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FOR THE SAFETY OF AIR NAVIGATION

EUROCONTROL

EIGHT-STATES FREE ROUTES AIRSPACE PROJECT
Human Performance Measurements - Summary Report

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Abstract

A requirements on the Eight States Free Routes Airspace Project (FRAP) Feasibility Study is the controller impact assessment. A series of human performance measurements were conducted. The following report summarises the results according to major issues and themes uncovered. Along with each of the major themes, supporting evidence is provided. Supporting evidence is drawn from objective measurements (e.g. eye tracking measures) as well as more subjective data (e.g. survey and debrief notes).

On the basis of human performance measurements, three broad areas of requirements are identified: system support (tools), airspace redesign, and training. It is concluded that, although new tools, sectorisation and working methods will require some new skills (and therefor training challenges), training must also, at least as importantly, emphasise for controllers new knowledge and attitudes about ATC under FR. Beyond establishing the essential human performance feasibility of FR, where the human performance measurements seem most valuable is in identifying the specific areas (e.g workload, monitoring) in which controllers' attitudes do not agree with the objective data—in short, exactly those areas most critical for knowledge training.

Keywords

Free Routing	ATC	Workload	Human Factors
Physiological	MTCD	FRAP	FRAC
Communication	Teamwork	Role	System Support
Training	Acceptance	Sectorisation	Military

Contact Person	J. KJÆR-HANSEN	**Unit**	DIS/HUM
Authors	B. G. HILBURN, H. NIJHUIS and M. JOOSSE (NLR)		

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EUROCONTROL
EATMP Infocentre
96 Rue de la Fusée, B-1130 BRUSSELS
Tel: +32 (0)2 729 5151, Fax: +32 (0)2 729 9984
Open 08:00h - 15:00h UTC Monday-Thursday.
eatmp.infocentre@eurocontrol.int

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EXECUTIVE SUMMARY

From November 1999 to February 2001, EUROCONTROLs Free Route Airspace Project (FRAP) conducted a series of real time simulations at the EUROCONTROL Experimental Centre (EEC) in Bretigny into the concept of free route operations over eight northern European states. As part of this project, a series of human performance measurements was conducted, in parallel with real time simulations. The following report summarises the results of these human performance measurements. Results are summarised according to major issues and themes uncovered. Along with each of the major themes, supporting evidence is provided. Supporting evidence is drawn from objective measurements (e.g. eye tracking measures) as well as more subjective data (e.g. survey and debrief notes).

On the basis of human performance measurements, three broad areas of requirements are identified: system support (tools), airspace redesign, and training. It is concluded that, although new tools, sectorisation and working methods will require some new skills (and therefor training challenges), training must also, at least as importantly, emphasise for controllers new knowledge and attitudes about ATC under FR. Beyond establishing the essential human performance feasibility of FR, human performance measurements also seem to have been valuable in helping identify the specific areas (e.g. workload, monitoring) in which controllers' attitudes do not agree with the objective data—in short, exactly those areas most critical for knowledge training.

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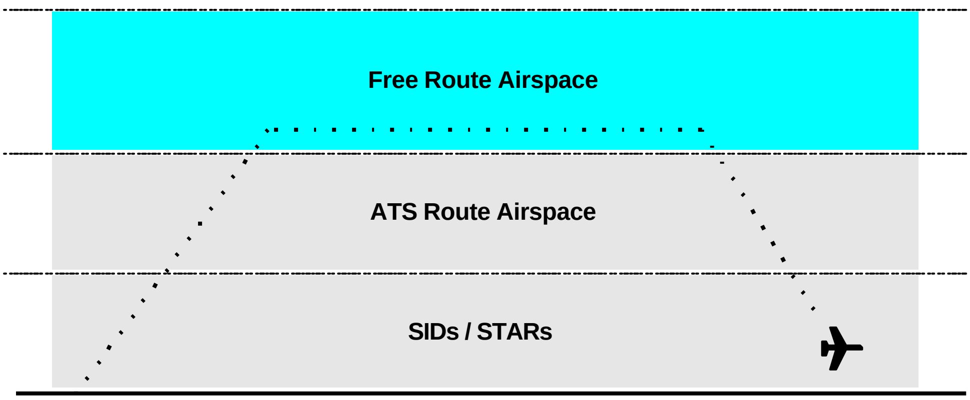
1. INTRODUCTION

1.1 Free Routing

Traffic in European airspace is expected to double over the next two decades. Free Routing (FR) is being proposed as one means to accommodate this predicted growth. Under FR, aircraft in upper air space (UAS) would be permitted greater flexibility in flying direct routes (i.e., without reference to the current ATS network) than is currently the case. As shown below, the Free Route Airspace Concept (FRAC) envisions keeping the current route structure (SIDs/STARs, ATS Routes) below the lower FR agreed flight level. Upon entering FR airspace, aircraft would be cleared to fly direct requested routes between FR entry and exit points. Exit from FR airspace would involve re-entering the ATS route structure and STARs.



The Free Route Airspace Concept

The Eight States Free Route Airspace Project (FRAP) is a collaborative effort by the civil and military ATC authorities of Belgium, Denmark, Finland, Germany, Luxembourg, the Netherlands, Norway, and Sweden. It seeks to lay an implementation plan for FR within northern Europe, by realising the following specific goals:

- Performing a feasibility assessment of FR;
- Demonstrating the Free Route Airspace Concept;
- Defining the procedures and support tools needed for FR;
- Developing a safety case for FR.

As part of this effort, EUROCONTROLs Free Route Airspace Project (FRAP) conducted a series of real time simulations at the EUROCONTROL Experimental Centre (EEC) in Bretigny, from November 1999 to February 2001, into the concept of free route operations over the eight previously mentioned states. A series of human performance measurements was conducted in parallel with these real time simulations. The following report summarises the results of these human performance measurements. First, this report shall review some of the potential human performance issues in free routing, and describe the measurement techniques used in the real time simulations. It will next present results from the series of simulations. Finally, this report will synthesise from these results the main lessons learnt for development of the Free Route Airspace Concept (FRAC).

1.2 Human Factors Issues in Free Routing

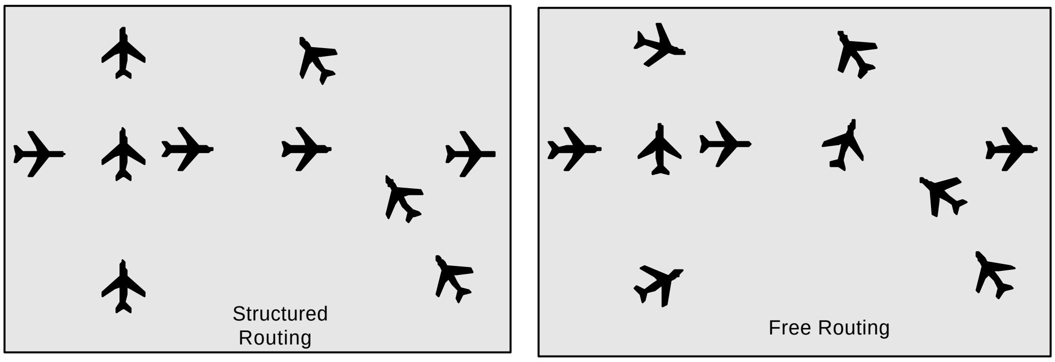
Free Routing (FR) is expected to provide benefits in terms of increased capacity, decreased number of airborne conflicts, cost savings to airspace users, and enhanced flexibility. FRAP intends to provide these benefits without avionics retrofits (that is, basic RNAV capability is sufficient for participation). Clearly, however, the evolution toward a mature FR concept involves more than simply abandoning the ATS structure. FR would represent a dramatic evolution in ATM, and would present serious operational, technical, and even political challenges, and would carry implications for airspace definition, automation tools, training, selection, and controller working methods and procedures. Many current ATM conventions (such as the notion of fixed sector boundaries) would become quickly obsolete. Before FR can be introduced, a number of questions must first be answered. Amongst the most urgent of these are questions that relate to human factors.

Under likely FR scenarios, the controller would continue to play an important (albeit altered) role. This new role raises a number of potential human performance problems, including:

- Workload extremes (either underload or overload);
- Monitoring (conflict detection) problems;
- Situation awareness (SA) deficits;
- Difficulties in error recovery;
- Transient overload effects (as they relate to strategies and task performance); and
- Changes in control strategy, or team interaction.

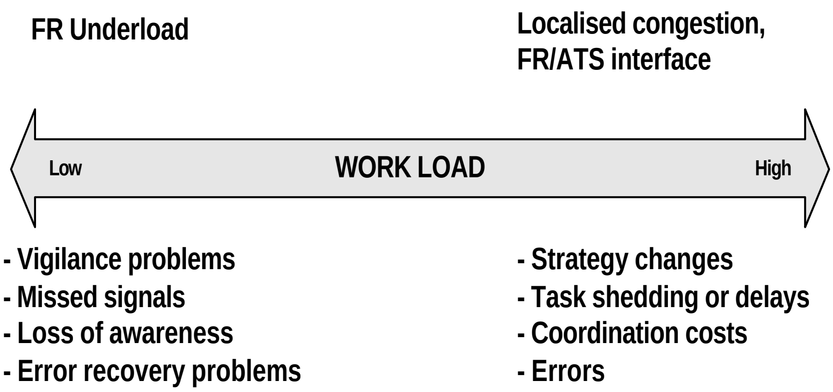
As an example of how profoundly FR could impact ATC human performance, consider how controllers' monitoring (i.e. conflict detection) performance could be influenced by Free Routing. One of the most salient characteristics of FR would likely be the absence of defined ATS airways for en route traffic. The current traffic pattern of en route aircraft (i.e., navigation via defined airways) limits the number of points at which losses of separation might occur. It is therefore reasonable to speculate that the presence of such an airway structure facilitates the controller's monitoring for separation conflicts.

Consider the following simple diagram, which depicts the principles of structured and free routing in en route airspace. Assume that all aircraft are at the same altitude. The diagrams are identical, except that the headings of four (of the ten total) aircraft have been changed under FR. Notice how much more difficult this makes the task of anticipating traffic conflicts. Under structured flight, with defined airways, there are a limited number of intersections at which conflicts can occur. Indeed, the historical reasons behind the current-day fixed route structure have more to do with human limitations than with technical or procedural concerns. Under FR, monitoring for losses of separation is now a potentially daunting task for the controller.



Monitoring for losses of separation under structured (left) and free routing (right)

ATC can be a very demanding job, and the assessment of ATC workload has often focused on the possible overload condition. Indeed, operational data support the view that ATC overload poses a very real threat to air safety. Although design efforts usually focus on the task over-load condition, operational and theoretical evidence reveal that **under-**load poses at least as large a threat to air safety. A review of ATC incidents in Canada (Stager, 1991), for example, showed that most occurred during low or moderate traffic load and normal traffic complexity. Similar data have emerged from studies of US ATC operational errors (Redding, 1992). The suggestion has been made that controllers can adapt to heavy traffic peaks, but become error prone as traffic lightens (Fowler, 1980). It is generally agreed among the human factors community that either extreme of workload, high or low, has the potential to introduce serious (and very different types of) human performance problems. The following figure shows some of the potential causes and resultant human performance problems that can accompany either extreme of workload under Free Routing.



Some example causes (top) and effects (bottom) of workload extremes under FR

2. OBJECTIVES AND MEASUREMENT TECHNIQUES

2.1 Objectives and Scope of FRAP Human Performance Measurements

The Free Route Airspace Concept has been developed on the basis of input from civil and military ATS service providers. Feasibility of the concept has been assessed over the last two years through a combination of rapid prototyping, safety modelling, cost-benefit analysis, and simulation trials. A series of four small-scale, and two large-scale, real time simulations were conducted at EUROCONTROL Experimental Centre, Bretigny. The general goals of the parallel human performance measurements were to assess the workload and other human performance implications of FR, especially as they relate to training and system support issues.

2.2 Research Questions

In order to draw meaningful lessons with regard to the system support and training requirements for FRAP implementation, the series of human performance measurements posed a number of research questions. Given the slight difference in focus for each of the realtime simulations, there were obvious differences in the research questions each asked. The following list summarise the major research questions across the entire series of simulations:

- How does FR influence overall controller **workload**, as assessed through both objective psychophysiological indicators and subjective self reports?
- How tolerant is controller workload to **transient taskload peaks**, as introduced through scripted nominal (e.g., traffic fluctuations) and non-nominal (e.g. diversion requests) events?
- What **strategies** do controllers employ to handle traffic overload (e.g., holds, vectoring, changes in RT communications), and how do these differ between ATS and FR scenarios?
- What **error recovery** methods do ATCos use, as revealed through post-test verbal protocols (i.e., “mental walkthroughs”)?
- Does FR influence **monitoring efficiency**, in terms of both response time and hit rate (accuracy) in detecting scripted non-nominal events?
- Does **ATCo acceptance** of FR concepts, as assessed through post-session surveys, reveal potential problems?
- Does FR seem to influence **team aspects** of ATC (e.g. role changes between EXE and PLC)?
- Is there any observed difference in overall **system efficiency** (in terms of, for instance, the number of vector commands)?

- What lessons can be drawn for **system support** (in terms of conflict detection, co-ordination, and flight planning)?
- What implications can be drawn for **selection and training** of future ATCos?

2.3 Measurement Techniques

2.3.1 Heart Rate Variability (HRV)

An electrocardiogram (ECG) signal was measured through electrodes stuck to the chest (left and right) and to the sternum. The R-wave in this ECG signal was detected by a wave form detection device, the so called Groningen Trigger, and fed into a locally logged computerised data recording device (Vitaport), which was programmed to measure the inter-beat interval (IBI) between R-waves. Variance in the IBIs can be revealed with spectral analysis. In general, spectral analysis of IBIs will produce three distinct frequency components-- a low frequency band, a mid frequency band and a high frequency band. Mental workload affects the mid-frequency band in such a way that the power in this part of the spectrum decreases with increasing mental workload. Possible artefacts, for example caused by breathing, speech, and muscle activity were factored out of the measurements.

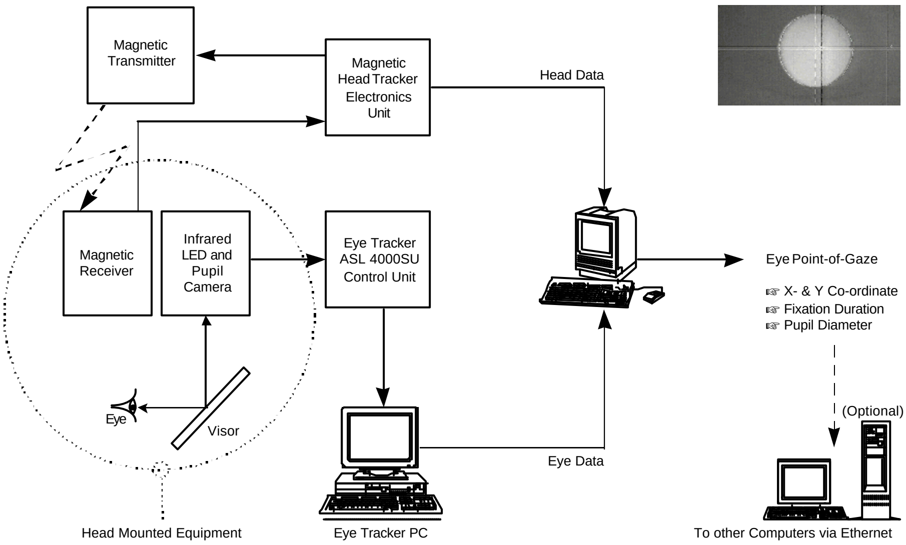
2.3.2 Gaze and eye tracking

GazeTracker® is a combined head / eye tracking system that records point-of-gaze and pupil diameter / blink data in real-time. It uses the “bright pupil” technique to determine the pupil-to-cornea reflex angle, and corrects for head movements through a magnetic orientation sensing system. Unlike older systems, which required that a recorded image from a “scene camera” be analysed with respect to line of gaze, and digitised post hoc frame-by-frame, this system provides the following information in real time, with a sampling rate of 50 Hz:

- Point of gaze, expressed in X and Y co-ordinates relative to the viewing plane.
- Fixation dwell time, in milliseconds.
- Millisecond-accurate time stamp (fixation start/stop time), to permit referencing to simulation events.
- Pupil diameter, which can be converted into micrometers.
- Surface identification, for translating pre-defined planar co-ordinates into viewing surfaces (e.g., separate static elements of an ATC workstation).

GazeTracker® consists of component eye tracking, motion tracking, and calibration/pre-processing subsystems. The eye tracking system is controlled by a dedicated AT class 486 computer. The Applied Series Laboratories 4000 eye tracker, together with associated optics, is affixed to a helmet. Corneal reflection is obtained using an infrared LED whose beam is directed coaxial with the viewing axis of the pupil camera. A sub-miniature video camera captures at a rate of 50 Hz the image of both the corneal reflection and the pupil. Pupil centre is determined through software. The angular difference between corneal reflection and pupillary axis, when corrected for head position and location, provides line-of-gaze. Fixation point, expressed in X and Y surfaces on the viewing plane, is then written to data file. A magnetic field disturbance system incorporates a fixed reference transmitter, affixed to a stationary surface near the participant, and a small head-mounted receiver, to track head position and orientation, with a maximum resolution of .3 cm for position and .5

degrees for orientation. The following two figures, respectively, show a functional schematic of the GazeTracker system, and a photo of the system in use during one of the FRAP realtime simulations.



Functional schematic of the GazeTracker® eye tracking system

ECG and eye tracking systems in use during a FRAP realtime simulation.

2.3.3 Questionnaires

Three different questionnaires were administered. In addition to basic demographic data, these collected data on controllers' attitudes (both preconceptions, and attitudes after exposure to Free Routing), knowledge, and skills. A Pre-questionnaire, filled out before the experiment started, contained background questions (age, years of ATC experience, mother tongue, experience with free routing and experiments). After each experimental session, a 'Session Questionnaire' was handed out, with questions about the realism of the simulated traffic, levels of safety and service that were provided, etc. At the end of the experiment, controllers were surveyed via questionnaire on their thoughts about free routing and the experiment.

2.3.4 Subjective workload measures

The FRAP realtime simulations used two subjective (i.e. self report) workload measures: the NASA Task Load Index (TLX), a broadly accepted multivariate instrument used in various settings; and the Instantaneous Self-Assessment (ISA). The ISA is a technique originally developed by the UK Civil Aviation Authority to evaluate controllers' subjective workload, through periodic self-report. As configured for this experiment, each control position was equipped with a small box containing 5 buttons, with labels ranging from "Very High" to "Very Low." At five-minute intervals throughout the test session, the controller was prompted by a flashing red light to press one of five buttons corresponding to his perceived workload during the previous five minutes.

2.3.5 Group discussions

At the end of each day, a group discussion was organised in which each controller and several operational and experimental experts participated. Each day, a different aspect of free routing was discussed. These were important sessions for eliciting discussion on subtle aspects of the FR concept, and allowed controllers to share observations and experiences. Experimenters made notes on this process during the post-test group discussions.

2.4 Specific Measures

The following list summarises the main measures collected (or derived) from the series of realtime simulations:

- *Pupil diameter*—a measure of mental workload, which is generally seen to increase with increases in workload;
- *Dwell time*—the average time spent fixating a location, before moving gaze to a new location;
- *Blink rate*— in terms of blinks per minute, which generally decreases with increases with mental workload;
- *NASA TLX*- a multivariate, composite subjective workload measure;
- *ISA*— a univariate, periodic subjective workload measure;
- *Radio communication pattern*— average number and duration of ground-to-air radio calls;
- *Response time and recovery method*— average time between onset of a scripted non-nominal (e.g. radio outage, aircraft diversion request, etc) and the controller's response;

- *Survey responses* — to pre-test questionnaires and post-session questionnaires;
- *Anecdotal information*—quotes, stories and observations from controllers during debrief sessions, and informal chat sessions;
- *Heart Rate Variability*— defined as spectral power on the middle (.1Hz) frequency, a widely-measure of workload, which generally decreases with increases in mental workload;
- *Visual scan pattern*— a qualitative analysis of the pattern with which controllers scanned the plan view display, including the percentage of time that various elements of the screen were fixated;
- *Clearance type*— an indication of control strategy, a count and analysis was made of the clearances controllers tended to issue to aircraft;
- *Team communication*—by logging both the RT button/footswitch usage, as well as voice switch (VOX) activations, we could differentiate when controllers were communicating with aircraft, and when they were communicating with other controllers. This could also be combined with eye tracking data, to sharpen the definition of team co-ordination (e.g. was a controller looking at his PLC controller?);
- *Number of Short Term Conflict Alerts (STCAs)*—as an indirect measure of how safe and efficient a given traffic scenario was, we logged and assessed the number of system STCAs.

2.5 Overview of the Realtime Simulations

FRAP realtime simulations ran, again, between November 1999 and February 2001. The following table lays out the run dates of each simulation, as well as the general setup and broad objectives of each. Two types of simulations are distinguished: the *Short Scale Realtime Simulations* (SRTs) and the *Large Scale Realtime Simulations* (LRTs).

Simulation	Dates	Setup and Objectives
SRT-1	Nov-Dec 1999	FR v RN; General workload, safety issues
SRT-2	Jan-Feb 2000	FR v RN; non-nominals; training effect
SRT-3	May 2000	FR + tools (MTCD, APW); general workload
SRT-4	Sep 2000	Military; Non-nominals; anecdotal information
LRT-N	Nov-Dec 2000	Optimised FR airspace; Traffic Level; Tools
LRT-S	Jan-Feb 2001	FR v RN LRT; Tools

3. HUMAN PERFORMANCE FINDINGS

This section will briefly review the results of the FRAP human performance assessment, across the series of small and large scale realtime simulations. The following result sections are arranged thematically, and broadly categorised by human factors issue. Although results are not presented chronologically, reference is made to the supporting realtime simulation (e.g. SRT-1) as appropriate. Details of the relevant results can be found in the referenced simulation report.

3.1 Controller Acceptance of FRAC

Overall, controllers were decidedly positive in their survey responses toward Free Routing. They felt that FR procedures were easy to use, and permitted then to provide a better level of service (SRT1; SRT2). Concerns were raised about the presence of MTCD (SRT-3; LRT/N; LRT/S), and whether it in fact it suffered from both false alarms (SRT-3; LRTs) and, more dangerously, misses (SRT-3). Having said that, controllers felt that MTCD (or a similar tool) would be required for them to properly use FR (SRT-4; LRTs). Active TRAs also reduced acceptance both for the military and as more beneficial (in terms of potential capacity increase) than FR per se (SRT-4). Finally, concerns were also raised about the perceived effort required to monitor for separation conflicts under FR (LRT/S).

Controller opinion was more split on whether either monotony (i.e., does the job become more boring?) or safety benefited from Free Routing. Opinion was also sharply split on whether FR increased traffic capacity. For example, 100% of SRT-1 controllers agreed (at least slightly) with the statement that free routing enabled them to handle more traffic. In SRT-2, on the other hand, 77% of controllers disagreed with the same statement.

Military and civil controller acceptance both seem high (SRT-4). However, civil controllers in particular prefer to fall back into RN operations when Temporary Reserved Airspace (TRAs) become active.

One interesting opinion, voiced by at least two controllers in the same SRT, was that MTCD, although desirable, should not be seen as essential to implementing FR. Their feeling was that FR can provide benefits even in the absence of additional toolkits, and that FR should be permitted to come on-line (if only in limited usage) before fully capable MTCD could be deployed. It is not known what percentage of participating controllers would agree with the sentiment, but it raises the interesting possibility that, although controllers feel the need for additional tools (e.g. MTCD) for the full potential of FR to be realised, they also see the benefits of FR even in the absence of MTCD.

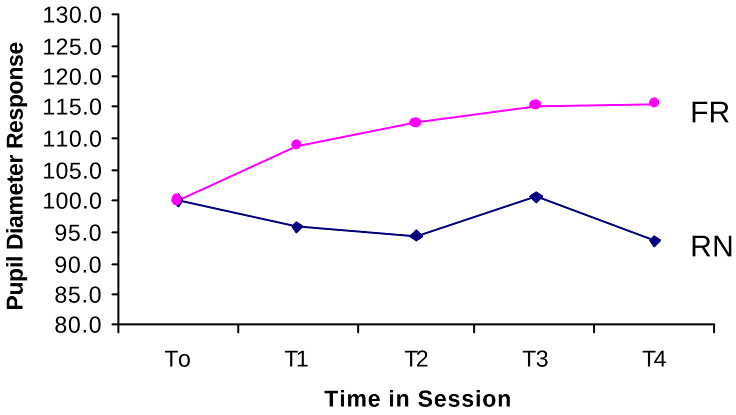
In summary:

- Controller acceptance of Free Routing was generally high, as evidenced by survey and anecdotal data;
- Controllers felt that FR would require MTCD (at least if the full benefits of FR were to be realised);
- Controllers worried that monitoring demands were excessive under FR; and
- There was a lack of consensus on how/whether FR would impact either ATM safety or job monotony.

3.2 Workload

Overall, Free Routing appeared to benefit workload. However, there were enough differences across simulations, and measurement techniques, to suggest that there were a number of possible secondary factors at play. For instance, SRT-1 results showed a clear workload decrease across the physiological measures. Four physiological measures were used, and averages were obtained for each of two sectors. For seven of these eight comparisons, workload was reduced under FR (relative to RN). One interesting trend from SRT-1, however, was that the benefit (in terms of workload reduction) appeared noticeably greater for one of the two sectors. Further, the benefit was greater for the one sector (of all tested during the series of FRAP realtime simulations) that is, arguably, most similar to FR operations in its current working methods (e.g. close EXE-PLC co-ordination, tactical PLC role, etc). A similar difference was seen in the same simulation (SRT-1) on how controllers from the two sectors monitored the PVD under FR and RN conditions. An additional point concerns the transfer of sector-specific knowledge from RN to FR in the same sector. Subjective workload data (SRT-2) suggest that there might be a cost of transferring from RN to FR operations in a sector that is overly familiar. These data, however, must still be confirmed through other means.

Although most of the simulations indicated a workload benefit (i.e. reduction) under FR, one simulation (SRT-2) in which the opposite occurred, provided an interesting possible insight. Unexpectedly (after the results of SRT-1 that showed clear workload benefits of FR), SRT-2 data showed equally clearly that RN resulted in lower objective (physiological) workload than FR conditions. Reasons for this result were speculated. More interestingly, there seems to be a positive feedback of workload—that is, high workload increases over time. This seems intuitive: as an ATC traffic scenario evolves it builds on itself in such a way that workload snowballs, and a hard situation becomes even harder over time. This is a potentially important argument for careful workload measurement: that any workload differences are likely to snowball, and magnify themselves over time. This effect (from SRT-2) is shown below.



Average pupil diameter over time, RN versus FR conditions (from SRT-2).

One of the concerns in assessing workload under FR was the potential transient workload effects of non-nominal situations. That is, even if FR seemed to reduce overall workload, it could still be that workload under rare system malfunctions (e.g. a secondary radar outage) would be unacceptably high under FR. SRT-2 and SRT-3 provided differing pictures of this effect, and on balance no conclusion can be drawn. Although SRT-2 data showed a post-event increase in workload, the same increasing trend appeared under normal sessions (i.e. in which no scripted anomaly occurred). At the least, we can conclude that there was no reason to think that FR or RN would be any better, in terms of transient workload, in accommodating non-nominal events (such as a aircraft calling for a diversion). Subjective workload results showed no transient workload peaks (notice that the ISA provides 5 minute resolution of workload ratings) around the time of non-nominal events, in either route condition (SRT-4).

MTCD seemed to be an important factor in the observed workload levels (SRT-3; LRT/S). It seems that MTCD by itself was generally associated with higher controller workload (as assessed through both objective and subjective techniques). The presence of MTCD interacted, experimentally speaking, with the Route condition factor in such a way that workload benefits, when apparent, were generally observed only under baseline conditions, in which no tools were present (SRT-3; LRT/S).

In summary:

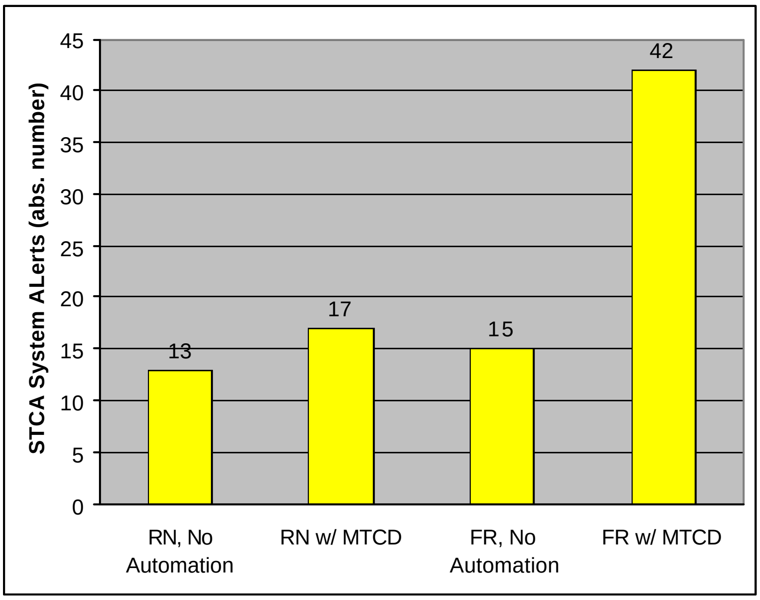
- Overall, FR appeared to benefit workload;
- Workload reduction seemed roughly equal for EXE and PLC;
- Subjective and objective measures sometimes disagreed;
- There were sector differences in workload benefit;
- There was no evidence of transient workload increase (i.e. after a non-nominal event);
- Workload differences under FR seem to magnify over time; and
- FR workload results were highly influenced by presence of MTCD.

3.3 Operational Errors

One of the most critical considerations in implementing FR is whether it will be as safe as RN operations. “Operational errors” are generally defined as situations in which aircraft separation standards are violated—that is, two (or more) aircraft pass within 5 nm laterally and 1000 feet vertically, under RVSM conditions. Notice the distinction between such losses of separation, and “human error” as will be discussed in section 3.4: human error may or may not result in a loss of separation.

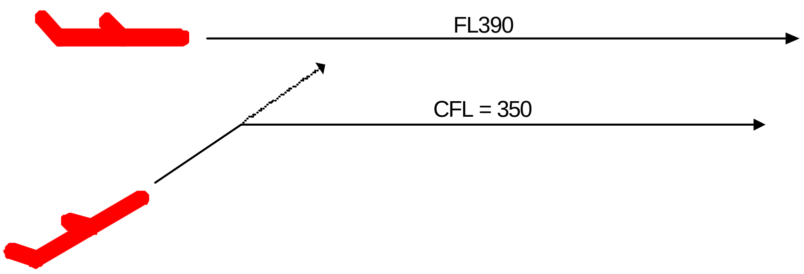
As is often the case in high fidelity simulations with fully-trained controllers, obvious losses of separation were too infrequent to provide meaningful data. Unfortunately for research purposes (but fortunately for those of us who fly regularly), critical ATC errors are simply too infrequent to provide much information. It was therefor decided to analyse the number of Short Term Conflict Alerts (STCAs), as an indirect measure of separation losses. Given that STCA algorithms are subject to bias (either by false alarming, or by failing to detect impending losses of separation), they can only ever serve as a proxy measure of safety. Nonetheless, assessing the number of STCAs could tell us something about how the entire controller-automation system was performing.

Data from SRT-1 showed that the total number of STCAS was 16% higher under FR than under RN. Although similar data were seen in LRT/S (i.e. more STCAs under FR than under RN), an interesting effect became clear from the LRT/S data: MTCD had a far more deleterious effect on number of STCAs than did Route condition. The combination of MTCD with FR, as shown in the following figure, resulted in an especially high number of STCAs. Notice that these results, which are shown in the following figure, exclude repeated alerts on the same aircraft (which could happen if two aircraft remained close to minimum separation for some period of time).



Number of system Short Term Conflict Alerts (STCAs), by Route and Automation condition (from LRT/S).

It must be stressed that differences in the occurrence of STCAs do not necessarily reveal problems in controller performance per se. Other factors that can contribute, to differing degrees, to the number of STCAs include differences in traffic closure geometries under FR, or incompatibilities between FR geometries and current STCA algorithms. For example, consider the following diagram, which shows one way in which an STCA algorithm can trigger a false alarm. Although the climbing aircraft has been cleared to stop its climb with adequate vertical separation from the cruise aircraft, the "dumb" STCA logic predicts (based on a simple extrapolation of current trajectory) a loss of separation between the two.



One hypothetical STCA false alarm scenario

Additional analyses (e.g. computing actual losses of separation, and comparing these events to the numbers of STCAs) should be performed, to determine whether observed Route differences were attributable to differences in either the number of actual separation losses (which implies human error), or to the false alarm rate of the STCA (which implies shortcomings in the STCA algorithm, or fundamental incompatibilities between the FR traffic scenarios and the current STCA algorithm).

In summary:

- Operational errors (i.e. losses of separation) were too infrequent to yield meaningful data;
- STCA alerts appeared more often under FR (especially when combined with MTCD). It is not clear whether this is a human performance issue per se, or an airspace or algorithm design issue;
- Additional analysis should be conducted on available simulation data to determine whether number of actual separation losses differed by route condition.

3.4 Human Error

EUROCONTROL's ongoing HERA project has spent two years developing a technique for identifying the mechanisms of human error in the ATM environment. Given sufficient data, the technique is capable of describing the nature of the error, the cognitive mechanisms underlying the error, and the associated environmental and contextual factors (c.d. EATMP HRT, in press).

As part of the HERA project, observational data were collected in parallel with the FRAP SRT-4 simulation in September 2000. The HERA effort in FRAP had the following objectives: First, to verify that errors could be captured on-line; and second, to compare two different HERA data collection approaches. During SRT-4, a human factors expert conducted over-the-shoulder observations during eight simulation sessions (each roughly 60 minutes long), and logged behavioural markers using a HERA paper-and-pencil instrument. For each observed error, the following data were noted:

- Brief description of the error;
- HERA categories;
- Error Type;
- Error Detail;
- Error Mechanism (EM);
- Information Processing (IP) Level;
- Recovery of error;
- Contextual conditions; and
- Any additional remarks.

In all, 22 errors were recorded over the approximately eight hours of observation. Nineteen of these were classified down to the most detailed level that HERA permits. Three of the 22 were only classified to the top level (that of observable behaviour). Of the nineteen classified errors, 10 (or 53%) were categorised as “perception/vigilance” errors. A smaller percentage was identified as “working memory” or “response execution” errors (both 16%), “long-term memory” errors (11%) or “planning/decision making” errors (5%). This result is captured in the table on the next page.

Perhaps the most critical goal of the HERA data collection was as a proof-of-concept, that the technique could be used in a realtime controller-in-the-loop simulation. Beyond that, it was thought that the results could be fed into the FRAP analysis in such a way that meaningful conclusions could be drawn about the factors under study in FRAP. These factors were as follows:

- Route condition (Free Routing versus Route Network)
- Organisation (Basic versus Advanced tools) As it turned out, logistical realities limited the HERA data collection to eight sessions, whose experimental conditions are defined as follows:

Traffic Sample	Route Condition	Organisation
T2	FR	Advanced
T1	RN	Advanced
T3	FR	Advanced
T5	FR	Advanced
T4	FR	Advanced
T3	FR	Advanced
T2	FR	Advanced
T1	RN	Advanced

Assuming that the traffic samples (T1, T2, etc) were fairly unique, the above design permitted no means to compare HERA results, in terms of the FRAP factors. That is, it was hoped that clear differences would emerge between the RN and FR conditions. Unfortunately, comparing results across route conditions requires comparing different traffic samples—a clear experimental confound.

Perception &Vigilance		**Working Memory**		**Long-term Memory**		**Planning & Decision Making**		**Response Execution**	
EMs		**EMs**		**EMs**		**EMs**		**EMs**	
No detection (visual)	8	Prospective memory failure	2	No recall of stored information	2	No decision or plan	1	Selection error	2
Misidentifi-cation	1	Forget to perform action	1					Incorrect information transmitted	1
Mishear	1								
IPs		**IPs**		**IPs**		**IPs**		**IPs**	
Out of sight bias	8	Memory capacity overload	3	Insufficient learning	2	Cognitive fixation (?)	1	Manual variability	2
Spatial confusion	1							Slip of the tongue	1
Stimulus overload	1								

In summary, the HERA data collection:

- Succeeded in its first goal of demonstrating that the technique could be used to identify controller errors during realistic human-in-the-loop simulations;
- As for the second goal (adding to the FRAP analysis), logistical limitations limited factorial analysis (i.e. analysis on the basis of relevant experimental factors) for the FRAP experiment.

3.5 Monitoring and Vigilance

Scripted non-nominal events (SRT-2; SRT-3; SRT-4) demonstrated no response time differences on the basis of route condition. That is, controllers responded just as quickly to unexpected events (such as an aircraft busting its assigned altitude), regardless of whether they were operating under FR or RN conditions. The limitations of this statement must be noted, however: it is not realistic, in a high fidelity simulation, to present controllers a sufficient number of non-nominal events (you cannot, after all, realistically present 10 aircraft diversions per hour) to satisfy strict experimental concerns. In short, the data are based on a limited number of scripted events.

Despite the fact that no response time difference was observed between RN and FR conditions, self-report data suggest that controllers were worried about the increased monitoring demands imposed by FR (SRT-4; LRT/N; LRT/S). For example, fully 95% of responding controllers in the two LRTs (same percentage in each) agreed that monitoring traffic under FR requires more attention than under RN. Further, controllers are also worried that monitoring for separation near the sector boundaries will be much harder under FR (e.g. 60% of LRT controllers agreed).

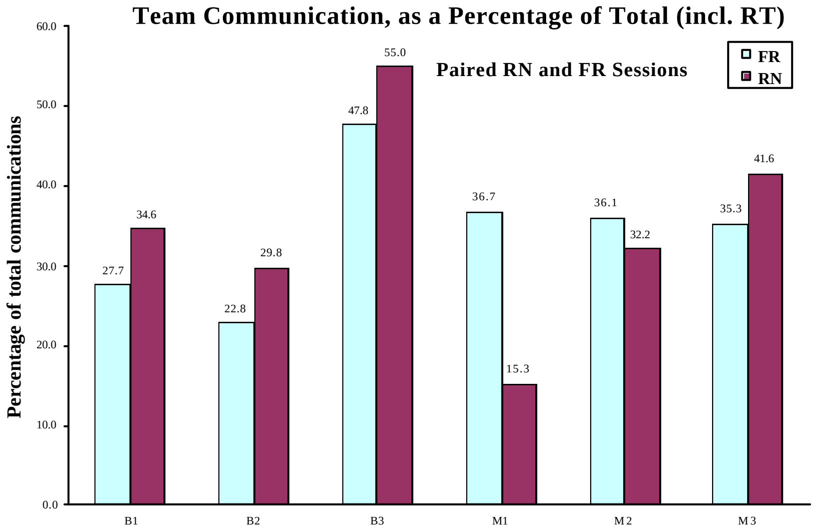
In summary:

- There was no evidence that monitoring for, and responding to, non-nominal events suffered under FR;
- However, survey data indicate that controllers are very concerned about the monitoring demands imposed by FR.

3.6 Intrateam Co-ordination and Communication

It has been speculated that FR can change the fundamental relationship within the Executive-Planner team, and force a shift toward more tactical operations, with both controllers essentially assuming the role of an EXE controller. Objective data on visual scan pattern (i.e. where controllers were looking) and the intra-team communication patterns (i.e. when they were talking to their partner) indicated that Free Routing both decreased the amount of intra-team communication (i.e. between EXE and PLC) and increased the percentage of time fixating the screen (LRT-S). SRT-1, on the other hand, found a slight increase in screen fixation time, but only for one of the two tested sectors. For the other sector (perhaps not coincidentally, the same sector previously mentioned as the one currently most similar to FR in its working methods), PVD fixation time actually decreased under FR. The following figure (LRT/S) shows how intra-team (i.e. between the EXE and PLC controller) verbal communication varied as a function of route condition and MTCD condition (absent versus present), for the LRT/S simulation.

Controllers in LRT/N noted that lack of an MTCD makes the need for a strong PLC more critical.



Intra-Team communication, as a function of route and MTCD condition (from LRT/S).

In summary:

- Free Routing appeared to decrease the amount of intra-team communication (i.e. between EEX and PLC);
- The influence of FR on screen fixation time was less clear, and might vary with other factors.

3.6.1 Roles of the executive and planner controller

Survey and debrief data were split on whether FR would introduce large changes in the roles of the EXE and PLC controllers. Controllers in SRT-2 felt that no large changes would be required, and that the current skill set would still be applicable. In other simulations, however, controllers reported having to blur the distinction, in their working methods, between the traditional EXE and PLC roles (SRT-3; SRT-4). It seems that under FR, controller pairs have to work more closely together, with the PLC controller assisting the EXE in tactical control, and tending to work off of the same screen (SRT-4). Opinions were expressed that, if the PLC assumed the role of joint problem solver, extra burden would be shifted to other colleagues. Overall, the issue seems a potentially important one, and one that should receive at least some attention in transition training.

It was interesting to observe the difference in how teams from the two SRT-1 measured sectors differed in their manner of team interaction. This was partly attributed to the use of paper strips in the Copenhagen sector. Dealing with these strips requires a great deal of attention from the planner. He therefore has little time to actively assist the executive. In the Maastricht sector (without paper strips), the roles of the two controllers are more intertwined. During the free routing scenarios, the Copenhagen controllers seemed to change their strategy, in that they worked more like the Maastricht controllers. The paper strips also seemed to be of less help to their jobs (ordering them in a meaningful way is almost impossible under free routing circumstances).

In summary:

- Objective (eye tracking and voice) data indicate that controllers under FR talk less within a team, and tend to focus more on the PVD;
- The tendency to focus on the PVD might be influenced by other factors;
- Some controllers expressed concern that the PLC might have to adopt a more tactical role under FR. This concern should be addressed in training;
- The degree of role shift is likely to vary by sector;
- Similarly, attitudes regarding team aspects of the ATC task should be addressed, as FR might have the potential to shift roles and responsibilities among colleagues.

3.7 Intersector Co-ordination

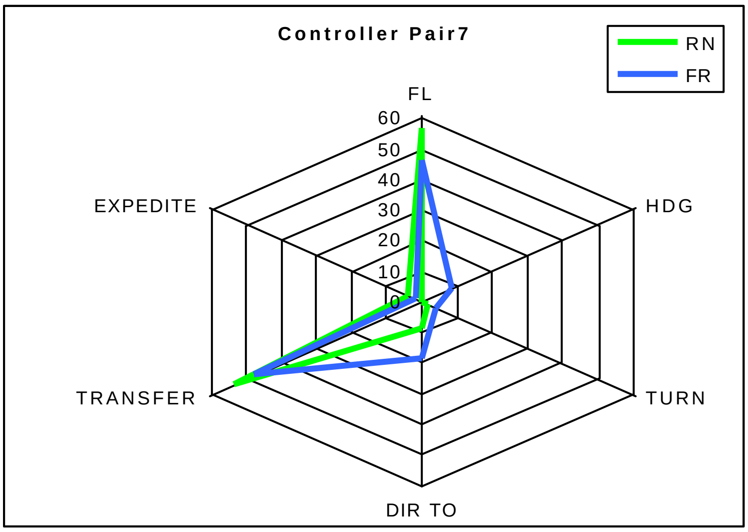
Several controllers also worried about inter-sector co-ordination (LRTs). How, for instance, could they ever give a heading to a point in a downstream sector. A related point concerns the role of the Planner controller: his role in FR is mainly seen as an early filter for conflict detection (few minutes before an aircraft enters the sector). The planner will also need a simple, intuitive way of co-ordinating electronically with adjacent sectors. The current co-ordination is not sufficiently intuitive. Other aspects of operations under FR that were identified as especially difficult were: Bringing aircraft back into RN airspace; and re-sequencing aircraft (e.g. before entrance to a RN sector, or before approach).

3.8 Control Strategies and RT Communication

It was clear c.f. section 3.5) that Route condition (as well as other factors) appeared to influence the pattern of communication within the EXE-PLC team. Further, FR seemed to influence the pattern with which controllers communicated with aircraft. In SRT-1, it was found that controllers tended to make fewer, albeit longer, calls under FR. The results of two later simulations, (SRT-3; LRT/S) both suggested that the presence of MTCD also had an influence on how often, and for how long, controllers would communicate with aircraft via RT.

In terms of the clearances that controllers actually issued under FR, one hypothesis had been that FR would force a move toward more tactical control. It was assumed that, if so, this would be observable by the pattern of clearances controllers tended to issue.

This analysis (LRT/S) showed several things. First, FR generally resulted in a higher number of DIRECT TO clearances than did RN conditions. This is hardly surprising, and one of the chief assumptions underlying Free Routing—namely, that aircraft can fly more direct routes. Another positive aspect of FR was the lower number of EXPEDITE (either climb or descent) commands issued than under RN conditions, for most of the controller pairs. This suggests that, overall, FR might have been less disruptive and tactical than RN conditions. This does not immediately agree with controllers' comments and debriefing data, which showed that (at least some) controllers felt that FR forced a more tactical mode of operation. Further, notice that FR was associated with more HEADING commands and TURN commands than was the RN condition, suggesting that, in fact, Free Routing did require more tactical intervention, at least in accomplishing lateral manoeuvres (notice that EXPEDITE commands were associated with either climb or descent commands).



Clearance type and count, by Route condition (from LRT/S).

In summary:

- FR appeared to influence the style of RT communications, and also the types of clearances issued;
- Despite controllers' subjective reports, there was no evidence from RT communications that FR was any more tactical than RN;
- FR might be associated with a different style of traffic handling, whereby heading clearances are used more often.

3.9 Recovery from Non-nominal Situations

The following non-nominal situations were inserted into test scenarios:

- Aircraft requires diversion to other airport
- Aircraft busts altitude
- Aircraft is on wrong frequency
- Aircraft is on wrong heading
- Aircraft is blocking entire frequency

Non-nominal situations were inserted in both the RN and the corresponding FR scenario. Each occurrence was scripted so as to occur at a comparable moment in corresponding RN and FR sessions. The consequences were observed and written down by the experimenter. Where necessary, the non-nominal events were discussed with the controllers after the simulation.

Results of both SRT-2 and SRT-3 showed no effect of route condition on recovery from the scripted non-nominal events. Although there was some evidence that transient workload in SRT-2 increased after non-nominal events, it appears that this was a general time-on-task effect (that is, the same workload increase over time was seen under FR, even within normal (i.e. "non-non-nominal") sessions). SRT-4 results showed no transient workload increase (over five minute intervals) around the time of non-nominals.

Further, there were no major differences reported in the strategies controllers use to recover from these non-nominal events, under either FR or RN conditions.

In summary:

- Controllers uniformly handled scripted non-nominal events without great difficulty;
- No strategy differences were found between route conditions in the strategies controllers use to recover from non-nominal events.

3.10 Co-ordination between Civil and Military Units

SRT-4 was the main simulation to focus on military controllers, and the potential for FR to impact the co-ordination between the civil and military sides. In SRT4 a limited number of military Windows (i.e. flight levels) was available. The military controller had to make sure that all military traffic stayed within this window. Civil control was responsible for keeping its traffic separated from the military traffic. In principle, civil traffic was allowed to enter the window, but the civil controller remained responsible for separation. On the basis of observational and self-report data, a few conclusions could be drawn from SRT-4. First, these procedures will force changes in the way the military controller works. He will work more like the civil side used to do before the introduction of free routes: leading traffic along airways. Civil control, on the other hand, would work more like the military in the past, with more freedom to route aircraft. Another consequence is a drop in the need for co-ordination. In the old days, civil controllers had to negotiate separation for each military aircraft. Now they only have to stay away from the window or stay clear of the traffic in it when passing through. In SRT-4, it was observed that silent communication between sectors was predominant. As a consequence few phone calls were made, and controllers could use the available time for other tasks. These procedures lessened the need for co-ordination between military and civil sectors.

Beyond the question of co-ordination between military and civil control, survey and anecdotal data were also informative regarding military controllers' acceptance of FR. Although FR was acceptable to both military (in the Belgian and Dutch airspace) and civil controllers, this was only true when no Temporary Reserved Airspace (TRA) was active. As soon as TRAs became active, civil controllers showed a strong preference for RN operations. SRT-4 data anecdotal data also suggested that civil controllers were very satisfied with the military FRAP implementation. Further, both civil and military controllers found the introduction of RVSM a bigger help in their jobs than the introduction of free routes (SRT-4).

In summary:

- Military controllers' acceptance of FR was generally high;
- Civil controllers' acceptance of a mixed civil/military scenario decreased when TRAs became active;
- FR can force a fundamental change in how civil and military controllers operate, with each becoming more similar to the other's current working methods (i.e. civil traffic might become less structured, but military traffic more structured).

3.11 Observational and Anecdotal Evidence

Objective measures such as pupil diameter indications of workload, or recordings of time spent per RT clearance, clearly only tell part of the story from simulations such as those for FRAP. As is often the case from realistic simulations like these, which use fully trained controllers, much of the most valuable information is obtained in the form of subjective reports (either through interviews, informal chats, or verbal walkthroughs after an event). This section roughly categorises some of the miscellaneous points gleaned from various anecdotal data, which were collected over the course of the FRAP realtime simulations.

3.11.1 Potential procedural voids under Free Routing

During the free routing simulations, particular procedures appeared to be lacking. During free routing, controllers will actually have to plan several sectors ahead (depending on the size of the free routing area and the position of the sector therein). Current procedures do not foresee such a situation. As a consequence it was not always obvious how to clear an aircraft as efficiently as possible (i.e. via the shortest route) to an exit point of the free routing area. “Direct” clearances were not always possible, because controllers do not know the waypoints in downstream sectors. Closely related to this issue is the lack of a procedure on how to bring a free routing aircraft back into the ATS route structure, after it exits Free Route airspace (either laterally or by descending beneath the FR floor altitude).

3.11.2 Controllers’ opinions of new system functionality

Controllers were asked if they would need additional functions in their current systems to compensate for the introduction of free routes (LRTs). Under FR, controllers sometimes have no good overview of the situation in the adjacent sectors. Controllers would like a certain buffer zone around their own sector in which aircraft are of concern to them (although not under control). The MTCD and STCA should also work on these aircraft (which will never be in their sector). Area proximity warnings would be nice, but might not be absolutely necessary, controllers felt.

3.11.3 Controllers’ opinions of resectorisation

Although strictly speaking outside the scope of the human performance measurements, the issue of airspace design was emerged from anecdotal data (either in debriefs or during between-session chats). It was clear (SRT-2) that some controllers strongly felt that the re-entry points between FR and RN airspace have to be optimised. Further, it seems that sectorisation must take into account current traffic movements, and not invite traffic streams that either verge on sector boundaries, or that converge at one joint boundary (e.g. a “four box” sector boundary).

Sector design will clearly have a large influence on the benefits realised under free routing. In parallel with the FRAP realtime simulations, an optimised FR sectorisation was created, on the basis of FRAP fast-time analysis. LRT/N, for instance, made use of such an optimised FR airspace. It was notable that one of the sectors that participated in the LRT/N simulations has been recently optimised for route network operations (at least through its own borders), and is therefore not keen to adopt a new FR sectorisation. Maastricht controllers, as another example, did not see much difference between their current daily work and the FR implementation. They have used their basic current working methods for more than 20 years. One major difference is, however, that under FR airlines can file a FR-flightplan.

Some of the various concerns raised regarding sectorisation under free route operations include, in no particular order, the following:

- A merging point of four sectors will cause excessive work for the co-ordinator;
- It must be ensured that aircraft do not exit and enter a sector repeatedly, which can cause a great deal of confusion;
- Military areas are difficult, because they block most of the possible advantages of FR;
- The split level between RN and FR operations can be a source of some disagreement;
- The entry and exit points (connecting FR and RN) need to be adapted, since they are crucial for the success of FR.

Overall, it was felt that the employed sectorisation (based on fast time simulations) was not ideal. Although it was agreed that dynamic sectorisation was not feasible, it was proposed to use a library of fixed sectorisations (e.g. based on the TRAs that are active or particular expected streams of traffic). The current CFMU, however, can probably not deal with such a level of flexibility.

Another observation concerned the inherent difficulty in comparing FR and RN operations, when the current day sector has been optimised for FR operations. For example, one controller noted that the sector in which he normally works is very busy. Under FR, his sector was split in two new sectors, which of itself (and quite apart from the issue of free routing) dramatically reduces his workload under FR conditions.

3.11.4 Controllers' opinions of paper strips

Controllers confirmed that paper strips are less relevant under FR than under RN, but still they would like to keep them (LRTs). This point underscores that cross-sector differences in controllers' current toolkit (and preferences) would influence the likely benefits of free routing operations. That is, it could be that controllers do not realistically assess the benefits of the tools with which they currently work. If moving to a FR like environment also involves the removal of tools (such as strips) to which they have become accustomed, they might be predisposed toward non-acceptance of the new concept (in this case, free routing). Further, this emphasises that changes in system support (such as stripless systems) fundamentally change how controllers operate (e.g. a tendency toward more tactical operations). This influence is independent of FR operations.

3.12 Summary of Human Performance Findings

Overall, controller acceptance of the FRAC, and FR operations, was quite high. Controllers were less positive, however, about the MTCD algorithm, as employed during these trials. Although controllers generally felt that a fully functioning MTCD would be necessary for the full benefits of FR to be realised, some controllers voiced the opinion that MTCD is not necessary for initial implementation of FR (perhaps on a pre-operational basis). Trials took place under RVSM operations, and controllers were generally more positive about RVSM itself, than FR, as a means of enhancing capacity.

Although controllers were concerned about monitoring demands under FR, there was no evidence of performance decline, or excessive workload demands under FR. In fact, overall, FR seemed to benefit (i.e. reduce) workload, although differences were found on the basis of sector and, more clearly, on the basis of MTCD. Both EXE and PLC seemed to enjoy similar workload reductions, and there was no evidence found that transient workload increased as a function of Route condition.

As expected (because of their infrequency), operational errors did not seem to differ by route condition, although the number of STCAs did differ dramatically between RN and FR conditions. Further analysis should confirm whether this relates to a difference in false alarm rate, or a difference in actual number of separation losses. If the former, it would suggest the importance of adapting STCA algorithms for operation with FR traffic patterns (and/or sector design).

There did not appear any route influence on controllers' ability to quickly detect and respond to abnormal system events (such as a diversion request). However, controllers reported great concern about the monitoring demands imposed by FR. This view was supported by evidence that EXE controllers spend more time looking at the PVD during FR than under RN.

According to survey data, controllers felt that FR required more close co-ordination between PLC and EXE, with both tending to share one screen. This view was not supported by objective (voice and eye tracking) data, which showed that team interaction (at least verbal communication by the EXE toward the PLC) might decrease under FR. Controllers' subjective view that FR would increase tactical traffic handling was also not supported by objective data (the clearances they actually issue). Nonetheless, it seemed that FR might change the style of RT communications and the types of clearances that controllers choose to issue aircraft: FR might increase reliance on lateral (i.e. HEADING) as opposed to vertical (CLIMB) clearances.

Controllers felt that FR would force a fundamental change in how both civil and military ATC operate, and each would become more like the other in its working methods. Active TRAs were a source of strong concern for civil controllers, who tended to revert to RN operations when TRAs became active.

Finally, although it was not an explicitly integrated part of the FRAP realtime simulation program, the results of the HERA error analysis deserve some notice. The HERA results demonstrated that the HERA taxonomy can be applied in realtime simulations. This can potentially provide richer information on the mechanisms underlying human error in ATM.

4. HUMAN PERFORMANCE REQUIREMENTS

The requirements following from the Human Performance findings are provided in the following.

4.1 Training

Training, specifically transfer training for controllers accustomed to RN operations, appears one of the most critical elements of successfully implementing FR. Training needs to address new skills (such as medium term conflict detection, and different ways of co-ordinating between sectors). However, as anecdotal and observational evidence suggests, the basic skill set required of FR is not likely to differ much from today's. What is likely more important than specific skills, is the attitude controllers bring to the new FR way of working, to ensure adequate acceptance of FR. Beyond establishing the essential human performance feasibility of FR, human performance measurements also seem to have been valuable in helping identify the specific areas (e.g. workload, monitoring) in which controllers' attitudes do not agree with the objective data—in short, exactly those areas most critical for knowledge training.

Communication and screen fixation patterns differed under FR and RN conditions, although the meaning of these differences is open to speculation. For instance, it could be that these differences indicate that FR decreases the co-ordination demands (and thus reduces talking), or that FR requires more effort (and thus decreases the opportunities for idle chatting between EXE and PLC). On the basis of the workload data, the former interpretation seems more plausible. In any event, this finding raises another issue for transition training: that the nature of team interaction is likely to change under free routing.

Again, many of the issues raised from these simulations derived from qualitative or subjective sources (such as debriefs, or informal chats between test sessions). In simulations such as this, in which highly trained and highly motivated controllers are taking part in realistic simulations, it is often the case that their expert opinion provides a valuable (if not complete) impression. In cases in which the objective data (such as eye tracking data or voice registration) dissociate from controllers' own subjective views, it can provide valuable information for training—namely, such dissociation pinpoints areas of attitude or concerns that should be addressed in training. Transition training, after all, should not only provide controllers with the rudiments of ATC under FR, but should ideally also address their potential concerns about potentially new ways of working. Controllers might need to be informed during training of the actual impact of FR on their workload and methods of working, to help foster acceptance and facilitate the transition to FR. Specific areas of concern that might be stressed in training (with the goal of raising awareness and, hopefully, building controller acceptance) include:

- Monitoring demands under FR;
- Inter-sector co-ordination, and the need for MTCD;
- Need for close EXE-PLC co-ordination, especially in the absence of MTCD;

- Potential for increasingly tactical PLC role;
- Potential for FR to change RT communications pattern;
- Potential for FR to change the ATC control style (e.g. to increase the use of HEADING clearances);
- Sector effects (i.e. knowing how traffic operated in a given sector under RN) might hamper the transition to RN for that sector.

The FRAP human performance measurements, in addition to helping establish the basic feasibility of the FR concept, also helped identify areas where controllers' knowledge and attitudes do not agree with objective data (e.g. regarding workload, monitoring, or communication patterns). It is exactly these areas that can benefit most from knowledge training.

4.2 System Support

Two areas of system support stand out: the need for medium term conflict detection, and the need for TRA status information. It appears that a fully functional MTCD is essential to fully realising the potential benefits of FR. However, early deployment of FR might provide some measure of capacity gain, even in the absence of such an MTCD. On the basis of controller opinion, it seems that buffer zones around a given sector, in which STCA and MTCD operated, would also be advantageous to controllers.

There is also the related need for controllers to have an accurate indication of TRA status (active or not). This must present not only current status, but also future status, for reasons of planning. Area Proximity Warnings were felt to be nice, but not essential.

4.3 Airspace Design and Sectorisation

On the basis of the realtime simulations, the human performance assessment suggests a few things. First, airspace must be designed with sensible (to the controller's thinking) entry and exit points from FR/RN airspace. Further, sector design must take account of traffic flows, so that predominant routes do not tend to verge on or repeatedly cross sector boundaries, nor verge at multiple (e.g. four square) sector boundaries—both of these challenge controllers' reported ability to monitor.

4.4 Summary of Requirements

FRAP human performance assessments integrated the results of objective measures if controller performance, with subjective and observational data. On the basis of this measurement, three critical areas emerged: the need for system support (tools), the importance of airspace design (resectorisation), and the need for training.

The requirements for the first two areas seem straightforward: controllers need a fully functioning MTCD, an indication of TRA future status, and an airspace optimised for free route operations. Beyond these (not insignificant) changes, controllers felt that FR would require essentially the same skill set as is currently required, under RN operations. What does appear at least as critical to these airspace and tool developments, is the provision of transition training for controllers. Beyond some training in new tool and working method skills that FR would require, controllers most clearly need knowledge and attitude training. Without such training, initial acceptance is likely to suffer, and with it the successful transition to FR operations.

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ABBREVIATIONS AND ACRONYMS

For the purposes of this document the following abbreviations and acronyms shall apply:

ANOVA	Analysis of Variance
AR	Air Routes
ATC	Air Traffic Control
ATCo	Air Traffic Controller
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
ATS	Air Traffic Server
CFL	Cleared Flight Level
CNS	Communication, Navigation and Surveillance
COTS	Commercial Off The Shelf
CWP	Controller Working Position
ECG	Electrocardiograph
EEC	EUROCONTROL Experimental Centre
EXC	Executive Controller
FIR	Flight Information Region
FL	Flight Level
FR	Free Routing
FRAC	Free Route Airspace Concept
FRAP	Free Route Airspace Project
HERA	Human Error in ATM
HRV	Heart Rate Variability
HEART	Human Factors Evaluation, Data Analysis and Reduction Techniques
IBI	Inter-Beat Interval
ISA	Instantaneous Self Assessment
LED	Light Emitting Diode
MANOVA	Multivariate Analysis of Variance
MTCA	Medium Term Conflict Alert
NLR	National Aerospace Laboratory
NM	Nautical Mile
PDR	Pupil Diameter Response
PLC	Planning Controller
RAF	Royal Air Force
RNAV	Area Navigation
ROC	Rate of Climb
ROD	Rate of Descent
RT	Radio Telephony
RVSM	Reduced Vertical Separation Minima
SA	Situation Awareness
SID	Standard Instrument Departure
STAR	Standard Arrival Route
STCA	Short Term Conflict Alert
TRA	Temporary Reserved Airspace
TLX	Task Load Index
UAS	Upper Air Space
UIR	Upper Information Region
XFL	Exit Flight Level