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**GRADE ANALYSIS AND DESIGN
OF THE MAASTRICHT UAC
A PILOT STUDY**

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TITLE:

**GRADE ANALYSIS AND DESIGN OF THE MASSTRICHT UAC
A PILOT STUDY**

Author	Date	Pages	Figures	Tables	Appendix	References
R.Merrilees J.Watkins C.Day	12/96	iv + 39	20	11	4	

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Abstract:
The report describes the use of graphical airspace analysis and design techniques, originally designed by the FAA, on European airspace.

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Graphical Analysis and Design of the Maastricht UAC A Pilot Study

1. Introduction

1.1 History

Among the principal objectives of the EUROCONTROL ATC Harmonisation and Integration Program (EATCHIP) is the assessment, and subsequent improvement, of European air traffic control capacity. The analysis of the sectorisation and aircraft routeing in European airspace, spanning multiple boundaries (sector, centre, and national boundaries), would allow for the systematic improvement of the expeditious flow of aircraft through those regions. To address this objective, the EUROCONTROL Experimental Centre (EEC) and the US Federal Aviation Administration (FAA) embarked upon a joint pilot study to investigate the use of graphical analysis and design techniques, developed in the US for the FAA, on European airspace.

The Graphical analysis and design capability rests upon the use of the **Gr**aphical **A**nalysis and **D**esign **E**nvironment tool (GRADE), developed and owned by the ATAC Corporation[1] in the US. GRADE is used by ATAC to support the FAA Office of System Capacity and Requirements[2] in the graphical analysis and design of large regions of US airspace.

1.2 Objectives

A joint FAA/EEC project team was established in September 1995 to evaluate the use of the graphical analysis and design techniques, generally, and the GRADE software, specifically, at the EEC. This project team was charged to conduct a pilot project, called **E**UROCONTROL **Gr**aphical **A**nalysis and **De**sign (EGRADE), which would:

- Implement a version of the GRADE software, tailored to EUROCONTROL requirements, at the EEC,
- Use graphical analysis and design techniques to evaluate a region of European Airspace.

These two objectives were achieved by November 1996. This note reports on our findings.

[1] ATAC Corporation, 757 N. Mary Avenue, Sunnyvale, California, 94086 USA. Tel: 1-408-736-2822.

[2] For information on the Office of System Capacity and Requirements (ASC-200), contact: Richard Nehl, US Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC, 20591 USA. Tel: 1-202-267-8788.

2. Methodology

2.1 EGRADE Team

The EGRADE project team consisted of:

- Peter Crick, representing the EEC,
- Robert Merrilees, under contract from ATAC, providing operational expertise in the use of GRADE,
- Richard Nehl, representing the FAA, and
- John Watkins, under contract to the EEC providing technical project management support.

Additional technical and operational support was obtained from outside the EGRADE team. This support was provided by:

- The ATAC Corporation in the US, for customising GRADE for EUROCONTROL use and for handling the transformation of GRADE data into simulation data suitable for SIMMOD (see Section 2.3 below),
- Claude Dagneau and Ian Fuller of the EEC RAD Centre of Expertise, for converting RADAR data into a format suitable for importing into GRADE (see Section 2.2),
- Jean-Claude Vollant of the EEC for the navigational aid and geographical data used in the analysis (see Section 2.2.3),
- Jacques Pirson and John Hird of Maastricht UAC for the sectorisation data and RADAR data used in the analysis (see Section 2.2.3),
- Christian Vandenberghe of EUROCONTROL's DED 4 Statistics and Forecasting Section for the traffic sample forecasts (see Section 2.6.2), and
- Stephen Hockaday and his Airspace Modelling Section, also from EUROCONTROL DED 4, for the aircraft routeing corresponding to the Airspace Route Network Version 2 proposal used in the evaluation (see Section 2.6.2).

Additional ATC operational support was provided by:

- Jim Lambert of EUROCONTROL DED 4 for the selection of Maastricht Centre for this study, and
- Rudi Claes of Maastricht UAC along with Jean-Marie LeBoutte and Fritz Werthmann of DEI 3 for explanations of operating procedures in Maastricht UAC.

2.2 GRADE Overview

2.2.1 General Description

GRADE is a state-of-the-art tool that provides advanced 3-dimensional visualisation of essentially any information that can be described in latitude and longitude co-ordinates. Examples include:

- Flight tracks with their associated flight plan information from recorded RADAR data,
- Airspace sectorisation (centre and sector boundaries, both existing and proposed),
- Navigational aid locations,
- Airport locations, and
- Geographic information (national boundaries, terrain, street plans, etc.).

2.2.2 Associated Utilities

In addition, there is a suite of utilities associated with GRADE that aid in the analysis of the geographical data. Some examples of these utilities include:

- Import static and dynamic data, reformatted for visualisation in GRADE,

- Calculate flight paths relative to the sectorised airspace, determining sector occupancy statistics over time,
- Aid the user in designing airspace, providing a graphical sector-building tool,
- Aid the user in developing simulation route networks from the recorded flight tracks, and
- Create flight data for subsequent simulation analysis (assigning flights to the route network described above).

2.2.3 GRADE at the EEC

The GRADE software required minor modifications for use at EUROCONTROL. These modifications include utilities for:

- Importing static data (navaids, airports, national boundaries, sectors, etc.) that conform to the EEC Real-time Simulator standards,[3]
- Importing RADAR flight track data transformed into ASCII by the EEC,[4]
- Importing ASTERIX[5] format flight plan data and linking those flight plans with flight tracks in the RADAR data, and
- Importing ASTERIX format RADAR flight track data.

The GRADE software, along with its associated utilities, was installed at the EEC in October 1995. An integrated data conversion utility, which transforms EUROCONTROL data into GRADE format, was delivered by ATAC in December 1995.

As GRADE runs on the UNIX operating system, a Hewlett Packard UNIX Workstation (HP 735i) was selected as the computer platform for GRADE at the EEC.[6] GRADE was installed on this workstation and a three-day training period was provided by ATAC staff at the EEC for familiarisation with GRADE and its associated file formats. Additional technical support and training was provided via “e-mail” and telephone exchanges with ATAC.

2.3 GRADE with Simulators

While GRADE provides an extremely useful data visualisation environment for examining and designing airspace,[7] it is not in itself a simulator. In order to measure the relative impacts of airspace changes on aircraft travel times and delay times, it is necessary to simulate the modified airspace (identified as simulation scenarios) and compare it with a simulation of the existing airspace (identified as the baseline).

GRADE has built-in utilities that aid in the preparation of data for use in a simulator. These utilities aid the user in creating what is effectively a “flight plan” from the RADAR data for use in a simulator. This “flight plan” differs from an actual flight plan in that it reflects the actual flight path of the aircraft rather than that which was requested. For example, an aircraft filing a flight plan to fly from “A to B to C” might actually be given a “fly-direct” controller action, changing the path to “A to C”. This GRADE “flight plan” is then used to create the airspace route network and traffic sample for the simulation.

GRADE is not directly associated with any simulation system. It is feasible to link GRADE output to any of the standard airspace simulators such as SIMMOD (the US FAA’s Airport and Airspace Simulation Model), RAMS (The EEC’s Reorganised ATC Mathematical Simulator), or TAAM (The Preston Group’s Total Airport and Airspace Model).

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[3] As described in the document _Guide Opérationnel pour la Préparation des Données des Simulations en Temps Réel_, August 1994, Version 8, EUROCONTROL Experimental Centre.

[4] Transformation of RADAR data into an ASCII format was performed by the RAD Centre of Expertise at the EEC. An example of the format can be found in Annex A.

[5] ASTERIX refers to the All-purpose Structured EUROCONTROL Radar Information eXchange format, as described in the document _User Interface Definition of the MADAP Track Server_, February 1995, EUROCONTROL Maastricht UAC Systems Division.

[6] GRADE hardware requirements, as well as the workstation specifications for the EEC machine, are detailed in Annex B.

[7] For the purpose of this discussion, “airspace” refers to the sector geometry and the flight tracks that pass through it.

To perform the evaluation of the use of graphical analysis and design techniques at the EEC, it was necessary to choose the simulation engine that would be linked with GRADE. The ATAC Corporation uses SIMMOD as their simulation engine and had already developed the software that translates GRADE output into SIMMOD input. ATAC agreed to make this software available to the EEC. As the EEC also has extensive experience with SIMMOD, SIMMOD was selected for this pilot study (thereby saving the effort required to create the software utilities that would convert GRADE output into RAMS input).

2.4 SIMMOD Modelling

SIMMOD is a comprehensive planning tool for air traffic planners, airspace designers, airport designers and managers, and airlines. Analysts use the model to study and improve airspace, airport, and airline operations.

SIMMOD represents the air and ground system as a series of nodes (or points) connected by links. Airspace nodes describe airspace locations such as navigational fixes, hold stacks, or flight path conflict points. Airspace links represent routes upon which the flights travel from their origin to their destination. On the ground, the links and nodes represent airport apron areas, taxiways, departure queues, staging areas, runways, etc. SIMMOD is extremely flexible with regards to the level of detail that can be used: The model can be applied to a specialised problem with a gate or runway structure or to a more complex problem involving the airspace of multiple enroute ATC centres.

The analyst is able to use SIMMOD to simulate the existing situation (called the Baseline) and the proposed modifications (called the Scenarios), comparing the results. For airspace studies, SIMMOD is typically used to measure:

- Aircraft travel time,
- Aircraft delay time, and
- Aircraft flows through sectors.

By measuring these values for the Baseline and each Scenario, relative improvements in the flow of traffic can be determined. Annex C provides additional details on the SIMMOD Simulation System.

The EEC has been using SIMMOD for over six years. Through the Memorandum of Co-operation with the FAA, the EEC:

- Actively uses the SIMMOD system, having performed over 20 simulation studies using SIMMOD,
- Serves on the SIMMOD Development Team,
- Participates in the European SIMMOD Users Group (ESUG), and
- Provides SIMMOD technical support to European SIMMOD users.

2.5 Study Scenarios

2.5.1 Study Area

To evaluate the use of graphical analysis and design techniques for European airspace, Maastricht UAC was selected as the subject area for the pilot project. Maastricht UAC was selected because:

- It is a EUROCONTROL facility, aiding in the co-ordination with the Operational and Systems Experts from the facility,
- It is already under study for capacity-increasing initiatives,
- It is an area in the “core” region of Europe, and
- The results of this study could be incorporated in a larger-scale project, including bordering German and French airspace, if desired.

2.5.2 Scenario Descriptions

Three scenarios for Maastricht UAC were examined:

- Baseline - The situation of Maastricht Centre on 30 August 1995,

- Maastricht Nattenheim Proposal - Modifications to the routeing and sectorisation proposed for the Nattenheim region of Maastricht UAC, and
- Air Route Network Version 2 (ARN V2) - Draft changes to the aircraft routeing that would affect all of the Maastricht UAC.

2.6 Data Description

A variety of data, both static and dynamic, were used for this pilot study. The following sub-sections summarise the types of data used.

2.6.1 Static Data

Using the combination of GRADE, for the graphical analysis and design work, and SIMMOD for the simulation engine to calculate the scenario statistics, requires static data that describes the airspace. This data includes the geographical data, navigational aids, and sector definitions.

2.6.1.1 Geographical Data

The geographical data describes the national boundaries in the vicinity of Maastricht UAC. Data were obtained from the CFMU which describes the national boundaries of France, The Netherlands, Belgium, Luxembourg, and Germany. These data were obtained in latitude and longitude co-ordinates in ASCII format. The ASCII data were converted into GRADE format using utilities provided by ATAC.

2.6.1.2 Navigational Aids

The geographical reference points used in the analysis include navigational aids (such as VORs and VORTACs), charted reporting points, and user-defined reference points. In the Baseline and Nattenheim Proposal scenarios, these points were obtained in latitude and longitude co-ordinates from CFMU data in ASCII file format. For the Air Route Network Amendment Version 2 scenario, additional data points were received from EUROCONTROL’s Airspace Modelling Section in DED 4, in ASCII format. The ASCII data were converted into GRADE format using utilities provided by ATAC.

2.6.1.3 Sectors

The sector geography was obtained from Maastricht UAC directly. Each sector is defined by a series of geographical co-ordinates, in latitude and longitude, describing the sector polygon. Each sector also has an associated floor and ceiling corresponding to the lower and upper altitudes of the sector, respectively. Finally, for use in SIMMOD, each sector is given a sector cap (that is, the maximum number of aircraft that can be active in each sector at any one time). The following sub-sections describes the sectorisation and sector caps for each of the scenarios.

2.6.1.3.1 Baseline

The Baseline simulation consists of eight standard sectors. These sectors span between flight level (FL) 245 and FL500. The following table provides the list of Sectors and the associated Sector Caps provided by Maastricht UAC:

Table 1

Sector ID	Sector Name	Sector Cap
S1	Brussels West	16
S2	Brussels Olno	13
S3	Brussels Luxembourg	10
S4	Hannover Ruhr	14
S5	DECO Coastal	16
S6	Hannover Solling	12
S7	DECO Delta	18
S8	Hannover Hamburg	14

At prescribed times during the day, up to two "upperhigh" sectors, extending from FL345 to FL500, may be activated. These sectors include:

Table 2

Sector ID	Sector Name	Sector Cap
S9	Brussels Upperhigh (overlaying Brussels West and Brussels Olno)	16
S10	Delta Upperhigh (overlaying DECO Delta)	18

When these upperhigh sectors are active, the corresponding sectors' (Brussels West, Brussels Olno and DECO Delta) control jurisdiction is reduced to FL245 to FL345. The figure below provides a two-dimensional diagram of the eight standard sectors:

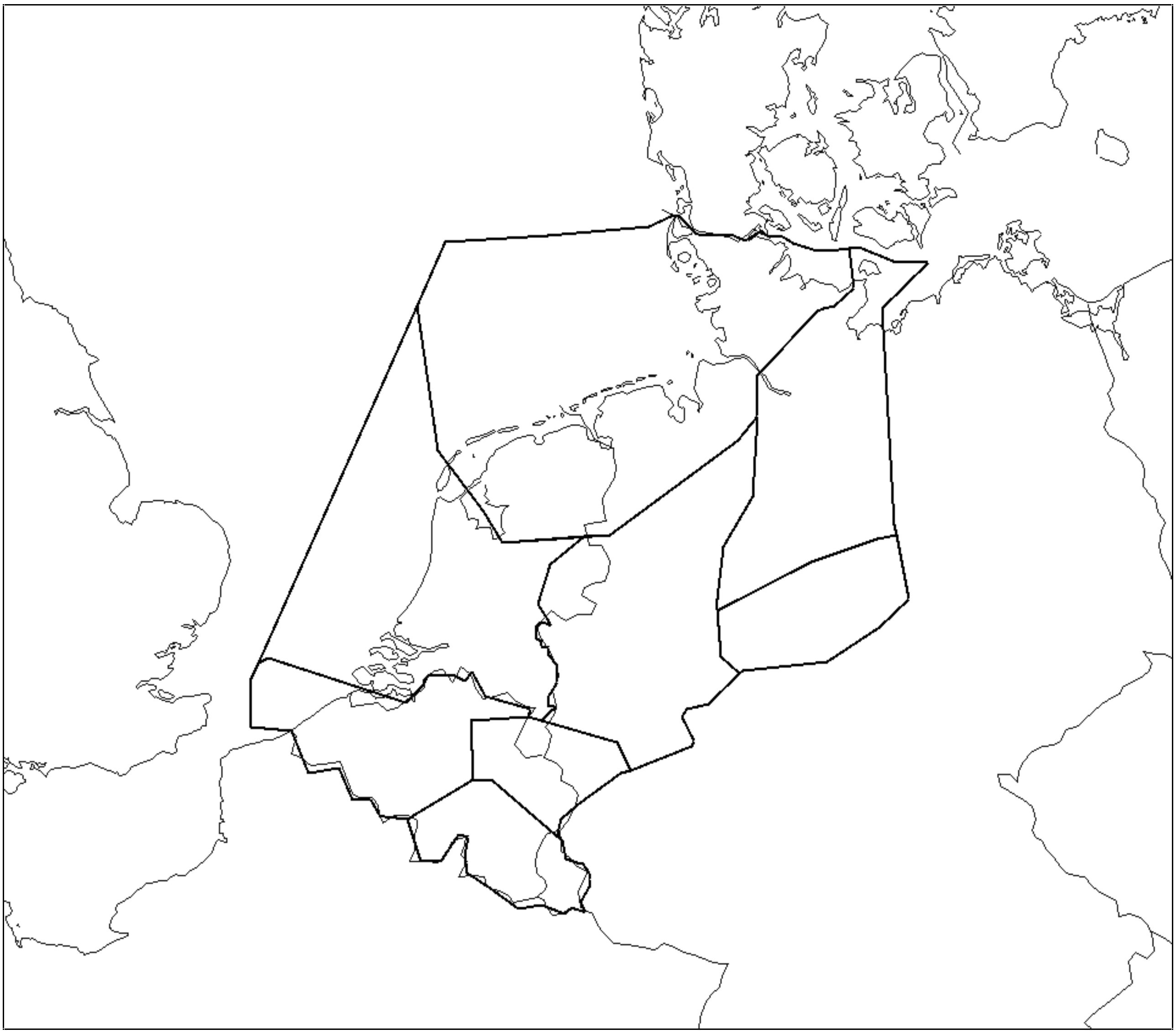

Figure 1

The sector co-ordinates can be found in Annex D.

2.6.1.3.2 Nattenheim Proposal

The sectorisation in the Nattenheim Proposal scenario is identical with that of the Baseline scenario except for the following modification: A small region of airspace is added at the East boundary of the Brussels Olno and Brussels Luxembourg sectors. The modification of the aircraft routeing in this region, described in Section 2.6.2.1.2, is expected to increase the capacity of the Brussels Luxembourg Sector. Thus the Sector Cap of Brussels Luxembourg was increased from 10 (found in the Baseline) to 12 for this scenario.

The traffic in this region of airspace is controlled by either of these two sectors, depending upon the routeing of the aircraft. The figure below provides a two-dimensional diagram of this region of the airspace:

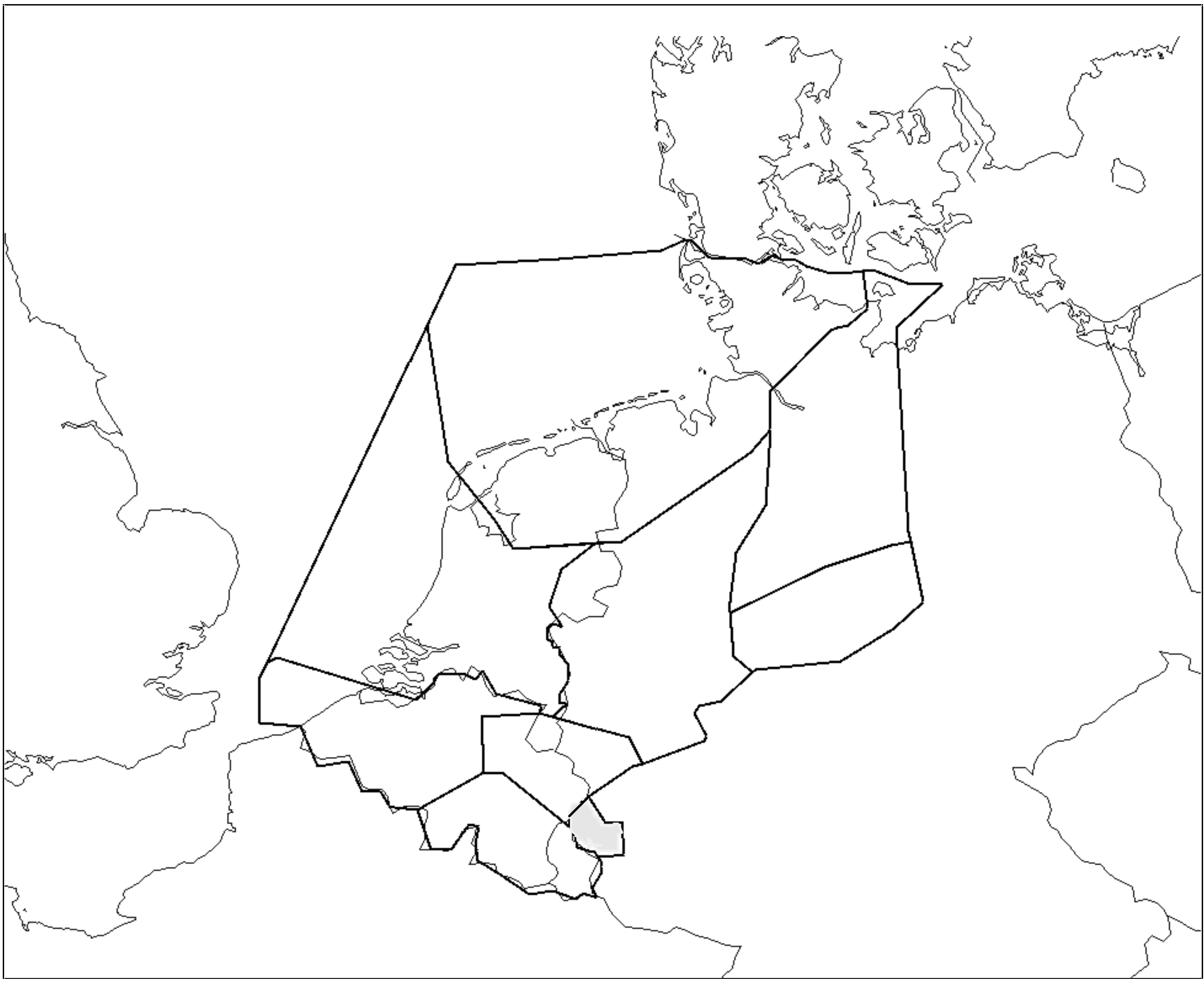

Figure 2

The co-ordinates of this new airspace are found in Annex D.

2.6.1.3.3 Air Route Network Version 2

The geographical definition of the sectorisation used for the Air Route Network Version 2 is identical to the sectorisation in the Nattenheim Proposal. Only the aircraft routeing was changed for this scenario (see Section 2.6.2.1.3).

As the new route network is intended to simplify the airspace, it is assumed that the new route network will result in an increase in capacity for the sectors in Maastricht UAC. In order to examine the effects of increased sector capacity, two sets of sector caps were examined: A 10% increase in the sector caps in the Nattenheim Proposal and a 20% increase in the sector caps in the Nattenheim Proposal.

The following table summarises the sector cap values for these three cases:

Table 3

Sector ID	***Sector Name***	***Sector Cap***	***Sector Cap +10%***	***Sector Cap + 20%***
S1	Brussels West	16	18	19
S2	Brussels Olno	13	14	16
S3	Brussels Luxembourg	10	11	12
S4	Hannover Ruhr	14	15	17
S5	DECO Coastal	16	18	19
S6	Hannover Solling	12	13	14
S7	DECO Delta	18	20	22
S8	Hannover Hamburg	14	15	17
S9	Brussels Upperhigh (overlaying Brussels West and Brussels Olno)	16	18	19
S10	Delta Upperhigh (overlaying DECO Delta)	18	20	22

2.6.2 Dynamic Data

In airspace simulation projects using a graphical design tool (such as GRADE) to capture actual points of air traffic interaction, the dynamic data are a direct result of the RADAR data corresponding to the airspace region under study (Maastricht UAC, in this case). The RADAR data are used to define the route network and simulation flight events (which are subsequently simulated using SIMMOD to provide scenario statistics). The following sub-sections describe the RADAR data that were used for the creating the route networks and flight events used in this analysis.

2.6.2.1 RADAR Data Description

Legal RADAR recordings for the date of 30 August 1995 were obtained from Maastricht UAC in ASTERIX format. These data contained both the flight track information and the flight plan information. The flight track data were converted by the EEC into an ASCII file format (adhering to the file format specified for the flight recordings of the real-time simulation facility, SIM5+, at the EEC). The ASCII formatted data were then converted into GRADE format using utilities provided by ATAC. The ASTERIX format flight plan data were converted directly into GRADE format using utilities provided by ATAC.

A total of 21,746 flight tracks were recorded by the Maastricht UAC RADAR facility on this day. Of these 2,485 tracks had associated flights plans (that is, 2,485 aircraft were “handled” by Maastricht UAC, the remainder were aircraft that never entered the Centre’s control).

In GRADE, the flights are represented using a colour-coded system. The colour-coded system is intended to provide an indication of arrival, departure, intraflight, and overflight status for the tracks. The colour assignments for this study are as follows:

- Red: Departure flights, an aircraft that begins below 7,500 feet and climbs above 7,500 feet while under Maastricht RADAR coverage.
- Green: Arrival flights, an aircraft that begins above 7,500 feet and descends below 7,500 feet while under Maastricht RADAR coverage.
- Yellow: Intraflights, an aircraft that begins below 7,500 feet, climbs above 7,500 feet, and then descends below 7,500 feet while under Maastricht RADAR coverage.
- Blue: Overflight, an aircraft the remains above 7,500 while under Maastricht RADAR coverage.

The figure below illustrates the 21,746 RADAR tracks, colour-coded as described above:

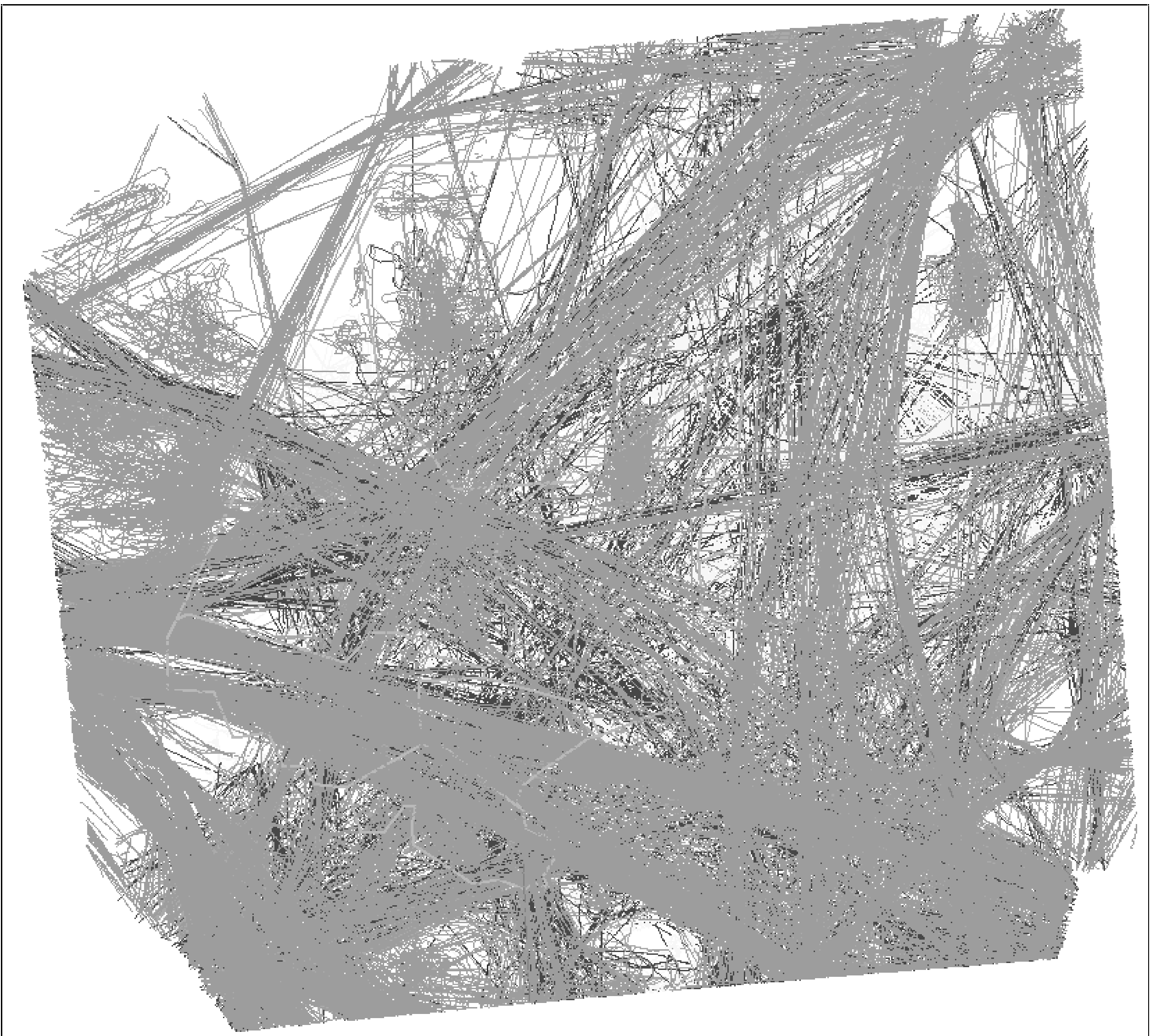

Figure 3

The figure below illustrates the 2,485 flights that had associated flight plans, colour coded as described above:

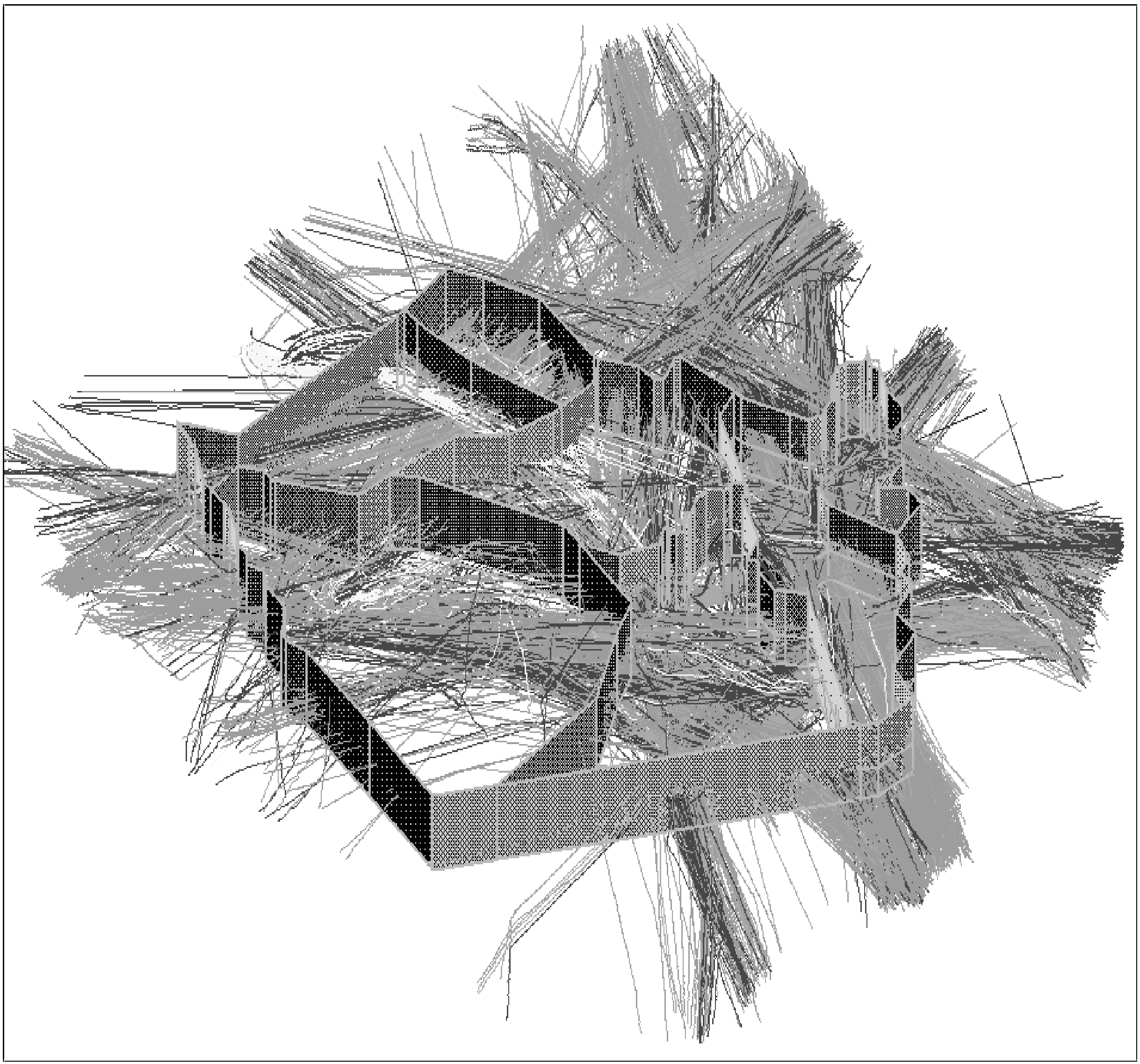

Figure 4

2.6.2.1.1 Baseline

The RADAR data obtained from Maastricht UAC for those flights under the control of Maastricht UAC (that is, those flights in the RADAR data that had flight plans) were used to build the route network for the simulation phase of this study. By using RADAR data to develop the three-dimensional route network, the actual flight paths are available for use in the simulation rather than relying upon flight plans which may not accurately represent the tracks flown by the flights. The route network developed from the RADAR data accurately reflects the paths flown by the aircraft while flight plan data may miss various flight path modifications (such as a “fly direct” control action).

GRADE was used to select RADAR flight tracks that pass through the same airspace with comparable trajectories (considering all three dimensions). These RADAR flight tracks were then used to create a Virtual Flight Track (VFT). The flights used to build the VFT were then allocated to that VFT for subsequent use in SIMMOD. This was accomplished by using GRADE to create an ASCII file that contains a list of VFTs, their associated points (corresponding to navaid points and conflict areas), and the flights assigned to each VFT. Utilities provided by ATAC then converted this ASCII formatted GRADE output file into the format necessary for SIMMOD.

The route network developed using GRADE is used in SIMMOD to define routes to which aircraft in the traffic sample are assigned. Each SIMMOD route is a three-dimensional flight path that reflects the trajectory of the aircraft flying through the simulation study area. The route is defined by a series of points in three dimensions that correspond to locations of navigational aids and conflict points (those points where two trajectories cross in either the XY plane or in altitude).

The figure below illustrates the resulting Baseline scenario route network, developed from the RADAR data in GRADE for use in SIMMOD:

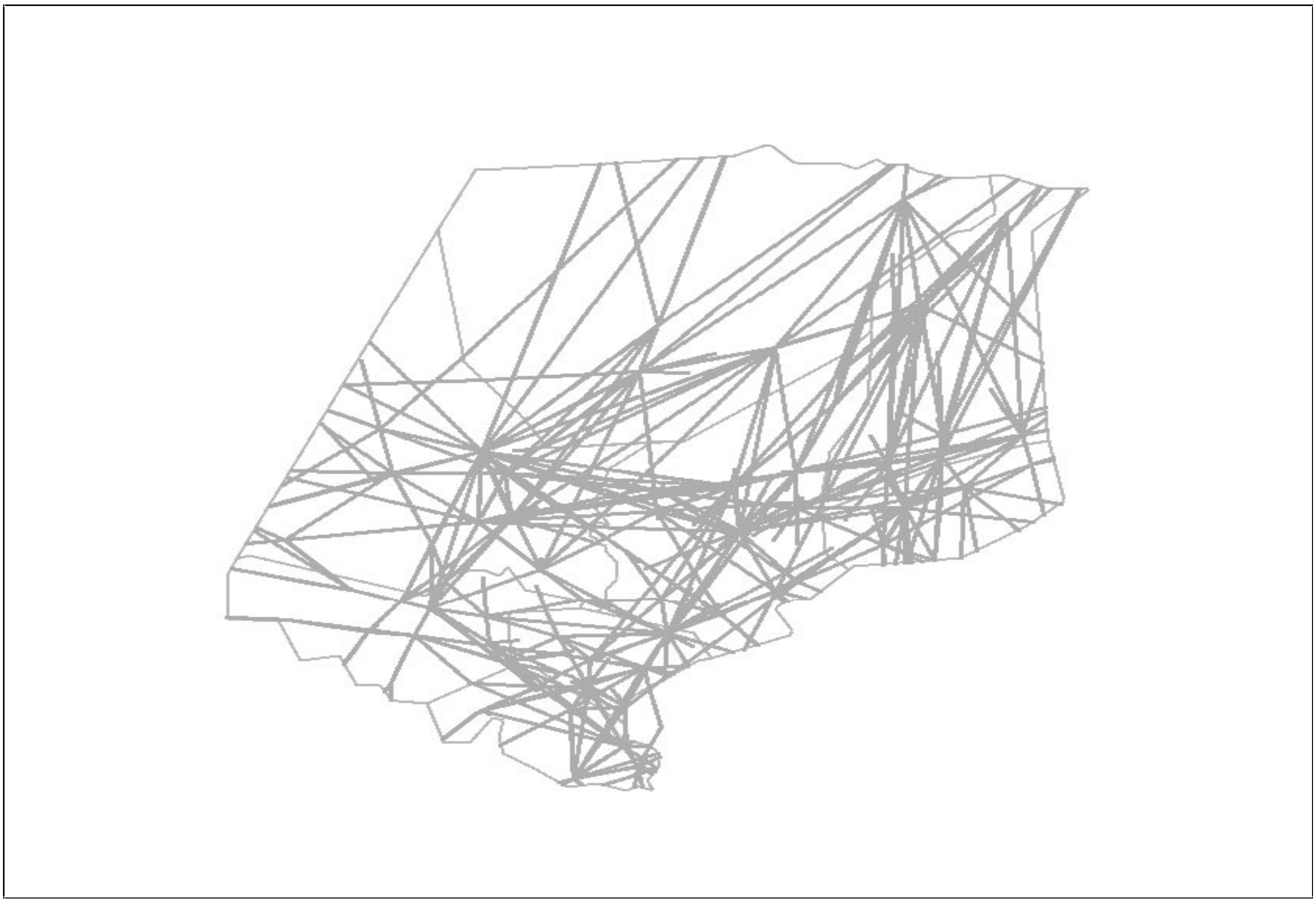

Figure 5

2.6.2.1.2 Nattenheim Proposal

The route network developed for the Baseline case was used for the Nattenheim Proposal. The VFTs from the Baseline were edited to reflect:

- Traffic inbound to EBBR from KRH or FFM is re-routed to ADENU (15 NM East of NTM) - BUFLO (20 NM Southeast of GOTIL) - GOTIL. This new route crosses the German military training area ED-R304.
- EDDF departure traffic is to be routed KIR-RUWER (current routeing), then via a new waypoint located roughly at 49°44'N-005°52'E and then direct to REM VOR in France.
- Traffic originating from Düsseldorf FIR with destination to Madrid FIR, Portugal FIR and Canaries to be routed on a new routeing via MAS VOR direct to CIV VOR. Traffic should cross MAS at FL160 and be at CIV at FL330.
- The segment LNO-ADORA on route UR15 is to be removed.
- Overflying traffic south-westbound currently on UR15/UH19/UN872 NOR-LNO-ADORA-REM or on UR15/UR7/UR10/UR15 NOR-LNO-DIK-MMD-REM to be routed on a new route NOR-KENUM, thenvia a new waypoint located roughly at 40°44'N - 005°52'E and then direct to REM VOR inFrnace.
- The remaining Düsseldorf FIR originating traffic currently on these routeings and unable to be at KENUM at FL245+ should proceed via MAS-LNO-UR7-DIK then via a new waypoint located roughly at 49°44'N-005°52'E and then direct to REM VOR in France. Traffic able to be above FL245 at KENUM shall proceed as above.
- North-westbound traffic on UH100/UN873/UH15/UR15 RINAX-MEDIX-MMD-ADORA-LNO-NOR or on UH100/UN873/UH110/UR7/UR15 RINAX-MEDIX-DIK-LNO-NOR should proceed MEDIX-LUXIE direction KENUM until intersection with UJ905.

The figure below illustrates the resulting route network for the Nattenheim Proposal scenario:

Figure 6

2.6.2.1.3 Air Route Network Amendment Version 2

The Air Route Network Amendment Version 2 scenario represents a substantial modification from the routeing described in the previous two scenarios. These modifications, developed by the Route Network Development Sub-Group (RNDSG) co-ordinated by EUROCONTROL's DED4, are intended to increase European ATC capacity through the development of:

- A future route network,
- An optimised associated airspace structure and sectorisation, and
- Improved TMA structure.

For this graphical analysis and design pilot, only the future route network was examined.

The EGRADE team co-ordinated with DED4 and ATAC to obtain the ARN V2 route structure for this pilot study. The traffic sample (obtained from the RADAR data, see Section 2.6.2.2, below) was given to DED 4's Airspace Modelling Section for processing. Using utilities they developed for analysis of the proposed route structures, DED 4 was able to assign the aircraft in the traffic sample (according to their origin and destination airports and aircraft model types) to the appropriate routes in the ARN V2 route network. DED4 provided the route descriptions (as points with latitude and longitude co-ordinates) and the reassigned traffic sample to the EGRADE team in ASCII file format. Using a utility developed by ATAC to convert the reassigned traffic and route network into GRADE VFTs, the data were transformed into SIMMOD file format.

The figure below illustrates the resulting ARN-V2 route network used for this study:

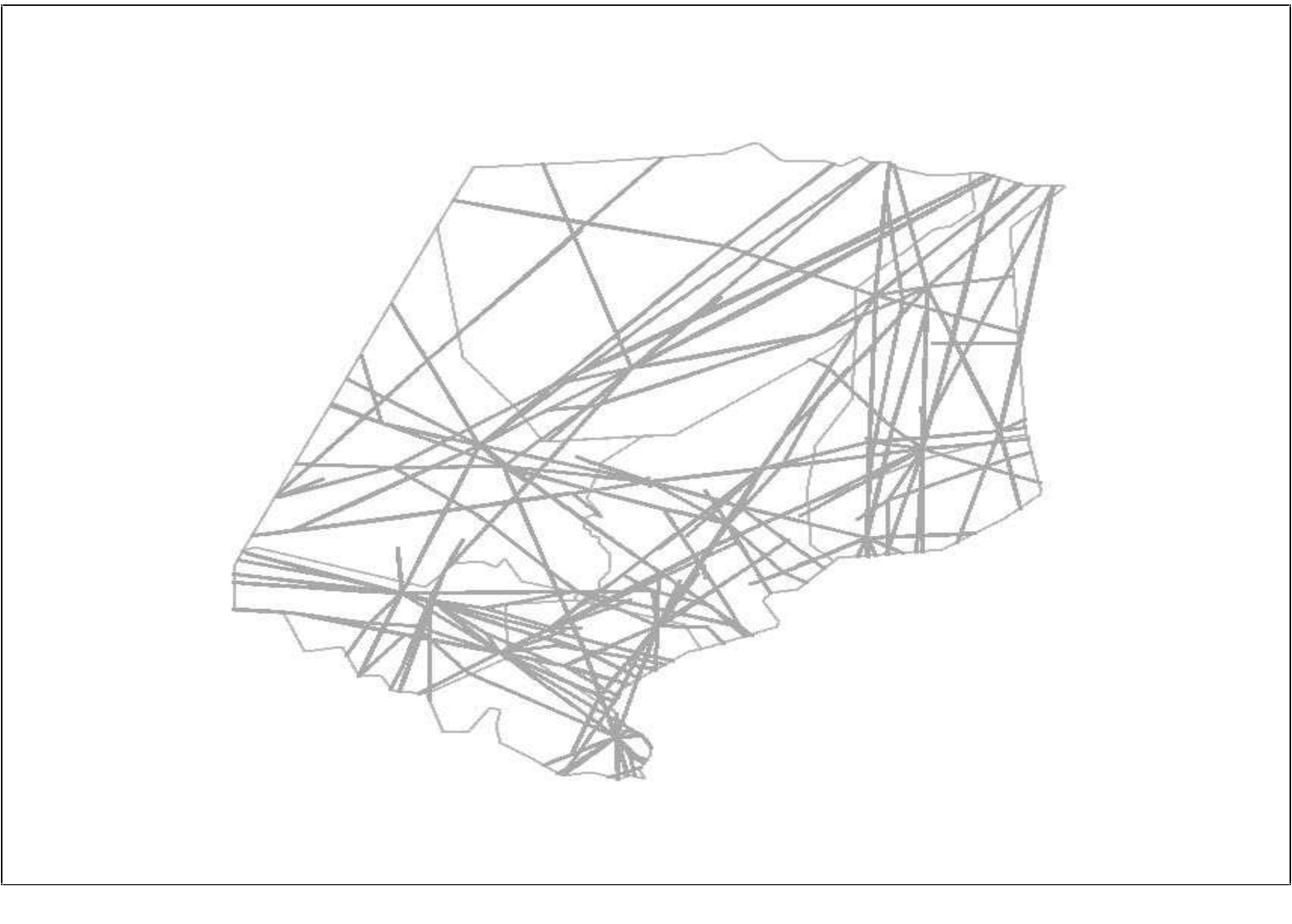

Figure 7

2.6.2.2 *Traffic Sample*

The traffic sample provides the demand on the airspace system during the simulation. It represents the flights in the airspace being simulated. The movement of these flights is then tracked by the simulator, permitting the estimation of aircraft travel times, delay times, and sector flows for each scenario. The following sub-sections describe how the traffic samples used in the pilot study were obtained.

2.6.2.2.1 RADAR Data to Traffic Sample

The process of building the route network from the RADAR tracks, described in Section 2.6.2 above, also yielded the initial traffic sample. With the combination of RADAR tracks and flight plan information, it was possible to determine:

- Time of entry into Maastricht UAC
- Aircraft Call Sign
- Aircraft Model Type, and
- Airspace “route” it flew.

The resulting traffic sample contained 2,485 flights, reflecting the traffic demand for 30 August 1995. The traffic sample was converted by ATAC into the format required by SIMMOD.

2.6.2.2.2 Forecasting

The traffic sample created from the RADAR data for the 30 August 1995 sample was used as a basis for creating traffic forecasts for the years 2000 and 2005. EUROCONTROL’s STATFOR Section of DED 4 analysed the 1995 traffic sample by origin/destination and aircraft model and applied traffic growth estimates, by city pair, to that sample to arrive at traffic levels for the years 2000 and 2005 (Note: the traffic growth factors vary by origin/destination city pair). The table below summarises the demand levels for each of the traffic samples:

Table 4

Traffic Sample ID	***Year***	***Number of Flights***	***% Increase over F0***
F0	1995	2,485	0
F1	2000	3,088	24.3
F2	2005	3,781	52.2

These forecast levels were used for the Baseline and Nattenheim proposal scenarios.

For the ARN V2 scenario, the new route structure (described in section 2.6.2.1.3) results in a reduction in the number of aircraft passing through Maastrict UAC. Of the 2485 flights found in the Baseline, the new route structure reduces them to 2284. This results from some of the routeings in the Baseline being re-routed completely outside Maastricht UAC.

For ARN V2, the same percentage growth described above in Table 4 was applied to obtain 2824 and 3385 flights for the years 2000 and 2005 respectively.

2.7 Simulation Scenarios

The combination of static and dynamic data described in the previous sections was used to define the simulation scenarios. The table below summarises the characteristics of each simulation scenario:

Table 5

SIMMOD Scenario ID	Scenario	Traffic Sample	Sector Configuration	Sector Cap
BL,F0,0UH,C	Baseline	1995	8 Sectors	Base Standard
BL,F1,0UH,C	Baseline	2000	8 Sectors	Base Standard
BL,F2,0UH,C	Baseline	2005	8 Sectors	Base Standard
BL,F0,1UH,C	Baseline	1995	9 Sectors	Base Standard
BL,F1,1UH,C	Baseline	2000	9 Sectors	Base Standard
BL,F2,1UH,C	Baseline	2005	9 Sectors	Base Standard
BL,F0,2UH,C	Baseline	1995	10 Sectors	Base Standard
BL,F1,2UH,C	Baseline	2000	10 Sectors	Base Standard
BL,F2,2UH,C	Baseline	2005	10 Sectors	Base Standard
NH,F0,0UH,C	Nattenheim	1995	8 Sectors	NH Standard
NH,F1,0UH,C	Nattenheim	2000	8 Sectors	NH Standard
NH,F2,0UH,C	Nattenheim	2005	8 Sectors	NH Standard
NH,F0,1UH,C	Nattenheim	1995	9 Sectors	NH Standard
NH,F1,1UH,C	Nattenheim	2000	9 Sectors	NH Standard
NH,F2,1UH,C	Nattenheim	2005	9 Sectors	NH Standard
NH,F0,2UH,C	Nattenheim	1995	10 Sectors	NH Standard
NH,F1,2UH,C	Nattenheim	2000	10 Sectors	NH Standard
NH,F2,2UH,C	Nattenheim	2005	10 Sectors	NH Standard
V2,F0,0UH,C10	ARN V 2	1995	8 Sectors	Base Standard +10%
V2,F1,0UH,C10	ARN V 2	2000	8 Sectors	Base Standard +10%
V2,F2,0UH,C10	ARN V 2	2005	8 Sectors	Base Standard +10%
V2,F0,1UH,C10	ARN V 2	1995	9 Sectors	Base Standard +10%
V2,F1,1UH,C10	ARN V 2	2000	9 Sectors	Base Standard +10%
V2,F2,1UH,C10	ARN V 2	2005	9 Sectors	Base Standard +10%
V2,F0,2UH,C10	ARN V 2	1995	10 Sectors	Base Standard +10%
V2,F1,2UH,C10	ARN V 2	2000	10 Sectors	Base Standard +10%
V2,F2,2UH,C10	ARN V 2	2005	10 Sectors	Base Standard +10%
V2,F0,0UH,C20	ARN V 2	1995	8 Sectors	Base Standard +20%
V2,F1,0UH,C20	ARN V 2	2000	8 Sectors	Base Standard +20%
V2,F2,0UH,C20	ARN V 2	2005	8 Sectors	Base Standard +20%
V2,F0,1UH,C20	ARN V 2	1995	9 Sectors	Base Standard +20%
V2,F1,1UH,C20	ARN V 2	2000	9 Sectors	Base Standard +20%
V2,F2,1UH,C20	ARN V 2	2005	9 Sectors	Base Standard +20%
V2,F0,2UH,C20	ARN V 2	1995	10 Sectors	Base Standard +20%
V2,F1,2UH,C20	ARN V 2	2000	10 Sectors	Base Standard +20%
V2,F2,2UH,C20	ARN V 2	2005	10 Sectors	Base Standard +20%

3. Results and Analysis

Recalling that the objectives of this pilot study were to evaluate the use graphical analysis and design techniques on European airspace, the following subsections elaborate on:

- The application of GRADE software on Maastricht UAC airspace to build up a SIMMOD simulation, and
- The simulation findings for the three scenarios and their associated traffic samples (those scenarios being the Baseline, Nattenheim Proposal, and the Air Route Network Version 2).

3.1 GRADE to SIMMOD

The GRADE software system was used to build the SIMMOD simulation data from the static and dynamic data described in Section 2.

As one of the objectives for this pilot study is the evaluation of the use of graphical analysis and design techniques on European airspace, the following subsections describe the steps in the process, using the Baseline and Nattenheim Proposal scenarios as examples. Detail of the data used for the simulation phase are described in Section 2, above.

3.1.1 Step 1: Visualising Data

As GRADE provides a 3-dimensional environment for the visualisation of data, the analyst is able to examine the interaction of static data (such as sector boundaries, navigational aid locations, etc.) with dynamic data (such as the aircraft tracks and flight plans obtained from the RADAR data). GRADE was successfully modified to allow the visualisation of both static and dynamic data that were obtained from EUROCONTROL.

The figure below illustrates the static data (navigational aid locations and sector boundaries) and the associated RADAR flight tracks obtained for the Brussels Luxembourg Sector.

Figure 8

3.1.2 Step 2: Building a Route Network from RADAR data

Using functions in the GRADE software, the user is able to select those flights sharing common flight paths using the mouse. The analyst then uses these flights to create a series of 3-dimensional points that eventually become a Virtual Flight Track (VFT). The flights are then assigned to the VFT and their RADAR tracks removed from the screen. Thus the analyst can step through all of the sectors, using the RADAR tracks to construct the VFTs.

The figures below illustrate the process using the flights in Brussels Luxembourg Sector.

Figure 9: Depicts the plan view of a stream of arrivals landing at Frankfurt (EDDF). The yellow line represents the VFT which will be converted to a SIMMOD route. The points used to define this route are the result of the analysis of the radar tracks. These are also depicted in Figure 10 on the following page.

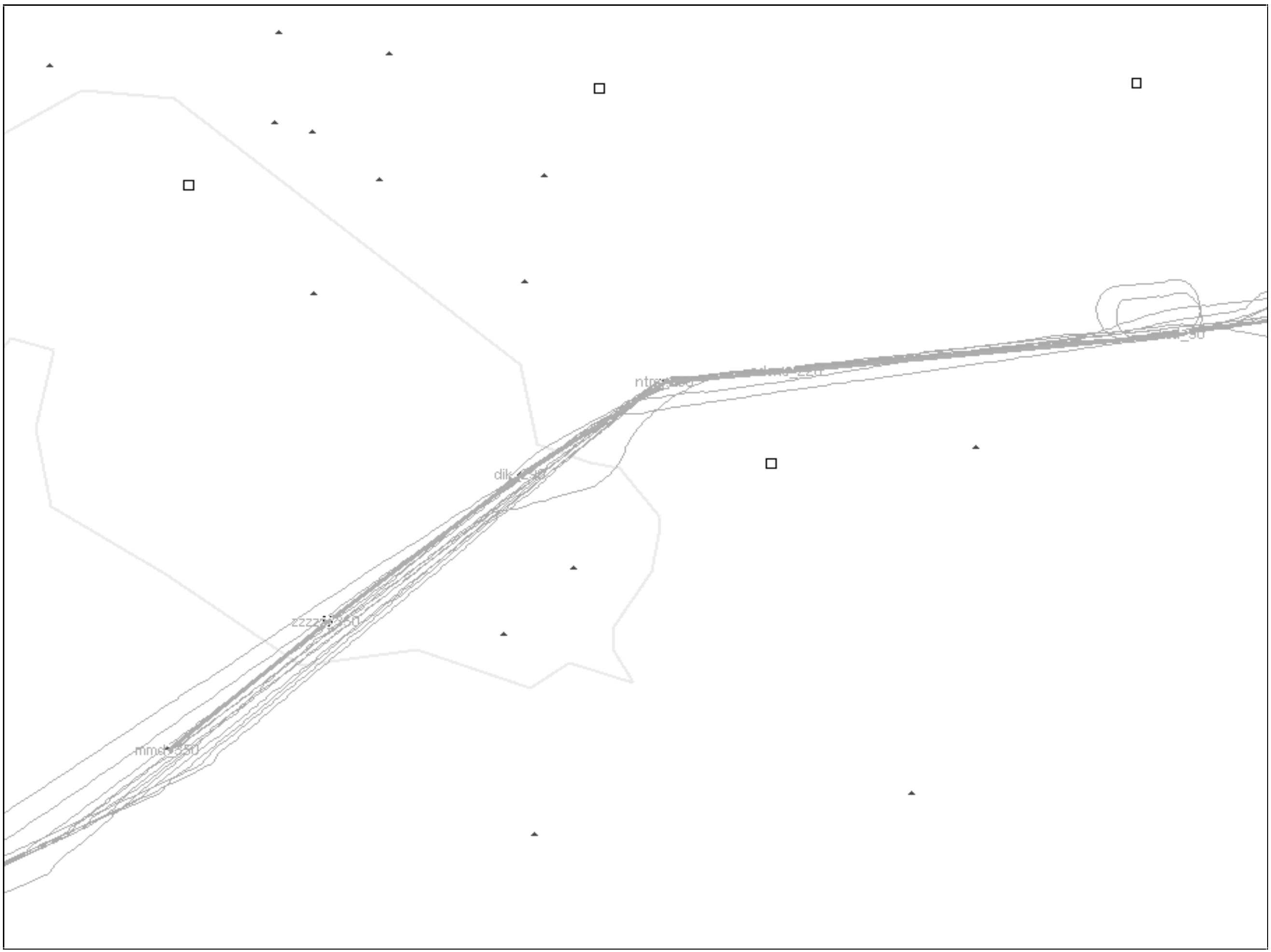

Figure 9

The yellow line in Figure 10 below is the same as the yellow line in Figure 9. In this view, looking from the southeast to the northwest, the descent profiles can be veiwed. This information was used to develop additional simulation routings.

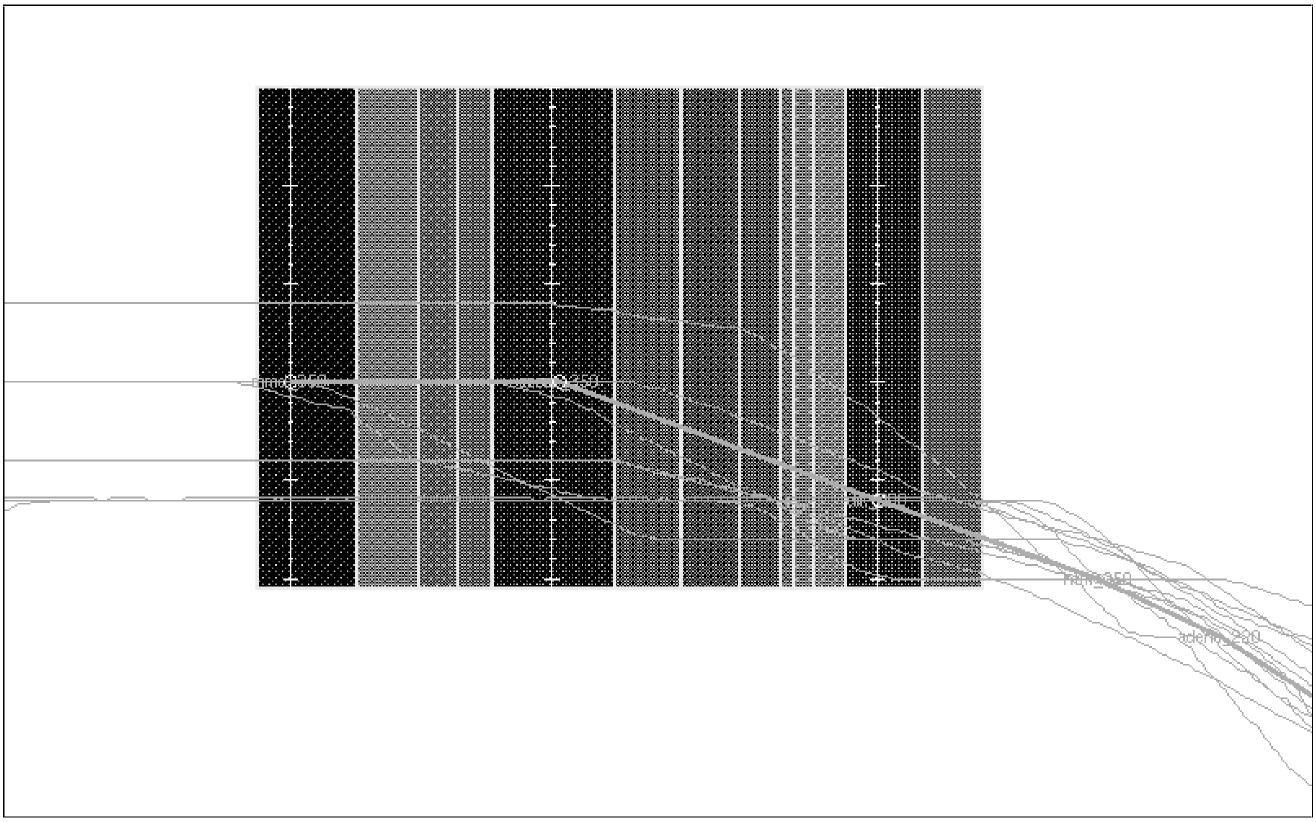

Figure 10

3.1.3 Step 3: Preparation of SIMMOD Data

Using the process above, an integrated route network of VFTs for Maastricht UAC, based upon the RADAR data of 30 August 1995, was built. These VFTs were then processed to create the SIMMOD input data that define the airspace route network and the flights in the 1995 traffic sample, assigned to their respective routes. GRADE was used successfully to build the VFT structure for all of the Maastricht UAC.

The figure below illustrates the final route network used for the Baseline scenarios.

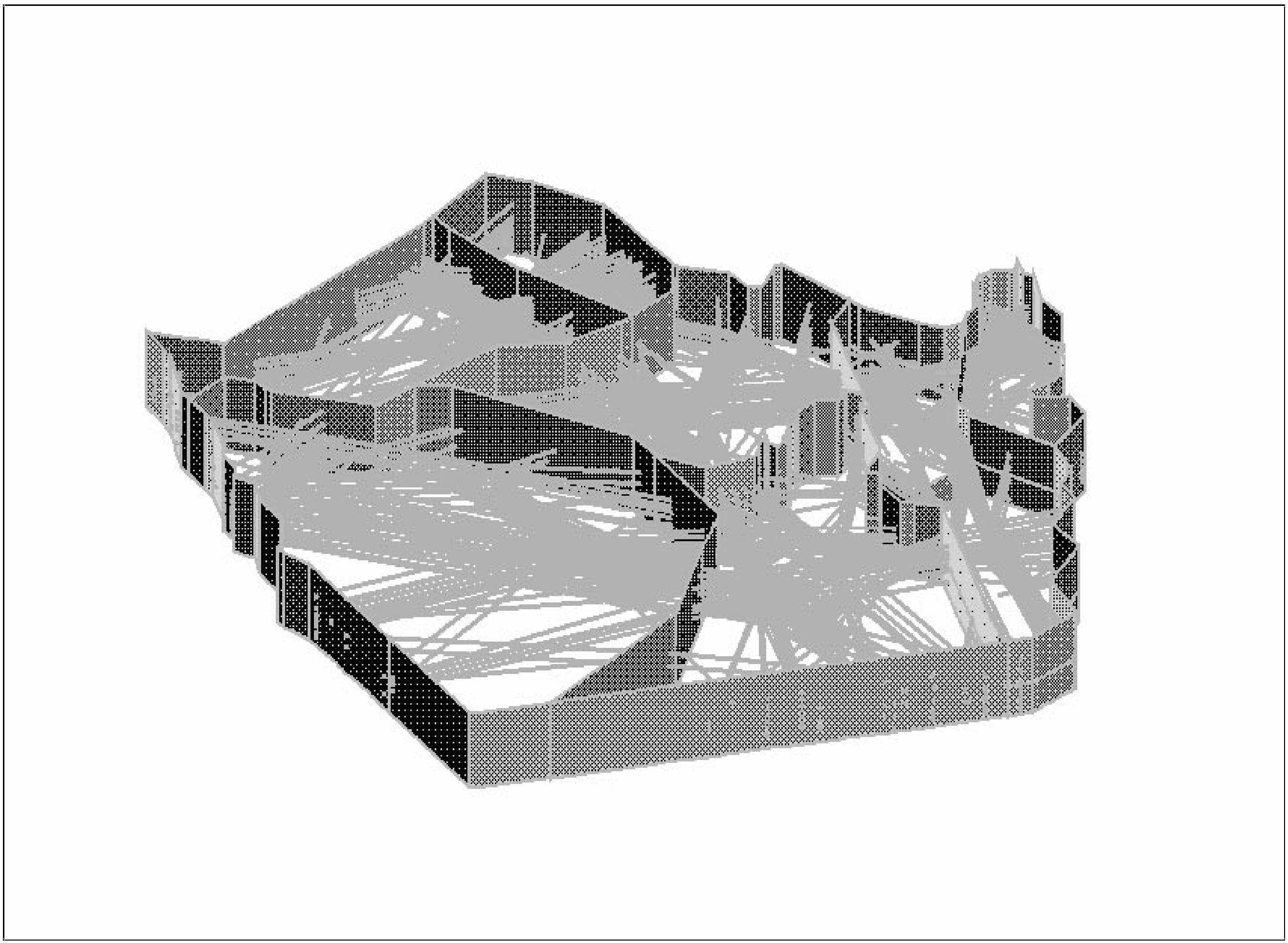

Figure 11

3.1.4 Step 4: Resectorisation and Re-routeing

Once the Baseline sectorisation and route network are built, they can be used as a basis to examine subsequent modifications. For example, the Nattenheim Proposal in this pilot study began with the Baseline sectorisation and traffic sample that was then modified to reflect:

- The airspace addition, described in Section 2.6.1.3.2, using the GRADE sector building tool, and
- The re-routing, described in Section 2.6.2.1.2, which was effected by manipulating the Baseline VFTs.

Using GRADE, the baseline data were successfully modified to reflect the Nattenheim Proposal changes to the airspace. The figures below reflect the changes made to this region of the airspace.

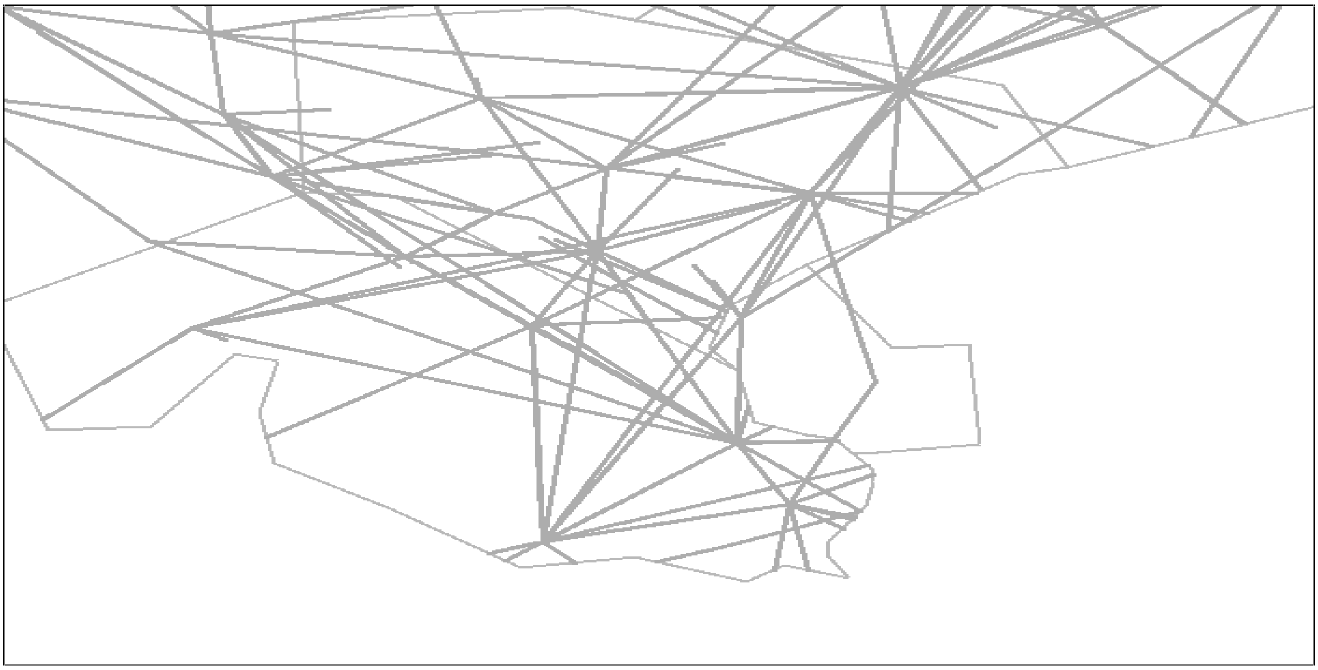

Figure 12

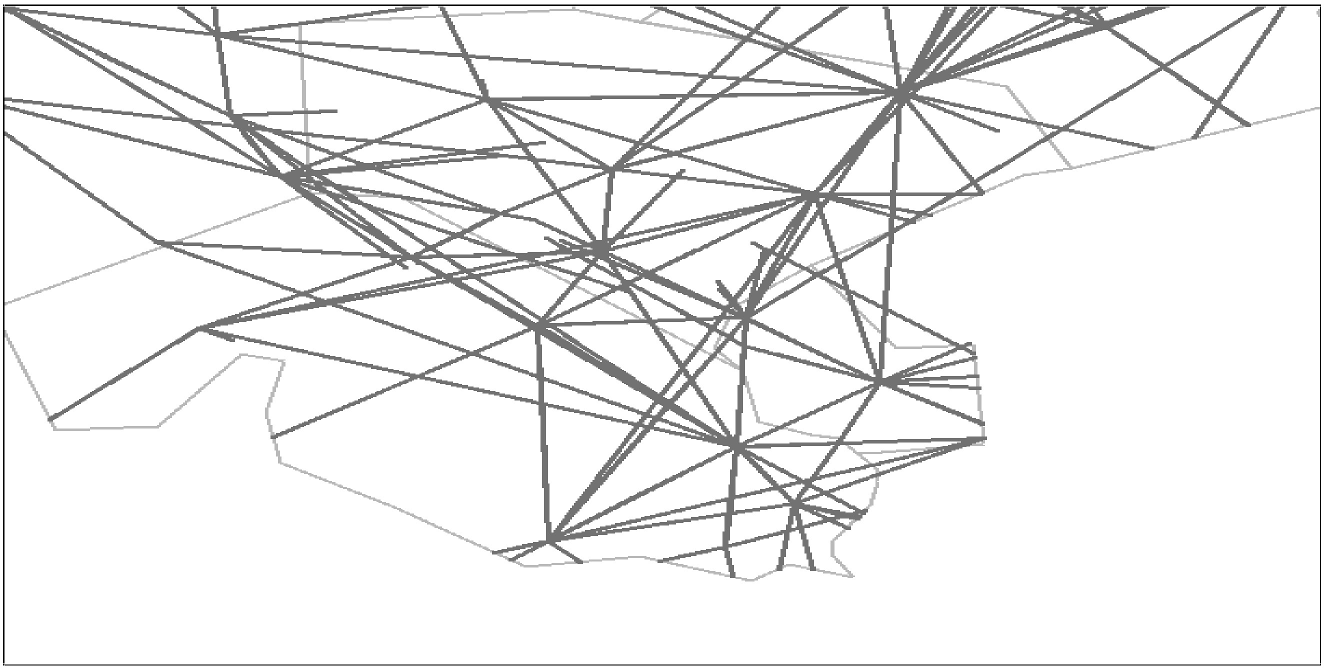

Figure 13

3.1.5 Step 5: Future Traffic Samples

Steps 1-3 of the data-building process, described above, were used as the framework for the traffic samples obtained for the years 2000 and 2005. The flights in this traffic sample, which correspond to increased demand by city-pair and aircraft type, were added to the route network created for the 1995 traffic sample. This was accomplished using a database that links the reference flight from the 1995 traffic sample (and its corresponding route in the route network) with the additional flight(s) found in the future traffic samples. For example, flight FIN880 flying between LEBL and EDDL in the 1995 traffic sample generated 2 flights in the 2000 traffic sample, reflecting the increase expected in demand between those city pairs. These 2 “new” flights were then assigned to the same route in the route network as the original flight.

3.1.6 Commentary

The process described in the proceeding sections was used throughout this pilot study to examine Maastricht UAC. As a result:

- A version of GRADE was established at the EEC,
- GRADE was modified to support EUROCONTROL data formats,
- European-specific static and dynamic data were imported into GRADE, and
- These data were used to define the scenarios for the subsequent simulation phase.

3.2 Simulation Results

The data prepared during the graphical analysis and design phase for the three scenarios were simulated using SIMMOD to determine the

- Aircraft travel times, describing the undelayed time an aircraft flew through the simulated airspace,
- Aircraft delay times, describing the delay incurred by each aircraft (where delay arises from sector capacity limits or conflict resolution requirements),
- Aircraft flight times, describing the total flight time for each aircraft (equal to the sum of the aircraft travel and delay times), and
- Great circle distance comparisons, which compares the great circle flight distance into and out of the simulated MUAC airspace for the different scenarios.

The sub-sections below summarise SIMMOD simulation results for the three scenarios: Baseline, Nattenheim Proposal and the Air Route Network Version 2 for the 8-sector (0 Upperhigh), 9-sector (1 Upperhigh) and 10-sector (2 Upperhigh) configurations at the three traffic levels (1995, 2000, 2005).

3.2.1 Travel Times

The travel time for the aircraft in these simulations is a function of the route distance flown (determined by the route network for each scenario) and the flight performance characteristics (part of the standard SIMMOD data). The following table summarises the travel time results, representing the average undelayed flight time per aircraft, for each of the simulation scenarios (Note: Travel time does not change as a function of the sectorisation as sectorisation does not change the flight distance or aircraft performance characteristics):

Table 6

	Baseline	Nattenheim	V2-C10	V2-C20
	OUH	OUH	OUH	OUH
1995	19.56	20.08	20.63	20.63
2000	19.06	19.57	20.25	20.25
2005	18.34	18.86	19.92	19.92
	1UH	1UH	1UH	1UH
1995	19.56	20.08	20.63	20.63
2000	19.06	19.57	20.25	20.25
2005	18.34	18.86	19.92	19.92
	2UH	2UH	2UH	2UH
1995	19.56	20.08	20.63	20.63
2000	19.06	19.57	20.25	20.25
2005	18.34	18.86	19.92	19.92

Comparing among the scenarios, the following figures summarise the same travel time results graphically, comparing the Baseline, Nattenheim, and V2 scenarios for the basic 8-sector configuration:

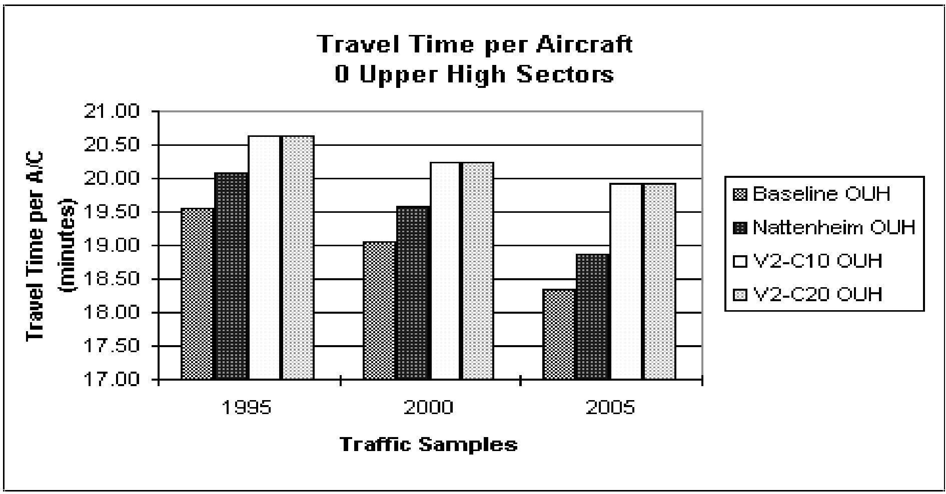

Figure 14

Examining these results, the following trends are observed:

- The increase in traffic levels, reflected in the traffic samples for 1995, 2000, and 2005, actually results in a decrease in travel time. This stems from the fact that the traffic growth is not homogeneous: There is a higher growth rate in short-haul traffic than for long-haul traffic. As a result, the average flight time through the simulated airspace actually decreases as the traffic increases from 1995 to 2005.
- The Nattenheim Proposal simulation scenarios yield systematically higher travel times than those of the Baseline (approximately 0.5 minutes more travel time, on average, per aircraft). This is a natural result of the fact that the size of the airspace for the Nattenheim Proposal scenarios increased in comparison with those of the Baseline.
- The ARN V2 simulation scenarios yield systematically higher travel times than those of either the Baseline and Nattenheim (approximately 1.0 minutes more travel time than the Baseline and 0.5 minutes more travel time than the Nattenheim Proposal, on average, per aircraft). This results from both the increase in size of the airspace (by including the Nattenheim Proposal airspace) and the significant route changes proposed in the ARN V2 network. While the ARN V2 network is significantly simplified in comparison with those in the Baseline and Nattenheim Proposal, the actual flight distances are slightly increased, thereby increasing the travel time.
- The results for ARN V2 obtained for both 10% and 20% increases in sector caps are identical. This results from the nature of the data measured. Travel time represents the undelayed time for the aircraft. The sector caps serve to reduce flow through the sectors. Since there is no delay time reported in the travel time measurement, the values are identical.

3.2.2 Delay Times

Delay for the aircraft in these simulation scenarios stems from two sources: Sector capacity limits and/or separation requirements along the airspace routes and at route intersection points. The following table summarises the delay time results, representing the average delay time per aircraft, for each of the simulation scenarios:

Table 7

	Baseline	Nattenheim	V2-C10	V2-C20
	OUH	OUH	0UH	0UH
1995	0.13	0.08	0.05	0.04
2000	0.32	0.25	0.14	0.08
2005	2.82	2.75	1.19	0.29
	1UH	1UH	1UH	1UH
1995	0.09	0.05	0.04	0.04
2000	0.22	0.16	0.12	0.07
2005	2.52	1.79	1.11	0.26
	2UH	2UH	2UH	2UH
1995	0.09	0.05	0.04	0.04
2000	0.21	0.16	0.12	0.07
2005	1.17	1.07	1.04	0.25

Comparing among the scenarios, the following figures summarise the same delay time results graphically, comparing the Baseline, Nattenheim, and V2 scenarios (by sector configuration of 8 Sectors, 9 Sectors, and 10 Sectors):

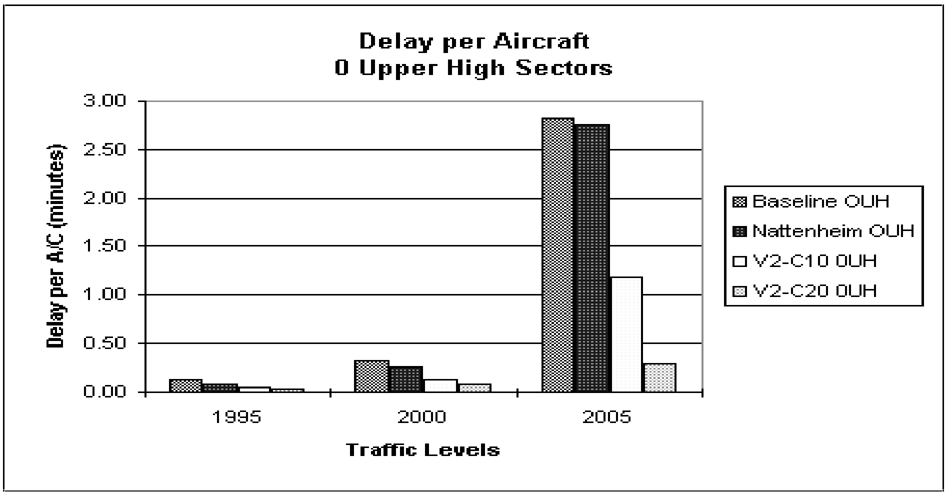

Figure 15

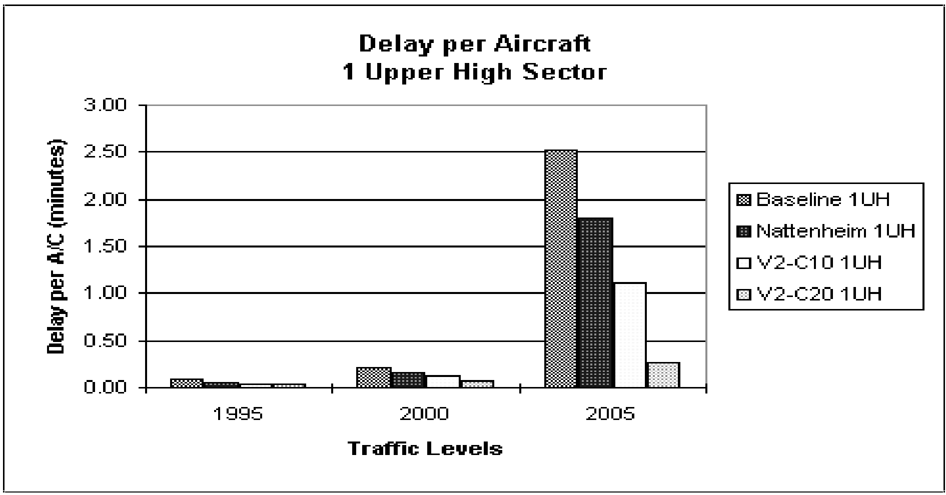

Figure 16

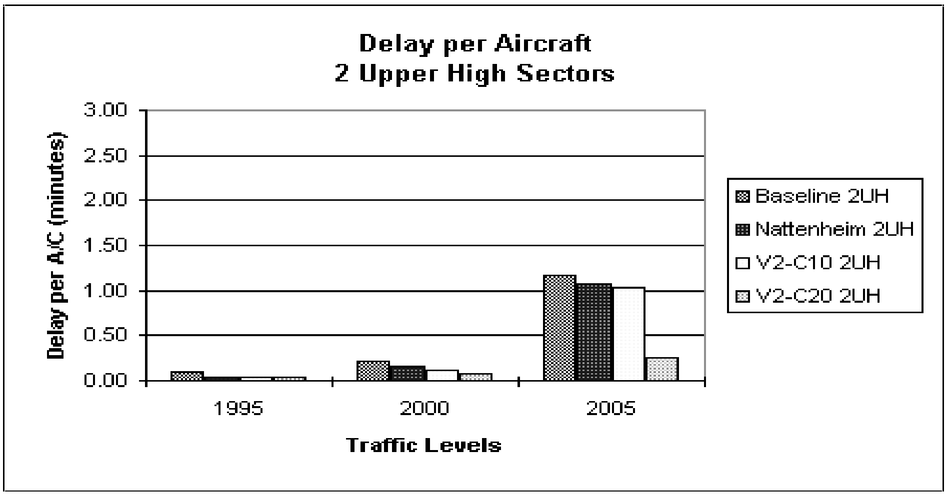

Figure 17

Examining these results, the following trends are observed:

- For all of the scenarios, the delay values measured for the 1995 traffic level are very low. As the traffic increases for the years 2000 and 2005, the sector capacities and route congestion result in increasing delays.
- For all of the scenarios, the delay values decrease as the number of sectors increase from 8 to 10. This decrease in delay results from the fact that the airspace is "cut" into more sectors (by the addition of one or two upperhigh sectors), thereby increasing the instantaneous capacity of the airspace region.
- The Nattenheim Proposal simulation scenarios systematically yield slightly lower travel times than those of the Baseline for all three sectorisations. This results from the 20% increase in the capacity of the Brussels Luxembourg Sector (the sector cap increases from 10 in the Baseline to 12 in the Nattenheim Proposal) and the simplification of the airspace structure in the region.
- The ARN V2 simulation scenarios, obtained for both 10% and 20% increases in sector caps, systematically yield markedly lower delay times than those of either the Baseline and Nattenheim. The ARN V2 C20 cases, with a 20% increase in sector cap values, register the lowest delay. These delay reductions result from the increase in the sector cap values (of either 10% or 20% as compared to the Baseline caps) and the simplification of the route structure (which reduces the amount of route intersection points in comparison with the Baseline and Nattenheim Proposal scenarios).

3.2.3 Flight Times

The flight time for an aircraft corresponds to the combination of the travel time and the delay time. The following table summarises the flight time results, representing the average time in flight (travel and delay) per aircraft, for each of the simulation scenarios:

Table 8

	Baseline	Nattenheim	V2-C10	V2-C20
	OUH	OUH	OUH	OUH
1995	19.69	20.17	20.68	20.67
2000	19.38	19.82	20.39	20.33
2005	21.16	21.61	21.11	20.21
	1UH	1UH	1UH	1UH
1995	19.65	20.13	20.67	20.66
2000	19.28	19.73	20.37	20.32
2005	20.85	20.65	21.04	20.18
	2UH	2UH	2UH	2UH
1995	19.65	20.13	20.67	20.66
2000	19.27	19.73	20.37	20.32
2005	19.51	19.93	20.96	20.18

Comparing among the scenarios, the following figures summarise the flight time results graphically, comparing the Baseline, Nattenheim, and V2 scenarios (by sectorisation configuration of 8 Sectors, 9 Sectors, and 10 Sectors):

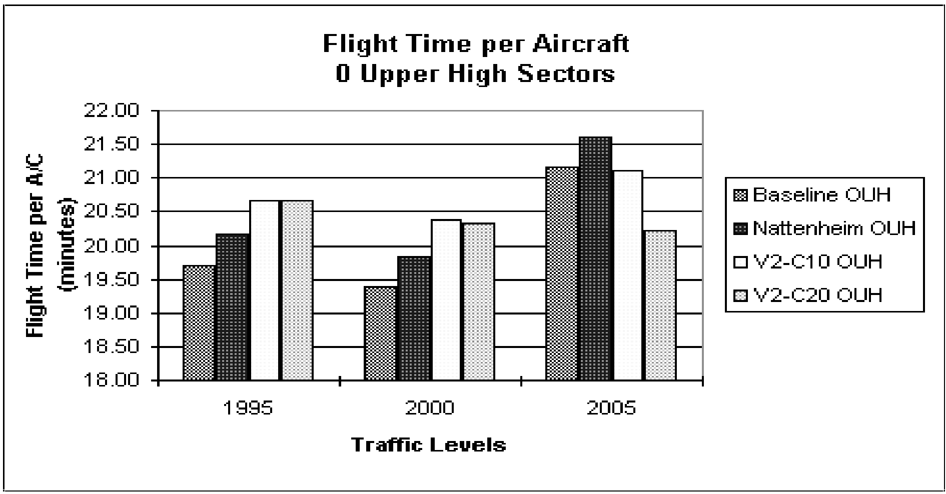

Figure 18

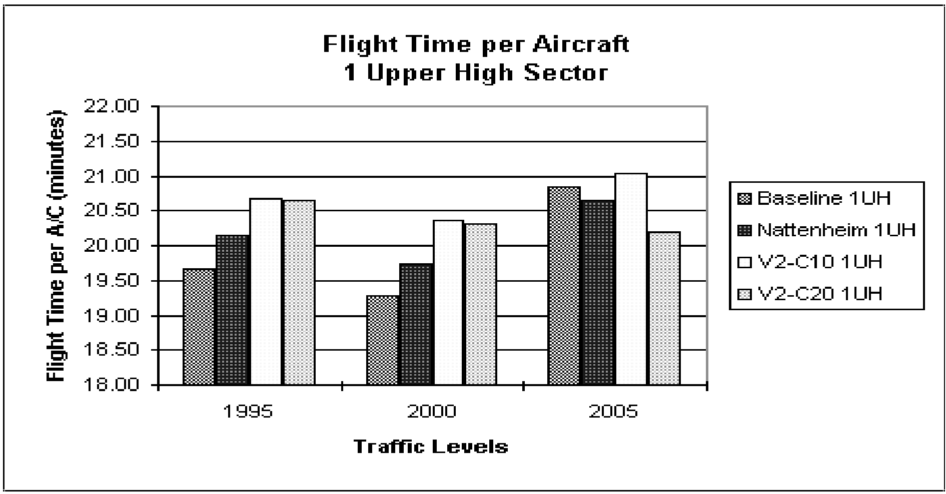

Figure 19

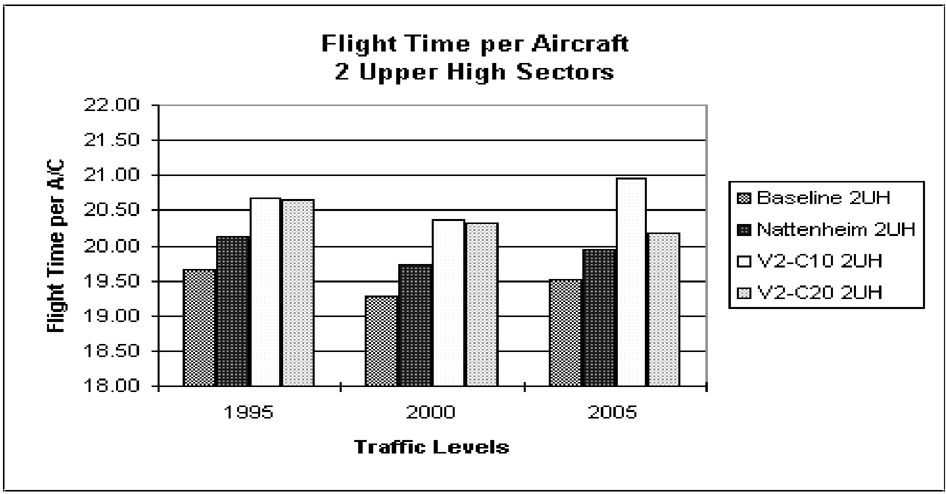

Figure 20

Examining these results, the following trends are observed:

- For all the scenarios measured, the flight times for the year 2000 are lower than those measured for the year 1995. The results from the fact that the reduction in travel time (seen in Section 3.2.1) outweighs the increase in delay time seen in Section 3.2.2.
- In general, the Nattenheim Proposal scenarios have slightly higher average flight times when compared with those of the Baseline. In only one case, for the 2005 traffic sample and one upper-high sector, is the Nattenheim Proposal flight time less than the Baseline flight time. The increase in travel time between the Nattenheim Proposal and the Baseline scenarios, seen in Section 3.2.1, outweighs the small reduction in delay time seen in Section 3.2.2.
- For the 1995 and 2000 traffic samples, the flight times for the Nattenheim Proposal and the ARN V2 scenarios are systematically higher than the Baseline scenarios. This is seen for both the 10% and 20% increase sector cap cases. This indicates that the increase in travel time, seen in Section 3.2.1, outweighs the reduction in delay time seen in Section 3.2.2.
- For the 2005 traffic samples, the comparison of the Nattenheim Proposal and ARN V2 scenarios with the Baseline is variable. As the number of sectors increases from 8 to 10, the Nattenheim Proposal and the ARN V2 flight time values increase in relation to the Baseline values. Thus, as the number of sectors increases, the delay reductions seen in Section 3.2.2 are outweighed by the increase in travel time, seen in Section 3.2.1.

3.2.4 Great Circle Distances

As can be seen from the results presented in the three previous sections, travel time changes among the three scenarios influence the relative impact on total flight time[8]. To clarify this effect, an analysis was performed to determine the changes in the great-circle distances flown for the aircraft in the 1995 traffic sample. For these aircraft, the great-circle distance from the origin airport to the point of entry in the simulated airspace was calculated for each flight. The flight distance inside the simulated airspace was determined from the simulation output. Finally, the great-circle distance from the point exiting the simulation airport to the destination airport was calculated. The table below summarises the results:

Table 9

Direction of Travel	***Distance (nm) Total (2284) Flights***			***Distance (nm) By Flight***		
	Baseline	***NTM***	***V2***	***Baseline***	***NTM***	***V2***
To MUAC	1,097,123	1,092,942	1,092,308	480.35	478.73	472.24
In MUAC	344,001	352,356	355,124	150.61	154.34	155.48
From MUAC	1,129,829	1,124,918	1,128,302	494.67	492.74	494.00
Total	**2,570,953**	**2,570,216**	**2,575,734**	**1,125.64**	**1,125.81**	**1,127.73**

This table indicates that the average flight distance of the Nattenheim Proposal is nearly identical to the Baseline while the V2 network is approximately 2 nm greater than that in the Baseline, considering the great-circle routeings outside of the simulated airspace and the corresponding simulated route networks inside the simulated airspace. Though slightly longer within the Maastricht UAC airspace, the ARN V2 route network simplifies the airspace considerably (in comparison with the Baseline) by reducing the number of route intersections.

[8] For the comparison, all scenarios used the 2284 flights found in the ARN V2 1995 traffic sample. See section 2.6.2.2.2 for discussion of traffic samples.

4. Conclusions

The EGRADE Pilot Study achieved two principal objectives:

- The implementation of a version of the GRADE software system, for use with "European" data at EUROCONTROL, and
- The use of graphical analysis and design techniques to evaluate a region of European Airspace - Maastricht UAC in this study.

The following subsections examine each of these objectives.

4.1 GRADE Objectives

The EGRADE project allowed the EEC to:

- Obtain a version of GRADE, tailored for us at EUROCONTROL,
- Import and manipulate static data that describe European geography and airspace (national boundaries, navigational aid locations, sectors, etc.),
- Import and manipulate ASTERIX format RADAR data, and
- Import and manipulate ASTERIX format flight plan data.

In addition, the GRADE software was briefly evaluated to determine the suitability for use with other simulators. GRADE was modified to accept file formats used for the SIM5+ real time simulation facility at the EEC. Using these utilities, the static data (such as sector definitions) and the pseudo-radar recordings obtained from SIM5+ were successfully imported for visualisation in GRADE. This experiment illustrated the ease with which data used in other simulators, such as RAMS, could be displayed in the GRADE 3-dimensional environment.

4.2 MUAC Evaluation

The EGRADE project successfully evaluated a region of European airspace using the combination of the GRADE software (for data visualisation and manipulation) and SIMMOD (as the fast-time simulation engine). This evaluation examined a total of three airspace configurations (the Baseline, Nattenheim Proposal, and ARN V2 re-routeing), allowing the comparison of aircraft travel and delay times among them. Those comparisons yielded the following conclusions:

- Nattenheim Proposal **-** There are delay savings, relative to the routeings described in the Baseline, in this proposal. These savings stem principally from the increase in capacity expected for Brussels Luxembourg sector. At the same time, there is an increase in travel time that results from both the increase in the airspace assigned to Maastricht UAC and the route modifications region. Comparison of the great-circle distances from origin to destination, however, shows that the total flight distance is nearly identical to that of the Baseline. This indicates that the same travel time increase seen in the Nattenheim proposal scenario results in virtually no change in total flight distance. Using the forecasts for traffic, the Nattenheim proposal yields delays (of approximately one minute or less per aircraft) until the year 2005 if two upper-high sectors are used. If only one upper-high sector is used, delays exceed one minute after the year 2000.
- Alternative Route Network, Version 2 **-** Again, there are delay savings, relative to the routeings described in the Baseline, in this proposal. These savings stem principally from the increase in capacity for the Maastricht UAC sectors (both 10% and 20% increases in capacity were examined). While the complexity of the routeing was reduced as compared to that in the Baseline, the ARN V2 route network results in an increase in travel time in Maastricht UAC. This increase in travel time corresponds approximately to a five nautical mile increase in travel distance, on average, for the aircraft in Maastricht UAC. Looking at the great-circle travel distances from origin to destination, however, shows that the flight distance increase over the total city pair route is only two nautical miles. Using the forecasts for traffic, the ARN V2 proposal delays remain at approximately one-minute or less per aircraft in both the one upper-high sector and two upper-high sector configurations.

Annex A

Extract of RADAR Data
ASCII FORMAT

The table below is an extraction of the RADAR data used for this analysis. The RADAR data, converted into ASCII format, consist of a series of data recordings, each corresponding to an aircraft location in time. Each record provides the time, a flight ID (in this case, the sequential appearance of the flight in the 24 hour RADAR recording), the SSR Code associated with this flight's flight plan, the X and Y position (relative to the RADAR system), the Flight Level, the conversion of the X and Y position into Lat and Long, and finally a "unique" flight ID (in this case the same as the Flight ID). These recorded "hits" can then be linked together to provide a graphical image of the aircraft's recorded trajectory in GRADE.

Table 1

Time	Flt ID	SSR Code	X Position	Y Position	FL	Lat	Long	Flt ID
00:02:00.32	1	161	-78.3906	-48.5313	190	50.1750	5.9697	1
00:02:04.95	1	161	-78.2969	-48.8906	190	50.1691	5.9724	1
00:02:09.75	1	161	-78.1875	-49.2500	190	50.1632	5.9755	1
00:02:14.52	1	161	-78.0469	-49.6250	190	50.1570	5.9794	1
00:02:19.47	1	161	-77.9063	-49.9844	190	50.1511	5.9833	1
00:02:24.25	1	161	-77.7656	-50.3438	190	50.1452	5.9872	1
00:02:29.07	1	161	-77.6875	-50.7031	190	50.1392	5.9895	1
00:02:33.91	1	161	-77.5313	-51.0313	190	50.1339	5.9937	1
00:02:38.71	1	161	-77.4531	-51.3750	190	50.1282	5.9960	1
00:02:43.53	1	161	-77.3438	-51.7344	190	50.1223	5.9991	1
00:02:48.33	1	161	-77.2031	-52.1250	190	50.1158	6.0030	1
00:02:53.12	1	161	-77.1250	-52.4375	190	50.1107	6.0052	1
00:02:57.95	1	161	-76.9844	-52.8125	190	50.1045	6.0091	1
00:03:02.75	1	161	-76.8906	-53.1406	190	50.0991	6.0118	1
00:03:07.53	1	161	-76.7656	-53.5313	190	50.0926	6.0153	1
00:03:12.35	1	161	-76.6875	-53.8750	190	50.0870	6.0175	1
00:03:17.19	1	161	-76.5469	-54.2031	190	50.0816	6.0214	1
00:03:22.07	1	161	-76.4219	-54.5469	190	50.0759	6.0248	1
00:03:26.80	1	161	-76.2656	-54.8906	190	50.0703	6.0291	1
00:03:31.67	1	161	-76.1250	-55.2188	190	50.0649	6.0330	1
00:03:36.56	1	161	-76.0313	-55.5469	190	50.0595	6.0356	1
00:03:41.35	1	161	-75.9375	-55.9375	190	50.0530	6.0383	1
00:03:46.16	1	161	-75.8125	-56.3281	190	50.0466	6.0418	1
00:03:50.62	1	161	-75.7031	-56.6406	190	50.0414	6.0448	1
00:03:55.42	1	161	-75.6094	-57.0313	190	50.0350	6.0475	1

Annex B

GRADE System Requirements

The table below summarises the basic computer system requirements for use of GRADE as well as the EEC system configuration:

Table 11

System Component	Minimum Requirement	EEC Implementation
HP UNIX Workstation	HP 9000 700 Series	HP 9000 735 i
RAM	64 Mbytes	256 MBytes
Monitor	20” Colour	20” Colour
Keyboard	Standard HP	Standard HP
Operating System	HP-UX 9.03 or higher	HP-UX 9.04
Swap Disk Space	350 MBytes	500 MBytes
Program Disk Space	~10 MBytes	~10 MBytes
Data files	~250 MBytes per dataset	~1 GBytes

ANNEX C: SIMMOD DETAILS

How are the end results achieved ?

The complete air and ground system is represented by a network of points and connecting segments along which the aircraft 'navigate'. Along with other point qualities, an altitude is associated to each point. This altitude is usually derived from free profiles but can be modified to represent, for example, height restrictions, SIDs, STARs, etc.

The simulation module is the core of the SIMMOD system. The module traces the "steps" through time and space of each aircraft defined in the traffic sample from one point to the next along its route. Potential violations of any of the modelled separation requirements between two or more aircraft moving towards a given point are detected and then resolved by adjusting their arrival times at the point. Depending on the importance of this adjustment, the controller action deemed to be causing it is interpreted as either track adjustment, speed control, holding or re-routeing of aircraft. Such specific occurrences as overtaking in the air, shuffling aircraft in the departure queue, as well as many other ATC procedures and actions either on the aerodrome, in the approach/departure environment or in en-route airspace can be simulated by careful selection of the input parameters.

Input requirements
The SIMMOD input is constructed in a number of files. The validity and correctness of the input data is crucial for the accuracy and realism of the simulation. The SIMMOD files constructed will contain detailed information regarding:

- Geographical boundaries of airspace and restrictions,
- Geographical boundaries of sectors and restrictions (capacities),
- Points data and restrictions (separation standards),
- Route data and restrictions (separation standards),
- Airfield data and restrictions (aircraft size limitations),
- Aircraft data and restrictions (wake turbulence),
- Scheduling of events (list of flights), and
- Weather considerations (reduced visibility operations).

Output
Output data is produced in a report format which may also be converted into charts and graphs. The data available from SIMMOD includes:

Airfields, which includes:

- Runway utilisation,
- Ground delays at gates, holding points or during taxiing,
- Average times for completing ground movements.

Sectors, which includes:

- Total number of aircraft that crossed the sectors within a specified time period,
- Maximum number of aircraft in each sector's area of responsibility at any one time within a specified time period,
- Average flight times for the sectors,
- A workload index for the sectors, and

- Number of aircraft in level flight, climbing or descending for each sector within a specified time period.

Points, which includes:

- Rate of traffic flow over points,
- Number of aircraft climbing, descending or in level flight at a point,
- Number of potential conflicts that will require ATC intervention.

Routes, which includes:

- Average flight times on each route, and
- Number of aircraft on each route.

Simulation Animation

In addition to the output data, the SIMMOD post-processor module produces an animated high resolution colour display of the simulation. All aircraft can be displayed during all stages of flight, or ground movement, following procedures defined in the input data.

During the animation run various items can be analysed:

- Evolution of a traffic situation and traffic flow,
- A visual check of the simulation's realism,
- Verification that procedures defined for the model do not violate the defined separation specifications, and
- Areas of scheduling congestion can be located.

Disadvantages - Limitations

SIMMOD is designed as a "quick look" simulation tool and has the following limitations:

- No resolution of conflicts during a simulation by changing an aircraft's level, and
- A global view only, no detail regarding an individual controller or operating position.

Annex D

Sector Co-ordinates
Latitude and Longitude

Sector: BRUSSELS_WEST FL245 to FL500 (FL 345 if upperhigh active)

50.316666	4.083333
50.350834	3.785000
50.349998	3.716667
50.491669	3.600000
50.500000	3.350000
50.766666	3.183333
50.733334	2.766667
51.083332	2.550000
51.116669	2.000000
51.500000	2.000000
51.647499	2.112500
51.683334	2.250000
51.275002	4.133333
51.408333	4.361111
51.483334	4.450000
51.491669	4.783333
51.433334	4.947222
51.500000	5.050000
51.295834	5.213889
51.166668	5.833333
51.106945	5.786944
51.098057	5.010278
50.616669	5.000000
50.316666	4.083333

Sector: BRUSSELS_OLNO FL245 to FL500 (FL 345 if upper high active)

51.098057	5.010278
51.106945	5.786944
50.835556	6.982500
50.597221	7.133889
50.583332	7.000000
50.355556	6.377778
50.250000	6.150000
50.133331	6.083333
50.064445	6.151111
50.593613	5.252500
50.616669	5.000000
51.098057	5.010278

Sector: BRUSSELS_LUXEMBOURG FL245 to FL 500

50.616669	5.000000
50.316666	4.083333
49.966667	4.233333
49.966667	4.516667
50.166668	4.766667
50.141666	4.883333
49.998611	4.822222
49.851944	4.851389
49.716667	5.152222
49.533333	5.500000
49.549999	5.816667
49.466667	6.116667
49.508331	6.225000
49.463333	6.396667
49.463333	6.396667
49.525002	6.350000
49.566666	6.350000
49.666668	6.466667
49.733334	6.494444
49.766666	6.500000
49.815727	6.448624
49.860832	6.401389
49.875000	6.322222
49.916668	6.183333
50.064445	6.151111
50.593613	5.252500
50.616669	5.000000

Sector: HANNOVER_RUHR RUHR FL245 to FL500

53.391666	9.316667
52.738888	9.144444
52.360001	8.665278
51.933334	8.511111
51.841667	8.504167
51.466667	8.487500
51.313889	8.716667
51.083332	8.266667
51.066666	7.966667
51.000000	7.883333
50.799999	8.027778
50.755554	7.991667
50.597221	7.133889
50.835556	6.982500
51.065834	5.970556
51.141666	6.108333
51.161110	6.175000
51.183334	6.122222
51.172222	6.083333
51.250000	6.066667
51.366669	6.225000

51.516666	6.216667
51.608334	6.108333
51.655556	6.133333
51.674999	6.033333
51.716667	6.041667
51.741669	5.966667
51.833332	5.966667
51.866669	6.066667
51.833332	6.183333
51.916668	6.116667
52.016666	6.016667
52.333332	6.233333
52.541668	6.733333
52.541668	7.100000
53.208332	9.000000
53.391666	9.316667

Sector: DECO_COASTAL FL245 to FL500

54.500000	4.533333
55.000000	5.000000
55.000000	6.500000
55.000000	8.000000
55.066666	8.333333
55.066666	8.441667
54.916668	8.666667
54.891666	8.750000
54.875000	9.183333
54.808334	9.383333
54.875000	9.633333
54.816666	9.733333
54.808334	9.950000
54.750000	10.083333
54.666668	10.416667
54.650002	10.583333
54.647221	10.883333
54.325001	10.883333
54.200001	10.575000
54.191666	10.416667
54.180557	10.333333
53.722221	9.375000
53.391666	9.316667
53.208332	9.000000
52.541668	7.100000
52.541668	5.575000
52.805557	5.333333
53.320278	4.730000
54.500000	4.533333

Sector: HANNOVER_SOLLING FL245 to FL500

51.466667	8.487500
51.841667	8.504167

	52.160000	9.868056
	52.283333	10.808333
	52.291943	11.080833
	51.758331	11.145833
	51.566666	10.700000
	51.333332	9.936111
	51.333332	8.766667
	51.313889	8.716667
	51.466667	8.487500

Sector: DECO_DELTA FL245 to FL345 MA

	54.500000	4.533333
	51.647499	2.112500
	51.683334	2.250000
	51.275002	4.133333
	51.408333	4.361111
	51.483334	4.450000
	51.491669	4.783333
	51.433334	4.947222
	51.500000	5.050000
	51.295834	5.213889
	51.166668	5.833333
	51.106945	5.786944
	51.065834	5.970556
	51.141666	6.108333
	51.161110	6.175000
	51.183334	6.122222
	51.172222	6.083333
	51.250000	6.066667
	51.366669	6.225000
	51.516666	6.216667
	51.608334	6.108333
	51.655556	6.133333
	51.674999	6.033333
	51.716667	6.041667
	51.741669	5.966667
	51.833332	5.966667
	51.866669	6.066667
	51.833332	6.183333
	51.916668	6.116667
	52.016666	6.016667
	52.333332	6.233333
	52.541668	6.733333
	52.541668	5.575000
	52.805557	5.333333
	53.320278	4.730000
	54.500000	4.533333

Sector: HANNOVER_HAMBURG FL245 to FL500

	54.647221	10.883333
	54.647221	11.033333

54.500000	11.500000
54.474998	11.675000
54.450001	12.000000
54.133331	11.258333
52.373611	11.070278
52.291943	11.080833
52.283333	10.808333
52.160000	9.868056
51.841667	8.504167
51.933334	8.511111
52.360001	8.665278
52.738888	9.144444
53.391666	9.316667
53.722221	9.375000
54.180557	10.333333
54.191666	10.416667
54.200001	10.575000
54.325001	10.883333
54.647221	10.883333

Sector: BRUSSELS_UPPER FL345 to FL500 (when active)

50.616669	5.000000
50.316666	4.083333
50.350834	3.785000
50.349998	3.716667
50.491669	3.600000
50.500000	3.350000
50.766666	3.183333
50.733334	2.766667
51.083332	2.550000
51.116669	2.000000
51.500000	2.000000
51.647499	2.112500
51.683334	2.250000
51.275002	4.133333
51.408333	4.361111
51.483334	4.450000
51.491669	4.783333
51.433334	4.947222
51.500000	5.050000
51.295834	5.213889
51.166668	5.833333
51.106945	5.786944
50.835556	6.982500
50.597221	7.133889
50.583332	7.000000
50.355556	6.377778
50.250000	6.150000
50.133331	6.083333
50.064445	6.151111
50.593613	5.252500

	50.616669	5.000000

Sector: DELTA_UPPER FL345 to FL500 (when active)

54.500000	4.533333
51.647499	2.112500
51.683334	2.250000
51.275002	4.133333
51.408333	4.361111
51.483334	4.450000
51.491669	4.783333
51.433334	4.947222
51.500000	5.050000
51.295834	5.213889
51.166668	5.833333
51.106945	5.786944
51.065834	5.970556
51.141666	6.108333
51.161110	6.175000
51.183334	6.122222
51.172222	6.083333
51.250000	6.066667
51.366669	6.225000
51.516666	6.216667
51.608334	6.108333
51.655556	6.133333
51.674999	6.033333
51.716667	6.041667
51.741669	5.966667
51.833332	5.966667
51.866669	6.066667
51.833332	6.183333
51.916668	6.116667
52.016666	6.016667
52.333332	6.233333
52.541668	6.733333
52.541668	5.575000
52.805557	5.333333
53.320278	4.730000
54.500000	4.533333

Sector: NEWSPACE FL245 to FL500 (Nattenheim Proposal only)

50.250000	6.150000
50.133331	6.083333
50.064445	6.151111
49.916668	6.183333
49.875000	6.322222
49.860832	6.401389
49.815727	6.448624
49.816666	6.513888
49.825001	6.800000
50.108334	6.800000

50.108334	6.586111
50.355556	6.377778