Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

NLR-TP-2000-644

RASMAR Final Report
Risk Analysis of Simultaneous Missed Approaches on Schiphol converging Runways 19R and 22

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Summary

The increase in air traffic implies that for busy airports, such as Schiphol, new and advanced Air Traffic Management (ATM) procedures are being developed. For some proposed ATM procedures, ICAO regulations do not yet exist and a thorough safety assessment that incorporates the role of Air Traffic Control (ATC) and pilots is required.

This study concerns a risk analysis of simultaneous missed approaches on Schiphol converging runways 19R and 22, where the Obstacle Clearance Altitude (OCA) of runway 22 is proposed to be reduced from 350 ft to values below 200 ft. This allows the use of runway 22 during actual CAT-I weather conditions, which will support the optimisation of the arrival scheduling.

Some guidelines for the adoption of a risk criteria framework to judge the acceptability of collision risk are given. Based on integration of three NLR facilities – Information System for Safety and Risk analysis (ISTaR), Traffic Organization and Perturbation AnalyZer (TOPAZ) and Flight Track and Aircraft Noise Monitoring System (FANOMOS) – an existing risk model is extended to enable determination of the collision risk related to the proposed ATM procedure.

Numerical evaluations show that the collision risk may attain an unacceptably high level under certain conditions, especially when approaching aircraft on runways 19R and 22 both make a straight missed approach, and ATC does not intervene. For trying to maintain the collision risk at a low and acceptable level, some risk reducing measures are identified. In particular, ATC monitoring and instructing – turn right! or climb to! – to aircraft conducting a missed approach on runway 19R in case of a previous straight missed approach on runway 22 is required.

Provided that the identified measures are applied, the proposed reduction of the OCA of runway 22 to values below 200 ft is risk neutral within a broad spectrum of missed approach procedural aspects, and may be judged adequately safe. This conclusion is also valid for the possible future situation, where the final missed approach altitude is raised from 2000 to 3000 ft and/or the wind criteria for the use of runway combination 19R / 22 is changed toward 20/7 knots.

Contents

1 Introduction

The increase in air traffic implies that for busy airports, such as Schiphol, new and advanced ATM procedures are being developed. For some proposed ATM procedures, ICAO regulations do not exist and a safety assessment incorporating the role of ATC and pilots is required.

This study concerns a risk analysis of simultaneous missed approaches on runways 19R and 22, where the OCA of runway 22 is proposed to be reduced from 350 ft to values less than 200 ft. The current OCA of 350 ft has been established as from ILS installation in 1993, when a ‘bend’ in the ILS localizer signal just before 200 ft was noted. According to reference 7, the ILS localizer signal is currently of sufficient quality to allow the proposed reduction of the OCA.

A reduction of the OCA may allow the use of runway 22 in actual CAT-I weather conditions, which will support the optimisation of the arrival scheduling, in particular for forecasted CAT-I conditions. However, a reduction of the OCA moves the decision point of making a missed approach closer to the runway threshold. This will affect the distance between the prescribed missed approach trajectories of runways 19R and 22, which could result in an increase of the collision risk. The primary objective of the research can be formulated as follows:
The quantification and evaluation of the risks of simultaneous missed approach procedures on runways 19R and 22, up to and including ILS CAT I circumstances.

The next Section describes the currently prescribed (missed) approach procedures for runways 19R and 22, including requirements concerning the usage of this runway combination, the role of ATC and pilots. Section 3 deals with the adoption of a risk criteria framework to judge the acceptability of collision risk, including identification of suitable metrics and assessment of safety requirements for the collision risk between aircraft. Section 4 describes the extension of an existing risk model to enable determination of the collision risk. This extended model is developed through an integral usage of three NLR facilities: ISTaR, TOPAZ, and FANOMOS. In Section 5, sixteen representative scenarios, with varying operational aspects, will be evaluated and the worst case scenario will be identified. The role of ATC monitoring and instructions and some possible future procedural changes are investigated, thereby examining the necessity of possible risk reducing measures. Based on the numerical results and the identified hazards, Section 6 contains the safety criticality assessment of the proposed reduction of the OCA to values below 200 ft, and some operational feedback concerning the necessity of (re)design of the proposed procedures for runways 19R and 22. The conclusions and recommendations with respect to the safety of the independent usage of runway 22 as a CAT-I ILS runway will be given in Section 7.

2 Identification of requirements and procedures

2.1 Schiphol runway combination 19R and 22

Runway 19R is one of the primary runways for arriving aircraft in the S4S2 system. In this system 19R is favourable because of noise restrictions and the minimum impact on the other runways. Arrivals on runway 22 are not favourable with respect to noise as the approach is right across the centre of Amsterdam. Combined use of 19R and 22 is in principle limited to inbound peak time periods, and in general not allowed during the night.

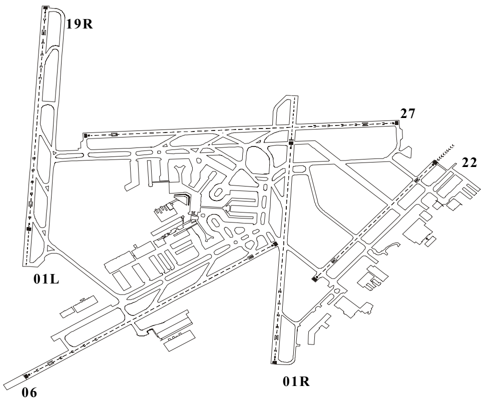

Figure 1 Schiphol runway lay-out

Specific visibility and wind selection criteria apply for the use of runway combination 19R/22 for landing [Ref. 2]. Typically this runway combination will be used with either moderate south westerly wind in lower visibility operations (i.e. wind criteria 15/5 knots, cloud base 400-1000ft or visibility 1500 - 5000m) or strong south westerly wind 15-40 knots from heading 150 - 220^{o}. Note that in the near future the wind criteria is expected to change toward 20/7 knots.

2.2 Aircraft missed approach procedures

The missed approach procedure for runway 19R is straight ahead on runway track, whereas the procedure for runway 22 prescribes a left turn to track 160° MAG, i.e. the required track change is 223°-160°=63° [Ref. 6]. For safety reasons, the turn may only be initiated after completion of the initial missed approach phase [Ref. 19], which comprises an aircraft type dependent task breakdown. The manoeuvre during the initial missed approach phase necessitates concentrated attention of the pilot especially when establishing climb and changes in configuration, and it is assumed that the guidance equipment cannot be fully utilised. No requirements to change the flight direction are acceptable in this phase. The initial approach phase may require up to 30-40 seconds (or 1.0 to 1.8 Nm travelled) before *at the earliest* lateral navigation can be adjusted and the turn *initiated*. Relevant missed approach rulemaking normally covers only a special case for the initiation of a missed approach: no visual contact at decision height due to low clouds and/or reduced visibility in fog. Although it can be argued that low-visibility is the most critical reason when considering obstacle clearance, there are other missed approach triggering reasons, resulting in a variety of possible initiation altitudes from DH to 2000 ft or more [Ref. 2, 6].

2.3 Air Traffic Control procedures

ATC is responsible for the safe and efficient management of air traffic on and around the airport [Ref. 10]. Tower Control maintains control of the aircraft from the point that the aircraft is established on ILS localiser until either the aircraft

- leaves the runway and is transferred to the ground controller, or
- initiates a missed approach and is transferred to approach control for new line up for landing

The tasks for the controller focus on final approach sequencing, monitoring of the (missed) approach, provision of a landing clearance and the necessary R/T communications. Usually two different tower controllers manage the aircraft on the arrivals for 19R and 22, using different frequencies for communication with aircraft conducting a missed approaching [Ref. 2]. Pilots will not automatically be aware of the other aircraft initiating a missed approach other than from visual reference or when being informed by ATC. Although the procedure for runway 19R does not prescribe a turn, in reality ATC often instructs aircraft conducting a missed approach on this runway to also initiate a turn away from the nominal trajectory for runway 22 [Ref. 4], and will also provide instructions (e.g. “turn right”, “turn left”, “climb to”) to avoid collisions.

2.4 Differences between current and proposed procedures

This study focuses on the current situation of runways 19R and 22, where the OCA for runway 22 will be reduced from 350 to values below 200 ft. This reduction might allow a DH of 200 ft, enabling the use of runway 22 in actual CAT-I weather conditions. The missed approach procedure for runway 19R will not be changed, provided that an acceptable level of safety can be obtained. It is also not expected that a change in procedure for runway 22 will have an effect on ATC tasks / procedures or communication, or will have an effect on the approaches to runway 19R. Most important aspect is that the point where a missed approach is initiated, *when the missed approach is based on visibility conditions or unstabilized approach*, moves to a point further down the approach for runway 22 (the nominal distance to threshold reduces from about 1.1 Nm to 0.6 Nm). The missed approach path for runway 22 will move closer to the missed approach path for runway 19R, which is a factor that might increase the risk of collision.

Runway selection is based on meteorological data that has a resolution of 100ft. The tower supervisor will probably decide *not* to use the runway combination 19R/22 when a broken cloud base of 200 ft is reported, since the margin with the 200ft DH is too small. Therefore the lowest (forecasted) ceiling for the selection of runway 22 as landing runway will be reduced from BKN 400 ft to BKN 300 ft, which is a factor that might influence the missed approach rate [Ref. 2].

3 Risk criteria framework

3.1 Introduction

Up to now, the most commonly used risk criteria framework for the collision risk between aircraft in the airport surroundings include:

- A single risk metric defined in terms of the collision risk probability per approach;
- A risk requirement based on the Target Level of Safety (TLS) approach.

As an example, previous research studies undertaken for the NLA proposed a risk criteria framework based on a maximum collision risk probability per approach of between 10^{-8} and 10^{-9} [Ref. 13, 14]. Recent research studies for the European Commission and Eurocontrol show a tendency to also investigate the possible application of:

- risk metrics that convey the costs and benefits of possible decisions more clearly, and
- risk requirements that are based on the As-Low-As-Reasonably-Practicable approach.

Risk (or safety) requirements are usually based on the principle that an inverse relationship should exist between probability of occurrence and magnitude of its consequences.

3.2 Identification of suitable collision risk metrics

The suitability of risk metrics for the collision risk between aircraft is studied [Ref. 2, 13, 14]. A rationale is developed and applied for evaluating the suitability of possible risk metrics. Two suitable risk metrics to regulate and control collision risk around the airport are proposed:

1. *Collision probability per movement* (i.e take off or landing):
   Commonly used for evaluation of risk events during the approach and take off part of a flight. It fits well within the present safety requirements for air traffic operations, but does not take into account an increase in runway capacity.
2. *Collision probability per year* (or expected average time interval between 2 risk events):
   This metric takes into account the runway capacity and the steady increase in air traffic. As an aid to planning and decision making, it might therefore be more appropriate to use.

Economic risk might be used as an *informative* metric to convey costs and benefits of possible decisions more clearly [Ref. 2]. Since economic risk is open to more than one interpretation, this metric should *not* be used for regulation (i.e. no controls should be based on it).

3.3 Target Level of Safety (TLS) approach

The TLS approach is based on a division of the risk continuum into two regions, where the TLS provides the boundary value between safe and unsafe. A TLS specifies a maximum acceptable level of assessed risk (i.e. point estimate). Several methods for TLS assessment have been used [Ref. 14], and methods based on historical accident data – sometimes factored for improvement – are most popular. Some existing and proposed TLS in aviation are [Ref. 2]:

1. *Existing TLS for collision with obstacles (ICAO-OCP)*:
   Maximum collision probability per approach of 1.0×10^{-7}
2. *Existing TLS for mid-air collisions (ICAO-RGCSP)*:
   Maximum collision risk per flight hour per dimension of 5×10^{-9}
3. *Existing TLS for aircraft accidents during all flight phases (ICAO-AWOP)*:
   Maximum aircraft accident risk of 1.0×10^{-7} per flight hour or 1.5×10^{-7} per mission
4. *Existing TLS for aircraft accidents during approach and landing (ICAO-AWOP)*:
   Maximum aircraft accident risk of 1.0×10^{-8} per mission
5. *Existing TLS for failure conditions of individual aircraft systems (JAR-25)*:
   Maximum probability of occurrence per flight hour of 1.0×10^{-9} per system failure condition
6. *Proposed TLS for accidents with an ATM contribution (Eurocontrol-ESARR4)*
   Maximum probability of ATM directly contributing to an accident of a commercial air transport aircraft of 2.5×10^{-8} accidents per flight hour or 3.5×10^{-8} per movement

Note that some applications of the TLS concept (e.g. the first and second) provide detailed guidelines for the numerical method to be used for assessment of the risk.

3.4 As-Low-As-Reasonably-Practicable (ALARP) approach

The ALARP approach is based on a banded assessment of decision structure, which contains a tolerable region bounded by maximally negligible and minimally unacceptable levels of risk. Within the tolerable region the risk must be proven to be ALARP in order to be acceptable [Ref. 16, 18]. Cost-Benefit Analysis (CBA) is a method that can be used to demonstrate that any further risk reduction in the tolerable region is impracticable. Up to now, ALARP has mainly been used in industries other than aviation (e.g. the chemical, offshore, nuclear and some transport industries). Recently development of the ALARP approach has been investigated within the context of Reduced Vertical Separation Minimum (RVSM) in ECAC countries [Ref. 16]. It was concluded that for aviation there seems to be no case for replacing any accepted TLS with ALARP. However, since most practical applications of ALARP use fixed risk criteria like the TLS to determine the ALARP region, there appear to be grounds for *combining* the TLS and ALARP for aviation risk management for certain studies. An advantage of ALARP might be that it provides better means to account for a difference between calculated and actual risk.

3.5 Adoption of safety requirements

On behalf of the NLA, it was decided to judge the acceptability of the estimated collision risk by a relative comparison of the collision probability per approach of the current and proposed situation for runway 22. Moreover, the magnitude of the absolute risk value will be compared with the EUROCONTROL proposed TLS for accidents with an ATM contribution [Ref. 17].

4 Risk assessment model

4.1 Risk assessment methodology and tools

For the assessment of the collision risk related to simultaneous missed approaches on Schiphol runways 19R and 22, three NLR methodologies and tools are integrated and used:

- NLR's Information System for Safety and Risk analysis (ISTaR);
- NLR's Traffic Organization and Perturbation AnalyZer (TOPAZ);
- NLR's Flight Track and Aircraft Noise Monitoring System (FANOMOS).

As the basis for the development of the collision risk assessment model use is made of the TOPAZ methodology to assess accident risks for ATM operations [Ref. 20]. TOPAZ supports a spiral development cycle that is of the form:

A. Design of an ATM operational concept.
B. Assessment of the ATM concept, resulting in a cost-benefit overview.
C. Detailed analysis of the assessment results, resulting in recommendations to improve the ATM concept.
D. Review of ATM concept development strategy and plan.
E. Back to A: adapted and/or more detailed ATM concept design using the results from C resulting in a new or optimised ATM concept.

The TOPAZ methodology is based on a stochastic modelling approach towards risk assessment and has been developed to provide designers of advanced ATM with safety feedback following on a (re)design cycle, see Figure 2.

During the assessment cycle four stages are sequentially conducted:

1. Identification of operation and hazards (upper left boxes in Figure 2)
2. Mathematical modelling (right boxes in Figure 2)
3. Accident risk assessment (middle box in Figure 2)
4. Feedback to operational experts (lower left box in Figure 2)

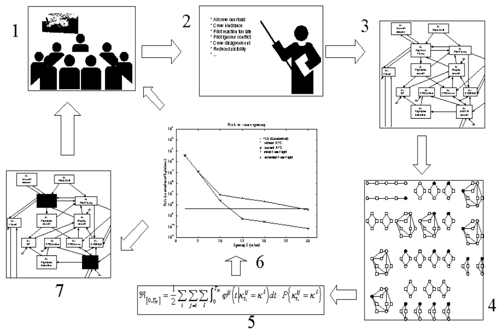

Figure 2 TOPAZ risk assessment cycle

4.2 Identification of hazards

The main issues lie in the fact that, contrary to all other published procedures at Schiphol, the missed approach procedure for runway 22 is not a procedure straight ahead on runway track and prescribes a left turn to track 160 ° MAG at the MAPt. Humans involved (flight crew and ATC) must act according to the published procedures, nevertheless it must be considered that the flight crew delays, forgets, or chooses not to initiate a turn early in the missed approach. Therefore reasons for not complying with the published were identified [Ref. 2, 4, 5]:

- The ATCOD incident database of the Dutch ATC [Ref. 5] was used to derive baseline reasons in relation to aircraft conducting a missed approach on runways 19R and 22;
- For the turning missed approaches, possible hazards as well as the impact of these hazards on the aircraft turning track (including location where the turn will be initiated, turn radius, and vertical climb performance) was assessed [Ref. 2];
- For the missed approaches straight ahead on runway track, possible hazards were supplemented with hazards derived during previous NLR research studies [Refs. 11, 12, 13, 14].

A brainstorm session was held, where representatives of NLR, NLA, and LVNL discussed possible hazards that might occur. The following relevant factors were noted [Ref. 4]:

- Although the missed approach procedure for runway 19R does not prescribe a turn, in reality ATC often instructs aircraft conducting a missed approach on this runway to also initiate a turn away from the missed approach turning trajectory for runway 22;
- The Jeppesen approach plate for runway 22 might lead to confusion of pilots conducting a missed approach. The fact that the ILS plate also contains information for a Non-Precision Approach (NPA) procedure might lead to pilots interpreting the information wrongly, e.g.:
  - The MAPt and required turn can be interpreted as being located *before* the DH;
  - The visibility criteria may be interpreted as being equal to 1200 m (applicable to the NPA procedure) instead of the 1800 m applicable to the ILS procedure;

- Runway 22 has currently no ILS CAT-I approach and runway lighting, but will be equipped with stopbars in the near future.
- The Jeppesen approach plates for runways 19R and 22 differ from the AIP approach plates on significant details, e.g. Jeppesen omits the mentioning of specific procedures that apply in case of a missed approach under communication failure.

4.3 Missed approach model

A statistical model for the uncertainties about the missed approach flight phase has been developed [Ref. 2, 3]. This model accounts for the specific nature of the procedures for runways 19R and 22, where the latter includes a turning trajectory with turns 'as soon as practicable'.

Probability distributions for the lateral and vertical deviations
For the *straight* missed approaches, the ICAO CRM data is used [Ref. 8]. However, for the rare *turning* missed approaches, reliable data can not be obtained easily. Therefore, in co-ordination with the NLA, it was decided to use FANOMOS turning departure data – together with an assessment of the impact of the main differences with turning missed approaches – to represent deviations about the turning missed approach path, as being the best feasible modelling option. Schiphol departure data has been analysed using ISTaR goodness-of-fit tools [Ref. 2].

*Probability distribution for the missed approach turning poin*t
A statistical model for the missed approach turning point, representing a probability distribution for the time required before lateral navigation can be adjusted and the turn initiated has been developed. This model is based on expert knowledge of (airline) pilots at NLR.

Table 1 Boeing 737 / Airbus A320 Missed approach task breakdown

Task	Earliest possible time	50% percentile	95% percentile	End time
1: Decision to initiate missed approach	T0	2 seconds	3 seconds	T1
2: Triggering go-around FD mode	T1	1 second	3 seconds	T2
3: Thrust change for go-around	T2	6 seconds	9 seconds	T3
4: Adjusting pitch angle	T1 + 1 second	4 seconds	8 seconds	T4
5: Raising flaps for climb-out	T1 + 2 seconds	6 seconds	10 seconds	T5
6: Raising the gear	T4	3 seconds	10 seconds	T6
7: Engaging the autopilot	T6 & passed 1000 ft	1300 ft	1600 ft	T7
8: Turn, adjust lateral navigation	T6 & passed 400 ft	600 ft	900 ft	T8
9: Level off, adjust vertical navigation	passed altitude of 2000 ft – (10% of climb rate)	1700 ft	1900 ft	T9

An example of elicited duration times for the task breakdown of the Boeing 737/Airbus A320 is given in the above Table 1. Task duration and sequencing depends on aircraft type, therefore similar tables have been elicited to represent turn behavior of pilot flying other aircraft approaching 19R and 22 [Ref. 2].

Reasons and altitude for missed approach initiation

It is assumed that the statistics for the baseline reasons and likely altitude for initiation of a missed approach is based on a combination of α% at Decision Height (DH) and 100-α% based on references 6 and 2. For 100-α% Table 2, which show the reasons and likely altitude for initiation of a missed approach, is used [Ref. 2, 3]. Note that the columns indicate the type of probability distribution used. Within this study, for the parameter α a value of 20% is chosen.

Table 2 Reasons and probability density of height for initiation of a missed approach

	Density type	**Dirac**	**Dirac**	**Dirac**	**Uniform**	**Uniform**
Reason	**Percentage**	**100 ft**	**300 ft**	**600 ft**	**600-1200 ft**	**100-1200 ft**
Runway occupied	27.2%	4.5%	22.7%			
Unstable approach	20.4%		6.8%	4.5%	2.3%	6.8%
Turbulence	6.8%	4.5%				2.3%
Flap problems	13.6%			2.3%	4.5%	6.8%
Wind-shear	22.7%	11.3%	6.8%	2.3%	2.3%	
Weather	2.4%					2.4%
Other	6.9%	2.3%	2.3%			2.3%
Percentage	100%	22.6%	38.6%	9.1%	9.1%	20.6%

Missed approach rates for runways 19R and 22

Reliable data on the percentage of executed missed approaches is difficult to obtain, especially with respect to particular airports or runways. Reference 6 mentions frequencies in the order of 0.001 to 0.002, on the basis of worldwide KLM data. During the brainstorm session [Ref. 4], it was noted that the rate for runway 22 will probably be higher than average, because taxiing aircraft have to make a sharp turn when leaving this runway, i.e. the Runway Occupancy Time (ROT) is relatively high. Within this study, for the missed approach rates of runways 19R and 22 therefore reference values of 0.002 and 0.01 respectively have been chosen.

Probability distribution for the aircraft vertical climb performance

Since the majority of conflict situations is expected to occur after the aircraft have reached the missed approach level altitudes, the following aspects have been analysed [Refs. 2, 3]:

- The elapsed time necessary for different aircraft to climb to final missed approach altitude;
- The percentages of different aircraft that have climbed to final missed approach altitude as a function of distance from runway threshold.

4.4 Integration of mathematical models

For the integration of the mathematical models the Dynamically Coloured Petri Net (DCPN) approach is used [Ref. 3]. Also a modular system engineering type of representation of the ATM design for double missed approaches has been identified by taking for each main functionality in the ATM scenario one module, and additionally taking for each aircraft in the system a module describing its trajectory. If an ATM module is aircraft specific, then such a module is introduced for each of the aircraft. Modules A refer to an aircraft individually. Modules B may affect several aircraft. An overview of these modules is:

A1	Level of skill of pilot	B1	Level of skill of Tower controller
A2	Level of performance of pilot not flying	B2	Level of performance of Tower controller
A3	Level of performance of pilot flying	B3	Surveillance
A4	Aircraft module	B4	ATC system
A5	Aircraft airborne system	B5	Communication, global
A6	Aircraft landing system	B6	Navigation support, ground
A7	Cockpit display and computer	B7	Level of maintenance, ground
A8	Type of weather	B8	Runway degradation
A9	Navigation equipment aircraft		
A10	Communication, local		
A11	Level of maintenance, aircraft		

The ATM modules and their interrelations are depicted in Figure 3. For the aircraft module a RASMAR specific local Petri net representing the aircraft evolution is modelled [Ref. 3].

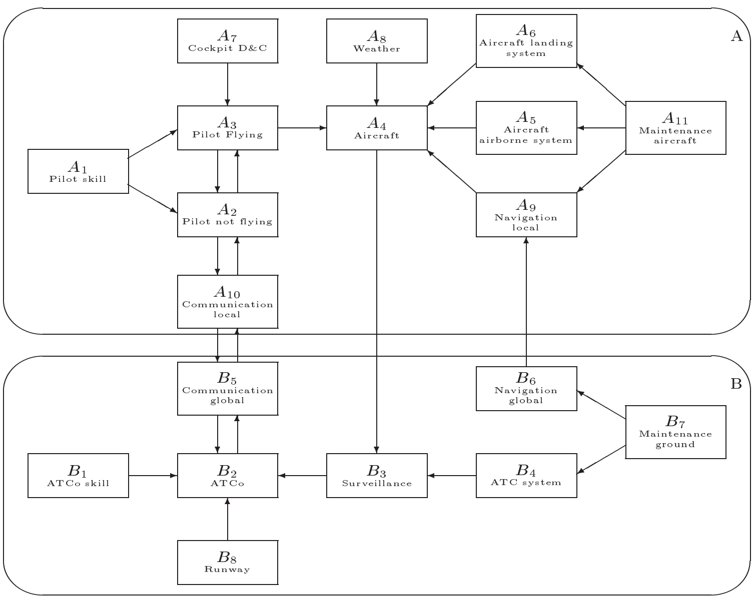

Figure 3 Functional representation of ATM modules and their interrelations.

4.5 Collision risk given a double missed approach

To determine the collision risk given a simultaneous (double) missed approach on runways 19R and 22, a Collision Risk Tree (CRT) is constructed. In the following, first the collision risk concept is described, taking into account the diversity of different aircraft types that may approach runways 19R (mainly Mediums and Heavies) and 22 (Lights and Mediums only).

Collision risk concept

Let $y_t^i := (y^i_{x,t}\ ,\ y^i_{y,t}\ ,\ y^i_{z,t}\ )$ and $v_t^i := (v^i_{x,t}\ ,\ v^i_{y,t}\ ,\ v^i_{z,t}\ )$ be the 3D location and 3D velocity of aircraft *i*, and the subscripts *x, y* and *z* refer to the 3 dimensional axis system. Let $y_t^{ij} := y_t^i - y_t^j$ be the distance between 19R aircraft *i* and 22 aircraft *j* at time *t* and let $v_t^{ij} := v_t^i - v_t^j$ be the relative velocity of 19R aircraft *i* and 22 aircraft *j* at time *t*. Define D^{ij} as the collision area of $\{y_t^{ij}\}$, such that $y_t^{ij} \in D^{ij}$ means that aircraft *i* and *j* have collided. The collision area D^{ij} is a rectangular box, defined as $[-d_x^{ij},\ d_x^{ij}] \times [-d_y^{ij},\ d_y^{ij}] \times [-d_z^{ij},\ d_z^{ij}]$, with $d_r^{ij} \stackrel{\Delta}{=} \left(d_r^i + d_r^j\right)/2$ and where the parameters d_x^i, d_y^i and d_z^i represent the size of aircraft *i* respectively. The first *incrossing* – occurrence of process $\{y_t^{ij}\}$ entering the area D^{ij} – defines a collision. Following reference 15, the risk is expressed as the expected number μ of incrossings, or collisions, between aircraft conducting a simultaneous missed approach on runways 19R and 22 in an appropriate time-interval:

$$\mu = \int_0^T \varphi^{ij}(t)\, dt \qquad (1)$$

where $\varphi^{ij}(t)$ is the incrossing rate between aircraft *i* and aircraft *j*, which is defined as

$$\varphi^{ij}(t) \stackrel{\Delta}{=} \lim_{\Delta \downarrow 0} \frac{P(y_t^{ij} \notin D^{ij},\ y_{t+\Delta}^{ij} \in D^{ij})}{\Delta}$$

In the sequel time *T* is always parametrised such that there is a negligibly small probability that the aircraft pair (*i,j*) collides after final time *T*.

Aircraft type combinations

Twelve aircraft type combinations κ^{ij} are considered, consisting of 3 aircraft *i* on runway 19R and 4 aircraft *j* on runway 22. That is $\kappa^{ij} = (\kappa^i,\ \kappa^j)$, with $\kappa^i = 1,2,3$ and $\kappa^j = 1,2,3,4$. The 19R aircraft *i* are heavy and medium weight aircraft, where Boeing 767/Boeing 747 is representative for heavy aircraft, and Boeing 737/Airbus A320 and Fokker 50 are representative for medium aircraft. The 22 aircraft *j* are medium and light aircraft, where Boeing 737/Airbus A320 and Fokker 5 are representative for medium aircraft, and Swearingen Metro II and Cessna 172 are representative for light aircraft [Ref. 2].

Conditional incrossing risk

Conditioning on these possible aircraft type combinations in equation (1) gives

$$\mu = \sum_{\kappa^i=1}^{3}\sum_{\kappa^j=1}^{4}\int_0^T \varphi_\kappa^{ij}(t)\, dt \cdot P\left\{\kappa^{ij} = \left(\kappa^i,\kappa^j\right)\right\}$$

where $\varphi_\kappa^{ij}(t)$ is the conditional incrossing rate between aircraft *i* and aircraft *j*, defined as

$$\varphi_\kappa^{ij}(t) \overset{\Delta}{=} \lim_{\Delta \downarrow 0} \frac{P(y_t^{ij} \notin D^{ij},\, y_{t+\Delta}^{ij} \in D^{ij} \,|\, \kappa^{ij} = \kappa)}{\Delta}$$

Following reference 15, the following equation is derived:

$$\begin{aligned}\mu = \sum_{\kappa^i=1}^{3}\sum_{\kappa^j=1}^{4}\sum_{r=x,y,z}\int_{\tau_r^{ij}}^{T_H}\int_{\underline{D}_r} &\left\{\int_0^\infty v_r^{ij}\, p_{y_t^{ij}\, v_{r,t}^{ij}\,|\,\kappa^{ij}}\left(\underline{y}_r^{ij}, -d_r^{ij}, v_r^{ij}\,|\,\kappa\right) dv_r^{ij}\right.\\ &\left.+\int_{-\infty}^{0} -v_r^{ij}\, p_{y_t^{ij}\, v_{r,t}^{ij}\,|\,\kappa^{ij}}\left(\underline{y}_r^{ij}, d_r^{ij}, v_r^{ij}\,|\,\kappa\right) dv_r^{ij}\right\} d\underline{y}_r^{ij}\, dt \cdot P\left\{\kappa^{ij} = \left(\kappa^i,\kappa^j\right)\right\}\\ = \sum_{\kappa^i=1}^{3}\sum_{\kappa^j=1}^{4}\sum_{r=x,y,z} &I_r^{ij}\left(\kappa^i,\kappa^j\right)\cdot P\left\{\kappa^{ij} = \left(\kappa^i,\kappa^j\right)\right\}\end{aligned} \tag{2}$$

with

$$\begin{aligned}I_r^{ij}(\kappa) \overset{\Delta}{=} \int_{\tau_r^{ij}}^{T}\int_{\underline{D}_r} &\left\{\int_0^\infty v_r^{ij}\, p_{y_t^{ij}\, v_{r,t}^{ij}\,|\,\kappa^{ij}}\left(\underline{y}_r^{ij}, -d_r^{ij}, v_r^{ij}\,|\,\kappa\right) dv_r^{ij}\right.\\ &\left.+\int_{-\infty}^{0} -v_r^{ij}\, p_{y_t^{ij}\, v_{r,t}^{ij}\,|\,\kappa^{ij}}\left(\underline{y}_r^{ij}, d_r^{ij}, v_r^{ij}\,|\,\kappa\right) dv_r^{ij}\right\} d\underline{y}_r^{ij}\, dt\end{aligned} \tag{3}$$

where $p_{y_t^{ij}\, v_{r,t}^{ij}\,|\,\kappa^{ij}}(\cdot)$ is the conditional probability density function for the aircraft relative position and velocity, $\underline{D}_r$ is equal to collision area D^{ij} but without the *r*-th component, and $\underline{y}_r^{ij}$ is equal to the aircraft relative position y_t^{ij} without the *r*-th component, $r = x,y,z$. Also, for 19R aircraft *i* and a 22 aircraft *j* , stopping times τ_r^{ij} for $r=x,y,z$ are defined as

$$\tau_r^{ij} \overset{\Delta}{=} \inf\left\{t; \left|y_{r,t}^{ij}\right| = d_r^{ij}\right\}$$

The above equation can be represented in the form of a Collision Risk Tree (CRT) [Ref. 2]. By definition of $I^{ij}(\kappa) = \sum_{r=x,y,z} I_r^{ij}(\kappa)$, the collision risk given a double missed approach can be expressed by the following equation:

$$P_{collision\,|\,double\ missed\ approach} = \mu = \sum_{\kappa^i=1}^{3}\sum_{\kappa^j=1}^{4} I^{ij}\left(\kappa^i,\kappa^j\right)\cdot P\left\{\kappa^{ij} = \left(\kappa^i,\kappa^j\right)\right\} \tag{4}$$

The values for the probabilities $P\{\kappa^{ij} = (\kappa^{i}, \kappa^{j})\}$ are derived from statistical FANOMOS data giving the percentages of landing heavy/medium/light aircraft on Schiphol runways 19R and 22. Note that the TOPAZ evaluations of equation 4 will be executed for 16 key scenarios (see section 5.1), each producing a value for the collision risk given a double missed approach

4.6 Determination of collision risk metrics

Below a description is given of the mathematical procedure to derive the collision probability per approach and per year. They are expressed on the basis of collision risk given a double missed approach, and other relevant missed approach procedure aspects. These are:

- Missed approach rates for runways 19R and 22, denoted with r_{19R} and r_{22} respectively;
- Correlation factor ρ , representing the extent to which the initiation of missed approaches on runways 19R and 22 are dependent, where 0[ρ [1 and ρ=1 gives full dependency;
- Probability metrics for the adherence to the published missed approach procedures:
  - Probability that the missed approach on 19R is straight ahead on runway track α_{19R} ;
  - Probability that the missed approach on 22 is straight ahead on runway track α_{22} .

In close co-ordination with the RLD, 16 scenarios k ∈ {1,2,…,16} will be selected. For each of these scenarios, the *scenario dependent* collision probability per approach, Risk (k), is given by

$$Risk\,(k) = P_{collision\ per\ approach}(k) \ = \ P_{double\ MA} \cdot P_{collision|\ double\ MA}(k)$$

where the occurrence probability of a simultaneous missed approach is given by

$$P_{\text{double MA}} = (1-\rho) r_{19R} r_{22} + \rho \ r_{19R}$$

The probability of a collision per approach is determined by

$$P_{collision\ per\ approach} = P_{double\ MA} \cdot \{(1-\alpha_{19R})(1-\alpha_{22}) Risk_{T\,;\,T} + \alpha_{19R}(1-\alpha_{22}) Risk_{S\,;\,T} + (1-\alpha_{19R})\alpha_{22} Risk_{T\,;\,S} + \alpha_{19R}\alpha_{22} Risk_{S\,;\,S}\}$$

where the subscript of Risk indicates the execution of a straight missed approach (S) or turning missed approach (T) on runways 19R and 22 respectively.

To determine the collision probability per approach for a given Decision Height (DH) and given missed approach level altitudes, therefore 4 scenarios need to be numerically evaluated with regard to the collision risk given a double missed approach, using equations (1) to (4). To quantify the current (DH=350 ft) and proposed situation (DH=200 ft), 8 scenarios are required.

The next step is to determine the collision probability per year, using the runway statistics of runways 19R and 22. Combined use of runways 19R and 22 is only applied during *peak* time periods. Using statistics on the total number of approaches, divided into *night, peak*, and *off peak* time periods [Ref. 16], the collision probability per year can be determined by

$$P_{collision\ \ per\ \ year} = 1 - [1 - P_{collision\ per\ approach}]^N$$

where N is determined by the total number of approaches to runways 19R and 22 [Ref. 2].

5 Collision risk assessment

5.1 Definition of key representative scenarios

In close co-ordination with the NLA and LVNL, 16 key scenarios have been selected. These scenario's are determined by four main procedural aspects and are given in Table 3.

- Decision Height (DH) runway 22 — 200 ft, 250 ft, 300 ft, and 350 ft
- Final Missed Approach Altitudes (FMAA) — 2000 ft and/or 3000 ft
- Missed Approach Turn on 22 — YES (turn as soon as practicable) or NO
- ATC induced MA Turn on 19R — YES (turn as soon as practicable) or NO

Table 3 Key representative scenarios (Ref. 2)

Scenario	MA Turn on	DH runway 22	FMAA 19R / 22	MA Turn on 22
1	YES	350 ft	2000 ft / 2000 ft	YES
2	YES	300 ft	2000 ft / 2000 ft	YES
3	YES	250 ft	2000 ft / 2000 ft	YES
4	YES	200 ft	2000 ft / 2000 ft	YES
5	NO	350 ft	2000 ft / 2000 ft	YES
6	NO	200 ft	2000 ft / 2000 ft	YES
7	YES	350 ft	3000 ft / 3000 ft	YES
8	YES	200 ft	3000 ft / 3000 ft	YES
9	YES	200 ft	2000 ft / 3000 ft	YES
10	YES	200 ft	3000 ft / 2000 ft	YES
11	YES	350 ft	2000 ft / 2000 ft	NO
12	YES	200 ft	2000 ft / 2000 ft	NO
13	YES	350 ft	3000 ft / 3000 ft	NO
14	YES	200 ft	3000 ft / 3000 ft	NO
15	NO	350 ft	2000 ft / 2000 ft	NO
16	NO	200 ft	2000 ft / 2000 ft	NO

In the current situation of the Schiphol converging runways 19R and 22, the DH of runway 22 is 350 ft, whereas in the proposed situation the DH will be reduced to 200 ft. For both the current and proposed situation the following cases can be distinguished (see also Table 4):

- *Straight MA's* Aircraft approaching 19R and 22 make a straight missed approach;
- *Nominal Case* Aircraft approaching 22 make a turning missed approach and aircraft approaching 19R make a straight missed approach;
- *ATC Corrected Case* Aircraft approaching 22 make a straight missed approach, and ATC instructs missed approaching aircraft on 19R to initiate a turn;
- *Turning MA's* Aircraft approaching 22 make a turning missed approach, and ATC instructs missed approaching aircraft on 19R to also initiate a turn.

Table 4 Current and proposed scenarios, with final MA altitudes of 2000ft.

	Current **DH on RWY 22 is 350ft**	**Proposed** **DH on RWY 22 is 200ft**
Straight MA's	scenario 15	scenario 16
Nominal Case	scenario 5	scenario 6
ATC Corrected Case	scenario 11	scenario 12
Turning MA's	scenario 1	scenario 4

In addition to these scenarios, eight more scenarios will be evaluated to also support other possible changes in the missed approach procedures for runways 22 and 19R. These are:

- Decision Height on Runway 22 in between 350 ft and 200 ft (e.g. scenarios 2 and 3);
- Final Missed Approach Altitude on Runway 22 and/or 19R raise from 2000 ft to 3000 ft (scenarios 7, 8, 9, 10, 13, 14).

It was shown in section 4.7 that the probability of a collision per approach can be expressed in terms of collision risk values given a double missed approach (determined for the 16 scenarios), and in terms of parameters which represent relevant missed approach procedure aspects. The parameter values chosen are defined in reference 2 and given in Table 5 below.

Table 5 Occurrence probabilities for relevant missed approach procedure aspects

MA procedure aspect	**Symbol**	**Interval**	**Reference value**	**Worst value**	**Best value**
Pr{19R straight}	α_{19R}	[0,1]	**0.2**	0.9	0.1
Pr{22 straight}	α_{22}	[0,1]	**0.15**	0.5	0.05
MA rate 19R	r_{19R}	[1/1000,1/100]	**0.002**	0.01	0.001
MA rate 22	r_{22}	[1/200,1/50]	**0.01**	0.02	0.005
MA correlation factor	ρ	[0,1]	**0.05**	0.1	0.005

The collision probability per approach and per year will be determined for the reference value, worst value and best value case, where it is assumed that these values are equal for the current (DH = 350 ft) and proposed situation (DH = 200 ft). Subsequently a sensitivity analysis is performed for the missed approach procedure parameters, where each of the parameter values is varied between the best and worst values as given in Table 5.

5.2 Collision risk given a double missed approach

The collision risk given a double missed approach is determined for all 16 key representative scenarios, through 16 fold execution of the 3 step-procedure given in section 4.6:

1. Determination of *conditional incrossing risk* for each of the 12 aircraft type combinations;
2. Determination of *incrossing risk* for each of the 12 aircraft type combinations;
3. Determination of *collision risk given a double missed approach*.

Step 1: Determination of conditional incrossing risk

Equation (4) is numerically evaluated using the TOPAZ toolset. This leads to an assessment of the risk that a missed approaching aircraft on runway 19R collides with aircraft conducting a missed approach on runway 22 [Ref. 3]. For the *nominal case* scenarios 5 (with DH = 350 ft) and 6 (with DH = 200 ft) the numerical results for each of the possible aircraft combinations are given in Tables 6 and 7. Similar tables have been determined for the other 14 scenarios [Ref. 3].

Table 6 Conditional incrossing risk values (upper bound) for scenario 5

Scenario 5 Missed Approach Straight on 19R; Missed Approach Turn on 22; Final Missed Approach Altitudes are 2000 ft; DH runway 22 is 350 ft			
Conditional Incrossing risk	Heavy 767/747 on RWY 19R	Medium 737/320 on RWY 19R	Medium F50 on RWY 19R
Medium 737/320 on 22	9.3×10^{-8}	2.0×10^{-8}	1.6×10^{-8}
Medium F50 on 22	7.0×10^{-8}	1.5×10^{-8}	1.1×10^{-8}
Light SW II on 22	2.5×10^{-6}	9.3×10^{-7}	6.9×10^{-7}
Light C172 on 22	1.7×10^{-6}	5.7×10^{-7}	4.0×10^{-7}

Table 7 Conditional incrossing risk values (upper bound) for scenario 6

Scenario 6 Missed Approach Straight on 19R; Missed Approach Turn on 22; Final Missed Approach Altitudes are 2000 ft; DH runway 22 is 200 ft			
Conditional Incrossing risk	Heavy 767/747 On RWY 19R	Medium 737/320 on RWY 19R	Medium F50 on RWY 19R
Medium 737/320 on 22	1.4×10^{-7}	3.2×10^{-8}	2.5×10^{-8}
Medium F50 on 22	1.1×10^{-7}	2.2×10^{-8}	1.8×10^{-8}
Light SW II on 22	3.2×10^{-6}	1.1×10^{-6}	8.4×10^{-7}
Light C172 on 22	2.3×10^{-6}	7.8×10^{-7}	5.1×10^{-7}

The above tables show that the collision risk varies considerably for different types of aircraft combinations approaching the runways 19R and 22. It appears that the collision risk increases in case of light aircraft conducting a missed approach on runway 22.

Step 2: Determination of incrossing risk

The values for the probabilities $P\{\kappa^{ij} = (\kappa^i, \kappa^j)\}$, representing the probabilities that each of the possible twelve aircraft type combinations occur, are derived from the statistical data for the percentages of landing heavy/medium/light aircraft on runways 19R and 22 as obtained from FANOMOS [Ref. 3]**.** The results are presented in Table 8.

Table 8 Probability distribution of the twelve aircraft type combinations.

Aircraft type combination probabilities	Heavy 767/747 on RWY 19R	Medium 737/320 on RWY 19R	Medium F50 on RWY 19R
Medium 737/320 on 22	0.0935	0.166	0.166
Medium F50 on 22	0.0935	0.166	0.166
Light SW II on 22	0.0165	0.029	0.029
Light C172 on 22	0.0165	0.029	0.029

The *incrossing risk* values for each of the twelve possible aircraft type combinations can now be determined by taking the entry-wise product of Table 8 with the conditional incrossing risk values (e.g. tables 6 and 7 for the nominal cases). The numerical incrossing risk value tables for all 16 key scenarios are given in [Ref. 3].

Step 3: Determination of collision risk given a double missed approach

The collision risk given a double missed approach can now be determined by using equation (4). Below the numerical results are presented according to the following procedural aspects:

- Variations in Decision Height (DH) on runway 22;
- Variations in turning versus straight missed approaches on 19R and 22;
- Variations in missed approach altitudes.

Variations in Decision Height on runway 22

Table 9 and Figure 4 show the probability of a collision given a double missed approach for the scenarios with turning missed approaches on both runways as function of Decision Height (DH values are 200, 250, 300 and 350ft) with FMA altitude equal to 2000ft (i.e. scenarios 1-4). The results shows that the risk decreases only slightly for an increasing value of the decision height.

Table 9 Impact of Decision Height of Runway 22 on conditional collision risk

Scenario	DH on Runway 22	Collision risk
1	350 ft	9.0×10^{-9}
2	300 ft	9.3×10^{-9}
3	250 ft	1.0×10^{-8}
4	200 ft	1.1×10^{-8}

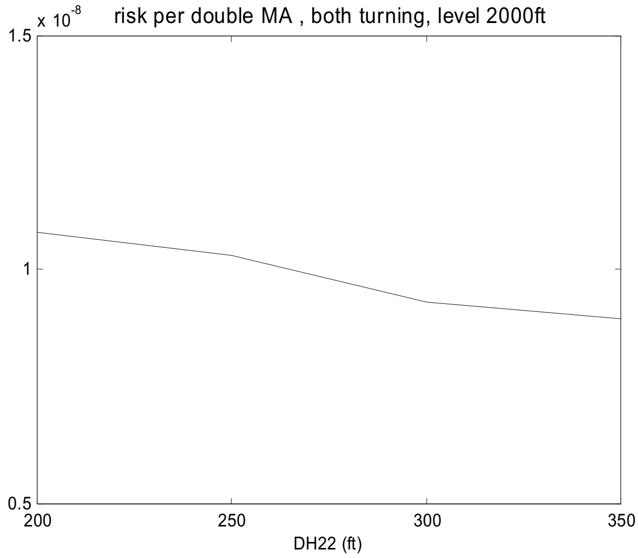

Figure 4 Impact of DH runway 22 on conditional collision risk

Variation in turning versus straight missed approaches on 19R and 22

For the four cases in Table 4 the collision risk given a double missed approach with final MA altitudes of 2000ft are given in Table 10. As expected, the risk is highest with straight missed approaches on 19R and 22, and lowest with turning missed approaches on 19R and 22. The latter can be seen in Table 11 with final MA altitudes of 3000ft.

Table 10 Conditional collision risk with final MA altitudes of 2000ft.

	Current DH on RWY 22 is 350ft	Proposed DH RWY 22 is 200ft
Straight MA's	3.6×10^{-3}	3.6×10^{-3}
Nominal Case	1.7×10^{-7}	2.3×10^{-7}
ATC Corrected Case	1.2×10^{-7}	1.2×10^{-7}
Turning MA's	9.0×10^{-9}	1.1×10^{-8}

Table 11 Conditional collision risk with final MA altitudes of 3000ft.

	Current **DH on RWY 22 is 350ft**	**Proposed** **DH on RWY 22 is 200ft**
Straight MA's	-	-
Nominal Case	-	-
ATC Corrected Case	1.2×10^{-7}	1.2×10^{-7}
Turning MA's	9.0×10^{-8}	1.1×10^{-8}

The above two tables show that – for each of the 4 cases - the impact of the proposed reduction of the DH from 350 ft to 200 ft on the conditional collision risk given a double missed approach is relative low. The numerical results also show the following:

- The collision risk attains an unacceptably high level when the approaching aircraft both make a straight missed approach, and ATC does not intervene (*straight MAs*);
- The impact of ATC instructions – "turn right!" – to aircraft missed approaching runway 19R *in case of a preceding* ***straight*** *missed approach on runway 22* is considerable, and can be seen as a very efficient collision risk reducing measure (*ATC corrected case*);
- The impact of ATC instructions – "turn right!" – to aircraft missed approaching runway 19R *in case of a preceding* ***turning*** *missed approach on runway 22* is noticeable, and can be seen as a measure to further reduce the collision risk, if necessary (*Turning MA's*);
- The impact of raising *both* final missed approach altitudes from 2000 ft to 3000 ft is – with the exception of the *Turning MA's* low, and may be seen as a risk neutral change.

Variation in final missed approach altitude

Table 12 below shows the conditional collision risk given a double missed approach for the turning MA scenarios with proposed DH of 200 ft, and with varying final MA altitudes.

Table 12 Conditional collision risk with DH 22 is 200 ft, and varying final MA altitudes

Scenario	**MAA 19R / 22**	**Collision risk with** **Turning MA on 19R and 22**
4	2000 ft / 2000 ft	1.1×10^{-8}
8	3000 ft / 3000 ft	1.1×10^{-8}
9	2000 ft / 3000 ft	3.0×10^{-10}
10	3000 ft / 2000 ft	8.8×10^{-11}

It turns out that the impact of increasing *one* of the final missed approach altitudes from 2000 ft to 3000 ft lowers the collision risk significantly, and may therefore be implemented safely. The collision risk is comparable in case the missed approach level altitudes of 19R and 22 are equal.

5.3 Collision risk per approach and per year

The collision risk per approach and per year are calculated for the current DH (350 ft) and the proposed DH (200 ft), with final missed approach altitudes of 2000 ft, through execution of the procedure described in section 4.6. Three values are provided – based on sensitivity analysis as described in reference 3 – showing the uncertainty about the calculated reference risk value.

Table 13 Collision risk per approach

	Current DH_{22} = 350ft	**Proposed DH_{22} = 200ft**
Reference Value	**1.3×10^{-8}**	**1.3×10^{-8}**
Worst Value	6.4×10^{-8}	6.3×10^{-8}
Best Value	3.2×10^{-9}	3.2×10^{-9}

Table 14 Collision risk per year

	Current DH_{22} = 350ft	**Proposed DH_{22} = 200ft**
Reference value	**1.3×10^{-4}**	**1.3×10^{-4}**
Worst value	6.4×10^{-4}	6.3×10^{-4}
Best value	3.2×10^{-5}	3.2×10^{-5}

Subsequently a sensitivity analysis is performed for the missed approach parameters, where each of the parameter values is varied between best and worst values as given in Table 5, while keeping the other parameters in accordance with the reference values [see Ref. 3].

The above tables and the sensitivity analysis show that the collision risk per approach and per year are comparable for the current DH (350 ft) and proposed DH (200 ft). This implies that a reduction of the OCA to values below 200 ft is risk neutral within a broad spectrum of changes.

5.4 Impact of the assumptions

Some model assumptions have been adopted. To assess the impact of all assumptions on the calculated collision risk, a qualitative analysis of the expected direction and magnitude of the impact of the assumptions has been undertaken [Ref. 3]. The overall conclusion of the analysis is that most assumptions have a negligible effect on the calculated risk. Assumptions that do have a noticeable impact (i.e. major or significant) are pessimistic, i.e. due to the model assumptions in reality the collision risk is smaller than that calculated. Noteworthy pessimistic assumptions are that TCAS is switched off and that pilots do not use see-and-avoid. The first has a major impact, whereas the second has a significant impact under good visibility conditions and a negligible impact in actual CAT-I weather conditions.

Besides the model assumptions, a number of parameters have been used to represent relevant missed approach procedure aspects. Most important parameters are:

- Missed approach rates for runways 19R and 22, denoted with r_{19R} and r_{22} respectively;
- Probability metrics for the adherence to the published missed approach procedures:
    - Probability that the missed approach on 19R is straight ahead on runway track α_{19R} ;
    - Probability that the missed approach on 22 is straight ahead on runway track α_{22} .

From the calculated worst, reference, and best value for the collision risk – as given in section 5.3, tables 13 and 14 – it is concluded that these parameters have a significant impact.

The conclusion can be drawn that the magnitude of the collision probability per approach is less than the reference value calculated, provided that the following conditions are satisfied:

- *The missed approach rate for runways 19R is less than 0.2 %;*
- *The missed approach rate for runway 22 is less than 1.0 %;*
- *The probability that the missed approach on runway 19R is straight ahead is less than 0.2;*
- *The probability that the missed approach on runway 22 is straight ahead is less than 0.15.*

Note that this study – following reference 7 – assumes that the ILS of runway 22 functions well below 350 ft, and does therefore not consider the risk of Controlled Flight Into Terrain (CFIT).

6 Safety and operational feedback

6.1 Safety criticality assessment

To judge the acceptability of the collision risk, it was decided to execute a two-fold comparison of the *reference* value for the collision probability per approach:

- A relative comparison of the current and proposed situation for runway 22;
- An absolute comparison with the EUROCONTROL proposed TLS for accidents with an ATM contribution, i.e. 3.5×10^{-8} accidents per movement

It was shown that a reduction of the DH of runway 22 from 350 ft to 200 ft is risk neutral, and that moreover the absolute value of risk is less than the EUROCONTROL proposed TLS. The conclusion can be drawn that – provided that certain conditions are satisfied – the independent use of runway combination 19R / 22 in actual CAT-I weather conditions is adequately safe.

This conclusion is also valid for the possible future situation, where the final missed approach altitude is raised from 2000 to 3000 ft and/or the wind criteria for the use of runway combination 19R / 22 is changed toward 20/7 knots. The latter is expected to have a negligible impact on the collision risk between aircraft approaching the runway combination 19R and 22.

6.2 Key safety bottlenecks and criticalities

It is clear that – provided that certain conditions are satisfied – the proposed reduction of the OCA of runway 22 to values less than 200 ft may be judged adequately safe. From a safety perspective, of importance is to also locate the factors that contribute most to the collision risk. This might allow for further safety improvements if appreciated. The key safety bottlenecks are those that might lead to either a missed approach executed straight ahead on track of runway 22 or might lead to aircraft not conducting an ATC induced turn on runway 19R (Refs. 2, 3):

1. Reasons for aircraft conducting a straight missed approach on runway 22;
2. Reasons for aircraft not conducting an ATC induced missed approach turn on runway 19R;
3. Reasons for aircraft not conducting an ATC induced missed approach climb.

6.3 Measures to improve and monitor safety

Although the proposed reduction of the OCA from 350 ft to values less than 200 ft is risk neutral, the following recommendations are provided to further improve the level of safety:

Design the new AIP approach plates in such a way that current possible confusion of pilots on the position of the MAPt, required turn, and visibility criteria is alleviated:

- *Turning missed approach:*

  For a missed approach following a precision approach, turns may be prescribed at a designated Turning Point (TP) or altitude/height or 'as soon as practicable' [Ref. 19]. For non-precision approaches a MAPt must be specified, and turns must commence at a designated TP (i.e. the MAPt) or at a specific altitude/height. The present approach plate identifies a turning point for the LOCalizer (LOC) glide slope unserviceable (GS u/s) approach. No specific guidelines are given for turn initiation for the ILS approach, it may be assumed that the turn should be initiated 'as soon as practicable'. Noteworthy is, that the LOC (GS u/s) MAPt lies *before* the point where the DA is crossed on a full ILS approach. It is recommended that:
  - The words 'as soon as practicable' are added for the MA following an ILS approach;
  - To avoid possible confusion, the MAPt for the LOC (GS u/s) approach should lie behind the point where the ILS GS intersects the DA. With a DH of 195 ft, this means that the MAPt for the LOC u/s should lie not earlier than 0.6 NM before the runway threshold.
- *Required visibility:*

  Presently, the required visibility for the ILS procedure is higher than for the LOC (GS u/s) approach. This might lead to confusion for pilots in marginal visibility conditions. It is recommended to either decrease the required visibility for the ILS approach or, just to avoid this confusion, increase the required visibility for the published non-precision approach.

Monitor the FMS missed approach coding by different database manufacturers

Missed approach segments are routinely coded in the FMS to aid lateral navigation in a missed approach segment. The coding of the missed approach may pose some problems for database manufacturers because ‘as soon as practicable’ is not easily translated into a FMS waypoint. Because of the potential criticality of the initiation point of the missed approach from runway 22, the NLA is encouraged to specifically monitor the FMS implementation of the published missed approach procedure by the different database manufacturers.

Monitor the reasons and circumstances related to missed approaches

The reasons and circumstances that may lead to aircraft initiating a missed approach as well as the missed approach rate are aspects that are relatively uncertain. It is therefore recommended that ongoing safety monitoring activities – such as the ATCOD data base of Air Traffic Control The Netherlands (LVNL) – are continued, possibly to be extended with the following:

- Information about position of missed approach initiation (altitude / distance to threshold);
- Information about the position of initiation of a turn (time after initiation of missed approach or altitude or distance from / passed threshold)
- Information about the reason for initiation of a missed approach.

Furthermore, the LVNL may explicitly request aircraft executing a missed approach from runway 22 to submit a company report, which can then be analysed.

7 Conclusions and recommendations

7.1 Conclusions

A probabilistic safety assessment of the collision risk related to simultaneous missed approaches on Schiphol converging runways 19R and 22 has been carried out, focusing on the proposed reduction of the OCA of runway 22 from 350 ft to values less than 200 ft. This reduction will allow a DH of 200 ft, enabling the use of runway 22 in actual CAT-I weather conditions.

Two suitable risk metrics – collision probability per movement and per year – have been identified. On basis of a review of safety requirements, some guidelines on how to judge the acceptability of collision risk results have been given. An existing risk model has been extended to enable determination of the collision risk between aircraft simultaneously conducting a missed approach on runways 19R and 22. This model is developed through an integral usage of 3 NLR facilities: ISTaR, TOPAZ, and FANOMOS. Application to 16 scenarios showed that:

- The collision risk may attain an unacceptably high level under certain conditions, e.g. when aircraft on 19R and 22 both make a straight missed approach, and ATC does not intervene;

- ATC monitoring and instructing – “turn right!” or “climb to!” – to aircraft conducting a missed approach on runway 19R *in case of a preceding **straight** missed approach on runway 22* is required. It is explicitly stated that such ATC instructions are ***not*** necessary *in case of a preceding **turning** missed approach on runway 22*.

Provided that the identified risk reducing measures are applied, the proposed reduction of the OCA of runway 22 to values less than 200 ft is risk neutral within a broad spectrum of missed approach procedural aspects, and may be judged adequately safe. This conclusion is also valid for the situation where the final missed approach altitude is raised from 2000 to 3000 ft.

7.2 Recommendations

Although the proposed reduction of the OCA from 350 ft to values less than 200 ft is risk neutral, the following recommendations are provided to further improve the level of safety:

1. Design the new AIP approach plates in such a way that current possible confusion of pilots on the position of the MAPt, required turn, and visibility criteria is alleviated;
2. Monitor the FMS missed approach coding by different database manufacturers;
3. Monitor the reasons and circumstances in relation to missed approaches on 22, e.g. through yearly inspection of the ATCOD incident database of the LVNL.

It is also recommended that Dutch interest groups discuss internally and agree upon a risk criteria framework to regulate and control collision risk around Dutch airports.

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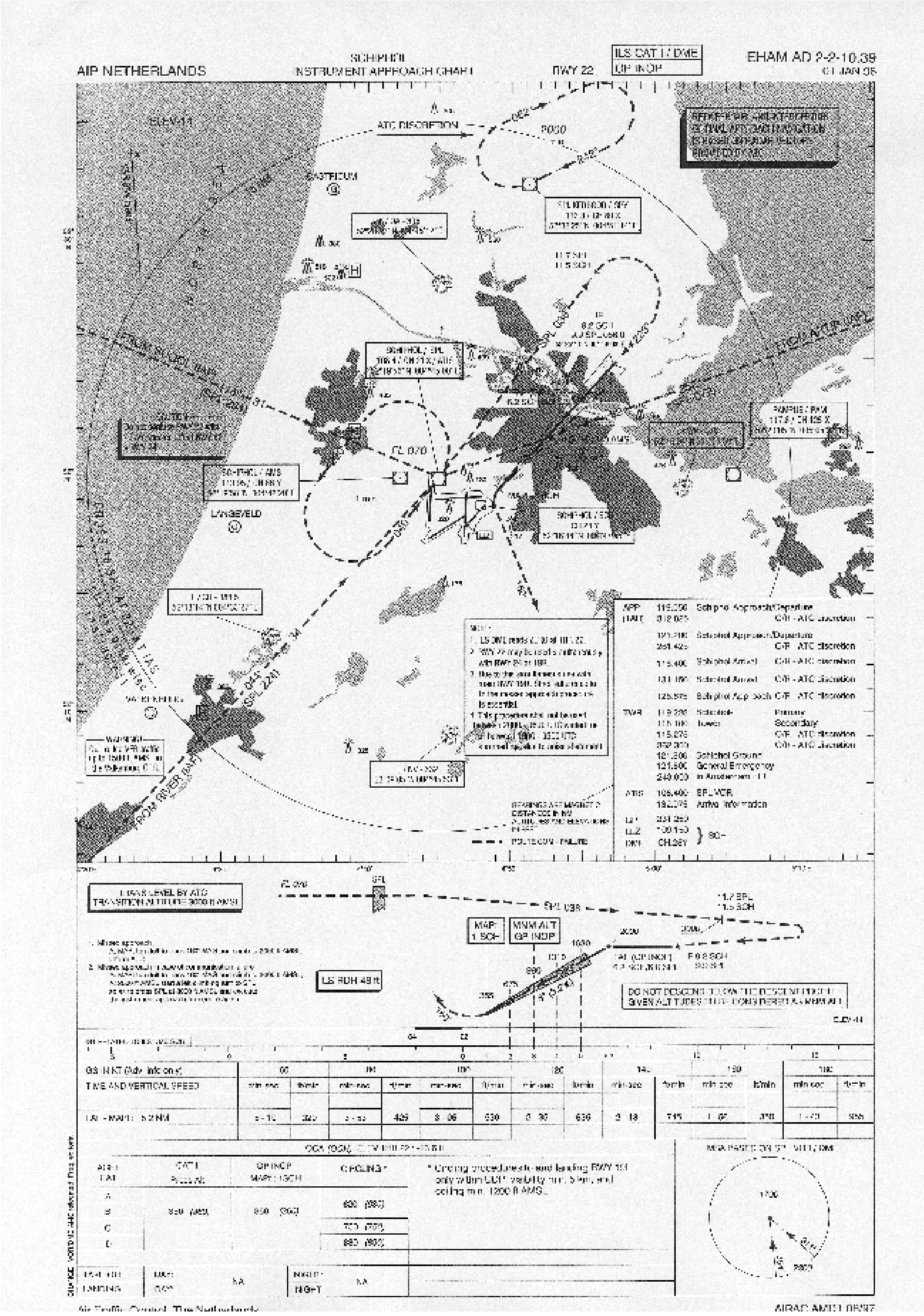
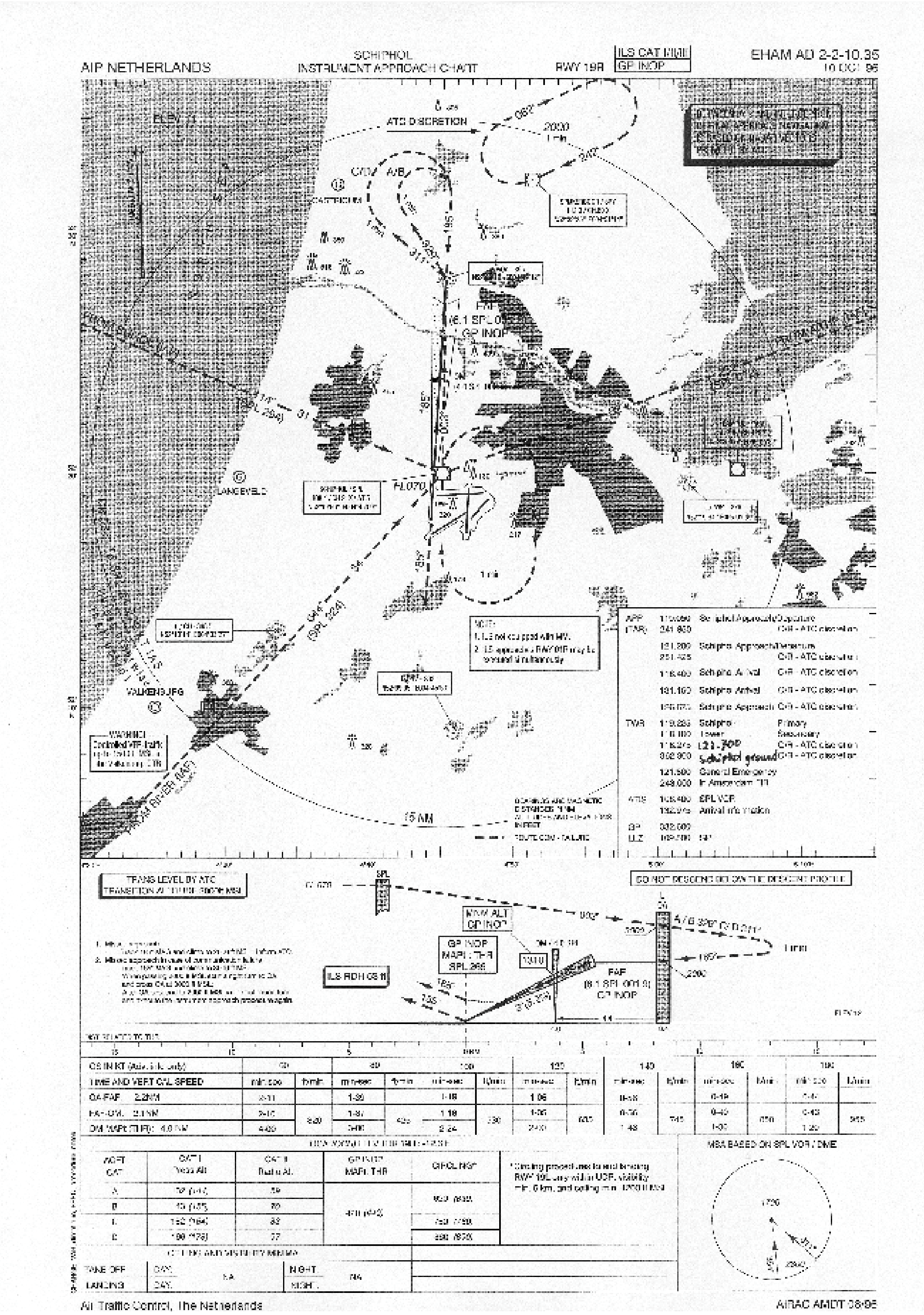
Appendix A Current AIP approach plates for Schiphol runways 19R and 22




AIP NETHERLANDS
SCHIPHOL
INSTRUMENT APPROACH CHART
RWY 19R
ILS CAT I/II/III
GP INOP
EHAM AD 2-2-10.35
ATC DISCRETION
CASTRICUM
LANGEVELD
VALKENBURG
FL070
15 NM
TRANS LEVEL BY ATC
TRANSITION ALTITUDE 3000ft MSL
DO NOT DESCEND BELOW THE DESCENT PROFILE
MNM ALT
GP INOP
FAF
MSA BASED ON SPL VOR / DME
Air Traffic Control, The Netherlands
AIRAC AMDT 08/95