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Evaluation of Runway Visualization Concept (MVC) for Multiple Runway Aiming Points (MRAP) operations using GBAS

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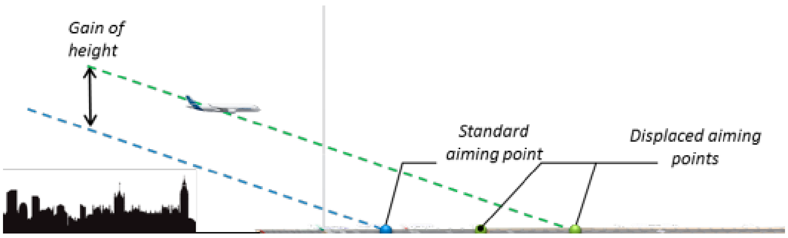

REPORT NUMBER
NLR-TP-2016-344

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REPORT CLASSIFICATION
UNCLASSIFIED

DATE
May 2017

KNOWLEDGE AREA(S)
Vliegoperaties
Cockpit
Luchtverkeersmanagement (ATM)- en luchthavensimulatie en -validatie
Luchtverkeersmanagement (ATM)- en luchthavenoperaties
Vliegtuiggeluidseffecten op de omgeving

DESCRIPTOR(S)
GBAS
MRAP
MVC
displaced threshold
flight simulation

Problem area

A Ground Based Augmentation System (GBAS) enables new types of approach- and landing operations. One of these is Multiple Runway Aiming Point (MRAP) Operations. MRAP operations allow different aircraft to use different thresholds on the same runway, which can all be active simultaneously. The overarching hypothesis is that a runway visualization concept (i.e. additional markings and lighting) is required in order for pilots to accept MRAP operations.

Description of work

In the context of the hypothesis and in the scope of SESAR Project 6.8.8 “Enhanced Arrival Procedures Enabled by GBAS”, NLR has defined and evaluated a runway visualization concept, called MRAP Visualization Concept (MVC).
The MVC was defined based on the simultaneous use of three thresholds and in accordance with ICAO regulation to the maximum extent possible. The evaluation consisted of an experiment with test subjects on NLR’s Generic Research Aircraft Cockpit Environment (GRACE) flight simulator. These piloted simulations were used to check whether this MVC is indeed necessary and sufficient to safely conduct MRAP operations. Also, it was checked that nominal operations on the original, first threshold were not unacceptably affected by the MVC. Scenarios included both good and marginal visibility conditions. Pilot ratings have been collected in questionnaires.

Results and conclusions

From the analyses of the ratings it could be concluded that a clear and intuitive MRAP Visualization Concept (MVC) has been defined. This MVC turned out to be necessary for MRAP operations to become acceptable in terms of safety, at least under good visibility conditions. With the MVC activated, the safety of nominal approaches and landings on the first, original threshold remain highly acceptable. As the safety was acceptable for all thresholds, the MVC also is a sufficient measure. It is therefore recommended to use the MVC for MRAP operations.

Applicability

Although the simulator experiment was performed at a particular runway and airport, it is believed that the conclusions will apply for other airport and runway configurations. This may be further assessed.

GENERAL NOTE

At the time of issuing this report, a conference has not been defined where the content of this report could be presented.

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CUSTOMER	**Netherlands Aerospace Centre**
CONTRACT NUMBER	**ACQ/DIR/PPR/01262292/CIG 5519123 C5E**
OWNER	**NLR**
DIVISION NLR	**Aerospace Operations**
DISTRIBUTION	**Unlimited**
CLASSIFICATION OF TITLE	**UNCLASSIFIED**

APPROVED BY :		
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DATE 15 05 17	DATE 23 05 17	DATE 24 05 17

Summary

A Ground Based Augmentation System (GBAS) is positioned at an airport and provides augmented GPS signals to aircraft in the vicinity. The augmented signals contain GPS error information regarding the aircraft's position, as well as integrity information. The use of GBAS enables the aircraft to fly new precision approaches, whereby for example flight path angle and touch down point can be varied for each aircraft. Approaches using Multiple Runway Aiming Points (MRAP) allow different aircraft that are approaching a particular runway, to choose their optimal threshold on that runway. The idea of MRAP in this study is that all thresholds are active simultaneously.

The overarching hypothesis is that a new type of runway visualization concept is required in order for pilots to accept MRAP operations. In this context, and in the scope of SESAR Project 6.8.8 "Enhanced Arrival Procedures Enabled by GBAS", NLR has defined and evaluated a runway visualization concept, called MRAP Visualization Concept (MVC). The MVC was defined based on three thresholds and in accordance with ICAO regulation to the maximum extent possible. The evaluation consisted of an experiment with test subjects on NLR's Generic Research Aircraft Cockpit Environment (GRACE) flight simulator. These piloted simulations were used to check whether this MVC is indeed necessary and sufficient to fly MRAP operations. Also, it was checked that nominal operations on the original, first threshold were not unacceptably affected by the MVC. Scenarios included both good and marginal visibility conditions. Pilot ratings have been collected in questionnaires.

From the analyses of the ratings it could be concluded that a clear and intuitive MRAP Visualization Concept (MVC) has been defined. This MVC turned out necessary for MRAP operations to become acceptable in terms of safety, at least under good visibility conditions. With the MVC activated, the safety of nominal approaches and landings on the first, original threshold remain highly acceptable. As the safety was acceptable for all thresholds, the MVC also is a sufficient measure. It is therefore recommended to use the MVC for MRAP operations.

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Abbreviations

ACRONYM	DESCRIPTION
AIGS	Adaptive Increased Glide Slope
AGL	Above Ground Level
AP	Auto Pilot
ATC	Air Traffic Control
ATM	Air Traffic Management
CAVOK	Ceiling And Visibility OK
CG	Centre of Gravity
DOF	Degrees Of Freedom
DS	Double Slope
EFIS	Electronic Flight Instrument System
EHAM	ICAO code for Amsterdam international airport Schiphol
FP	Flight Procedure
ft	feet
GBAS	Ground Based Augmentation System
GLS	GBAS Landing System
GPS	Global Positioning System
GRACE	Generic Research Aircraft Cockpit Environment
ICAO	International Civil Aviation Organization
IGS	Increased Glide Slope
ILS	Instrument Landing System
LDA	Landing Distance Available
LOC	LOCalizer
m	meter
MAC	Mean Aerodynamic Chord
MCDU	Multi-function Control and Display Unit
MDA	Minimum Descent Altitude
MRAP	Multiple Runway Aiming Points
MVC	MRAP Visualization Concept
ND	Navigation Display
NLR	Netherlands Aerospace Centre
NM	Nautical Mile
PAPI	Precision Approach Path Indicator
PEQ	Post Experiment Questionnaire
PF	Pilot Flying
PFD	Primary Flight Display

PM	Pilot Monitoring
PRQ	Post Run Questionnaire
RAP	Runway Aiming Point
RNP	Required Navigation Performance
RVR	Runway Visual Range
SCB	Solid Cloud Base
SESAR	Single European Sky ATM Research
VHF	Very High Frequency
VIS	VISibility

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1 Introduction

A Ground Based Augmentation System (GBAS) (Ref.1) is positioned at an airport and provides augmented GPS signals to aircraft in the vicinity (see Figure 1). The augmented signals contain GPS error information regarding the aircraft's position, as well as integrity information and are transmitted to the aircraft using a VHF datalink. In principle, the use of GBAS enables the aircraft to fly new precision approaches to the airport. Among such approaches are (Adaptive) Increased Glide Slope ((A)IGS), Double Slope (DS), curved RNP approaches to GLS and MRAP. Such new approaches are evaluated within SESAR (Ref.2) in general and in Project 6.8.8 in particular, as they may be beneficial in terms of noise reduction, environmental sustainability and runway capacity/ throughput.

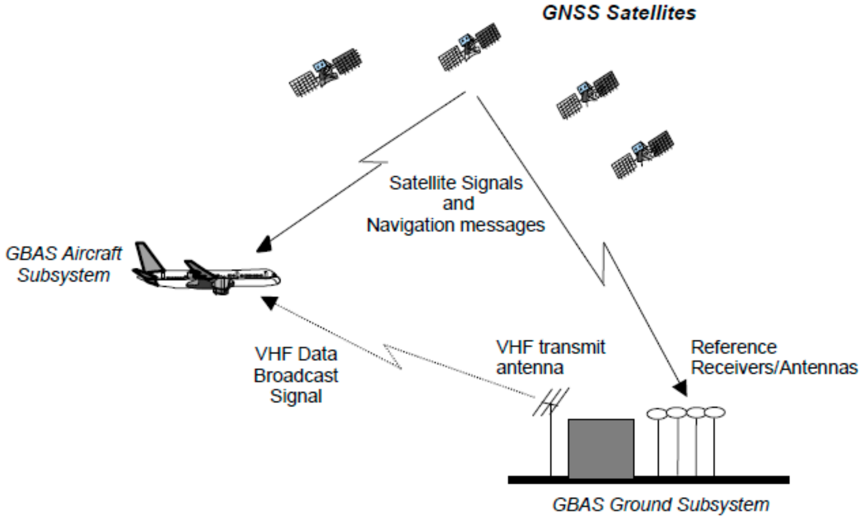

Figure 1: GBAS system overview

MRAP operations allow different aircraft that are approaching a particular runway, to choose their optimal threshold on that runway (see). This can either be the nominal threshold (i.e. the first threshold) or a displaced threshold. Depending on the runway, more than one displaced threshold is possible. The idea of MRAP is that all thresholds are simultaneously active.

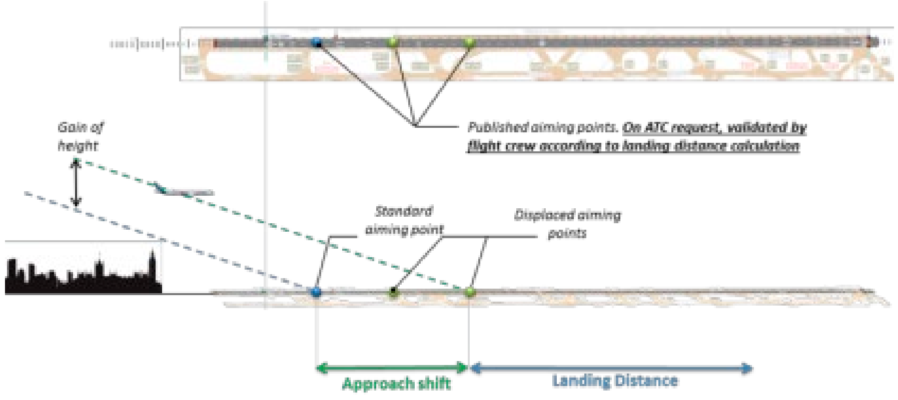

Figure 2: Overview MRAP concept

The overarching hypothesis regarding the activities described in this paper is that a new type of runway visualization concept is required in order for pilots to accept MRAP operations. In this context, and in the scope of SESAR Project 6.8.8 “Enhanced Arrival Procedures Enabled by GBAS”, NLR has defined and evaluated a runway visualization concept. The evaluation consisted of an experiment with test subjects on NLR’s GRACE flight simulator.

The structure of the paper is as follows. Chapter 2 provides the objectives with respect to such a visualization concept and its evaluation in the simulator. The visualization concept itself is explained in chapter 3. Chapter 4 discusses the experiment with which the concept is tested in the simulator. Description of the simulator and project specific adjustments to it are covered in chapter 5. Chapter 6 focuses on the experiment execution and provides some insight into the number of sessions, background of the test subjects, etc. In chapter 7, the data extracted from the experiment is analyzed and the results are explained. Conclusions and recommendations are given in chapter 8. Finally, acknowledgements and references can be found in chapters 9 and 10 respectively.

2 Objectives

It is believed that a new type of visualization on the runway is necessary for MRAP operations to be acceptable to pilots. Therefore the first objective was to define a concept for such visualization, called the MRAP Visualization Concept (MVC). Subsequently, this MVC was to be evaluated on NLR's GRACE flight simulator in Amsterdam (see chapter 5). The objectives for this evaluation were to check whether this MVC is indeed necessary and sufficient to fly MRAP operations. The objective was to check this for different atmospheric conditions:

- Good cloud ceiling and visibility (CAVOK)
- Low overcast cloud base with ceiling just above Minimum Descent Altitude (MDA) and with good visibility below
- Marginal visibility conditions

Also, it was checked that nominal operations - i.e. operations on the first original threshold – were not unacceptably affected by the MVC.

In above context, a number of research questions are of interest. These are given in the description of the experiment set-up in chapter 4.

Summary of objectives:

1. Define a clear and intuitive MRAP Visualization Concept (MVC) which contains markings, lighting and PAPI concept
2. Check necessity of the MVC for different atmospheric conditions
3. Check sufficiency of the MVC for different atmospheric conditions
4. Check nominal operations are still acceptable with the MVC activated

3 MRAP Visualization Concept (MVC)

Brainstorm sessions at NLR resulted in a total of five experimental runway markings/lighting concepts, called MRAP Visualization Concepts (MVC). The MVC was to be defined for situations where there is – except for the nominal threshold and aiming point – also a second and third set of displaced threshold and aiming point. In the entire experiment, as well as in this paper, these thresholds and aiming points are respectively designated Alpha (A), Bravo (B) and Charlie (C).

The brainstormed designs have been assessed with an experienced test pilot during a meeting at NLR in Amsterdam. In this meeting, one concept was selected for the MRAP experiment on NLR's GRACE flight simulator. Bottom line in the assessment was to have an MVC in accordance with ICAO Annex 14 (Ref.3) to the maximum extent possible. However, given the nature of the new MRAP operations, no MVC can be entirely in accordance with ICAO. Where ICAO could not be followed, the MVC has been defined in the same 'line of thought' as ICAO.

Amsterdam Airport Schiphol runway 18R has been chosen for the experiments. The MVC selected for the experiments has been tailored to this particular runway. However, it is thought that an MVC (as a concept, thus not literally the one defined here) can in principle be applied to any runway. The differences in MVC may show in number and position of thresholds and aiming points.

The selected MVC for runway 18R at Schiphol is illustrated in Figure 3 and Figure 4. Figure 3 shows the runway marking concept, while Figure 4 shows the lighting concept.

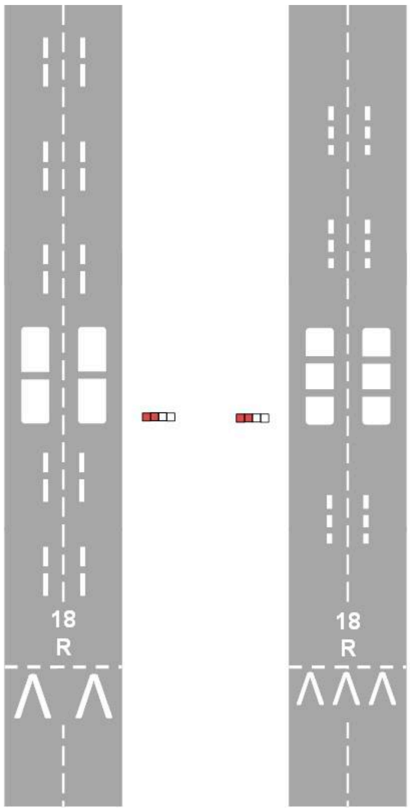

Figure 3: Marking concept for threshold, aiming point and touchdown zone Bravo (left) and Charlie (right) – not to scale

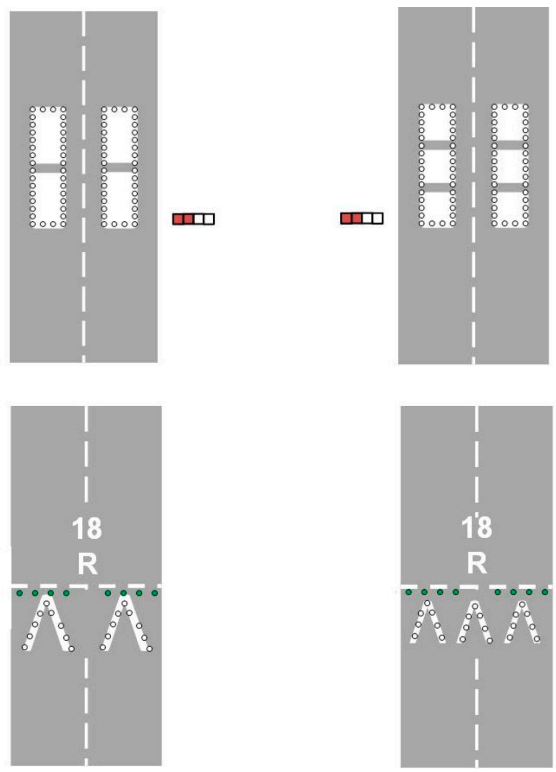

Figure 4: Lighting concept for threshold and aiming point Bravo (left) and Charlie (right). Only the additional lighting is shown including PAPI. Not to scale

The distance between threshold A and B is the same as the distance between threshold B and C and is 920m. The threshold markings for B and C start at the end of the touch down zone of respectively A (nominal threshold) and B.

The ICAO logic (Ref. 1) has been followed as much as possible. However, it was deemed necessary to somehow clearly identify the additional thresholds and make it easy/intuitive for the pilots to distinguish between the additional thresholds. It was chosen to do this with clearly visible white chevrons: two for threshold B and three for threshold C. Chevrons are already used to indicate temporarily displaced thresholds, which in fact is a way to interpret the additional thresholds. As all three thresholds are in operation simultaneously, it is assumed most consistent to have all thresholds identified with “18R” markings.
The Runway Aiming Point (RAP) markings follow the logic in that they are again rectangles. However, to distinguish them from each other, they are partitioned into two or three parts respectively.
Touch-down zone markings are included for thresholds B and C as is done for the nominal threshold A at Schiphol runway 18R. In front of RAP B there are two pairs of line markings (all lines divided into two parts, as a reference to threshold B), while behind RAP B there are three pairs. For RAP C, these are one pair, respectively two pairs. Touch-down zone markings for RAP C are divided in three parts (again in reference to the applicable threshold, in this case C).

Lighting consists of the threshold outlined in green lights, open in the center. The chevrons are outlined by white lights. All lighting is non-flashing and has equal intensity as the nominal lighting.
The PAPI position beside the runway alternates as an additional identifier of the particular threshold. This means that for additional threshold B the PAPI will be at the right hand side of the touch down aiming point, whereas for additional threshold C, the PAPI will again be on the left hand side (like for threshold A).

4 Experiment Set-up

Research questions

The research questions that are of interest are given in Table 1. For each question the associated objective from chapter 2 is referred to in the last column.

Table 1: Research Questions

Nr	Question	Objective (chapter 2)
	Do the pilots agree that the...	
1	MVC markings and lighting are clearly recognizable and intuitive?	1
2	simultaneous use of three PAPIs (one for each threshold) is acceptable?	1
3	safety level of MRAP operations at threshold B are unacceptable without using the MVC?	2
4	safety level of MRAP operations at threshold B are acceptable when using the MVC?	3
5	safety level of MRAP operations at threshold C are unacceptable without using the MVC?	2
6	safety level of MRAP operations at threshold C are acceptable when using the MVC?	3
7	safety level of MRAP operations at threshold A are acceptable when using the MVC?	4

Independent variables

The independent variables for the experiment are given in Table 2. As the influence of the MVC will be evaluated, it is switched on for some runs and off for others (see respectively Figure 5 and Figure 6). The marginal visibility of 600 m Runway Visual Range (RVR) was chosen to check how pilots rate the approaches to thresholds B and C for situations in which the first thing they see is lighting/marking of that particular threshold (see Figure 7 and Figure 8). For threshold B, the pilots may see part of the end of the touch down zone of the nominal runway. The solid cloud base is chosen about 100 ft above the MDA at 300 ft Above Ground Level (AGL). Visibility below this cloud base is always good. This condition is meant to expose the pilots to situations in which they instantly see the ‘whole picture’, but have limited time to interpret it.

Table 2: Independent variables

Nr	Independent variable	Number of levels	Value of levels	
1	MRAP Visualization Concept (MVC)	2	ON OFF (nominal markings/lighting will be on)	Figure 5 Figure 6
2	Visibility (VIS)	2	GOOD MARGINAL	Figure 7 Figure 8
3	Solid Cloud Base (SCB)	2	NO (no clouds) YES (solid cloud base slightly above MDA)	

Dependent measures

The dependent measures for the experiment are given in Table 3.

Table 3: Dependent measures

Nr	Dependent measure
1	Pilot ratings in Post Run Questionnaire (PRQ)
2	Pilot ratings in Post Experiment Questionnaire (PEQ)

Figure 5: MVC ON (point of view: threshold B, 200 ft)

Figure 6: MVC OFF (point of view: threshold B, 200 ft)

Figure 7: Visibility GOOD (point of view: threshold C, 50 ft)

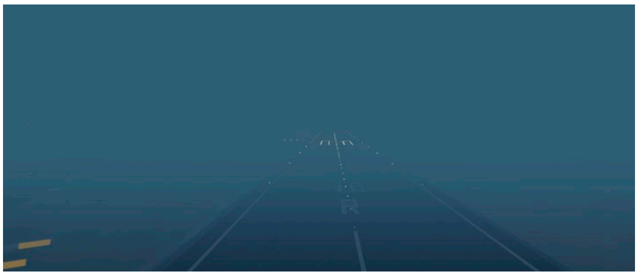

Figure 8: Visibility marginal (point of view: threshold C, 50 ft)

The Post Run Questionnaire was filled out by the test subjects after each run. This questionnaire was rather brief and asked amongst others to rate the safety of the MRAP run. The Post Experiment Questionnaire was more elaborate. This questionnaire asked the test subjects to rate an entire range of topics based on their experience gained during the entire simulator session. Amongst others, the following items had to be rated: (i) recognizable and intuitive markings and lighting, (ii) use of three simultaneously active PAPI's and (iii) acceptability of the MVC.

<u>Experiment matrix</u>

The Flight Procedures (FP) that have been used in the experiment are given in Table 4.

Table 4: Flight Procedures

Flight Procedure	**Description**
	Aircraft established on LOC ILS18R at EHAM. Approach, landing and roll out on threshold ...
FP A	Alpha
FP B	Bravo
FP C	Charlie

The experiment matrix is given in Table 5. It is a full factorial design for thresholds B and C, except for the combination of marginal visibility and solid cloud base. From an MVC point-of-view, the latter is no different than marginal visibility together with no clouds. The runs to threshold A have been added to test the MVC influence on nominal operations. This has only been done for good visibility and no clouds conditions, basically because the number of test runs had to be limited. For marginal visibility however, it is expected that there is no difference in approaching threshold A between MVC activated and MVC switched off. The experiment matrix runs have been randomised differently for each test subject in order to minimize the influence of learning effect on the responses of the test subject.

Table 5: Experiment matrix

			INDEPENDENT VARIABLES		
			MVC	VIS	SCB
CASES/SCENARIOS	FP A	1	OFF	GOOD	YES
		2	ON	GOOD	YES
	FP B	3	OFF	GOOD	NO
		4	ON	GOOD	NO
		5	OFF	MARG	NO
		6	ON	MARG	NO
		7	OFF	GOOD	YES
		8	ON	GOOD	YES
	FP C	9	OFF	GOOD	NO
		10	ON	GOOD	NO
		11	OFF	MARG	NO
		12	ON	MARG	NO
		13	OFF	GOOD	YES
		14	ON	GOOD	YES

Scenarios

Based on the flight procedures enumerated inTable 4, a set of 14 different scenarios was used, all being approaches to runway 18R at Schiphol airport. These scenarios varied with respect to the independent variables, being the usage of MVC, the visibility (VIS) and the presence of a solid cloud base (SCB) (see Table 5). Apart from the variations in the independent variables, all scenarios were the same. The initial position of the aircraft was 10 NM out of runway 18R at 2000 ft. All approaches were flown in daylight period.

The subject pilots were asked to fly the approaches as close as possible to how they would fly such an approach in real life, except that they were instructed to switch off the Auto Pilot (AP) at around 700 ft AGL in order for them to be able to actually fly the approach (instead of merely monitor the approach flown by the autopilot). The crew consisted of two persons: the subject pilot in the role of Pilot Flying (PF in the left hand seat) and a researcher in the role of Pilot Monitoring (PM in the right hand seat).

5 Simulator Set-Up

The MRAP experiments have been performed using NLR's Generic Research Aircraft Cockpit Environment (GRACE) flight simulation facility in Amsterdam (see Figure 9 and Figure 10). GRACE is a research simulator, capable of being tailored to the needs of research projects. It comprises a simulator-cab with a (cross-cockpit) wide visual projection system on a 6 Degrees Of Freedom (DOF) motion platform.
Both this visual system and motion platform have been used in the MRAP experiment. The switchable elements of the MVC markings and lighting were added to the visual system of GRACE. For an impression, see figures in chapter 4. The use of the motion simulation in GRACE increases the realism of the flights which in turn increases the ability of the subject pilots to make statements about the flyability and the perceived safety of the flights.

Figure 9: Grace Simulation facility (exterior)

Figure 10: Grace Simulation facility (interior)

For the experiment, the A320 simulation model of NLR is used. This relatively small aircraft is well capable of flying different MRAP procedures, especially those with shorter landing distances. A mass of 58 tonnes at a Centre of Gravity (CG) of 30% Mean Aerodynamic Chord (MAC) were programmed into the simulation model. This resulted in an approach speed of 132 knots and an in-flight landing distance of approximately 800 meters, well within the Landing Distance Available (LDA) for threshold C (1690 m).

From an operational point-of-view, the GBAS guidance looks and feels the same as ILS guidance. Within GRACE, the existing ILS logic has been used to simulate the GBAS logic. Only those parts of the Electronic Flight Instrument System (EFIS) and Multi-function Control and Display Unit (MCDU) that are visibly related to GBAS have been modified. These parts are listed below and indicated by red boxes in Figure 11:

- GBAS indications on the Primary Flight Display (PFD): the GBAS ident and its corresponding channel number are displayed where ILS information is displayed for an ILS approach.
- GBAS indications on the Navigation Display (ND): The GBAS runway identification (different from a regular identification, in this case e.g. 'RW18R**B**') is displayed where the ILS runway information is displayed for a regular ILS approach.
- GBAS indications on the MCDU: The GBAS runway identification is displayed.

Figure 11: GBAS indications on the PFD (left), ND (center), and MCDU (right) outlined in red

6 Experiment Execution

The experiment was carried out from February 1st up and until February 9th, 2016. A simulator session, including briefing and debriefing, took either a morning or an afternoon. Most of the days, two sessions were carried out. A total of 12 sessions have been performed, in which 12 pilots have been subjected to the experiment. Each session started with some training runs in which the test subject could familiarize himself with the simulator, aircraft model, etc.

An overview of the test subjects is given in Table 6. The twelve participating pilots were all male, in the age between 28 and 62. Nine of them flew for a major airline company, while three of them flew for smaller companies. Their total number of flight hours varied between 1,200 and 16,000. All have been involved in simulator experiments at NLR before. The ratings collected from these test subjects is analysed in chapter 7.

Table 6: Test subjects

Nr.	Age	Gender	Total flight hours	Years short/long haul	Current rank	Test subject before
1	62	Male	>5,000	26/0	Captain	Yes
2	56	Male	10,900	Yes/yes	Capt/tech pilot	Yes
3	45	Male	14,000	8/17	Captain	Yes
4	31	Male	>1,200	4/0	First Officer	Yes
5	51	Male	10,400	8/16	Captain	Yes
6	36	Male	7,000	7/6	First Officer	Yes
7	38	Male	8,200	10/4	First Officer	Yes
8	--	Male	7,500	11/0	First Officer	Yes
9	28	Male	3,100	1/3	First Officer	Yes
10	52	Male	5,000	7/5	First Officer	Yes
11	55	Male	16,000	12/19	Captain	Yes
12	40	Male	4,800	4/7	First Officer	Yes

7 Analysis and Results

In this chapter, the research questions as listed in chapter 4 will be answered one by one, applying statistical tests to the questionnaire data. A summary and description of the results is given at the end of the chapter. In the figures showing the pilot ratings (below), the error bars present the standard error: the standard deviation of the sample divided by the root of the sample size. This is done to provide a visual representation of the significance of the difference. When the error bars represent values that do not overlap, the difference is significant.

The questionnaire data allows for the comparison of conditions or a comparison against a median, by means of t-tests. T-tests can be applied on data that follows a normal distribution. The data from this experiment however did not show a normal distribution, which is probably due to the small number of observations. The analysis was however proceeded based on the assumption that the data is normally distributed.
In the notations of the outcomes of the test, *M* represents the mean value, *t* the computed t-value and *p* the probability that the difference in the values could be coincidental. When *p* is smaller than 0.05, the difference is considered significant.

<u>Research question 1</u>
In order to answer the question whether the MVC markings and lighting are clearly recognizable and intuitive, information from the Post-Experiment Questionnaire was analyzed. In the Post-Experiment Questionnaire, pilots rated their agreement to several statements on the visual cues provided by the MVC, on a scale of 1 (completely disagree) to 6 (completely agree). The statements and pilot ratings are given in Figure 12.

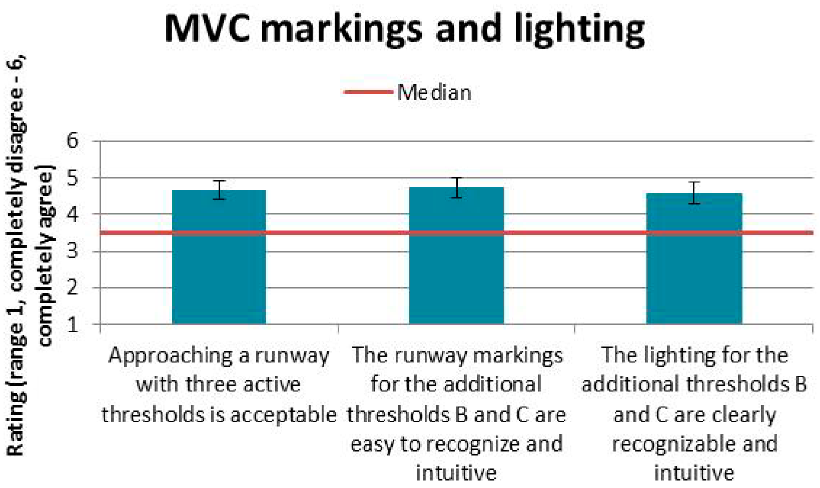

Figure 12: Post-experiment agreement ratings on MVC markings and lighting

The pilot ratings were tested against the median of 3.5 to indicate if the ratings are significantly above or below the median, indicating whether they agree or disagree to the statement. The pilots agree that:

- Approaching a runway with three active thresholds is acceptable (M=4.7, t(11) = 4.553; p < .01).
- Runway markings for the additional thresholds B and C are easy to recognize and intuitive (M=4.7, t(10) = 4.5; p < .01).
- Lighting for the additional thresholds B and C are clearly recognizable and intuitive (M=4.6, t(11) = 3.767; p < .01).

Research question 2

This question concerns whether simultaneous use of three PAPIs (one for each threshold) is acceptable. The pilot ratings (see Figure 13) on the associated question on the Post-Experiment Questionnaire have been tested against the median. The pilots agreed that the simultaneous use of three PAPIs is acceptable (M=4.5, $t(10) = 3.389$; $p < .01$).

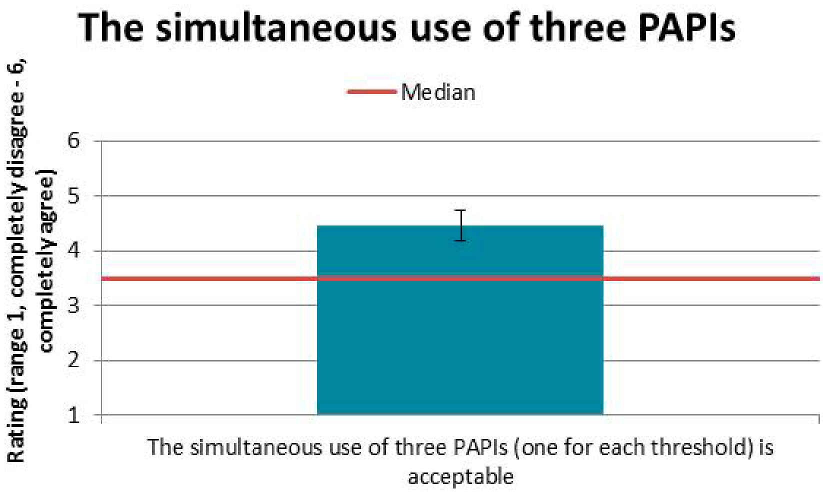

Figure 13: Post-experiment agreement ratings of three PAPIs

In the Post-Experiment Questionnaire, the test subjects were also asked to rate other PAPI configurations, although these have not been flown in the simulator by the subjects. The configurations concerned are:

- Only one activated PAPI at the nominal threshold A (also when flying to another threshold)
- Only one activated PAPI at cleared threshold for 'number one' (i.e. 'number two' may also see this PAPI which may not be the PAPI associated to his/her approach)
- No PAPIs at all

Pilots did not agree nor disagree on the acceptability of having only one activated PAPI at the nominal threshold A.
Pilots agreed that having only one activated PAPI at the cleared threshold for 'number 1' was acceptable ($t(10) = 2.3$; $p < .05$).
Pilots agreed that having no PAPIs at all was not acceptable ($t(10) = -2.3$; $p < .05$).

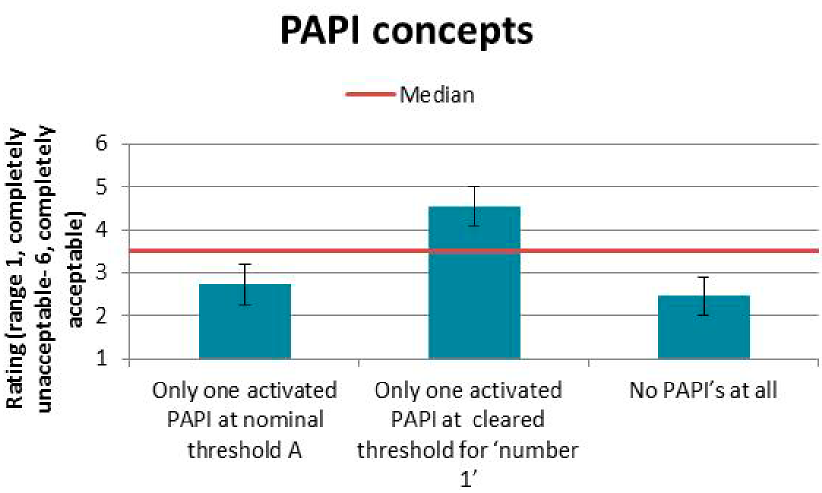

Figure 14: Post-experiment agreement ratings on acceptability of different PAPI concepts

Research questions 3 and 4

Research questions 3 and 4 respectively concerned the necessity and sufficiency of the MVC for different atmospheric conditions for threshold B. Question 3 looked at whether the pilots agree that the level of safety of MRAP operations at threshold B are unacceptable without using the MVC, whereas Question 4 looked at acceptability when MVC is used.

Firstly and generally, the acceptability of safety was rated significantly higher with MVC on in all three weather conditions (see Figure 15), compared to MVC off. This is valid in good visibility and no clouds ($t(11) = -5.011$, $p < .01$), in marginal visibility and no clouds ($t(10) = -2.588$, $p < .05$), and in good visibility with a solid cloud base ($t(11) = -4.45$, $p < .01$).

Secondly, when MVC is not used, the safety was neither acceptable nor unacceptable.

Finally, when MVC was used, the safety was rated acceptable only in good visibility (regardless of clouds) ($t_{NoClouds}(11) = 12.90$, $p < .01$; $t_{CloudBase}(11) = 6.916$, $p < .01$). For use of MVC under marginal visibility conditions, safety was again neither acceptable nor unacceptable.

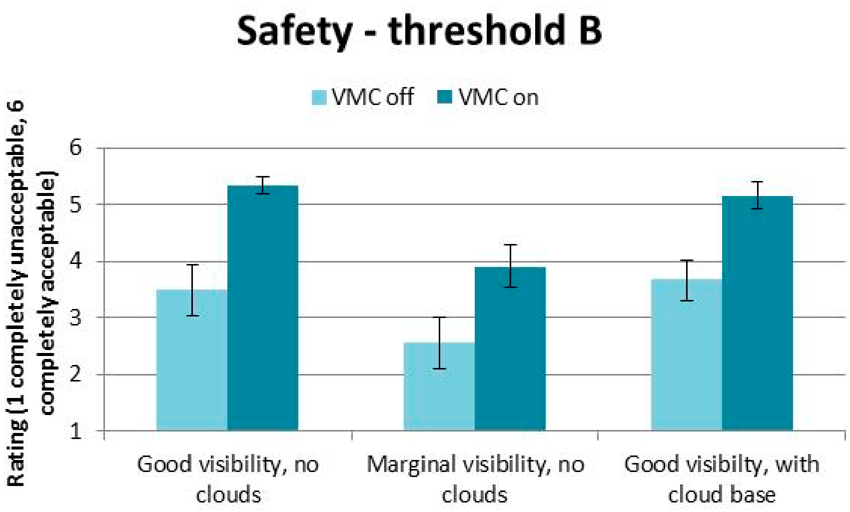

Figure 15: Post-run acceptability ratings of safety for approaches on threshold B

Research questions 5 and 6

Research question 5 and 6, are the same as Questions 3 and 4, but now applied to threshold C.

Like for threshold B, also for threshold C, acceptability of safety was rated significantly higher with MVC on in all three weather conditions (see Figure 16). This is valid in good visibility and no clouds ($t(10) = -5.333$, $p < .01$), in marginal visibility and no clouds ($t(10) = -4.1$, $p < .01$), and in good visibility with a solid cloud base ($t(10) = -3.4$, $p < .01$).

When the MVC was not activated, the safety was rated unacceptable under the marginal visibility conditions ($t(10) = -3.292$, $p < .01$), while for the good visibility scenarios, safety was rated neither acceptable nor unacceptable.

When MVC was used, the safety was rated acceptable only under good visibility conditions (regardless of clouds) ($t(10) = 4.54$, $p < .01$) and in good visibility with cloud base ($t(11) = 9.75$, $p < .01$). For use of MVC under marginal visibility conditions, safety was again neither acceptable nor unacceptable.

Research question 7

Question 7 concerned the acceptability of safety for situations in which nominal approaches and landings are made on threshold A, while the MVC is still active (e.g. for an aircraft behind, that may land on threshold B or C). Although the acceptability of safety for activated MVC was rated lower than for situations where it was switched off, both cases are quite acceptable and score well above the median (see Figure 17).

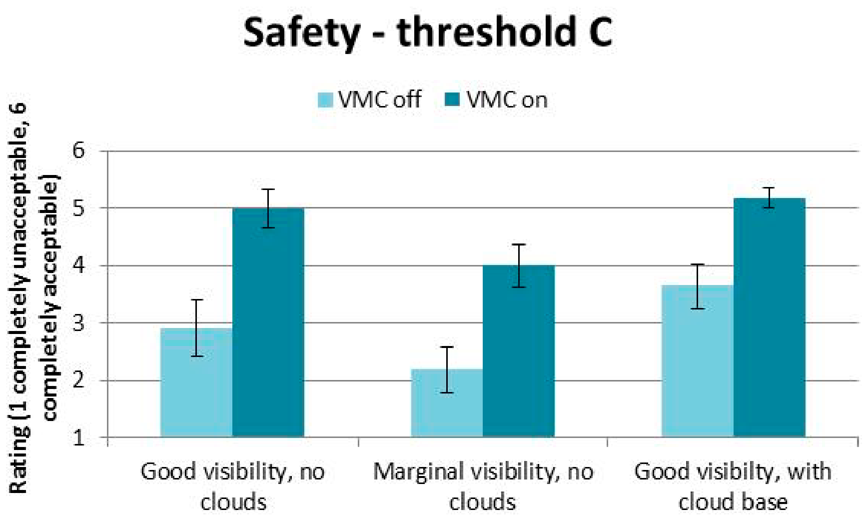

Figure 16: Post-run acceptability ratings of safety for approaches on threshold B

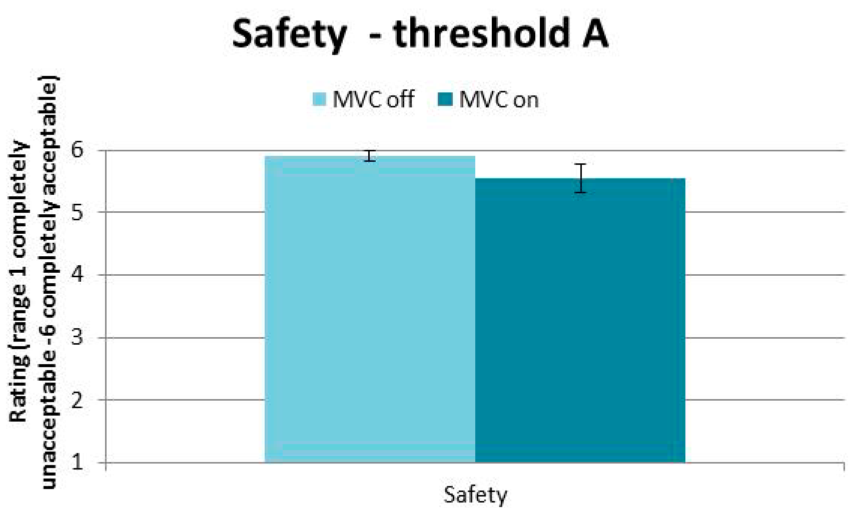

Figure 17: Post-run acceptability ratings of safety for approaches on threshold A

<u>Summary of results</u>

The answers to the research questions are given in Table 7 and described below.

The principle of having three different thresholds activated simultaneously was acceptable to the test subjects. The developed MVC provided clearly recognizable and intuitive markings and lighting. Also the simultaneous use of three PAPIs was acceptable. Two remarks are in place with respect to lighting. First, lighting in the simulation sessions does not 'get to you' the way it does in real life. Real life intensities and contrasts are more intense than in the visual system of simulators. So, this may influence the ratings on the use of PAPI(s). Second, only three particular weather scenarios have been tested. One could think of other weather conditions that may influence the ratings as given by the subjects. For instance, visibility conditions may be chosen such that the PAPIs become visible successively for aircraft approaching and landing on threshold C (whereas in this experiment all PAPIs were either visible or not). The subjects were asked to rate three other PAPI configurations that they did not fly in the sessions. From these three, only the configuration with one active PAPI at the correct threshold for 'number one' was rated acceptable. However, this configuration will necessarily include switching of the PAPIs, which is prone to errors and is not well received by ATC.

Table 7: Summary of results

Nr	Question	Answer	
	Do the pilots agree that the...		
1	MVC markings and lighting are clearly recognizable and intuitive?	YES	Markings threshold B/C
		YES	Lighting threshold B/C
	Related acceptability question	YES	Three active thresholds
2	simultaneous use of three PAPIs (one for each threshold) is acceptable?	YES	*(Only this PAPI configuration was flown in the simulator sessions)*
	Related acceptability question	UNDECIDED	Only one activated PAPI threshold A
	Related acceptability question	YES	Only one activated PAPI at cleared threshold
	Related acceptability question	NO	No PAPIs at all
3	safety level of MRAP operations at threshold B are unacceptable without using the MVC?	UNDECIDED	Good visibility, no clouds
		UNDECIDED	Marginal visibility, no clouds
		UNDECIDED	Solid cloud base with good visibility below
4	safety level of MRAP operations at threshold B are acceptable when using the MVC?	YES	Good visibility, no clouds
		UNDECIDED	Marginal visibility, no clouds
		YES	Solid cloud base with good visibility below
5	safety level of MRAP operations at threshold C are unacceptable without using the MVC?	UNDECIDED	Good visibility, no clouds
		YES	Marginal visibility, no clouds
		UNDECIDED	Solid cloud base with good visibility below
6	safety level of MRAP operations at threshold C are acceptable when using the MVC?	YES	Good visibility, no clouds
		UNDECIDED	Marginal visibility, no clouds
		YES	Solid cloud base with good visibility below
7	safety level of MRAP operations at threshold A are acceptable when using the MVC?	YES	

When the MVC is not used (either for threshold B or C), safety was not rated acceptable. Although for some cases, acceptability of safety could not be determined statistically. This means that some kind of concept/system needs to be implemented to make safe MRAP operations possible. The ratings show that the MVC can serve this purpose for at least the good visibility conditions. In marginal visibility conditions the safety could not be proven.
Last but not least, approaches and landings on the nominal threshold A with active MVC remain highly acceptable.

In general, the above results show that the MVC improves MRAP safety to an acceptable level, at least under good visibility conditions. This result is confirmed by two questions the subjects had to rate on the Post Experiment Questionnaire and which are shown in Figure 18 and Figure 19.

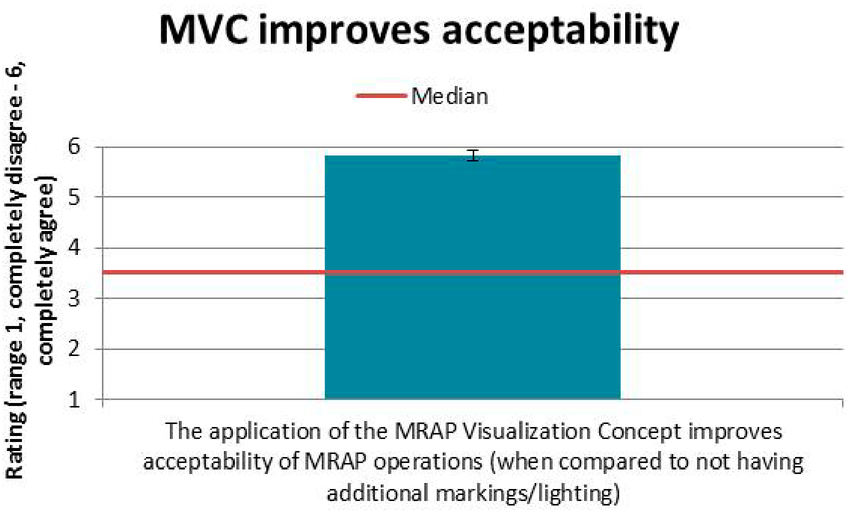

Figure 18: Post-experiment agreement ratings on MVC improving acceptability of MRAP

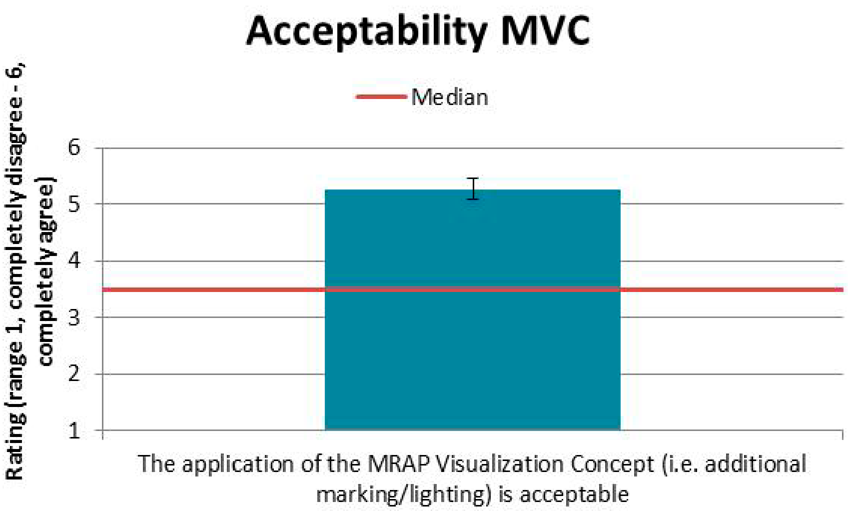

Figure 19: Post-experiment agreement ratings on acceptability of MVC

8 Conclusions and Recommendations

From the results in the previous chapter, it can be concluded that the objectives from chapter 2 have been met. A clear and intuitive MRAP Visualization Concept (MVC) has been defined. This MVC turned out necessary for MRAP operations to become acceptable in terms of safety, at least under good visibility conditions. The safety for the use of MVC under marginal visibility conditions was rated neither acceptable nor unacceptable. With the MVC activated, the safety of nominal approaches and landings on the first, original threshold remain highly acceptable. As the safety was acceptable for all thresholds, the MVC also is a sufficient measure. In summary, the MVC enables operations at multiple, simultaneously active thresholds on one runway, at least under good visibility conditions.

Based on the conclusions, it is recommended to use the MVC for MRAP operations. Although the experiment in this paper was performed at a particular runway and airport, it is believed that the conclusions will hold for other airport and runway configurations. This may be further assessed.
Furthermore, the simultaneous use of three PAPIs (as part of the MVC) should be further investigated. This should be done because not all relevant weather conditions could be tested and also because the PAPI intensities and contrasts are relatively low in simulators when compared to real life. It is also recommended to perform piloted simulations for the PAPI configurations that – in this experiment – could only be rated theoretically by the test subjects in the post experiment questionnaire.
Finally, the use of MVC under low visibility conditions needs to be evaluated further.

As a next step, it is also recommended to evaluate the MVC under real circumstances. From a practical and financial point-of-view, flight testing of the MVC could start with only the markings (i.e. leaving out the additional lighting concept). This should initially be performed under good visibility conditions and in daylight.

9 Acknowledgements

The authors want to thank all people who participated in the success of the SESAR project 06.08.08: AIRBUS, ALENIA, NLR (C-LVNL), DFS, ENAV, EUROCONTROL, HONEYWELL, NATS, NORACON, SEAC, THALES and the SESAR Joint Undertaking.

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