



ERAT - Final Report



ERAT Consortium

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ERAT | Final report

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List of abbreviations

ACDA	Advanced Continuous Descent Approach
AEM	Advanced Emission Model
AGL	Above Ground Level
AMAN	Arrival Manager
ANP (database)	Aircraft Noise and Performance (database)
ANSP	Air Navigation Service Provider
APM	Approach Path Monitor
APV	Approach Procedures with Vertical guidance
APW	Area Proximity Warning
ARN	Stockholm Arlanda
ASAS	Airborne Separation Assurance System
ATC	Air Traffic Control
ATM	Air Traffic Management
ATS	Air Traffic Services
B-RNAV	Basic Area Navigation
CCD	Continuous Climb Departure
CDA	Continuous Descent Approach
CDM	Collaborative Decision Making
CDO	Continuous Descent Operations
CONOPS	Concept of Operations
CPDLC	Controller Pilot Data Link Communications
CSJU	CleanSky Joint Undertaking
CTA	Controlled Time of Arrival
CTD	Controlled Time of Departure
DMAN	Departure Manager
DMEAN	Dynamic Management of the European Airspace Network
DoW	Description of Work
EC	European Commission
ECAC	European Civil Aviation Conference
EEC	EUROCONTROL Experimental Centre
EMIS	Estimation of Mission Emissions (Airbus proprietary software)
E-OCVM	European Operation Concept Validation Methodology
ERAT	Environmentally Responsible Air Transport
eTMA	Extended Terminal Manoeuvring Area (extended terminal airspace)
FAB	Functional Airspace Block
FAF	Final Approach Fix
FL	Flight Level
FMS	Flight Management System
FP6	6 th Framework Programme
FTS	Fast-Time Simulation
FUA	Flexible Use of Airspace
GRACE	Generic Research Aircraft Cockpit Environment (NLR flight simulator)
HF	Human Factors
HMI	Human Machine Interface
IAF	Initial Approach Fix
ICAO	International Civil Aviation Organisation
INM	Integrated Noise Model
ISA	Instantaneous Self Assessment
ITD	Integrated Technology Demonstrator (part of CleanSky)
KPA	Key Performance Area
LAMP	London terminal control Airspace Management Programme
LHR	London Heathrow
MTCD	Medium Term Conflict Detection
NADP	Noise Abatement Departure Procedure
NLCP	Noise Level Calculation Program (Airbus proprietary software)



NM	Nautical Miles
NPD	Noise Power Diagram
OI	Operational Improvements
PMT	Project Management Team
P-RNAV	Precision Area Navigation
RMA	Radar Manoeuvring Area
RNAV	Area Navigation
RNP	Required Navigation Performance
RTA	Required Time of Arrival
RTS	Real-Time Simulation
RVSM	Reduced Vertical Separation Minima
SA	Situational Awareness
SGO	Systems for Green Operations (part of CleanSky)
SID	Standard Instrument Departure
SJU	SESAR Joint Undertaking
STAR	Standard Terminal Arrival Route
STCA	Short Term Conflict Alert
TBO	Time Based Operations
TMA	Terminal Manoeuvring Area (terminal airspace)
TP	Trajectory Predictor
ToD	Top of Descent
TTA	Target Time of Arrival
TTOT	Target Take-Off Time
WP	Work Package

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Executive Summary

The ERAT project is co-funded by the European Commission through the EU 6th Framework Programme. ERAT stands for Environmentally Responsible Air Transport and the work is done by a consortium consisting of 11 partners with various aviation stakeholder roles.

Objective

The objective of project ERAT was to develop and validate Concept of Operations for the extended terminal airspace of a medium and a high density traffic airport, in such a way that the environmental impact of air traffic in 2015 should be significantly reduced while maintaining safety levels and airport and airspace capacity. The concepts were directly related to the concept work from SESAR members in ERAT, which they would undertake in the SESAR work programme.

Scope

Project ERAT focused on more efficient and environmentally friendly operations in the extended terminal airspace by facilitating more Continuous Descent Approaches (CDA) and Continuous Climb Departures (CCD).

The validation activities focused on the effects on the environmental, safety, capacity and human factors. For both concepts, real-time simulation exercises were planned and performed to assess the aforementioned benefits and impact. The objective of the validation plans was to bring it as close to the target operational environment as possible, supporting the ultimate goal to deploy the concept of operations.

Concept development work for Stockholm Arlanda (ARN)

The ERAT concept aimed at establishing an early arrival sequence where aircraft capabilities were used in order to improve efficiency of descent operations. The Standard Arrival Route (STAR) is defined all the way to the runway, allowing for a precise planning. The arrival route design is such that there is a free corridor allowing continuous climb departures. The important elements of the concept included:

- Arrival Manager (AMAN) development.
- Controlled Time of Arrival (CTA) point and accuracy.
- Development of a Human Machine Interface (HMI) to better support controllers.
- Parallel routes.
- Procedure for short-haul traffic.

Concept development work for London Heathrow (LHR)

Three concepts were proposed for validation through simulations. They were researched in ERAT using two concept development cycles.

- A 'Two Hold' concept which used present day holds but switched between using just the easterly or westerly two holds depending on wind direction.
- The HEART1A concept which used P-RNAV transitions to deliver traffic from two holds (which were higher and closer than present day holds) to final approach. The 'Two Hold' concept proved to be an important element in HEART1A. The varying usage of the P-RNAV transitions in this concept was also investigated.
- A refined concept called ERAT LHR concept which used an evolved HEART1A design with the addition of Point Merge and Path Stretching/Shortening features.

The ERAT Concepts of Operations for London Heathrow aimed to deliver benefits to both arrival and departure traffic into and out of London Heathrow. The latest concept was the innovative ERAT LHR concept, based on:

- High level airborne holding
- Precision navigation approach transitions
- Path stretching and shortening
- Point-merge

Conclusions ARN concept

Two real-time simulations have been conducted to prove the feasibility of the ERAT concept and to validate performance benefits with specific focus on efficiency, environmental sustainability and safety. The concept targeted medium to high traffic levels in a medium complex environment. Overall, LFV was very satisfied with the results of the concept development and validation work undertaken in this project. The most important conclusions are summarised below.

- Two route designs with (P-RNAV and RNP) STARs have been validated with this concept. The concept proved to be able to accomplish a landing rate between 30 and 34 per hour. The arrival planning and predictability of operations were improved, allowing an increase in continuous descent operations, reaching approximately 80% up to 100% of all traffic. The current day operations proved to be very efficient due to short vectoring by air traffic controllers.
- The fuel burn results for the P-RNAV STARs were comparable to the baseline situation, however the track miles were approximately 10 NM longer. When the RNP STARs were used, the track miles were comparable to the current day operations and approximately 3% fuel burn and CO₂ reduction for arrivals was achieved. The short flights (less than 30 minutes) were now included in the arrival planning and could absorb delays on the ground rather than in the air. This allows for potentially further fuel burn reductions.
- The fixed arrival route structure caused less lateral flight track dispersion which subsequently reduced the noise exposure on the ground locally. The noise footprint areas were reduced up to approximately 20% when compared to the current day situation.

The concept had no influence on Continuous Climb Departure (CCD) which was quite often allowed in the current day operations. The controllers judged that the current safety levels were also maintained. The simulations have demonstrated feasible advanced AMAN functions with associated HMI to run time based operations. A further concept refinement and other remaining issues will be addressed in those SESAR projects which follow-up on the ERAT achieved results.

Conclusions LHR concept

Although the results may not be so promising, NATS was satisfied to have been able to perform this second concept development cycle to further develop the initial concept. Therefore these conclusions only address this second cycle as they form input for follow-up development cycles.

- By using FTS the cost of the project could be minimised while several design options could be explored before initiating a RTS that usually comes at higher cost.
- In the LHR concept, the current landing rate of 42-44 per hour could be maintained thanks to Point Merge.
- The fuel burn analysis revealed that the concept caused a net increase of roughly 7%, where Continuous Climb Departures (CCD) could save approximately 2% which was offset by an increased fuel burn in arrivals due to 19% longer distance

flown. The locations of the Initial Approach Fixes (IAF) in combination with the route design have contributed to the longer distance flown from the TMA entry point. The route design showed similarities to the previous concept (HEART1A) and facilitated a free corridor for CCDs. The CCD has shown improved fuel efficiency and provides potential for more if flights were cleared to their cruise flight level.

- Environmental assessment of the concept showed that noise footprints were re-distributed and showed both local increases and decreases of noise exposure on the ground. The comparison between the current departure procedure that included a level-off at 6,000 ft and a CCD, resulted in an interesting trade-off between less noise (in the case of levelling off) and lower fuel burn (with a CCD).

Although this concept would not be implemented as it was designed in ERAT, several concept elements were taken over for further development by SESAR projects and NATS' internal London TMA airspace management programme (LAMP). An example of future development was the RTS of this concept with four holds instead of two to reduce the track distance flown. This led to addressing many of the limitations of this concept.

Recommendations for SESAR

The ERAT consortium recommends to SESAR:

- To take an example of concept development and validation work undertaken for Stockholm Arlanda terminal airspace. The ARN concept provides a good showcase of Time Based Operations for SESAR, with system support on the ground.
- To learn from airspace and route design work undertaken for London Heathrow in SESAR work dealing with high traffic density terminal airspace. The development cycles have revealed some very useful concept elements (e.g. point merge) and route design considerations in a complex airspace.

The tools and methodologies used for the ERAT environmental assessments (both for the ARN and LHR cases) were presented to SESAR projects 16.6.3 and 16.3.1. The contribution of ERAT in this process lies in providing new insights in their ongoing discussion on set of tools and methodologies to be used in SESAR projects. Realising that a real-time simulation (RTS) is an essential part of concept validation in SESAR, currently there is not yet a tool that can analyse the RTS output with the hi-fidelity of Airbus models. It was also observed that the aircraft performance models used in FTS and RTS platforms need to be improved. Especially the way vertical profiles were modelled, because their output determined the input suitability for environmental analysis.

Focus on Eastern Europe, specifically Romania

Participation of a Romanian partner National Company Bucharest Airports (NCBA) in project ERAT showed their commitment to make Romania a leading country in that region to introduce environmentally friendly operations. The dissemination plan of ERAT therefore included meeting events where the ERAT consortium exchanged information with Romanian stakeholders with the intention that elements of the ERAT work could be adopted and implemented for the Romanian situation.

1 ERAT project description

1.1 Problem statement and conceptual framework

For many European airports, the environmental aspect in their activities plays an important role. Various aviation stakeholders consider the environment as one of their key performance areas for their operations. In addition, the national authorities have imposed stringent environmental regulations to protect citizens living in the surrounding of airports and therefore the aviation stakeholders must innovate in order to grow within given constraints.

Innovations in air transport can be categorised in aeronautics (directly related to the aircraft, such as airframe structures, aerodynamics and engines) and air traffic management (ATM). This latter comprised of advanced (operational) concepts and/or enabling technologies in the fields of communications, navigations and surveillance (often referred to as CNS) to safely manage air traffic flows efficiently in terms of time, costs and environmental aspects.

Environmentally Responsible Air Transport (ERAT) a project co-funded by the EU through its Sixth Framework Programme (6th FP) which has been undertaken by a consortium with 11 partners. In project ERAT, it was decided to select the terminal airspaces above the airports Stockholm Arlanda and London Heathrow as reference site to focus the development of concepts aimed at improving environmental performance in terms of noise, fuel burn and emissions.

Before the start of project ERAT, the Swedish air navigation service provider LfV participated in “Green Flights” live trials allowing efficient flights from departure until arrival to gain environmental benefits. By then, they also had a vision that by 2012, approximately 80% of all arriving traffic should be offered a “green” approach into Swedish airports.

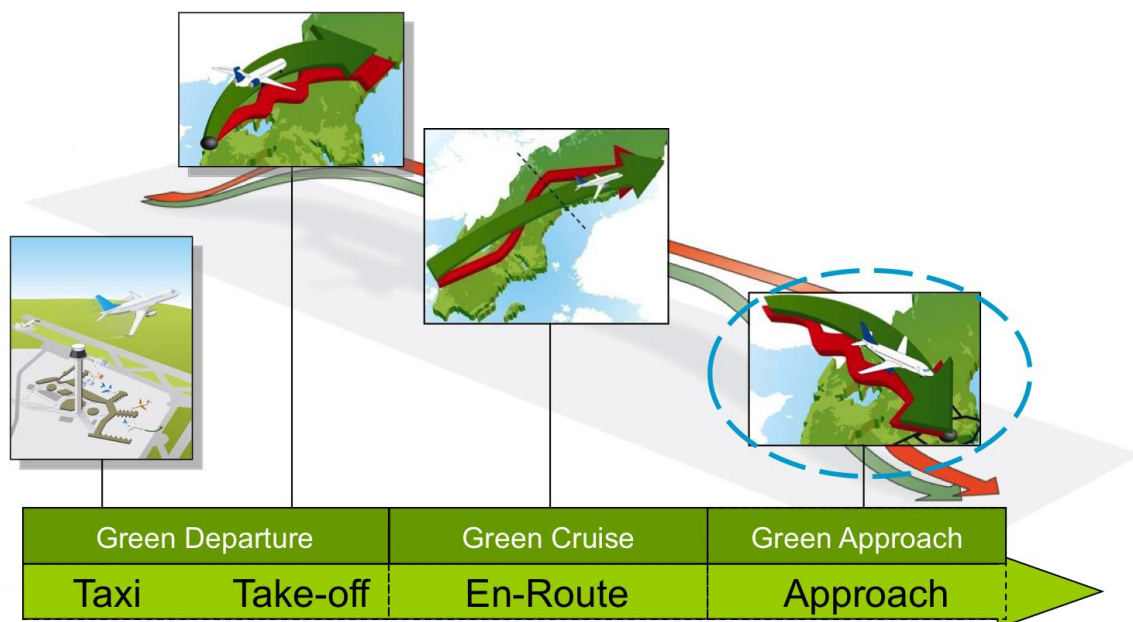


Figure 1: LfV Green Flights programme

The need to accommodate these green approaches required a concept that is different from current day operations. The objective of project ERAT was to develop such concept for Stockholm Arlanda terminal airspace, providing building blocks for Time Based Operations, as envisaged by the SESAR Operational Concept storyboard.

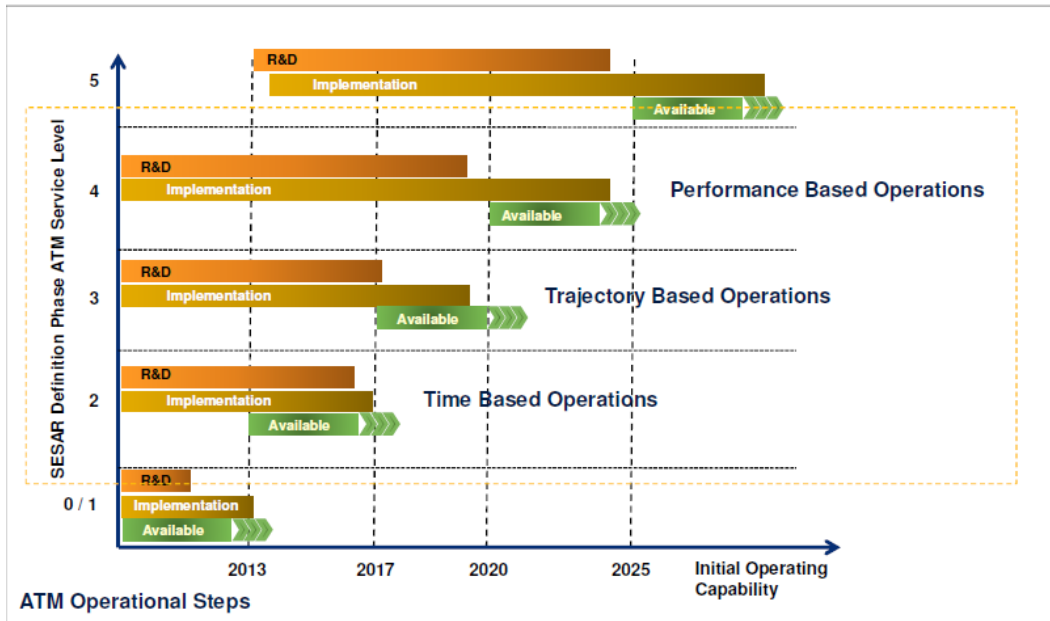


Figure 2: The three operational concept steps of SESAR

The situation for the London airport Heathrow is totally different. For years, this airport operated at its maximum capacity requiring many flights to hold before they receive a landing slot. The London terminal airspace is organised such that it includes the five most important civil airports in the Greater London area. Therefore the airspace is characterised by a high traffic density and high complexity.

In 2008, NATS became the first air traffic management company in the world to calculate the baseline CO₂ performance of its airspace and to set a clear target to reduce air traffic related CO₂ emissions, by an average of 10% per flight by 2020. The NATS participation in the ERAT project gave NATS the opportunity to assess the feasibility of new concepts of operations designed for environmental benefits, while at the same time maintaining current capacity and safety levels. The ERAT outcome was meant to feed a NATS internal programme dealing with the redesign of the London TMA airspace and this programme was also aligned with the SESAR work programme.

1.2 Project background

The ERAT project started in November 2007 and at that time SESAR was still in its Definition Phase. Due to various circumstances, the project had a late start and the progress slipped in time. In December 2008, the SESAR Joint Undertaking (SJU) was officially established and new roles and responsibilities between the EU project officers and SJU staff were defined. In practice this meant that SESAR was playing a more important role in determining the usefulness of project results as input for SESAR. The SESAR Operational Concept was still in development and environmental activities were in the start-up phase. So in the first quarter of 2009, the EC and SJU requested to revise ERAT's first Description of Work (DoW) in order to align ERAT activities with the SESAR

Work Programme and make the project management routines more efficient while still complying with EC rules. A lengthy negotiation and change process followed and eventually the DoW moved to version 3.3 which was accepted by both the EC and SJU.

Pursuant to recommendations from EC and SJU, the Work Package Breakdown Structure (WBS) has been changed followed by a project reorganisation in terms of partners' roles, effort and budget. The main changes can be summarised as follows:

- The scope and objectives were more focused on developing operational concepts aimed at environmental benefits, while maintaining safety and capacity levels.
- The project structure was split into two operational threads: one for Stockholm Arlanda airport (ARN) and one for London Heathrow airport (LHR).
- The remaining effort at the time of reorganisation had to accommodate the new WBS and difficult choices had to be made on which activities should remain and/or cancelled.
- A revised focus on validation plans and activities initially meant to pave the way for live flight trials, however the actual flight trials could not fit in the new WBS and were beyond the scope of this project. The validation objective remained to bring it as close to the target operational environment as possible, supporting the ultimate goal to deploy the ERAT concepts.

The relationship between the WBS en project activities is further explained in section 1.4.

1.3 Project setup

1.3.1 Project objective

The objective is to develop and validate CONOPSs for the extended terminal airspace (eTMA) of a medium and a high density traffic airport, in such way that the environmental impact of air traffic in 2015 is significantly reduced while maintaining safety levels and airport and airspace capacity. The concepts are directly related to the concept work from SESAR members in ERAT, which they would undertake in the SESAR work programme. ERAT should contribute as building block for an intermediate step towards one of the SESAR performance targets to reduce the environmental impact per flight by 10% in 2020.

1.3.2 Scope

Project ERAT focuses on more efficient and environmentally friendly operations in the eTMA by facilitating CDAs and CCDs. Figure 3 shows the ERAT working domain as part of all flight phases.

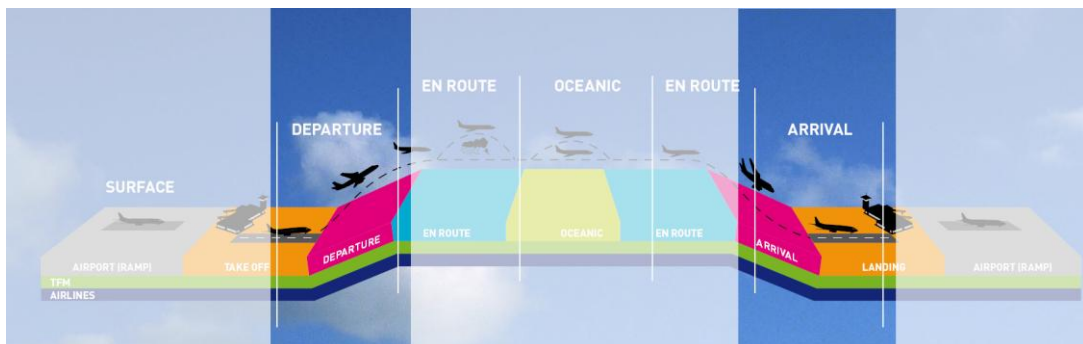


Figure 3: The ERAT domains (adapted from: SJU, Annual Report 2007 – 2008)

Focus in the CONOPS development was on the ATC working environment required to accommodate CDAs and CCDs. Some aspects that were covered: advanced arrival management, procedures and the human machine interface.

The validation activities focused on the effects on the environmental, safety, capacity and human factors. For both concepts, real-time simulation exercises were planned and performed to assess the aforementioned benefits and impact. The objective of the validation plans was to bring it as close to the target operational environment as possible, supporting the ultimate goal to deploy the CONOPS. The actual execution of live flight trials were however beyond the scope of the ERAT project.

The concept development and validation work in ERAT should directly feed the national activities of NATS and LFV (as SESAR members) in support of the SESAR work programme. This ensured that the activities in ERAT were aligned with SESAR.

1.3.3 Consortium members

The ERAT project was co-funded by the European Commission through the EU 6th Framework Programme. The project started in November 2007 and lasted until end of April 2011. The total project budget was approximately € 7 million. As ERAT was developing new air traffic management operational concepts focused on gaining environmental benefits, starting January 2009 the project was technically supervised by the SESAR Joint Undertaking to ensure alignment of activities with the SESAR work programme.

The ERAT consortium consisted of 11 partners, geographically spread across Europe and they fulfilled various aviation stakeholder roles, as shown in the list below.

- NATS En Route Ltd. (air navigation service provider, United Kingdom)
- Luftfartsverket LFV (air navigation service provider, Sweden)
- National Company Bucharest Airports (airport operator, Romania)
- Deutsche Lufthansa (airline, Germany)
- National aerospace laboratory NLR (research establishment, the Netherlands)
- Deutsches Zentrum für Luft und Raumfahrt DLR (research establishment, Germany)
- EUROCONTROL Experimental Centre (research establishment, France)
- Airbus Operations (aircraft manufacturer, France)
- Snecma (engine manufacturer, France)
- Envisa (small enterprise, France)
- To70 (small enterprise, the Netherlands)

1.3.4 Approach

The ERAT project aimed to identify operational initiatives, develop concept elements, integrate them and validate a concept of operations that reduced the environmental impact of the air transport operation in all phases of flight in the (extended) terminal area.

At very high level, the phases required to undertake the development of an operational concept for air traffic management could be summarised as:

- Inventory of concept elements
- Define validation plan
- Define Concept of Operations (CONOPS)
- Summarise findings

The ERAT consortium has worked out these phases towards following stepwise approach:

1. Identifying operational initiatives and develop concept elements with the potential to reduce the environmental impact;
2. Selecting the operational concept elements to be included in the CONOPSs;
3. Embedding those concept elements within CONOPSs for the terminal airspace of two airports (one with medium density and one with high density traffic, respectively Arlanda and Heathrow airport) based on the SESAR CONOPS;
4. Develop a validation strategy and validation plans for the concepts at both airports;
5. Undertake validation activities of the CONOPSs (e.g. with Real Time Simulation sessions);
6. Assess quantified benefits of the concept of operations in terms of environmental impact, safety and capacity;
7. Continue with validation and verification activities focused on preparing for live trials and deployment orientation.

1.4 Two locations: Stockholm Arlanda and London Heathrow

As LfV and NATS were consortium partners in ERAT, it was decided at the beginning of the project that respectively Stockholm Arlanda and London Heathrow were the centre points of the developed concepts. Arlanda (ARN) being representative as a medium traffic density airport and Heathrow (LHR) being representative for a high traffic density airport. It was obvious that although the approach to concept development would be generally the same for both, a certain degree of customisation was required.

Therefore the project Work Breakdown Structure (WBS) was split in order to reflect the two operational threads, as shown below in corresponding columns.

Development phases	Stockholm Arlanda ARN	London Heathrow LHR
Inventory of concept elements	WP1 and WP3	WP1 and WP3
Define Validation plan	WP2	WP2
Define ConOps	ARN4	LHR4 and LHR10
Validate ConOps	ARN5, ARN6, ARN7, ARN8	LHR5, LHR6, LHR8, LHR10
Summarise findings	ARN7 and WP10	LHR10 and WP10

Figure 4: Relation between work breakdown structure and concept development steps

The regular WP numbers (1 to 3) were WPs derived from the original Description of Work (DoW) and their initial results were applicable for both operational threads. The split started from the fourth WP onwards and for clarity purposes, each airport's designator was added to the WP number. As some activities have been cancelled during the project reorganisation, certain numbers may seem skipped.

1.5 Structure of the report

The structure of this report has been agreed by the EC and SJU and imposed upon the ERAT consortium, as this would best reflect the overview of underlying project structure and activities leading to the final results.

Chapter 1 deals with the project related items such as background, structure, scope, objectives and consortium partners. The Stockholm Arlanda operational thread is captured in chapter 2, while for London Heathrow that is in chapter 3. The project dissemination activities are highlighted in chapter 4. Finally, chapter 5 covers the main conclusions and recommendations for SESAR.

The annexes comprised of the results from the inventory phase and the how the ERAT results have been picked up by various SESAR projects, NATS' internal airspace management programme and the benefits it has delivered for others.

Purpose of the document

This final report gives an overview of the objectives, the undertaken activities and the achieved results in the ERAT project.

Intended audience

This document is intended for aviation stakeholders with an interest to get a general overview of what the project is about and the achieved results without having to read all produced deliverables.

For those who considers to use these results for his/her (ongoing) project and therefore require more technical detail about specific activities, he/she is advised that all deliverables are downloadable from the ERAT project website (www.erat.aero).



2 Arlanda airport

2.1 Background and tailored objectives

The ERAT concept targeted environmental benefits as a result of the multi-criteria and trade-off selection process. In this activity the concept elements together with a number of options were described. Each concept element was assessed against the ERAT Key Performance Areas (KPA). This process turned out to be difficult to apply. Conceptual elements had different levels of description and maturity, so the originally planned process was later changed. The work for Arlanda eventually resulted in an initial concept description reflecting the three most important focus areas for the project: environment, human factors and safety together with capacity. See also Annex A.1.

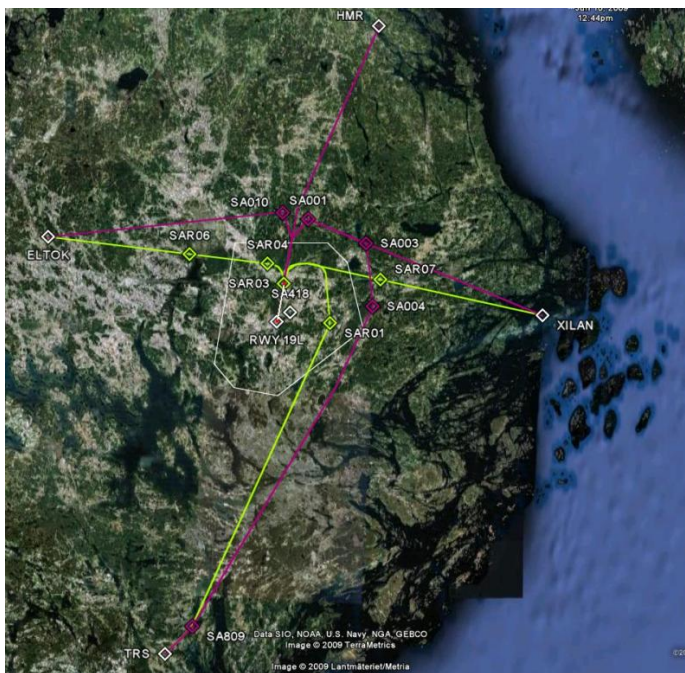


Figure 5: STARS in Stockholm TMA

The concept aimed at arrival management improvements with the intention to allow more optimised arrival profiles in medium to high traffic without degrading the capacity. Furthermore, development of system support through an advanced Arrival Manager (AMAN) was also required to support such arrival planning.

Departures were also included in the considerations, but they were already quite efficient today for the airborne part at Arlanda. The concept recognised the importance of airspace design for de-confliction in a terminal airspace to allow efficient climb and departure operations. Therefore part of the objective was to validate that departures were not negatively influenced by the new concept.

2.2 Concept of operations

The following sections highlight some of the characteristic elements of the Stockholm Arlanda (ARN) concept of operations, however for full details please refer to ERAT deliverable ARN D4-1 (ref.[14]).

2.2.1 Current operations in brief

Arrivals are sequenced using the Maestro tool, but managing the aircraft is predominantly done by vectoring. Frequently, continuous descent approaches can be accommodated without having to change the sequence built up. However, there are short flights (less than 30 minutes) arriving at Arlanda that “pop up” on the radar screens after they take off, which often result in disruption of ATC operations. These disruptions impact the arrival sequence and increase the controller workload.

Departures are given clearances for continuous climbs whenever traffic situation allows and this is quite often the case. It also helps that the current ARN route structure is such that there is limited interference between departure and arrival flows.

2.2.2 Limitations

The ERAT concept developed for Arlanda was targeting medium traffic levels. The concept was meant for traffic levels below maximum capacity where the initiatives were expected to improve efficiency without degrading capacity. For the very demanding traffic levels, development of system support is not expected to provide enough assistance for e.g. advanced CDA within the targeted timeframe of 2015.

2.2.3 Concept outlines

The ERAT concept aimed at establishing an early arrival sequence where aircraft capabilities were used in order to improve efficiency of descent operations. The Standard Arrival Route (STAR) has been defined all the way to the runway, allowing for a precise planning. The key elements of the concept were:

- Improved arrival sequencing with the support of an AMAN
- STARs defined to the threshold
- Aircraft capability used – Controlled Time of Arrival (CTA)

The arrival sequence should be established in advance from Top of Descent (ToD), in order to allow for optimisation of the descent phase. The arrival route design was such that there is a free corridor allowing continuous climb departures, just like the current day operations. Therefore the focus of research was predominantly on arrivals. Departures of short flights (less than 30 minutes) within the arrival management horizon and processed by the Arrival Manager (AMAN) tool, were a problem due to the uncertainty of the departure time. The concept assumed the uncertainty to be managed through a CDM-process. Still, the exact departure time will not be known before the actual departure.

For aircraft where the arrival planning sequence remained the same (thus a “stable” situation) before Top of Descent (ToD), a Controlled Time of Arrival (CTA) proposal is produced and communicated to the pilot. The CTA point in this environment has been set to approximately 30 NM from touchdown. The objective was to avoid/reduce interventions from ATC during the approach.

With the STARs defined to the runway the pilot had means to optimise the descent phase, to improve efficiency. The airport planning would also benefit from the improvement in predictability, so ground handling operators could better anticipate the actual aircraft arrival time.

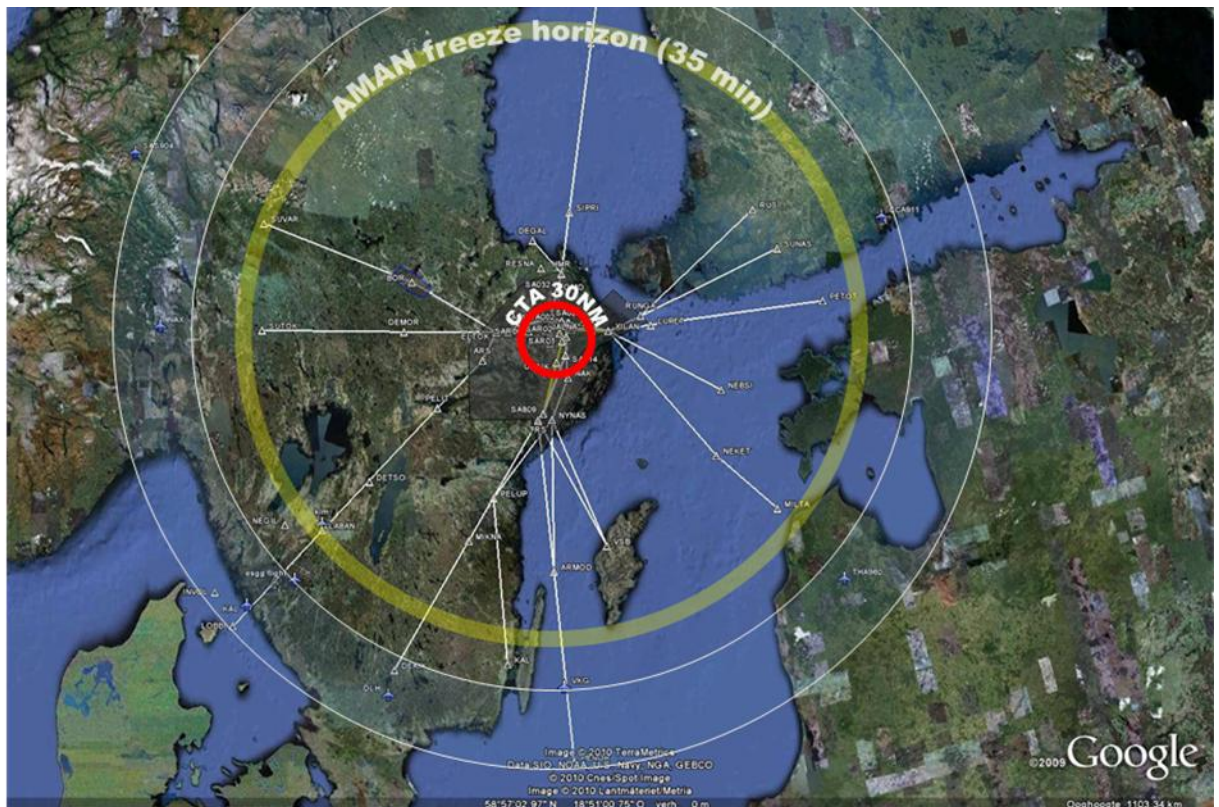


Figure 6: AMAN freeze horizon, main routes with CTA points indications (red circle)

2.2.4 Concept details

The concept development has been built on previous experience from other projects and from live trials performed at Arlanda airport. One important driver in the work was capturing future requirements to allow more efficient arrival operations in higher traffic volumes. Therefore this project was considered an important bridge for future implementation. In order of importance the concept proposed:

- **AMAN development.** The required AMAN for this concept should plan aircraft trajectories such that a workable sequence could be built, taking into account the requirements of fixed STARs and separation minima between aircraft. The trajectory prediction should also include the CTA allocation and communication lead times.
- **CTA point and accuracy.** The Controlled Time of Arrival (CTA) point was proposed to be 30 NM from touchdown, following experience from several previous real-time experiments. The concepts assumed that aircraft meet their CTA point with an accuracy of ± 30 seconds.
- **Development of an HMI to better support controllers.** The HMI has been developed to support the controller in the CTA dialogue and status and it should help him/her to understand the metering requirements and the proposed sequence.
- **Parallel routes.** Parallel routes were proposed as a solution for increasing controller confidence in allowing aircraft to perform optimised descents. This was a means to de-conflict traffic and mitigate the increase in uncertainty when moving from active control towards monitoring. At the same time there was limited space for parallel routes and they may create problems for departures having to cross two routes.

- **Procedure for short-haul traffic.** The short-haul procedure assumed that a CDM mechanism was in place producing a Target Take-Off Time (TTOT) for the departure within the AMAN horizon. This time was set as a -2/+3 minute window for the AMAN planning.

2.2.5 Procedures

The traffic situation currently at Arlanda can be characterised as medium/high traffic for many hours per day. The driver was to realise environmental benefits when possible and not to bring adverse effect on the arrival peaks. CTA was a means to implement the sequence, a strategic constraint needed for the achievement of the sequence. For situation awareness the controller needs understanding of the metering requirements. Time is a secondary dimension for ATC, relative sequences is the primary understanding.

The controller is increasingly put in a monitoring position when we are moving towards time-based operations. When needed for sequencing or separation purposes, the controller could use traditional means to solve the problem or to reduce trajectory uncertainty. After the CTA point and/or when aircraft from different directions need to merge for final approach, the controllers may have to vector aircraft to ensure appropriate separations. The figures below show the two developed (fixed) arrival routes for Stockholm Arlanda:

- In blue in Figure 7, the P-RNAV Standard Arrival Route (STAR).
- In green in Figure 8, the RNP Standard Arrival Route (STAR).

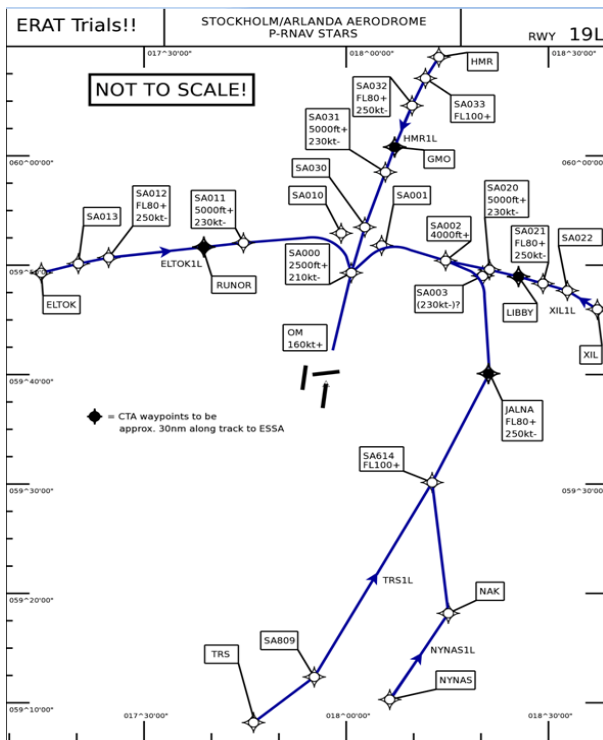


Figure 7: STARs with parallel part and CTA points

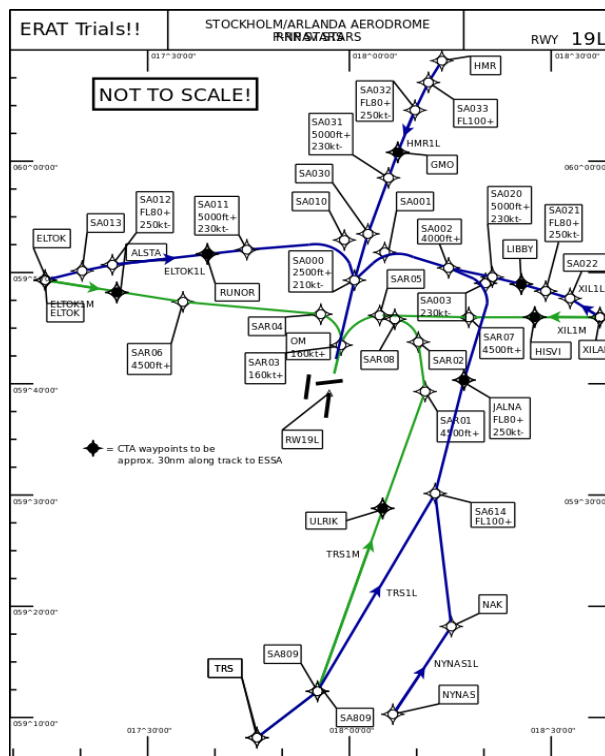


Figure 8: Short RNP STARs and P-RNAV STARs

2.3 Validation approach

2.3.1 Validation plan

In general the expectations of various aviation stakeholders are:

- Airline operators are expecting to make full use of advanced technical equipment currently onboard their modern aircraft, to increase the efficiency and punctuality.
- The airport operator is interested in undisturbed, predictable operations, ensuring medium to high throughput but with low environmental impact.
- The ANSP expects to reduce the environmental impact in medium to high traffic density levels. Advanced planning and new procedures shall contribute to reduce tactical intervention, while maintaining the current safety level. Overall, the current workload level is expected to be maintained.

For the ERAT Arlanda concept of operations, the prime validation areas were indicated through the validation expectations. For Arlanda airport, the ERAT project partners wanted to progress on a better integration of CDA operations in the ATC environment at medium to high traffic loads and under realistic operational conditions. With the available ATC tools at hand, this came down to a trade-off between

- operating CDA arrivals with minimum ATC interventions;
- achieving medium-high throughput, i.e. 30-34 landings per hour;
- maintaining controller acceptability.

The validation expectations have been transformed into high level objectives, and for each type of objective, hypotheses have been defined. The high level objectives for the Arlanda concept evaluations were:

- Demonstrate possibility of executing accurately planned CDA arrival operations maintaining throughput and safety during medium-busy traffic with sufficient operability and controller acceptability.
- Demonstrate the efficiency and environmental benefits of medium density CDA operations.
- Demonstrate the capability of ground-based tools (AMAN/TP) to perform sequence planning at an early stage with good controller support
- Demonstrate the possibility to accommodate efficient departure operations during advanced CDA operations.

These high level objectives were assessed by measuring the impact of the ERAT concept on the following Key Performance Areas (KPA's):

- predictability
- efficiency
- environmental sustainability
- capacity
- safety
- controller operability and acceptability
- flexibility

Recommendations made in SESAR project 4.2.3. Modelling, simulation and validation tools were used to review and adapt the validation exercises and validation techniques. The validation exercises for the ARN CONOPS were defined during expert groups meetings and following performance assessments of the CONOPS, which resulted in adjustments as necessary. It was then decided that for a more realistic operational feasibility and performance assessment, a real-time simulation to validate the concept was required.

2.3.2 Technical development and preparation of the RTS platform

The simulations were run at LFV in Malmö (RTS1) and at NLR in Amsterdam (RTS2) both using the NARSIM radar simulation platform. This platform comprised of modules that work together to form a complete simulation of an ATC environment. Examples of such modules include an airport, weather, radar, controller working position, AMAN and trajectory prediction module.

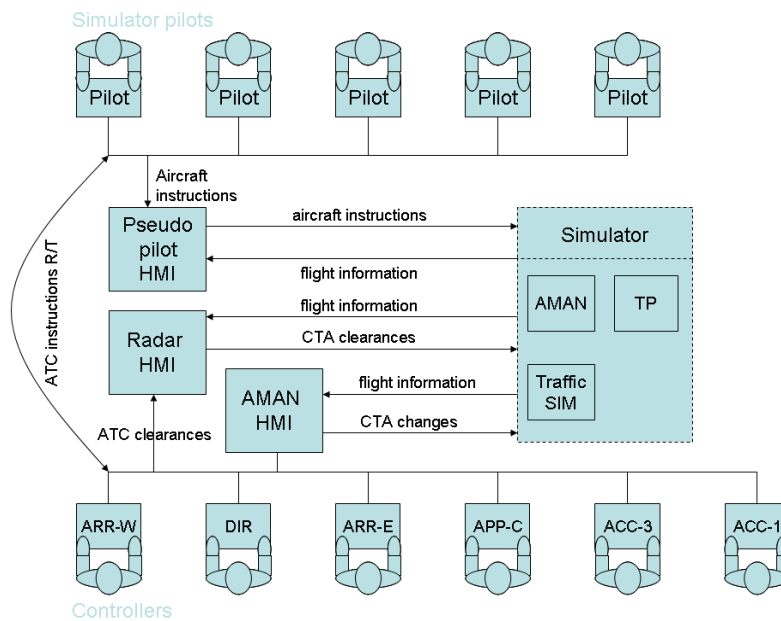


Figure 9: Schematic illustration of NARSIM simulation set-up for Arlanda

The figure above illustrates the set-up of the simulation during RTS1 in Malmö. The Arlanda simulation consisted of six controller working positions and five to seven simulator-pilot workstations connected to the different simulation components.

The controllers communicated with the simulator-pilots using voice commands (R/T) in the same way as in current-day practice. In addition, the controllers were presented a radar-screen that closely resembles the operational system. For the ERAT trials the controller working position was enhanced to facilitate the time based CTA operations. All information regarding sequence, metering or CTA proposal was presented in the target label on the radar screen. In addition, controllers (except the final director) were presented an AMAN sequence window with a timeline that displays the current arrival sequence planning.

The role of the simulator-pilots was to provide the controllers with realistic interaction (R/T) and to control the aircraft by providing inputs to the simulator following the instructions of the controllers.

DLR's TrafficSIM module, connected to the NARSIM, was used to generate the traffic. TrafficSIM is a BADA 3 based traffic generator that is considered adapted to evaluate the feasibility of ATC operational concept within real-time ATC simulations. It has, among others, the capability to fly CDAs and also provides CTA functionality. TrafficSIM still had to be connected to NARSIM and eventually interfaced seamlessly with NARSIM.

2.3.3 NARSIM ATC simulator components

The simulator consists of a large number of components. The main components that were specifically developed to evaluate the ERAT concept for Arlanda airport are briefly discussed below.

Arrival Manager (AMAN)

The AMAN is a key component in the ERAT RTS. Its main task was to generate an optimal arrival sequence by predicting the future behaviour of aircraft. The AMAN had the following (ERAT specific) features that were developed and prototyped within the project:

- scheduling of regular short-haul flights based on flight plans;
- accommodation of CDAs by proposal of CTAs in line with the proposed sequence;
- provision of advice about an optimal route where alternative routes are available (for traffic from the south);
- monitoring and warning function for CTA agreements that become invalid due to (manual) sequence changes.

Trajectory Predictor

The trajectory predictor (TP) was a key enabler in the simulation. The TP provides information to the AMAN that bases its sequence on these predictions. The AMAN feeds the current position of an aircraft and flight plan information to the TP. On the basis of this and a prediction of the wind, the TP calculates the trajectory and the timing of it, which is fed back to the AMAN. The AMAN, which is building a sequence between aircraft and performing limited conflict checking of the trajectories of these aircraft, can provide alternative routes or certain constraints for which the TP recalculates the 4D trajectory. The TP can also generate a starting position for the trajectories instead of taking the current radar position.

For performance data per aircraft type, the TP uses EUROCONTROL's Base of Aircraft Data (BADA) revision 3.6 with updates (LFV and DLR/NLR) based on aircraft behaviour around Arlanda airport.

TrafficSIM

TrafficSIM is the component that simulates aircraft and responds to pseudo-pilot instructions. TrafficSIM calculates 4D-trajectories for the aircraft in the simulation based on a list of waypoints describing the route from current position to the destination, altitude and time constraints, the aircraft's performance data (as published by EUROCONTROL in the Base of Aircraft Data (BADA)), and an accurate weather forecast.

The 4D trajectories should be representative for 2015, having less environmental impact (e.g. low thrust, low noise) but still allowing sufficient flexibility for the controller to provide instructions for managing separation with other aircraft.

The calculated top of descent determines to a large extent the flexibility and environmental impact of a 4D-approach-trajectory. Currently TrafficSIM uses a ToD point 3NM before the point that would be calculated for the most optimal profile from an environmental perspective.

The foreseen airspeeds depend on phase of flight and type of aircraft. Optimum speeds for different flight phases were published for most aircraft types in BADA. When a pseudo-pilot is given a CTA, the TrafficSIM will calculate the possibility of achieving it and determine the ToD for the particular aircraft.

AirSIM

During the second series of trials in RTS2, NLR has decided to use AirSIM as dedicated flight simulator to the simulation. AirSIM is the PC-based model of NLR's moving platform research flight simulator. This was expected to provide more detailed and more complete



modelled functionality. This functionality is used to test reactionary critical parts of the simulation experiment. The objectives were:

- To validate performance of AMAN/TP functionality in following 4D-FMS planned and guided aircraft operations,
- To evaluate the concept under variation in aircraft types in maintaining separations in medium to high density CDA flows,
- To evaluate the impact of FMS-guided aircraft behaviour in descent operations on controller involvement and workload,
- To provide increased realism as a transition mode to shadow-mode trials and to validate prototypes of ground-based ATM tools for use in shadow-mode applications.

2.3.4 Generic Controller HMI description

A common working position HMI was prepared for all controllers. The HMI was intended to be used both for “conventional” ATC as well as time based (CTA) operations. The main window of the HMI presents the current air traffic situation and allows for controller interaction.

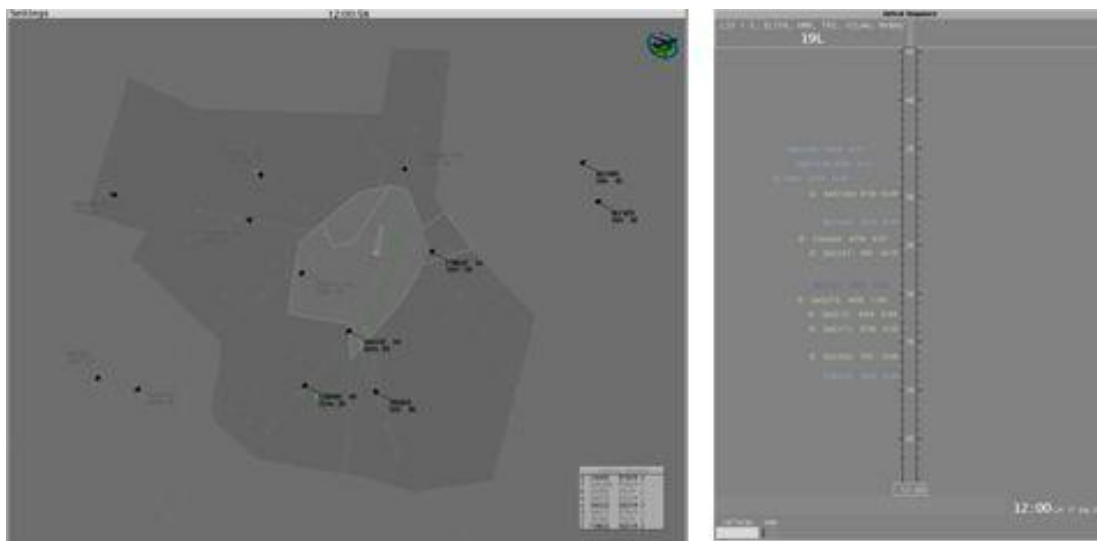


Figure 10: Controller HMI, with radar display (left) and AMAN time line (right)

Aircraft trajectories and predicted times over waypoints can be displayed on the radar display on controller request. In the ERAT concept runs, the AMAN sequence is visualised on the radar display by sequence numbers in track data labels and in the integrated Landing Sequence list (shown in the bottom right corner of the main window).

An additional Arrival Sequence window was made available for the controllers in the ERAT runs. The arrival sequence is presented in this window in the form of a “time-line” with aircraft labels. Labels are attached to the time line at the position corresponding to the target time over the selected waypoint/runway.

2.3.5 Time based CTA related HMI features

The display of the air traffic situation and arrival sequence windows offered the controllers most of the common functionality of current day ATC systems. Special CTA related features were added to support the ERAT ARN concept.



Figure 11: CTA field in label, before and after CTA input

The track data labels present information on RTA equipment status of a flight and support the controller in making inputs reflecting the establishment and cancellation of CTA agreements with pilots.



Figure 12: CTA input menu

A CTA input menu allowed the ACC controller to propose a time over the CTA to the pilot. The CTA was first proposed to the pilot; the response can be either accept or unable. Once a CTA has been agreed between controller and pilot a clock-like symbols appears in the label and the required time over the CTA point is included in the extended label.

2.3.6 Arrival Management related HMI features

The AMAN is capable of supporting time based (CTA) operations. The arrival planning and assigned arrival times were presented to the relevant ACC/APP controllers in an intuitive way. HMI and AMAN time line presentations were tailored to the different control positions.

2.3.7 Experimental plan for the RTS

To make a balanced comparison with present operations, two types of simulation setups were developed and exposed to identical operational conditions for comparison:

- Arlanda baseline, a reference condition with the AMAN as developed and working with conventional arrival routes, without the use of time based operations and executed by conventional speed control and vectoring.
- Arlanda ERAT concept with advanced AMAN using CTA for early sequencing and applying CDAs whilst transitioning to traditional speed control and vectoring when necessary.

Furthermore certain factors are of influence on the results. These factors were varied over the different runs and randomised.

- Traffic samples, representing the situation in 2015. The 2015 traffic mix included different traffic densities and aircraft types with forecast levels of automation with respect to navigation and 4D capabilities.
- Wind conditions, i.e. different wind fields with realistic errors between actual and forecast wind for use onboard and within ATC
- Controller seating, to rotate participants over the different working positions and avoid personal influences
- Disruptions, activated as necessary to investigate the robustness of the concept and tools against realistic traffic disturbances.

During the RTS evaluations, measurements were taken, which consisted of:

1. Subjective assessment of controllers perception of the concept through questionnaires & debriefings (e.g. workload, feeling of safety);
2. Observations by experts monitoring the experiment;
3. Simulator data loggings (e.g. number of movements, flight profiles, track miles), reflecting measurement of direct performance variables from simulation; and
4. Derivations such as fuel consumption and flight duration.

Preparations were made to organise two RTS sessions to validate the ARN concept. Each session was planned to last one week of measured runs. The first one (RTS1) was held in June 2010 at LFV in Malmö (Sweden). Feedback from controllers, pseudopilots and capturing important data were analysed in order to improve the simulation platform. The second session (RTS2) took place in September 2010 at NLR in Amsterdam.

Prior to each RTS session, the controllers were familiarised during test sessions in the same simulation environment and a briefing on the project objectives. Controllers were also provided a briefing guide explaining the HMI features and concept. In total, 12 to 14 measured runs were made during every test week.

Between the two simulation sessions, a number of changes and improvements were made to the RTS2 setup.

1. Based on the findings and operational feedback from RTS1, the AMAN logic and HMI was improved.
2. A shorter RNP based STAR was added in RTS2 to make a further step in improving the environmental benefits, as it was concluded that a shorter STAR may increase efficiency and operability of the concept.
3. The traffic behaviour as generated by TrafficSim, of which the realism was very high according to the controllers, showed quite uniform behaviour over different airlines. For RTS2, the TrafficSim operated with different cost indexes for airlines as well as a more random aircraft by aircraft variation.
4. In RTS1, the controllers had the opinion that in the traffic samples the departing traffic, overflights and short haul flights could be increased to represent a more realistic mix of traffic in relation to the number of inbound aircraft. For RTS2, busier traffic samples were generated representing a more realistic traffic mix.
5. For part of the RTS2 sessions, some aircraft within the samples were generated by means of four AirSim aircraft simulators instead of TrafficSim. This allowed for the

evaluation of the concept from the pilot point of view. This also added variation, as observed in reality, in the aircraft operational behaviour.

2.3.8 Environmental assessment methodology

Noise assessment was done through Airbus official operational external noise prediction tool, the Noise Level Calculation Program (NLCP), using the Leq metric, and applied on the traffic generated with TrafficSim during the first RTS week. Fuel burnt was directly derived from the TrafficSim trajectories.

The traffic needed to be modified in order to use aircraft manufacturer's models, and dedicated runs were performed with the replacement of non-Airbus aircraft by equivalent Airbus ones.

The numbers given in the assessment results shall not be taken as absolute values due to the limitations of the project as mentioned below. However, the project was able to identify the qualitative trends of the environmental impact of the developed concept of operation.

The main limitations of this assessment were:

- The use of dedicated runs, with a fleet composed of Airbus aircraft only;
- The 1-day traffic was re-built from the simulation of a 1-hour traffic;
- The A/C models used to generate the A/C trajectories during the RTS did not ensure full representativity of A/C performance and systems behaviour.

2.4 Results

Two real-time simulations have been conducted to prove the feasibility of the ERAT concept and to validate performance benefits with specific focus on efficiency, environmental sustainability and safety. The concept targeted medium to high traffic levels in a medium complex environment. Two different airspace arrival procedures were evaluated:

- P-RNAV STARs with ILS intercept at around 10 NM final. The results were reported in deliverable ARN D7-6a (ref.[16]).
- RNP STARs intercepting the final approach at around 5 NM final. The results were reported in deliverable ARN D7-6b (ref.[17]).

2.4.1 RTS1 results

The first RTS evaluation of the ERAT Arlanda concept was carried out at LFV in Malmö, which focused on evaluating the ERAT concept with the standard P-RNAV STARs, comparing against a simulated baseline situation with current tools and practices. Results showed that the ERAT concept could be operated with medium traffic density of 30 to 32 landings per hour and temporary peaks up to 34 landings. Around 20% more CDAs were flown with the ERAT concept compared to the current day operating procedures during the experiment baseline conditions.

Controllers' confidence in the operating concept and the developed support tools was high. The advisories generated by the system (CTA times, sequence numbers, time to lose/gain) were in accordance with ACC controllers' expectations. On the other hand, the APP controllers found the provided time to lose/time to gain not useful, the information provided should at least be updated more often. The arrival sequence number was appreciated by the APP controllers. In the RTS1 simulation a decrease in the number of instructions and the coordinations by APP concept was observed with the ERAT concept.

This may indicate a decrease in taskload for APP controllers. For the ACC controllers the ERAT concept did not influence the number of instructions and coordinations in a positive or negative trend, indicating no influence on the ACC task load.

Overall, the acceptability of the ERAT concept and operating procedures by both the approach and en-route controllers was rated positively. During the trials some suggestions were made for improving the concept.

- Improved performance modelling of heavy aircraft and turboprop aircraft;
- Potentially increase the 100 seconds interval over the CTA point;
- Improve the trajectory prediction with down-linked parameters.

The ATM system and HMI was also rated positively by both ACC and APP controllers, while several improvements were suggested. ACC controllers rated a slight decrease of Situation Awareness with the ERAT concept. The overall score was still sufficient so that this was not considered an issue with the traffic loads tested in RTS1.



Figure 13: Approach control positions during ERAT Arlanda trials

RTS 1 gave insight in the consequences of the design of the routes, in the timing of providing CTAs and potential improvements to the AMAN/TP. As a result the following improvements were identified for implementation in RTS2:

- Improvement of the AMAN algorithm for integrating short haul flights.
- The AMAN cost index that AMAN uses internally to select the optimal sequence and CTAs could be improved using controller feedback.
- The trajectory predictor could be improved by better modelling of aircraft performance, ILS interception and FMS CTA behaviour.
- Information could be added in the AMAN timeline display to support the controller in determining whether an aircraft was increasing or decreasing speed in order to meet its CTA.
- Time to lose / time to gain information from AMAN can be removed from the radar display once the aircraft entered the TMA.
- The AMAN timeline display can be extended with a visual warning that indicates when manual changes to the arrival sequence infringe required separation.

2.4.2 RTS2 results

The second RTS evaluation was carried out at NLR in Amsterdam. This RTS2 session evaluated the concept and system improvements that were made based on the results and feedback from the RTS1 evaluations. Experience from RTS1 was also used to further enhance realism of the simulation and the operating environment to be in a better position to assess validation results. In addition, the more innovative concept of applying shorter RNP arrival routes in a busier environment was evaluated.

The achieved level of realism for RTS2 was high. Similar to RTS1, ACC sectors for Stockholm ATCC were combined into two large sectors. These sectors also comprise airspace today managed by other centres. Overall traffic levels were higher than in RTS1 in order to better evaluate the effect on departing traffic and also to create more complex situations for CTA allocation. To keep workload for the ACC controllers at an acceptable level, the number of overflights, Arlanda departures, and Bromma traffic was limited compared to reality. The APP controller on the West sector mentioned that the exercises were more challenging compared to RTS1 due to the more complex traffic sample. However, the RNP STARs also challenged the modelled aircraft operational behaviour and some deficiencies were seen in this context.

Under the more demanding and realistic simulated traffic conditions, using the standard P-RNAV STARs, the achieved success rate of CDA arrivals remained high during RTS2. The short RNP based arrivals scored a lower success rate which became visible in the higher amount of controller intervention during the final part of the approach compared to the standard P-RNAV arrivals. A number of reasons were identified. E.g. controllers and pilots were relatively unfamiliar operating the shorter procedures, resulting in a steep learning curve. Also, operational (altitude) constraints in the STAR definition resulted in unrealistic high speeds during the last part of the procedure.

In terms of fuel efficiency, the shorter RNP based arrivals did produce reduced fuel consumption figures and flight times compared to the P-RNAV based arrivals from top-of-descent to landing, despite more vectoring with the shorter procedure. This was probably fully attributable to the overall reduction in track distance to be flown with the shorter procedure.

In terms of capacity the RTS2 trials indicated again that the standard P-RNAV arrivals could well accommodate landing rates of 32 including higher traffic peaks. As already indicated the RNP arrivals were tested under the same traffic conditions but resulted in a larger amount of interrupted CDAs and vectored final approaches. It was mentioned by controllers that the RNP arrival route may be better workable and feasible under lower traffic loads than now experienced in RTS2. The efficiency and acceptability of the short RNP routes should be improved in several areas, e.g. route redesign to better handle departures and review of altitude and speed constraints. The confidence in the ATC system support (AMAN and CTA functionality) during RTS2 scored positively by ACC and APP controllers.

2.4.3 Environmental assessment results

The fuel burn assessment resulted in a 3% improvement with the shorter RNP STARs, and no significant differences in the fuel burn with the P-RNAV STARs within the same traffic sample. The noise contour surfaces were reduced by 10 to 20% with the ERAT concept of operations (except for the highest noise levels close to the runway), and their shapes were very different between the 2 concepts, meaning a displacement of the impacted areas. More details of the environmental assessments for the ARN concept can be found in deliverable ARN D8-1 (ref.[18]).

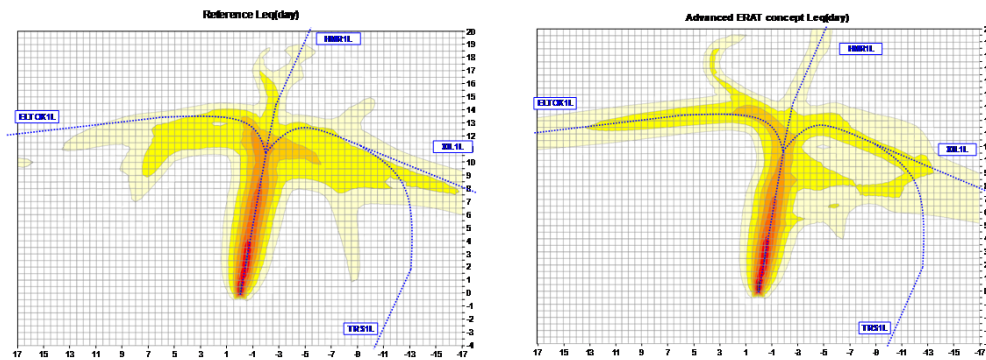


Figure 14: Comparison of the Leq contours for the baseline and the advanced ERAT concept (no scale)

2.5 Conclusions and lessons learnt

2.5.1 Conclusions for ARN concept

The ERAT Arlanda simulations have definitely proven benefits of the concept regarding predictability and efficiency. The concept and the advanced arrival management tool that have to support the concept seemed to cater for possibilities to reach higher efficiency. It was also enabling time based operations and providing means to improve environmental sustainability. More than 32 arrivals per hour were accommodated with P-RNAV procedures, and up to 30 for the RNP organised arrival routes. Overall, the participating controllers found the concept feasible and acceptable and judged the safety to be maintained. The concept is limiting flexibility, but is considered to be acceptable in these traffic loads.

The RTS1 trials showed that with the ERAT concept, CDA procedures were feasible in medium/high traffic density with an acceptable way of working for the controllers. During RTS2 a shorter RNP based STAR was assessed on its efficiency and acceptability in addition to the P-RNAV based arrival routes. The experience gained with these RNP STARS was quite limited with five measured exercises that were comparable to equal scenarios and seating runs with the P-RNAV based STARS.

Controllers and pilots were familiarised in two runs with the new RNP procedures and it should be noted that a steep learning curve was visible after just a week of simulation. However, given these limitations the results seem quite promising.

The flexibility of the ERAT concept and RNP routes was not explicitly tested with e.g. runway changes or closings due to the limited number of available runs. However, the ERAT concept with the used P-RNAV and RNP routes showed enough flexibility to deal with short haul flights and turboprop operations, which can be a disturbing factor in actual operations.

2.5.2 Lessons learnt from the ARN concept development work

For future RTS validation exercises, a proper definition of a baseline should be developed. This will benefit comparisons during the assessments. Defining what is a good baseline is not easy because there are many variables determining the outcome of a simulation run. In the case of Stockholm Arlanda, it was found that the controllers currently managed the air traffic quite efficiently already.

Prior to the validation exercise, the environmental assessment methodology should be determined so that adjustments could be made to the traffic scenario in such a way that the validation results comply with the input requirements of the applied tools. It was not possible to obtain exact figures for emissions in an RTS platform.

The realism of traffic behaviour is very important in a RTS exercise mirroring advanced arrival management. Therefore platform preparation and setting up a RTS was a very serious task. It needed to be well coordinated and iteratively checked. This required longer lead times, which was not always available in project ERAT. Finally, the personal relationships among team members formed an important success factor.

3 London Heathrow airport

3.1 Background and tailored objectives

In the ERAT project, NATS planned their activities such that they could undertake two concept development cycles. These cycles included the initial route procedure design and validation stages.

Three concepts were proposed for validation through fast-time and real-time simulations:

- A 'Two Hold' concept which used present day holds but switched between using just the easterly or westerly two holds depending on wind direction.
- The HEART1A concept which used P-RNAV transitions to deliver traffic from two holds (which were higher and closer than present day holds) to final approach. The 'Two Hold' concept proved to be an important element in HEART1A. The varying usage of the P-RNAV transitions in this concept was also investigated.
- A refined concept called ERAT LHR concept which used an evolved HEART1A design with the addition of Point Merge and Path Stretching/Shortening features.

All of these concepts were designed to enable Continuous Climb Departures (CCDs), allow more Continuous Descent Approaches (CDAs) where traffic situation allows, both with the objective to reduce fuel consumption and emissions, and assume the use of enhanced-AMAN to reduce airborne holding.

3.2 Concept of operations

3.2.1 Current operations in brief

The London TMA airspace covers five civil airports of the greater London area. These airports are Heathrow, Gatwick, Stansted, Luton and City. Arrivals for London Heathrow are directed from en-route to one of the four holding positions situated at the four corners of Heathrow, from which each aircraft is then vectored towards the runway. There are no fixed arrival routes and continuous descent clearance from 7000 or 8000 ft may be given on ad-hoc basis whenever the traffic situation allows.

These working procedures of managing air traffic make it difficult for airlines and for NATS to estimate track miles and fuel consumption for each arrival prior to the actual flight. In addition, there is also no track predictability which makes arrival planning in advance very difficult.

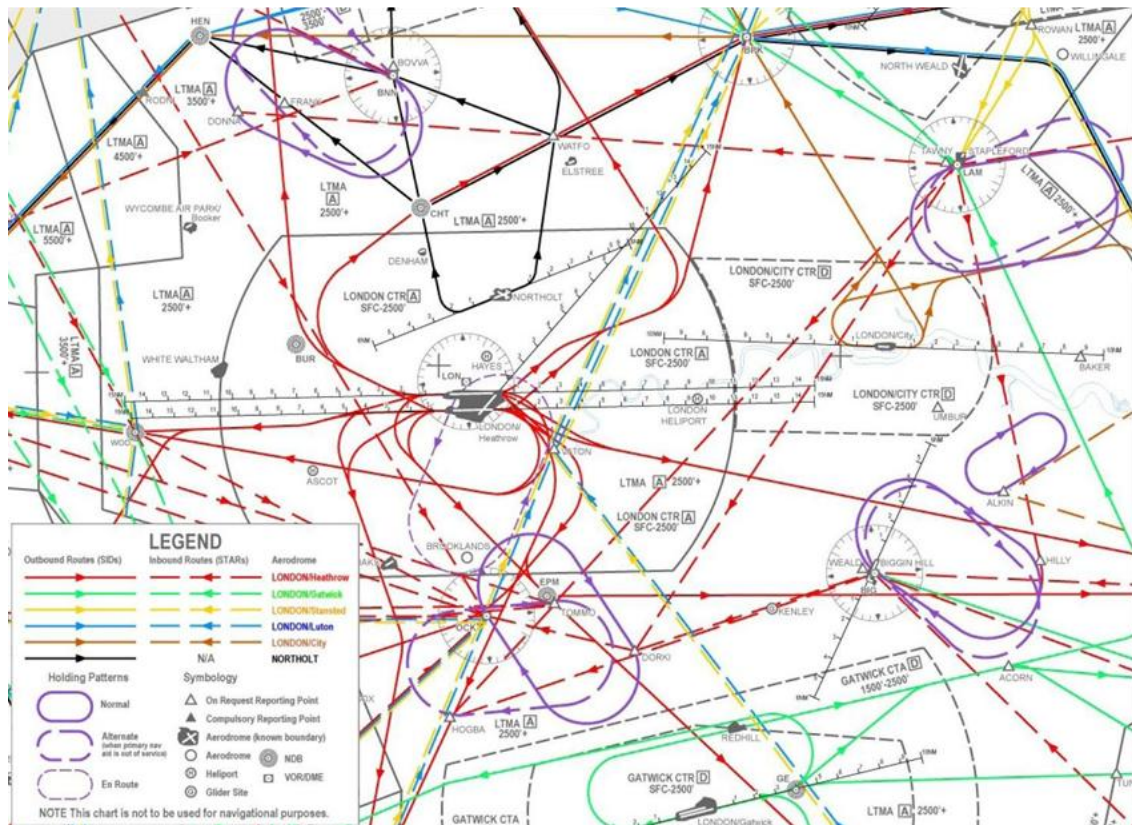


Figure 15: Current operations London Heathrow

However this working method allows for a high airport throughput as each gap between aircraft can be filled. The current landing rate varies between 42 and 44 per hour per runway.

Departures are cleared to climb to 6000 ft and have to fly level until they are clear of the arrival flows. For the many long haul flights from Heathrow this cost lots of fuel, especially because each departing aircraft is heavy as it carries fuel for the rest of the trip.

3.2.2 Two-stack switchable procedure / 'Two Hold' concept

The 'Two Hold' concept was heavily based upon the current mode of operation at Heathrow, but utilised just two of the existing four inner holding stacks at any one time. It was hoped that the removal of two of the holds will facilitate improved, perhaps even continuous and unconstrained, climb departure profiles. Presently departing traffic is forced to step-climb and is subject to sustained periods of level flight. This is in order to ensure vertical separation between the arrival and departure flows.

This concept utilised two of the existing four holding stacks in a 'switchable procedure'. For 'Westerly Operations' where Runways 27L and 27R are in use, Lambourne (LAM) and Biggin Hill (BIG) would be in use for North-side and South-side holding respectively. For 'Easterly Operations' where Runways 09L and 09R are in use, the available holding facility would switch to Bovingdon (BNN) and Ockham (OCK).

In the event of degradation in the available runway capacity (i.e. temporary runway closure, weather) which results in a demand/capacity imbalance, the concept allowed for a reversion to the four stack system. In such instances departure traffic would be

constrained by the presence of all four holding stacks (as is the case today) albeit for a temporary period of time until the demand/capacity balance is resolved.

The 'two hold' concept relies upon enhanced AMAN capability to deliver a smoothed and metered flow of traffic into the TMA.

3.2.3 HEART1A concept

The HEART1A concept for London Heathrow was an innovative queue management concept aimed to deliver benefits to both arrival and departure traffic into and out of London Heathrow.

This concept was based on Performance Based Navigation (PBN) procedures within the Terminal Manoeuvring Area (TMA). The procedure is a wholly systemised 'closed-loop' environment in which the aircraft are expected to fly in fully automated flight to achieve Precision Area Navigation (P-RNAV) conformance criteria.

The over-riding principal behind this concept was that pre-defined 3D paths were established within close proximity to the airfield, such that the airspace dimensions of the Radar Manoeuvring Area (RMA) were reduced. The vertical and lateral profile was designed in such a way as to strategically de-conflict arriving and departing traffic. This allowed departing aircraft to fly a much improved climb profile. Where today departing traffic is forced to step-climb and is subject to periods of level flight in order to ensure vertical separation from arriving traffic, this concept will facilitate improved, perhaps even continuous and unconstrained, climb departures.

Points ALPHA and BRAVO served as the Initial Approach Fix (IAF) for the procedure, for the north and south side respectively. The IAFs are located at approximately 8NM from the airfield. In addition, the minimum level at the IAFs is considerably higher (approximately FL120) than would typically be expected of an IAF in such close proximity to an airfield. The combination of a 'close-in, high up' IAF meant that a relatively elaborate lateral route was required to accommodate the required descent. As such a certain amount of manoeuvring was necessary from the IAF to the Final Approach Fix (FAF). See also Figure 16.

The HEART1A concept relied upon an enhanced Arrival Manager (AMAN) capability to deliver a smoothed and metered flow of traffic into the two holds. In addition, the enhanced AMAN should provide advanced capabilities such as:

- the potential to significantly reduce airborne holding;
- optimise threshold delivery based on a number of factors (including wake vortex optimisation and stack departure time calculations);
- offer a significant reduction in workload for Tactical Traffic Managers (especially during 'non standard' conditions) and
- a high degree of flexibility to react to changing situational factors (temporary stack closures, stack prioritising, etc.).

More in-depth details can be found in ERAT deliverable LHR D4-1 (ref.[19]).

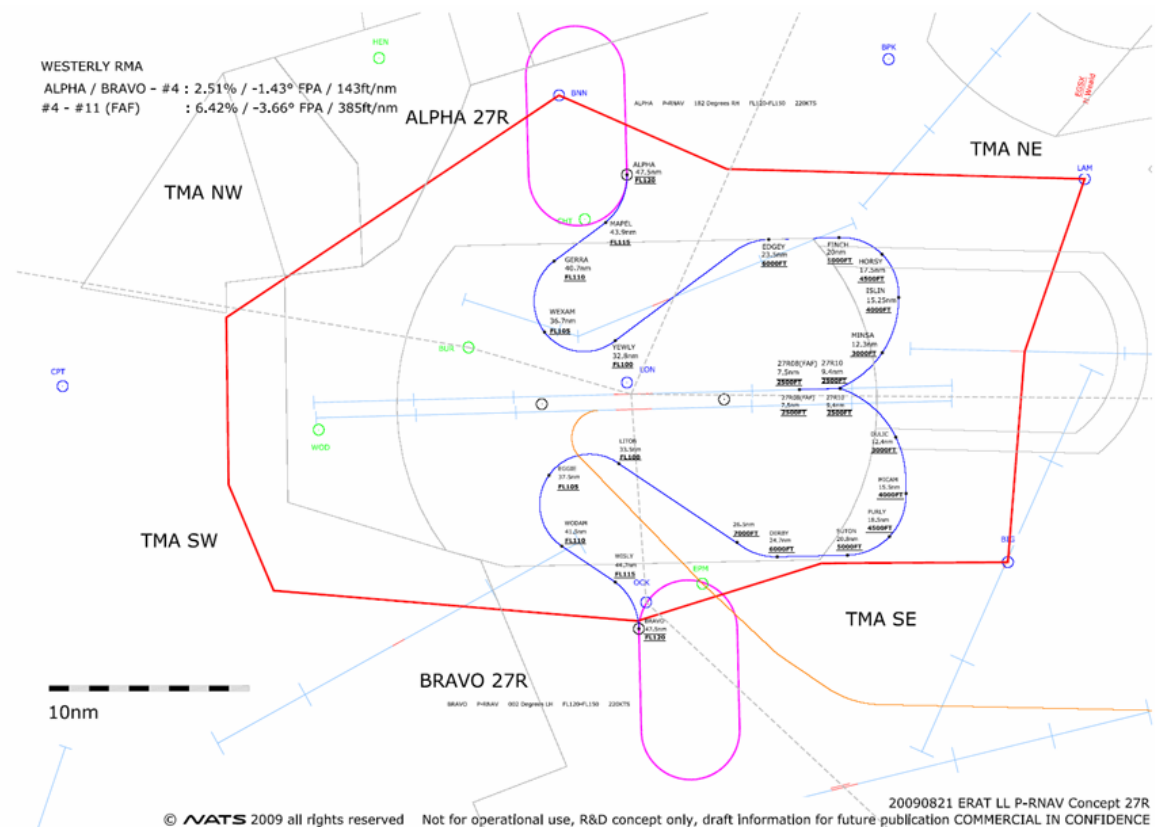


Figure 16: HEART1A concept

3.2.4 ERAT LHR concept

The proposed concept aimed to deliver benefits to both arrival and departure traffic into and out of London Heathrow. The refined ERAT Concept of Operations for London Heathrow described an innovative arrival concept based on:

- High level airborne holding;
- Precision navigation approach transitions;
- Path stretching and shortening;
- Point-merge.

In present day operations, the holds at London Heathrow severely restrict the departing aircraft's ability to achieve a continuous climb profile. The location and vertical extent of the existing holds serve as a blocker to departing traffic, resulting in departing aircraft flying significant portions of level flight underneath the holds in order to achieve vertical separation from arriving aircraft. The proposed concept of operations targeted the removal of these blockers to enable unconstrained, continuous climb departure profiles.

The concept built upon results in earlier work streams (HEART1A concept) that considered high level airborne holding alongside closed loop systemised arrival transitions for Heathrow approach. The refined concept maintained higher level holding for arrivals but also incorporated procedures for path stretching and point-merge transitions into the precision navigation approach path with the aim to increase the arrival landing rate from the previous concept of operations.

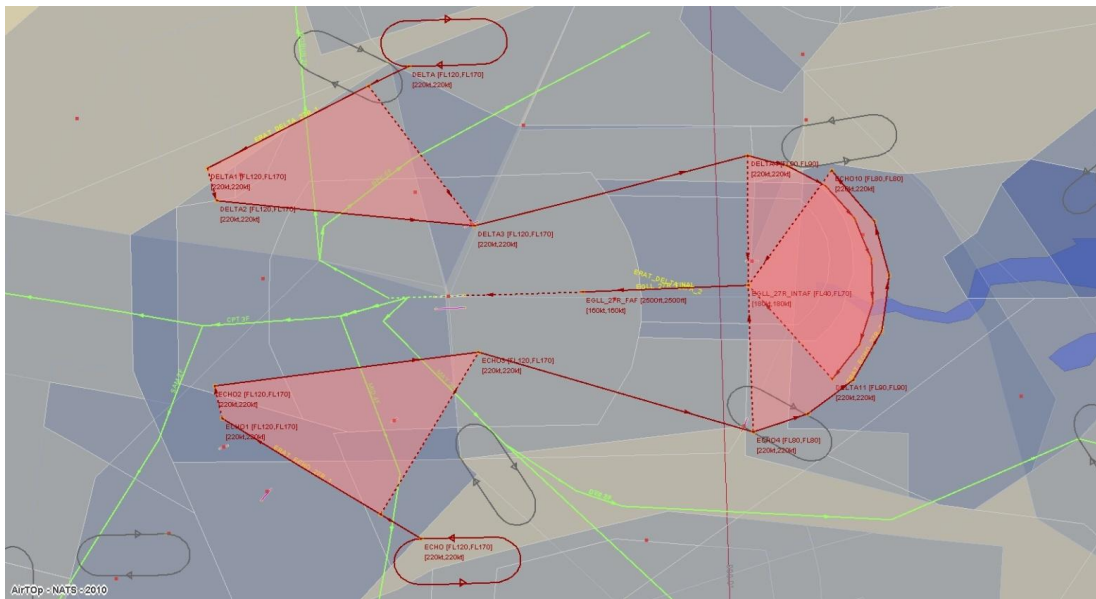


Figure 17: ERAT LHR concept

Concept characteristics

The following characteristics were expected to contribute to benefits.

- Efficient and Optimized Climb Profiles (Continuous Climb)
 The provision of less constrained and uninterrupted departure climb profiles was the main environmental driver behind both the HEART1A concept and the ERAT LHR concept. Presently, aircraft departing on Standard Instrument Departures (SIDs) from Heathrow are restricted to 6000ft on the initial climb. This is due to a prohibitive Minimum Stack Level (MSL) of the conflicting inner holding stacks set at FL70 (dependent on barometric pressure). The removal of the existing low-level inner holding stacks removed this blocker.

The two new holding fixes were located in a similar region to today’s four stacks but were placed higher so as not to be in conflict with aircraft departing on Heathrow SIDs. As such, departing aircraft would be able to realise far improved departure profiles than is presently the case.
- Efficient and Optimized Descent Profiles (CDAs)
 The concept of holding higher up was expected to facilitate improved climb profiles for aircraft departing from LHR airport. However, in addition to the main departure benefits, arriving aircraft were expected to benefit from more efficiently optimised descent profiles. P-RNAV transitions were designed to facilitate improved Continuous Descent Approaches (CDAs) to be flown in a safe and consistent manner.
- Improved flight efficiency
 The P-RNAV environment should optimise the use of onboard navigation systems and allow more accurately flown trajectories, leading to better predictability as well. Furthermore, the concept was predicated upon the use of an advanced Arrival Management (AMAN) tool and as such the amount of airborne holding was expected to reduce over present day levels. Whilst a certain amount of holding was required to maintain the reservoir of aircraft available to the Approach Controllers

with which to service the landing rate, an overall reduction in stack holding was expected.

- **Concept Maturity**
The ERAT LHR Concept of Operations is evaluated according to the European Operational Concept Validation Methodology (E-OCVM) as level V1, 'Scope'. The validation activities planned within this project aimed to bring the concept into V2, 'Feasibility'. The Concept of Operations would be refined as research matures through the validation lifecycle. Further NATS internal validation work planned after the completion of the reported validation activities and SESAR research (Work Packages 5 and 6), would aim to develop the concept through the later stages of V2 into V3 and V4.

As the concept was viewed as V1 at that time, the concept was necessarily considered immature and at a high level. Therefore, the validation activities described herein made use of fast time simulation to test the theoretical environmental impact of the new concept against the previous HEART1A concept and today's operation. The platform would enable a first look at whether or not the new concept would deliver an improved landing rate in comparison to the HEART1A concept, and allow for sensitivity analysis to consider the robustness of the findings to different assumptions and concept elements. More in-depth details can be found in ERAT deliverable LHR D10-1 (ref.[23]).

3.3 Validation approach

3.3.1 Validation plan

Real Time Simulation (RTS) was utilised to validate both the Two Hold and HEART1A concepts. As controller acceptance of any developed concept was imperative and no known future validation activities were planned, an RTS was the only suitable method for providing a comprehensive assessment of the concepts.

A number of factors influenced the decision to utilise FTS for the concept refinement. RTS validation is expensive and provided limited scope for measuring many different scenarios. It was known at the time of taking the decision to validate the concept refinement that further RTS validations were planned within the NATS Airspace Management Programme and SESAR related projects. A logical approach would therefore be to inform and de-risk these RTS validation activities with output from the ERAT FTS whilst allowing a more dynamic range of scenarios to be tested under ERAT for the LHR concepts.

Validation for the ERAT LHR concept was currently only at the proof-of-concept stage. The modelled scenarios considered the concept in isolation and did not consider the impact on the rest of the larger London TMA. Given the lack of concept maturity at that time and the desire to assess the impacts of small changes in input parameters, it was decided that FTS would be the most suitable tool to achieve the aims of this project.

3.3.2 RTS preparation for HEART1A

The main purpose of the real-time simulation was to assess the feasibility of the HEART1A concept and the 'Two Stack Switchable' procedure.

The objectives were:

- To assess the operational feasibility of the proposed concepts;
- To assess and quantify environmental impact reduction against baseline data;

- To provide evidence to support the safety assurance required of the proposed airspace, associated route structure and procedures;
- To determine the capability of the revised airspace to support simulated traffic levels;
- To assess the suitability of the revised vertical and lateral dimensions RMAs/Controlled Airspace;
- To assess the suitability of the proposed P-RNAV transitions
 - Assess the controller's ability to achieve target spacing
 - Assess the suitability of the phraseology
- To assess and develop procedures with regard to non-normal scenarios
 - Runway change (direction)
 - Runway closure (temporary)
 - Missed Approach Procedure (MAP)
 - RT failure
 - Aircraft equipage (P-RNAV) failure
 - P-RNAV non-conformance (i.e. aircraft not sticking to the profile)
- To assess the suitability the proposed holds;
- To assess the suitability of the holding procedures
 - Determine the most appropriate release point
 - Determine the lowest feasible release point
 - Determine the highest feasible release point.

Please refer to deliverable LHR D5-1 (ref.[20]) for further details of the experimental plan.

3.3.3 Flyability check HEART1A

As a part of assessing the HEART1A concept at London Heathrow Airport, the flyability of the developed procedure needed to be evaluated from a pilot point of view. For NATS this flyability check was meant to determine if such procedure could be introduced and to evaluate if it delivered the benefits as what designers had expected. In addition, the results from the check may reveal what changes were required to optimise it for the airspace users. When NATS took the decision to continue with such procedure for their follow-up concept designs, the results of this check would also contribute to the corresponding route design structure.

The NLR moving base flight simulator (GRACE) and the Lufthansa Flight Training Simulator were used to perform an initial evaluation test performed by an experienced pilot. Lufthansa had offered to deploy the A320 and A330/ A340 full flight training simulator for this purpose.

In preparation of the flyability check in the flight simulator, the Flight Management System (FMS) database needed to be updated to include the developed routes and waypoints for navigation. The arrival and departure routes used in the LHR ERAT CONOPS were different from the current routes and therefore not yet available in the FMS database.

During the flyability check in the Lufthansa simulator, several aircraft performance data would be measured as well as subjective data using questionnaires. Finally, flight safety would also be assessed as part of the flyability check.

3.3.4 FTS validation for the ERAT LHR concept

The aims of this FTS were:

- To assess HEART1A against current day operations, and compare the results with the results of the RTS in ERAT Phase 1. The aim of this is to provide some validation of the FTS by comparing it to equivalent RTS;
- To assess the incremental benefits of ERAT LHR against HEART1A;
- To assess ERAT LHR against current day operations.

Assessments would be made by comparing key environmental, safety, capacity and efficiency metrics for each of the concepts. For the purposes of this project, LHR is viewed in isolation. The wider implications of these new concepts on the London TMA were outside the scope of this project and were not considered.

Key Performance Areas

The following section provides an overview of the Key Performance Areas (KPA) which would be assessed for each of the concepts being modelled in the FTS tool AirTOP.

- Safety

The Concept of Operations for London Heathrow should allow for no reduction in the baseline safety index. The following safety benefits relate to enhanced situational awareness and a reduced workload for approach controllers.

 - Enhanced Situational Awareness

The pre-defined P-RNAV vertical and lateral paths would deliver increased predictability of aircraft performance for both Air Traffic Controllers and Flight Crew. Predictability is a key element in establishing and maintaining robust levels of Situational Awareness (SA).
 - Reduced Workload

The shift from a wholly tactical vectoring environment to one predicated on the use of systemized P-RNAV routes within the TMA would deliver considerable reductions in controller and flight crew workload. Specifically, Radio Telephony (RT) transmissions were expected to reduce in number as a consequence of the change.
- Capacity
 - Runway Capacity

Whilst the proposed concept for London Heathrow did not explicitly target capacity gains, it should be recognized that the concept should allow for no reduction in baseline (2010) capacity. London Heathrow is a capacity constrained airport with the runway resource scheduled at approximately 98% available throughput. It is therefore fundamental that the concept maintained this rate and allowed for no degradation in runway throughput or overall system capacity.
 - London TMA Capacity

It was expected that increased movements to and from London's four other major airports would result in a noticeable increase of TMA traffic levels in 2015. The concept would therefore be required to successfully accommodate this growth.
 - Radio Telephony (RT) Capacity

It was expected that the high number of RT transmissions characteristic of a tactical vectoring environment would be significantly reduced, thereby releasing valuable RT capacity.

- Environment
The ERAT LHR Concept of Operations for London Heathrow was primarily driven by targeted Environment Key Performance Areas. The primary benefits were expected to come from Continuous Climb Departures and Continuous Descent Approaches.
- Efficiency & Cost Effectiveness
The Concept of Operations for London Heathrow was expected to deliver improved flight efficiency in terms of shorter flights (time and distance) and reduced fuel burn (and emissions).

3.3.5 Environmental assessment methodologies

Two different methodologies were applied on the London Heathrow case:

- One environmental assessment, using Airbus' performance and environmental models.
- One environmental assessment, using publicly available environmental models (INM and AEM), and based on trajectory data from traffic simulations. Although there may be other models to be used, these models have been chosen because they are the most commonly used when assessing noise and emissions.

Both methodologies have their own strengths and limitations, and none proved to be perfectly adapted to the evaluation of an advanced concept of operations. The major strengths and limitations are summarized below.

The first assessment was based on manufacturer's data, both for the aircraft performance models and the environmental models.

- The performance models used allowed to generate trajectories that were representative of the real aircraft design. The tools not only allowed to represent the climb, acceleration, descent and deceleration capabilities of the aircraft, but also the trajectory predictions from the FMS (for departure and approach). These predictions translated into indications or cues to the flight crew, which allowed representativity of the trajectories.
- On the other hand, these tools were not fully appropriate to model real operational trajectories. In particular they required a lot of iteration steps to compute each trajectory. For this reason, there was no easy solution to account for specificities of individual trajectory, such as tactical intervention from the ATC.
- The environmental models were the most accurate data available, in terms of noise (NLCP) as well as emissions and fuel consumption (EMIS). In particular, Airbus' tools allowed the modelling at approach, of aircraft configuration change or the impact of speed.
- On the other hand, only Airbus aircraft could be considered with this methodology, which required performing a fleet substitution for a mixed fleet.

The second assessment was based on publicly available models:

- It used the trajectories coming out of the traffic simulation performed at NATS. A review of the models developed by NATS to feed their RTS platform has concluded that they were simplistic as they focused on airspace modelling rather than aircraft performance. They did not account for flight mechanics equations, and even do not consider major parameters for aircraft performance and environmental impact,

such as the engine thrust or landing gear position. For these reasons, they were not considered usable for the environmental assessment conducted by Airbus, and required to reconstruct some parameters for the assessment performed by To70.

- On the other hand, and even though the trajectory data could not be used directly but require significant post-treatment, this methodology made use of trajectories from the traffic simulations, which meant that it accounted for lateral path dispersion, per ATC radar-vector instructions.
- Due to the simplistic modelling of the aircraft performances in the traffic model, the vertical part of the trajectory was considered not representative of the real climb or descent capabilities of the aircraft, which obviously affected the assessment of noise and emissions.
- The noise model (INM) relied on limited physical assumptions that limited their use for assessment of real operational procedures: approach NPD (Noise Power Distance) data available in the Aircraft Noise and Performance (ANP) database were provided for a single reference speed and aircraft configuration (Configuration 3 / landing gear down in the case of Airbus aircraft). Hence, computed noise was relevant only for the part of the trajectory flown around this reference speed and in configuration 3 aerodynamic configuration / landing gear down.

Further than a matter of absolute level, it was an issue of sensitivity: along with altitude and thrust, speed and aircraft configuration were the main parameters that drove noise in approach. It was therefore not possible to assess the enhancement brought in approach by an operational concept while not considering these parameters. The above limitation in current Doc.29 / Doc.9911 was recognised within international working groups such as ICAO-CAEP/MDG and SAE A-21 Committee, which investigated modelling improvements to address the issue.

3.4 Results

There were two concept development cycles for London Heathrow (LHR) which followed up each other. Both concepts were defined with the aim to reduce environmental impact while maintaining current capacity and safety levels. The airport throughput was an important and decisive factor in both concept designs. As explained earlier, two different validation means were used:

- RTS for the Two Hold and HEART1A concepts. The results were reported in deliverable LHR D6-3 (ref. [21]).
- FTS for the refined LHR concept. These results were reported in deliverable LHR D10-3 (ref. [25]).

3.4.1 RTS results of the concepts: Two Hold and HEART1A

The real-time simulations were held at NATS' Corporate and Technical Centre (CTC) in September and October 2009. Three Heathrow positions were fully simulated (Final, Intermediate North and Intermediate South directors) with valid ATCOs manning these positions and four TMA feed positions.

Two Hold Concept results

The landing rate when operating the 'Two Hold' concept was not adversely affected. However when changing runway directions, the process of switching between East and West holds significantly increased the TMA feed controllers' workload as they had to coordinate between themselves to stream traffic into one hold from opposite directions. They commented that the process was complicated and identified the lack of procedures as an issue.

Raising the minimum stack level was the concept that the controllers found most acceptable. The landing rate was not significantly affected, however the controllers commented that the current system was not perfect and that, on days with high atmospheric pressure, they sometimes had difficulty dealing with all of the arriving traffic. Reducing the number of available levels even further would exaggerate this problem.

HEART1A Concept results

The simulations highlighted a number of limitations, particularly with regards to the service delivery aspects of the concept. Results showed that the concept caused numerous problems and disadvantages in the simulated Heathrow environment and as such the concept was unsuited for busy and complex airports during their normal intensity operations.

The landing rate was significantly reduced during the HEART1A runs. The amount of holding increased and the controllers expressed concerns about the safety implications of the concept. The Heathrow controllers gave several reasons why the landing rate was reduced:

- They found it difficult to judge spacing between aircraft on curved transitions;
- The transitions did not provide enough flexibility to establish and maintain the appropriate landing sequence;
- Due to moving from four holds to two, it was harder to achieve the optimum order of aircraft to achieve optimum (minimum) wake turbulence separation.

Changing from four holds (each with ten levels) to two holds (each with four levels) with no mitigating procedures meant that it was unsafe for the TMA feed controllers to continuously stream arrivals into Heathrow. To maintain a safe operation the TMA feed controllers held aircraft further out from ALPHA and BRAVO until there were clear levels. This resulted in aircraft flying into ALPHA and BRAVO in waves instead of a steady stream. The TMA feed controllers' workload also increased significantly as they had to coordinate with each other to stream traffic into one hold from opposite directions.

With the level of traffic used in the RTS, it was impossible to merge two streams of aircraft (from the North and South P-RNAV transitions) into one final approach stream, with aircraft spaced as closely as possible and in the optimum order, using only speed control without any tools support. Two P-RNAV transitions feeding into one approach sequence was found not to work at an airport as busy as Heathrow. The intermediate (INT) and final (FIN) directors needed to be able to vector aircraft to maintain the required spacing. Speed control alone was not enough.

The Heathrow directors raised safety concerns over the separation required between aircraft on P-RNAV transitions and aircraft which have been given vectors. Taking an aircraft repeatedly on and off a P-RNAV transition exacerbated this problem and the controllers said that this would be unacceptable to pilots.

3.4.2 HEART1A recommendations for follow-up concept development cycles

There were fundamental problems with the HEART1A concept when applied to Heathrow. If solutions to these were found then it may be worthwhile investigating the concept further. Otherwise progression of the HEART1A concept at Heathrow is not recommended. However it may be worthwhile investigating the use of the HEART1A concept at other airports which are quieter than Heathrow (e.g. medium density and complexity) and do not have other medium/high complexity and density airports within such close proximity. The capacity of these airports may not be affected by systemised approaches and they could take full advantage of improved departure profiles.

As the RTS main focus was on the Heathrow directors, the TMA positions were feeds and as such they were not simulated fully. However, as some of the biggest problems were found in the TMA feed positions, future RTS should simulate the TMA positions more accurately. This would involve splitting the TMA sectors and including other traffic in the samples. It may also be beneficial to simulate TMA coordinator and Intermediate support (INT SPT) positions.

Revising the STARs and SIDs to de-conflict arriving and departing traffic should be investigated. A complete airspace redesign may be needed to allow the concept to work. This RTS did not feature enhanced AMAN, using instead traffic streamed as if AMAN was in use. Future work should assess how an enhanced AMAN display would affect the concept and some of the tools support and HMI issues associated with this.

A method or concept to cope with the reduced number of holds (and holding levels) should be found. The reduction in the number of holds and holding levels reduces the amount of redundancy available within the system to deal with temporary runway closures and special flights. Outer holds would need to be created. Only two holds also reduces the flexibility available to the INT directors over choosing the order of aircraft to deliver to the FIN director (to enable optimum wake turbulence separation ordering).

If the 'Two Hold' (using ALPHA/BRAVO instead of current holds) and 'Raising the minimum stack level' concepts were to be investigated further, those investigations should take into consideration all other traffic and procedures which weren't simulated in this RTS. Additional scenarios, such as temporary runway closures and missed approaches, should also be simulated. Using just two holds could be an option if there were more than four levels in each stack and if those holds did not switch according to wind direction (i.e. use ALPHA and BRAVO but with more levels).

3.4.3 Flyability check HEART1A

Following the real-time ATC simulation by NATS on the overall HEART1A concept, a flyability check was prepared and executed to evaluate the operational acceptability from an airline perspective. These evaluations were performed using the GRACE flight simulator of NLR Amsterdam and the Lufthansa full flight training simulator in Frankfurt. The procedure was flown with different conditions:

- Aircraft types: A320 and A330, representing respectively a medium and heavy aircraft category;
- Weather: two adverse weather conditions were selected in accordance with NATS flyability assessment criteria.

On the NLR and DLH A320/A330 flight simulators combined, there were approximately 24 evaluation runs executed, during which the ERAT HEART1A procedures were flown according to and evaluated against airline standard operating procedures.

Main conclusions were that the HEART1A approach procedure as proposed by NATS was flyable for A320/A330 aircraft types, however not all tested scenarios appeared to be fuel efficient, and some scenarios were expected to have a negative impact on airport throughput, considering the required speed profile needed to comply with all pre-defined speed constraints at waypoints along the designed route. For runs with wind, the speed profile was judged negative and for some runs even unacceptable (due to turn overshoots and potential risk of meeting merge traffic from opposite direction). The HEART1A procedure was judged safe to fly and as such acceptable from a pilot point of view. For all runs the aircraft was stabilised at 1000ft AGL and the procedure was flyable towards the runway under the tested wind conditions.

3.4.4 FTS results of ERAT LHR Concept

One baseline (representing current day operations) and two new concepts were modelled in the Fast Time Simulation tool AirTOp using London Heathrow as the airport of focus. These two concepts were:

1. HEART1A – to be assessed against current day operations.
2. ERAT LHR (a refinement of the HEART1A concept with the addition of 2 manoeuvring areas) - to be assessed against current day operations.

Both concepts 1 and 2 were based on a minimal holding environment using an advanced AMAN. Currently the Heathrow AMAN does not provide this environment, which meant that the operating environment envisaged for the new concepts (1 and 2) represented a significant divergence from current day operations. For the ERAT project, it was vital to distinguish between the changes brought about by AMAN and those caused by the changes to approach and departure operations. For this reason the new concepts (1 and 2) were assessed against a baseline with AMAN. For context, a baseline was also modelled of current operations (without AMAN). In addition, for ERAT LHR environmental impact was assessed.

As the purpose of the fast-time simulations was to compare various Heathrow concepts of operation, only aircraft flying to and/or from Heathrow were modelled. The maintenance of the arrival throughput was considered to be essential to the viability of the concepts. Key results from the simulation are mentioned below.

HEART1A compared to the Baseline

- HEART1A could not achieve a landing rate greater than 26 arrivals per hour which was well below the 39-43 arrivals per hour achieved in the baseline. This was partially achieved through larger AMAN separation criteria.
- Arrivals flew an average 44 NM (7.6 minutes) more than in the baseline. 18 NM of the 44 NM were due to the higher levels of holding.
- When averaged over both arrivals and departures, HEART1A movements showed a 9% increase in the distance flown in UK Airspace and a 7% increase in the time spent in UK Airspace. If the AMAN separation criteria were set to match the baseline, these values could be expected to increase greatly as significantly more time would be spent in the holds.
- The vertical profiles of the arrivals in HEART1A were significantly different to the baseline with aircraft holding at higher levels and then descending continuously to the glide slope.

ERAT LHR compared to the Baseline

- The ERAT LHR arrival rate was closer to that achieved in the baseline, fluctuating between 39 and 43 arrivals per hour during the busy hours. Arrivals flew an average of 44 NM (8.8 minutes) more than in the baseline. 27 NM of the 44 NM were due to the longer approach paths between the Initial Approach Fix (IAF) and touchdown.
- When averaged over both arrivals and departures, ERAT LHR movements showed a 9% increase in the distance flown in UK Airspace and a 10% increase in the time spent in UK Airspace. This result was clearly dominated by the extra track mileage accumulated by inbound aircraft.
- The vertical profiles of the arrivals in ERAT LHR were significantly different to the baseline with aircraft meeting the IAF on average 3000ft higher than in the baseline. However, unlike HEART1A, there were only some sections along the approach path during which the aircraft were able to descend continuously.

3.4.5 ERAT LHR recommendations for follow-up concept development cycles

The fast-time modelling was undertaken as early assessment of the considered concepts. The recommendations were made in order to progress and develop the concepts and the robustness of the results. They are:

1. This simulation assumed perfect delivery of the metered traffic streams. It is recommended that further research is carried out to understand the comparable robustness of the new concepts against less than perfectly streamed arrival traffic.
2. The fast-time environment used in the reported analysis lends itself well to exploring the effects of design changes to new concepts, except for a detailed assessment of the environmental impact. It is recommended that the effects of increasing or decreasing sizes or altitudes of the path-stretching or point merge regions of the ERAT LHR could be explored.
3. The work used a single day traffic sample and demand times. It is recommended that further research explores the effects of different traffic mixes and demand times.
4. Westerly runway configurations were used in this research. It is recommended that the comparative effects for easterly operations should be modelled.
5. It should be noted that the location of the North Atlantic tracks affects the load balance between the Northerly and Southerly stacks. Therefore consideration should be given to the choice, use and analysis of Northabout or Southabout days.
6. Adapt the ERAT LHR concept in a manner to reduce the increased distance flown for arrivals as much as possible because the additional fuel burn in arrival easily outrun the savings in the continuous departure climbs.

3.4.6 Environmental assessment results for the LHR concepts

Although an environmental assessment was made for each concept validation cycle, both results led to similar trends and were therefore combined in this section. The environmental impact of the validated concept of operations showed the following results:

- Fuel burn & CO₂ increase (~2% for HEART1A and ~7% for ERAT LHR, calculated with different methodologies and therefore not comparable) mainly due to the longer approach flight path, whose effect was not offset by the benefits of removing the 6,000ft level flight for departures.
- Displacement of the areas impacted by the noise of departing aircraft, leading to a local noise increase under the current flight level at departure and local noise decrease after the flight level. For approach, the noise contours were very different between both concepts, and the procedures were designed with slopes not optimally designed to enable aircraft to descend continuously in a low-power low-drag condition.
- Marginal NO_x emission increase (+1% for HEART1A).

More details on the LHR environmental assessments can be found in deliverables LHR D8-1 (ref. [22]) and in the appendix of LHR D10-3 (ref. [25]).

3.5 Conclusions and lessons learnt

3.5.1 Conclusions for LHR concepts

The HEART1A concept has shown unfavourable results. The current rate could not be maintained by far, although its innovative route design opened new insights to allow continuous climb departures, where environmental benefits were potentially better than for the arrivals. Therefore, the HEART1A evolved into a more refined concept, called ERAT LHR concept with the addition of path stretching and point merge elements.

The ERAT LHR proved to maintain current landing rates and allow for continuous climbs. However, the route design for arrivals and the use of only two holds resulted in longer track miles. Despite of small stretches where continuous descents could be facilitated, it could not compensate the extra fuel burn.

NATS has learnt many lessons from these concept development cycles in ERAT and has brought these insights into their SESAR projects focused on queue management in a high traffic density, complex terminal airspace.

3.5.2 Lessons learnt from the LHR concept development work

The work undertaken in ERAT showed that the increased fuel burn due to extra miles flown could not be compensated by CDAs. Furthermore, for a high capacity airport, the holding stacks will remain necessary as reservoir to maximise the runway capacity, however with higher holding levels and locations further away, fuel burn for arrivals could be reduced.

Similar to the ARN situation, prior to the validation exercise, the environmental assessments methodology should be determined and the traffic scenario adjusted such that the exercise results comply with the input requirements of the applied tools.

4 Project dissemination

4.1 Dissemination strategy

During the project, the ERAT dissemination strategy was similar to most EU co-funded projects. ERAT was aiming at a broad target audience through the project website, organising dedicated events and a newsletter.

After results were available, the ERAT consortium has chosen for a different dissemination strategy than most EC projects. In this phase, the dissemination strategy was focused on the primary target audience: people involved in European ATM projects, such as SESAR, CleanSky, etc.

The objective of this approach was to ensure that ERAT results would be taken into account in further research and development projects.

4.2 Website

At the start of the project, the project website (www.erat.aero) was developed and information added about the project objectives, approach and activities. During the course of the project, the website was further improved and expanded. Besides regular news updates, the website also contains an overview of the relation between ERAT and other ATM projects and project deliverables. Nearing the end of the project, also a summary of the results was added to inform a broad audience of the achievements of ERAT.

The visitor numbers have increased over time. The table below shows the visitor number of the last 12 months.

Month	Unique visitors
May 2010	117
June 2010	140
July 2010	99
August 2010	96
September 2010	138
October 2010	126
November 2010	131
December 2010	97
January 2011	117
February 2011	103
March 2011	146
April 2011	155

Table 1: Visitor numbers ERAT website over the last year

4.3 Meetings & events

ERAT has organised its own events, but also contributed in many different ways to other events. An overview of all events is found in the table below.

Date	Name/description	ERAT contribution
9-11 March 2010	ATC Global Exhibition 2010	Distribution of ERAT newsletter
13 April 2010	ERAT meets Romania	Organisation and presentations
3 June 2010	ERAT Visitors Day Malmö	Organisation and demonstration of ARN RTS
13-16 June 2010	Inter-Noise	ERAT paper in conference proceedings
18 June 2010	Clean Sky conference	Distribution of ERAT newsletter

Date	Name/description	ERAT contribution
12 October 2010	Meeting CleanSky SGO WP3	Presentation and distribution of ERAT newsletter
16 Feb 2011	Meeting SESAR 5.7.4	Presentation and distribution of ERAT factsheets
3 March 2011	Meeting SESAR 16.6.3	Presentation and distribution of ERAT factsheets
8 March 2011	Meeting SESAR 5.6	Presentation and distribution of ERAT factsheets
8-10 March 2011	ATC Global Exhibition 2011	Presentation and distribution of ERAT factsheets
30-1 April 2011	Aerodays 2011	Presentation and distribution of ERAT factsheets
8 April 2011	Lufthansa Aviation Group	Presentation and distribution of ERAT factsheets
11 April 2011	Meeting SESAR 5.6.1	Presentation and distribution of ERAT factsheets
13 April 2011	ERAT meets Romania	Organisation and presentations
19 April 2011	Final meeting EC/SJU	Organisation and presentations
12 May 2011	Meeting CleanSky SGO WP3	Presentation and distribution of ERAT factsheets

Table 2: List of dissemination meeting and events

4.4 Visualisations

The ERAT consortium has developed several visualisations (videos) for dissemination purposes. These visualisations explain the concepts of operations in a manner that is easy to understand for all audiences. The ERAT website shows all visualisations that were produced in the project.

HEART1A - London Heathrow

For the HEART1A concept a visualisation was created that shows the current operations at London Heathrow and the HEART1A concept of operations. This video was based on the data gathered during the real-time simulations in October 2009.

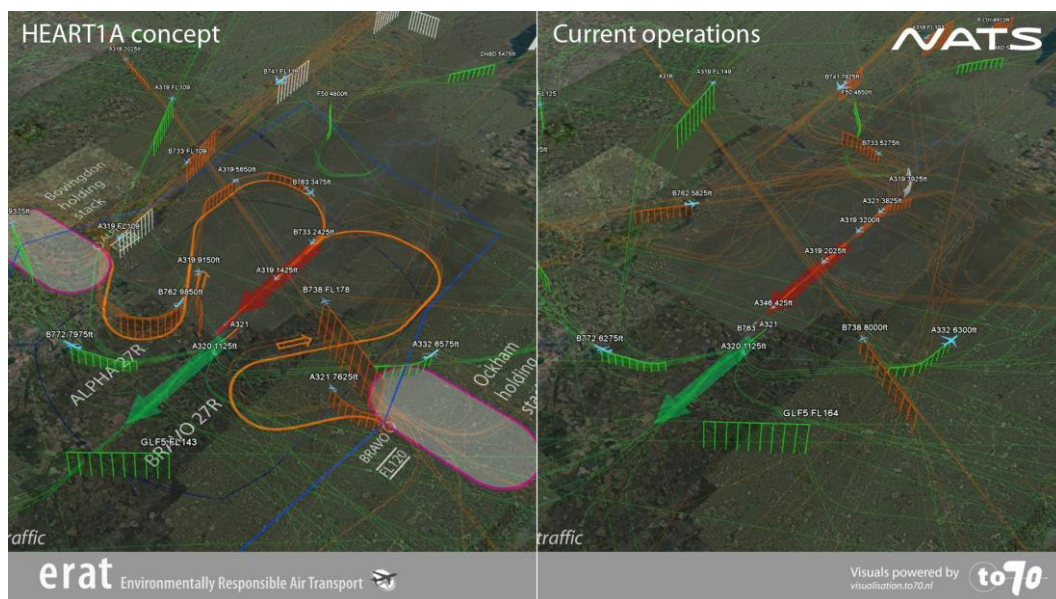


Figure 18: Snapshot visualisation HEART1A concept

LHR concept - London Heathrow

The LHR concept was visualised in two different videos.

The first video shows the current operations at London Heathrow side-by-side with the LHR concept. This gives a good impression of the size of the route structure and the



mode of operations. The video was based on data gathered during the fast-time simulations in November 2010.

The second video visualises the noise footprint for a departure from London Heathrow. On the left side the noise footprint as computed by INM (based on data from FTS) of a departure in the current operations is shown and on the right side the continuous climb departure of the LHR concept. The INM calculations using FTS data are bound to several limitations (please see deliverable LHR D8-1 (ref. [18])).

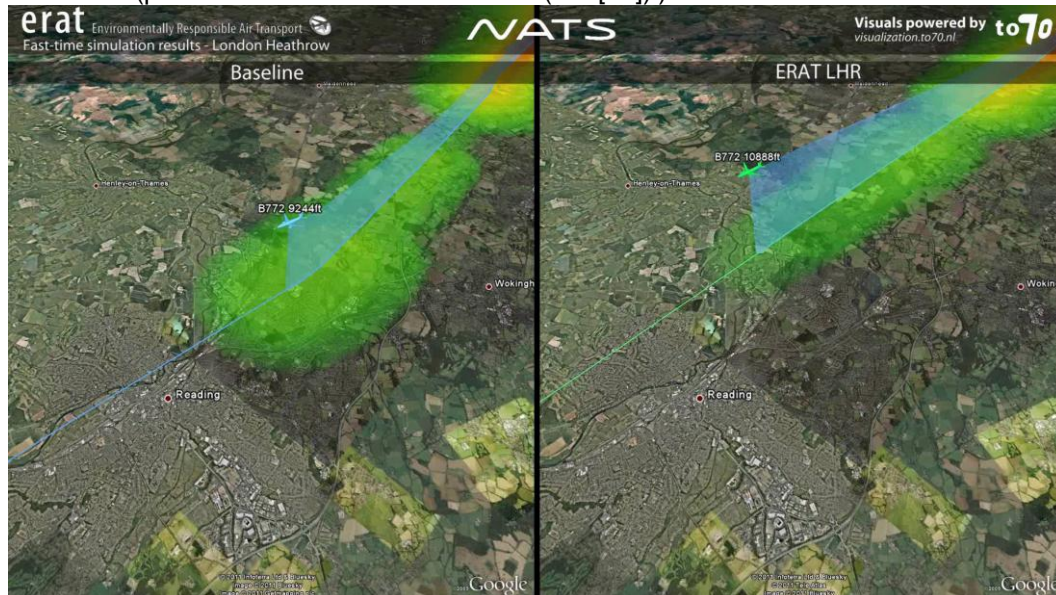


Figure 19: Snapshot visualisation noise footprint LHR concept

ARN concept – Stockholm Arlanda

The Arlanda concept needed a different kind of visualisation. The focus of the concept is time based operation and this is better shown from the point of view of the air traffic controller. Therefore a video was made, which shows how an individual aircraft is handled when approaching Stockholm Arlanda.

Environmentally Responsible Air Transport

Concept of Operations Arlanda Airport
 General Controlled Time of Arrival (CTA) allocation example
 European/intercontinental & regional flight

Visualized chain of events

NLR, Amsterdam, The Netherlands
 NARSIM Real-time ATC simulator
 September 2010

Environmentally Responsible Air Transport

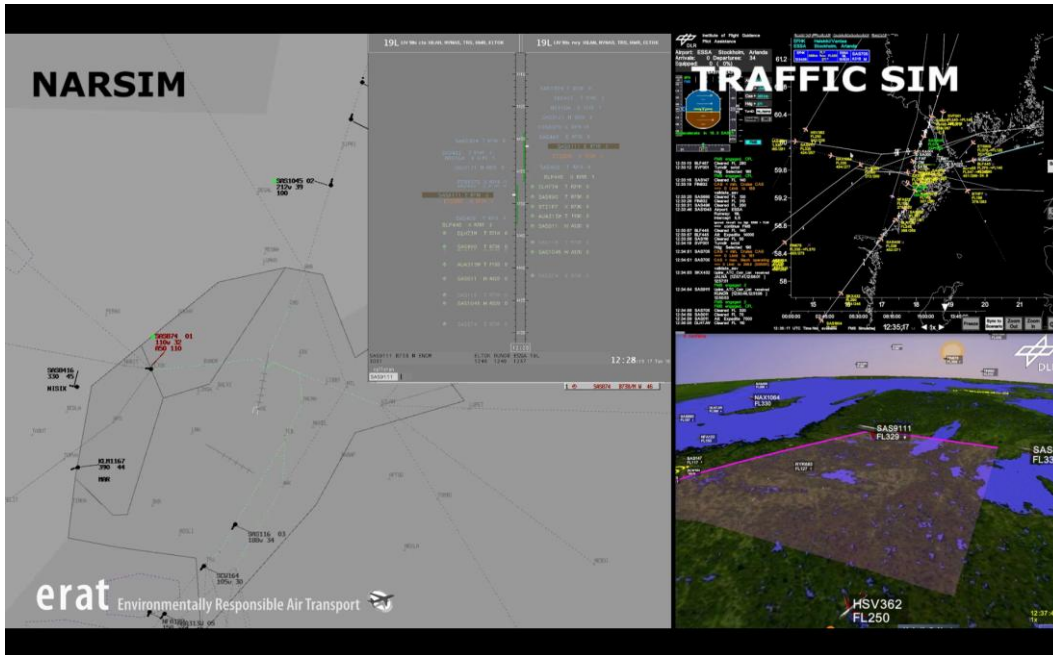


Figure 20: Snapshots visualisation Stockholm Arlanda concept

4.5 Print material

In February 2010 an ERAT newsletter was printed with information about the project objectives, the past and planned activities and the first results. This newsletter was distributed first at ATC Global 2010 and later during other meetings and events.



Figure 21: ERAT print material

In February 2011 all results were available for dissemination and therefore two factsheets were developed. Each factsheet is dedicated to one of the reference airports and contains an explanation of the concepts of operations and a summary of the results. The factsheets were distributed during the dissemination meetings at the end of the project.

4.6 Other activities

4.6.1 ICAO Environmental Report

Every three years, ICAO publishes its environmental report, which gives an overview of activities worldwide on reducing the environmental impact of aviation. In 2010, ERAT was given the opportunity to publish an article in the ICAO Environmental Report 2010.

See Figure 22: ERAT article in ICAO environmental report 2010 for the published article.

4.6.2 ERAT LinkedIn Group

In November 2009, ERAT has set up a group on LinkedIn. People interested in ERAT and its results can join the group and receive regular updates on the progress of the project.

More than 80 people have joined the group by May 2011.

The Environmentally Responsible Air Transport (ERAT) Project

The Environmentally Responsible Air Transport (ERAT) project is a research project, co-funded by the European Commission under the Sixth Framework Programme which addresses the ATM community's need to reduce the environmental impact per flight to allow for sustainable growth. The project is carried out by a consortium of 11 project partners: Airbus, DLR, ENVISA, EUROCONTROL Experimental Centre, LFV, Lufthansa, National Company Bucharest Airports, NATS, NLR, Snecma, To70. The objective of ERAT is to improve the environmental performance of air transport by developing and validating Concept of Operations (CONOPS) for two airports, London Heathrow and Stockholm Arlanda. Both CONOPSS aim for environmental benefits from the top of descent, to touchdown, by focusing on more efficient operations (i.e. less radar vectoring and holding), and enabling Continuous Descent Approaches and Continuous Climb Departures.

The initial results for the London Heathrow concepts showed that the small environmental benefits in terms of less fuel burn, emissions and noise, are at the expense of runway capacity. The London Heathrow concept is planned to be refined and assessed in the fourth quarter of 2010. Two sets of real-time simulations concepts are planned in the second half of 2010 to assess the concept of operations for Stockholm Arlanda, and the results are expected to be available at the end of 2010.

Project ERAT website: <http://www.erat.aero> ■

Figure 22: ERAT article in ICAO environmental report 2010

5 Conclusions

5.1 Main conclusions

Overall, LFV was very satisfied with the results of the concept development and validation work undertaken in this project. The most important conclusions are summarised below.

- Two route designs with (P-RNAV and RNP) STARs have been validated with this concept. The concept proved to be able to accomplish a landing rate between 30 and 34 per hour. The arrival planning and predictability of operations were improved, allowing an increase in continuous descent operations, reaching approximately 80% up to 100% of all traffic. The current day operations proved to be very efficient due to short vectoring by air traffic controllers.
- The fuel burn results for the P-RNAV STARs were comparable to the baseline situation, however the track miles were approximately 10 NM longer. When the RNP STARs were used, the track miles were comparable to the current day operations and approximately 3% fuel burn and CO₂ reduction for arrivals was achieved. The short flights (less than 30 minutes) were now included in the arrival planning and could absorb delays on the ground rather than in the air. This allows for potentially further fuel burn reductions.
- The fixed arrival route structure caused less lateral flight track dispersion which subsequently reduced the noise exposure on the ground locally. The noise footprint areas were reduced up to approximately 20% when compared to the current day situation.
- The concept had no influence on Continuous Climb Departure (CCD) which was quite often allowed in the current day operations. The controllers judged that the current safety levels were also maintained. The simulations have demonstrated feasible advanced AMAN functions with associated HMI to run time based operations. A further concept refinement and other remaining issues will be addressed in those SESAR projects which follow-up on the ERAT achieved results.

Although the results may not be so promising, NATS was satisfied to have been able to perform this second concept development cycle to further develop the initial concept. Therefore these conclusions only address this second cycle as they form input for follow-up development cycles.

- By using FTS the cost of the project could be minimised while several design options could be explored before initiating a RTS that usually comes at higher cost.
- In the LHR concept, the current landing rate of 42-44 per hour could be maintained thanks to Point Merge.
- The fuel burn analysis revealed that the concept caused a net increase of roughly 7%, where Continuous Climb Departures (CCD) could save approximately 2% which was offset by an increased fuel burn in arrivals due to 19% longer distance flown. The locations of the Initial Approach Fixes (IAF) in combination with the route design have contributed to the longer distance flown from the TMA entry point. The route design showed similarities to the previous concept (HEART1A) and facilitated a free corridor for CCDs. The CCD has shown improved fuel efficiency and provides potential for more if flights were cleared to their cruise flight level.
- Environmental assessment of the concept showed that noise footprints were re-distributed and showed both local increases and decreases of noise exposure on the ground. The comparison between the current departure procedure that

- included a level-off at 6,000 ft and a CCD, resulted in an interesting trade-off between less noise (in the case of levelling off) and lower fuel burn (with a CCD).
- Although this concept would not be implemented as it was designed in ERAT, several concept elements were taken over for further development by SESAR projects and NATS' internal London TMA airspace management programme (LAMP). An example of future development was the RTS of this concept with four holds instead of two to reduce the track distance flown. This led to addressing many of the limitations of this concept.

5.2 SESAR recommendations

Much of the achieved results were exchanged and/or transferred from ERAT project team members to others working directly for SESAR projects, particularly when for the same organisation which was often a SESAR member. The informal exchange of information varied from attending meetings where views could be exchanged to presentations of conducted work and giving the ERAT deliverable to interested persons. This process happened even before ERAT was officially finalised depending on the need from corresponding SESAR project team member(s) as some projects were in start-up phase while others have already progressed in their project.

Therefore it could not be traced back which recommendation was given, but it can be said with certainty that SESAR team members have used ERAT results for their benefit in the SESAR work. Annex A.3 details how various SESAR projects made use of ERAT results.

5.2.1 Recommendations for concept development work

The ERAT consortium recommends to SESAR:

- To take an example of concept development and validation work undertaken for Stockholm Arlanda terminal airspace. The ARN concept provides a good showcase of Time Based Operations for SESAR, with system support on the ground.
- To learn from airspace and route design work undertaken for London Heathrow in SESAR work dealing with high traffic density terminal airspace. The development cycles have revealed some very useful concept elements (e.g. point merge) and route design considerations in a complex airspace.

5.2.2 Recommendations for SESAR environmental projects

The tools and methodologies used for the ERAT environmental assessments (both for the ARN and LHR cases) were presented to SESAR projects 16.6.3 and 16.3.1. SESAR project 16.3 is tasked to develop an environmental case methodology and tools which allow the concept validation work in SESAR projects. The contribution of ERAT in this process lies in providing new insights in their ongoing discussion on set of tools and methodologies to be used in SESAR projects.

Realising that a real-time simulation (RTS) is an essential part of concept validation in SESAR, currently there is not yet a tool that can analyse the RTS output with the high-fidelity of Airbus models. It was also observed that the aircraft performance models used in FTS and RTS platforms need to be improved. Especially the way vertical profiles were modelled, because their output determined the input suitability for environmental analysis. This discussion was also referred to as the "gap analysis" in both abovementioned projects.

6 References

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- [3] "D2-2 Key performance areas, objectives and assessment methods" by ERAT consortium, March 2008
- [4] "D2-3 Tailored multi criteria method" by ERAT consortium, April 2008
- [5] "D2-6 Validation strategy" by ERAT consortium, November 2009
- [6] "D2-8 Validation Plan Stockholm Arlanda" by ERAT consortium, November 2009
- [7] "D2-7 Validation Plan London Heathrow" by ERAT consortium, November 2009
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- [10] "D3-3 Supporting document: Trade-off report Heathrow" by ERAT consortium, April 2009
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- [12] "D10-1 Work Plan WP10: Dissemination Plan" by ERAT consortium, February 2008
- [13] "D2-1 Work Plan WP2: Validation Requirements" by ERAT consortium, December 2007
- [14] "ARN D4-1 Concept of operations Arlanda Airport" by ERAT consortium, December 2009
- [15] "ARN D7-1 Arlanda RTS Experiment Plan" by ERAT consortium, March 2010
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- [17] "ARN D7-6b RTS2 Results for Stockholm Arlanda airport" by ERAT consortium, December 2010
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- [23] "LHR D10-1 Refined concept of operations for London Heathrow" by ERAT consortium, November 2010
- [24] "LHR D10-2 Validation plan for London Heathrow concept refinement" by ERAT consortium, December 2010
- [25] "LHR D10-3 Validation results for London Heathrow concept refinement" by ERAT consortium, January 2011



A Annexes

A.1 Inventory and survey results leading to an operational concept

The first chapter in the Annexes describes the initial work of project ERAT, conducted in the first three work packages. That work focused on several inventories and surveys to evaluate which operational measures, concept elements and/or enabling technologies were useful and required to include in the subsequent work defining an operational concept. As such, this stage of the project was characterised by convergence of ideas to outline the more specific operational concepts for both Stockholm Arlanda and London Heathrow.

Reducing en-route environmental impacts

The first inventory covered past research projects which seemed to offer the possibility of reducing aviation's environmental impact through changes to the ATM system as a whole (including the communication-navigation-surveillance components). It particularly focused on the opportunities to reduce aviation's environmental impact during the en-route phase of flight. Full details can be found in ERAT deliverable D1-3 (see ref. [2]) and below follows a brief summary.

The main environmental concerns associated with en-route air traffic are climate change, resulting from the emission of greenhouse gases and the formation of contrails. The science of contrail impact still being inconclusive, the focus of the inventory was generally based on the underlying assumption that reducing fuel burn will deliver consequent reductions in harmful emissions.

There were essentially three ways that changes to the ATM system can result in a decrease of the amount of fuel burnt per journey, namely:

1. the aircraft fly the most direct route in the horizontal dimension,
2. the aircraft fly the most optimum vertical profile
3. delays in the form of either ground delays (e.g: holding for takeoff, engine running), or airborne delays (e.g.: hold stacks or track extensions -"tromboning") are eliminated

The inventory comprised of 15 relevant programmes/initiatives/projects/studies which either have been completed or are still on-going. Through analysis, some of them have been selected to take into consideration in future airspace redesign programmes striving to reduce aviation's environmental impact. The programmes/projects considered relevant for use in the ERAT project were AIRE, ASPIRE, RNAV procedures and the ground delay program. A brief description of these programmes/projects is given below.

AIRE

The AIRE (Atlantic Interoperability Initiative to Reduce Emissions) programme fits in with the co-operation protocol signed by the European Commission and the FAA (Federal Aviation Administration) to co-ordinate two major programmes on air traffic control infrastructure modernisation, SESAR in Europe and NEXTGEN in the United States. AIRE made it possible to speed up the application of new technologies and operational procedures which will have a direct impact on greenhouse gas emissions in the short and medium term.

ASPIRE

The ASPIRE (Asia & Pacific Initiative to Reduce Emissions) programme is designed to reduce the environmental impact of aviation across Asia and the South Pacific with each partner to focus on developing ideas that contribute to improved environmental standards

and operational procedures in aviation. ASPIRE is all about raising the industry's environmental performance in reducing fuel burn and CO₂ emissions.

RNAV Procedures

RNAV is a method of navigation, which permits aircraft operation on any desired flight path within the coverage of referenced navigation aids or within the limits of capability of self-contained aids or a combination of these:

- 2D RNAV relates to RNAV capabilities in the horizontal plane only;
- 3D RNAV includes a guidance capability in the vertical plane;
- 4D RNAV provides an additional timing function.

The RNAV system has access to a sophisticated on-board navigation database containing details of the pre-programmed routes, the airspace through which the routes pass, the navigation aids servicing this airspace and the departure, destination, and planned diversion aerodromes. The system identifies the next waypoint on the planned route, selects the most appropriate navigation aids to determine the aircraft position and usually provides steering inputs to the autopilot.

The introduction of RNAV procedures has a variety of benefits in the areas of safety, capacity, access, and efficiency. RNAV brings greater flexibility for procedure designers as well as significant environmental, economic and operational advantages for aircraft operators and ANS providers. This is expected to be achieved mainly through the use of:

- more direct routing;
- optimised vertical profiles;
- parallel offsets; and
- reduced route spacing,

all of which will lead to a more efficient use of available airspace. Direct routes improve airspace capacity and relieve congestion while reducing direct operating expenses, such as a fuel cost, to the aircraft operator.

These benefits are expected to lead to the more efficient design of airspace procedures and collectively, to improvements in safety, access, capacity, predictability, and operational efficiency for airlines and ATC. In the ERAT project P-RNAV was recommended to be used with RNP-1 routes to reduce flight dispersion for short (regional) flights to Stockholm.

Ground delay program

The main purpose of a *Ground Delay Program* (GDP) is to allow flights to take their delay on the ground as opposed to in the air. Based on an airlines' schedule, when demand at an airport surpasses capacity, flights inbound to that airport, which had not yet taken off, are issued a delay to decrease the demand on the airport.

Basically when a capacity shortfall occurs, each flight is assigned the next available arrival slot, using the arrival order as a priority order. This mechanism is known as *Ration by Schedule* (RBS), which is based on the same first-planned-first-served principle that governs the EU slot allocation done by the *Central Flow Management Unit* (CFMU). The principal output of RBS is a *Controlled Time of Departure* (CTD) for each flight in the GDP. Calculation of a CTD is accomplished by assigning a *Controlled Time of Arrival* (CTA) to each flight and then computing a CTD by subtracting the estimated en-route time from the CTA. By using GDP airlines are able to save fuel and also to increase safety.

Measures, effects and enabling technologies

The second inventory comprised potential measures, effects and required enabling technologies that had the prospective to deliver environmental benefits such as reduced noise and emissions in the eTMA. Please refer to ERAT deliverable D1-2 (ref.[1]) for more detailed information.

To reduce the environmental impact of aviation noise and emissions continued development and optimization of operational procedures is essential. As described in some R&D projects, emissions and noise reduction can be substantial. As the growth of the aviation sector will be defined and constrained by its environmental legacy, these technologies hold the key to the successful future of the industry.

Some of the key procedures found were:

- Airport Arrival/Departure and traffic flow procedure. By modifying or optimising the departure and traffic flow of aircraft around the airport;
- Steeper Approaches;
- Noise Abatement Procedures (NAPs) for Approach and Departure. NAPs are widely recognised as being efficient in decreasing noise and are currently adopted successfully by European airports. Regarding the Noise abatement approach procedures, the results show that procedure concepts conceived in the design process do result in noise benefits. This achievement not only makes the procedures general but overall gives the possibility of adapting the concept for specific cases (fleet mix, airport, etc.);
- Continuous Descent Approach (CDA) procedures and Advanced CDA procedures. Advanced CDA would require adapted aircraft technology and ground infrastructures in order to support advanced procedures without negative effects on safety and capacity.

The key message that can be taken from this inventory result is that there are actors in the aviation sector who are striving to achieve efficiencies in the many aviation procedures through technological development. Investigations have been made on selected short-term procedures, which showed a significant benefit in terms of noise and emissions. The discussed key procedures, in particular increased glide slope (steeper approaches) and continuous descent approaches were worthy of being validated in a real environment. Also considered for the medium term were procedures that bring potential benefit solutions, such as advanced continuous descent approach operations. This one showed potential for a successful integration into the overall ATM system.

Before starting the on-site operational testing of these procedures, the potential benefits for aspects such as safety, certification constraints, capacity, crew/controller workload and airport layout, needed to be assessed.

The next step was to decide how these key procedures could be integrated with concept elements which again formed building blocks to develop an operational concept. This concept would have to comply with the current environmental constraints imposed on the (national) aviation sector. It was recommended to define certain selection criteria such as current status of required technology, development stage of a targeted procedure, etc. in order to allow easy implementation. Based on the outcome, a focused R&D task could bring the selected procedure forward towards pre-operational implementation. At the time of inventory, SESAR was still in its Definition Phase and many aviation stakeholders took a pending attitude towards new developments in order not to deviate from SESAR envisioned concepts and technologies.

Concept elements as building blocks for an operational concept

The inventory results from the first work package was fed into work package 3 focused on describing and analysing the concept elements for each reference airport site, being Stockholm Arlanda and London Heathrow. The concept elements have been considered in the multi-criteria and trade-off methodology performed within ERAT. Each concept element was assessed on its own merits against the ERAT KPAs (as described in WP2) and would be combined in WP4 into an operational concept. ERAT deliverable D3-3 (see ref. [8]) captured the output of the selection process.

The selection process showed that the most promising concept elements were:

- (Advanced) CDA;
- Advanced Arrival Manager (AMAN), also to support advanced CDA;
- Departure Manager (DMAN);
- Route design procedures according to RNAV- and/or RNP principles;
- Continuous Climb Departures (CCD);

The next step was to use them as building blocks to shape an initial outline for the operational concept, which was part of ERAT WP4. The revised project work breakdown structure catered for two separate WPs named ARN4 and LHR4.

Initial concept outlines for Arlanda

The ERAT concept was meant to be an environmental friendly concept for Stockholm Arlanda airport. It is including all phases of the flight from top of descent for arrivals to top of climb for departures. The initial concept included the arrival phase, turn around process including CDM and the departure phase.

The links and interrelationships of the different phases are important for an efficient ATM concept aimed at reducing the environmental impact. Knowledge about and tactical information from the Departure Management process will increasingly be used in the Arrival planning and also in the tactical phase. The two processes will gradually be more integrated in order to improve predictability, efficiency and to reduce environmental impact. It is important to maintain a holistic view in the development and understanding of the ERAT concept.

The ERAT concept for Arlanda was not targeting peak traffic situations. The ERAT concept was meant to cope with traffic levels below maximum capacity where the initiatives were expected to improve efficiency. During these traffic levels the concept was not expected to have an adverse effect on capacity. For the very demanding traffic levels, system support was not expected to provide enough help for e.g. advanced CDA within the targeted timeframe of 2015.

Initial concept outlines for London Heathrow

The initial ERAT concept for London Heathrow was based on utilising Performance Based Navigation (PBN) procedures within the Terminal Manoeuvring Area (TMA). This innovative queue management concept is a wholly systemised 'closed-loop' environment in which the aircraft are expected to fly in fully automated flight to achieve Required Navigation Performance (RNP) conformance criteria.

The over-riding principal behind this concept is that pre-defined three dimensional (3D) paths were established within close proximity to the airport, such that the airspace dimensions of the Radar Manoeuvring Area (RMA) was significantly reduced from that of today's operational requirements. Both the vertical and lateral profile would be designed in such a way as to strategically de-conflict arriving and departing traffic. This allowed departing aircraft to fly a much improved climb profile. Where today's departing traffic is

forced to step-climb and is subject to sustained periods of level flight in order to ensure vertical separation from arriving traffic, this concept would facilitate improved, perhaps even continuous and unconstrained (optimised) climb departures.

A.2 ERAT links with SESAR

The table below shows the identified links between the activities in ERAT and SESAR project. It was the intention that the achieved results should feed into the SESAR projects.

Table 3: Cross links between ERAT and SESAR work packages

SESAR WP no.	SESAR activities	ERAT WP no.	ERAT activities & contributions to SESAR
5.2 (4.2)	Consolidation of Operational Concept Definition and Validation	3, ARN 4 ConOps Development, ARN 7 LHR 4 ConOps Development, LHR 6 and LHR 10	The ERAT CONOPSS are based on the SESAR CONOPSS and have been designed in detail taking the local situation into account for the year 2015. The ERAT CONOPSS descriptions and their validation results are valuable inputs for the development and refinement of the SESAR CONOPSS.
5.3 (4.3)	Integrated and Pre-operational Validation & Cross Validation	LHR 6, ARN 7	The ERAT CONOPSS features concept functions/elements for TMA operations i.e.: Controlled Time of Arrival (CTA) using advanced AMAN and predictable CDAs in Arrival Management. Validation of these elements is carried out in ERAT using RTS. The results can contribute to the pre-operational validation of concept elements/functions of the TMA operations.
5.4	TMA and en-route co-operative planning	LHR 6, LHR 10	The LHR validation outcome will have potential interference effects on other London airports. The SESAR projects under SWP 5.4 will address them.
5.5	TMA trajectory management framework	ARN 7, LHR 6 and LHR 10	Airspace (re)design and route structure in TMA as developed in ERAT provide insight to SESAR projects dealing with similar issues. This is also linked with project 5.7.4
5.6	Queue Management in TMA and En Route	3, ARN 4, ARN 7 LHR 4, LHR 6, LHR 10	RTS results regarding the use of optimised flight profiles for environmental (and economic) benefit, both for arrival and departure in time based operations using CTA (RTA) and advanced AMAN system.
5.7	Full implementation of P-RNAV in TMA	LHR 6, LHR 10, ARN 7	Results from FTS/RTS concerning airspace and route design in high complexity, high density TMA.
6.8	Coupled AMAN – DMAN	ARN 6	The development of an advanced AMAN serves as good input for the development of future ground support tools.

SESAR WP no.	SESAR activities	ERAT WP no.	ERAT activities & contributions to SESAR
9.1	Airborne Initial 4D Trajectory Management	ARN 7	The ERAT ARN concept with the use of CTA is a key factor for this project that focuses more on the airborne systems. In coordination with project 5.6.1 the ERAT ARN outcome is re-used to feed project 9.1.
10.9	Queue management and route optimisation	ARN 6	Development of an AMAN and its integration with the ATCO HMI, validated in RTS environment.
16.3 16.6	Environmental Sustainability	ARN 8, LHR 8	The environmental assessment methodologies in ERAT bring lessons learnt towards the environmental projects in SESAR WP16 about the strengths and limitations of current tools and methodologies

The relationship with the CleanSky programme was less obvious as it is more focused on innovations in aeronautical development.

A.3 The next steps of ERAT concept development work

The ERAT project outcomes can be categorised in various domains, such as concept development work, the development of an advanced Arrival manager (AMAN) and environmental assessment methodologies. Each of these domains is covered by different SESAR work packages and their projects.

It was obvious that the ERAT achievements have been fed into the various SESAR projects. Depending on their objectives, they select the parts of the ERAT results relevant to them. In some cases their project activities bring the ERAT concept one step further to the target operational environment. The following text sections highlight how the achievements from ARN and LHR concept development work was used in various SESAR projects. In addition, the findings of environmental assessment work were also fed into SESAR.

ARN results fed into SESAR

Through LFV staff, the earlier established links between SESAR and ERAT were initiated during the course of ERAT to assess which information could be of added value. Eventually the achievements from ARN have been fed into the following SESAR projects:

- 5.6.1 QM1 – Ground and airborne capabilities to implement sequence
- 5.6.2 QM2 – Improving vertical profile
- 5.6.4 QM4 – Tactical TMA and en-route queue management
- 5.6.7 QM7 – Integrated sequence building / Optimisation of queues
- 6.8.4 – coupled AMAN-DMAN
- 9.1 – Airborne Initial 4D Trajectory Management (through coordination with 5.6.1)
- 10.9.2 – Multiple airport arrival/departure management
- 10.9.4 – CDA and CCD in high density traffic

As project 5.6.4 gave a follow-up to both the developed ARN and LHR concepts, a very brief description of the project is given for clarity purposes. This project organised several RTS validations for four different cities, among which are Stockholm and the greater

London area. Their objective was to validate concepts (whether that is a refinement of an already available concept or a newly developed concept) in order to bring them one step closer to the target operational concept allowing time based operations. The use of an advanced AMAN such as developed in ERAT and the upstream coordination planning with en-route sectors play an essential role.

In the case of Stockholm Arlanda, the type of work results that went from ERAT to SESAR consisted of concept development work and ground systems development, which will be explained in the next text sections.

Concept development work

The developments and findings were of primary interest for the Queue Management projects under the 5.6 group. The most obvious link is the 5.6.4 project which took over much of the work and further developed the concept. The ERAT validation work has demonstrated the feasibility of the concept with its system support and that more operational details still require further analysis to make the concept more robust for disruptions (e.g. scenarios with strong wind, snow sweeping, etc.)

The ERAT experience was transferred through meetings and was also secured through the same staff continuing in 5.6.4. On a detailed level, knowledge and understanding of concept maturity has been transferred. Results from ERAT validations have been used to understand possibilities and also to help focus on important areas. Concept elements with a high validation maturity and demonstrated as proven to work, have been pointed out as well as areas where uncertainty remained. In this way the 5.6.4 work has been more focused and therefore more efficient. In the following areas ERAT has contributed to project 5.6.4 work:

- Understanding Concept maturity
- Validation planning
- Experimental planning
- Platform requirements
- AMAN functionality
- Controller HMI
- Procedures
- Results

Project 5.6.4 has undertaken a real-time simulation in October 2011 to validate these areas. The validation plan as it was executed in ERAT together with the definition of objective, hypothesis and metrics were very useful to take on board. The platform requirements were important to understand in order to do valuable RTS experiments. Ground system support including the AMAN tool from ERAT was used and further developed. Functions and fidelity required for the traffic generation was also communicated to the project.

The knowledge gained in ERAT about optimising the descent profile has also been transferred into project 5.6.2 through the same LFV staff working in both projects.

Further work detailing Controlled Time of Arrival (CTA)

The two SESAR projects 5.6.1 and 9.1 make use of the ERAT operational concept for Stockholm Arlanda in their project activities.

Project 5.6.1 focused on the concept element of Controlled Time of Arrival (CTA) including the required datalink technology to enable a direct aircraft – ATC data communication. The validation activities included a live flight trial in coordination with

project 9.1 which is led by Airbus. Project 9.1 aims to define and pre-develop the airborne capability for Initial-4D trajectory management. This project, together with operational projects and ground system projects, was setting-up common air-ground validation exercises, coupling air and ground systems and prototypes in order to validate the Initial-4D concept element.

In this framework, one key validation exercise was a flight trial with an A320 flight test aircraft, flying from Toulouse to Copenhagen and then continued its journey towards Stockholm. That flight trial took place on 10 February 2012. The plan during the trial was that before the top of descent, the aircraft should provide its Estimated Time of Arrival (ETA) window to the ground. This time window showed the earliest and latest time an aircraft was supposed to land on the runway. Afterwards it will receive a Controlled Time of Arrival (CTA) and can perform a Continuous Descent Approach (CDA) from Top of Descent (ToD).

Ground systems development

The ERAT project has also looked at the requirements for an advanced AMAN working in a context of Time Based Operations. Sequencing strategies and integration of departures within the AMAN horizon are key areas to improve the efficiency of Arrival Operations. Project 5.6.7 mainly deals with the AMAN requirements and is responsible for the shared wide scale validation exercise with project 5.6.1, led by LFV. The AMAN requirements and algorithms developed in ERAT was an interesting basis for the work in project 5.6.7 but as this project is focused on the long term, it is expected the team will wait until other SESAR projects has further developed the AMAN.

In SESAR project 6.8.4, the focus lies on efforts to couple AMAN and DMAN functionalities. The ERAT knowledge has been transferred through various workshops organised by 6.8.4.

The HMI for the controller roles, as developed in ERAT, has been re-used in the real-time simulation planned by project 5.6.4 by end of 2011. Strategies for more efficient operations using ground system support together with adequate procedures were also communicated. LFV has clearly expressed its satisfaction about the ERAT HMI with an integrated AMAN and this is an important indicator for the ground systems projects in SESAR WP10, especially projects 10.9.2 and 10.9.4 in which both Thales participates. Thales also happened to be the ATC ground system provider for LFV and is therefore keen to see what system is required and desired for future concepts.

LHR results fed into SESAR and LAMP

NATS' involvement in both SESAR and ERAT ensured that the technical links could be established. Therefore the achievements from the LHR development work have been fed into the following SESAR projects:

- 5.7.4 – Full implementation of P-RNAV in TMA
- 5.6.4 QM4 – Tactical TMA and en-route queue management
- 5.3 – Integrated and pre-operational validation & cross validation
- 5.4.1 – TMA-1 Co-operative planning in the TMA
- 5.4.2 – TMA-2 Co-operative planning requirements and validation
- Integration of work at European level with NATS internal London TMA Airspace Management Programme (LAMP), which subsequently is directly connected with SESAR.

In the case of London Heathrow, the type of work results that went from ERAT to SESAR consisted of concept development work and arrival management development, which will be explained in the next text sections.

Concept development work

The developments and findings were of primary interest for the projects 5.7.4 and 5.6.4. In project 5.7.4 a RTS was planned for the London airports Heathrow, Gatwick and Stansted. Due to the direct links between NATS' work in both projects, the findings of ERAT found their way easily as input towards 5.7.4. The use of point merge and path shortening (via P-RNAV compliant waypoints) in the Heathrow design demonstrated that a point merge centric P-RNAV route design could maintain the necessarily high runway throughput that is symptomatic of many high-complexity TMAs.

The results of ERAT simulations at London Heathrow showed the need to carefully manage the trade-off between vertical profile improvements and lateral track extension:

- For the next concept development cycle based on ERAT results, NATS was questioning the suitability of the assumption that "the greater the CDA/CCD availability, the better" for the London TMA airspace.
- Possible reconsideration of London TMA design, e.g. keep four stacks instead of reducing to two (to reduce track miles).

Project 5.7.4 required to get airspace user feedback on potential trade-offs of the KPAs and it should follow the recommendations in the ERAT LHR D10-3 deliverable (ref. [25][25]), i.e. test a greater range of permutations, including:

- Arrival Management at sub-100% efficiency levels
- Varying traffic predominance (Easterly/Westerly, Northabout/Southabout, etc)
- Non-nominal scenarios

The ERAT results also highlighted the importance of testing the airspace design with dynamic arrival management, i.e. inclusion of En-Route in simulations. This was planned to be achieved by integrated validation of 5.7.4 with 5.6.4.

Arrival Management development

In the ERAT LHR concepts, the presence of an advanced AMAN has always been assumed. The use of such AMAN increases the planning horizon and affects the en-route phase of flight as well (often referred as upstream coordination). As mentioned before in previous chapters, for the LHR concept development work in ERAT, an assumption has been used that there is an advanced AMAN which regulates the traffic flow. So this was clearly a subject that needed to be addressed by other projects.

Therefore a link with projects dealing with both TMA and en-route operations, could easily be established by NATS and they were:

- Project 5.6.4 (Tactical TMA and en-route queue management)
- Projects 5.4.1 and 5.4.2 (both projects deal with co-operative planning requirements and validation for the TMA).
- NATS has also indicated that there is also a potential use of the ERAT results by project 5.3 (covering pre-operational validation).

Environmental assessment methodologies as input for SESAR

The conducted environmental assessments for both ARN and LHR concepts have highlighted the difficulty of conducting a fleet-level environmental assessment without suitable tools and methodologies:

- Current traffic generation tools used in FTS & RTS did not provide for representative and validated trajectories because they were not based on flight mechanics equations, and because they didn't account for important parameters such as engine thrust or landing gear position, which were also major drivers for the environmental impact of the operations.
- Current Airbus performance tools are not capable of real-time simulation.
- Noise public tools rely on limited physical assumptions that limit their use for assessment of real operational procedures
 - No multi-speed / multi-configuration capability in INM.
- Airbus noise and emissions tools were only capable of Airbus aircraft.

This learning is an important input to SESAR WP16 projects developing improved tools and methodologies for environmental assessment of the SESAR concepts of operation.

A.4 ERAT benefits for others

In addition to SESAR projects, the results achieved in ERAT have also generated a spin-off for other (on-going) activities and/or projects, which will be elaborated on below.

CleanSky

CleanSky is an EU co-funded programme with more than a billion Euro budget focused on aeronautics. The CleanSky programme aims to accelerate the introduction of new, radically greener technologies in new generation aircraft. CleanSky will capitalise on the results of previous and on-going European studies, like ERAT. The programme is structured according to Integrated Technology Demonstrators (ITD) which are synonymous for work packages. One of them called Systems for Green Operations (SGO) deals with the Management of Trajectory and Mission (MTM). Their interest in project ERAT consists of the designed routes in the ARN concept allowing an optimisation of the vertical profile from Top of Descent (ToD). It is their long term goal to develop algorithms to be used for a next generation Flight Management System (FMS) onboard the aircraft.

Benefits for airport operators

The ERAT results have shown the way for increasing continuous descent operations towards medium traffic density airports. Having more CDAs contributes to improve the 'green image' of that airport. In addition, when the information about improved planning and predictability of operations are shared among aviation stakeholders according to the principles of Collaborative Decision Making (CDM), then this will make the airport processes more efficient.

Eastern Europe

At the time of submitting the proposal, Romania was one of the new EU member states and part of the EU policy is to contribute to improve the aviation developments in the new member states. An important contributing factor in project ERAT was the objective to reduce the environmental impact of air transport for the future by introducing a new concept of operations in the TMA airspace. Participation of a Romanian partner National Company Bucharest Airports (NCBA) in project ERAT showed their commitment to make Romania a leading country in that region to introduce environmentally friendly operations.

The dissemination plan of ERAT therefore included meeting events where the ERAT consortium can exchange information with Romanian stakeholders with the intention that operational and/or conceptual elements of the ERAT work could be adopted and implemented in the Romanian situation.

National Company Bucharest Airports (NCBA) used the ERAT logo and distinctive media elements as well as results from partners' work, to address the following:

- **Knowledge:** Know what results ERAT has achieved and what can be learned from these results as to be applied in Romanian airspace design and operation.
- **Attitude:** Realise the importance of ERAT's results and have a positive attitude towards the possible benefits these results can produce.
- **Behaviour:** Use ERAT results, documents and tools when developing concepts of operations on other airports.

NCBA has organised two dissemination meetings in Otopeni (Romania) at the headquarters of the company: one in April 2010 and the second one in April 2011. The ERAT partners were invited to present project results to representatives of Romanian Civil Aviation Authority, Romanian Air Traffic Services Administration ROMATSA, Romanian Air Transport TAROM, meant to promote environmentally friendly concepts for air transport in Romania.

Part of knowledge sharing and one of the goals of the meetings was to discuss the possibilities for future implementation of ERAT concept elements in Romania. The meetings consisted of presentations and discussions between ERAT partners and Romanian stakeholders. Based on ERAT's latest outcomes and SESAR environmental objectives, Romania's aviation strategy was expected to encompass a movement towards generating a holistic approach to help measure, monitor and mitigate the impact of air transport on the environment. These meetings had shown that ERAT outcomes are positive towards Romanian airspace design and civil aviation operations.

With a positive attitude towards innovations, NCBA felt confident that the Romanian stakeholders were willing to adopt the ERAT results for their concept development and continue to work on flight trials. Along with SESAR implementation there was an expectation of a regional deployment in the near future.