AIRSPACE DESIGN PROCESS FOR DYNAMIC SECTORISATION

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Abstract[1]

Air Traffic Control in core Europe reaches the limits of available airspace capacities. Therefore new roles are introduced to shift workload away from the executive (radar) controller, who operates at the limit and is the capacity bottleneck, towards a more planning oriented but yet adaptive control function – the Multi Sector Planner. This Multi Sector Planner will be responsible for the expeditious flow through several sectors. The new role will execute a set of actions on both, airspace and traffic flows to reduce workload for the sector team or balance workload between sectors, so that overall centre capacity is increased. One of the central support tools is fine-grained, tactical, dynamic airspace management in conjunction with tactical flow measures.

The study presents the airspace design process and tools that have been applied for the development of the future airspace of the Maastricht Upper Area Control Centre, based on the principles of dynamic airspace management.

Introduction

In the research for improvements of the ATM system, there is a paradigm shift ongoing which integrates asynchronous and synchronous air traffic services. That consists of a number of operational and technical improvements at the boundaries between the deterministic and the stochastic parts of the system. In simple words it means that flow and capacity management becomes more tactical on one side; and air traffic control becomes more strategic on the other side.

Tactical Flow Management (TFM) is the predictive side to fill this gap, and typically deals with tactical rerouting and capping of flows away from capacity problem zones. Its granularity may go down to the aircraft level.

Strategic Traffic Organisation (STO) is the complement to TFM and fills the adaptive side of the gap. Hypothesis 1 is that STO produces significant additional overall system capacity and safety. Hypothesis 2 is that STO is very well suitable for automation, if not full-automation, and will contribute to an overall increased system performance.

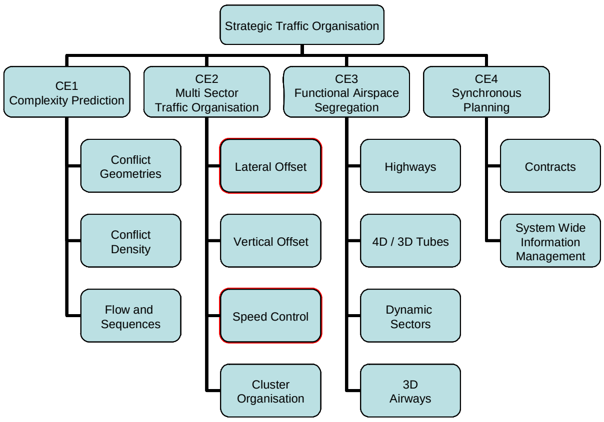

Figure 1 - Conceptual Breakdown of Strategic Traffic Organisation

Figure 1 shows the conceptual breakdown of STO. One of the elements is the functional airspace segregation, with a sub-element of dynamic sectorisation.

Maastricht UAC is an upper area control centre that controls the area of the Netherlands, Belgium, Luxembourg, and parts of Germany from above flight level 245. The MANTAS (Maastricht New Tools And Systems) project is working on a total redesign of the Maastricht airspace focussing on an implementation for the year 2009. It has developed a new airspace design based on the principles of dynamic airspace sectorisation. This required the development of a new airspace design process and new tools.

Literature Review

The literature research via Internet and EUROCONTROL internal documentation found

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[1] 26th DASC, 2007, Dallas, Texas, USA

the following results. There is some high-level documentation available from research ([2][3]). There is existing literature for optimal configurations (e.g. [4][5]), and for airspace design tools ([6][7]) and both ([8][9][10]). Automated route network design is not part of the concern and is therefore not considered (e.g. [11][12]).

Amongst the found research there is no documentation understood to treat dynamic airspace management explicitly. Some of the tools seem to have provided functions that treat a facet of dynamic sectorisation and would be very helpful, but like e.g. in the case of the HADES tool from the EUROCONTROL Experimental Centre [6], this knowledge is lost. Sector optimisation, however, found its way from research into operations with the soon coming OPTICON tool provided by the CFMU.

Concept of Dynamic Airspace Management

Functional airspace segregation is a key function for STO that should create high rates of additional capacity by adapting the airspace to the demand. The trigger function may be complexity and workload prediction; and also traditional traffic forecast for the day. The dynamicity of the airspace adaptation may span from traditional strategic long-term airspace planning several months ahead to very reactive modification in a relatively short look-ahead time of down to 15 minutes, similar to current de-collapsing and collapsing of sectors. The segregated airspace elements may be dynamic sectors and highways, 3D airways, or 4D tubes.

Dynamic sectorisation is a specialisation of functional airspace segregation and the MANTAS project uses a definition from the MANTAS Basic Operational Concept [1]: Dynamic airspace is conceived based on atomic air blocks that are then further regrouped into traffic volumes that serve as operational sectors. Upon change of the traffic demand, the sectors will adapt and change their shapes vertically and horizontally for an optimised efficiency of the individual controller as well as for the controller teams. Figure 2 illustrates an example of a simple resectorisation where some blocks change from one operational sector to another.

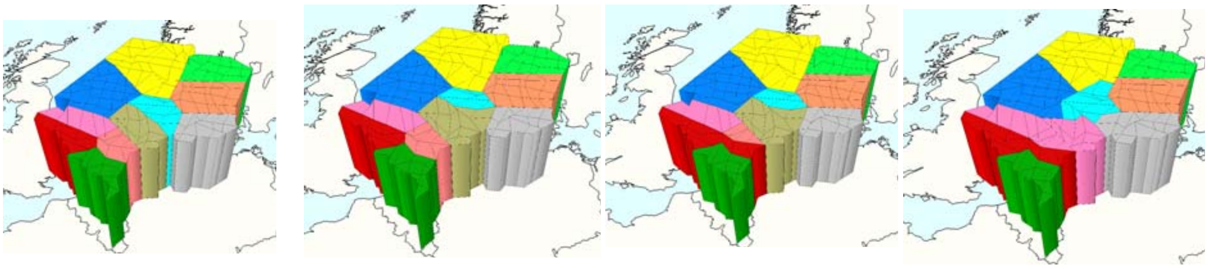

Figure 2 – Example Dynamic Sectorisation

Workload and complexity prediction is the key-decision support for dynamic sectorisation. Because of the longer prediction horizon of 15 minutes and more, but typically 30 to 45 minutes, the uncertainty of the predicted air situations is still very high; Maastricht e.g. counts approximately 30% of traffic that is still at the airport 15 minutes before entering the airspace, which makes this traffic highly unpredictable. Furthermore this traffic is climbing, which makes the precise trajectory prediction difficult due to level winds. The other traffic, however, is either close to destination or in over-flight, which allows for relative precise predictions. That example illustrates that other than the known mechanisms must be elaborated, possibly based on stochastics, which is also part of the project. In this document however only the dynamic sectorisation is further evaluated.

The decision making function for dynamic sectorisation is called the Meta Sector Planner, that is a specialisation of the Multi Sector Planner, and is functionally allocated between sector supervision and flow management. The strategies might be divers, e.g. a balance of workload amongst the sectors, or a concentration of overload into one area that would further be regulated to force reroutes and delays for a limited zone, or an adaptation of workload to the sector team etc. In all cases it should create higher capacity and efficiency, and possibly also safety.

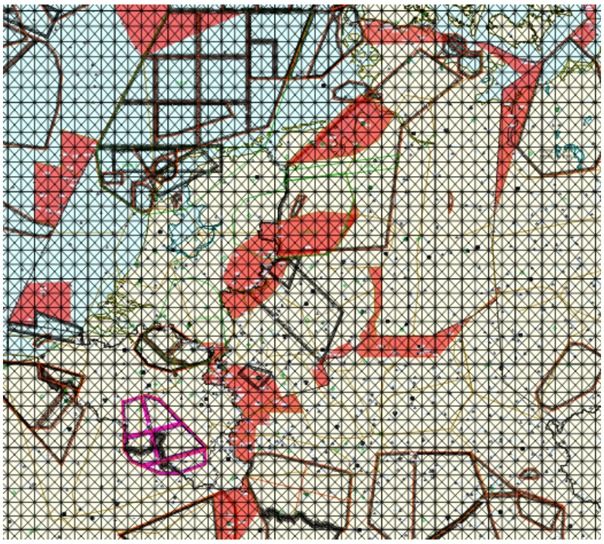

Figure 3 – Mathematical grid

Airspace Design Process

The design process targets a completely new airspace design for the year 2009, based on the principles of dynamic airspace management. The short term objective is to identify a suitable airspace definition for a real-term simulation in spring 2007.

The approach to this objective is taken by grouping a number of sector supervisors and air traffic controllers and built a new airspace using a set of tools. Three iterations have been conducted:

Iteration 1

Starting point for the from-scratch airspace design is a mathematical grid, as depicted in Figure 3. The geometry of the grid is small triangles, because it allows for straight sector boundaries and for a good approximation to sectors. The length of the sides of the triangles is set using common sense and some examples printed on maps. It must allow for a fine-grained airspace boundary around smaller flows, and must also lead to a number of geometries that can be handled by humans. It is decided not to rotate the axes of the triangles. The grid is then projected on an airspace map lacking any route structures, and only showing military areas. The first task of the operational experts is to identify the gates (sorts of extended navigation points in form of a line) with the entry and exit constraints. This may be arrival and departure gates, or lateral and internal gates.

Next all problem areas are identified, classified and marked on the map, starting from airport problems, transition problems, and over-flight problems. In total 25 problem areas are identified, that are called the ‘parents’.

The next step is to mark 2-dimensional boundaries for the atomic air blocks, starting from the parents. When there are clear transition between parents, then a clean line is drawn; however, when the airspace surrounding the parents can be allocated to several parents, then it is subdivided per flow creating little air blocks that are called ‘children’. Children in MANTAS can be allocated to one or several parents to form sectors. 36 children air blocks are created. Figure 4 depicts the result of the first iteration for the definition of atomic air blocks, strictly sticking to the mathematical grid.

The following task is to group all the atomic air blocks into sectors. The applied concept permits for an unlimited number of division flight levels (DFL) and for balconies, but not for stairs in the airspace (double balcony). First the expert team is not constrained in the maximum number of sectors and this leads to unrealistically many sectors (26, compared to a maximum of 15 for 2006). Next the number of sectors is reduced to match a more constrained forecast target for the year 2009, around 20 reflecting the sustained traffic growth of 6% per year in the last years.

Several options for DFLs are tested, one option for unique DFLs that are valid for the entire centre, another for changing DFLs per region and adapted to the need, another for no, one, two, or three DFLs etc.

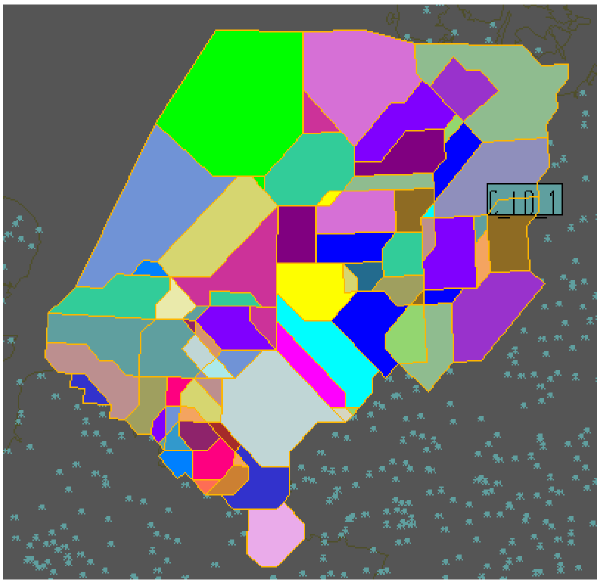

Figure 4 – Iteration 1 Problem parents and children

This terminates the first iteration of airspace design. It is now digitized and fed into a fast-time simulation tool (RAMS[2]) that evaluates the theoretical capacities of the production. The traffic for the simulation corresponds to a forecast for 2009 and is either highly rerouted on direct routes, or is strictly kept on the currently filed fixed route network. The results serve as input for the next design iteration.

Iteration 2

The second airspace development iteration concentrates on the vertical sectors. The constraints to draw on the grid are relaxed, and lines between all points are admitted; yet no additional points are allowed.

The exercise repeats the steps of creation of atomic air blocks and definition of sector configurations, but the expert team is instructed to think in vertical terms only. Figure 5 shows the resulting atomic air blocks.

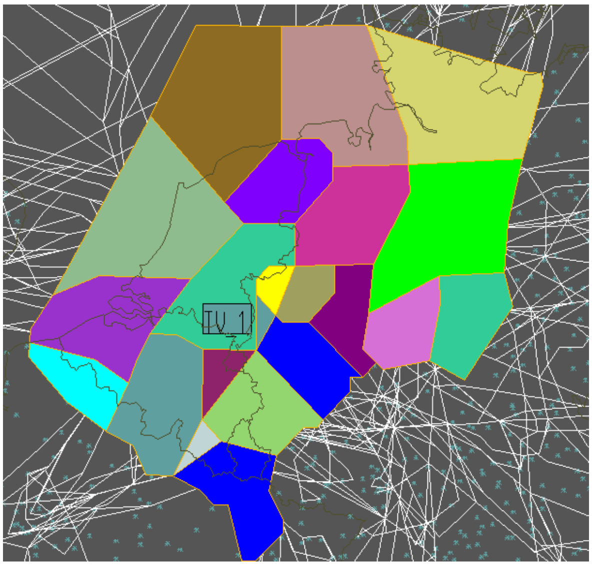

Figure 5 – Iteration 2 Vertical Thinking

It can be seen that the total number of parents and children are reduced. A much smaller number of options are created in the horizontal sense. However, the number of vertical possibilities increases in the same proportion, and the second iteration produces a higher number of combinations than the rather horizontal exercise from the first iteration.

The creation of valid sector configurations is very cumbersome and creates frustration amongst the experts, partly due to repetition, but mainly due to the very high complexity of the work (‘Task for a computer’). The simulation tool is not reactive enough for what-if scenarios. That is found to be a major limitation.

Only a limited amount of sector configurations comprised of 2 and 3 layers, respectively 1 or 2 DFLs, is simulated and analyzed regarding theoretical capacity.

Iteration 3

In iteration 3 the results from iteration 1 are adapted to those of iteration 2 and both combined, together with boundaries around military areas. The grid is abandoned and some boundaries are adjusted to minimize sector clips and skips.

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[2] RAMS – Reduced ATC Mathematical Simulator [13]

Figure 6 – Iteration 3 Combined Refined Boundaries

That leads to new boundaries on both vertical and horizontal layers. Figure 6 shows the horizontal boundaries emanating from this process. It can be noted that new scenarios are created with an intensive use of flow restrictions and flight level allocations reminding of microscopic channels or tubes for part of the airspace that is already considered ‘optimal’ or ‘atomic’ i.e. the Brussels sectors.

Further a limited airspace is chosen for the MANTAS real-time simulation nr 4, i.e. that not the entire airspace is considered anymore. The reduced scope makes a human definition of fine-grained sectors possible again. Each unique sector is named and different configurations are elaborated, resulting in a high number of possible sector configurations (50). The configurations vary the number of operational sectors between 3 and 5, plus military sectors. Fast-time simulations run through all of the possible configurations. The results lead to an expert selection and in some cases also to modifications of viable configurations, bringing their total number down to 40 for the selected airspace.

In a last step the experts define a transition matrix of allowed centre schedules. The rationale is that not every sector configuration may transit to another one, the allowed transitions are defined with a state chart. Therefore transitions may require passing via predefined sequences in order to achieve the wanted configuration; a strategy for sector configuration schedules is required. Once again this task is found too complex and too dynamic for humans, especially if it is to be executed on-the-fly in operations.

This concludes the step of the airspace development process. The results are used for the real-time simulation in spring 2007. The next section describes the tools that have accompanied the process in more detail.

Airspace Design Tools

Several tools drive the airspace design process.

Maps and Transparent Layers

The experts are tasked to design on a paper map in A0 format. Transparent papers are overlaid to allow adding information. Iteration 1 e.g. worked with 6 overlays and 3 additional variations for the sector configurations. Figure 7 depicts a sample from iteration 1. The tool enables simultaneous work of several experts in groups or individually, easy to use, and proves successful. The conversion of the output into digital format however is highly manual and very cumbersome.

Figure 7 – Paper Maps

Flow Charts

Flow charts are created to support the creation of boundaries, especially for avoiding clips and skips. A picture is created based on CFMU filed and corrected traffic that is simulated in the fast-time simulator. Corrected flight plans are generated by CFMU by correlating filed flight plans and radar data; and adjusting the flight plans. The flows are further visualised in layers of two flight levels, or combined. Figure 8 illustrates one example for a picture for the corrected flows between flight levels 235 and 255. This step uses the features of the ATC Playback application.

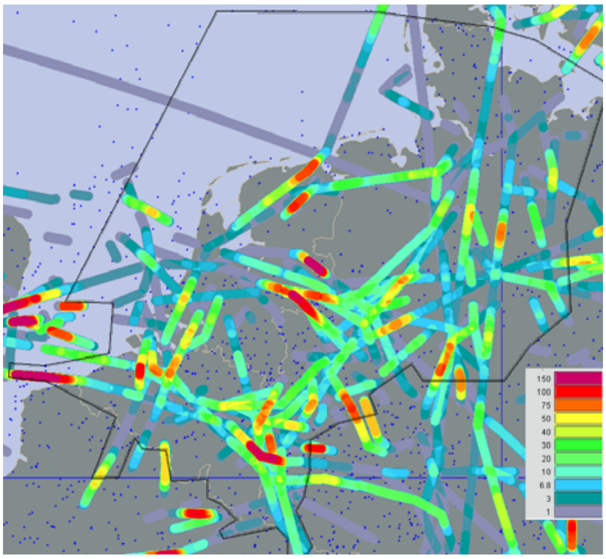

Figure 8 – Level band flows (e.g. FL 235 – 255)

Fast-time Simulation

RAMS is used for fast-time simulation for a refined analysis of task-load[3]. The principle of the fast-time simulator is to navigate aircraft, and generate events whenever something occurs to flights e.g. entering a sector or flying over a navigation point, change of responsibility between controllers and centres, conflict detection, resolution etc. The task-load model is fine grained with a high number of dynamic events that can be configured and attributed to the task-load. The model of the air traffic controllers interacts with the flights and eventually modifies trajectories to create higher degrees of realism.

The airspace is part of the specific setup for the simulations. The airspace design is digitised and converted into RAMS format. In iteration 3 the RAMS airspace editor is used by the operational experts to introduce smaller modifications and shifting corners and boundaries.

The simulated traffic is the other main setup for the specific simulation. A random forecast of 120% of a whole day real traffic from April 26, 2006, as filed to CFMU is used. The traffic is further filtered and two scenarios are built, one to simulate with and the other without military activity. In the non-military scenario the traffic is assumed to flow on directs from centre entry to exit points, as it is the case on weekend days in Maastricht UAC. The military scenario only reroutes two flows and puts them on the fixed route network around the military active area.

The result of the simulation is a computation of workload and occupancy per sector, which are put into relation to compute the theoretical capacity. In addition some other workload and complexity parameters are extracted to support the analysis of the developed airspace, e.g. task-load per aircraft, task-load per categories (Figure 9), average crossing times, counts of entries and exits on walls, floors and ceilings, number of intersections etc.

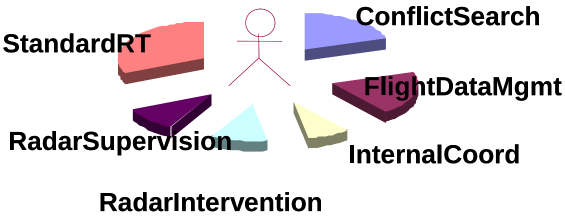

Figure 9 – Example Task-load Categories

This permits a detailed static and dynamic analysis of the simulated day and the comparison of the behaviour of the traffic scenarios. The statistics are given per sector, per sector configuration and per traffic sample.

Sim-Maker

A high number of simulations are required for the study; therefore an automation tool is created. It largely automates the entire setup, the running and the analysis of the simulations, and the binding into a document. The tool is baptised SimMaker. In its current first version it is capable to generate RAMS airspace based on a definition of airspace in a spreadsheet; manipulate traffic for filtering of

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[3] Task-load is used as synonym for workload.

flows; manipulate traffic for rerouting of flows; manipulate traffic for setting constraints of flows, e.g. entry/exit levels; manipulate traffic for level capping flows; manipulate traffic for trimming flows in an area; manipulate traffic for random forecast on flows; manage traffic scenarios for combinations of the filters; manage traffic scenarios for automatic preparation of scenarios for many days of traffic; generate RAMS simulations for all combinations of traffic scenarios for many days and airspace configurations; exporting the traffic to CFMU, RAMS and IPAS formats; automatically analysing the simulation results; automatically binding the analysis results into a Word document.

Figure 10 illustrates a flowchart for the fast-time simulation process as it evolved for this project. The former GASEL tool has largely been replaced by the new SimMaker tool. SimMaker wraps RAMS and ATM Analyser tools into one environment. Imports and exports are done via the SimMaker where already available, e.g. for the real-time simulation chain starting at IPAS. Airspace data is converted to the Data Preparation Facility (DPF), so that the operational environment does not have to be introduced manually but can start from the fast-time results. Visual output is provided by ATC Playback and SAAM (example this document), where more advanced functions in SAAM for route network assignment are not used yet.

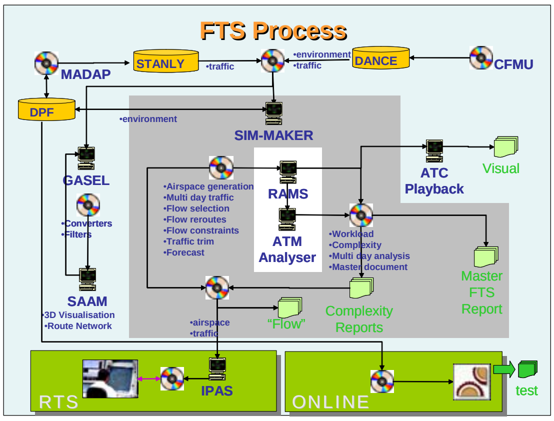

Figure 10 – Enhanced Fast-Time Simulation Process

Conclusions

- The airspace design is highly depending on traffic demand and traffic flow, which is a permanently changing process. Therefore the airspace design must be kept dynamic as a whole and must be quickly reactive for change. Instead of a static airspace layout, a floating airspace baseline is created. The challenge of operations is to create systems (people, procedures, equipment) that have the same reactivity.
- The combinatory logic of creating sectors from air blocks and configurations from sectors and taking into account constraints like shapes and division flight levels and their dynamics is beyond the limit of human capabilities. A mathematical optimisation tool is required to support this process.
- It is of highest usefulness to iterate through the airspace design process by applying capacity-simulations. Each iteration still takes about 3 weeks in the current practice due to the fast-time simulation: even if this is much better than the past, also considering the high flexibility and dynamics of the process, this is still too long. It would be nice to have faster tools with higher reactivity, e.g. to have what-if scenarios during the design itself.
- The high number of simulations and the corresponding flood of data to be analyzed can only be handled with an add-on tool to the fast-time simulator. The development of the SimMaker tool has already shown benefit. It has the additional advantage to fix the airspace design process, because many features of the tool are customized for the airspace design process developed here.

The full validation of the airspace design process is only possible with real-time simulation, and later operations, which are both yet to come. Nevertheless it can already be stated that this process is a milestone in Maastricht airspace design. It pre-validates a completely new airspace based on new procedures using fast-time capacity simulations ([13][15][16]).

Biography

Rüdiger Ehrmanntraut is a scientist at the EUROCONTROL Experimental Centre in the research area Innovation (EEC-INO), currently in delegation at the Maastricht Upper Area Control Centre. Since 2003 he has been working on a PhD thesis investigating the automation of air traffic management. He has been co-ordinator of the TALIS consortium, an EC project that finished in spring 2004. From 1999 until 2003 he has been CNS Business Area Manager. From 1996 until 1999 he has conducted several projects on air-ground integration. Before joining EUROCONTROL in 1996 he worked as a software engineer for an industrial company. He holds a diploma of telecommunications engineer from RWTH Aachen, Germany in 1991.

Stuart McMillan, BSc MSc MRAes, is deputy supervisor, capacity coordinator and air traffic controller at the EUROCONTROL Maastricht UAC Air Traffic Control Centre. He has worked more than 10 years as an Air Traffic Controller. Prior to joining Eurocontrol, he spent 3 years at the University of Liverpool and received a Bachelor of Science degree with Honours in physics (BSc HONS). From 1991 until 1992, he studied at the University of Cranfield and received a Master of Science degree in aerodynamics (MSc). He is a Member of the Royal Aeronautical Society (MRAes).

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