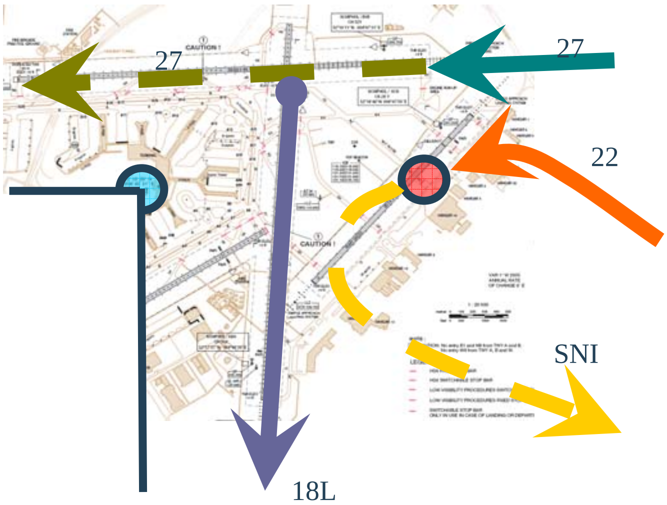
Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

Executive summary

Evaluation of a steep curved rotorcraft IFR procedure in a helicopter-ATC integrated simulation test



Problem area
In the European Commission Framework VI project **OPTIMAL: "Optimised Procedures and Techniques for the Improvement of Approach and Landing",** steep and possibly curved-segmented, rotorcraft IFR procedures have been developed in order to increase airport capacity, improve efficiency and reduce the noise footprint of rotorcraft.
Two special features of the rotorcraft IFR procedures are 1) a steep glideslope of 6º-10º, and 2) a final segment that may contain a curve. The procedural flexibility this affords in an ATC environment, when properly laid out, is to enable a rotorcraft to simultaneously operate with fixed-wing IFR traffic without interference. This concept is called SNI: Simultaneous Non-Interfering.
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Description of work
A particular, curved, steep IFR procedure was designed and tested in NLR's ATC simulator, coupled with NLR's helicopter simulator, in the simulated Amsterdam Airport environment. As a baseline procedure the present ILS approach on runway 27 was used with a break-off at about 500 ft in order to land on the adjacent runway 22. Furthermore 3 guidance display types for the helicopter pilot were designed for evaluation.

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ATC simulation

This report is based on a presentation held at the 34th European Rotorcraft Forum, Liverpool, 14-19 September 2008.

Results and conclusions

Evaluation using Air Traffic Controllers and helicopter pilots indicated a definite increase in the airport's capacity, but some deficiencies in the procedure design. Suggestions for improvement were given by ATC, notably a reduction of the convergence angle. Of the 3 guidance display types the "raw-data" type of RNAV-ILS display was least preferred due to its lesser information content.

Applicability

The newly developed SNI-type of IFR procedure, with improvements, could be used to have rotorcraft operate under IFR while minimizing the interference with other fixed-wing aircraft at busy airports, and so increase the airport's capacity.

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Summary

In the European Commission Framework VI project **OPTIMAL: "Optimised Procedures and Techniques for the Improvement of Approach and Landing",** steep and possibly curved-segmented, rotorcraft IFR procedures have been developed in order to increase airport capacity, improve efficiency and reduce the noise footprint of rotorcraft.
Two special features of the rotorcraft IFR procedures are 1) a steep glideslope of 6º-10º, and 2) a final segment that may contain a curve. This affords a greater level of flexibility in enabling a rotorcraft to operate simultaneously with fixed-wing IFR traffic without interference. This concept is called SNI: Simultaneous Non-Interfering.
A particular, curved, SNI-type of IFR procedure was designed and tested in NLR's ATC simulator, coupled with NLR's helicopter simulator, in the simulated Amsterdam Airport environment. Evaluation using Air Traffic Controllers and helicopter pilots indicated a definite increase in the airport's capacity, but some deficiencies in the procedure design. Suggestions for improvement were given by ATC.

Contents

Abbreviations

ADI	Attitude Director Indicator
ATC	Air Traffic Control
ATCo	Air Traffic Controller
BVI	Blade-Vortex Interaction
DA/H	Decision Altitude / Height
FAF	Final Approach Fixe
FATO	Final Approach and Take-Off area
FROP	Final Roll-Out Point
GBAS	Ground-Based Augmentation System
GNSS	Global Navigation Satellite System
GPA	Glide Path Angle
HPS	Helicopter Pilot Station
HSI	Horizontal Situation Indicator
IAF	Initial Approach Fix
IF	Intermediate Fix
IFR	Instrument Flight Rules
ILS	Instrument Landing System
MAPt	Missed Approach Point
NARSIM/TWR	NLR Air Traffic Control Research Simulator
OPTIMAL	Optimised Procedures and Techniques for the Improvement of Approach and Landing
RIP	Roll-In Point
RMS	Root Mean Square
RNAV	aRea NAVigation
RNP	Required Navigational Performance
SA	Situational Awareness
SBAS	Space-Based Augmentation System
SID	Standard Instrument Departure
SNI	Simultaneous Non-Interfering
VPA	Vertical Path Angle

1 Introduction

In the course of the European-sponsored OPTIMAL project simulation trials were performed to validate newly developed rotorcraft steep IFR procedures. From February 2006 until May 2006 a so-called "*stand-alone*" simulation trial was conducted at NLR; results were reported at the European Rotorcraft Forum at Maastricht, The Netherlands in 2006 (Ref.[1]). In this case the helicopter simulator was run independently from the Tower research simulator NARSIM/TWR. Aim was, among others, to evaluate the handling qualities and pilot acceptability with variations in terms of level and descending turns and curves and steep glideslope angles on IFR procedures, flown at constant speed or as a decelerating approach. Possibly a "best procedure" or approach technique could be distilled from the results, as well as some lessons learned.
In the second phase of simulations an *integrated* simulation trial was performed about one year later, in which NLR's rotorcraft fixed-base simulator, the Helicopter Pilot Station (HPS), was linked to the NARSIM/TWR Research Simulator of NLR, in order to evaluate Air-Traffic-Control-rotorcraft related issues, especially where it concerns the application of Simultaneous Non-Interfering 'SNI' operations. In this concept the rotorcraft on the SNI-type of IFR procedure is supposed to not interfere with other approaching fixed-wing IFR traffic. This trial was scheduled in the year before the final year of the project, in which (limited) validation flight tests would be carried out.

The scope of the simulation trials contained testing 2 approach procedures, viz. the standard ILS RWY 27 as the 'baseline' procedure, and a so-called RNP-RNAV (GNSS) IFR approach procedure with a curved-final approach and a very short straight final GBAS-guided xLS approach segment, set up in a Simultaneous Non-Interfering (SNI) concept. The glideslope of this procedure is 7.5º. A more detailed description of the procedure is given in chapter 3.

The two procedures were tested in 4 scenarios, which are described in para. 5.1.

The simulation exercise took three days of testing, with three pilots and 3 Air Traffic Controllers (ATCos), one of each per day. Testing the 4 scenarios, including training runs, breaks, etc., took a full day per pilot and/or ATCo.

1.1 Understanding the ATM Problem and Operational Concept

The problem which is addressed with the new type of helicopter IFR operations is the consequence of the ongoing growth in the number of IFR flight movements. According to Eurocontrol, the traffic levels in 2025 are forecast to be 1.6 to 2.1 times the 2003 traffic levels.

The consequences of the traffic growth are increasing airport congestion; and airports, especially international hubs, operating more and more at their operational limits as prescribed by physical, political, and environmental constraints.

For helicopter operations the consequence of the airport congestion is that airports sometimes choose to reduce or even ban helicopter movements, because they interfere directly or indirectly with the fixed-wing operations. One novel way to approach this problem is the use of the so-called 'SNI' concept, i.e. where **S**imultaneous, **N**on-**I**nterfering operations take place. These SNI operations are set up such that:

1. SNI-type of IFR procedures can be flown simultaneously with other IFR fixed-wing traffic, i.e. these procedures are flown on an inactive runway or FATO (Final Approach and Take-Off area), or make use of an IFR procedure which is oriented differently from the other procedures-in-use, usually including a turn at some point to bring the rotorcraft close to the airport.
2. SNI-type of IFR procedures can be flown independently of other IFR fixed-wing traffic (e.g. no controller intervention is needed to maintain separation).
3. SNI-type of IFR procedures may contain steep final descents to keep rotorcraft noise footprints within the airport perimeters, thus with rotorcraft starting the steep descent when close to the airport.
4. SNI-type of IFR procedures may contain segmented or curved flight paths to avoid noise-sensitive areas.

2 Objectives of research

After considerable deliberation the following list of objectives, to be investigated in the experimentation, was set up:

1. Determine the safety of operations of an SNI-type of rotorcraft IFR approach procedure in terms of procedure acceptance, ATCo's workload, etc.
2. Determine the effect of the SNI-type of rotorcraft IFR procedure on airport capacity, for example.
3. Determine the level of interaction/interference with other fixed-wing and/or rotary-wing traffic in terms of e.g. ATCo workload, pilot workload, etc.

Items related to the effect on the environment in terms of noise and emissions could not be addressed in this simulation. The use of glideslopes steeper than the standard 3º is known to decrease the rotorcraft BVI noise, while as an accumulative effect additionally the noise footprint is reduced. So the use of steep helicopter IFR procedures will therefore be beneficial by themselves in terms of noise impact, however, the exact magnitude in dB reduction, for example, is beyond the scope of this investigation.

3 SNI-type of IFR procedure

The experimental SNI-type of rotorcraft IFR procedure designed for the Amsterdam Airport environment has a curved final segment and an initial (final) approach course that converges towards the fixed-wing traffic flow approaching the airport on the ILS of runway 27. The angle of convergence with ILS 27 is 54º, reducing to 12º after the descending curve.

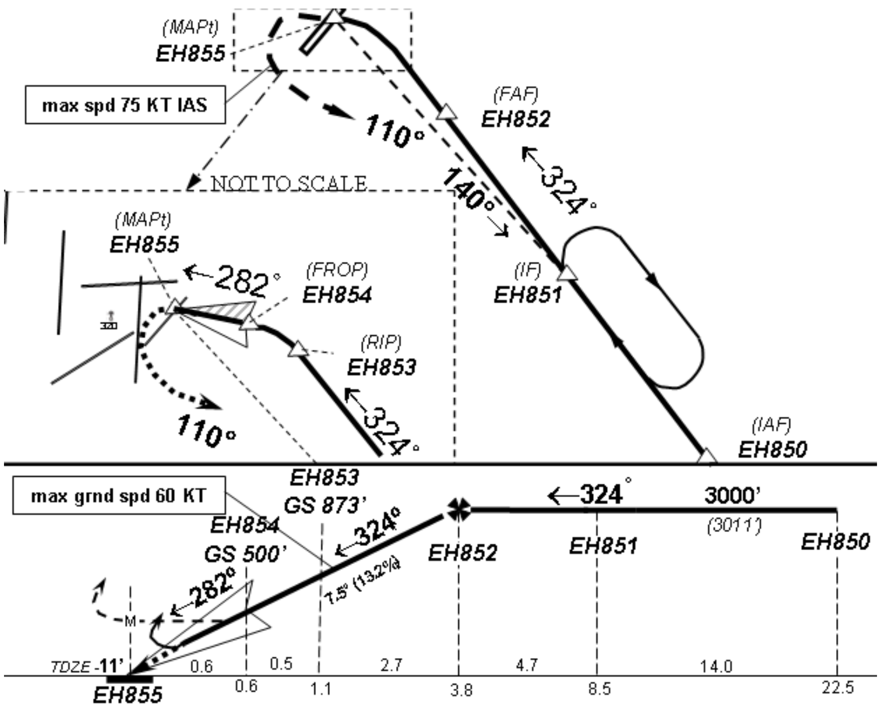

Figure 1 Steep curved final approach procedure

In Figure 1 the steep, curved final approach procedure, taken from the approach chart as given to the pilot, is shown. Notice that the missed approach section contains a turn of more than 180º, starting at the MAPt. This was done in order to stay away from RWY 18L when executing a missed approach.

The SNI concept is evidenced by the fact that the rotorcraft on this IFR procedure approaches the airport “between” the two active runways (in this set-up), viz. RWY 27 and RWY 18L. In order to prevent getting “too close” to the final approach segment of RWY 27, a curved segment is included, reducing the convergence angle from 54º to 12º. It is hoped that this reduction will be acceptable to the ATC controllers when handling this flight, while simultaneously fixed-wing IFR traffic is approaching on the ILS of RWY 27.

4 Guidance displays and deviation sensitivities

4.1 Guidance displays

Since per scenario, which lasted one hour, three rotorcraft flights were to be made, it was possible to evaluate 3 (lateral) guidance display features simultaneously. The following three guidance displays were evaluated:

1. *'RNAV-ILS'*: this guidance concept shows on the NAV display (lower part in Figure 2) the (curved) route. For lateral guidance along the route the pilot is shown the amount of deviation from track in a window, which is positioned on that side of the track to which the flight path correction is to be made. In Figure 2 the pilot is to correct to the right in order to keep his deviation within 0.1 NM. Normal ILS indications (localizer and glideslope deviation bars) are given in the normal way left and below the attitude direction indicator (ADI). These ILS deviations refer to the very final straight approach path on a track of 282º, where high-accuracy ILS-like signals can be provided by GBAS, for example (that would make this procedure a hybrid one, using both ground-based and airborne-based signals). This guidance display can actually be regarded as the baseline guidance display, which present-day rotorcraft have.

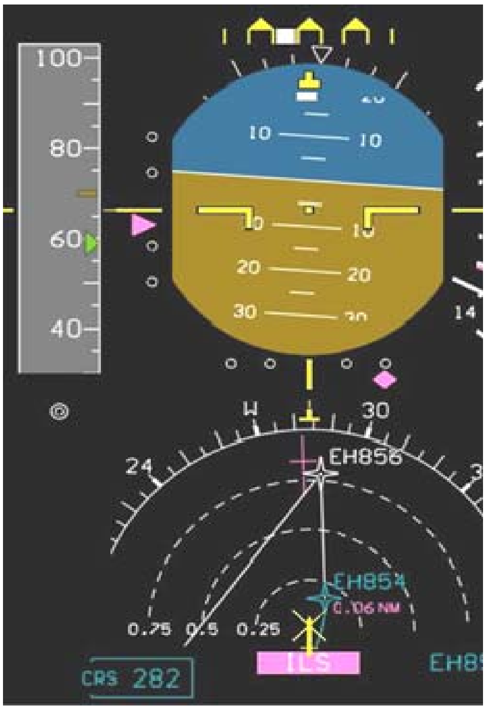

Figure 2 RNAV-ILS *and* ILS-one *guidance display*

2. *'ILS-one'*: this guidance display is identical to the *RNAV-ILS* display, except that computed ILS-like glideslope and track deviation signals are displayed for each segment of the entire approach, based on certain sensitivities, see para. 4.2.

3. *'ILS-squared'*: the NAV display part is identical to the previous two displays. Regarding the ILS indications there are now 2 sets of ILS deviation symbols (hence 'squared'), consisting either of solid symbols or dashed symbols, see Figure 3.

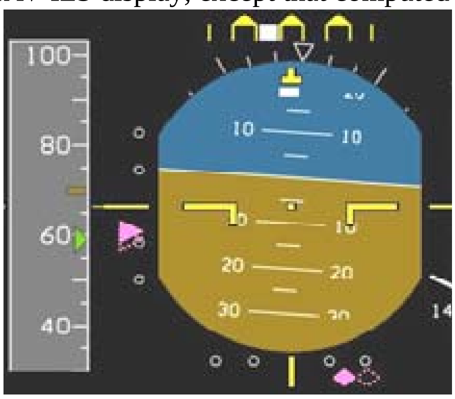

Figure 3 ILS-squared *guidance display*

The solid symbols portray the ILS glideslope and localizer/track deviation with respect to the *present* track, while the dashed symbols indicate the ILS deviations with respect to the *next* track. The advantage is that, e.g. while on the curved segment, the pilot can already see what his deviation is going to be for the upcoming straight final segment (similar to the *RNAV-ILS* display), except that on the curved segment the pilot is guided this time by the glideslope and "localizer" deviation indicators.

There was a fourth type of display, viz. the so-called "*square-root*" indicator developed by Eurocopter, see Figure 4. This display only gives vertical guidance information to the pilot and was used throughout the simulations. On the vertical speed scale a magenta line indicates the required vertical speed in order to pass over the next waypoint at the proper altitude. On the altitude scale there is a magenta horizontal line which indicates the required altitude at the moment, based on linear interpolation of the required altitude of the two waypoints behind and ahead of the rotorcraft. As portrayed in Figure 4 the two lines show up like a square root symbol, $\sqrt{}$, where it derives its name from.

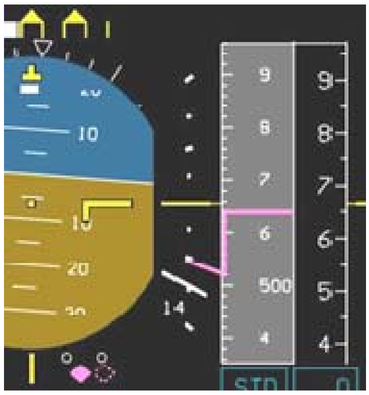

Figure 4 Square-roots *display*

4.2 ILS deviation sensitivities

For displaying the ILS glideslope or localizer deviations in dots a scale sensitivity has been designed into the system, by setting the 1-dot deviation (full-scale deflection is 2 dots) equal to a specific value in nautical miles (for lateral deviation) or feet (for vertical deviation) for the different waypoints on the approach, from IAF to MAPt, with linear interpolation in between. Normally the variation with distance is angular for an ILS system, which was also the case here. The relevant data is given in Table 1.

Table 1 ILS 1-dot sensitivities for glideslope and localizer deviations

	WPT					
type deviation	**MAPt**	**FROP**	**RIP**	**FAF**	**IF**	**IAF**
lateral (NM)	0.029	0.04	0.049	0.1	1.0	1.0
vertical (ft)	0.42	20.09	36.48	125.	125.	125.
distance (NM)	0.	0.6	1.1	3.8	8.5	22.5

The above data provides for a lateral 1-dot angle of 1.07° and vertically for a 1-dot angle of 0.31° from the MAPt to the FAF. Beyond the FAF the vertical 1-dot deviation is constant

(125 ft), while the lateral deviation changes more quickly from 0.1 NM at the FAF to 1.0 NM at the IF (a gradient of 10.8º or 19.1%), and remains constant between the IF and the IAF. Note that the distance given in Table 1 is the distance along the path, including curves if present. Deviations from the required path are displayed using localizer and glideslope deviation indicators.

It was learned later that in a verification exercise on Eurocopter's real-time simulator a vertical deviation law of

"± vertical full-scale deflection $\Delta\gamma$ (2 dots) = ± ¼ GPA".

had been used. This has been derived from the definition of a 50 ft maximum error deviation at 200 ft DA/H being equal to a 2–dot deviation. This is 2 times as much (i.e. less sensitive) as used in the simulations by NLR. The steep IFR procedure was also flown at Eurocopter on autopilot and therefore there is no basis for comparison of glide path performance or pilot workload.

5 Experimental set-up

5.1 Scenarios

Four scenarios were defined in order to evaluate various aspects of the SNI-concept rotorcraft steep IFR procedure:

- *Scenario 1*: the rotorcraft flies as a baseline procedure the ILS approach on RWY 27 in daylight. The helicopter flight is given a time slot so as to operate in between approaching fixed-wing aircraft, while fixed-wing traffic is departing from runway 18L. Total fixed-wing traffic load in all cases is about 60 flights per hour. The visibility and cloud base have been adjusted such that a circling-to-land approach from this ILS can be flown (as a time saver) on runway 22.
- *Scenario 2*: the rotorcraft flies the SNI-concept rotorcraft IFR procedure in daylight, with the same fixed-wing traffic arriving on RWY 27 and departing from RWY 18L.
- *Scenario 3*: equal to scenario 2, but with nighttime conditions simulated.
- *Scenario 4*: equal to scenario 2, but one or two rotary-wing and one or two fixed-wing missed approach is carried out, with a total of 3 missed approaches.

In each scenario 3 rotorcraft flights are carried out, i.e. on average at every 20 min. interval. Testing each scenario took about 1 hour.
For the ATC simulation a situation was chosen at Amsterdam Airport where two runways, one for landing (RWY 27) and one for departures (18L) were selected, with the General Aviation

runway, RWY 22, selected for use by the rotorcraft. A displaced helispot (FATO) was set up on that runway at the intersection of RWY 22 and taxiway G3.

5.2 Research environment/vehicles

For the experiment the Helicopter Pilot Station (HPS) and NARSIM/TWR simulator were used as real-time simulation platforms in an integrated, coupled set-up. The experiment simultaneously had a rotorcraft pilot, an air traffic controller and a pseudo-pilot, all acting in their respective roles together.

The HPS is a fixed-based helicopter simulator with a three-channel visual system and force feedback on the controls. The helicopter has a total glass cockpit based on touch screens. The visual scenery offers a 135º horizontal x 33.5º (i.e. 11.5º up, 22º down) vertical range view. A typical view of the HPS is shown in Figure 5.

Figure 5 Helicopter Pilot Station

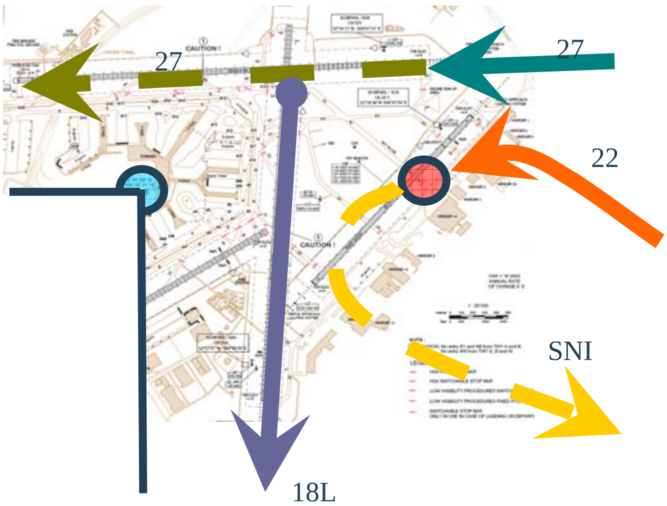

Figure 6 Airport environment used for simulations

The NARSIM/TWR is a tower simulator with 270 degrees out-of-the-window view[1]. The airport environment as used for the simulation is given in Figure 6. There is traffic arriving on the ILS of runway 27, and in the occasional event a straight missed approach applies. Fixed-wing traffic is also departing from runway 18L, entering the runway via Entry E5, which is the entry for RWY 18L just before crossing RWY 27. Various standard instrument departures are available. With the steep rotorcraft IFR procedure in progress the rotorcraft flight arrives from the South-East, makes a curve (on final) in order to land on the

[1] In 2008 this has been expanded to a full 360º view.

displaced helispot, see the red circle. In case of a missed approach starting from the decision altitude the yellow-colored path is followed with an early turn in the missed approach.

As one can see, with the 270º viewing angle the runway controller has a good view of all the traffic operating from runways 18L, 27 and 22.

The runway control position has a standard tower set-up with approach radar, airport surveillance including labels, flight plan information, METAR information, and paper flight strips. For the SNI approaches no additional functionality has been added.

A view of the NARSIM/TWR simulator (with controller) is shown in Figure 7.

Figure 7 Standard Runway Controller

Figure 8 Pseudo-pilot working station

The pseudo-pilot station, from where the pseudo-pilot interacted with the tower controller and from where he controlled the incoming or departing (fixed-wing) flights, is shown in Figure 8. He acted as a pseudo-pilot both for arriving as well as departing traffic. With 50-60 movements per hour (i.e. per scenario), and with 4 scenarios, this meant he had to spend a lot of time “talking” (just like the ATCo by the way).

5.3 Experimental factors

The total of experimental factors involved in the experimental set up, related to the objectives set forth in para.2, and their levels were:

- *Approach procedure*: 2 levels applied, viz. 1) a baseline procedure, i.e. the ILS approach on rwy 27 with circle-to-land on rwy 22, with a standard 3º glideslope, and 2) a new procedure, viz. the ‘RNAV28’ procedure, which was the SNI-type steep IFR procedure described in chapter 3, with a 7.5º glideslope. This approach procedure is in fact a so-called ‘LPV’ procedure (Lateral Precision with Vertical guidance), where lateral guidance during the initial and intermediate approach is provided by RNAV, and lateral and vertical guidance on the curved final approach is provided by SBAS (Space-

Based Augmentation System), providing RNP0.1 (Required Navigational Performance) performance. For the very straight final segment GBAS can be used, making it a hybrid procedure. The on-board FMS must be capable of navigating along curved navigational legs.

- *Wind*: 2 levels applied viz. ‘calm’ (<5 Kt) and ‘moderate’ (15-20 Kt) crosswind conditions. The crosswind applied with respect to the final approach course of 282º. The wind itself was generated according to the boundary layer model. No turbulence was simulated, as for a fixed-base simulator this would not be effective.
- *Pilot guidance displays*: 3 levels applied, viz. 1) *RNAV-ILS* display, 2) *ILS-one* display, and 3) *ILS-squared* display. These have already been explained in chapter 4.
- *Day-night*: 2 levels (obviously) applied, viz. 1) day and 2) night. This factor related to such matters as testing the visibility environment of the airport during night hours and its effect on the ATCo’s workload and situational awareness.
- *Missed approach*: 2 levels (actually 3) applied viz. 1) no missed approach, 2) missed approach by a fixed-wing aircraft and 3) missed approach by a rotorcraft. The combination of both making a missed approach was deemed too remote a possibility to occur.

The guidance display and crosswind factors were added since each scenario lasted for one hour, during which at least 3 rotorcraft flights were made. This allowed for the possibility of testing these additional factors, in this case an operational one (i.e. wind) and a more truly experimental one, viz. guidance display. With the advanced type of approach one of the interesting issues is the question which guidance display would be adequate to guide the pilot along the curved path towards the FATO. The factor of *wind*, however, had no effect on the ATC part of the simulation since fixed-wing flights were not affected by it (e.g. no speed adaptations were made or other wind corrections, and the groundspeed remained unchanged).

5.4 Test matrix

A repeated measures full-factorial experimental design was set up, although the 2 wind conditions (‘calm’ and ‘moderate’) were “nested” within the pilots, assuming that there would be no interaction between pilots and wind speed. This “nesting” reduced the number of tests to be performed (from 20 to 12). This led to the following test matrix:

Table 2 Test matrix of procedures x displays x day-night x missed-appr. x winds

PROCE-DURE	DAY/NIGHT	MISSED APPR.	GUIDANCE DISPLAY	WIND SPEED P1	WIND SPEED P2	WIND SPEED P3	SCENARIO	SORTIE
Baseline	Day	No	RNAV-ILS	m	c	m	***Baseline***	1
				m	c	m		2
				c	m	c		3
SNI-type	Day	No	RNAV-ILS	m	c	m	***SNI-day***	4
			ILS-one	m	c	m		5
			ILS-squared	c	m	c		6
	Night	No	RNAV-ILS	m	c	m	***SNI-night***	7
			ILS-one	m	c	m		8
			ILS-squared	c	m	c		9
	Day	Yes	RNAV-ILS	m	c	m	***F/W-MA***	10
			ILS-one	m	c	m	***R/W-MA***	11
			ILS-squared	c	m	c	***?***	12

Note: P1 = Pilot 1, etc.
‘c’ = calm wind; ‘m’ = moderate wind

A total of 12 runs/sorties per pilot, each of about 20 minutes was flown on the simulator. Including training runs and rest periods each pilot/ATCo was in the simulator for about one day (8 hrs). Three pilots and 3 ATCos were involved in total.

6 Experimental results

6.1 General

The data generated by the experiment generally falls into two categories, viz. subjective data and objective data. Subjective data are data collected e.g. through questionnaires, where the variable queried is an ordinal variable (e.g. acceptance of a procedure, with “values” of ‘well accepted’, ‘not accepted’, etc). Objective data are such parameters like speed, time, number of flights, etc.

The more important variables are the workload of the pilot and the Air Traffic Controller (ATCo). For the pilot the workload was obtained from the pilot’s questionnaire using the McDonnell workload scale to rate workload, or as it is named: “demand on the pilot” (see Ref.[2]). It is an adjectival scale, of which McDonnell proved that it was in fact linear, indicating that the demand on the pilot rating can be treated as an interval-scale variable.
The workload of the ATCo was obtained also from a questionnaire, where this time the well-known NASA-TLX scale was used, with which the ATC community is familiar. This is a non-adjectival, free scale consisting of 6 dimensions or sub-scales to rate the workload. The sub-scales are ‘*Mental demand*’, ‘*Physical demand*’, ‘*Temporal demand*’, ‘*Performance*’, ‘*Effort*’ and ‘*Frustration*’. A special process applies to combine the individual scales together, see Ref.[3], although in this experiment individual ratings were used, or averaged.

To ascertain whether or not a particular factor has a significant effect on the variable investigated a so-called ANalysis Of VAriance (ANOVA) is performed. This analysis applies only to interval-scaled variables. With the F(isher)-test the variance ratio of an effect of the experimental factor is tested for significance, which is expressed in terms of a probability p. Here p denotes the probability of omission, i.e. the probability of being “wrong”. If $p<0.1$ then the effect is supposed to be weakly significant, $p<0.05$ denotes a significant effect, and $p<0.01$ signifies a highly significant effect, in statistical terms.

For ordinal-scale variables (e.g. most of the questionnaire data) non-parametric tests are used, e.g. the Wilcoxon matched pairs test, Friedman ANOVA on ranks, etc. More information on these tests, methods and analyses can be found in Ref.[4].

6.2 Discussion of results

6.2.1 Human factor issues

6.2.1.1 Pilots' SNI-type IFR procedure acceptance

A major outcome of the experiment was how the steep, curved RNP-RNAV rotorcraft procedure in the SNI concept would be accepted by the pilot and/or the ATCo. Hence a question was asked both in the pilot's post-scenario questionnaire, as well as the ATCo's questionnaire. A separate part of the approach procedure, viz. the missed approach part, was rated for acceptance separately in the pilot's debriefing questionnaire. Also pilot and ATCo comments, given in the debriefing, were used to evaluate the SNI-type of IFR procedure.

The acceptance rating of the SNI-type of IFR procedure by the 3 pilots is given in Figure 9, both for the procedure as a whole as well as for the missed approach part only.

As evidenced from the figure, the SNI-type of IFR procedure was *well* accepted by the pilots, but the missed approach was at best *neutrally* accepted or *not* accepted (rejected). Pilots commented that the turn in the missed approach should either start as early as possible, without having to continue first to the missed approach point, and more "length" of the missed approach procedure would be nice, since one pilot felt that the *initial* missed approach segment before the turn could be made was rather short. The initial missed approach is that part of the missed approach where the pilot initiates the conversion from descent to climb configuration, including retracting the landing gear[2], and recovering or increasing the speed, if necessary. Once established in the climb the initial missed approach segment is completed. The missed approach shown on the approach chart showed the turn to start at the MAPt, which one pilot apparently felt would be too close (i.e. "immediate") for comfort. It must be stated though that for the "normal" go-around the missed approach would be initiated at the decision altitude/height of

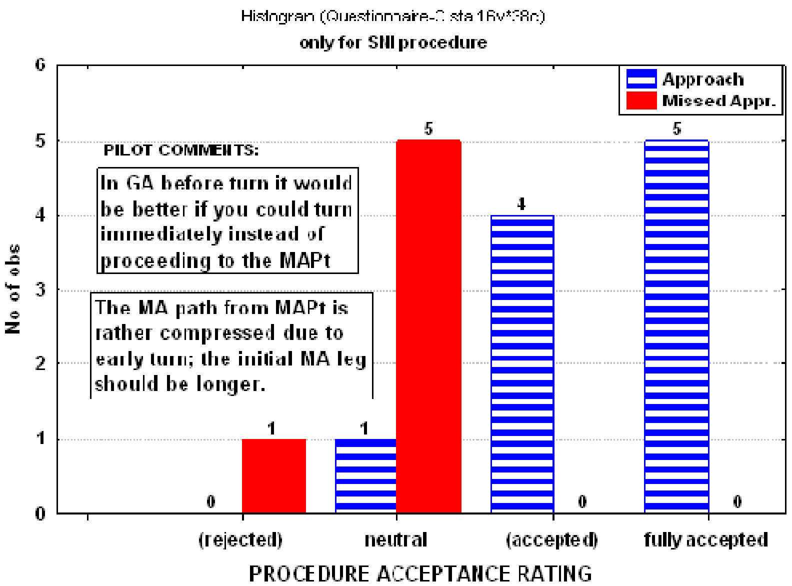

Figure 9 SNI-type procedure acceptance

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[2] This was not the case with the rotorcraft model used.

200 ft, which is still some distance *before* the MAPt (463 m to be exact). A missed approach initiation at the DA/H never occurred anyway.

Furthermore the pilots commented that the curve on the very final part of the procedure made it difficult to stay within the one-dot lateral deviation. All the workload came at the very final end of the procedure. A better situation might be to finish the curve/turn at 1000ft instead of 500ft as with this SNI-type of IFR procedure.

6.2.1.2 Pilot workload per procedure

In order to analyze the effect of 'procedure type' and 'wind' on the pilot's workload, both these factors were used in a 2 (procedure) repeated measures x 2 (windspeed) grouped ANOVA. Data from scenario 1 and 2 were used. Only cases where the *RNAV-ILS* guidance display was used were taken into consideration, since this was the only display type that was common to both procedures. Mean values of the demand on the pilot per procedure are given in Figure 10.

It turned out that the type of procedure had a statistically significant ($p<0.05$) effect on the demand on the pilot, $F(1,2)=19.786$, $p=0.047$. The windspeed did not have any main effect at all ($p>0.1$) on the demand on the pilot. Overall the demand on the pilot for the ILS approach was close to "largely undemanding", while for the steep IFR, SNI-type of procedure it increased on average to "mildly demanding".

The helicopter pilot's workload did increase slightly for the class of rotorcraft missed approaches, but not significantly ($p>0.1$), in a statistical sense, $F(1,2)=1.135, p=0.398$. This tendency for the workload to increase can be well explained by the fact that making a missed approach calls for quite a few actions to be performed, e.g. changing glide path angle by applying

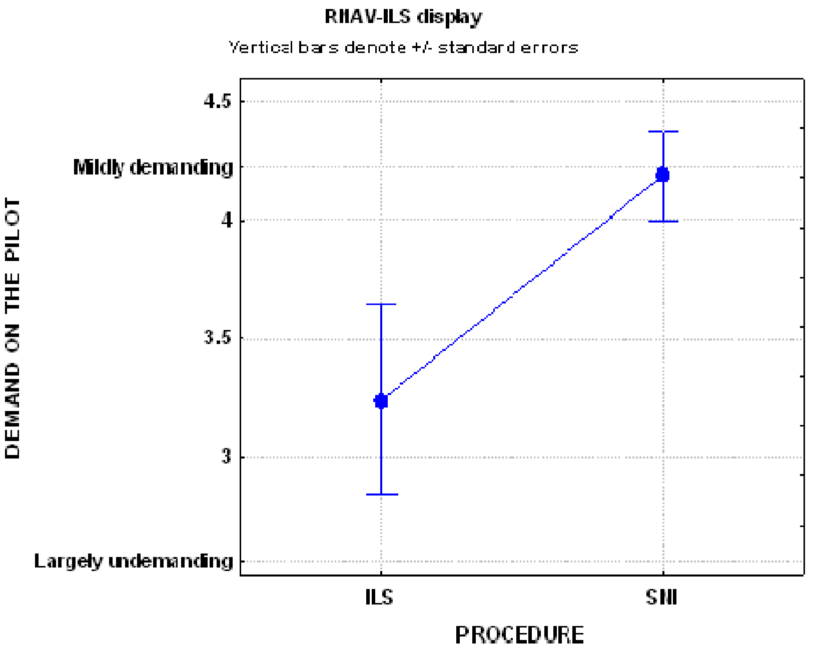

Figure 10 Effect of type of procedure on the demand on the pilot

power, maintaining track and orientation while changing flight speed to missed approach speed (from 60 KT to 75 KT IAS), informing ATC, etc.

6.2.1.3 Pilots' situational awareness

Before the experiment the rotorcraft pilots were instructed about the meaning of situational awareness, the literal meaning being his awareness of the ATC and aircraft situation around him in terms of aircraft positions, movements, etc. The pilot rated situational awareness on a 5-point adjectival scale, from 'bad' to 'excellent'. The Wilcoxon's matched pairs test was applied to the pilot's situational awareness rating data to test the effect of procedure type. The outcome of the Wilcoxon matched pairs test showed the effect to be just not significant, p=0.109. Although not yet weakly significant (p<0.1) the values of the main effect are shown in Figure 11.

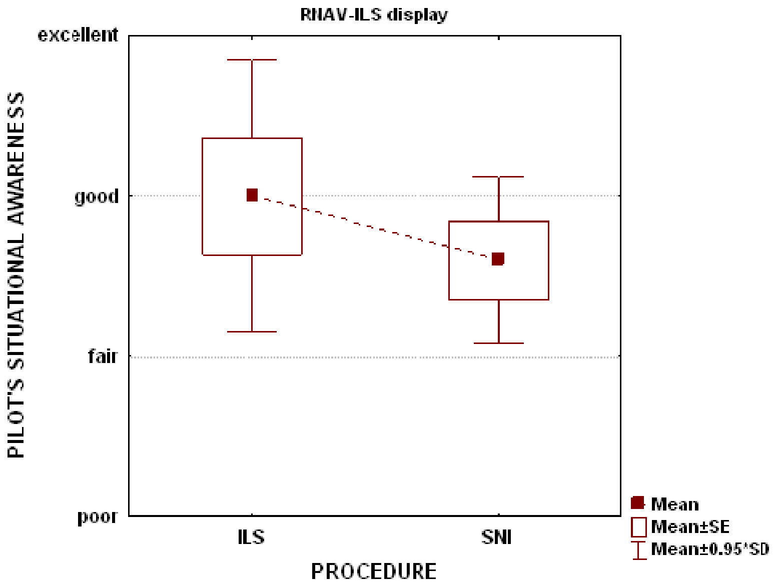

Figure 11 Effect of procedure type on pilot's situational awareness

Pilots rated the situational awareness for the SNI-type IFR procedure, with the same type of guidance display as for the ILS, to be slightly ***less***, i.e. between '*fair*' and '*good*', than the (average) situational awareness for the ILS procedure, rated '*good*'. Queried about his rating one pilot commented that he had a better 'awareness' of where other fixed-wing traffic was on the ILS, viz. simply either before or behind him; in case of the SNI-type of IFR procedure the location of the other fixed-wing aircraft was more complicated to ascertain owing to the convergence of tracks, and hence more difficult to asses.

It was odd to find that, while flying the SNI-type IFR procedure, the helicopter pilot's situational awareness improved when a *fixed*-wing aircraft on the RWY27 ILS approach made a go-around, as evidenced from the non-parametric Friedman's ANOVA on ranks test, χ^2 (N=4,df=1)=4.0, p=0.0455. Mean "values" of the situational awareness for the two groups (no missed approaches, fixed-wing missed approaches) are given in Figure 12.

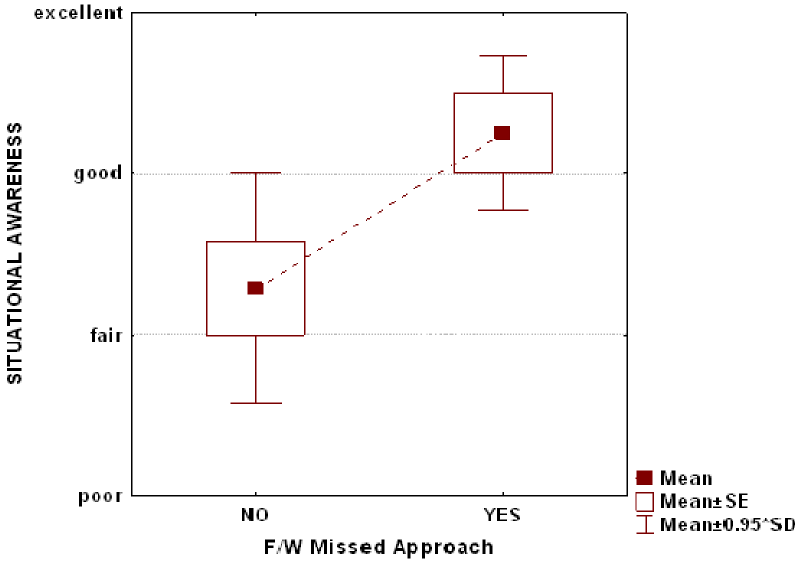

Figure 12 Main effect of F/W missed approach on rotorcraft pilot's situational awareness

There is no explanation for this. It is possible that because of the rare event, any *F/W* missed approach was psychologically rated as a big, dominating event also due to the additional radio communication associated with the event, and with the rotorcraft pilot perhaps trying to visualize its position and movement more than anything else because of the possible implications of flight path clearance. No additional comments were given by the rotorcraft pilots concerning the rating they gave, however, also because this trend was detected after the fact, during the data analysis.

6.2.1.4 ATCo's SNI-type of IFR procedure acceptance

Procedure acceptance by the ATCo was rated using a complex of questions. They also commented that the SNI-type of IFR procedure was only just acceptable (on conditions), and needed modifications, in that it wasn't truly independent. There was interference with departing traffic on 2 standard instrument departures (SID) in terms of altitude conflicts, which couldn't be resolved since no deviations may be made from a SID below 3000ft. For the Amsterdam situation the SNI-type steep IFR procedure could be made to converge less towards ILS 27, e.g. a track of 300º instead of 342º could be used. The ATCos were reluctant to believe the rotorcraft pilot would properly follow the curve on final, asking him on many occasions to report starting the turn.

6.2.1.5 ATCo's workload per procedure

After each scenario was completed the ATCo had to fill out his workload rating form, so in fact the workload represents an average over the last hour.

In order to eliminate individual differences and biases in the ATCo ratings they were first standardized per sub-scale and then normalized by using the overall, or grand, mean and standard deviation of all the sub-scale ratings combined. The ratings were then corrected for learning effects by removing any linear trend (per sub-scale) across the scenarios. Concerning the effect of the SNI-type of IFR procedure, its effect can be determined by comparing the ATCo's workload ratings of scenario 2 with those of scenario 1. The mean value of the ATCo's workload is given in Figure 13.

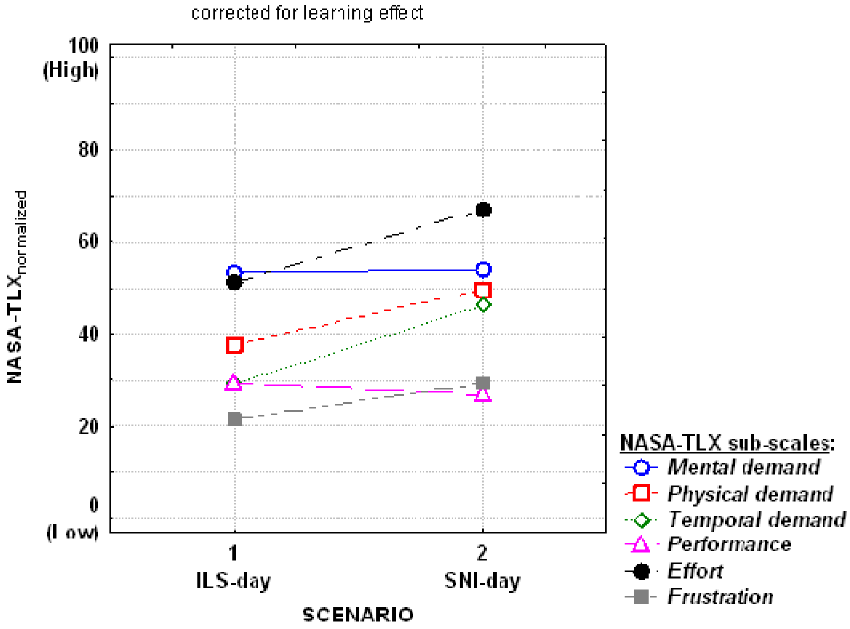

Figure 13 ATCo's workload for the two procedures – daylight conditions

There turned out to be a clear, statistically significant ($p<0.05$) workload *in*crease with the SNI-type IFR procedure, compared to the baseline ILS 27 procedure, except for '*Mental demand*' and '*Performance*'. One reason for the increase in workload was attributed by the ATCos to the convergence angle of the SNI-type of IFR procedure, compared to the nearby ILS approach.

One of the startling findings about missed approaches was that they had no effect on the ATCo's workload. For ATC apparently it did not matter whether or not there was a missed approach carried out, either by a rotorcraft on the SNI-type IFR approach or by a fixed-wing aircraft on a converging ILS approach.

6.2.1.6 ATCo's situational awareness

.The ATCo's overall situational awareness rating is given Figure 14. For the SNI-day scenario it was lower than for the other scenarios, however, an increasing trend can be observed that might indicate a learning effect.

Concerning the ATCo's situational awareness his comments given during the experiments and the debriefing were:

- Altitude information in the label of the rotorcraft on the SNI approach is necessary to judge safe separation with the fixed-wing traffic.
- If the rotorcraft traffic doing an SNI approach is within 3NM of the fixed-wing traffic then this is only possible if visual flight rules can be applied. The visual conditions within the experiment did not allow for the rotorcraft to maintain visual separation. A solution can be found in using the parallel approach rule.
- Double Missed Approaches for the fixed-wing and rotorcraft traffic is problematic with the given runway configuration. This needs coordination and makes the traffic flow dependent.
- The SNI-type of IFR approach procedure was conflicting also with outbound traffic.

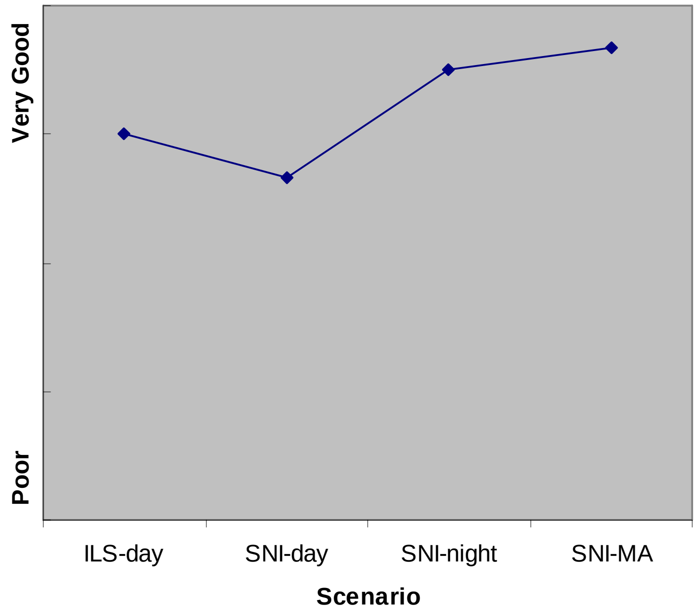

Figure 14 Overall ATCo's situational awareness

- The SNI-type of IFR approach procedure may not be acceptable due to the dependency.
- The SNI-type of IFR approach procedure as used in the experiment was, in the opinion of the controllers, not compliant with ICAO separation limits with respect to the traffic on ILS 27. For RNP 0.1 there is not yet a new and lower ICAO separation limit. This results in a separation problem, which makes this converging approach not acceptable for controllers.

During VMC conditions the SNI-type of IFR approach gives no separation problem, especially not with the displaced helispot, which had a separation distance of ±1000 m from the traffic on ILS 27.

6.2.1.7 Interference aspects of the SNI-type IFR procedure

Not only did the ATCo have to contend with arriving traffic, but also with departing flights from RWY 18L. The rotorcraft's initial altitude of 3000ft at the IAF of the SNI-type IFR procedure turned out to interfere with the altitude of aircraft on the ANDIK 2E or ARNEM 2E Standard Instrument Departures (SID) from RWY 18L, see Figure 15.

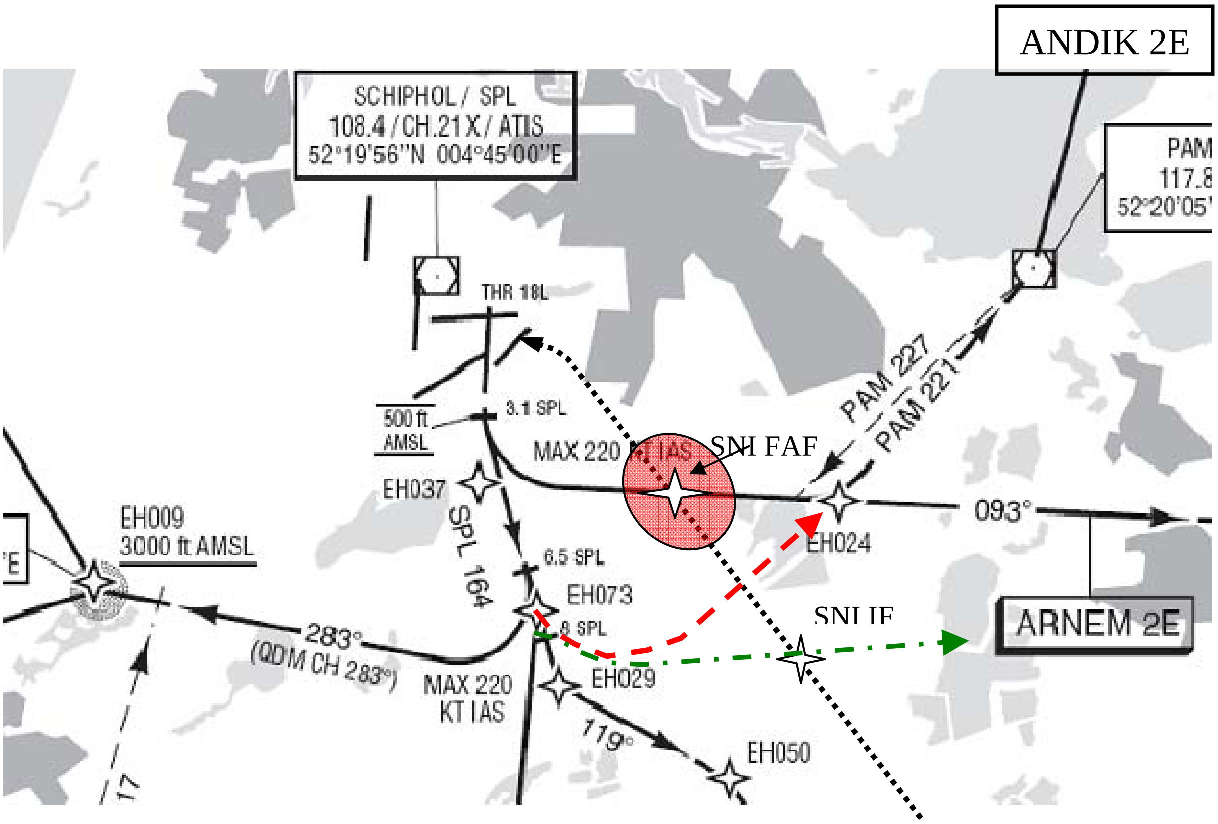

Figure 15 Location of the SNI procedure relative to ANDIK, ARNEM 2E SIDs

These SIDs would bring fixed-wing traffic close to the rotary-wing traffic in terms of altitude (see the red area above). Since giving deviating instructions to aircraft flying these SIDs, in order to stay clear of the rotorcraft, is only allowed above 3000ft, the task of the ATCo to control this separation in altitude is usually done by delaying those flights scheduled for these departure routes. An alternative could be to slightly revise the ANDIK 2E SID, see the dashed red arrowed line in the figure, where the aircraft departs via EH073 and then intercepts PAM radial 221° to EH024, and so on. A similar modification could be brought into the ARNEM 2E SID, e.g. by routing direct from EH073 to ARNEM intersection (see dash-dotted green line), assuming there is no interference with other (military) airspace. A perhaps better solution, as proposed by the ATCos, is to modify the SNI-type IFR procedure and make the final approach course to be more or less parallel with the ILS 27 approach course. As they suggested, at a large airport like Schiphol there are ample opportunities for locating a suitable SNI-type IFR procedure.

Another item of interference was the (possible) functioning of a TCAS system on board the fixed-wing aircraft. With the nearby presence of a rotorcraft it is conceivable that, had a TCAS been onboard, an advisory or alert might have been generated. In order to pre-warn the crews of approaching aircraft the ATCo advised fixed-wing traffic about the presence of the rotorcraft, and vice-versa. This constituted an additional communications load.

6.2.2 Airport's capacity

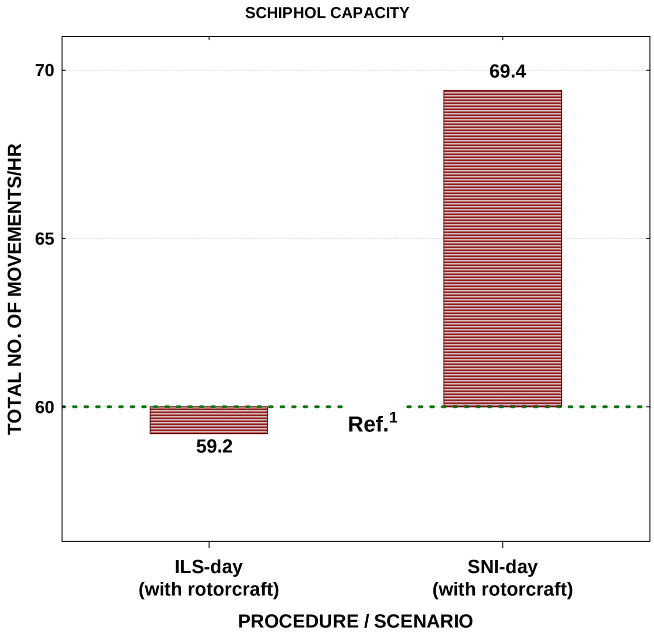

Figure 16 Average total number of movements per hour per approach procedure

Capacity refers to the ability of an airport to handle a given volume or magnitude of traffic (demand) within a specified time period. In the experiment it has been "measured" by counting the number of actual landings and/or departures that occurred within one scenario, which lasted one hour. The change, or increase, in this number with application of a different procedure is one of the objectives of investigation.

It turned out that the airport's capacity increased with application of the SNI-type of IFR procedure by about 17 percent relative to the baseline ILS procedure, see Figure 16. For the ILS procedure ***with rotorcraft*** the total number of movements per hour on average amounted to 59.2 (average of 3 testing days), while for the SNI-type of IFR procedure it amounted to 69.4 movements. The theoretical limit capacity for fixed-wing aircraft only would be about 60 flights (30 arrivals and 30 departures), see the Ref. line.

When the rotorcraft flew the ILS approach with the break-off towards RWY 22, departing traffic from RWY 18L was delayed in order to accommodate a possible rotorcraft missed approach (which would cut right across runway 18L), as well as less fixed-wing approach flights could be accommodated due to the lower speed of the rotorcraft. In case of the SNI-type of IFR approach procedure only some traffic departing from RWY 18L was delayed when the rotorcraft came "near" the airport. Due to the much lower speed on the SNI-type of IFR procedure this "decision" point was also much closer to the airport than for the ILS approach.

6.2.3 Flight performance

The flight tracks of both the ILS 27 baseline procedure, with circle-to-land on RWY 22, as well as the SNI-type IFR procedure, including the missed approaches, are shown in Figure 17.

There is no effect of crosswind discernable in the tracks. Crosswind had no significant main effect ($p>0.1$) on the lateral deviation RMS, $F(1,2) = 6.44$, $p=0.126$, but perhaps a trend can be noted, that with crosswind there is a 2 per-cent lower rms than without. This is partly attributable to the increased flight speed with wind, which meant a rotorcraft configuration with greater speed stability.

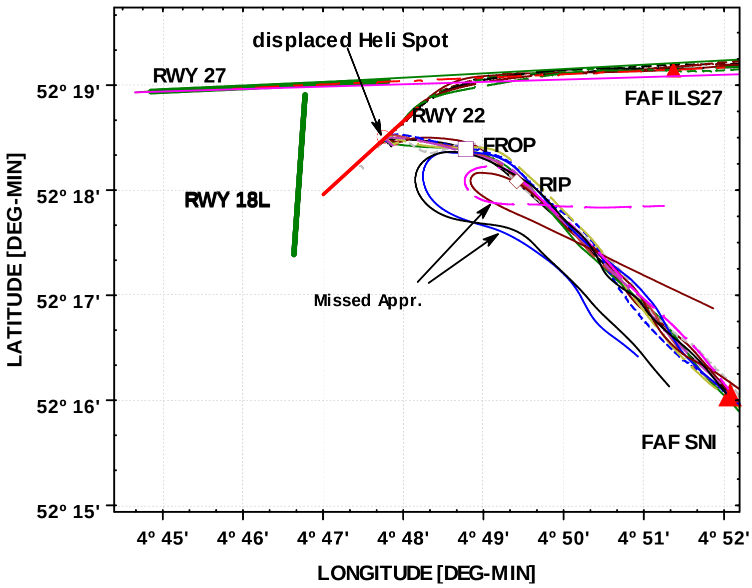

Figure 17 Flight tracks for the baseline and SNI procedures

The spread in the tracks for both procedures is comparable, even though the SNI-type of IFR procedure contained a curved final segment. The lateral deviation from track or approach course was not significantly different between the two procedures.

Of the missed approaches, two of them continued up until the FROP before making the turn; the other two were directed by ATC to start the turn sooner. All missed rotorcraft approaches were intentionally initiated at 1000ft AGL, i.e. just before descending through the RIP (where the curve would start). Due to the relatively slow speed (max.75 KT IAS) the turn radius was small, therefore all the missed approaches stayed well clear of the departure runway 18L.

6.2.4 Miscellaneous effects

6.2.4.1 Day-night

The effect of day-night was determined in principle by comparing data from scenario 3 with that of scenario 2.

In terms of pilot workload there was an overall weakly significant main effect ($p<0.1$) of day-night, $F(1,2)=9.878$, $p=0.088$. At night the demand on the pilot was slightly less than at day-time. Because of a computer network failure only 2 out of 3 pilots completely flew the night-time scenario, so the effect could be caused by the missing pilot generally having given higher workload ratings. Because of the small number of pilots no conclusions can therefore be drawn about the effect of day-night on the pilot's workload.

An interesting aspect is what effect day-night may have on the workload of the ATCo, in view also of the fact that part of his task involves seeing and observing incoming or departing traffic.

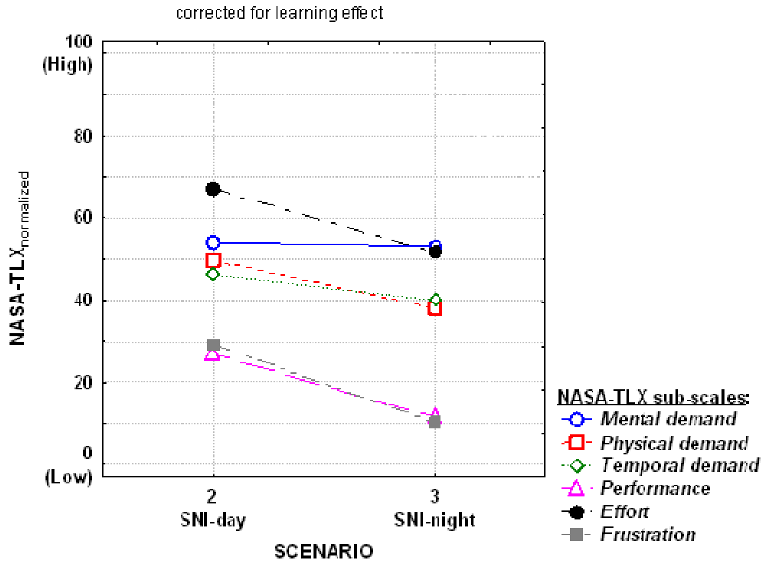

Figure 18 Main effect of day-night on ATCo's workload

Here the ambient lighting conditions may have a definite effect. For the ATCo's workload the size of this effect was obtained by comparing workload data of scenario 3 (night-time, SNI-type of IFR procedure-in-use) with that of scenario 2 (daytime, SNI-type of IFR procedure-in-use), without go-arounds being made. Mean values of the NASA-TLX sub-scale ratings are given for the two scenarios involved in Figure 18.

The results of the, in this case repeated measures, ANOVA of the NASA-TLX workload sub-scale ratings showed that the effect of 'day-night' was statistically not significant ($p>0.1$), mainly due also to the small sample size involved (only 2 ATCos). This is because of the same computer network failure as mentioned above. Based on this no overall conclusion can be drawn about the effect of day-night on the ATCo's workload.

6.2.4.2 Guidance display type

For the pilot some further parameters were investigated, viz. the guidance display type and wind influence. The guidance display type, i.e. the *RNAV-ILS*, *ILS-one* or *ILS-squared* display, did have an effect on a number of parameters. One of the more important ones is lateral deviation from track, expressed in dots rms, for example. Although overall the type of guidance display did not have a statistically significant main effect ($p>0.1$) on the

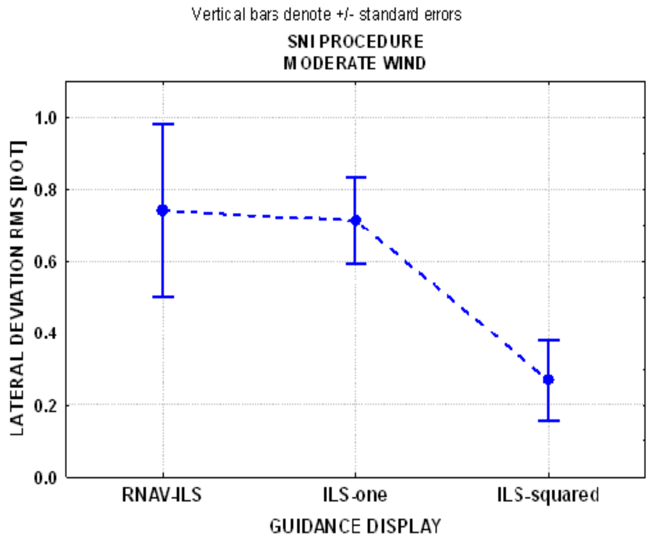

Figure 19 Effect of guidance display on lateral deviation RMS

lateral deviation rms on the final segment (i.e. including the curve), the mean values are shown in Figure 19, in case of moderate (cross)wind (where a full evaluation could be made)..

It looks like for the *ILS-squared* display the lateral RMS is lower than that for the other two displays, in case of moderate wind. A contrast analysis showed that indeed for the *ILS-squared* guidance display the lateral deviation RMS is at least weakly significantly lower ($p<0.1$) than the lateral deviation RMS of either of the other two displays, $F(1,1)=85.038$, $p=0.0688$. A smaller RMS implies an increased safety. So apparently in case of hard piloting work, due to the moderate wind, the *ILS-squared* display was a class of its own in terms of keeping the cross-track deviation to a minimum on a steep curved final segment. It is possible that the “lead-in” information about the lateral deviation on the straight xLS segment (i.e. the “next” track when on the curve) shown on the display helped the pilots to better stay on the last part of the final segment. This is substantiated by the results shown hereafter.

The guidance display main effect, in case of moderate wind, on the lateral rms deviation at the Final Roll-Out Point was also significant, $F(2,2)=17.495$, $p=0.054$. Mean values are shown in Figure 20.
For this moderate wind case one can clearly see a pattern of the lateral deviation for the *RNAV-ILS* and the *ILS-squared* displays being more or less the same at the FROP, i.e. about 0.3-0.5 dots, whereas for the *ILS-one* display the lateral deviation is much larger, viz. 1.5 dots. This supports the hypothesis that the moving localizer deviation signal (of the xLS segment) does help the pilots to better intercept and/or stay on the final short xLS segment than without it (as is the case with the ILS-one display). Notice also that all (mean) deviations at the FROP were positive, i.e. to the right of track. With the moderate crosswind coming from the left at this point this indicates that pilots were not compensating enough for the crosswind.

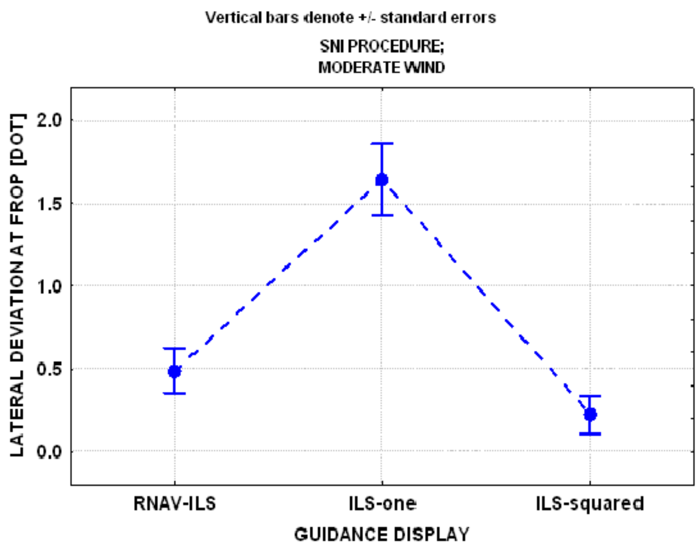

Figure 20 Guidance display main effect on lateral deviation at the FROP

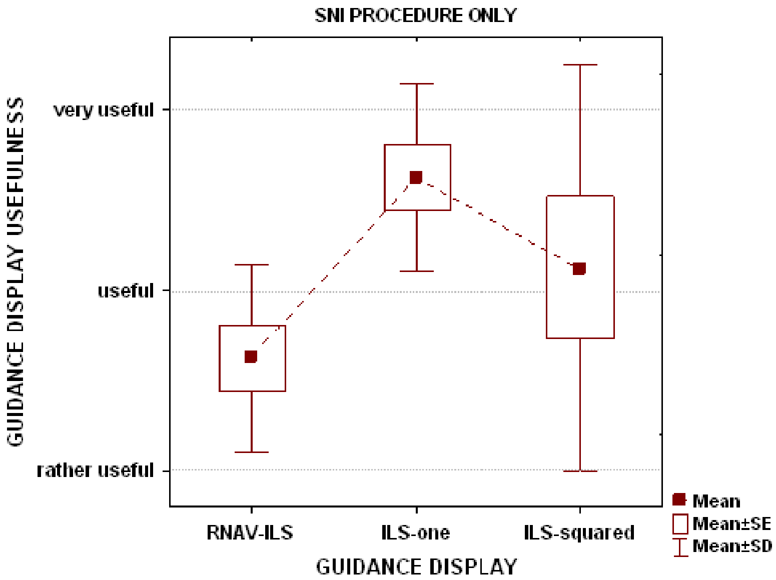

Figure 21 Usefulness of the guidance displays

When evaluating the usefulness of the guidance displays the mean results of display usefulness taken from the pilot questionnaire are as given in Figure 21.
The Friedman ANOVA on ranks test gave χ^2 (N=8, df=2) = 6.28, p=.0434, i.e. the effect of the guidance display on the usefulness of the display is significant (p<0.05). Especially the *RNAV-ILS* guidance display ranked lowest, while the *ILS-one* display ranked best. The *ILS-squared* display did not outrank the *ILS-one* display, and in general had a larger scatter of ratings, from '*very useful*' to '*hardly useful'*. This larger scatter was due to one pilot rating the *ILS-squared* display much less useful than the other two pilots did. Of the three pilots two had been exposed to the *ILS-squared* guidance display in the earlier experiment in 2006. With the least experience with this display type, the third pilot commented about the *ILS-squared* display that "*it contained too much information, which was misleading*", while the other two pilots, who had more experience with, and exposure to this display, commended this display and ranked its usefulness as '*useful'* to '*very useful*'. They also found the *ILS-squared* display to give good lead information when intercepting the next track. They considered the "best" type of display to be the *ILS-squared* display (for lateral information) together with the square-roots display (for vertical information). The *RNAV-ILS* display was the least useful at any rate.
The remarks one pilot made about "*misleading information*" indicate that more learning time and demonstration of the specific features of the *ILS-squared* display might be warranted.

6.2.4.3 Crosswind

For the SNI-type of IFR procedure the effect of the combination of display and wind could be assessed on a number of parameters, for example pilot workload, etc.

The Guidance display x crosswind interaction is shown in Figure 22. The main effect of crosswind on the pilot workload turned out to be weakly significant (p<0.1), F(1,9)=3.721, p=.0858. As expected the workload increased when the crosswind increased (from 'calm' to 'moderate'). This had obviously to do with the pilot having to re-adjust his crosswind correction in heading in order to stay on track, irrespective of the guidance display. The interaction was not significant, however, as the figure shows the difference in workload due to crosswind was larger for the *ILS-squared* display (and significantly so, F(1,9)=4.319, p=0.0674) than for the other 2 guidance displays. Apparently this *ILS-squared* display made it easier for the pilot to maintain the lateral flight track in case of calm wind due to more information being displayed, while with crosswind the workload was the same for all guidance display types. Note that overall the pilot's workload varied about 'mildly demanding'.

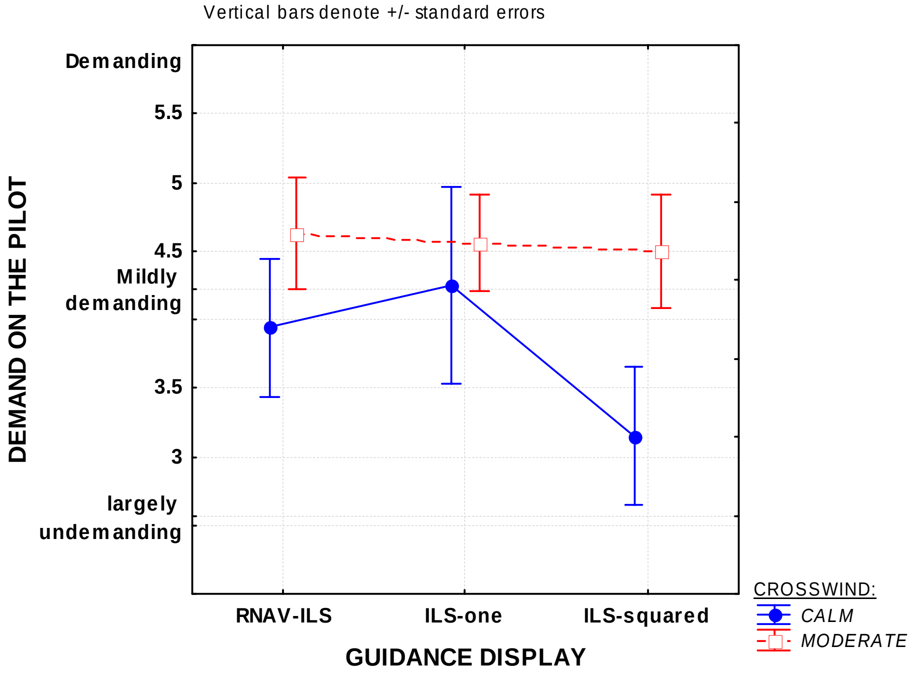

Figure 22 Interaction effect of crosswind and guidance display on pilot's workload for the SNI-type of procedure

Furthermore, although the crosswind had no significant main effect on the lateral deviation from track on the final segment, it did have a significant main effect on the lateral deviation at the Final Roll-Out Point 'FROP' (situated at 500 ft AGL), F(1, 9)=6.048, p=.0362. With calm wind the average deviation was 0 dots, while for the moderate crosswind it increased to +1 dot, i.e. to the right of track/flight path. Apparently the total lateral deviation, on average, along the descending flight path was not affected by the crosswind, but on a small, "local" scale at one point of the procedure (i.e. after the curve) there was a (statistically) significant effect.

7 Concluding remarks

The conclusions drawn in this experiment should be viewed within the limitations that apply, and the peculiar ATC situation that was simulated as well (viz. only runways 18L, 22 and 27 at Amsterdam Airport, with associated traffic). The SNI-type of steep rotorcraft IFR procedure was quite new to the ATCos, and had not been discussed in detail with them before they were being introduced to it during the training part of the simulations. Several other limitations applied, e.g. there was no influence of wind on the operations of the fixed-wing aircraft (i.e. no effect on groundspeed), although for the rotorcraft it did have an effect. Owing to the small number of test objects (ATCos, pilots) statistical inferences made are in several cases doubtful, especially when a missing case occurred. This was less so for the rotorcraft pilots, since they flew at least 3 runs within one scenario, while the ATCo gave only one rating per scenario.

Bearing this in mind it can be stated that a unique test of a real-time rotorcraft–ATC integrated, coupled simulation has been performed, successfully applying a rotorcraft SNI-type of IFR procedure within a busy airport environment. As a novel feature the new procedure contained a curve on the final segment. No major reservations were made by the helicopter pilots with respect to the SNI-type of IFR procedure, albeit that the curve on the final segment made it difficult to stay within acceptable performance limits. With the curve completed at a larger altitude than the 500ft AGL tested would ease pilot workload and improve lateral performance. The ATC-controllers would like to have the convergence angle of the descending part of the SNI-type of IFR procedure (before the curve) reduced so as to make it fully acceptable and independent of the other fixed-wing traffic. The missed approach procedure could be much improved by having a more or less straight missed approach rather than a turn, since traffic departing from runway 18L would be delayed anyway upon the rotorcraft's approaching the airport.

The ATCo's and pilot's workload for the SNI-type steep IFR procedure was higher than for the "standard", and more familiar ILS approach procedure. It is believed that unfamiliarity with this SNI-type of IFR procedure is the main reason for the higher ATCo's workload, besides the convergence angle aspect. The higher pilot's workload is difficult to reduce since the curve on final tends to induce a higher workload condition; however, the level of demand on the pilot was still 'mildly demanding'. It is remarked here that all rotorcraft flights were flown manually. Compared to the baseline ILS procedure the airport's capacity increased when using the SNI-type of IFR procedure for the helicopters.

The effect of day-night was inconclusive and could not be determined due to a computer breakdown that occurred with one pilot/ATCo combination.

The crosswind had a weak effect on pilot workload, and especially so with the *ILS-squared* guidance display, and had no effect on the lateral path deviations on final, but it did affect the lateral deviation at the roll-out point on final, at 500 ft AGL, i.e. on a small, “local” scale.
The pilot’s preferred guidance display was the *ILS-one* or *ILS-squared* display, i.e. the “raw data” *RNAV-ILS* display was least preferred, owing to the lesser information it provided.
ATCos commented that improvements in the layout of the SNI-type of IFR procedure should be made, and are possible, in order to reduce the level of interference that still existed. With the suggested improvements (e.g. convergence angle less than 30º) an even greater airport capacity increase and a “true” non-interference between fixed-wing and rotary-wing traffic should be achievable.

8 Acknowledgement

The author would like to acknowledge the invaluable contribution made by the participating pilots from CHC Helicopter Corporation, the air traffic controllers and the group of people involved in setting up and running the tower simulator NARSIM/TWR as well as the pseudo-pilot, Eurocopter for granting permission to use the AS365N Dauphin model as well as the use of related features, and the University of Liverpool for providing the AS365N FLIGHTLAB model. Furthermore the author would like to acknowledge the European Commission for sponsoring this project, under contract no. AIP3-CT-2004-502880. Also the partners in the European project OPTIMAL are acknowledged for granting permission to present these results.

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