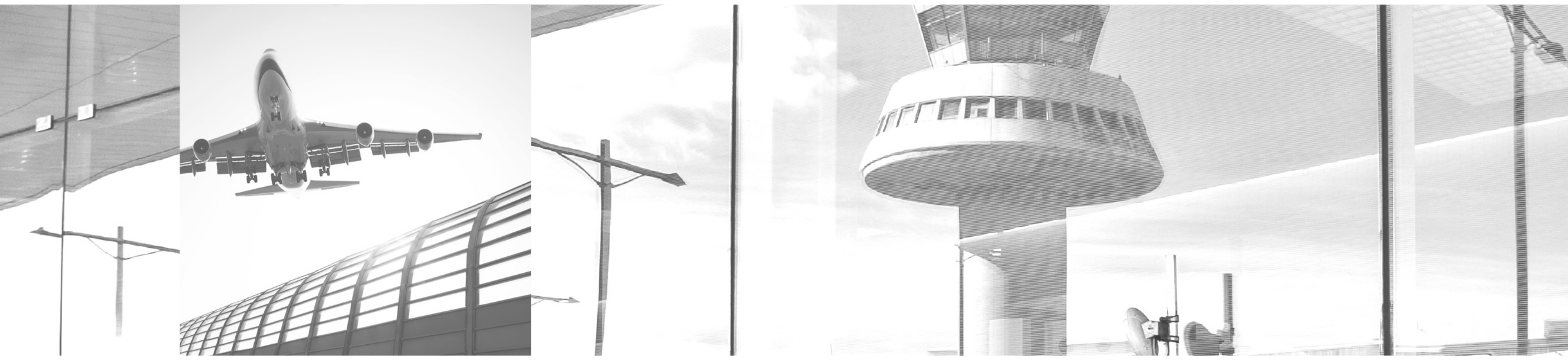

Holding Support for Area Control

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Colophon

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Summary

The operational concept in the Dutch Airspace does not include the use of holding patterns in nominal situations. Instead, vectoring is used to create the optimal approach sequence. Holding is only used during non-nominal conditions, because significant delays may need to be given to inbound flights under such conditions.

Nevertheless, holding operations happen regularly at Schiphol, for example due to stormy conditions or low visibility. Although the current holding procedures at Schiphol are safe, they are not always optimal. Therefore, improvements for holding operations may be possible that improve overall performance and predictability. One of the findings of current holding operations is the unpredictability of the duration of holding orbits. Turns sometimes take well above the expected 60 seconds, up to 100 seconds in the worst-case scenario.

This report provides a list of solutions based on two solution categories:

- Ground-based solutions
    - Flight procedure design
    - Air Traffic Controller (ATCO) systems
- Airborne solutions
    - Flight deck systems

These individual solutions are evaluated and combined in four high-level concepts. Concept 1 consists of manual airborne solutions. In this concept flight crew becomes responsible for Expected Approach Time (EAT) adherence. The flight crew will manually calculate the required duration for the remaining orbit(s) and adjust the legs accordingly in the Flight Management System (FMS).

Concept 2 is similar to concept 1 but includes automated features. In this case the FMS will automatically calculate and execute the required orbit durations to hit the EAT at the right time. In addition, using Controller Pilot Datalink Communications (CPDLC), EATs may automatically be uplinked.

Concept 3 aims to optimize current holding patterns by using altitude-based holding limits. Using shorter holding legs at the lowest levels, aircraft are being kept close to the fix when the EAT is nearby.

Concept 4 includes a different way of using the holding patterns. Instead of aligning the pattern with the route towards the airport, the holding is rotated 90 degrees and the holding fix is separate from the Initial Approach Fix (IAF). This will help the ATCO to vector aircraft out of the holding towards the fix while hitting the IAF at the EAT.

1 Introduction

1.1 Background

The Knowledge and Development Centre Mainport Schiphol (KDC) has given the consortium MovingDot-NLR the assignment to develop high level holding support concepts for Area Control. The operational concept in the Dutch Airspace currently does not include the use of holding patterns in nominal situations. Instead, vectoring is used to create the optimal approach sequence. Holding is only used during non-nominal conditions, because significant delays may need to be given to inbound flights under these conditions.

Nevertheless, holding operations happen regularly at Schiphol, for example due to stormy conditions or low visibility.

1.2 Objective

Current holding procedures at Schiphol are not always optimal. Therefore, improvements for holding may be possible that improve overall performance and predictability. This report assesses different types of possible solutions. Based on these solutions, several high-level concepts are designed.

1.3 Scope

The following aspects define the scope of this research:

- Only holding in disrupted conditions is considered
- Each solution will be verified for PANS-OPS compliance
- No full PANS-OPS design will be performed
- No simulations will be performed

1.4 Reading guide

This report includes the following chapters:

- Chapter 2 describes current holding procedures for Schiphol and provides background on the assignment's objective
- Chapter 3 explains the methodology used for this research
- Chapter 4 lists the identified individual solution elements
- Chapter 5 presents four high-level concepts
- Chapter 6 contains a list of recommendations

2 Status quo

Holding procedures in the Netherlands are currently used in disrupted situations, especially when the capacity of the TMA is lower than the demand. Current holding procedures as flown by aircraft are however not always fully compliant with procedure design regulations, namely PANS-OPS. The consortium also found that the actual holding performed by aircraft may differ significantly from the published criteria, meaning aircraft take longer than the defined time to execute the entire procedure. This chapter will elaborate on how holding procedures are defined and used in the Netherlands.

2.1 Holding in general

A standard holding pattern (Figure 1) uses a fix, such as a beacon (VOR, NDB, DME), a waypoint, a radial/DME fix or an RNAV waypoint, as the basis to define the whole procedure. It is defined as a racetrack pattern where the only geographically defined point is the previously mentioned holding fix, often corresponding to an Initial Approach Fix (IAF) or Missed Approach Fix (MAF). The fix is the start of the first turn of the maneuver. A standard holding pattern takes about 4 or 5 minutes of flight to complete – one minute for each 180° turn, and one minute or one and a half minutes for each straight leg, depending on the altitude. Source: ICAO Doc 8168 (PANS-OPS)

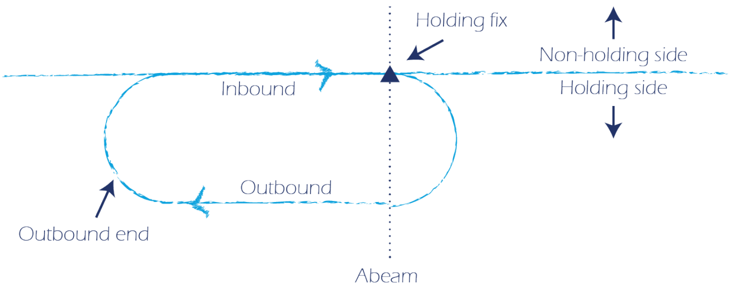
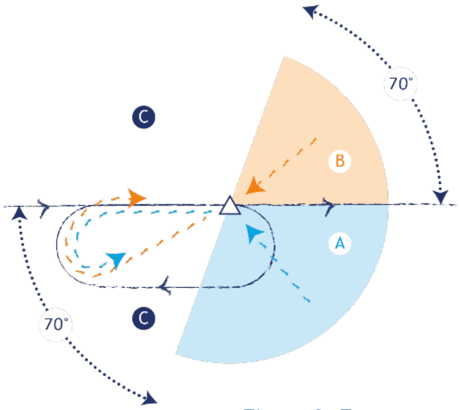


Figure 1. Standard holding pattern

A non-standard holding pattern may use, for example, left hand turns or other than standard values for the outbound legs. Most aircraft FMS can modify or generate a custom holding pattern, in which pilots can define the holding fix, the direction of the turn and the length of the legs.

The holding procedures are usually designed such that the inbound leg is aligned with the leg following the exit of the holding, towards the next fix. This means that it is not necessarily aligned with the incoming leg, and for this reason standard procedures are in place for joining the holding procedure. These procedures are defined in Figure 3. If coming in from the white region the holding is joined directly, and if coming from the other two regions either a parallel or teardrop entry is used.



The entry sector is based on the heading at which the aircraft approaches the fix. There are three different entry sectors with the following accompanying entry procedures:
***A.** Parallel entry*
***B.** Teardrop or offset entry*
***C.** Direct entry*

Figure 2. Entry procedures for holding patterns

As with all procedures, holding patterns also have a protection area associated with them and must be considered when designing such a procedure. As holding patterns are not flown in a strictly defined geographical area, but are rather time based, the protection areas end up being significantly large. These protection areas are then used to estimate where other routes can be placed in the proximity of the holding; a route's protection areas shall not penetrate the protection area of the holding.

The protection areas of the current holding patterns are shown in Figure 3. It can be seen that a big area of the airspace is occupied by the protection areas (shown in pink), which make it difficult to introduce new IAFs in the Dutch airspace – given the small size of the Amsterdam FIR - to accommodate more holding procedures.

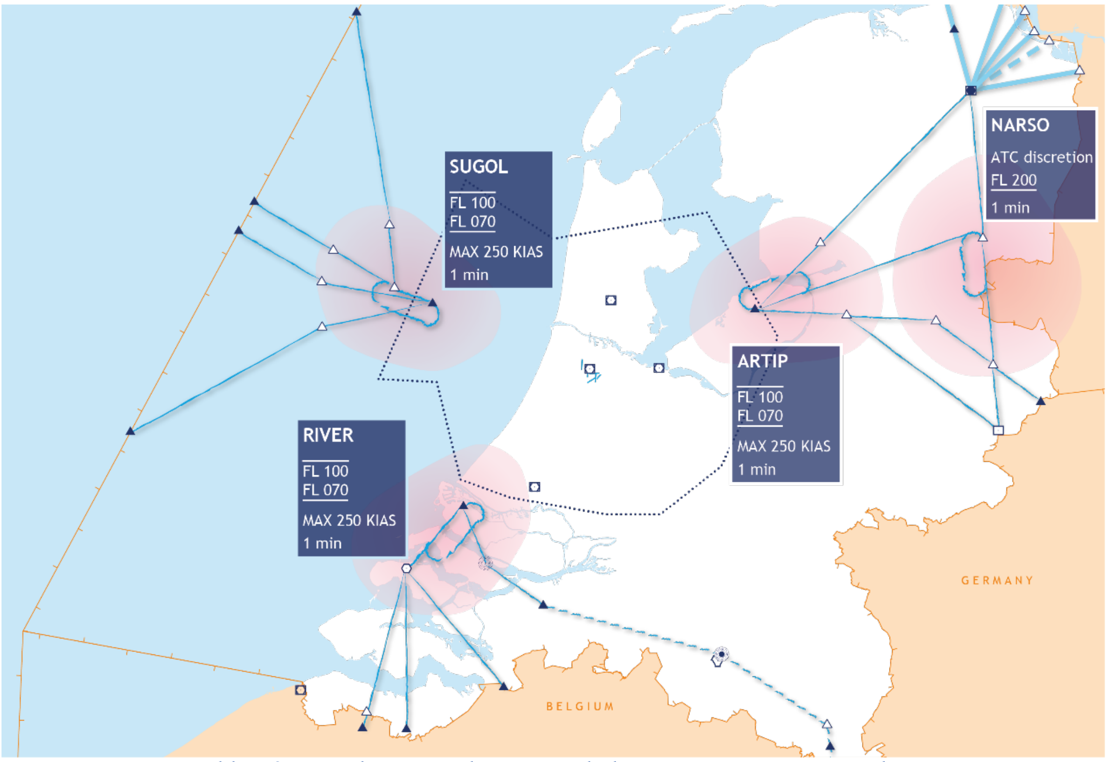


Figure 3. Holding fixes in the Amsterdam FIR, including protection areas in pink

After analyzing the holding performance for aircraft, and the way these are defined in the FMS, it became apparent that aircraft take longer than the defined time to complete the entire pattern. Although the straight leg time is well respected, the turning time is affected by parameters such as aircraft altitude, aircraft speed and atmospheric temperature. This led to the observation that each of the 180° turns takes well above 60 seconds and up to 100 seconds in the worst case scenario. This results in an unpredictable procedure, as the controller cannot reliably know when the aircraft can be expected to be at the holding fix again. Table 1 contains a set of values for different conditions of holding, which were calculated for this report:

Table 1. Turn duration in [s] for flight level, indicated airspeed and temperature

	190 KIAS			210 KIAS			230 KIAS		
Altitude	ISA-10 (cold)	ISA (avg)	ISA+10 (warm)	ISA-10 (cold)	ISA (avg)	ISA+10 (warm)	ISA-10 (cold)	ISA (avg)	ISA+10 (warm)
FL 070	73	74	76	81	82	83	88	90	91
FL 080	74	75	77	82	83	85	90	91	93
FL 090	75	77	78	83	85	86	91	93	94
FL 100	76	78	79	84	86	88	93	94	96
FL 110	77	79	81	85	87	89	94	96	98
FL 120	79	80	82	87	89	90	95	97	99
FL 130	80	82	83	88	90	92	97	99	101
FL 140	83	84	86	90	91	93	99	100	102

2.2 Holding in the Dutch ATM system

The current holding areas are located at the three Initial Approach Fixes (IAFs): ARTIP, SUGOL and RIVER. This allows Area control (ACC) to feed the TMA with flights at the required times, with optimized times to achieve maximum runway throughput. An additional holding fix, for situations when ARTIP has insufficient capacity, is located at waypoint NARSO. The holding fixes and accompanying holding procedures are shown in Figure 3.

The holding areas at the IAFs are all aligned with the inbound routes, so these holdings are normally entered directly. The entry procedure for the NARSO holding area depends on the origin of the flight. It must be noted that, unlike the holdings at the IAFs, the holding at NARSO has a left hand turn instead of the standard right turn.

Schiphol airport tries to avoid the use of holdings under nominal conditions, as opposed to other busy European airports. However, in non-nominal conditions the use of holdings is often necessary. The definitions of nominal and non-nominal conditions as used at Schiphol are given below.

Nominal conditions

Nominal conditions at Schiphol have the following characteristics:

- LVNL is able to handle the maximum declared capacity
- The operational concept during nominal conditions comprises merging traffic streams by means of speed control and radar vectors

Non-nominal conditions

Non-nominal conditions may be split into disrupted conditions and exceptional conditions.

Disrupted conditions have the following characteristics:

- Reduced capacity due to limiting conditions such as weather (winds or reduced visibility)
- Holding areas are used to accommodate the traffic surplus
- Disrupted conditions occur regularly

Exceptional conditions have the following characteristics:

- Airport or airspace closure due to emergency situations
- All traffic is instructed to hold
- Traffic already flying in the TMA may also be directed to holding areas
- Exceptional conditions occur rarely

Exceptional conditions are very rare at Schiphol. Development of solution strategies for these conditions require unique principles and considerations. Therefore, this report will focus on disrupted conditions.

Finally, it must be noted that the current holdings are not fully compliant with PANS-OPS criteria. PANS-OPS criteria prescribe that holdings for altitudes lower than FL140 shall have published straight legs of at least one minute, and 1.5 minute for altitudes higher than FL140. The holdings at the three IAFs (ARTIP ,SUGOL and RIVER), while published in the AIP for altitudes up to FL100, are allowed to be used up to FL240 according to the ACC manuals with one minute legs [ref. ACC manual], while PANS-OPS prescribes at least 1.5 minute legs for this case. The fourth holding, located at NARSO (east of the Amsterdam FIR), is published for use above FL200 with one-minute legs, which also contradicts the PANS-OPS criterion of at least 1.5 minute in terms of straight leg length for holdings above FL140.

2.3 ATCO support at LVNL

Currently, the ATCO has the following holding support tools at their disposal:

- Vertical view-window (Figure 4)
- Basic or extended stack list (Figure 5)

The vertical view-window aids with aircraft label decluttering and is geared towards augmenting the situational awareness of ATCOs responsible for managing holding flights, making optimum flight level management possible. However, this tool does not provide the ATCO with any form of automated decision support on how to manage holding traffic, specifically with ensuring that flights leave the holding on time. As such ATCOs must rely purely on their training and experience to control and separate the aircraft performing holdings. Although this approach works in practice, it has a negative effect on ATCO workload during peak demand periods. Additionally, the current method does not help ensure that flights leave the holding in accordance with the desired time, sequence and spacing, and can, therewith negatively influence runway throughput.

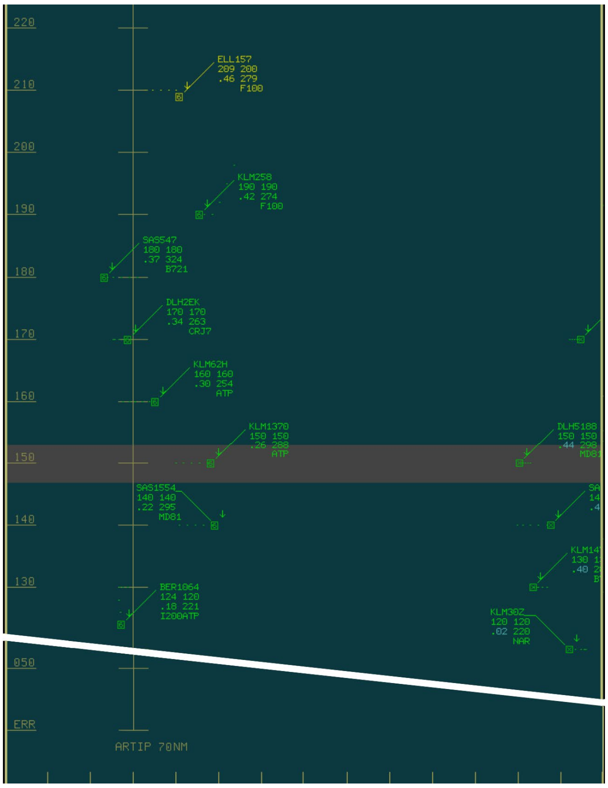


Figure 4. Example of the vertical view tool

The basic and the extended stack lists provide information on inbound flights arriving via one of the holding areas. Relevant information includes the Estimated Time Over (ETO), which is the estimated time the flight will reach the holding area, and the Expected Approach Time (EAT), which is the time when the flight is allowed to leave the holding area. When the EAT is later than the ETO, the flight in question needs to be delayed. This delay can be realized using a holding pattern, but for small delays it is also possible to use delaying radar vectors. The EAT is shared with the flight crew. The ACC ATCO is expected to deliver the aircraft at the holding fix at the EAT +/- 2 minutes.

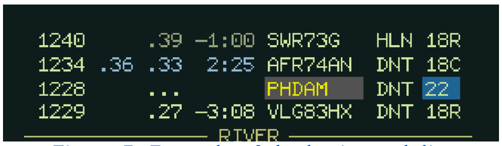


Figure 5. Example of the basic stack list

3 Methodology

3.1 Approach of this study

A step-by-step approach was used in this project to identify new options for holding procedures at Schiphol. The project began by identifying individual solutions that could improve holding performance in a brainstorm format. These individual solutions considered holding improvements from the perspective of the ATCO, flight-deck and holding procedures. Each identified solution was analysed to determine the potential impact for Schiphol holding operations. Subsequently, promising solutions were combined to develop holding concepts for Schiphol. These concepts were evaluated by operational experts (current and former ACC ATCOs and pilots) who rated the concepts using predefined evaluation criteria.

3.2 Solution categories

The proposed solutions were classified in two different categories, based on whether they pertained to modifications on the ground (flight procedure design or ATCO systems) or they affected the aircraft (flight deck systems).

3.2.1 Ground-based solutions

Flight procedure design

These solutions pertain to modifications to existing procedures considering the holding usage, based on existing designs elsewhere or by the introduction of completely new concepts that would enhance the efficiency of holding operations.

ATCO systems

These solutions involve a change of or addition to the tools a controller has available in his working position, or the introduction of additional logic in the working procedure.

3.2.2 Airborne solutions

Flight deck systems

These solutions involve changes and/or additions to the tools and systems onboard aircraft and to support the introduction of new capabilities on the FMS for improved performance.

3.3 Evaluation of solutions

Each of the identified new options was first described and then rated based on different criteria. First, the solutions were categorized based on the categories defined in section 3.2, with a description of what the solution aim at solving. After this description, the advantages and disadvantages of each solution were described, based on qualitative judgement of the project team, keeping ATCO, flight deck and procedure design aspects in mind.

3.4 High-level concepts

Once the individual solutions were fully characterized, the high-level concepts were described. As with the solutions, two main categories were defined: air and ground based concepts. Additionally, both these categories were further divided in two temporal sub-categories, namely the potential to be introduced in the short term or medium-to-longer term.

Based on these four high-level categories, the individual solutions that could pertain to each of them were marked accordingly. Taking the evaluation of the solutions into account, four final concepts were proposed, one for each of the proposed topics. These four concepts were developed by com combination of solutions. These high-level concepts were then submitted for rating to the operational experts (including ACC ATCO(s) and pilots) to have a broad overview of how beneficial each of the concepts could be. The rating was performed based on predefined evaluation criteria. The criteria took into account aspects such as complexity, workload, predictability and acceptability for both ATCOs and pilots, the expected increase of capacity and EAT adherence, as well as implementation difficulties and PANS-OPS compliance.

4 Individual solutions

4.1 Flight procedure design

Geographic uniformity

Since the current holding patterns are defined by time and aircraft fly at different speeds (based on aircraft performance), a large differentiation in pattern sizes may arise in a single stack. This has a a direct impact on ATCO workload as it makes aircraft position and heading less *predictable*.

One way to solve this is to define the holding legs based on distance (Figure 6). With this approach, the leg lengths will geographically be the same, irrespective of aircraft performance. Only the turn radius will depend on aircraft type. However, the downside is that slower aircraft will take more time to complete a single orbit.

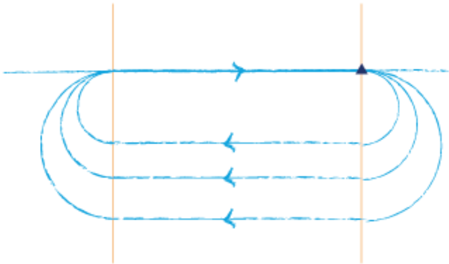


Figure 6. Distance-based holding patterns

Another solution is to set more restrictive speed limits in the holding. This will also result in a smaller range of pattern sizes. Upper limits of holding speeds are prescribed by PANS-OPS. However, aircraft operators want to fly a speed which is optimized for fuel efficiency.

A more rigid way to ensure uniformity is to use separate holdings based on aircraft performance (Figure 7). Separate category-based holding fixes would require a lot of space and complex procedures. Instead of using separate fixes, differentiating aircraft categories using left-hand turns and right-hand turns respectively is also suggested. This idea is complex and still requires a lot of space and probably being not very effective. Therefore category-based holding was not considered further.

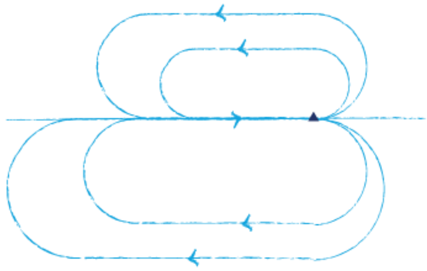


Figure 7. Category-based holding patterns

Solution		Advantages/disadvantages
Distance-based holding patterns	+	turn position will be more predictable
	-	slower aircraft will fly long patterns
Restrictive speed limits	+	smaller range of pattern sizes
	-	aircraft may not fly at optimal speed for fuel efficiency
Category-based holdings	+	more predictable patterns
	-	requires large amounts of space
	-	complex operations dependent on implementation

Spreading the workload

Using multiple stacks may spread workload amongst ATCOs. It must be noted that a stack at a single holding fix may also be divided amongst several ATCOs based on certain levels, but this solution does clutter the regular radar view. Using multiple holding fixes (Figure 8) may be more promising. Such a concept is already in place in the Amsterdam FIR, in the NARSO holding, which can be used as an overflow for the ARTIP holding.

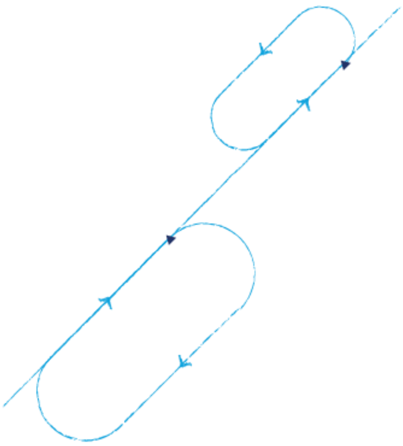


Figure 8. Multiple holding fixes

In the London TMA, lower holding levels are controlled by Approach (Figure 9). Although this spreads workload by decreasing ACC workload and introducing additional APP workload, it also entails a different operational concept. In London, the ACC ATCO is no longer responsible for on-time IAF delivery (at the EAT). Instead the Approach ATCO can take aircraft out of the holding pattern based on their own demand.

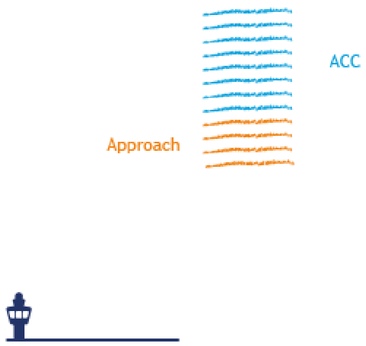


Figure 9. Lower stack levels managed by approach control

Solution		Advantages/disadvantages
Multiple fixes	+	increases holding capacity
	-	may not be possible in every sector due to lack of space
Divide stack levels over multiple ATCOs	+	spreads the workload
Lower stack levels managed by APP	+	decreases ACC workload
	-	increases APP workload
	-	does not fit in current operational concept

Separating the holding fix from the metering fix

Because the IAF is also the holding fix in the Amsterdam FIR, there is very little room to take aircraft out of the holding at the right moment over the IAF. This also adds to the fact that in the current situation, most aircraft are vectored out of the holding, instead of exiting the holding when passing the fix. Another problem with the current situation is that at lower levels, aircraft enter and leave the TMA when holding, while the aircraft is still under control of ACC.

By introducing a separate holding fix from the IAF, the ATCO is provided with more space to time the aircraft over the IAF (Figure 10). A more profound option is to change the holding orientation with respect to the intended direction (Figure 11). When the holding is oriented perpendicular to the outbound direction, there are only a few parts of the holding orbit in which the aircraft is flying away of the IAF. This makes it easy for the ATCO to vector the aircraft out of the holding at almost any point.

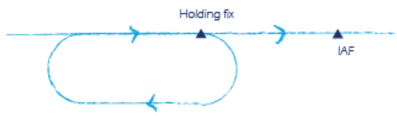


Figure 10. IAF separate from holding fix

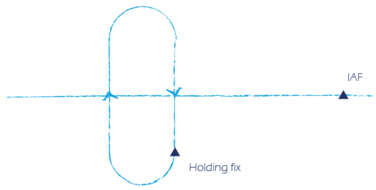


Figure 11. IAF separate from holding fix and changed holding orientation

One must note that the holding fix will be closer to the FIR boundary. This may make it more difficult to fill the stack at the lower levels.

Solution	Advantages/disadvantages
Separate holding fix	+ more space to vector aircraft to the IAF, or create a sequence - Holding fix will be closer to FIR boundary, so less time to descent aircraft to lower stack levels
Separate fix with changed holding orientation	+ Large part of the orbit accommodates easy vectoring out of the holding

Level-based designs

At a single holding fix, multiple holding designs can be put on top of each other (Figure 12). Reasons to do this are:

- PANS-OPS prescribes different design criteria for certain flight levels
- Another holding orientation might be required due to obstacles at lower levels, or routes at higher levels

Level-based holding designs is a useful method to meet multiple requirements at a single holding fix.

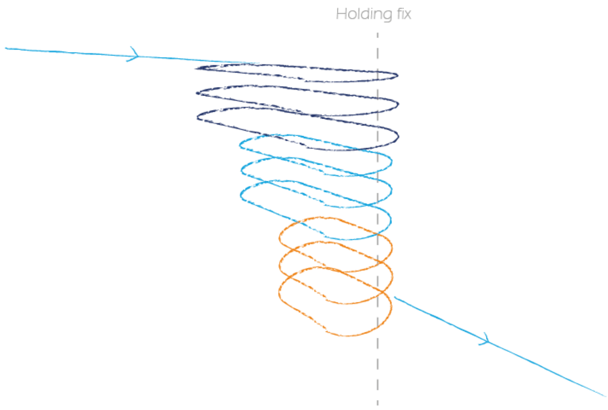


Figure 12. Level-based holding designs

Solution	Advantages/disadvantages
Level-based designs	+ Use different design criteria to meet PANS-OPS + Accommodate for obstacles and routes

Alternative designs

Conventional holdings consist of a fix, two straight legs (time- or distance-based) and two turns. This method suffices for inflight delay absorption but is less convenient for inbound timing and sequencing.

A triangular design (Figure 13) decreases the impact of the radius of the inbound turn in a conventional holding. Instead of flying 180° away from the fix, the maximum angle in a triangle is 120°. The effect is dependent on the length of the straight legs. Flying eight-shaped patterns (Figure 14) will let the aircraft always turn towards the fix.

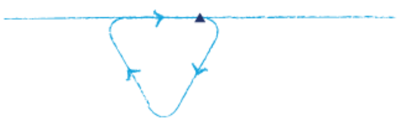


Figure 13. Triangular holding patterns

Figure 14. Eight-shaped holding patterns

The point-merge concept helps with sequencing and merging different traffic flows. For indefinite delay, holding is done before entering the point-merge arcs (Figure 15), but one could also think of flying the arcs in repetitive loops.

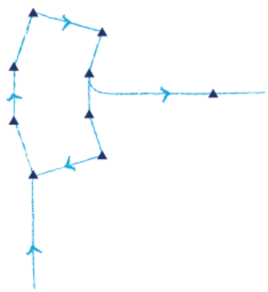


Figure 15. Repetitive point-merge arcs

Disadvantages to this solution are the amount of space required and the fact that current FMS-es are not capable of flying a route repetitively automatically.

These ideas are not investigated further because of the following reasons:

- PANS-OPS compliancy
- FMS is not capable of flying other than standard holding orbits
- Adds to existing complexity at Schiphol from a pilot perspective

Solution	Advantages/disadvantages
Triangular patterns	+ smaller turn angles - not PANS-OPS compliant
Eight-shaped patterns	+ always turn towards fix - not PANS-OPS compliant
Point-merge loops	+ helps with timing and sequencing - requires a lot of space - does not fit in current operational concept - FMS is not able to fly repetitive routes

4.2 ATCO systems

HMI improvements

Some relatively simple Human Machine Interface (HMI) improvements will provide the ATCO with additional information, such as:

- Showing the EAT / time remaining to EAT in the labels on the vertical view tool
- Colour coding aircraft on radar screen based on criteria such as time to EAT

Decision Support Tools

Support by a Trajectory Predictor (TP) will improve decision making. This will enable the ATCO to probe timing results before actually giving the vector-instructions. Trajectory prediction is not only beneficial for holding operations; for regular vectoring a TP can be helpful as well. A complex TP that can assess the time an aircraft needs to reach the holding fix taking into account turn rates and other dynamic aspects of the flight, could lead to ACC ATCOs feeding the TMA in a more accurate manner.

4.3 Flight deck support

Holding procedures are not designed for accurate fix metering, and as stated in Section 2.1, the orbit duration varies substantially based on altitude, aircraft speed and aircraft performance. Since the ATCO has an EAT to adhere to, the flight deck could help to make this happen. In the simplest way, the target time over the fix is communicated to the flight crew via R/T. The flight crew then adjusts the legs of the last few orbits to make the target time over the fix. This requires some calculations at the flight deck:

1. Determine the current orbit duration; especially the turn duration
2. Determine the time remaining until the target time
3. Adjust the outbound legs for the last or last two orbits

Although this increases the workload for the flight crew, it also enhances flight deck predictability. Added complexity is that flight crews need to be trained as this will be an exceptional procedure.

Of course, further steps would be automating this process:

- Communicating the target time via CPDLC instead of RT
- Making the FMS capable of adjusting orbit duration instead of merely leg length
- Making the FMS capable of meeting a target time over the fix by automatically adjusting the orbits

Current FMSs do not have the functionalities listed above. Since holding procedures usually only happen during exceptional situations, and because sequencing at other airports is solved by other means (e.g. Point-merge, or managing lower holding levels by Approach), a convincing business case for FMS upgrades is not expected.

Solution	Advantages/disadvantages
Manual flight deck EAT adherence	+ increased predictability for flight crew - increased flight crew workload - increases complexity (flight crews are not used to this) - EAT adherence depends on flight crew
Automatic FMS EAT adherence	+ improved EAT adherence

Solution	Advantages/disadvantages
	+ easy to use + reduced RT - current FMS-es do not have the required capability (and no positive business case is foreseen in the near future)

5 High level concepts

5.1 Concept 1 – Manual airborne-based solutions

Concept 1	
Characteristics	• Flight crew becomes responsible for EAT adherence • No system changes required
Options	• N/a
Time frame	• Short-term

Holding orbits take more than 4 minutes; turn duration depends on several factors and usually takes between 70 and 100 seconds per turn. The exact holding duration is therefore unknown to the ATCO. This concept moves EAT adherence responsibilities from ground to air, using the following steps:

- The ATCO communicates the intended time (e.g. EAT) over the metering fix (e.g. IAF)
- The flight crew will manually calculate the required duration for the remaining orbit(s)
- The lengths of the legs are manually adjusted accordingly in the FMS

This concept does rely on a certain EAT stability, since flight crews need to plan in advance towards a known and stable target.

5.2 Concept 2 – Automated airborne-based solutions

Concept 2	
Characteristics	• Flight crew becomes responsible for EAT adherence • FMS automatically adjusts holding orbits to reach IAF at the EAT • Current FMS-es do not have the required capabilities (hence dependent on FMS manufacturers)
Options	• EAT is automatically uplinked to the aircraft
Time frame	• Long-term

Similar to concept 1, responsibilities in the EAT adherence process are moved from the ground to the air, but with automated features. In this concept, the FMS is able to adjust the last orbit(s) to meet the desired time over the holding fix:

- The ATCO communicates the time over the metering fix
- The flight crew enters this time in the FMS
- The FMS will automatically calculate the required orbit durations and adjusts the orbits accordingly

Additional automation would be optional:

- The EAT is automatically uplinked to the aircraft and is continuously updated

5.3 Concept 3 – Optimization of holding procedures

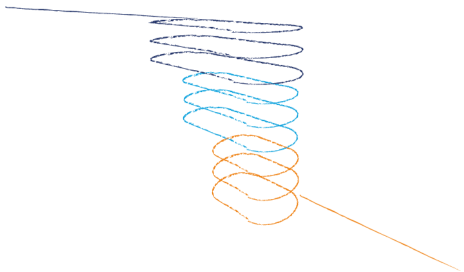
Concept 3	
Characteristics	• Altitude-based holding limits (speed and inbound timing) • Shorter holding legs at the lowest levels • Holding limits are compliant and optimized
Options	• HMI improvements to provide ATCO with additional information • Use multiple holding fixes along the arrival route
Time frame	• Short-term/medium-term

Procedure design

The current holding designs at the IAFs are 'one size fits all' and are not PANS-OPS compliant[1]. Concept 3 aims to optimize the current holding patterns, using the following methods:

- Create uniformity among the patterns
- Keep the aircraft close to the fix
- Provide the controller with additional information

For PANS-OPS compliance and holding optimization, holding limits will be based on altitude.



Example of altitude-based holding limits:

- Above FL200: 1.5 min / 265 KIAS max
- FL140-FL200: 1.5 min / 240 KIAS max
- FL70-FL140: 1 min / 220 KIAS max
- FL70-FL100: 0.5 min ATC discretion

Figure 16. Example of the procedure design aspects of concept 3

The lowest levels in the stack will have shorter legs compared to standard holdings, in order to keep aircraft closer to the fix. Although PANS-OPS does not allow to design standard holding patterns with legs below 1 minute, operationally this can be applied (tactically), accompanied by a note in the approach charts (such that flight crews are informed and know what to expect), e.g.:

"Expect 0.5 min inbound timing below FL100 by ATC discretion"

Optionally, two or more separate holding fixes can be used along the arrival route.

[1] When using time-based holding patterns, PANS-OPS prescribes the following inbound timings for a standard hold:
- 1 min at or below FL140
- 1.5 min above FL140

However, the standard holding patterns in the Amsterdam FIR have an inbound timing of 1 minute for all levels. The holdings at the IAFs do not mention an upper limit and are operationally used above FL140. The NARSO holding has a lower limit of FL200.

ATCO system support

Some relatively simple HMI improvements will provide the ATCO with some additional information, such as:

- Show the EAT / time remaining to EAT in the labels on the vertical view tool
- Indicate position in the holding pattern in the stack lists (e.g. moving away or towards holding fix, using colors)

5.4 Concept 4 - Rethinking holding procedures

Concept 4	
Characteristics	• Separate holding fix from IAF • Change in holding orientation • Holding limits are compliant and optimized • HMI improvements to provide ATCO with additional information
Options	• Develop trajectory predictor • Holding legs may be distance based • Use multiple holding fixes • Separate holding fix without change in holding orientation
Time frame	• Medium-term/long-term

Procedure design

The current holding patterns at the IAFs are aligned with the outbound route towards the airport. Since the IAF is used as the holding fix, the holding fix is also the metering fix. In order to hit the metering fix at the intended time, the ATCO uses vectors to accomplish the right timing. However, when the aircraft is in the outbound leg and it turns too late, the delay effect is doubled (delay from flying too long outbound plus the additional distance flying inbound).

Separating the holding fix from the metering fix gives the controller more space to hit the metering fix at the intended time. Changing the holding orientation with 90 degrees borrows principles from the point-merge concept. Regardless of the aircraft position in the pattern, the design enables the ATCO to vector the aircraft out of the holding towards the fix. Using distance-based legs, the holding pattern will become more uniform among different aircraft types.

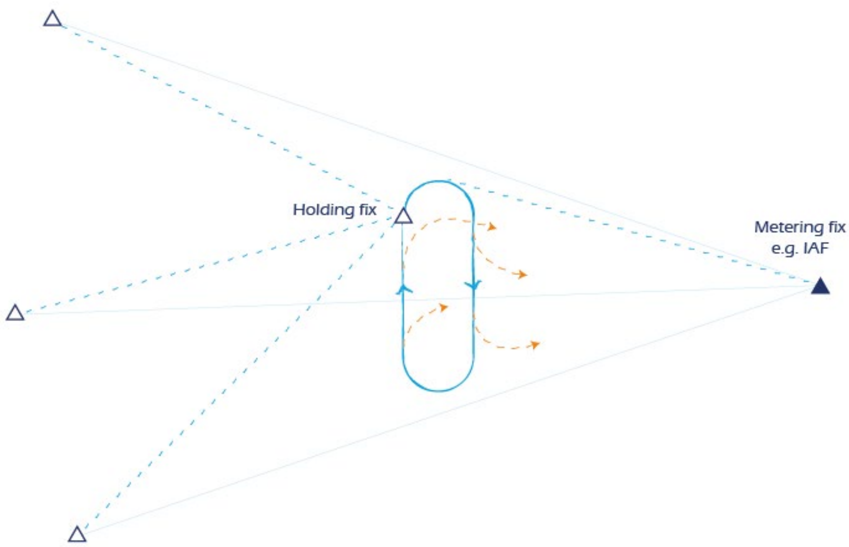


Figure 17. Schematic overview of the procedure design of concept 4

ATCO system support

As in concept 3, HMI improvements will provide the ATCO with additional information. Support by a Trajectory Predictor (TP) will improve decision making. This will enable the ATCO to probe timing results before actually giving the vector-instructions. Trajectory prediction is not only beneficial for holding operations; for regular vectoring a TP can be helpful as well.

5.5 Concept evaluation

This section will provide a summary of the evaluations done by various experts. The evaluation sheets can be found in Annex A.

ATCO perspective

From the ATCO perspective, the first two concepts are promising when aircraft are indeed able to hit the EAT. For the first concept, where the flight crew is required to manually adjust the orbits to make the EAT, ATCOs are a little hesitant. ATCOs indicate that maintaining control is desirable, since in the current situation accuracy is flight crew dependent.

The third concept will not drastically change operations compared to the status quo. Moreover, requesting pilots to fly shorter legs is already operationally feasible and is used when vectoring aircraft out of the holding pattern.

Concept 4 is considered the most promising by the ATCOs, since it is based on vectoring aircraft out of the holding pattern, which is already common practice. This design makes this practice easier and more efficient.

Flight crew perspective

Out of the four concepts, the pilot involved in this study found concept 4 to be the best balance of all the metrics considered. Although concept 4 introduces a radically new holding procedure, the pilot judged that this would not add to flight-deck workload when compared to current-day operations. Furthermore, the pilot regarded this concept to be very beneficial for EAT adherence and capacity utilization, while also being feasible in practice.

The pilot also found concept 2 to be very promising. In fact, this concept was deemed to be the best in terms of flight-deck workload, as long as the EAT provided to the flight-deck was stable. However, because this concept requires modifications to the FMS, the pilot, similar to the ATCOs, considered this concept to be unfeasible. Nonetheless, the underlying principle behind concepts 1 and 2, where the flight-deck becomes responsible for EAT adherence, was considered to be a good way to increase the predictability of holding operations for both the flight crew and for ATCOs.

The pilot was not in favour of concept 3. In his opinion, the added complexity of this concept would be detrimental to both the workload and the situational awareness of the flight-crew, and would require increased R/T with ATCOs to implement in practice.

Systems perspective

The AAA/iCAS systems expert involved in this project considered all concepts that included changes to ground and/or air-based systems most likely to yield tangible improvements to the ATM system in terms of EAT adherence and traffic flow predictability. However, he also acknowledged that these types of solutions are difficult to realize in practice because such technology-based solutions tend to be time consuming and expensive to develop, test, certify and introduce in daily operations. For these reasons, concepts 2-4, while judged to be good options for long-term upgrades, were not rated favourably in terms of implementation. In contrast, concept 1, which only requires some mild training updates for flight-crews, was regarded by the systems expert as likely to deliver measurable improvements during holding procedures in the short-term without the need for significant capital investment.

6 Recommendations

This report has highlighted various solutions and developed several high-level concepts for holding support. Before one of the concepts can be selected for further development, several follow-up steps are recommended.

- Perform an extensive functional analysis for Decision Support Tools (DST) to quantify both the functional and technical requirements for these systems
- A human centred approach to DST should be used such that controller situational awareness is increased without providing controllers with a fully automated approach to holding procedures
- Develop multiple prototype versions of the desired DST under consideration
- Fine-tune the parameters of novel holding procedures described in this report using Fast-Time Simulation (FTS) experiments. This will also help to *quantify* the benefits of such procedures. Perform Real-Time Simulation (RTS) experiments using current ATCOs and pilots to validate the design of holding procedures that were deemed to yield the best performance according to FTS. The results of RTS can be used to convince relevant stakeholders on the benefits of the newly developed procedures.
- Perform RTS to validate the design of ATCO DST for increasing ATCO situational awareness and predictability during holding procedures.
- For concept 4, simulate the effect of the fix position (also with respect to the FIR boundary).
- For concept 4, simulate the effect of the orientation angle.
- Design a new holding situation in concurrence with the airspace redesign project.
- Take into account requirements for iCAS/systems implementation.
- Through information sharing increase ATCO and pilot awareness of the factors that contribute to the variance in aircraft turn duration during holding procedures.

Abbreviations

A	ACC	Area Control Centre
	APP	Approach Control
	ATC	Air Traffic Control
	ATCO	Air Traffic Controller
	ATM	Air Traffic Management
C	CPDLC	Controller Pilot Datalink Communications
D	DST	Decision Support Tool
E	EAT	Expected Approach Time
	ETO	Estimated Time Over
F	FTS	Fast-Time Simulation
	FL	Flight Level
	FMC	Flight Management Computer
	FMS	Flight Management System
H	HMI	Human-Machine Interface
I	IAF	Initial Approach Fix
K	KDC	Knowledge and Development Centre Mainport Schiphol
	KIAS	Knots Indicated Airspeed
L	LVNL	Luchtverkeersleiding Nederland
M	MAF	Missed Approach Fix
N	NLR	Royal Netherlands Aerospace Centre
P	PANS-OPS	Procedures for Air Navigation Services – Aircraft Operations
R	RNAV	Area Navigation
	RTS	Real-Time Simulation
T	TMA	Terminal Control Area
	TP	Trajectory Predictor

Annex A Evaluation sheets

A.1 Instructions

The following instructions were used for the evaluation sheets:

Score the criteria using the following:

++ + *0* - --

The status quo (current situation) should be used as the baseline (except for Implementation).

PANS-OPS criteria do not need scoring.

A.2 ATCO 1

	Concept 1	Concept 2	Concept 3	Concept 4
ACC ATCO				
Usability	+	+	+	+
Complexity	0	++	-	0 in time ++
Workload	+	++	+	+
Predictability/situational awareness	++	++	0	+ in time ++
Acceptability	0	+	0	+
Flight crew				
Usability	--	++	0	0
Complexity	--	+	-	0
Workload	--	0	+	+
Predictability/situational awareness	+	++	-	-
Acceptability	-	+	0	0
ATM system				
EAT adherence	+	++	+	++
Capacity utilization	+	++	0	++
Compliance with current operational concept	-	--	-	--
PANS-OPS				
Compliance	n/a	n/a	Yes	Yes
Implementation				
Lead time, training, costs, etc.	+	--	-	--
Feasibility	0	--	+	+

A.3 ATCO 2

	Concept 1	Concept 2	Concept 3	Concept 4
ACC ATCO				
Usability/complexity	0	0	-	+
Workload	-	0	0	0
Predictability/situational awareness	+	+	-	0
Acceptability	0	+	0	+
Flight crew				
Usability/complexity	-	0	-	-
Workload	--	-	-	0
Predictability/situational awareness	++	++	0	0
Acceptability	+	+	0	+
ATM system				
EAT adherence	+	+	+	++
Capacity utilization	+	+	+	++
Compliance with current operational concept	+	0	0	0
PANS-OPS				
Compliance	n/a	n/a	Yes	Yes
Implementation				
Lead time, training, costs, etc.	-	--	-	-
Feasibility	+	+	+	+

A.4 Pilot

	Concept 1	Concept 2	Concept 3	Concept 4
ACC ATCO				
Usability/complexity	-	0	-	-
Workload	0	0	-	+
Predictability/situational awareness	+	++	+	++
Acceptability	0	0	-	0
Flight crew				
Usability/complexity	-	++	-	0
Workload	--	+	-	0
Predictability/situational awareness	+	++	-	+
Acceptability	0	+	-	0
ATM system				
EAT adherence	+	++	+	++
Capacity utilization	+	++	+	++
Compliance with current operational concept	-	-	0	0
PANS-OPS				
Compliance	Yes	Yes	Yes?	Yes
Implementation				
Lead time, training, costs, etc.	-	--	-	-
Feasibility	0	--	0	+

A.5 Systems expert

	Concept 1	Concept 2	Concept 3	Concept 4
ACC ATCO				
Usability/complexity	+	+	-	-
Workload	+	+	0	0
Predictability/situational awareness	--	-	+	0
Acceptability	0	+	0	0
Flight crew				
Usability/complexity	-	+	-	0
Workload	-	+	0	0
Predictability/situational awareness	++	++	+	0
Acceptability	+	++	+	0
ATM system				
EAT adherence	+	++	+	+
Capacity utilization	+	+	+	+
Compliance with current operational concept	0	0	-	--
PANS-OPS				
Compliance	n/a	n/a	Yes	Yes
Implementation				
Lead time, training, costs, etc.	+	--	-	--
Feasibility	+	-	-	--