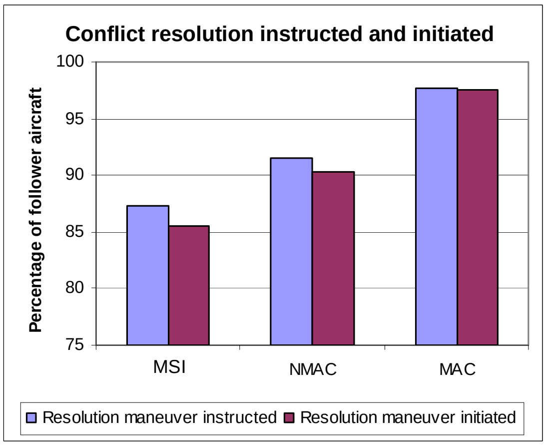

Figure 8: Percentage of follower aircraft that received conflict resolution instruction from ATCo and initiated the resolution maneuver before MSI, NMAC and MAC events.

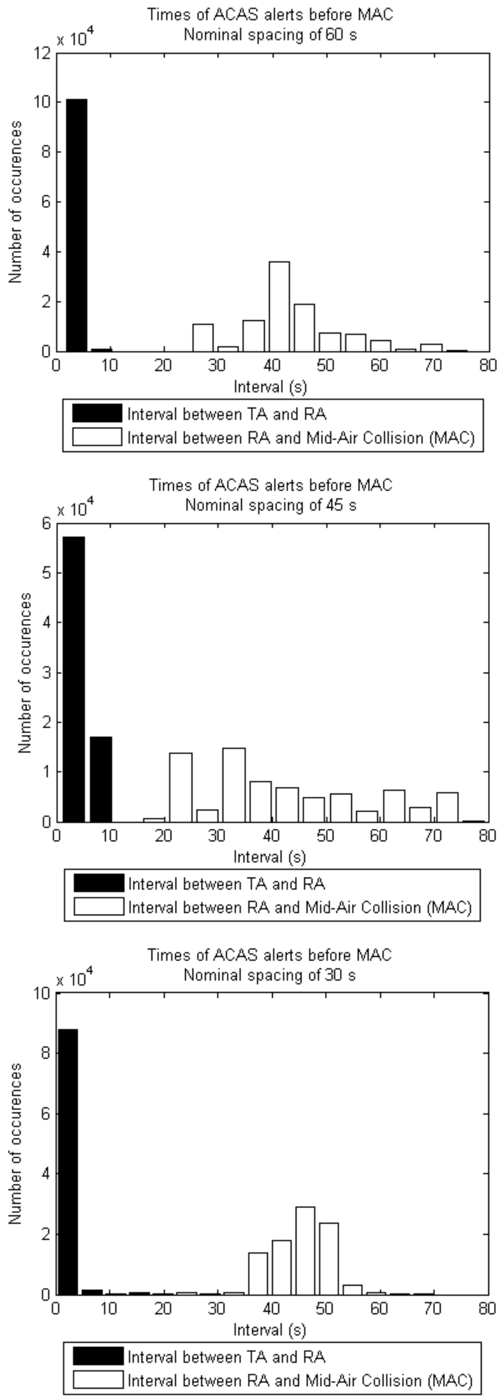

Figure 9: Distributions of time interval between TCAS II alerts TA and RA and between RA and Mid-Air Collision (MAC).

6. Interaction with ACAS

Since ICAO's prescribed TLS value does not take ACAS into account, ACAS was neither taken into account for the risk assessment. Because it is crucial to know whether ACAS works well together with ASAS-TBS, we had ACAS alerting logic running "hidden" from the simulated pilots, and data on alerts was stored by the simulation software. For the ACAS alerting logic the part of TCAS II Version 7.0 that applies to a trailing aircraft was implemented and well in line with [16] and [17].

The times of TCAS II Traffic Advisories (TA) and Resolution Advisories (RA) were analyzed for simulated cases that ended as MAC. Figure 9 show the distributions of time interval between TA and RA, and between RA and Mid-Air Collision (MAC). When flying in-trail with an aircraft, TCAS II evaluates the situation in a mode called DMOD, for which the triggers of TAs and RAs fire based only on current distance between aircraft. In the typical cases of this model-based risk assessment, TAs were issued when aircraft had around 0.75 nmi separation, and RAs when they had around 0.55 nmi separation.

An important finding from the results in Figure 9 is that all TCAS II alerts occur after the NMAC event, even when nominal spacing is 30 seconds. This finding means that ACAS/TCAS II does not interact too early with ASAS TBS related activities of pilots and ATCo.

7. Concluding Remarks

The model-based risk analysis of the Airborne Time-Based Spacing application here presented shows that it is both effective and safe when nominal spacing value is 60 seconds. For the 45 seconds nominal spacing value, we also investigated backward in time the simulated cases that ended in a MAC. This investigation showed that in almost all cases ASAS Spacing operation failed to work in time, and for a small percentage of the cases only ASAS Spacing operation did work in time but did not prevent the MAC from happening. This shows that at 45 seconds nominal spacing, ASAS spacing operation failure is the main contributor to collision risk, and the typical causes appeared to be: ASAS and ADS-B equipment failures; a too small initial separation caused by errors in the upstream sector(s); and too large airspeed difference between the aircraft pair, which may cause an ATCo to give a late maneuver instruction. It also appeared from the Monte Carlo simulations that with 45 seconds nominal spacing the ATCo almost always instructs the follower aircraft to maneuver out of the trail. Because of this, we may conclude that going significantly below 60 seconds nominal spacing seems to be an invalid option for the ASAS TBS operation considered.

Prior to extending the findings from the present model-based risk assessment to the true operation, however, differences between the model and reality, and their impact on assessed risk level remains to be analyzed. One of the important differences to be considered is the impact of multiple followers in one trail rather than one follower only. This will be addressed in a follow up study.

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