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THE MORE AUTONOMOUS - AIRCRAFT IN THE FUTURE AIR TRAFFIC MANAGEMENT SYSTEM

D40: Results of pilot-in-the-loop simulator trials for ASAS spacing

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Results of pilot-in-the-loop simulator trials for ASAS spacing

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Summary

Within the context of the MA-AFAS (The More Autonomous – Aircraft in the Future Air Traffic Management System) project a pilot-in-the-loop experiment is performed. Main question was to investigate pilot acceptance, behaviour and workload in a future ATM concept where more autonomy is provided to the aircraft. So called ASAS instructions were issued to the crew in the flight simulator for lateral and vertical passing manoeuvres and merge behind instructions. 10 crews participated, each for two days performing each 10 flights of about 45 minutes. During each flight three ASAS instructions were given apart from two reference flights per crew, 50% of runs communication was performed via R/T and 50% with CPDLC. Data obtained during the trials consisted of questionnaires (post instruction questionnaires, post flight questionnaires and the debriefing questionnaire), performance data recording and eye point of gaze measurements.
Concluded was that pilots acceptance was rated high, workload increases due to the added task to the crew but remained acceptable. The instruction set applied was found too complex as well as the used phraseology. Therefore it is recommended to simplify at least the phraseology but also limit the number of instructions. It was also concluded that CPDLC is not required to apply ASAS nor is an automatic speed control autopilot mode for the merge behind and remain behind instruction required, although well appreciated. The HMI was well appreciated though improvements can be made. Regarding the follow manoeuvres, pilots encountered difficulties in energy management but performed well. The pass below instruction in the descent was not appreciated. Pilots performed well executing the ASAS instructions.

Table of Contents

List of abbreviations

A/C	Aircraft
ADS	Automatic Dependent Surveillance
ADS-B	Automatic Dependent Surveillance-Broadcast
AFCS	Automatic Flight Control System
AOC	Airline Operations Control Centre
ASAS	Airborne Separation Assurance System
ATC	Air Traffic Control
ATCo	Air Traffic Controller
ATIS	Automatic Terminal Information Service
ATM	Air Traffic Management
BICCA	Bevonius ICAO Code Conversion Algorithm
CAS	Calibrated Air Speed
CCD	Cursor Control Device
CPA	Closest Point of Approach
CPDLC	Controller Pilot Data Link Communication
C&P	Crossing and Passing
DCP	Display Control Panel
DL	Data Link
DME	Distance Measuring Equipment
EFIS	Electronic Flight Information System
FID	Flight Identifier
FL	Flight Level
FLW	Follow
FMS	Flight Management System
GRACE	Generic Research Aircraft Cockpit Environment
GS	Ground Speed
HDG	Heading
HMI	Human Machine Interface
IAF	Initial Approach Fix
IAS	Indicated Air Speed
ICAO	International Civil Aviation Organisation
ILS	Instrument Landing System
JAA	Joint Aviation Authorities
JAR	Joint Aviation Requirements
LNAV	Lateral Navigation
LSK	Line Select Key
MA-AFAS	More Autonomous Aircraft in the Future ATM System
MCDU	Multipurpose Control and Display Unit
MP	Merge Point
ND	Navigation Display
PF	Pilot Flying
PFD	Primary Flight Display
PNF	Pilot Not Flying
RMSE	Root Mean Square Error
RSME	Rating Scale Mental Effort
RNAV	Area Navigation
R/T	Radiotelephony
SSR	Secondary Surveillance Radar

STAR	Standard Arrival Route
TFC	Traffic
TMA	Terminal Manoeuvre Area
T/D	Top of Descent
TWR	Tower
VNAV	Vertical Navigation
VPD	Vertical Profile Display
WAYPT	Waypoint
WP	Waypoint

1. Introduction

The main objective of the MA-AFAS (The More Autonomous – Aircraft in the Future Air Traffic Management System) project is to demonstrate the feasibility to perform flight operations in a future ATM concept where more autonomy is provided to the aircraft. The NLR flight simulator evaluation focused on a subset of these objectives. The covered subset here is the human factor element with respect to ASAS functionality.

This human factors experiment can be seen in the light of new JAA regulation (Interim Policy Human Factors aspects of Flight Deck design, JAR INT/POL/25/14) which requires human factors certification in case a new development introduces a novel feature as:

- novel technology or;
- novel concept or;
- novel use of existing equipment or;
- novel procedures.

In MA-AFAS this is certainly the case with respect novel technology, concept and procedures which means that if MA-AFAS equipment is to be transferred into a commercial product, a human factors certification needs to be applied. A human factors certification process means that the role of the crew needs to be evaluated in a structured way to investigate crew error and its safety impact. As contributing factors to crew error, situation awareness and workload need to be evaluated. The JAA regulations say that both test pilots and operational pilots should be involved in the process. Novel features should be evaluated against the current features in order to indicate the influence of the novelties in the operation. The pilot in the loop evaluation as part of MA-AFAS will not result in a complete human factors certification exercise, but the aim is setup an experiment which is an initial step in this direction.

This document describes briefly the setup of the simulator evaluation and in more detail the results of the evaluation in the NLR flight simulator having MA-AFAS functionality integrated.

The overall MA-AFAS concept can be found in D14, “Operational Services and Environment Document”.

2. Experiment objectives

The NLR flight simulator was used for a pilot-in-the-loop evaluation of the MA-AFAS functionality to investigate crew operation and evaluation of operational procedures. The objectives of the flight simulator trials of MA-AFAS was:

To evaluate the MA-AFAS functionality with its HMI, applying new procedures and new task distribution between air and ground, in a simulated environment regarding pilot situation awareness, crew/pilot workload, pilot/system performance, pilot acceptance and pilot behaviour.

This has been evaluated in a number of simulation runs in which system, procedure and/or environmental conditions were be varied between the runs. The experimental design integrates all conditions into one matrix covering all flights for all crews and makes sure that it is randomised over the crews. It must be noted that this experiment concentrated on ASAS functionality only. The MA-AFAS project had a broader scope, so this experiment zoomed in on specific functionality only, being ASAS. Measurements taken in order to meet these objectives cover both subjective as well as objective measurements.

The simulator evaluation must be seen in conjunction to flight trials also performed within MA-AFAS. Where flight trials are used to create a realistic and challenging environment for the system, simulator trials are used to create a realistic and challenging environment for the crew.

3. Experimental design

As defined in document D32 annex D: “Definition of Human Factors Evaluation in the Flight Simulator”, the following experimental variables were to be investigated in the experiment:

- CPDLC versus R/T
- Automatic speed control versus ‘manual’ speed control
- Role PF and PNF alteration between both crew members
- Lateral ASAS instructions
- Vertical ASAS instructions
- Longitudinal ASAS instructions (automatically continuing into remain behind)

In which the lateral ASAS instructions were:

- pass <X> Nm behind target then resume to <WAYPT>
- heading <HDG> until clear of target resume <WAYPT>

and the vertical ASAS instructions were:

- pass below target, descent to FL <FL>
- stop descent at FL <FL> when clear of target continue descent FL <FL>

For the merge behind instructions 50% of them started with a heading instruction and the other 50% were merge behind instructions without deviating from the flightplan. All these merge behind manoeuvres were base on time spacing, no distance spacing was applied.

After combining, it was concluded that 10 flights could cover all these experimental variables independently. Randomising using a Greaco-Latin square balanced the experiment over the 10 participating crews resulted in 100 experiment flights.

For each crew 10 flights were defined, each flight started at cruise level about 60-80 Nm before top of descent and ended at the runway with a landing. During the cruise phase (using cruise level FL350 or FL360) the first ASAS instruction was issued, during the initial descent the second ASAS instruction was issued and finally about halfway in the descent a merge behind instruction was given with or without an initial heading instruction. Over these flights the means of communication was varied, the role of the pilot being pilot flying (PF) or pilot not flying (PNF) was varied and the speed control mechanism to be applied during a merge behind (continuing in a remain behind) was varied. An example of a set of 10 flights for one of the crews is presented below:

Table 1 example experiment matrix for one crew

Flight #	Comm.	PF	Speed ctl	ASAS instruction 1	ASAS instruction 2	ASAS instruction 3
1	CPDLC	pilot 1	automatic	pass behind	continue desc	HDG merge
2	CPDLC	pilot 1	manual	HDG resume	continue desc	merge
3	CPDLC	pilot 2	automatic	pass behind	HDG resume	merge
4	CPDLC	pilot 2	manual	pass below	continue desc	merge
5	CPDLC	pilot 2	reference flight			
6	R/T	pilot 1	reference flight			
7	R/T	pilot 1	automatic	pass behind	pass below	merge
8	R/T	pilot 1	manual	HDG resume	pass below	HDG merge
9	R/T	pilot 2	automatic	continue desc	pass below	HDG merge

10	R/T	pilot 2	manual	HDG resume	pass behind	HDG merge

For the other 9 crews, 10 the same situations were created but the order of occurrence of an ASAS instruction and routes flown during the 10 flights were randomised using Graeco-Latin square balancing tables.

In a sequence of 10 flights for a crew, the means of communications remained unchanged for 5 consecutive flights, next the pilot role was changed after each second ASAS flight. As a consequence, the speed control mode had to be changed for each flight in order to create all necessary combinations. The order in which these conditions were applied were subject of the randomisation process.

Not included in table 1 are the applied routes. For the 10 defined flights, also 10 routes (including surrounding traffic) were defined and also these routes were randomised over the 10 flights. The following routes were used:

- Arriving at Schiphol runway 36R coming from the north-east (3 variations in surrounding traffic)
- Arriving at Schiphol runway 27 coming from the south (3 variations in surrounding traffic)
- Arriving at Schiphol runway 06 coming from the west (2 variations in surrounding traffic)
- Arriving at Catania runway 08 coming from the north (2 variations in surrounding traffic)

In order to be able to remain behind a target up to the ILS, for the used arrival and runway combination an RNAV arrival was defined which included the transition from the STAR to the ILS. In reality this is only available for two of the used arrival and runway combinations, being runway 06 at Schiphol and runway 08 at Catania. The other RNAV arrivals were defined according to the nominal vectored routes currently used. For each flight the FMS was initialised with the correct route including RNAV arrival, transition, approach and runway.

Each flight started at cruise level being FL350 or FL360 depending which route was used. In this starting position the simulator was on its route, the FMS pre-programmed for that route and the radio or data link set to the sector in which the flight started. In the cockpit, the descent, approach and landing checklists were available together with the arrival and airport charts for Schiphol and Catania. Also an ATIS message was provided for each flight with slightly varying weather conditions. The crews were asked to perform their normal duties, for example to prepare the descent, approach and landing including a crew briefing. Most of the flights were performed onto the runway and although the final approach and landing were not relevant for the MA-AFAS functionality as such, it forced the crews to actually prepare the approach and landing.

No abnormal situations were created for the crews, only normal operational situations were simulated.

As indicated the experiment comprised two days per crew. The first day pilots were briefed about the concept of ASAS spacing operations although all pilots received a briefing guide in advance and all pilots arrived well prepared. After the briefing the pilots were trained in the flight simulator for both the flight simulator as well as the MA-AFAS specific functions. Depending on the progress and questions from pilots this training included three or four flights of each 30 to 45 minutes. After this training session, the experiment flights started and all crews completed four experiment flights on the first day. The second day was used for the remaining six flights followed by the debriefing questionnaire and a debriefing discussion.

4. Flight simulator configuration and HMI

The flight simulator was used in its B747-400 configuration as the MA-AFAS project aims at the retrofit market rather than new aircraft. So, an existing aircraft type was used as baseline. The figure below depicts those flight deck elements which were used for the ASAS functionality of MA-AFAS. Used in this sense means new, or existing elements were adapted.

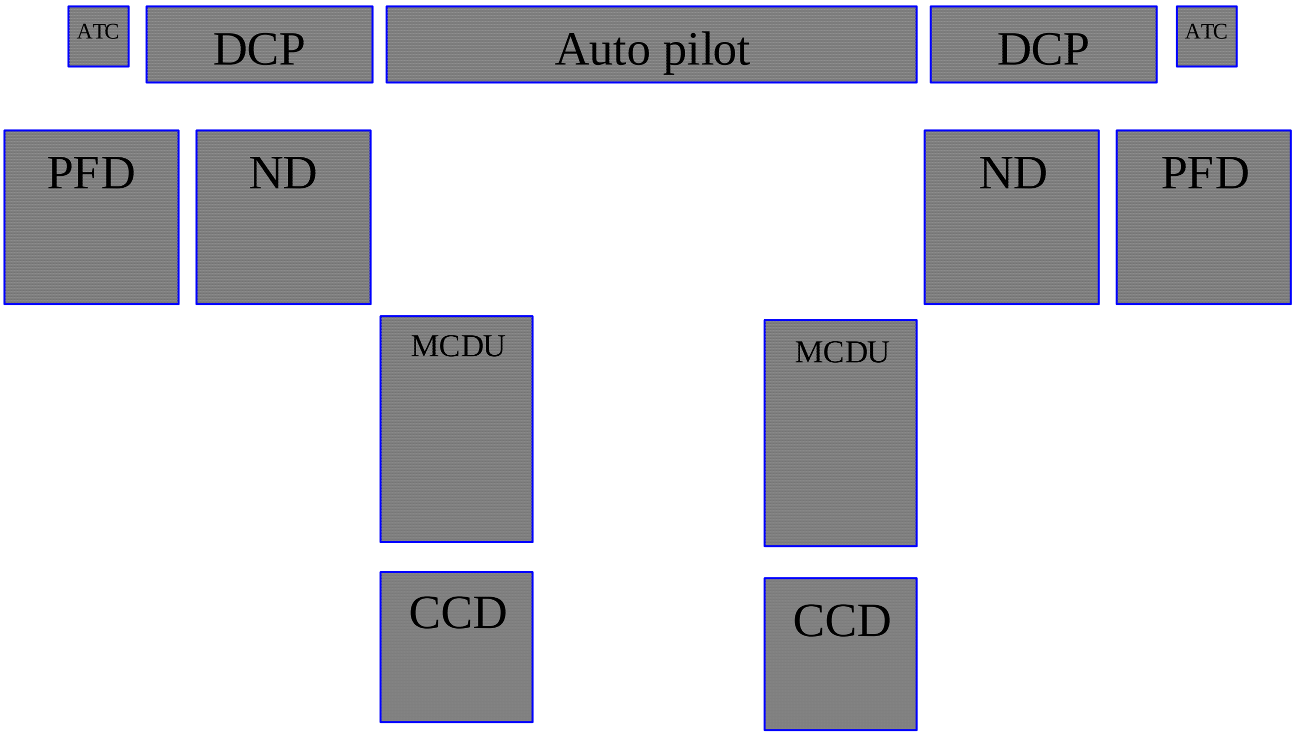


Figure 1 Schematic overview of used flight deck elements

From left to right, starting at the left upper corner the following elements were included:
ATC
This is a data link alert light, which was illuminated upon receipt of a CPDLC uplink from ATC. At the same time an aural alert was given. The data link light could be switched off by the pilot or was switched off automatically upon action taken on the received uplink.

DCP (Display Control Panel)
The existing display control panel was slightly adapted as the combined lateral and vertical view navigation display mode was selectable. On the display mode selector, the VOR mode was removed and instead this combined lateral and vertical mode was used.

Autopilot
Also on the autopilot panel one modification was made. In the speed control segment of the autopilot panel a pushbutton was added for selecting the automatic follow speed mode usable in merge behind and remain behind operation.

PFD (Primary Flight Display)
On the PFD, the amber no-go bands were added on the heading scale and the V/S scale, as a copy of information presented on the ND. On the speed tape a "follow" speed bug was added which indicates the CAS of the target aircraft with an altitude correction in case of an altitude difference between the target and the ownship. Flying the follow speed would keep the time between the target aircraft and the ownship constant. The FMA was adapted to annunciate the automatic follow mode if engaged.

ND (Navigation Display)
The ND is the element which is most affected. At the bottom of the ND a menu of softbuttons was added for activating ASAS functions, handling data link messages and set some display properties. In addition, on the map surrounding ADS-B traffic was displayed together with a data label. Specific ASAS instruction symbology appears upon activating an ASAS instruction. For the merge behind and remain behind function a dedicated time deviation scale was presented while for the other instructions amber bands on the heading scale and/or V/S speed scale was presented.

MCDU (Multi function Control and Display Unit)
The MCDU was extended with two hardware function keys, one for ASAS and one for ATC. Both function keys gave access to a set of MCDU pages which can be used for respectively ASAS or ATC. For both ASAS and ATC applies that the same function set is available as in the softbutton menu of the ND. It was possible to use both the MCDU and ND concurrently if desired by the pilot.

CCD (Cursor Control Device)
The softbutton menu of the ND was controlled by using the CCD. The CCD were positioned aft the MCDU's. Two CCD's were installed, however only the CCD for the left seat was an actual flight CCD while for the right seat a PC trackball was installed. During the experiment only the left seat CCD was used for experiment relevant tasks.

Below a picture of the flight simulator flightdeck is presented together with an artist impression of the outside (near future situation).

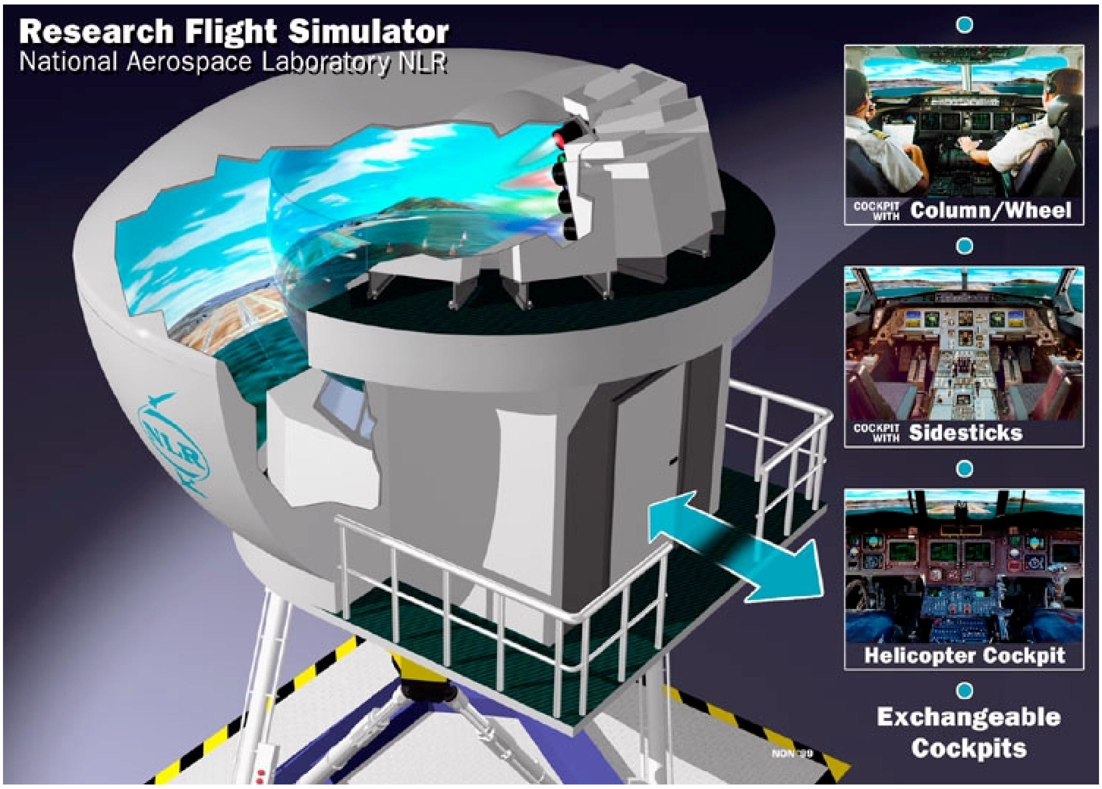


Figure 2 Flight simulator GRACE, Generic Research Aircraft Cockpit Environment

As can be seen from the list of flight deck elements, the ND in combination with the CCD and MCDU are the most affected elements used in the experiment. Therefore these HMI elements will be explained in more detail.

The Navigation Display consisted of several modes, for example a centre mode which is an existing mode and the vertical profile display (VPD) mode which is a new introduced mode here. At the bottom the menu of soft buttons can be seen.

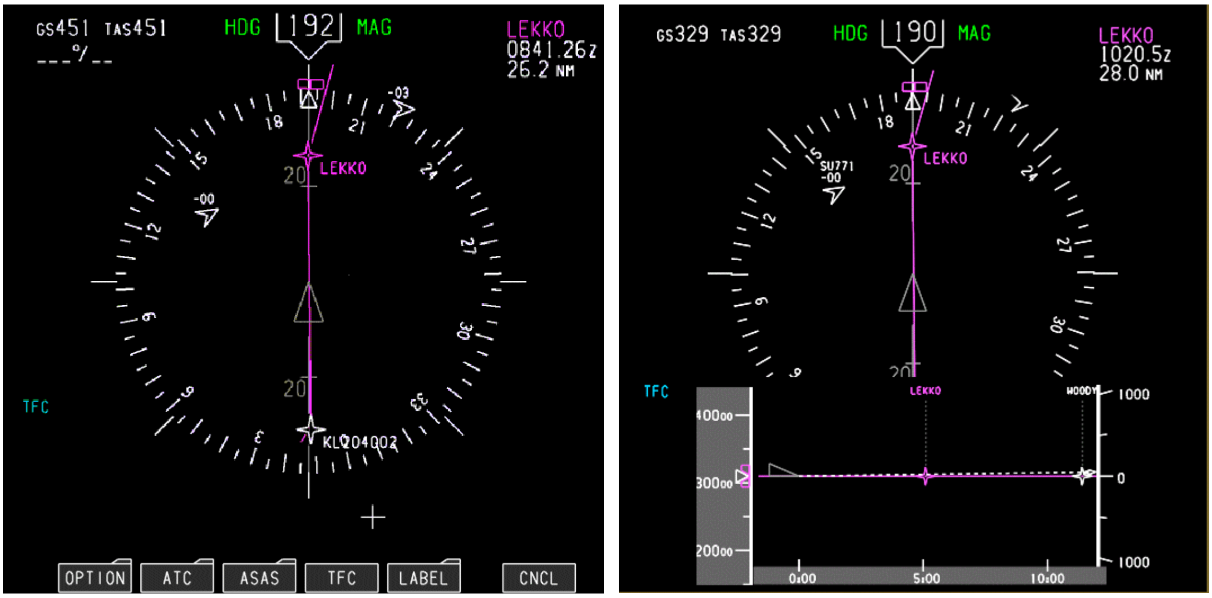


Figure 3 Navigation display with softbutton and vertical profile mode

The VPD presents the vertical profile of the route with on the left the altitude scale, horizontally the time scale along the planned route (in case no active flight plan available the time along the current track direction is used). On the right a vertical speed scale is presented which is the resultant of the altitude and time axis. The VPD is presented in the lower area of the ND usable area.
The VPD has three axis which are scaled automatically while changing the range of the ND.
The Navigation Display is controlled with the Display Control Panel (DCP).

As indicated earlier, both the MCDU and ND in combination with the CCD can be used for selecting an ASAS function. Both will be explained here by using a merge behind instruction as example.

The ASAS functionality in the MCDU is accessed by the **ASAS** button, resulting in the ASAS menu page.

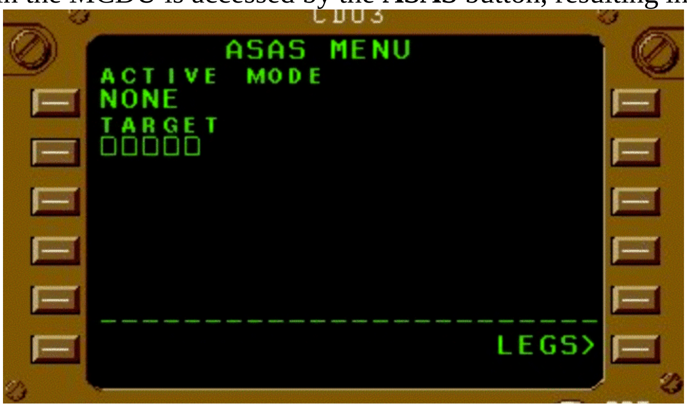


Figure 4 MCDU ASAS page, BICCA code to enter

Next to line select key (LSK) 1L (first key on left), the active ASAS mode is displayed.

On the ND, the ASAS menu is accessed by clicking the **ASAS** button:

Figure 5 Softbutton main menu

Using the CCD:

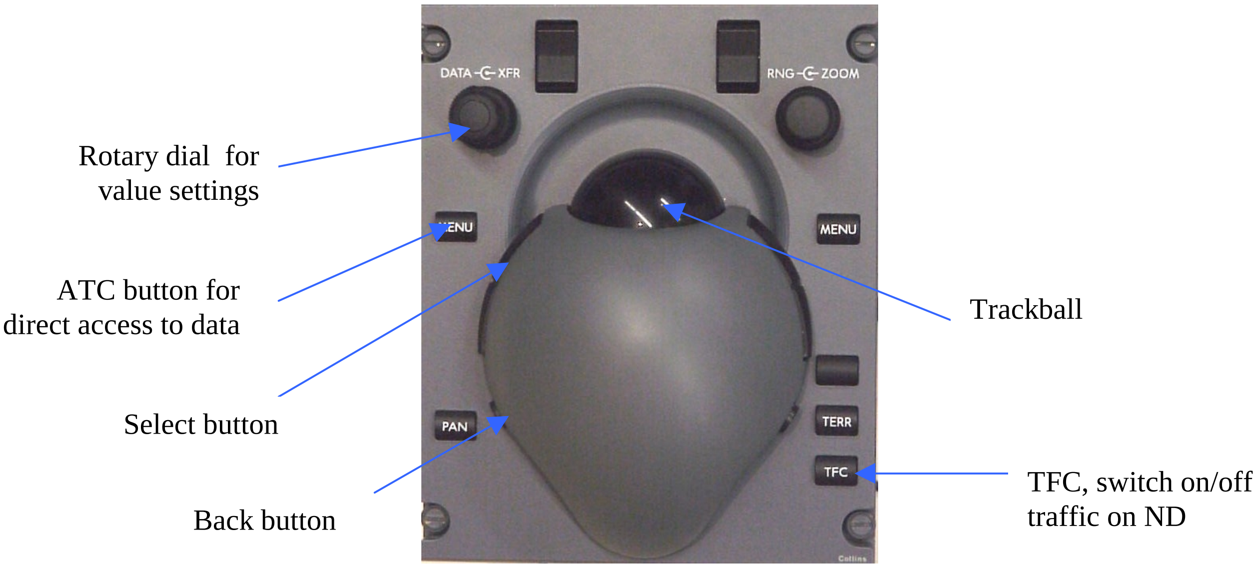


Figure 6 Cursor Control Device

Both MCDU and ND can be used in parallel at all times during the operation. It's upon pilot's discretion to use either one at any moment.

Upon receiving an ATC instruction to select a target, on the MCDU at key 2L, the 5 character BICCA code can be entered. BICCA codes of all aircraft are displayed on the ND in the label next to each aircraft. When this identification has been entered some ADS-B state parameters are presented on the MCDU page, see below.

Figure 7 MCDU ASAS page after BICCA code is entered and target found

The selected target is shown magenta now on the ND and the limited delegation functions are available on the right on the MCDU page.

Target selection on the ND is performed by selecting the target aircraft directly with the cursor using the CCD:

Figure 8 Target aircraft symbol

On the ND, the ASAS menu presents now:

Figure 9 Softbutton menu, ASAS submenu

Upon an ASAS instruction from ATC with respect to the selected target the sequence of events continues. For example a merge behind instruction on either MCDU or ND:
The MERGE page is accessed by pressing by LSK 3R on the ASAS MENU page, resulting in the following page.

Figure 10 MCDU ASAS page, Merge behind sub page

When all required information is entered (spacing time or distance and merge waypoint), the merge function can be activated by 1R and the merging related symbols will appear on the ND.
Activating the same merge instruction using the ND with CCD would show the following sequence of events:

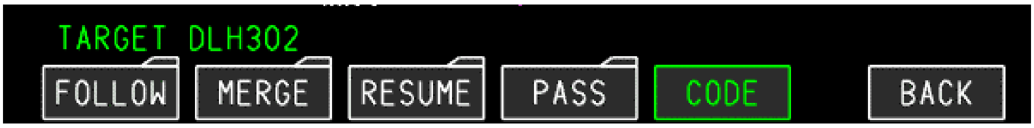


Figure 11 Softbutton menu, ASAS sub menu

The target is selected, next step is to select the **merge** button resulting in:

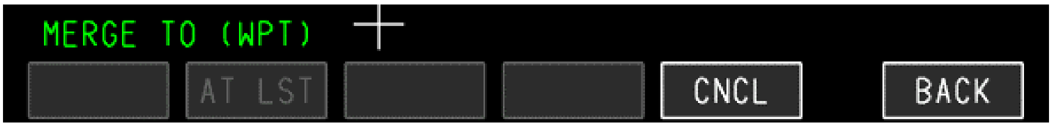


Figure 12 Softbutton menu, Merge behind sub menu, waypoint to be selected

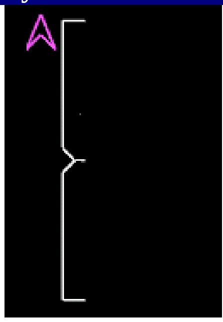
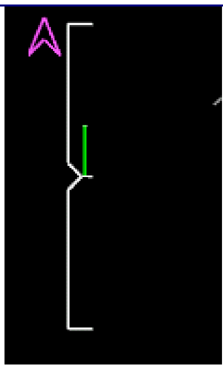
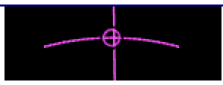
After having selected the waypoint with the cursor on the ND, the merge instruction will appear with a default value of 90 seconds which can be changed using the rotary dial of the Cursor Control Device.

Figure 13 Softbutton menu, Merge behind instruction completely defined

After having completed the selections for merge behind instruction the related symbols for the merge behind instruction are presented on the ND, see figure below.

Figure 14 ND in map mode with merge behind symbology

The following ND display elements are presented:

Name	Symbol	Remarks
Longitudinal spacing deviation scale (White) and pointer (Magenta)		Scale runs from required spacing distance +/- 1 Nm or if time is used +/- 10sec.
Spacing deviation trend indicator (Green)		Originates at centre of deviation scale Length gives deviation change in one minute based on current closure rate.
Selected target aircraft (Magenta)		Symbol filled, colour magenta.
Spacing symbol (Magenta)		Indicates map position of the ownship at which the required spacing will be reached
Active ASAS mode indication (Cyan)		Location: mid left. "D" for distance, "T" for time followed by the required distance or time in Nm or seconds.

At the same time a Follow (**FW**) will appear on the PFD speed indicator. This symbol shows the Indicated Air speed the ownship should fly in order to keep the time difference between ownship and target constant.

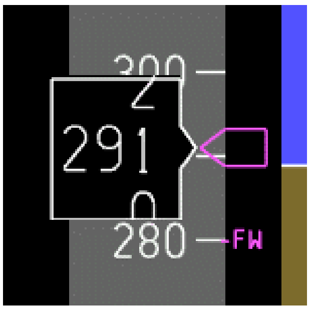


Figure 15 Detail of speed tape of the PFD with follow bug

Specific display elements used for the lateral and vertical passing ASAS instructions are the amber bands on the heading and vertical speed scales as shown below:

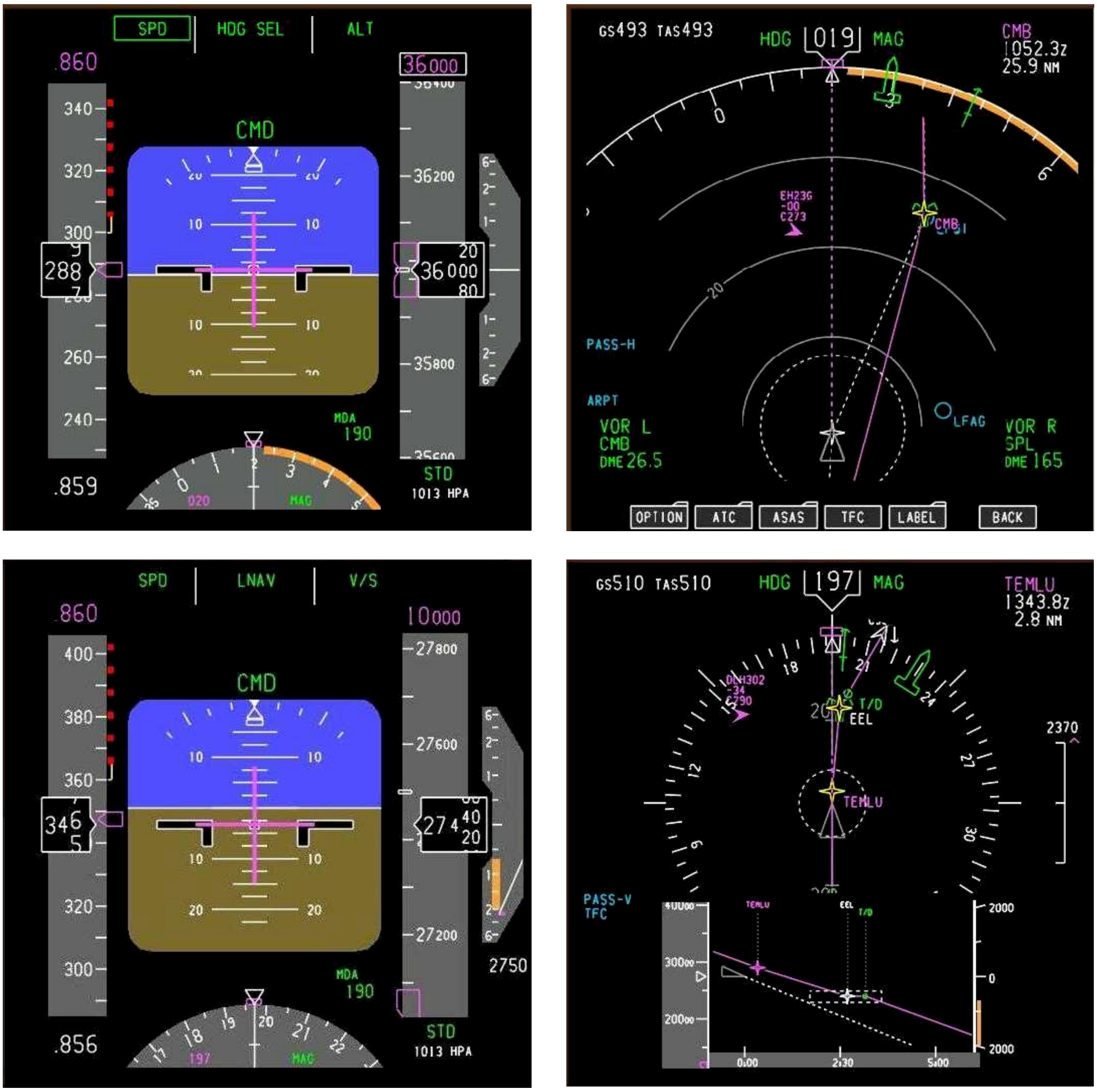
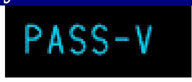
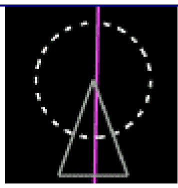
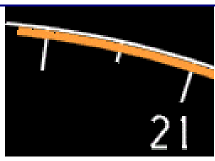
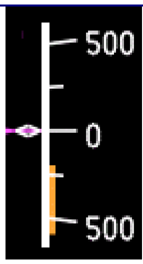


Figure 16 EFIS with pass symbology

With specific elements:

Name	Symbol	Remarks
ASAS active mode (Cyan)		Pass vertically in this example.
Spacing circle around ownship (White)		The circle is positioned around the ownship symbol with a radius of the required spacing distance.
ASAS no go heading indication (Amber)		All manoeuvres. When actual heading is in the amber band the required spacing will be infringed.
ASAS no go vertical speed indication (Amber)		Vertical manoeuvres. When actual vertical speed is in the amber band the required spacing will be infringed.

The traffic environment in which the flight simulator was operating was generated by the traffic manager which was also used by the pseudo air traffic controller.

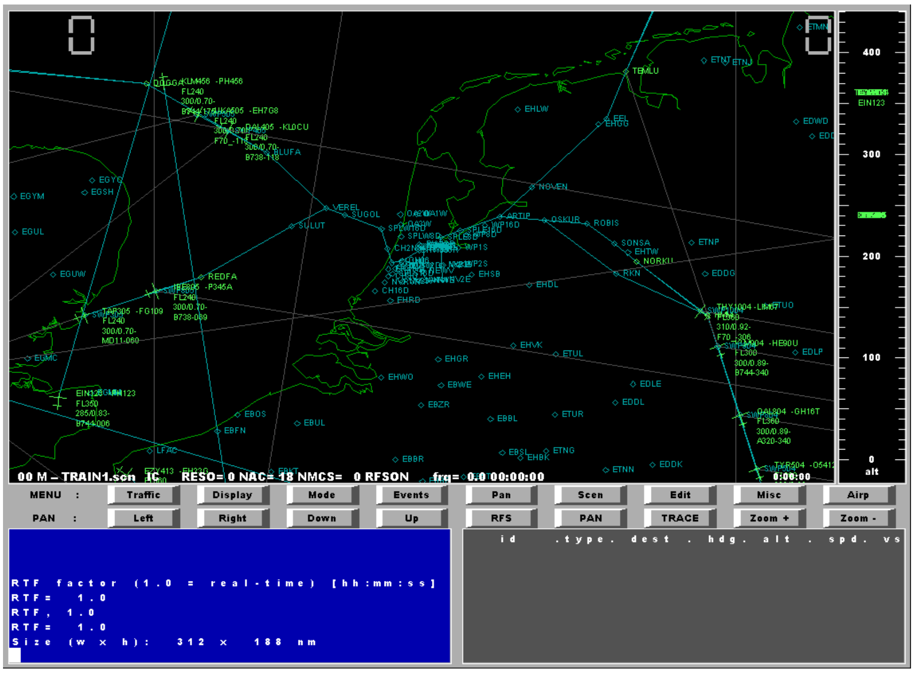


Figure 17 Traffic manager and pseudo controller working position

5. Measurements

During the experiment three types of data was collected: pilot opinion by means of questionnaires, performance by means of recorded simulator data and pilots' eye point of gaze using an eye tracker.

During the experiment three questionnaires were applied:

- post ASAS instruction questionnaire
- post flight questionnaire
- debriefing experiment questionnaire

The post ASAS instruction questionnaire was kept very limited because pilots needed to fill this in while the flight was continuing. It was therefore not intended to let pilot write down comments in this questionnaire since they were lacking time and attention for this. After completing a flight the post flight questionnaire was used which contained more questions and also allowed for writing comments down by the pilots. The debriefing questionnaire was used after all experiment runs were finished and it contained high level questions concerning the concept of ASAS but it contained also very detailed questions about specific items in the HMI for example.

Having performed 10 flights per crew for 10 crews this means that the total number of questionnaires is 600. The table below gives an overview of retrieved questionnaires.

Questionnaire	# per flight	# of flights	# of pilots	total
Post ASAS instruction	3	8	20	480
Post flight	1	10	20	200
Debriefing	-	-	20	20

The post ASAS instruction questionnaire and the post flight questionnaire were focussing on pilot acceptance of the ASAS concept and the system and on rated pilot workload. The debriefing questionnaire was apart from these issues, also containing questions about the HMI and procedures.

Data recording of the flight simulator induced, apart from normal flight parameters and pilot inputs, a number of parameters which are indicative for the performance of the crew during an ASAS manoeuvre. For the lateral and vertical passing manoeuvres the distance to, and altitude difference with, the target aircraft were measured and the time behind the target aircraft during a merge behind manoeuvre were measured. Although it concerns flight simulator trials here with the focus on pilot acceptance and pilot workload, still flight performance is relevant to consider. Not so much to investigate system capabilities and performance but pilot/system performance which can be related to acceptance and workload. If measures with respect to acceptance are positive and workload is acceptable this is only a positive result if the performance is acceptable as well. Therefore performance data is an integral part of the data analysis.

Eye point of gaze measurements were taken during a subset of the flights. Since it does not cover the complete set of flights only a limited analysis could be made.

6. Results

6.1. General

Twenty professional Dutch airline pilots participated as subjects in the experiment. The pilots had an age between 24 and 55 years old (average 38 years). Total flying experience reported was between 1500 and 16500 hours (average 7360 hours). Ten of the pilots were captain and the other were first officer on aircraft with a glass cockpit at the time of the experiment. Five of the pilots had a military background.

6.2. Pilot acceptance

Pilot acceptance ratings were collected in the post instruction questionnaires and the post flight questionnaires. All acceptability questions could be answered by using a six-point scale. The answers are pairwise combined in three categories: "disagree", "neither agree or disagree" and "agree". In the following figures the "agree" is coloured green, "neither" is yellow and "disagree" is amber. All answers from "agree" upto "disagree" add up to 100%. Figure 18 gives the overall acceptance of the six applied ASAS instructions. Except for the "pass below" instruction pilot acceptance is high.

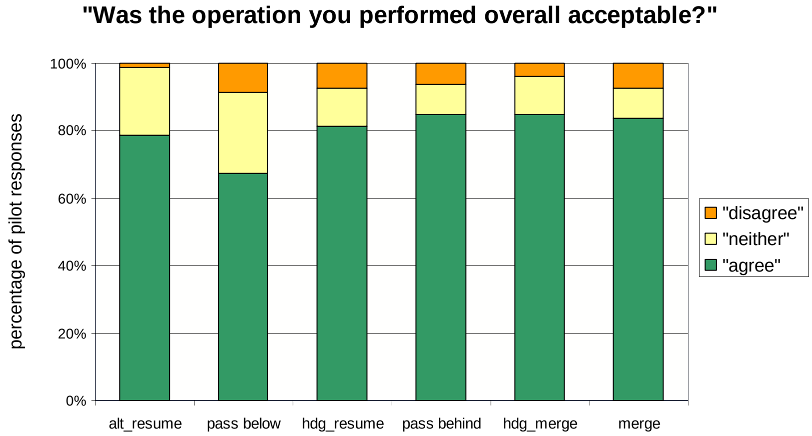


Figure 18 Acceptability per ASAS instruction

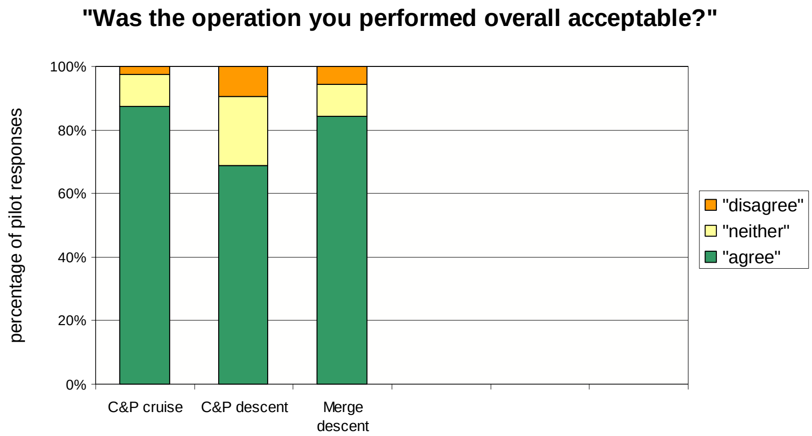


Figure 19 Acceptability per flight phase

Zooming in a deeper level looking at the flight phase the results show that the descent phase is less acceptable than the cruise phase for the vertical crossing and lateral passing (C&P) manoeuvres. A possible explanation for this is that a vertical manoeuvre is changing the descent planning in one dimension but a lateral manoeuvre is affecting the descent planning in more dimensions to be solved by the crew. This in combination with the current operation where ATCo interventions during initial descent are mainly vertical might be a reason for marginal acceptance during the descent.

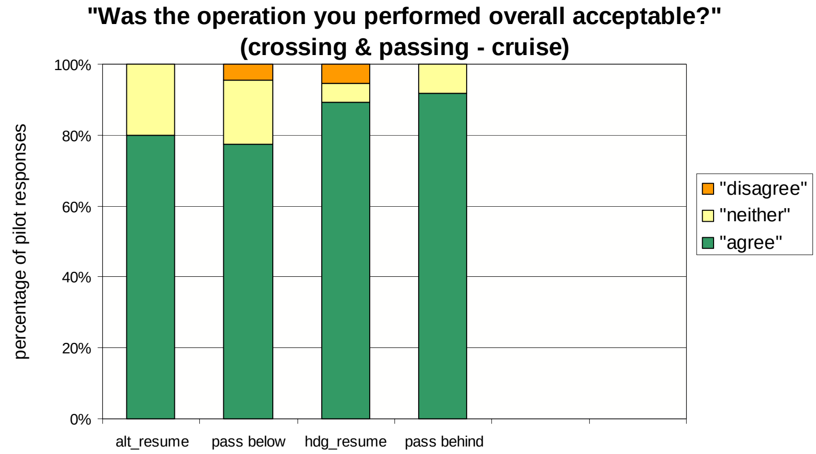


Figure 20 Acceptability in cruise per ASAS instruction

In order to have a better understanding of the differences in the acceptability in the cruise and descent phase, the four relevant instruction are presented here in two figures, one for the cruise and one for the descent phase. It shows that the horizontal manoeuvres “pass behind” and “heading then resume” are very well acceptable in the cruise phase but drops in acceptability in the descent phase, similar behaviour can be seen for the pass below operations. Pass below has a low acceptance in the descent due to aircraft performance and safety issues. Frequently quite high rates of descent had to be selected in order to pass below the target aircraft. There exists always the uncertainty among the pilot whether the target remain stable during the whole procedure. If not, hardly any option exist to solve the situation.

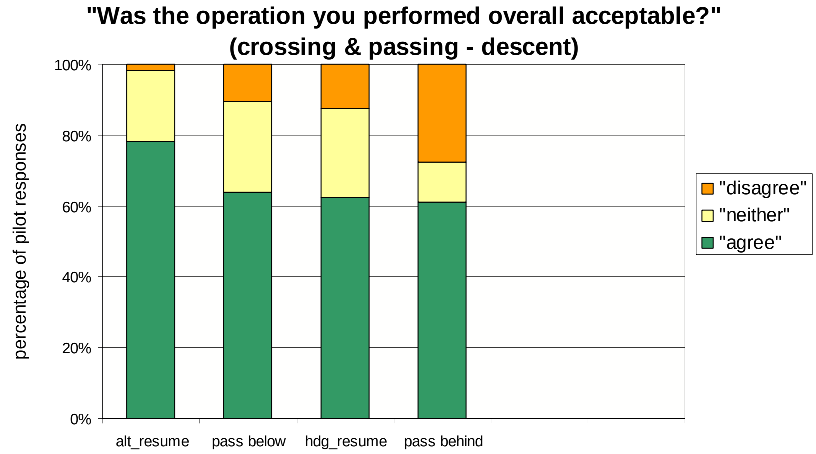


Figure 21 Acceptability in descent per instruction

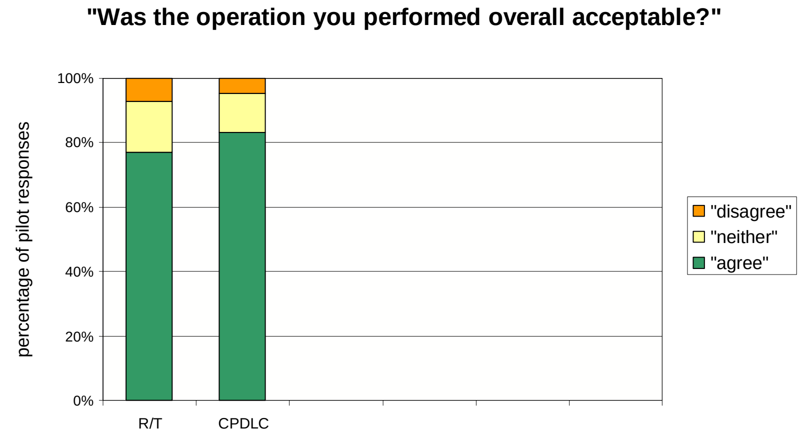


Figure 22 Acceptability per communication means

Looking at the means of communication, either radio telephony or data link, no real difference was found. For the automatic speed control the same applies, no difference was found.

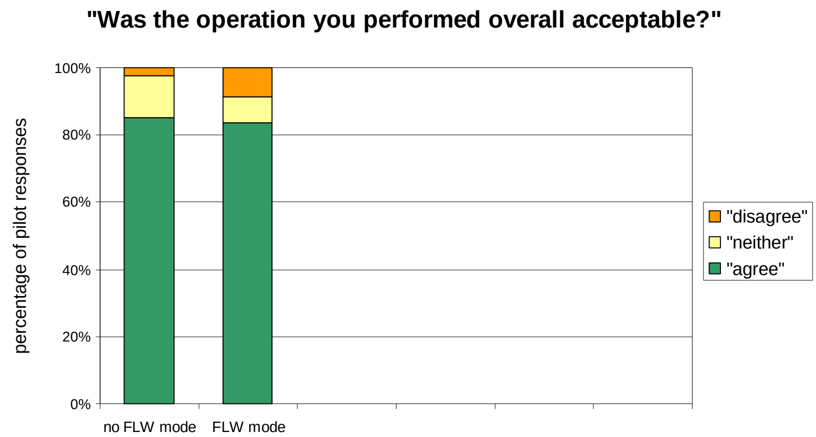


Figure 23 Acceptability with or with automatic speed control during merge

The “disagree” in the automatic follow mode can be explained because the speed limitation for the automatic mode were not well implemented and therefore the automatic mode could select a speed lower than the minimum clean speed or flap manoeuvring speeds.

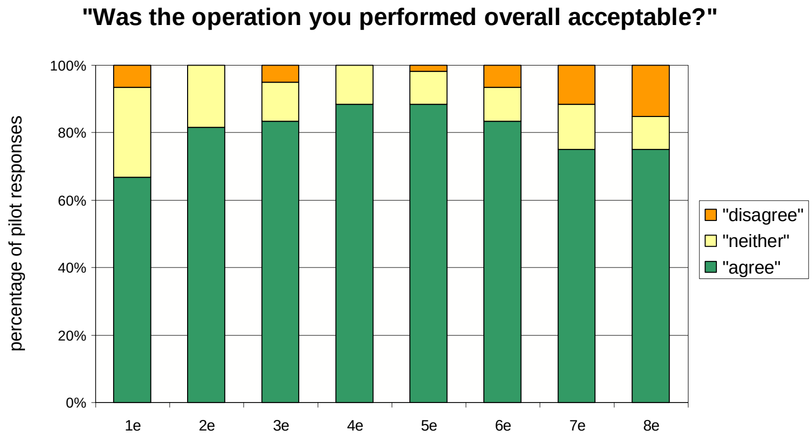


Figure 24 Acceptability as function of exposure (1st to 8th ASAS flight)

Looking at the change of acceptability over the two days trial the first effect to be seen is still a training effect and acceptability is growing. After the fifth flight however, the acceptability starts to drop again. A possible explanation of this is that pilots start to grasp the system and the concept and start to 'see' possible drawbacks of it and become more critical in their answers.

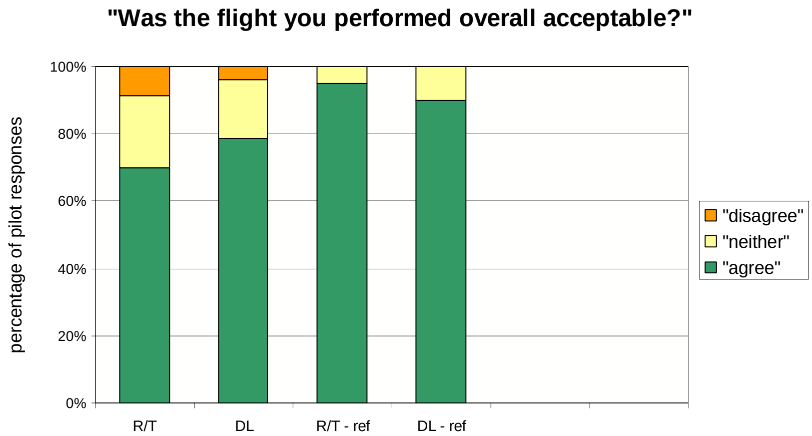


Figure 25 Acceptability per means of communication, against reference flights

Next, the comparison is made with the reference flights. It shows that the references flights, in which no ASAS instructions were given and ATC gave standard instructions, were rated more acceptable than the ASAS flights. This applies for both means of communication. The negative ratings given during the ASAS flights were all non communication means related.

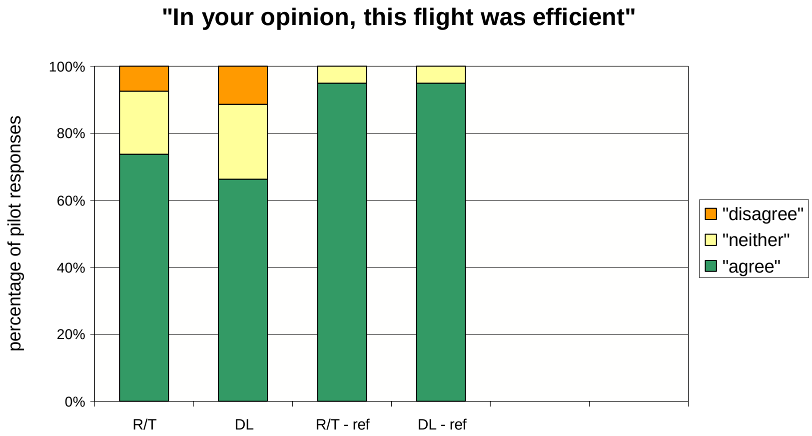


Figure 26 Rated flight efficiency per means of communication against reference flights

The rated efficiency is very high for the reference runs, but for the ASAS flights the efficiency was rated a lot lower. One important reason for these low efficiency ratings is the fact that less efficient instructions were given by pseudo ATC in order to apply all ASAS instruction according to plan. During the reference flights the pseudo ATCo issued similar inefficient instructions, but since no ASAS indications were presented on the flightdeck, it was less obvious to the pilots. No difference between R/T and CPDLC is found.

For the safety ratings of the pilots apply that again the reference flights are rated better than the ASAS flights. The negative ratings for the R/T ASAS flights are either caused by simulation mishaps or ATC instructions which were hardly or not possible to meet. The negative rating for the CPDLC ASAS flights is one event and due to a long interruption of a checklist by an ATC uplinked ASAS instruction.

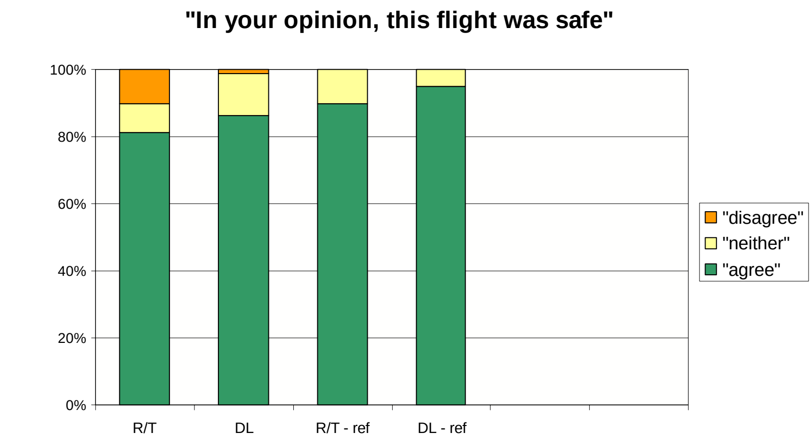


Figure 27 Rated flight safety per means of communication against reference flights

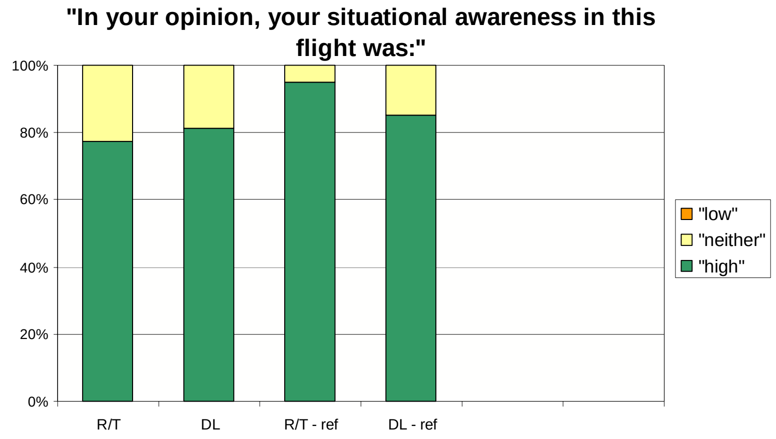


Figure 28 Rated situation awareness per means of communication against reference flights

Situation awareness was rated high for all flights basically. No disagree was given. Again no difference between R/T and CPDLC was found.

The ATC procedures are rated positive in general, but in a number of cases pilots gave a negative rating. These negative ratings are partly due to late ATC instructions or instructions which were hardly feasible and partly due to problems pilots experienced in remembering the BICCA code and all elements of an instruction. In other words the complexity of the instructions.

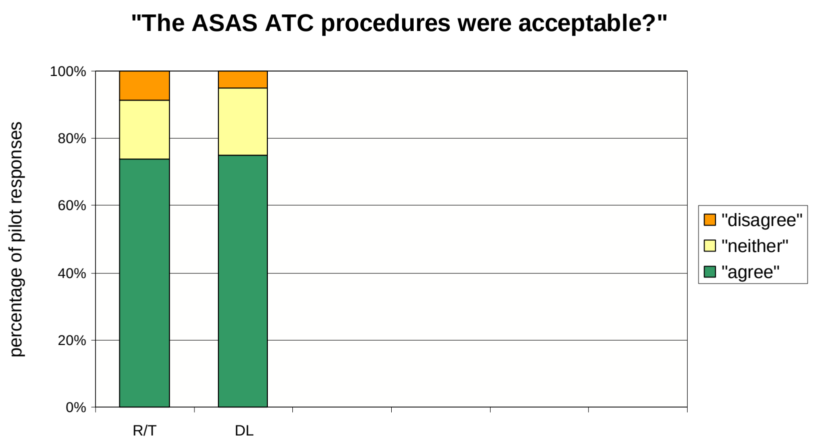


Figure 29 Acceptability of ATC procedures per means of communication

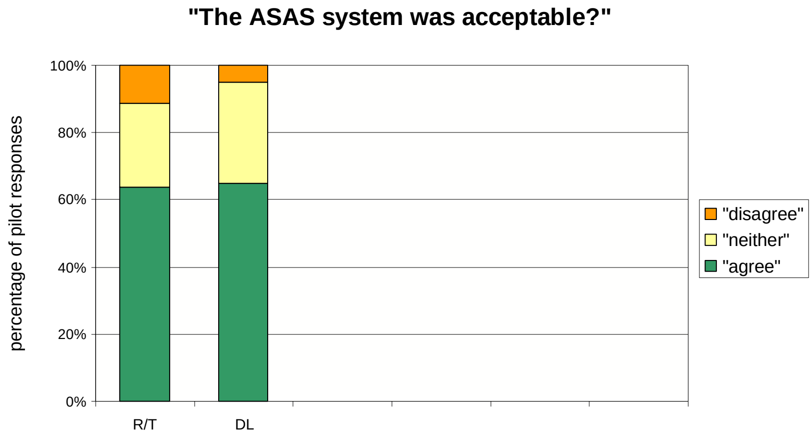


Figure 30 Acceptability of the system per means of communication

The ASAS system was rated less positive then the ASAS procedures. The negative ratings are to a large extent caused by mishaps in the ASAS functions and not caused by design flaws and by ATC instructions which were difficult to meet. However in one single case a negative rating was given using CPDLC because the pilot was confused whether he was working the "ASAS" submenu or the "ATC" submenu.

The allocation of the tasks to either the crew or the controller was clear.

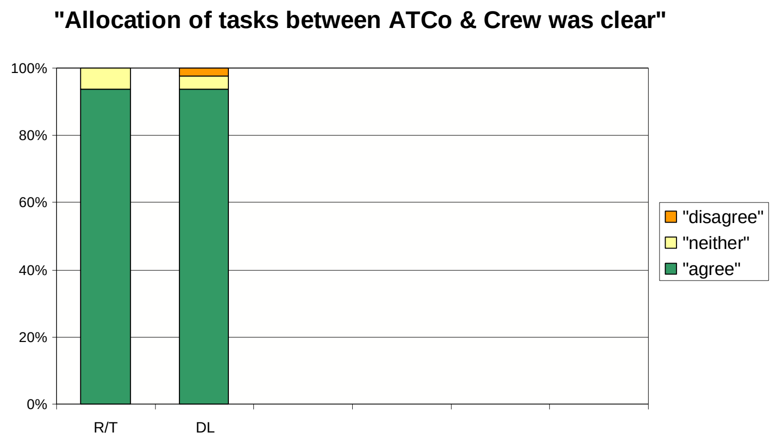


Figure 31 Task distribution per means of communication

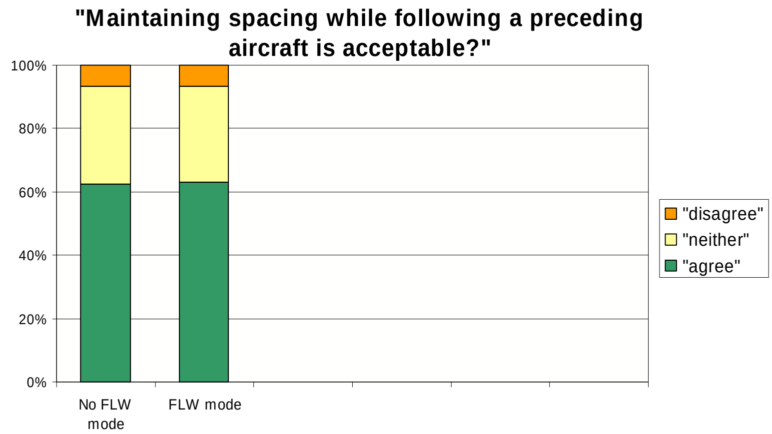


Figure 32 Acceptability of maintaining spacing following a preceding aircraft

Acceptability of following a preceding target aircraft scores relatively high in the "neither" answers, both for the automatic speed control and pilot speed setting. These neither answers indicate that the manoeuvre itself is not rated negative, but improvements are required. Comments from pilots indicate the following problems:

- the automatic follow mode selects speed below the minimum clean speed or minimum flaps speed;
- the automatic follow mode takes too much time to reduce the time error;
- too many speed changes occur during the whole manoeuvre;
- alerting should be provided in case separation might be infringed in the near future;
- cancelling the target should not require any flight deck action on final approach;
- energy management becomes more difficult since speed is now demanded by target behaviour;
- the trend vector on the deviation scale was difficult to interpret;
- additional attention to monitor the target behaviour for both automatic speed control (e.g for flap settings) and pilot speed settings.

6.3. Pilot workload

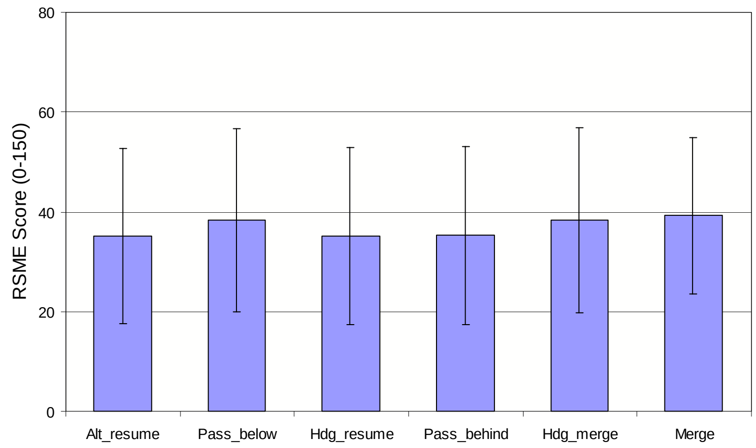


Figure 33 Rated workload per ASAS instruction

The workload ratings using the Rating Scale Mental Effort (RSME) are in general very acceptable. Typical average values are below 40 on the scale running from 0 to 150. For example 38 is "somewhat effortful". Looking at the rated workload divided over the various ASAS instructions, no differences were found.

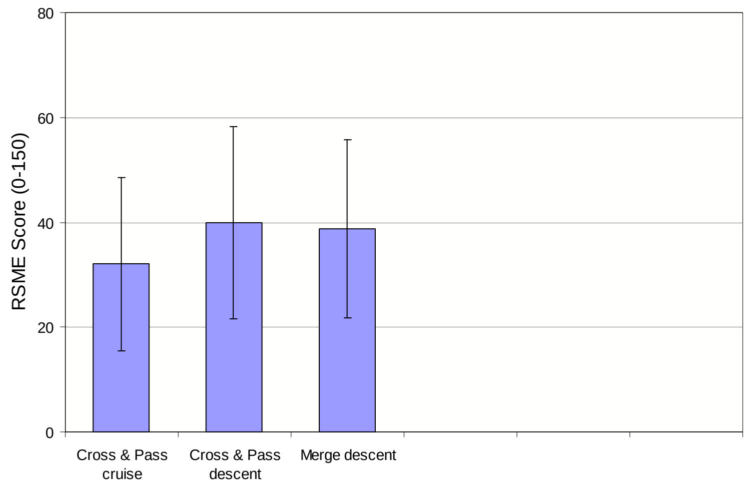


Figure 34 Rated workload per flight phase

Looking at the workload ratings per flight phase it shows that the ASAS instructions given in the cruise phase lead to the lowest workload. This is in line with the acceptability where the acceptability was rated highest in the cruise phase.

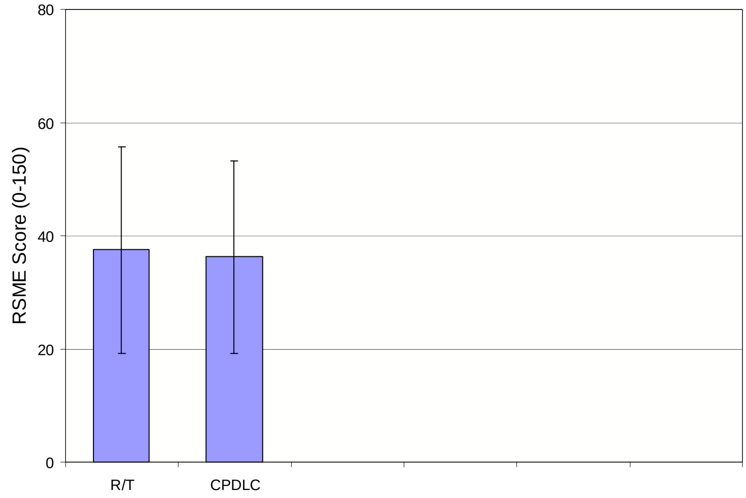


Figure 35 Rated workload per means of communication

No differences were found between R/T and CPDLC.

Workload experienced having the automatic follow mode coupled or having to set the speed using speed select mode of the autopilot does not lead to a difference in workload ratings. So, mental workload for monitoring the automatic mode and setting the speed themselves is rated identical.

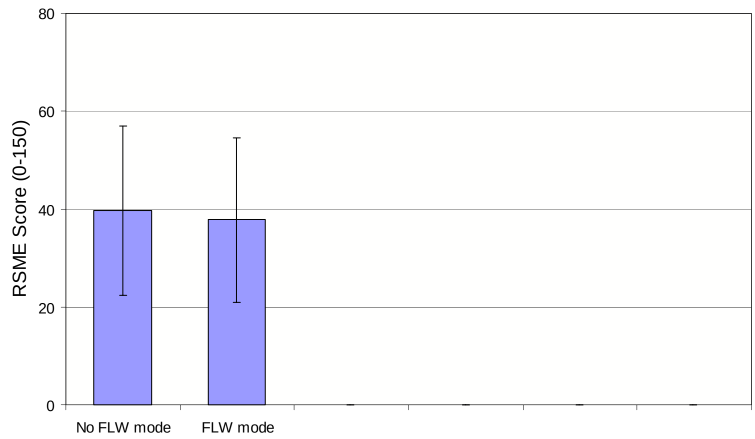


Figure 36 Rated workload with or without automatic speed control during merge

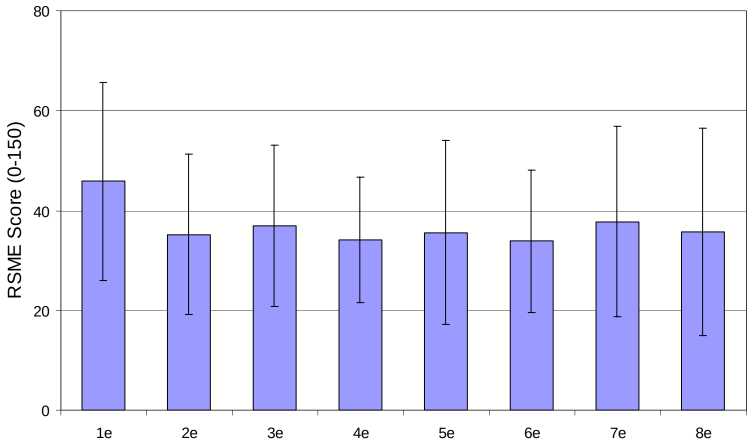


Figure 37 Rated workload as function of exposure (1st to 8th ASAS flight)

Looking at the progress over the 8 flights performed over the two days, the first flight leads to a higher workload, for the further flights, no real change could be observed. This is also in line with the acceptance building up during the first few runs, a training effect is assumed.

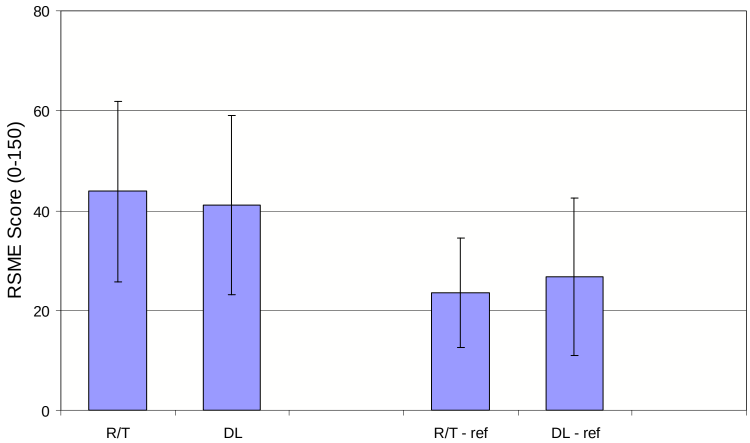


Figure 38 Rated workload as function of means of communication against reference flights

In line with acceptability, the reference flights score very well compared to the ASAS flights. No differences were found between R/T and CPDLC. Though the ASAS flights score around 40 this is considered to be quite acceptable, figures in the order of 70-80 or above would have given reason to concerns with respect to workload. One workload issue still remains open, also indicated by several pilots, namely the effect on workload caused by one pilot being temporarily distracted, e.g. by problems in the cabin, technical problems, communications with the company, bad weather. Pilots indicated that this kind of distraction happens frequently during the descent phase.

6.4. Detailed HMI and procedure questions

In the debriefing questionnaire a number of detailed questions concerning HMI and applied procedures were asked. It concerns a set of questions that could be answered on a six-point scale from "strongly disagree" to "strongly agree". Like for the acceptability questions the answers are pairwise combined in "disagree", "neither disagree or agree" and "agree".

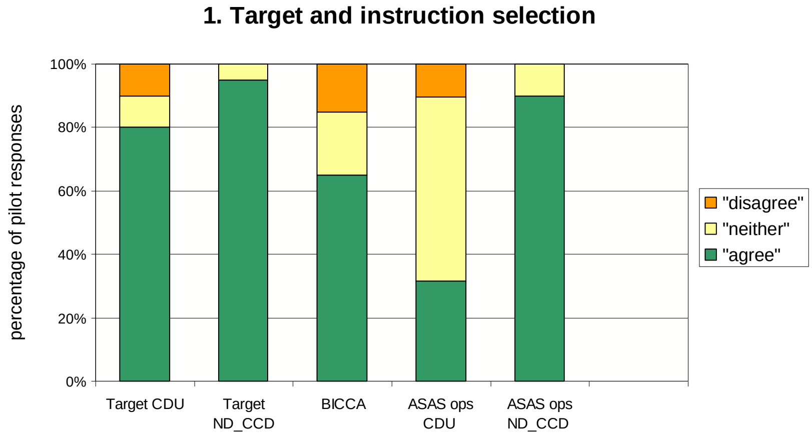


Figure 39 Rating of HMI for selecting a target and ASAS instruction

For selecting the target, the ND in combination with the CCD scores slightly better than the CDU. The same effect, but a lot stronger is observed for selecting the ASAS function. Though a number of improvements still could be made on the CDU, this rating quite strongly indicates that for ASAS instruction entries the CDU as head-down device is less preferred than the ND/CCD combination. Using the BICCA code is rated marginally acceptable, a rather high percentage of negative ratings and reservations were expressed as can be seen in the number of "disagree" and "neither" ratings.

Figure 40 Rating of the ASAS instructions

After having applied four times each instruction, the pass behind and the heading then resume are rated the best, next the altitude then resume and both merge instructions. For the vertical crossings the altitude resume is rated positive since it is a very natural way of operating, but the pass below was rated the worst of all instructions. One of the main reasons for this is the unpredictability whether the aircraft performance allows this manoeuvre or not. The other one is the uncomfortable feeling among pilots about the situation they would get trapped in when the other aircraft would start to descent, leaving almost no possibilities to orderly maintain the required spacing. Both above-mentioned concerns are potential safety issues.

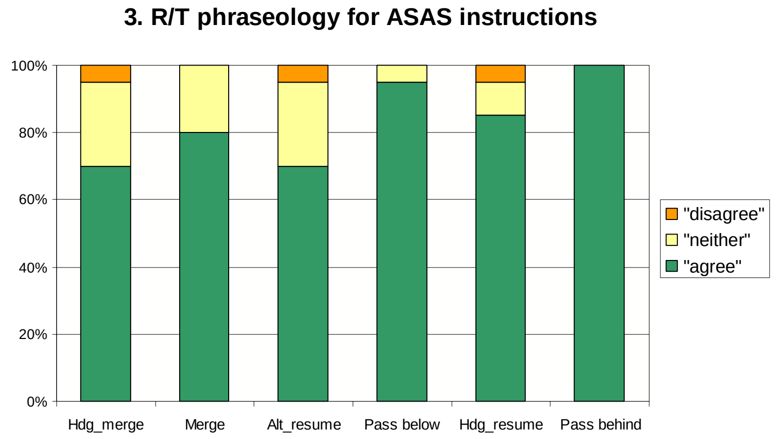


Figure 41 Rating of the R/T phraseology for ASAS instructions

Looking at the applied R/T phraseology, the most simple instructions as “merge behind”, “pass below”, “pass behind” are rated best in each class of ASAS operations (lateral passing, vertical crossing, and merge behind). The more complex instructions starting with a heading instruction or altitude instruction are rated less because of their high information contents. Note the high acceptance of the phraseology for “pass below” while the instruction itself is not well accepted.

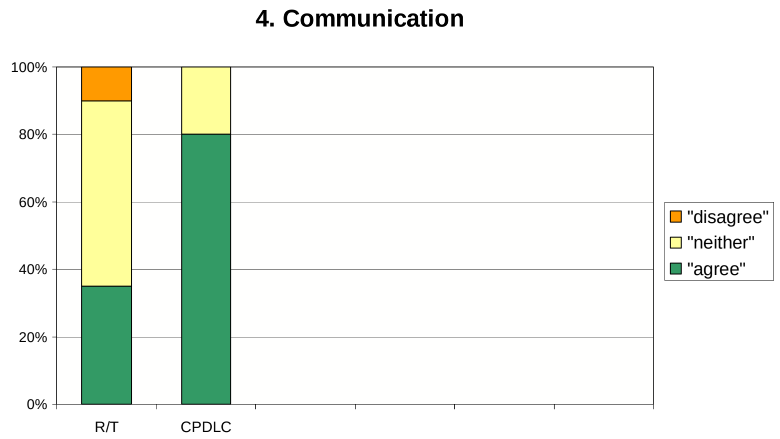


Figure 42 Rating of the means of communication for ASAS instructions

CPDLC is more appreciated than R/T for ASAS instructions specific. This result can not be supported by acceptability of the various functions using R/T or CPDLC as found in section 6.1. The structure of the questionnaires was such that at the end of the two-day session the debriefing questionnaires invited the pilots to compare different solutions, still in terms of acceptability. So the debriefing questions also have a rather strong preference component. The R/T variant had more operational difficulties to overcome, e.g. remembering and reading back quite long and complex ASAS instructions, and was from a conceptual point of view less preferred.

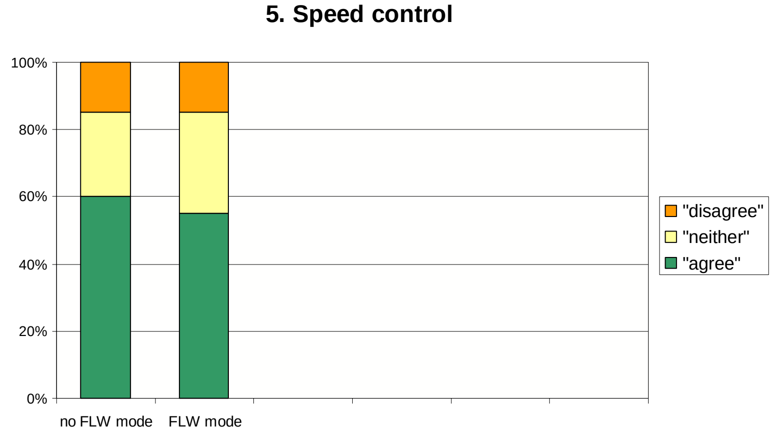


Figure 43 Rating of speed control, either automatic or pilot setting

No differences in ratings were found for the automatic speed control and pilot speed setting. Acceptance in general is not too high because it is a demanding task whether it concerns monitoring the automatic speed control and selecting the next flap setting in time or monitoring the behaviour of the target aircraft and changing the speed setting on the autopilot.
As these results are in line with the acceptability figure (fig. 32) at the end of paragraph 6.2 it can be concluded that the merge/follow operations are marginally acceptable. The percentage of negative ratings and reservations are rather high. The merge/follow operation needs to be improved and based on the concerns and issues mentioned in paragraph. 6.2 and anticipated improvements it is expected that considerable better results are feasible.

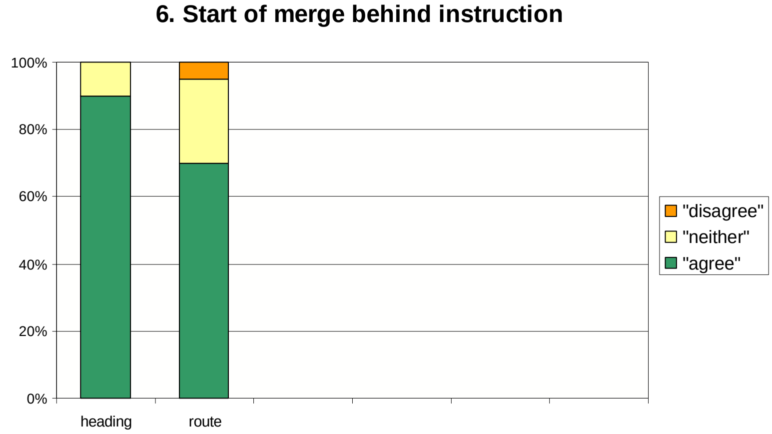


Figure 44 Rating of the initiation of a merge behind instruction

The merge behind function was used in two forms, initiated with a heading instruction or maintain the route as planned. As shown, the initial heading instruction was more appreciated than maintain the route. Main reason is that with a heading offset it is easier to acquire the required time to target than solely speed changes especially when a speed reduction is required while descending. It also was related to the initial conditions were occasionally a large time error (> 30 sec) had to be corrected during a typical distance to go to the merge point of 40-50 Nm. This could be achieved with the heading change to create more time spacing, but generally it could not be achieved with speed changes to bring the excessive time spacing within the 10-second tolerance.

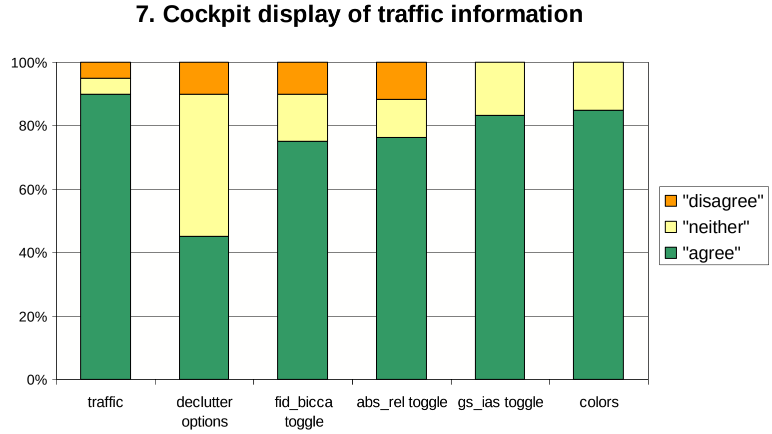


Figure 45 Rating of the CDTI elements

The CDTI in general was well accepted however the decluttering needs further attention mainly with respect to label presentation.

Regarding the SDEV indicator, the trend vector was low rated since it was experienced as being too complicated. The spacing symbol was low rated due it, sometimes, less predictable behaviour and easily being missed during a merge behind manoeuvre. The passing and crossing symbology was well accepted.

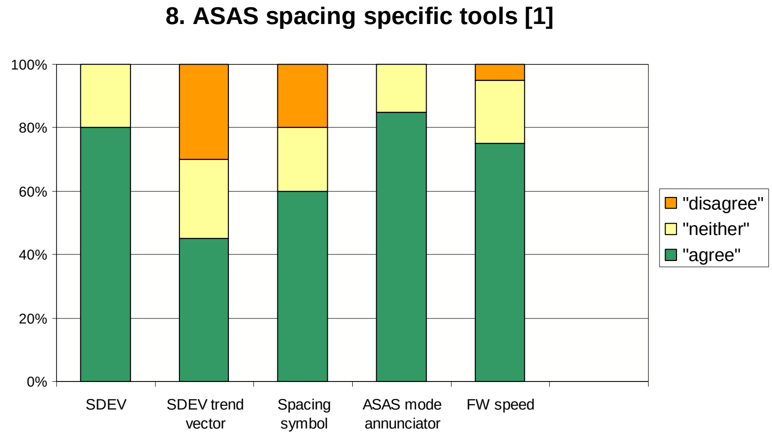


Figure 46 Rating of ASAS specific HMI tools 1/4

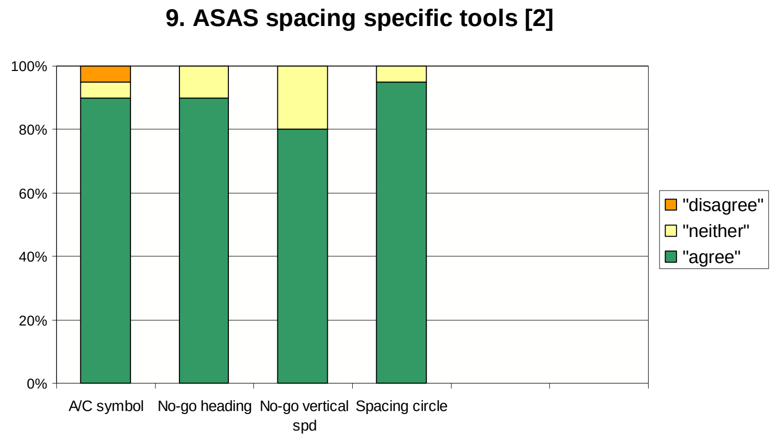


Figure 47 Ratings of ASAS specific HMI tools 2/4

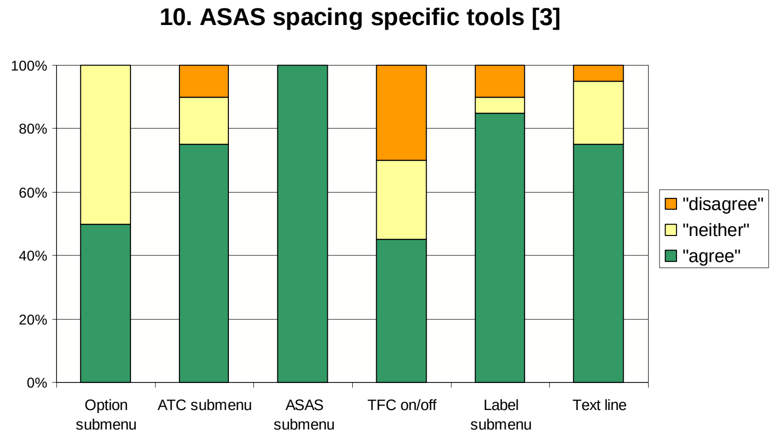


Figure 48 Rating of ASAS specific HMI tools 3/4

The options submenu and the traffic on/off switch was regarded as redundant since it was also available on the DCP. The negative ratings for the traffic switch were given because pilots preferred this to be a hardware switch rather than a softbutton on the ND. The ATC menu was rated not fully positive since an uplink message could sometimes not be presented as a whole, but scrolling by the pilot was required. A second reason was that after an uplink was responded and cleared, both pilots, PF and PNF, had to re-select the 'ATC' submenu again. The reservation with respect to the textline was that the distinction between an ATC uplink and a pilot entered ASAS instruction was poor, possibly leading to confusion.

The reservations with respect to the CCD were mainly simulator implementation related issues, the CCD itself was well accepted. The negative ratings for the menu next to an aircraft symbol were mainly due to not using the option at all and indicating that it was not missed, therefore not desired or required.

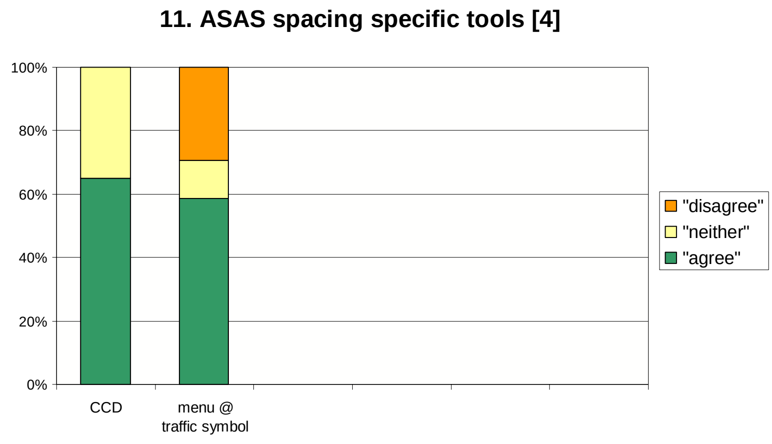


Figure 49 Rating of ASAS specific HMI tools 4/4

6.5. Performance

All pilot feedback in questionnaires can only be valid in case pilots performed as required. In this section the flight performance during each of the ASAS manoeuvres is presented by means of the delegated parameter against the time line. For the lateral manoeuvres, pass behind and heading then resume, the distance to the target aircraft is presented. For the vertical crossings, pass below and resume descent, the altitude difference with the target is presented. Finally for the merge behind manoeuvre, either with or without an initial heading, the time error relative to the instructed spacing time is presented.

The performance presented is the performance achieved by the pilots using information as presented mainly on the EFIS. The system was not applied in its full automatic FMS mode. This means that the performance presented here is the outcome of decisions and actions of the flight crew, decisions and actions based upon information as generated by the ASAS system. In the performance figures the coloured bar represents the average value of the applicable parameter and the error bar represents the standard deviation.

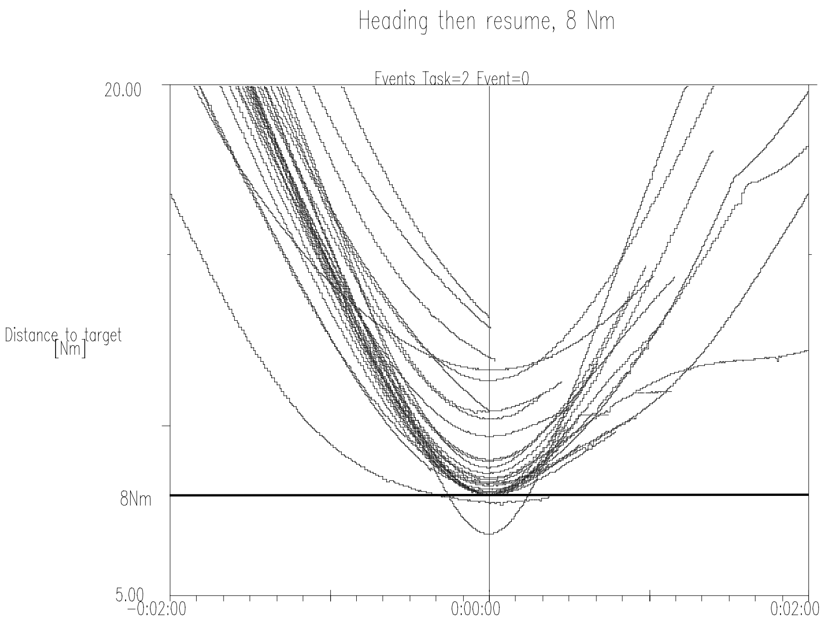


Figure 50 Distance to target during a heading then resume manoeuvre using 8Nm

For the heading then resume instruction, the distance to the target is presented for all flights, split in instructions using 5 or 8 Nm. In the heading then resume instruction using 8NM, two infringements were noticed. The most severe violation, 6.8 Nm at CPA, was due to a late and erroneous heading instruction of ATC. The other violation of the spacing requirement, 7.6 Nm at CPA, was due to an anticipation error of the flight crew. They anticipated that during the heading change towards the resume point the dynamics of the manoeuvre would allow a continuous turn in which the actual heading would remain outside the no-go heading band. Selected heading was therefore put well inside the no-go band and with a too optimistic anticipation a slight infringement occurred.

For the 5Nm heading then resume instruction the figure shows two situations in which the crew used 8Nm (default value of the system) instead of the instructed 5Nm.

It should also be noted that the manoeuvre was sometimes ended prior to the closest point of approach, in approx. 5 out of 40 cases. This is related to the situation on the flight deck, a situation in which the a/c is flying direct towards the resume waypoint and with an actual heading well outside the no-go heading band. After a while in this steady situation pilots became a comfortable feeling, decided that it was safe again and that the ASAS operation was completed. As a consequence the flight crew ended the delegation prior to reaching the closest point of approach.

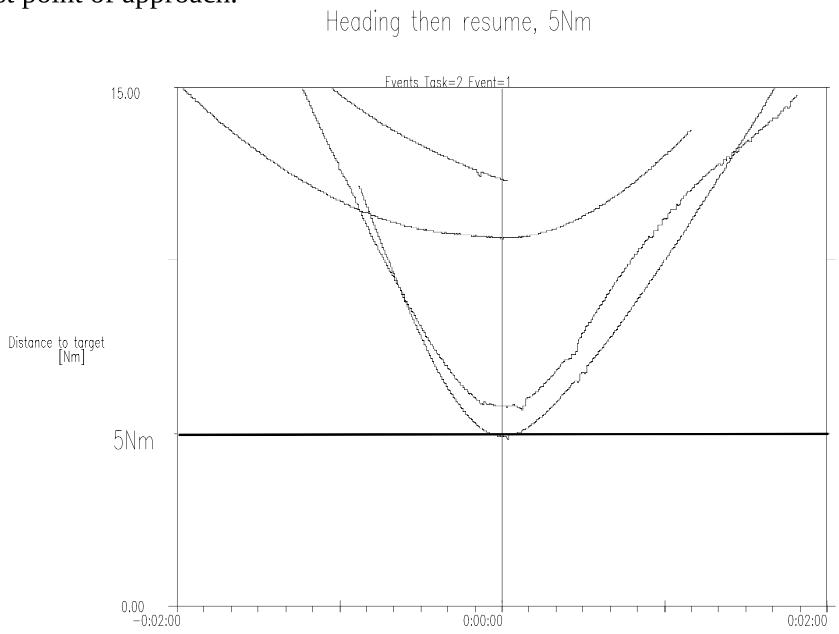


Figure 51 Distance to target during a heading then resume manoeuvre using 5 Nm

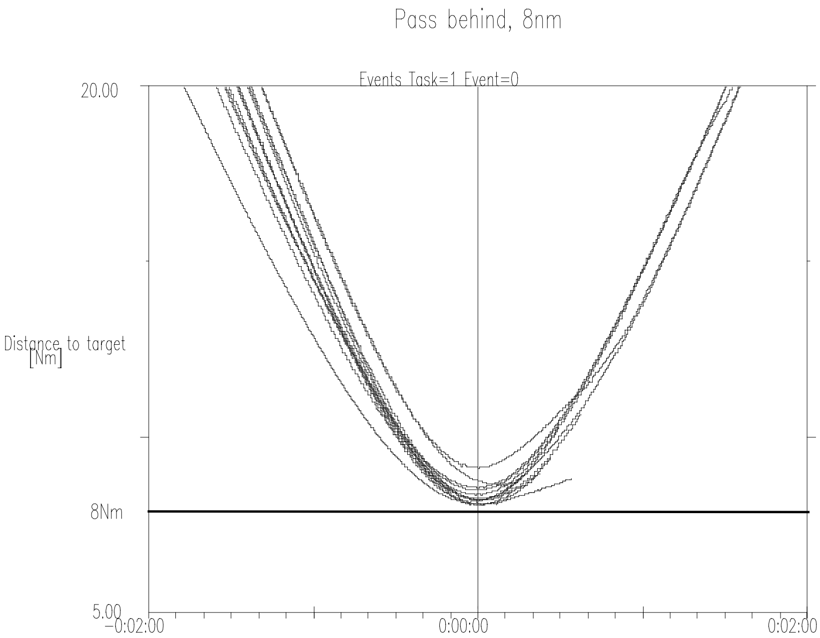


Figure 52 Distance to target during a pass behind manoeuvre using 8Nm

For the pass behind also the 8nm and 5Nm instructions are presented here. For the 8nm instruction, all manoeuvres were performed conform the instruction, no separation infringements and no excessive spacing was found.

In the 5Nm pass behind instruction a number of crews applied a manoeuvre passing 8Nm behind instead of 5Nm like it was earlier observed in the heading then resume instruction. One manoeuvre lead to a separation infringement (minimum distance 4.6 Nm), this was due to a direct to the resume waypoint which resulted in a heading change of about 5 degrees and an actual heading a few degrees inside the no-go heading band. After approx. one minute without heading correction this resulted in the spacing violation.

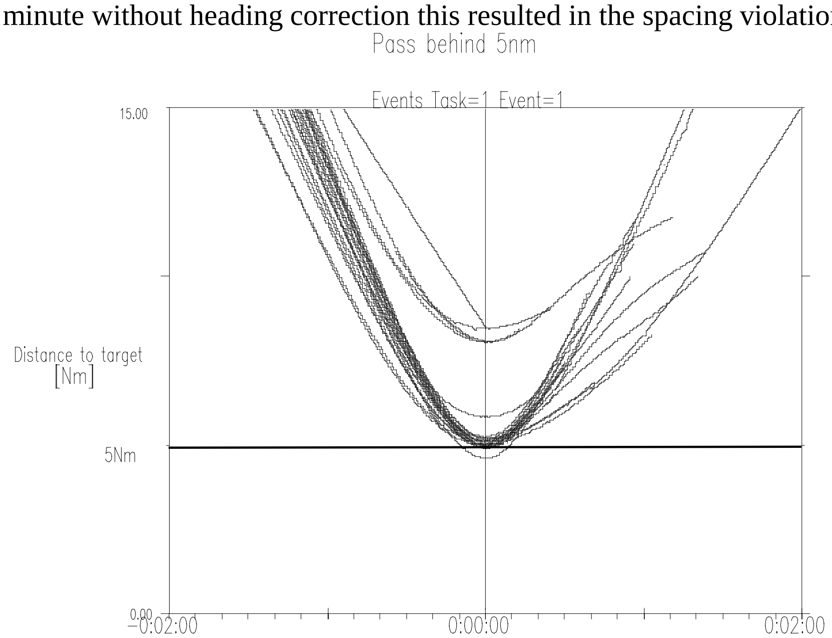


Figure 53 Distance to target during a pass behind manoeuvre using 5Nm

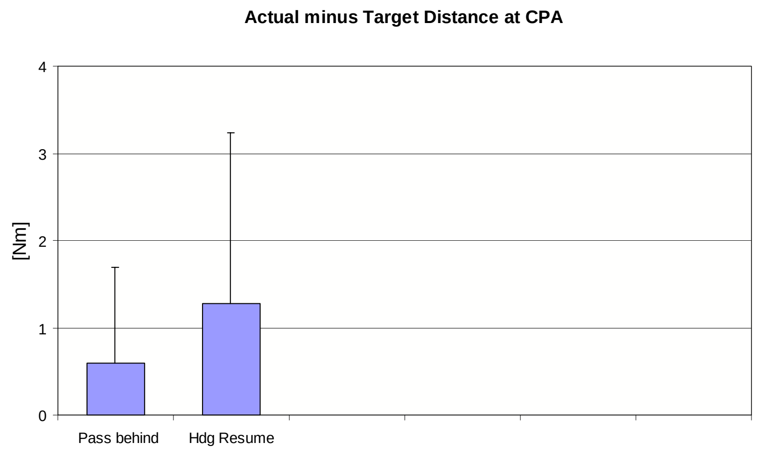


Figure 54 Accuracy of pass behind and heading then resume

This seems rather inaccurate, especially in the heading then resume instruction. However in a number of cases ATC instructed to use 5Nm while 8Nm is the default value the system starts with. In five cases the crews did not change this value and used 8Nm instead of the instructed 5Nm. Furthermore, the manoeuvre was sometimes ended well before passing the CPA, for these cases the actual minimum distance was not recorded. Having corrected for both conditions the situation changes as indicated below.

This shows that the accuracy is rather high, under condition that the correct value is applied. Any default value given by the system invites pilot not to alter it, either intentional or unintentional.

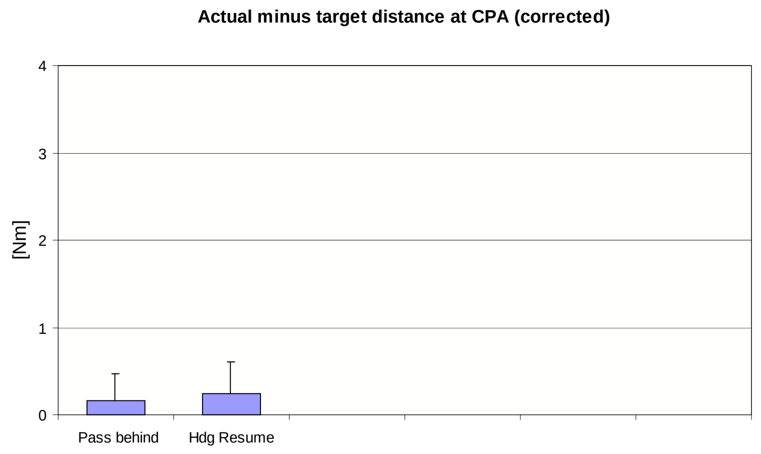


Figure 55 Corrected accuracy of pass behind and heading then resume

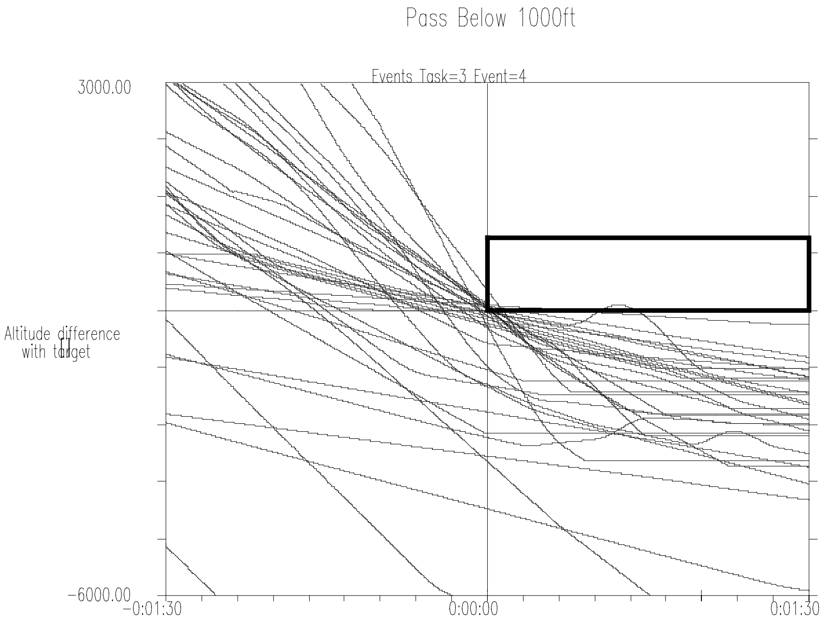


Figure 56 Delta altitude (ft) with target during a pass below manoeuvre

For the pass below instruction applies that three manoeuvres lead to an infringement. One was due to incorrect behaviour of the VNAV autopilot mode which started to climb instead of remaining level. The second infringement (400ft for 4 seconds) was due to a very high vertical speed demand in order to meet the ATC instruction. The third infringement (100ft for 10 seconds) was due to incorrect HMI amber band filtering. Other manoeuvres lead to a below descent path situation for which can be said that the manoeuvre could have been performed more efficiently, e.g. by passing above. In the previous sections it was observed that acceptability was relatively low and workload high for the pass below instruction. Here it can be observed that despite this reservation, pilots all performed well. But also it can be seen that a relatively high number of cases required a high to very high rate of descent (> 4000 fpm).
For the clear of target then continue descent instruction one infringement was observed which was caused by the simulator control system. In a number of cases crews seem to have maintained extra altitude buffer. Most of them are due to pilot decision to descend later or less steep from an efficiency point of view.

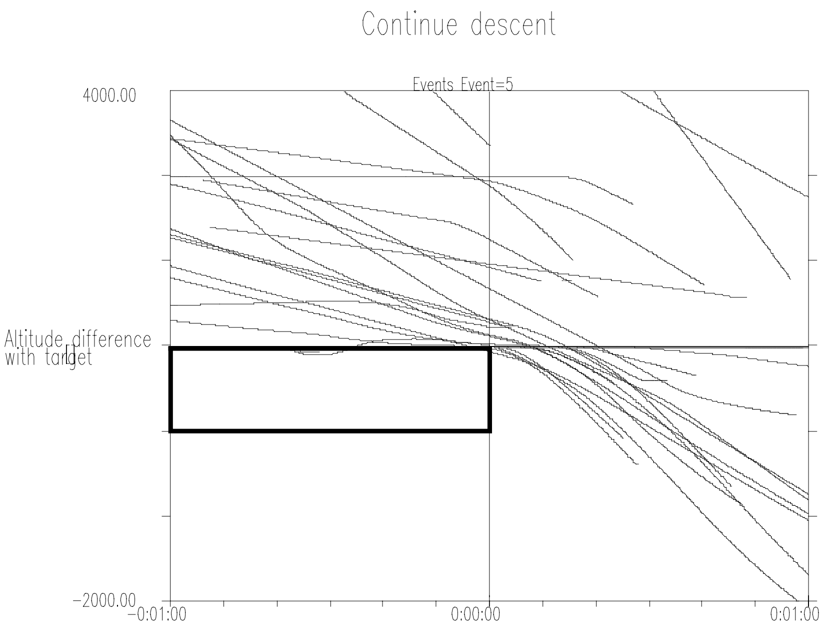


Figure 57 Delta altitude (ft) with target during a continue descent (or altitude resume) manoeuvre

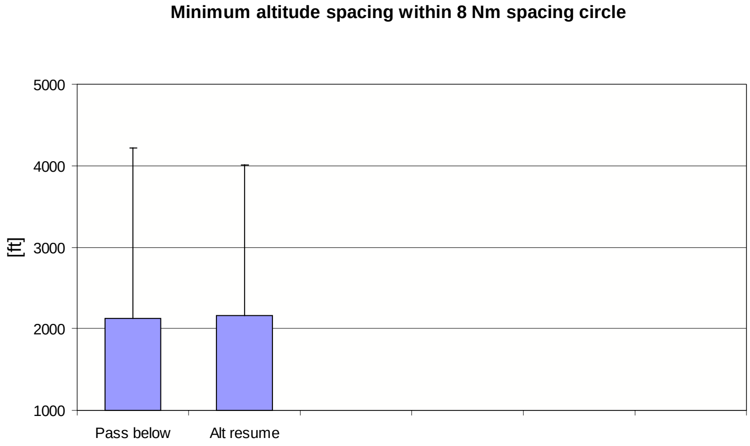


Figure 58 Altitude spacing during pass below and altitude resume instructions

The altitude spacing presented here is based on using the 8Nm horizontal spacing zone. During all instructions 1000ft spacing was required and as can be seen an average of more than 1000ft extra spacing was applied. Main reason for this large difference compared to the lateral manoeuvres is that the vertical spacing is more difficult to control, presentation on the HMI allows less accurate manoeuvring and a number of ATC instructions requested to maintain a flight level 2000ft above the target aircraft.

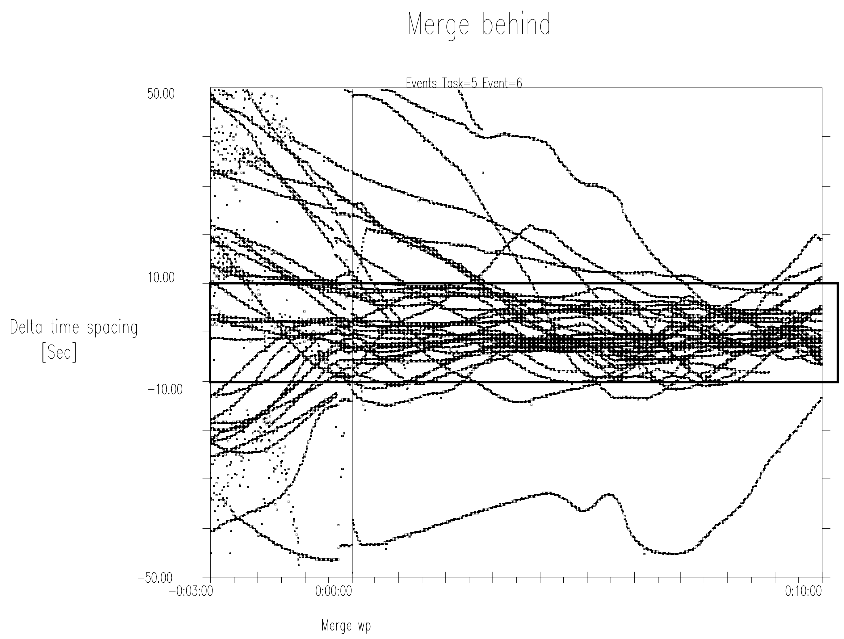


Figure 59 Time spacing error during a merge behind manoeuvre

For both merge behind instructions, the error to the required spacing time is presented as a function of time pre and post passing the merge waypoint. Negative time on the Y-axis represents the ‘early’ time and the positive values the ‘late’ time’. For the merge behind applies that small time errors were corrected before passing the merge waypoint. However, situations in which ATC gave the instruction while the initial time error was relatively large (> 30 sec at 40-50 Nm distance to the merge point), the time error was only corrected minutes after having passed the merge waypoint. For the heading then merge behind the ‘early’ time was often corrected before passing the merge waypoint. The figure also shows in quite a number of cases overshooting from being early into being late, main reason is the inadequate spacing symbol, representing the turn-in point.

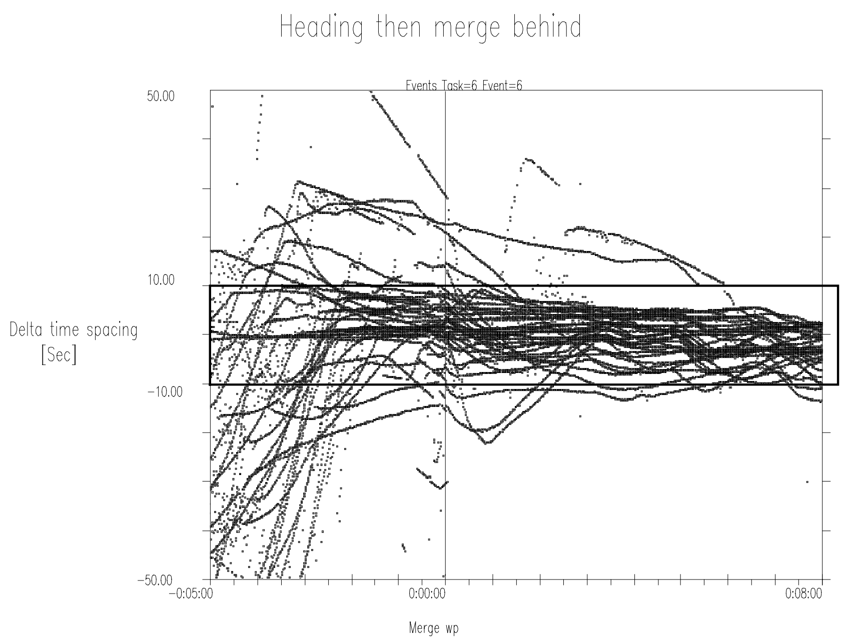


Figure 60 Time spacing error during a heading then merge behind manoeuvre

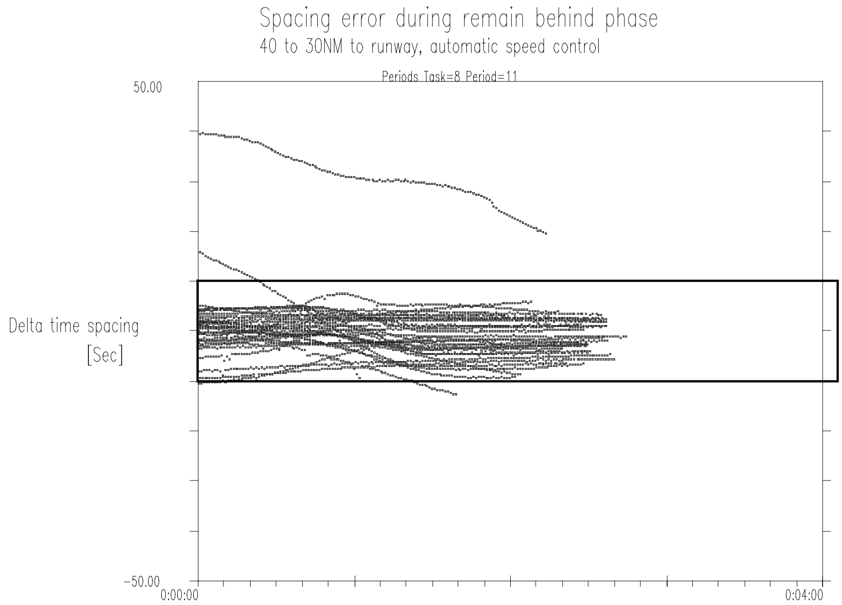


Figure 61 Time spacing error during a remain behind manoeuvre, automatic speed control

After passing the merge waypoint the merge behind manoeuvre is automatically continued in a remain behind manoeuvre. Figures here show again the time error for flights with automatic follow mode as well as flights in which the pilots controlled the speed by speed selections on the autopilot. Both figures show the situation 40 to 30 Nm before the runway, however the horizontal axis is given in time not in Nm. Both figures show that the spacing is closer to the 'early' 10 seconds boundary than the 'late' 10 seconds boundary. This is illustrative to the energy management difficulty experienced: reducing while descending already close to the minimum speed. The need to further reduce speed while already close to the minimum speed had to do with the frequent occurrence of closing in too much. Main reasons of closing in unintentionally were the differences in deceleration rates (in the traffic simulation the target a/c decelerated too quickly) and turn performance. One reason for closing in intentionally was the crew's decision to fly a slightly higher airspeed in order to avoid early flap selections.

For the remain behind with automatic speed control two flights are observed in which the spacing is still too high (too late). The initial time error was 80-90 seconds late, and error correction with speed control only is rather time-consuming. The one flight in which the spacing is just violated on the too early side was during the first flight of that crew into Catania. The aircraft ended up hot and high, due to the excessive workload caused by high terrain, non-standard ILS intercept procedure and FMS VNAV mode anomalies, resulting in an energy management problem.

For the flights in which the pilots controlled the speed it is visible that in some flights the pilots tried to create more space by letting the time spacing increase.
The one flight in which the spacing is strongly violated is caused by an initial condition approx. 40 seconds early in combination with a merge instruction without heading instruction, normally heading instructions are given to correct for the 'early' situations. The flight crew also indicated verbally that they normally would have called ATC to indicate that they were unable to comply. Now they continued to see what would happen, by refusing to select flaps at a very early stage they were unable to reduce to low enough speed to correct the time error.

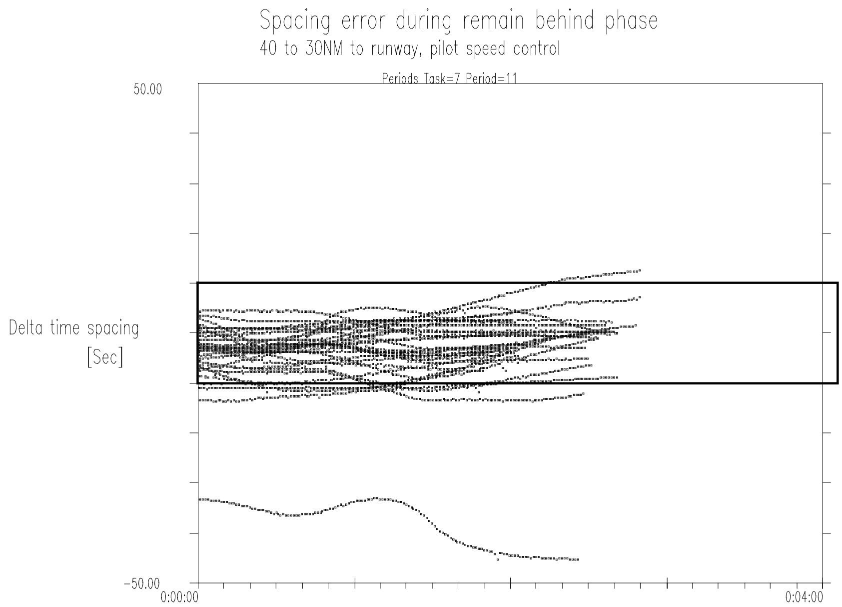


Figure 62 Time spacing error during the remain behind manoeuvre, pilot speed settings

Analysing the time errors in more detail, the root mean square errors are calculated in a number of flight segments starting from the merge waypoint up to 10Nm before the runway. The first segment is from the merge waypoint up to 50 Nm before the runway having various lengths due to the different scenarios flown. Next segments of each 10Nm are applied. For each of these segments the flights in which the automatic speed control was applied are separately presented from the flights where the pilot had to select the speed. It should be noted that only those flights are included in this analysis which had an absolute time error of less than 30 seconds when passing the merge waypoint.

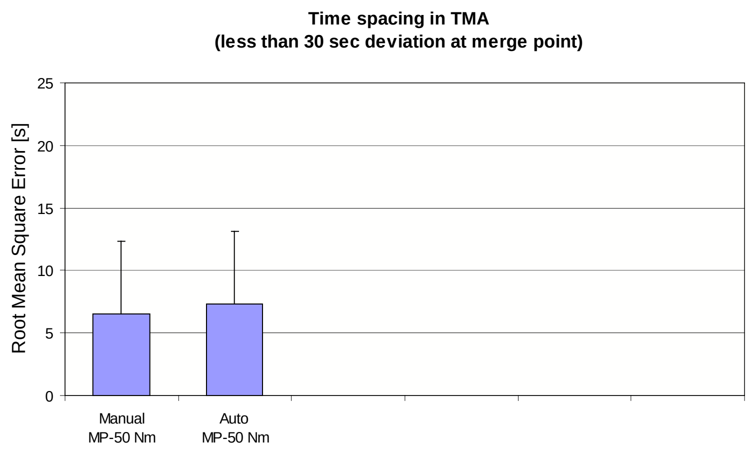


Figure 63 RMSE of time spacing from merge waypoint to 50Nm before runway

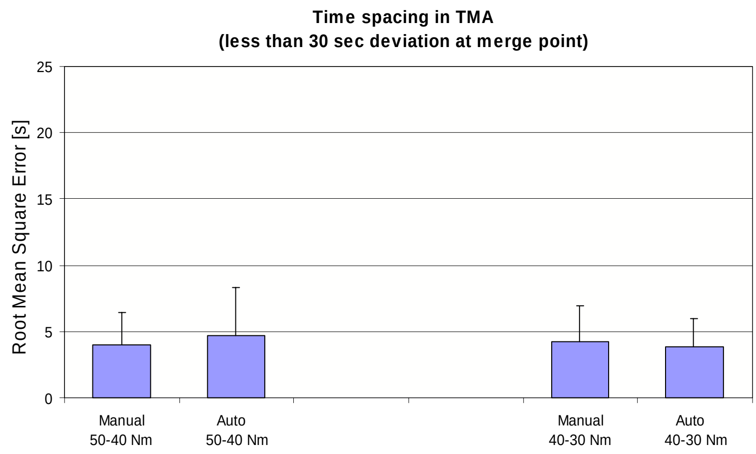


Figure 64 RMSE of time spacing 50-40Nm and 40-30Nm before runway

As a reminder, the spacing deviation scale on the ND had a scale running from –10sec to +10sec. So, from 50Nm to 20Nm before the runway, the deviation was within the range of the scale with a probability of 90%. While passing the merge waypoint until the 50Nm before runway point the deviation is higher meaning that the acquiring process is still ongoing.

After passing the 20Nm before runway point the deviation error increases again, which is mostly caused by different turn behaviour between the target aircraft and ownship. The last part of the approach contained a number of sharp turns, up to 90 degrees, with short time intervals between the turns. No performance difference is seen between the automatic follow mode and the selected speed mode in which the pilot had to change the target speed for all segments between the merge point and end of follow operation.

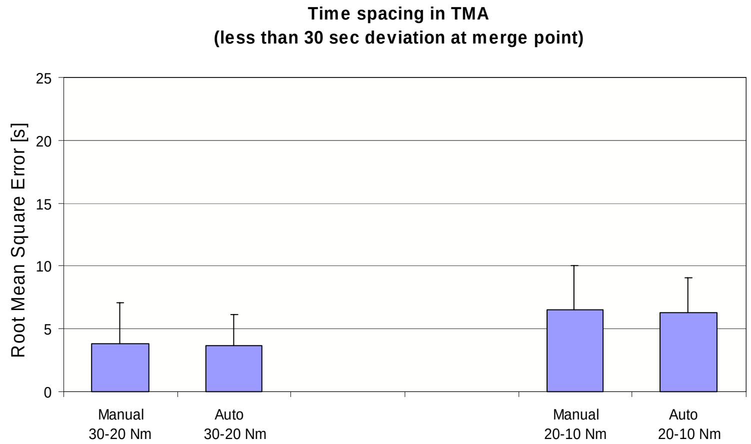


Figure 65 RMSE of time spacing 30-20Nm and 20-10Nm before runway

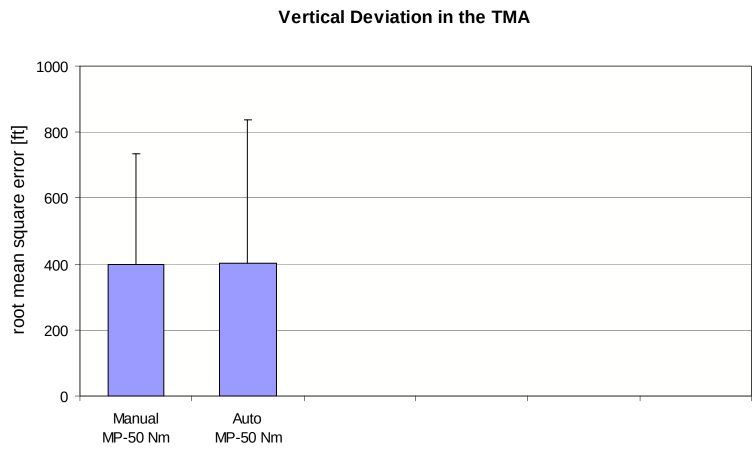


Figure 66 RMSE of vertical deviation during remain behind between merge waypoint and 50Nm before runway

During the arrival and approach not only the time behind target -as controlled by adjusting speed- is relevant, even more relevant is the vertical path in order to arrive at a proper altitude to capture the ILS. Energy management constitutes of both speed control and altitude control. Therefore the RMSE of vertical deviation is calculated in the same windows as previously done for the time errors. In the first segment, between the merge waypoint and the 50Nm before the runway point the vertical deviation is the largest. This is, as could be seen for the time error plots, still the acquisition phase. During the acquisition speed is used to acquire the target time spacing and can not be used, sometimes even counteracts, to control towards the descent path.
During the next segments the vertical deviation becomes less. With time spacing being controlled by speed adjustments, speed cannot be used anymore to ease the acquiring and maintaining phase of the descent path. In certain types of arrivals, to a certain extent the Catania 08 arrival in this experiment, this physical law might lead to energy management problems. This energy management issue should be investigated in more detail.

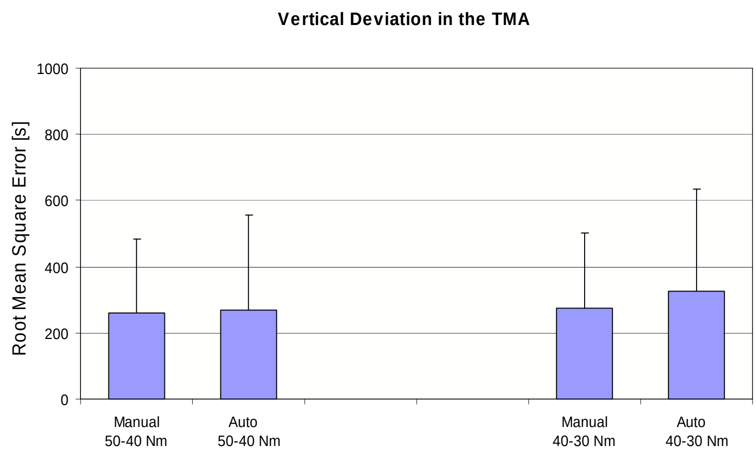


Figure 67 RMSE of vertical deviation during remain behind 50-40Nm and 40-30Nm before runway

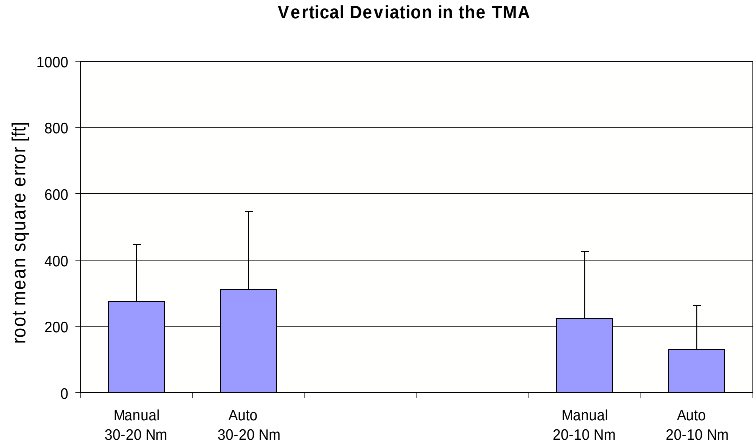


Figure 68 RMSE of vertical deviation during remain behind 30-20Nm and 20-10Nm before runway

In the last phase, 20-10Nm before the runway the vertical deviation is the smallest. Earlier it was observed that the time error increased again during this segment. The conclusion is that during this segment onto the ILS, the altitude becomes highly important and the time spacing less.

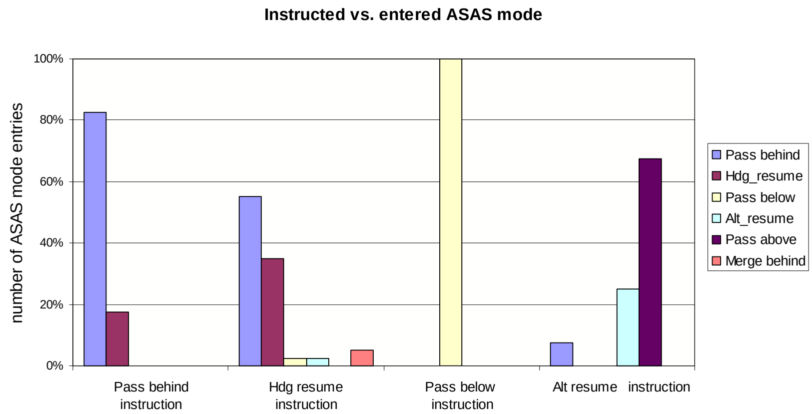


Figure 69 Instructed versus entered ASAS manoeuvre

As can be observed in a number of cases the pilot entered a different ASAS manoeuvre in the system than instructed by ATC. Most often the *heading then resume* instruction was entered using the *pass behind* manoeuvre and *altitude then continue descent* instruction was entered using the *pass above* manoeuvre. Comments from pilots indicated that the pass instruction fits very well with their 'mental picture' while the *heading then resume* and the *altitude then continue descent* require a translation to create a clear 'mental picture' often resulting in a *pass* manoeuvre.

6.6. Eye point of gaze measurements

During a number of flights eye point of gaze was measured. Since the duration of the experiment was rather long for the subject pilots only for two flights per crew eye point of gaze was measured. In addition some problems were experienced due to the new flight simulator, leading to a very small set of usable data. Therefore, the raw data is presented here and no analysis was performed.
Two situations are compared: the automatic speed control and the situation where the pilot selected the required speed, both in a stable remain behind situation. The data presented here show the percentages of eye fixation on the PFD, ND and other and covers 5 minutes of flight each.

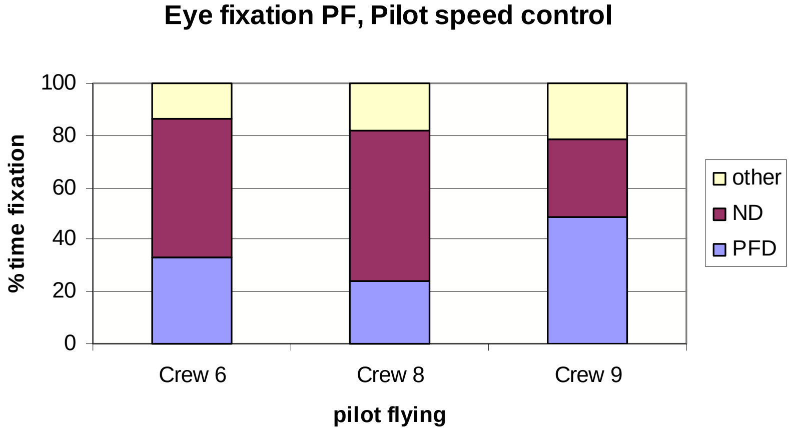


Figure 70 Eye fixations during remain behind with pilot speed control

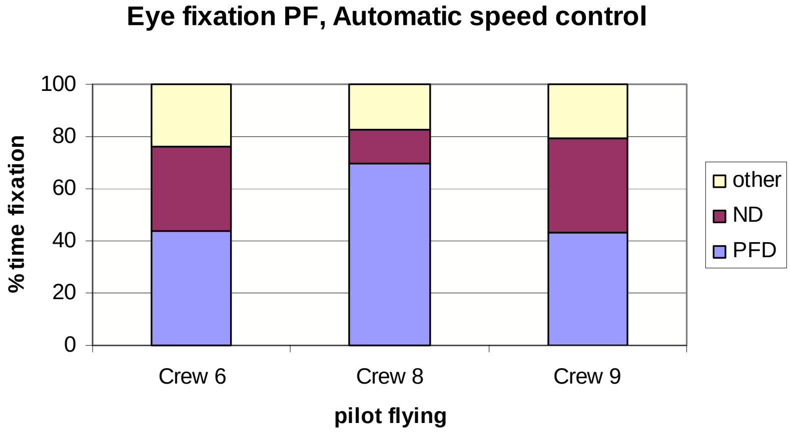


Figure 71 Eye fixations during remain behind with automatic speed control

The data set is too limited to draw general conclusions, but as can be observed from the two figures, for two of the three pilots, the percentage of fixations on the PFD is drastic lower when the pilot is controlling the speed than when automatic speed control is applied. So, a concern must be expressed that non-automated speed control might reduce the amount of time spent at the PFD. Since the remain behind function is often to be applied in relatively low altitude and low speed flight phases, the PFD should remain the primary instrument in the visual scan of the pilot flying.
These eye point of gaze measurement results are not reflected in the subjective results however. Earlier in this chapter it was observed that pilots did not indicate a difference in workload nor preference for the automatic speed mode in the questionnaire. The eye point of gaze data seems to indicate in a different direction though.

7. Conclusions

With respect to pilot acceptance and workload the following conclusions can be drawn:

- acceptance on ASAS spacing operations in general is high with the exception of the *pass below* during the descent which was not appreciated at all, and the lateral spacing manoeuvres during the descent which were less appreciated than during the cruise phase;
- the ASAS instruction set should be reduced, irrespective the means of communication;
- the ASAS instruction phraseology should be simplified: the number of information elements in one instruction should be limited;
- the HMI of the ASAS system was well appreciated, especially the interactive ND with CCD;
- room for improvement on the HMI is to be found on:
  - alerting
  - turn-in point for the heading then merge behind instruction
  - the trend vector on the spacing deviation scale;
- below FL100 the required actions to take on the flightdeck should be minimal;
- the additional task added to the crew task by means of the ASAS instructions increases the pilot workload, but remains acceptable;
- CPDLC is the preferred way of communication but is not required to make ASAS feasible;
- the automatic speed control mode of the autopilot/autothrottle is desirable but not required;
- the automatic speed control law needs to be improved;
- the merge behind and remain behind operations need to be investigated on feasibility with respect to:
  - arrivals where energy management problems are foreseen;
  - multiple aircraft with each a human in the control loop regarding stability of the 'train' of aircraft;
  - sensitivity to pilot distraction due to other tasks;

With respect to observed crew performance and crew behaviour, the following conclusions can be drawn:

- for lateral spacing manoeuvres applies that:
  - out 80 spacing manoeuvres only two pilot induced violations (both of 0.4 Nm) were observed;
  - in a number of cases pilots applied the default spacing value which was not in line with the ATC instruction;
- for vertical crossing manoeuvres allies that:
  - out of 40 *altitude until clear of target* manoeuvres, no violation have been observed;
  - out of 40 pass below manoeuvres, one pilot induced spacing violation has been observed;
  - the *pass below* instructions sometimes require a high to very high rate of descent, now and then very close to the aircraft performance capabilities;
- for the *merge behind* manoeuvres applies that:
  - instructions starting with a heading lead to better performance for spacing at the moment the merge waypoint is passed;
  - accuracy of time based following the target up to final approach is high;
  - accuracy is high for both automatic speed control and pilot speed setting.

8. Recommendations

With respect to the applied phraseology:

- simplify the instructions (for example: avoid including two altitudes in one instruction, but only the final altitude, use default spacing parameters so they do not have to be communicated);
- reduce the instruction set: use *pass* and *follow* as main keywords and omit *resume*, *merge* and *remain behind*.

With respect to the ASAS instruction set and ASAS operations:

- do not use pass below in the descend and pass above in the climb since it is difficult to predict whether the aircraft performance allows for a safe completion of the manoeuvre;
- allow more freedom for the crew (for example stepwise heading changes back in a lateral passing are to be expected as standard pilot behaviour);
- if an initial heading or altitude is required by the ATCo, split the R/T instruction in two parts, one with the heading or altitude and the other with the ASAS instruction;
- initiate a manoeuvre with a heading, speed or climb/descent instruction, followed by a pass or follow instruction. This leads to a more natural crew task distribution (PF and PNF) and is easier to monitor by the ATCo;
- only give merge instructions when the start conditions is within 30 second error (for 40-50 Nm track distance to merge waypoint), especially when the flight crew is only allowed to change airspeed to correct for the time error, on top of this accelerations should be omitted during the merge manoeuvre;
- investigate merge/remain behind operations for different types of arrival. Especially arrivals with altitude restrictions (terrain and/or traffic) and continuous descent approaches can lead to energy management difficulties;
- investigate merge/remain behind operations for ‘trains’ with multiple ‘pilot-in-the-loop’ aircraft. Mainly a stability issue;
- do not require the pilot to take actual action on the flight deck to cancel a target aircraft on final approach.

With respect to HMI and pilot behaviour:

- improve turn-in point presentation on the ND for “heading then merge” manoeuvres;
- improve control law of follow mode (do not allow speed targets below flap mark speed, do compensate time errors much quicker);
- improve consistency of terminology and methods to perform ASAS entries on the ND and CDU, also with respect to R/T of CPDLC terminology;
- improve (simplify probably) the trend vector of the spacing deviation indicator;
- improve ASAS alerting (time spacing near/outside tolerances, upcoming speed changes and flapsettings);
- investigate merge/remain behind operations in situations in which attention of at least one pilot is temporarily distracted (for example problems in the cabin, communication with the company about, system failures, bad weather etc) . This concerns a workload issue.

The majority of the above indicated recommendations could be combined into one generic recommendation describing a slightly different approach of the ASAS instructions. This one coherent approach could lead to the following:
Apply only two instructions: “*follow*” and “*pass*”. Follow is both used for a merge behind and remain behind. In case of a merge instruction, a merge waypoint is given and an initial heading or speed. Otherwise it is a remain behind instruction. The pass can be either a pass *behind*, *above* or *below*. For the pass above and below only the final altitude is given. So, no two altitudes in one instruction will occur. A pass behind

instruction will include an initial heading. The crew is free to leave this heading at any moment during the manoeuvre under the condition that the spacing/separation is maintained.
This mandatory initial tactical instruction might seem to increase complexity, but in fact it reduces not only number of variations, it also ensures faster action from the flight crew since the PF will start to execute the initial tactical instruction even before the PNF has performed any system action for setting up the manoeuvre. This makes the situation for both the crew and the ATCo easier to interpret and is safety increasing since, for example the heading instruction should be a diverging heading, not leading to a conflict situation. This approach limits the number of variations in ASAS instructions drastically, leading to a clearer situation reducing chances of misunderstandings and misinterpretations.