

# THE IMPACT OF AIRCRAFT INTENT INFORMATION AND TRAFFIC SEPARATION ASSURANCE RESPONSIBILITY ON EN-ROUTE AIRSPACE CAPACITY

*Rob Ruigrok ([ruigrok@nlr.nl](mailto:ruigrok@nlr.nl)) and Mario Valenti Clari([valenti@nlr.nl](mailto:valenti@nlr.nl))*

*National Aerospace Laboratory NLR*

*Anthony Fokkerweg 2, PO Box 1006 BM, Amsterdam, the Netherlands*

## Abstract

This paper will give an overview of the main simulation results obtained in the European INTENT project. The objective of INTENT is to link aircraft intent information, the location of responsibility for the separation assurance process (air, ground) and en-route airspace capacity. This has been done by means of fast-time simulations to generate the required objective data, and real-time simulations, to develop the fast-time models and validate the outcome.

Workload models for controllers and pilots have been derived and the results show an interesting effect of the location of separation responsibility on en-route airspace capacity. The use of aircraft intent information in ground and airborne conflict detection and resolution functions appears to have significant positive impact on flight efficiency, but not on airspace capacity.

## Introduction

The emerge of new datalink technologies and the continuous growth of air traffic over the last decades has sparked the discussion on how conventional separation assurance is limiting the air traffic system capacity. Air traffic separation assurance is one of the main components of Air Traffic Control (ATC), which is traditionally performed by air traffic controllers that guide traffic based on radar surveillance and, if available, aircraft flight plan information. One of the key questions is if en-route airspace capacity can be increased by the use of aircraft intent information for separation assurance, and how much intent information should be made available. Moreover, should the availability of intent information be combined with a shift of the separation assurance task from the ground-based controllers to the aircrew?

The INTENT project was initiated to provide essential data in order to answer these questions. The objective of INTENT is to link aircraft intent information to the location of responsibility for the separation assurance process (air, ground) and airspace capacity. The approach in INTENT is to perform fast-time simulations to generate the required objective data. These fast-time simulations require realistic models for both pilots and controllers. Therefore real-time simulations were performed to enable model development.

The INTENT project is co-funded by the European Union and the INTENT consortium. The INTENT project consortium consists of NLR, QinetiQ, ONERA, Rockwell Collins, Smiths Industries, AIRBUS, Eurocontrol, Delft University of Technology, Dutch Air Line Pilot Association VNV, KLM Royal Dutch Airlines, British Airways and Scandinavian Airlines System.

This paper will give an overview of the main results that were obtained in the real-time and fast-time simulations, giving an answer to the earlier-mentioned questions. The next sections will sequentially deal with the validation process and the simulation experiments for ground and airborne separation assurance concepts. Finally, the overall results and conclusions will be presented.

## Validation Approach

Validation is a key stage in the development of new Air Traffic Management (ATM) concepts. MAEVA work [1] has proven to be relevant and beneficial for the validation of the concepts under study [2]. The MAEVA validation guidelines were taken into account at the level of the experiment design. The validation road map is based on the following sequence of three simulations, which has been applied to both ground and airborne operational concepts:

- real-time part-task simulations, to develop workload models and assess acceptability of concepts incorporating aircraft intent,
- fast-time simulations, to generate significant data over a larger airspace,
- full-scale real-time simulations to validate the part-task and fast-time results.

To link aircraft intention information, the location of the traffic separation assurance process and airspace capacity, the following three-dimensional matrix has been defined:

### 1. Separation Assurance Concept

The following operational concepts, including the location of the separation assurance task and airspace structure, are defined:

- Ground-based separation assurance with structured airspace (fixed routes)
- Ground-based separation assurance with unstructured airspace (free routes)
- Airborne traffic separation assurance with unstructured airspace (free routes)

In all concepts, Reduced Vertical Separation Minima (RVSM) were assumed and Special Use Airspace (SUA) was partially active during the experiments.

### 2. Aircraft Intent Information Level

Aircraft intent information has been defined as the path in time-space that the aircraft intends to fly. Four levels of intent information were assumed:

- no intent, only aircraft position and state information (5 min look-ahead time)
- intent with 5 min look-ahead time
- intent with 10 min look-ahead time
- intent with 20 min look-ahead time

### 3. Traffic Load

Traffic samples for use in the simulations were produced according to the Eurocontrol's CARE INTEGRA Project method [3]. The baseline traffic data in INTENT consisted of flight plan data from Eurocontrol's Central Flow Management Unit (CFMU) for a six-week period in 2000. Traffic samples were created for traffic density 1, 1.3, 1.5, 1.7, 2, 3, 4 and 6. In these traffic samples, all traffic avoided the active SUAs.

## Ground Simulation Experiments

In December 2001 the first set of ground part-task simulations were performed, followed by a second set in March 2002. These simulations were followed up by fast-time simulations in June 2002. In August 2002, real-time full simulations completed the simulations on the ground ATM concepts. This section will present the validation platforms, the Conflict Detection & Resolution (CD&R) tool and the results.

### Ground Validation Platforms

NLR's ATC Research SIMulator (NARSIM) has been used for the ground real-time experiments (part-task and full). For these simulations, four controller working positions of NARSIM were occupied: a tactical controller working position, a planner controller working position and two feeder controller working positions. Pseudo-pilots controlled each up to 20 aircraft in the measured sector. The aircraft in the feeder sectors were controlled directly by the feeder controllers. Figure 1 shows the experiment set-up, including R/T lines and input devices.

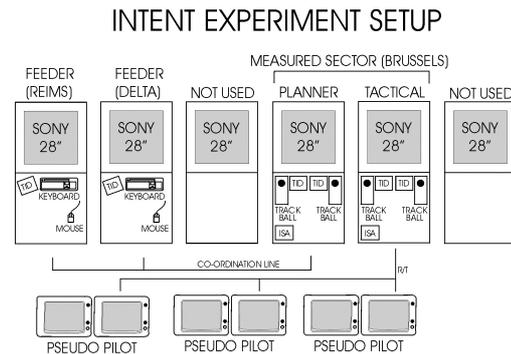


Figure 1: INTENT experiment set-up.

For the fast-time simulations, carried out in between the part-task and full simulations, QinetiQ's Flexible Airspace Modelling Environment (FLAME) was used. It has previously been used for several such applications including [4, 5]. FLAME simulates the movement of flights through airspace, collects statistics on quantities of interest, and provides traffic displays for scenario validation purposes. CD&R and workload model parameters have been implemented in FLAME.

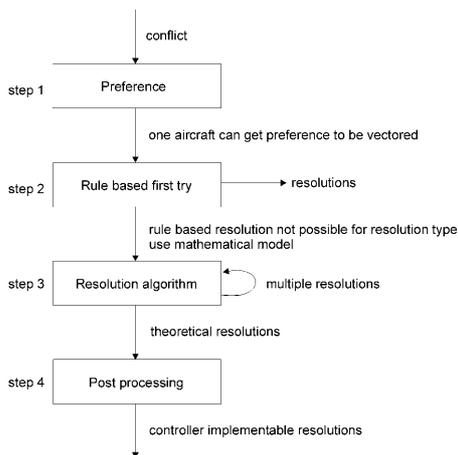
### CD&R Tool

The CD&R advisory function in en-route airspace is the only user of aircraft intent information in the ground concepts. It calculates

and displays conflicts and potential resolutions to the controller, based on received aircraft intent information.

The conflict detection process is based on a 4D Trajectory Predictor using aircraft intent information. It calculates whether there are conflicts for all possible aircraft pairs, using the predicted trajectories. Conflict detection is based on geometric mathematical algorithms [6]. The detected conflicts were displayed to the controllers by means of a notification in the Conflict Risk Display (CRD) and in the corresponding aircraft labels.

The controllers could query calculated resolutions by selecting the aircraft and the CD&R button on their Touch Input Device (TID). The resolution list would pop-up, from which they could select a resolution. Two different types of resolutions are calculated: applying vectors and level changes. The conflict resolution process is shown in detail in Figure 2.



**Figure 2: Conflict resolution process**

In step 1, one aircraft gets preference to be manoeuvred. An aircraft gets preference if it is involved in the most conflicts or, within the measured sector or with the highest ground speed. Step 2 tries to find resolutions for a conflict using the same rules that an air traffic controller could apply to solve conflicts. In step 3 the tool uses a mathematical algorithm to search for resolutions. Step 4 finally processes all resolutions to generate controller usable instructions.

### ***Part-task Simulation Experiment***

#### **Experiment Design**

A 2x2x3 design varied the following factors:

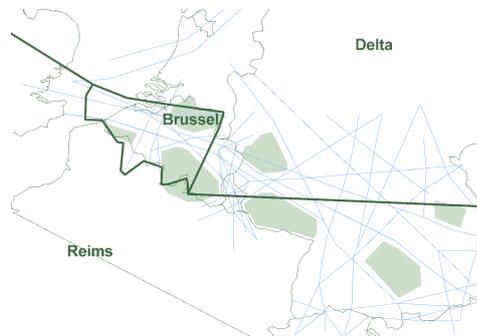
- 2 tools / intent levels – without CD&R tool and with CD&R tool
- 2 operational concepts – structured airspace and unstructured airspace
- 3 traffic loads – 1.0, 1.3 and 1.7 x today’s traffic load

The availability of aircraft intent information was in this respect implicitly coupled to the availability of the CD&R tool.

Due to controller availability, a full and balanced experiment matrix was not feasible. Moreover, in order to reduce training time, it was decided to perform the sessions without CD&R tool before the sessions with CD&R tool. It was recognised that this could cause a training effect in the results.

Traffic load 1.7 was tested in only 4 runs, since this was considered “too much” by the first controllers experiencing this traffic load.

En-route sectors were simulated in the experiments, above FL245, derived from the Eurocontrol project FRAP [7]. The sectors in the part-task simulations were: Brussels West, Delta and Reims. The Brussels West sector was the measured sector in the experiment. Delta and Reims were feeder sectors for the measured sector, as shown in Figure 3.



**Figure 3: Overview of sectors.**

Eight current controllers from Eurocontrol UAC Maastricht participated in the March 2002 experiment, each acting as tactical, planner and sometimes as feeder controller.

After each session, the tactical and planner controllers were asked to fill in a questionnaire. In addition, a questionnaire was used at the end of the day. During the sessions, subjective workload was assessed using the ISA (Instantaneous Self-Assessment) method at regular intervals of 2 minutes during each session.

## Results

The results from the NARSIM experiments can be divided into two parts:

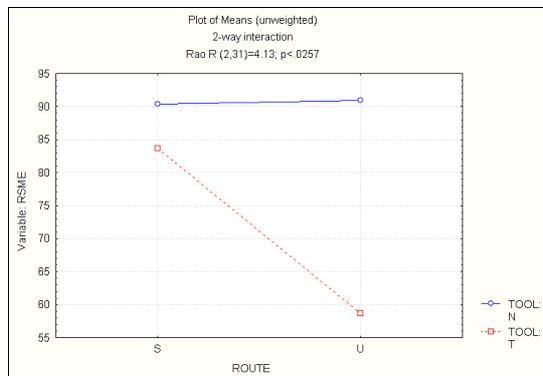
- controller workload model derived from the ISA measurements, taken every 2 minutes
- analysis of the questionnaires which were completed every run and after each day

After each run, the controllers were asked to rate their acceptability and workload on the Rating Scale of Mental Effort (RSME), [6].

A statistical analysis has been performed on the data obtained using ANOVA and MANOVA techniques [8]. It appears that the traffic load is a dominant and significant factor regarding controller workload. Traffic load 1.0 and 1.3 are considered workable, traffic load 1.7 shows an overload situation with the mean RSME well above “100” (“costing very much effort”).

The CD&R tool main effect appears not to be significant, but the route structure main effect is. Unstructured airspace significantly reduces workload and improves acceptability.

An interesting result is found when considering the controller workload and acceptability results with and without tool, in relation to the route structure, see Figure 4.



**Figure 4: Combined tool/route effect on workload.**

It shows that the route structure has little or no effect on controller workload if the CD&R tool is not present. It also shows that the CD&R tool is significantly reducing controller workload in unstructured airspace.

The results presented in this section have been derived with 4-way MANOVA analysis. It should be emphasised that with less powerful analysis techniques, only the traffic load main effect

remains significant. Moreover, given the incomplete and unbalanced experiment matrix, the results should be considered carefully.

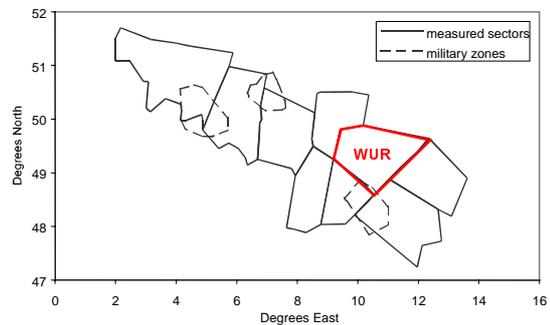
The debriefing results revealed that the Human-Machine Interface (HMI) and the CRD are generally “acceptable”. However, aircraft labels and conflict detection accuracy clearly needs more attention.

The workload model of planner and tactical controllers are developed based on the ISA measurements. Each model calculates a workload score as a linear combination of aircraft numbers and flows, and the Delahaye density. Each model also has an associated limit value that denotes maximum acceptable workload.

## Fast-time Simulation Experiment

Fast-time simulation experiments have been conducted using the controller workload models derived from the part-task simulations. CD&R tools as used in the real-time simulations, have been implemented in FLAME.

The measured airspace used for the fast-time simulations were nine sectors and three active SUAs as shown in Figure 5.



**Figure 5: The airspace simulated.**

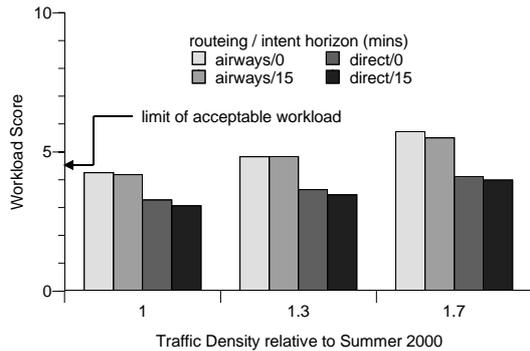
For the two operational concepts involving ground-based control, workload metrics were calculated for each sector in the measured airspace.

Experience from the part-task real-time simulations suggested that controllers were slightly overloaded at 1.7 times 2000 traffic levels. Therefore the project chose to use traffic densities of 1.0, 1.3 and 1.7 times 2000 levels.

## Results

Workload was computed for both controllers in the two ground concepts (airways and direct-routes) by using the derived workload models. It is

peak and near-peak workload that is of the most interest, so the 95th percentiles of workload scores were accumulated; these percentiles were estimated without storing individual observations by using the methods of Jain and Chlamtac [9]. Resulting percentiles for planning controller averaged over the three busiest sectors and six simulation runs for each set of experimental conditions (direct/airways routing and intent time horizon) are shown in Figure 6 (result for tactical controller is similar).



**Figure 6: 95th Percentiles of Workload Scores for Planning Controllers**

The following conclusions can be drawn:

1. Workload for both controllers is higher in airspace structured with airways than in airspace where all traffic flies direct routes.
2. Workload for both controllers is a little lower with automated CD&R support than without it.
3. With airways and without CD&R, workload is at the limit of acceptability for the 1.0 traffic load; with direct-routes it almost reaches the limit at 1.7 times this traffic density.

The conclusion from this part of our study must be that, if there is a workload and capacity benefit for ground-based controllers from automated CD&R enabled by shared aircraft intent information, then it is a very small benefit. The effect of unstructured airspace on controller workload is clearly more promising.

### Full Simulation Experiment

#### Experiment Design

The full simulations were to confirm the fast-time simulation results, giving confidence to the results. The results from the ground part-task simulations revealed that a different ATC sector should be studied to check and confirm that the controller workload models can indeed be used in

any ATC sector as was done in the fast-time simulations. Furthermore, the HMI should be improved, especially label decluttering, based on the debriefing results.

It was decided to only study unstructured airspace in the ground full-scale simulations, since this was considered the most interesting airspace from an airline cost/benefit point of view, and the CD&R tool was found to be most useful in unstructured airspace in the part-task simulations.

Part-task and fast-time simulations showed that traffic load 1.3 x today was manageable, but traffic load 1.7 x today was not manageable. Therefore, it was decided to test 1.0, 1.3 and 1.5 x today's traffic load in the full-scale simulations, with and without the CD&R tool.

A 2x3 within-subjects design resulted, varying the following factors:

- 2 tools / intent levels – without CD&R tool and with CD&R tool
- 3 traffic loads – 1.0, 1.3 and 1.5 x today's traffic load.

In order to reduce the training time, it was decided again to perform the sessions without CD&R tool before the sessions with CD&R tool.

Fast-time simulation results indicated that the Würzburg sector (WUR) was the most interesting sector to study as measured sector in the full simulations, see Figure 5.

Six current controllers from Eurocontrol UAC Maastricht participated in the August 2002 experiment, each acting as tactical and planner controller. All six controllers had also participated in the ground part-task simulations.

The same measurements were taken as during the ground part-task simulations.

#### Results

The ground full simulations confirmed the significant and dominant traffic load main effect on controller workload and acceptability. With traffic load of 1.3, controllers are operating to their limits with RSME ratings above "80" (close to "costing much effort") and acceptability rating "3.3" (slightly less than "acceptable").

Apart from the traffic load main effect, all other effects are highly insignificant ( $p > 0.50$ ). This means that there is no significant advantage of having the tool available to controllers. This is surprising and not in line with findings in the ground part-task simulations. There are 2 possible

explanations: (1) the characteristics of the sector affect the results or (2) training effect due to unbalanced experiment matrix.

The debriefing results reveal that the HMI is close to “acceptable”, but especially the aircraft labels should be improved further. The CRD is slightly worse than “acceptable” and should be improved. CD&R in general is undesirable and should be improved.

### **Results of Ground Simulation Experiments**

The results of the various ground simulations in INTENT show that traffic load is the dominant factor for controller workload. The CD&R tool, and with this aircraft intent, appeared to have little or no effect on controller workload.

The significant CD&R tool effect on controller workload found in the ground part-task simulations is believed to be caused by the training effect, which was less in the full-scale simulations.

The results of the ground full simulations have validated the results of the fast-time simulations, which found that the use of automated CD&R tools enabled by shared aircraft intent information has no significant effect on workload for both controllers.

### **Airborne Simulation Experiments**

This section will discuss the airborne real-time and fast-time simulation experiments. These experiments provide the airborne perspective for the overall validation objectives. The airborne fast-time simulations were part of the FLAME experiment that also encompassed ground fast-time simulations (June 2002). The airborne real-time simulations were subdivided over two phases, the part-task experiments, which were performed in March 2002; and full simulations, which were performed in August 2002.

Before discussing the experiments, a brief overview will be given of the validation platforms, the airborne operational concept (Free Flight) and some specific simulated aircraft systems.

#### **Airborne Validation Platforms**

The airborne fast-time simulations were performed with QinetiQ’s FLAME tool, which was already described above.

All airborne real-time simulations were performed on NLR’s Research Flight Simulator (RFS), shown in Figure 7. The RFS is a motion-base flight simulator that is mainly used for civil aircraft simulation studies. It consists of generic hardware and software for simulation of several civil aircraft types. This generic set-up makes it the ideal validation platform for Free Flight simulation experiments [10].



**Figure 7: NLR’s Research Flight Simulator.**

### **Free Flight Operational Concept**

Eurocontrol defines Free Flight as the flight through Free Flight Airspace (FFAS), [11]. In FFAS, aircraft equipment should enable information sharing with the surrounding traffic, and the airborne separation assurance responsibility by means of an Airborne Separation Assurance System (ASAS). In the airborne experiment in fact two types of ASAS systems were simulated, one basic system which only uses aircraft state information, and one advanced system that also incorporates aircraft intent information.

#### **Airborne Separation Assurance System**

When subdividing ASAS, one can identify at least the following subsystems [12]:

1. Airborne Surveillance and Separation Assurance Processing (ASSAP) system
2. Cockpit Display of Traffic Information (CDTI)
3. Alerting system

The CDTI and the Alerting system form the Human Machine Interface of ASAS to the pilots. The ASSAP system contains the logic for conflict detection, resolution (CD&R) and prevention.

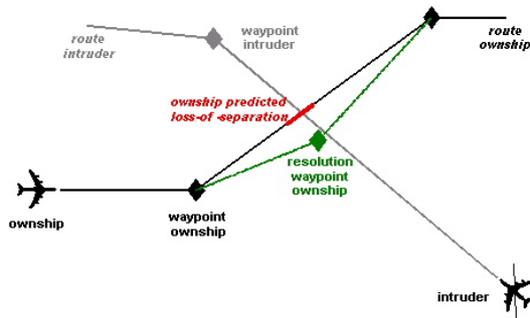
#### **State-based and Intent-based CD&R**

As part of the aircraft's ASSAP system, the conflict detection module detects only conflicts with aircraft for which an intrusion of the protected

zone takes place within a predetermined look-ahead time. This potential intrusion, or conflict, can be detected based on the aircraft state information (ground speed, track and vertical speed), or based on the aircraft intent information. This implies that there are in fact two types of conflicts, a state-based conflict and an intent-based conflict. Hence, calculated resolution advisories must match the type of the detected conflict. The conflict resolution module therefore makes a distinction when calculating and presenting resolution advisories.

For state-based conflicts the resolution module uses the Modified Voltage Potential algorithms [13], a method based on force field algorithms. The resolution advisory resulting from this method is presented on the CDTI as a resolution heading and vertical speed change. The aircrew can resolve the conflict by implementing one or both of the suggested state changes.

For intent-based conflicts the resolution is calculated and presented as an amendment to the active route. Figure 8 shows a conflict situation in which the ownship has detected a conflict using the intent-based conflict detection method. It is clear from the conflict position (i.e., the highlighted loss of separation) that the method has taken into account the intent (flight plans) of both aircraft. Based on the conflict geometry and the aircraft flight plans, the resolution module can now determine a route change that will resolve the conflict. The figure illustrates how the addition of a resolution waypoint resolves the conflict in the horizontal plane. This horizontal resolution includes automatically a recovery manoeuvre, represented by the leg after passing the resolution waypoint. Another option of resolving this conflict would be an altitude change in the flight plan of the ownship, as shown in Figure 9.



**Figure 8: Horizontal Intent-based Resolution.**



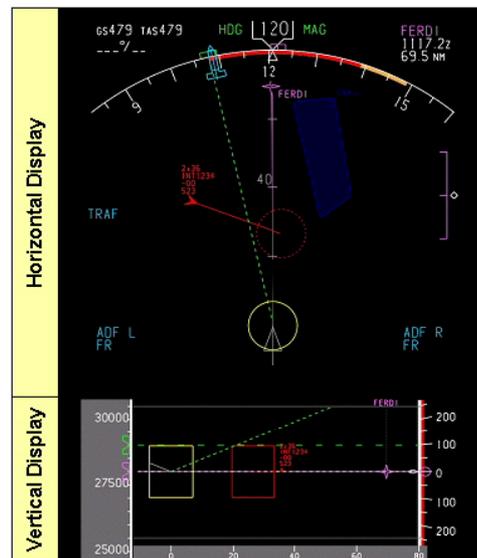
**Figure 9: Vertical Intent-based Resolution.**

**Conflict Prevention**

The purpose of conflict prevention is to provide pilots with additional situation awareness with respect to potential conflicts. Conflict prevention module determines if manoeuvres are conflict free. In the airborne simulation set-up conflict prevention indications were provided for both the state-based and the intent-based concept.

**Cockpit Display of Traffic Information**

The CDTI was integrated in the aircraft navigation display, and extended with a vertical display as shown in Figure 10.



**Figure 10: CDTI display.**

**Part-task Simulation Experiment**

The part-task simulations main objective was to generate data for pilot workload models and to assess the acceptability of the concepts.

**Experiment Design**

A 4x3 within-subjects design varied the following factors:

- 4 operational concepts: State-based with 5 minutes look-ahead time, Intent-based with 5, 10 and 20 minutes look-ahead time.
- 3 traffic loads: 1x, 2 x and 3 x today's traffic

A total of twelve experiment sessions were run per subject crew. The pilots were asked to fly an ASAS equipped aircraft on a pre-programmed Flight Management System (FMS) route and to be responsible for the separation with other aircraft.

A balanced experiment matrix was designed, which required ideally eight crews to participate. However, simulator availability allowed only six crews, causing a slight unbalance. Unfortunately the data gathered for crew 1 was considered not useable (data logging problems) and therefore, results are based on five crews.

The experiment consisted of a flight from London Heathrow (EGLL) to Munich (EDDM). The flight started at cruise altitude (FL280) just before the Belgian coast, with a planned route to Munich already implemented in the FMS. The route was guideline and determined by “the airline”, but since the flight was performed in FFAS, this route could be freely altered by the crew. The only constraints were some active SUAs, which were clearly depicted on the CDTI. The geographic area crossed and SUAs active were the same as in the ground part-task experiment.

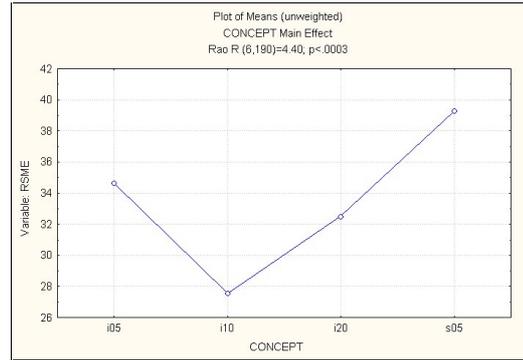
Traffic samples were created for traffic density 1, 2 and 3. In these traffic samples, all traffic avoided the active SUAs.

**Measurements**

The measurements focussed on human operator model parameters, workload (RSME), acceptability, flight efficiency and safety. For this purpose, the experiment was recorded on video including cockpit communication, and all cockpit button selections were logged. Questionnaires were taken after each run and at the end of the experiment. Moreover, ISA measurements were performed by pressing a button on the Control & Display Unit (CDU).

**Results**

Analysis of the measurements shows that both the state-based and the intent-based concepts are considered workable and acceptable (or better) for all traffic loads. Figure 11 illustrates that the intent with 10 minutes look-ahead time results in the lowest workload.



**Figure 11: Concept Effect on RSME for all traffic loads**

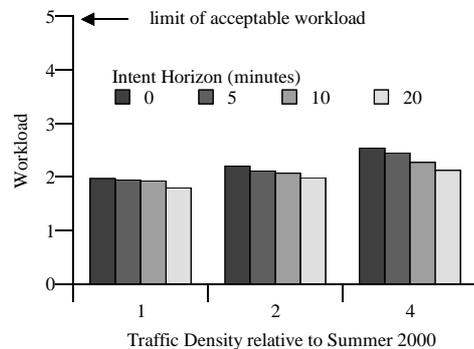
The traffic loads had a significant effect on the RSME. Nevertheless, ratings for all traffic loads were below 50 (“Costing some Effort”).

Debriefing results indicated the intent-based system as a preferred solution. Nevertheless, the option to fall back in the state-based mode, as was available during the experiment, was considered as a required back up (“don’t leave home without it”).

The ISA measurements were used to derive workload models for the aircrew [6], which were input to the Fast-time Simulation experiments.

**Fast-time Simulation Experiment**

Comparable to the ground simulations, the airborne results were used for fast-time simulations using the FLAME tool [14]. During these simulations workloads were computed for the Pilot Flying (PF) and Pilot Not-Flying (PNF) in the airborne CD&R operational concept, using the derived workload models. The 95th percentile of workload observations was estimated as described for controller workload above. Results for the PF are shown in Figure 12 (similar results for PNF).



**Figure 12: 95th Percentile of PF Workload.**

## Full Simulation Experiment

The main objective of the full simulations was to validate the fast-time results and to gain additional confidence for drawing conclusions.

Part-task and fast-time simulations showed that traffic loads up to 3x today were manageable. Results were promising so it was decided to expand the experiment domain by shifting focus from the cruise phase to the descent and climb phases. It was expected that workload ratings and acceptability would significantly rise and challenge the state-based and intent-based concepts.

Part-task simulations clearly indicated the effect of the traffic intent information level. It was therefore decided to only compare the state-based system, using 5 minutes look-ahead time, with the intent-based using 10 minutes look-ahead time. Lesson's learned from the previous experiment were incorporated in the CD&R system, and enhancements to the HMI were made

### Experiment Design

A 2x2x3 within-subjects design varied the following factors:

- 2 operational concept – state-based ASAS with 5 minutes look-ahead time, Intent-based ASAS with 10 minutes look-ahead time
- 2 flight phases – climb and descent
- 3 traffic loads – 1x, 2 x and 3 x today's traffic

Again a total of twelve experiment sessions, divided over two days, were run per subject crew.

Two experiment flights were flown, one for the climb phase and another for the descent. The first flight was from Frankfurt (EDDF) to New York (KJFK). It started in the climb phase at FL120, with a flight plan to New York already implemented in the FMS. Free Flight Airspace was assumed over Europe above FL100. The flight included the climb-out to cruise level (FL330) and part of the cruise flight.

The second experiment flight was from New York (KJFK) to Frankfurt (EDDF). This flight started in the cruise phase at FL390 about 10 minutes before top-of-descent, with a flight plan to Frankfurt already implemented in the FMS. This second flight included a part of the cruise and descent towards Managed Airspace (FL100).

### Results

Analysis of measurements reveals that the traffic load has a significant effect on the pilot workload and acceptability. Moreover it is

confirmed that workload significantly rises with respect to cruise flight. Nevertheless, traffic loads 1 and 2 are still considered to be workable, with RSME ratings below 50 (“Rather effortful”) and acceptability ratings of 3 (“acceptable”) or better. Traffic load 3 seems to become a problem with RSME rating towards “60” and acceptability ratings slightly less than “acceptable”.

Another significant result is shown in Figure 13. The figure illustrates that the workload for both concepts is lower in descent phase of flight. The same result is found for the acceptability. This effect is surprising, since it was expected that descending, (horizontally) converging flights would generate more workload than climbing, diverging flights. However, climbing flights appear to be vertically converging towards the popular cruise levels, an effect which appears significant.

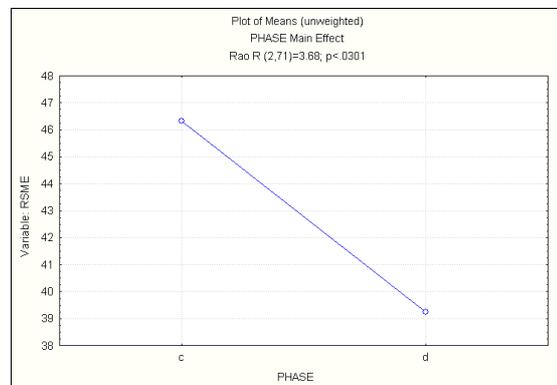


Figure 13: Flight phase effect on RSME.

Finally, a surprising result is that there was no significant concept effect on the workload. This is explained by the fact that intent-based CD&R “blocks” more airspace (combination of look-ahead time and conflict prevention), resulting in often fall-backs to state-based CD&R.

## Results of the Airborne Simulation Experiments

All tested flight phases and traffic loads were considered workable and acceptable (or better). The highest workload scores were gathered, as expected, in the climb and descent trials with 3 times the current traffic density. The intent-based ASAS with 10 minutes look-ahead time resulted in the best workload and acceptability scores in the part-task simulations; however this concept effect was not validated in the full simulations. Despite this, the subject crews in general “preferred” the intent ASAS and all pilots considered the

availability of state-based CD&R in the ASAS as a “required” back up mode.

## Conclusion

The project has explicitly chosen to investigate the effect of exchanging aircraft intent information on airspace capacity. The CD&R tool for the controller, as tested on various core European en-route sectors (roughly 100 nm<sup>2</sup>), was found to have little or no significant result on controller workload, and thus on airspace capacity. The airborne functions including intent information also did not provide significant increased airspace capacity, compared to the airborne state-based reference. However, conflict detection and resolution systems based on intent information are preferred over state-based systems, both on the ground and in the air.

Workload models for controllers and pilots have been derived. The controller workload model is dominated by the number of aircraft in the sector, the pilot workload model is dominated by the number of conflicts.

Ground simulations have found that unstructured routes do not only provide better flight efficiency, as expected, but also lower controller workload, especially when the ground CD&R tool was available. This indicates that sector size and characteristics (military areas, route structure) may be a factor for the successful introduction of advanced CD&R tools for controllers.

Fast-time simulations have shown that systems based on intent information are more efficient in terms of time, distance and fuel than systems based on only state information, both in ground and airborne concepts. This suggests that although exchanging aircraft intent information from an airspace capacity point of view might not be useful, it might be very beneficial from a flight efficiency point of view. Moreover, exchanging aircraft intent information for traffic separation assurance might be very valuable from a safety perspective, both in ground and airborne concepts.

The comparison between the results for controller workload and those for pilot workload, as tested in the project, is interesting: whereas controllers become overloaded at about 1.5 times the summer 2000 traffic density, pilots are still not overloaded at 3 times this density. This comparison suggests that, in the long term, ATM systems based on concepts where aircrews have the primary responsibility for separation are likely to offer

several times the capacity of those based on ground control concepts. Data on flight efficiency shows that additional fuel rather than pilot workload will be the factor that ultimately determines the traffic handling capacity of systems based on airborne separation concepts.

## References

1. MAEVA, April 2001, *A Master ATM European Validation Plan, “Validation Guideline Handbook”*.
2. Farges, J.L., A. Nuic, R. Ruigrok, October 2002, *Use of master Air Traffic Management (ATM) European validation plan (MAEVA) guidelines in the INTENT project*, THEATRE workshop, Bretigny.
3. Magill, S.A.N., 2001, *INTEGRA Metrics and Methodologies: Traffic Sample Generator User Guide*, EUROCONTROL, Brussels.
4. Magill, S.A.N., 1997, *Trajectory predictability and the frequency of conflict-avoiding action*, Confederation of European Aerospace Societies (CEAS) Conference, Amsterdam.
5. Magill, S.A.N., 1998, *The effect of direct routing on ATC capacity*, 2nd USA/Europe ATM R&D Seminar, Orlando, FL.
6. INTENT project, November 2002, *Results of real-time and fast-time simulations*, D2-3.
7. Eriksen P., Bonnier M, May 2001, *Eight-States Free Route Airspace Project Large Scale Real Time Simulation South Scenario*, EEC report no. 365.
8. <http://www.statsoftinc.com/>
9. Jain, R. and I. Chlamtac, 1985, *The P2 Algorithm for dynamic calculation of quantiles and histograms without storing observations*, Com. ACM, Vol. 28 No. 10.
10. Valenti Clari, M.S.V., R.C.J. Ruigrok, W.W.M. Heesbeen, J. Groeneweg, 2002, *Research Flight Simulation of Future Autonomous Aircraft Operations*, Proceedings of Winter Simulation Conference 2002, San Diego, USA.
11. Eurocontrol, 1999, *Operational Concept Document (OCD)*, EATCHIP, version 1.1.
12. ICAO, July 2000, *ASAS Circular*, SICASP.

13. Hoekstra, J.M., 2001, *Designing for Safety, the Free Flight Air Traffic Management Concept*, NLR-TP-2001-113, Amsterdam, the Netherlands.
14. Magill, S.A.N., P.A. Platt, October 2002, *A Fast-time Simulation Study of Shared Aircraft Intent Information*, 21st Digital Avionics Systems Conference, San Diego, USA.

## Keywords

Aircraft intent, airspace capacity, air traffic management, controller tools, airborne separation assurance, free flight, flight management system, ADS-B.

## Biographies

**ROB RUIGROK** ([ruigrok@nlr.nl](mailto:ruigrok@nlr.nl)) is a research engineer at the flight mechanics department of the National Aerospace Laboratory in Amsterdam, the Netherlands. He graduated in 1992 at Delft University of Technology on the design and analysis of automatic landing systems. After graduation he joined NLR where he is currently the project co-ordinator of the INTENT project and NLR project leader of the Mediterranean Free Flight project.

**MARIO VALENTI CLARI** ([valenti@nlr.nl](mailto:valenti@nlr.nl)) is a research engineer at the National Aerospace Laboratory in Amsterdam, the Netherlands. After his graduation from Delft University of Technology in August of 1998, he joined NLR and has since been involved in several international research projects dealing with Free Flight and future Air Traffic Management systems (INTENT, Mediterranean Free Flight, NLR/NASA Free Flight).