**Title**: Airspace Model Simulation of Continental RVSM

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**Date**: 3/96

**Pages**: 31

**Figs.**: 12

**Ref.**:

**Appendices**: EATCHIP Task Specification ASM.ET1.ST13

**EEC Task No.**: AG01

**Task No. Sponsor**: Period 1995

**Distribution Statement**: (a) Controlled by: Head of AMS

(b) Special Limitations (if any): None

(c) Copy to NTIS: YES / NO

**Descriptors (keywords)**: Controller Workload, Continental RVSM, Flight Level Allocation, Distribution of flights, Vertical separations, Radar controller, Radar conflicts.

**Abstract**: This report describes a simulation study of Reims Airspace using the EUROCONTROL Airspace Model on behalf of the NSGG, a subgroup of the ANT (Airspace and Navigation Team). The study evaluated several proposals for the introduction of Reduced Vertical Separation Minima in a continental airspace. The study consisted in the simulation of 2 different orientations of the flight levels above FL290. The conflicts found between aircraft were resolved in 2 main methods, radar or procedural. The proposals for the introduction of RVSM did not lead to major changes to the distribution of flights through the sectors. A global reduction of 10% has been recorded on the workload in the two main scenarios simulated with forecast 2000 traffic level. This reduction was mainly due to the reduction in the number of conflicts recorded. The tasks related to their resolution went down by 28% even in the less favorable scenario.
This report describes a simulation study conducted on Reims airspace with the EUROCONTROL Airspace Model on behalf of the NSSG. The objectives of the study were to assess the effects of the introduction of Reduced Vertical Separation Minima (RVSM) above FL290 in a continental airspace.

The study examined the effects of two flight level orientation systems (methods) using 1000ft vertical separation above FL 290. These effects were assessed through the distribution of the traffic per sector, the distribution of the conflicts, and the workload of the simulated controllers.

Three main organisations were simulated. Reference organisation A simulated the 1994 sectorisation (11 sectors) and flight level system in Reims centre. The level of traffic was 1994 and forecast 2000 (+27%). Very high workloads were recorded on the radar controller with year 2000 traffic but the main aim of this reference organisation was to use it as a yardstick for further comparisons with other flight level allocation systems above FL 290.

The first proposed organisation B simulated, with forecast 2000 traffic, a 1000ft vertical separation above FL290, each level being used in an opposite direction to the level immediately above or below i.e. a continuation of the standard flight level system below FL 290. The traffic samples were modified in order to distribute the traffic of the original levels of the reference organisation between the corresponding levels of the proposed organisation B. The principle used for this distribution was to divide equally the traffic of the reference organisation A between the 2 levels of organisation B. A global reduction of 8% in total workload was recorded with both the morning and afternoon traffic samples.

The second proposed organisation C simulated, with 2000 traffic, a different concept in the use of all the RVSM levels. The flight levels above FL 290 were used as pairs of levels, a pair of levels being two levels in the same direction. The traffic samples were modified using the same 50/50 principle as for proposed organisation B. A global reduction of 11% in total workload was recorded with both traffic samples.

In both proposed organisations two different conflict resolution methods were simulated. The radar resolution corresponding to radar manoeuvres given to solve the conflicts with the conflicting aircraft remaining at their original levels, and procedural resolution with the aircraft changing levels for conflict resolution purposes. A 3% global reduction was recorded between radar and procedural methods.
1. GENERAL DESCRIPTION OF THE STUDY

1.1. Introduction

In 1994, the NSSG requested a fast-time simulation (FTS) study using the EUROCONTROL Airspace Model. The purpose of the study was to assess the effects of the introduction of Reduced Vertical Separation Minima (RVSM) above FL290 in continental airspace. Reims upper airspace, which has both en route and climbing/descending traffic, was chosen as the simulated area.

The EUROCONTROL task number AG01 was assigned to the project which was carried out at the EUROCONTROL Experimental Centre in Brétigny-sur-Orge, France.

A first data preparation meeting took place in Reims in May 1994 prior to the beginning of the simulation, at the same time as a data preparation meeting of Reims Airspace Model simulation, EEC task AF49. An initialisation meeting took place in Brussels on 18 July 1994 and further specification meetings were held in Haren in Eurocontrol headquarters. The final results were presented in Brussels on the 20 September 1995.

This document is divided into the following chapters:

Chapter 1 General description of the study.
Chapter 2 Results of the reference organisation.
Chapter 3 Proposed RVSM scenarios with radar conflict resolution
Chapter 4 Proposed RVSM scenarios with procedural conflict resolution.
Chapter 5 Conclusions and recommendations

1.2. Objectives of the study

The main objectives of this Airspace Model simulation were to assess the effects of the introduction of Reduced Vertical Separation Minima in continental airspace on:

- The distribution of the conflicts between the aircraft.
- The workload of the controllers in charge of the traffic.

Several flight level allocation systems were tried to determine which was the optimum method of using the new flight levels available.
1.3. Traffic samples

Two three hour traffic samples were selected by Reims experts to be simulated in the study. The same day as for task AF49 was selected but one hour ahead. They were from 25 May 1994 and their main characteristics are tabulated below:

<table>
<thead>
<tr>
<th>Title</th>
<th>Start time</th>
<th>End time</th>
<th>Number of flights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morning 1994</td>
<td>07h00</td>
<td>10h00</td>
<td>339</td>
</tr>
<tr>
<td>Afternoon 1994</td>
<td>14h00</td>
<td>17h00</td>
<td>278</td>
</tr>
<tr>
<td>Morning 2000</td>
<td>07h00</td>
<td>10h00</td>
<td>430</td>
</tr>
<tr>
<td>Afternoon 2000</td>
<td>14h00</td>
<td>17h00</td>
<td>355</td>
</tr>
</tbody>
</table>

The increasing of the 1994 traffic, intended to represent possible traffic levels around 2000 was prepared. The growth percentages applied to the flows of traffic identified in the basic traffic samples were taken from the document 'Air traffic statistics and forecasts number of flights by region 1974 - 2000 and 2010 (Total airspace)' produced by division DEI.4 of EUROCONTROL.

The analysis of the above table indicates that between year 1994 and year 2000 a growth of 27% for the morning traffic sample and of 28% for the afternoon traffic sample.

The table below indicates, for some main airports inside and in the vicinity of the simulated area the number of aircraft in the traffic samples.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dep Orly</td>
<td>5</td>
<td>11</td>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td>Arr Orly</td>
<td>5</td>
<td>4</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Dep CDG</td>
<td>41</td>
<td>41</td>
<td>51</td>
<td>57</td>
</tr>
<tr>
<td>Arr CDG</td>
<td>52</td>
<td>27</td>
<td>62</td>
<td>33</td>
</tr>
<tr>
<td>Dep Le Bourget</td>
<td>6</td>
<td>3</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Arr Le Bourget</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Total Dep Paris TMA</td>
<td>52</td>
<td>55</td>
<td>63</td>
<td>75</td>
</tr>
<tr>
<td>Total Arr Paris TMA</td>
<td>60</td>
<td>36</td>
<td>71</td>
<td>43</td>
</tr>
<tr>
<td>Dep Geneva</td>
<td>11</td>
<td>8</td>
<td>14</td>
<td>11</td>
</tr>
<tr>
<td>Arr Geneva</td>
<td>6</td>
<td>3</td>
<td>8</td>
<td>3</td>
</tr>
</tbody>
</table>

From the above table it can be noted that the Paris TMA traffic was better balanced between departures and arrivals in the morning than in the afternoon traffic sample. The difference between departures and arrivals goes from 8 to 28 aircraft. The percentage of flights arriving / departing from TMAs in the vicinity of the simulated area was similar in both traffic samples, 36% of the total traffic. In conclusion, this indicates that the content of climbing and descending traffic was different despite the same proportion of it.
 Especially in the context of this simulation, the degree of occupancy of the flight levels was of major importance. Indeed the concentration of the traffic on certain levels will generate a higher amount of conflicts than an even spread of it through all the available levels.

The distribution of the year 2000 traffic through the flight levels above FL 290 is tabulated below:

<table>
<thead>
<tr>
<th>FL</th>
<th>Morning 2000</th>
<th>Afternoon 2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>FL290</td>
<td>40</td>
<td>15</td>
</tr>
<tr>
<td>FL310</td>
<td>60</td>
<td>77</td>
</tr>
<tr>
<td>FL330</td>
<td>81</td>
<td>74</td>
</tr>
<tr>
<td>FL350</td>
<td>94</td>
<td>82</td>
</tr>
<tr>
<td>FL370</td>
<td>54</td>
<td>36</td>
</tr>
<tr>
<td>FL390</td>
<td>21</td>
<td>17</td>
</tr>
<tr>
<td>FL410</td>
<td>10</td>
<td>2</td>
</tr>
</tbody>
</table>

From the above table, it can be calculated that:

In both samples, 80% of the flights were spread through five flight levels: FL290, 310, 330, 350, 370 with an evenly balanced distribution in the morning, while in the afternoon traffic sample, 66% were concentrated across three flight levels: FL310, 330, 350.

The following chart represents the number of flights per flight level in the different organisations simulated in the study.
1.4. Restrictions on the traffic

The constraints on the traffic which were found and identified in the original traffic samples were removed during the data preparation meetings. Those constraints concerned mainly FL modifications at the entrance of the simulated airspace generated by the letters of agreements in force between Reims and the adjacent centres. Other modifications such as the removal of the use of non-standard semi-circular level allocation were applied.

It has to be noted that in Reims area, all Northbound traffic flies at even levels while Southbound traffic flies at odd levels. In the neighbouring centres of control the same rules are not always applicable. That leads to necessary level change in order to provide the following centre with aircraft complying with the rules enforced.

1.5. Aircraft performances

The Airspace Model recognises more than 250 different types of aircraft. The different aircraft types have been grouped into 60 categories for aircraft performance.

Detailed data on the cruising speed, climb speed, rate of climb and rate of descent in each level band are available for each category of aircraft. Maximum and minimum acceptable levels for each category are also available.

The data used have been derived from previous simulations, airline operating practices and particular characteristics observed by operational controllers in each simulated area.

The aircraft performance data is used to construct the requested and final profiles of each aircraft within simulated airspace. Detailed information on the performance tables used in this simulation may be obtained from the EUROCONTROL Experimental AMS (ATC Model-simulations Studies).
1.6. Organisations simulated

Introduction

Three main organisations, actual and proposed, were simulated. A total of 12 exercises were simulated, including various conflict resolution rules.

The organisations were:

- Reference organisation A.
- Proposed RVSM organisation B.
- Proposed RVSM organisation C.

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**ORGANISATION OF THE STUDY**

**EUROCONTROL AIRSPACE MODEL**

**ORGANISATION A**

1995 Vertical separations

- A1 Morning 1994
- A2 Afternoon 1994
- A3 Morning 2000
- A4 Afternoon 2000

**ORGANISATION B**

Reduced Vertical Separations

- B1 Morning 2000
- B2 Afternoon 2000
- B3 Procedural Morning 2002
- B4 Procedural Afternoon 2002

**ORGANISATION C**

Reduced Vertical Separations

- C3 Morning 2000
- C4 Afternoon 2000
- C5 Procedural Morning 2002
- C6 Procedural Afternoon 2002

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**FLIGHT LEVEL ORIENTATIONS**

**EUROCONTROL AIRSPACE MODEL**

**ORGANISATION A**

FL380 FL360

**ORGANISATION B**

FL340 FL320

**ORGANISATION C**

FL300 FL280

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General description of the study
1.6.1. Reference organisation A

The reference organisation A simulated the current sectorisation in use in Reims Centre. The use of the flight levels simulated in this organisation was the 1995 one, i.e. 1000ft vertical separation below FL290 and 2000ft above. This flight level orientation is shown below:

The sectorisation, tabulated below consisted of 11 sectors:

<table>
<thead>
<tr>
<th>Sector name</th>
<th>Lower limit</th>
<th>Upper limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>UZ</td>
<td>265</td>
<td>320</td>
</tr>
<tr>
<td>ZU</td>
<td>320</td>
<td>660</td>
</tr>
<tr>
<td>UN</td>
<td>245</td>
<td>320</td>
</tr>
<tr>
<td>XN</td>
<td>320</td>
<td>660</td>
</tr>
<tr>
<td>UR</td>
<td>245</td>
<td>340</td>
</tr>
<tr>
<td>UY</td>
<td>340</td>
<td>660</td>
</tr>
<tr>
<td>UE</td>
<td>195</td>
<td>660</td>
</tr>
<tr>
<td>UH</td>
<td>195</td>
<td>660</td>
</tr>
<tr>
<td>UF</td>
<td>195</td>
<td>660</td>
</tr>
<tr>
<td>XF</td>
<td>245</td>
<td>660</td>
</tr>
<tr>
<td>RA</td>
<td>245</td>
<td>Unlimited</td>
</tr>
</tbody>
</table>
The RA sector mentioned above was simulated in order to prevent aircraft on the routes
1. RBT BRY TRO RLP
2. RBT BRY TRO EPL
3. BRY TRO RLP LUL
4. OL BRY TRO RLP
5. OL BRY TRO EPL,
from leaving the simulated airspace and entering it again later.

Reference organisation Involved the testing of 2 traffic samples simulated at 1994 and 2000 traffic levels, which gives a total of 4 exercises.

<table>
<thead>
<tr>
<th>EXERCISE</th>
<th>YEAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Morning 1994</td>
</tr>
<tr>
<td>A2</td>
<td>Afternoon 1994</td>
</tr>
<tr>
<td>A3</td>
<td>Morning 2000</td>
</tr>
<tr>
<td>A4</td>
<td>Afternoon 2000</td>
</tr>
</tbody>
</table>

1.6.2. Proposed organisation B

The sectorisation simulated in the proposed organisation B was geographically the same as the one of reference organisation A, i.e. 11 sectors, but the split at FL 320 between sectors UN and XN, UZ and ZU, was set at FL 325 and the one at FL 340 between UR and UY, was set at FL 345 to allow the use of FL 320 and 340, valid in an RVSM context. The modification in the split between superimposed sectors was made in order to try to leave aircraft in the same sector between reference organisation A and proposed organisation B.

The sectorisation and the FL orientation are outlined in the diagrams below:
The exercises simulated in proposed organisation B were:

<table>
<thead>
<tr>
<th>EXERCISE</th>
<th>TRAFFIC SAMPLE</th>
<th>CONFLICT RESOLUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>B3</td>
<td>Morning traffic 2000</td>
<td>Radar resolution</td>
</tr>
<tr>
<td>B3P</td>
<td></td>
<td>Procedural resolution</td>
</tr>
<tr>
<td>B4</td>
<td>Afternoon traffic 2000</td>
<td>Radar resolution</td>
</tr>
<tr>
<td>B4P</td>
<td></td>
<td>Procedural resolution</td>
</tr>
</tbody>
</table>

The difference between radar and procedural conflict resolutions consisted in the tuning of the simulation parameters. In a radar environment like Reims area, controllers resolve the conflicts between aircraft, especially in case of crossing tracks, by giving the appropriate headings to the aircraft so that they are radar separated. This conflict resolution is done with both aircraft remaining at their original flight level. Another way (the procedural way) of solving the conflict is to change the level of one of the conflicting aircraft.

In term of simulations, the weight of the 2 different actions that the controllers have to perform is completely different:

Case one radar resolution to perform
- Selection of the aircraft to be vectored
- First instruction to aircraft 1 (new heading)
- First instruction to aircraft 2 (maintain heading)
- Verification of aircraft’s 1 compliance with instruction
- Second instruction to aircraft 1 (parallel heading)
- Verification of aircraft’s 1 compliance with instruction
- Surveillance of aircraft on parallel headings
- Passing traffic information
- Third instruction to aircraft 1 (resume track)
- Surveillance of execution
- Second instruction to aircraft 2 (normal navigation)

The average total time necessary to perform those actions is of about 70 seconds per conflict.

In the case two where procedural resolution is to perform, the only actions the controller has to do is to select the aircraft which has to change of level, descent (or climb) the aircraft to the appropriate level, acknowledge the report of the pilot to the new level and, eventually reset the aircraft to its original level. In an automated environment, the average time necessary to perform those actions should not exceed 25 seconds.
General description of the study
1.6.3. Proposed organisation C

The Organisation C was the second main proposal of flight level orientation.

The sectorisation simulated in the proposed organisation C was geographically the same as the ones of reference organisation A and proposed organisation B, i.e. 11 sectors. The split between superimposed sectors was set at FL 315 between sectors UN and XN, UZ and ZU, and the one between UR and UY, was set at FL 335. The strategy used for the setting of those splits was to keep 2 levels in the same direction to the same sector in order to allow the simulated controller to use freely one those 2 levels in the case of a procedural conflict resolution.

The exercises simulated in proposed organisation C are tabulated below:

<table>
<thead>
<tr>
<th>EXERCISE</th>
<th>TRAFFIC SAMPLE</th>
<th>CONFLICT RESOLUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>C3</td>
<td>Morning traffic 2000</td>
<td>Radar resolution</td>
</tr>
<tr>
<td>C3P</td>
<td></td>
<td>Procedural resolution</td>
</tr>
<tr>
<td>C4</td>
<td>Afternoon traffic 2000</td>
<td>Radar resolution</td>
</tr>
<tr>
<td>C4P</td>
<td></td>
<td>Procedural resolution</td>
</tr>
</tbody>
</table>

The flight level orientation used in proposed organisation C was:
1.7. Positions simulated

Generally, two positions were simulated in each sector:
Executive controller (EC)
Planning controller (PC)

1.8. Air traffic control tasks used in the study

The Airspace Model analyses the progress of each flight as it transits the simulated area in order to detect the ATC actions necessary to process the flight. In determining these actions the Airspace Model is capable of identifying and recording up to 110 different ATC tasks.

These tasks are grouped into 5 broad categories:
1. Flight data management,
2. Coordinations,
3. Planning conflict search to determine ATC clearances,
4. Routine R/T communications,
5. Radar coordination, supervision and intervention.

The tasks are assigned to the appropriate simulated working positions (PC and/or EC). The tasks used in the study are derived from those used in the Airspace Model simulation of Reims, EEC task AF49.

A full set of tasks is included in the appendices to this document.

1.9. Presentation of the results

General results

An Airspace Model simulation produces a large number of results which can be classified as follows:

- Distribution of the traffic in simulated sectors.
- Distribution of working times by tasks category per sector and per organisation.
- Loadings on the simulated working positions
- Penalties imposed upon the traffic.

The results are presented in the following manner:

- Results of the reference organisation
- Results of RVSM implementation in proposed scenarios with radar conflict resolution
- Results of RVSM implementation in proposed scenarios with procedural conflict resolution.
- Conclusions and recommendations.
2. RESULTS OF THE REFERENCE ORGANISATION

2.1. Introduction

The reference organisation simulated the 1994 Reims sectorisation. Morning and afternoon traffic samples were simulated at 1994 traffic levels and 2000 expected levels.

2.2. Distribution of traffic per sector

Traffic distribution is not the most important measure for assessing ATC systems but the values are very important in that a significant number of repetitive ATC tasks are generated by the passage of the aircraft through a sector irrespective of the complexity of the traffic situation. These tasks concern flight data management, R/T communications, conflict searches and coordinations within and between sectors and centres.

The chart below shows the distribution of traffic per sector for the morning sample on the top part of the chart, and for the afternoon traffic sample on the bottom part. Values for 1994 traffic levels are shown on left bars and at those recorded at 2000 traffic levels on right bars.

Each vertical bar includes the number of controlled flights in the indicated sector.
The 1994 morning traffic sample contained 339 flights, 2000 level was 430 flights which is an increase of 27%.

Two sectors, ZU and UH, have significantly more aircraft than the other sectors.

The sectors in which the increase is the greatest are UY +40% and ZU +38%. Those 2 sectors being upper sectors, the increase in their number of controlled flights will have a major importance in an RVSM context which affects levels above FL290.

The number of sectors crossed per aircraft is similar between 1994 and 2000, i.e. 2.04 sectors per aircraft.

Afternoon traffic

In the afternoon traffic, 4 sectors, ZU, UR, UE, UH, were recorded with a high number of aircraft whereas in the morning 2 sectors were recorded with a high number of aircraft, even though the total number of aircraft was greater than that of the afternoon. The global aspect of the afternoon traffic is more balanced than the one of the morning.

The global average increase from 1994 to year 2000 was 28%. The increase was 37% for sectors XN and UY (2 upper sectors).

The number of sectors crossed per aircraft was 2.16 in the 2000 afternoon traffic sample which is 6% higher than for the morning traffic 2000.
2.3. Distribution of working times

The distribution of working times on the chart below shows the total number of work minutes recorded for the morning traffic sample at the top of the chart, and for the afternoon traffic on the bottom of the chart. The values indicated are for 1994 on the left bars and for forecast 2000 levels on the right bars. The figures per traffic sample represent the total working time in minutes spent on the various tasks recorded by the model in processing the traffic through all sectors in reference organisation A.

The working time, expressed in minutes, is divided into 5 main task categories.

- Radar.
- Routine R/T communications (Routine R/T).
- Conflict search.
- Internal and external coordinations.
- Flight Data Management.

The global increase of working times for the morning traffic was 35% which is 8 percentage points above the increase for the number of aircraft in the traffic samples. The workload increase with the afternoon traffic was recorded at 38% (against a 28% increase in traffic).
The various increases per task category from 1994 to 2000 traffic are tabulated below:

<table>
<thead>
<tr>
<th>TASK CATEGORY</th>
<th>MORNING TRAFFIC</th>
<th>AFTERNOON TRAFFIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radar</td>
<td>55%</td>
<td>64%</td>
</tr>
<tr>
<td>R / T</td>
<td>29%</td>
<td>30%</td>
</tr>
<tr>
<td>Conflict Search</td>
<td>29%</td>
<td>30%</td>
</tr>
<tr>
<td>Coordinations</td>
<td>31%</td>
<td>33%</td>
</tr>
<tr>
<td>Flight data</td>
<td>30%</td>
<td>31%</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>35%</strong></td>
<td><strong>38%</strong></td>
</tr>
</tbody>
</table>

From the above table, it can be seen that R / T, Conflict search, Coordinations and Flight data tasks increase by a percentage similar to the one of the traffic samples. For the radar tasks, the value is higher, the complexity of the handling of traffic does not increase linearly to the traffic.
2.4. Distribution of workload

The Air Traffic Control tasks recorded by the Airspace Model during a simulation, i.e. tasks generated by the passage of each aircraft through each sector, are allocated to different working positions in accordance with the sector manning and the distribution of duties specified for each sector. The Airspace Model is thus able to calculate the percentage loading for each working position.

The average percentage loading for each position represents the total time spent by a working position on the tasks recorded by the Model, expressed as a percentage of the duration of a simulation (3 hours).

The average 3 hour loadings are used to assess the balance of workload between working positions as well as assessing the workload on each position. Loadings for shorter periods based on a 30 minute incremental scale are also available in the annexed tables.

Experience gained from previous Airspace Model simulations and empirical evidence from various control centres have led to the development of approximate criteria for interpreting controller loadings in enroute sectors. In general, an average loading in excess of 40% is considered a heavy loading, whereas an average loading in excess of 50% is considered to be severe.
From the former chart it can be stated that:

At 1994 traffic levels

- Only sector UH has a high workload in the morning traffic sample.
- No sector has a high workload in the afternoon traffic sample.

At 2000 forecast traffic levels

- Sectors ZU, UE, UH, UF and RA have a workload higher than 40% in the morning traffic sample. It is in UY sector that the highest increase of workload is recorded (+65%).
- Sectors UR, UH, XF record a workload more than 40% in the afternoon traffic sample. The highest increase of workload in this traffic sample is also in UY sector but the coefficient is only of 36% which is more similar to the increase of the traffic sample.

In the morning traffic sample, it was in the area of TRO, ARPUS, ROLEX points that the highest number of conflicts was recorded by the Airspace Model. The highest number of conflicts was located around AUZON in the afternoon traffic sample.

2.5. Conclusions

In this chapter, two levels of traffic 1994 and forecast 2000 have been analysed in the current organisation of the airspace. Those results will be used in the following chapters as a yardstick for comparison purposes with RVSM scenarios.

In both traffic samples simulated, the sector UH has recorded the highest workload. This sector contained all the flight levels from 195. It will be mainly the traffic passing through it above FL290 which will be modified in the proposed RVSM organisations. The upper sector ZU will be easier to analyse because ranging between FL320 and above.

From the results recorded in this reference organisation, it's mainly for the 2 sectors ZU, UH where the workload over 3 hours has been found higher than 50%, that a reduction in the loadings is highly recommended.
3. RESULTS OF RVSM IMPLEMENTATION WITH RADAR CONFLICT RESOLUTION

3.1. Repartition of the traffic across the available flight levels.

The principle decided by the working group of the study to determine the rules to apply to modify the simulated traffic sample was on a 50% basis for each corresponding level of the reference organisation, as it can be seen from the chart « Distribution across the Flights level ».

For example, aircraft which required FL 350 for cruising in the reference organisation where distributed between FL340 and 360 in organisation B and between FL340 and 350 in organisation C. The theoretical optimum level required by the given aircraft was not taken into account for this distribution which was done on a half/half basis.

It has to be noted that this modification on the traffic samples led to a complete different set of aircraft using the same flight level between organisation B and organisation C.

The chart below shows, for morning and afternoon traffic samples, the repartition of the flights across the flight levels in each simulated organisation.

![Distribution across the Flight Levels](image)

It can be noted from the above chart that:

The levels which were the most requested for cruising in morning traffic were 350, 330 and 310 with a significantly decreasing number of aircraft on each of them. In the afternoon traffic sample, the same levels 350, 330 and 310, were the most frequently asked for but the number of aircraft asking for them was well balanced between the flight levels.

There were less flights above FL 390 in the afternoon traffic than in the morning.
3.2. Distribution of traffic

The chart below shows the number of aircraft per sector through the various organisations simulated. Each set of 3 bars shows to the left the number in organisation A, in the middle for organisation B and to the right for organisation C. The top chart indicates the values for the morning traffic sample and the bottom one for the afternoon traffic sample.

The following comments can be made:

The new distributions of the flights through the available levels does not affect significantly the number of flights per sector. For the sectors where there were no other superimposed sectors like UE, UH, RA, UF, XF, there was no logical reason for having a difference. Where sectors were superimposed like UN-XN, UZ-ZU, UR-UY there were 2 possibilities according to the level of the split.

When the split in the reference organisation was set at FL 320 like sectors UZ-ZU or UN-XN all the flights which were in a particular sector in organisation A remained in the same sectors in organisations B or C, with the exception of few flights for which a flight level change was different in various organisations.

When the split in the reference organisation was set at 340 like for the couple of sectors UR-UY, flights which were at FL330 or 350 in the reference organisation did not remain in the same sector in organisations B and C:

From organisation A to organisation B:

- FL330 sector UR in organisation A was divided into FL 330, sector UR and FL 350, sector UY in organisation B, 50% of the traffic going in each sector.
- FL 350 sector UY in organisation A was divided into FL 340, sector UR and FL 360, sector UY in organisation B.

From organisation A to organisation C, the flights mainly remained in the same sector.
The average number of sector penetrations per aircraft was 2.04 in the morning traffic sample and of 2.16 (+6%) in the afternoon one. This number did not change significantly from one organisation to the other. This number is important in a fast time simulation due to the fact that some tasks are directly related to the pierces of the sectors by the aircraft in the traffic samples.

In terms of comparison, for distribution of traffic purposes, between the 2 proposed organisations, organisation C is preferable because it gives a better balance between sectors UR and UY.

A general remark concerning the distribution of the traffic per sector is that the introduction of RVSM does not have a major impact on it, provided the vertical limits between the sectors have been modified in a coherent manner with the traffic samples.

3.3. Distribution of working times

The distribution of working times on the chart below shows the total number of work minutes recorded for the morning traffic sample on the top and for the afternoon one on the bottom. The figures represent the total working time in minutes spent on the various tasks recorded by the model in processing the traffic through all sectors.

The working time, expressed in minutes is divided into 5 main categories.

- Radar tasks
- Routine R/T communications (R/T)
- Conflict search
- Internal and external coordinations
- Flight data management

The chart below shows for each of the simulated organisations the values recorded by the model to handle the traffic in the 3 different organisations.
From the above chart, the following comments can be made:

For the morning traffic sample

⇒ The average working time per aircraft is 2.73 minutes in Org A.
⇒ The average working time per aircraft is 2.51 minutes in Org B.
⇒ The average working time per aircraft is 2.43 minutes in Org C.
⇒ The global decrease in the total working time from A to B is of 8%, from A to C 11%.

There are no significant differences between organisations A, B and C for the task categories Flight Data Management, Coordinations, Conflict Search and R/T. This is due to the fact that the tasks in these categories are directly related to the number of aircraft per sector. This number of aircraft per sector was not affected by the RVSM simulated in organisations B and C.

For the radar tasks, the difference between the organisations is very pronounced:

⇒ A reduction of 28% is recorded from organisation A to organisation B.
⇒ A reduction of 34% is recorded from organisation A to organisation C.
⇒ A reduction of 8% is recorded from organisation B to organisation C.

For the afternoon traffic sample

In the 3 simulated organisations, the working time per aircraft was higher than the morning traffic sample.

<table>
<thead>
<tr>
<th>ORGANISATION</th>
<th>Morning</th>
<th>Afternoon</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2.73</td>
<td>2.85</td>
</tr>
<tr>
<td>B</td>
<td>2.51</td>
<td>2.61</td>
</tr>
<tr>
<td>C</td>
<td>2.43</td>
<td>2.57</td>
</tr>
</tbody>
</table>

The global working time, as with the morning traffic sample goes down from organisations A to B to C. In the afternoon traffic sample, the radar tasks go down from A to B to C, but the percentage is not as high as with the morning traffic sample.

The above results are confirmed by the following scientific elements:

- The radar tasks, are proportional to the probability of conflicts.
- The conflict probability per cruising flights is reduced by about 50% when RVSM is implemented. The conflict probability increases relatively quicker than the number of flights.

Those 2 elements can be demonstrated by Hurras and perfect gas formulas.
3.4. Distribution of workload

The Air Traffic Control tasks recorded by the Airspace Model during a simulation, i.e. tasks generated by the passage of each aircraft through each sector, are allocated to different working positions in accordance with the sector manning and the distribution of duties specified for each sector. The Airspace Model is thus able to calculate the percentage loading for each working position.

The average percentage loading for each working position represents the total time spent by a working position on the tasks recorded by the Model, expressed as a percentage of the duration of a simulation (3 hours).

The average 3 hour loadings are used to assess the balance of workload between working positions as well as assessing the workload on each position. Loadings for shorter periods based on a 30 minute incremental scale are also available.

On the chart below, each set of 3 bars represents the workload recorded by the Airspace Model for each sector, for the morning traffic sample on the top chart, for the afternoon traffic sample on the bottom chart.

The following comments can be made:

With the morning traffic sample:

All the simulated sectors were recorded as having a reduction in the workload from organisation A to the RVSM ones (B and C).

The sector ZU has the highest reduction. This sector is highly concerned by RVSM, its lower limit being FL265 in the reference organisation. The sector UH records a high reduction too considering that its lower level is 195. Those 2 sectors had the same number of aircraft through the 3 organisations simulated.

In general, there is a slight decrease from organisation B to organisation C.
FLIGHT LEVEL ORIENTATIONS

EUROCONTROL
AIRSPACE MODEL
RVSM Continental Simulation

ORGANISATION A

410
370
330
300
270
240
210
180

ORGANISATION B

FL340
380
370
365
350
330
300
280
260
240
220
200
180

400

ORGANISATION C

FL325
380
370
365
350
330
300
280
260
240
220
200
180

400

RVSM radar conflict resolution
With the afternoon traffic sample:

The sector UR records a substantial increase from organisation A to organisation B. The number of flights had also increased due to the modification of the traffic samples.

The sectors for which an increase in workload is recorded had more aircraft to control.

The general tendency from organisation A to B and C is not so strong as for the morning traffic sample.

The conflict-to-conflict comparison between organisations B and C cannot be made due to the incomparability of the traffic samples. Nevertheless, the global number of conflicts recorded can be compared to give a general idea. The table below shows the number of supervisions and interventions recorded in the different simulated organisations.

<table>
<thead>
<tr>
<th></th>
<th>A3</th>
<th>B3</th>
<th>C3</th>
<th>A4</th>
<th>B4</th>
<th>C4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sup</td>
<td>171</td>
<td>103</td>
<td>117</td>
<td>150</td>
<td>98</td>
<td>101</td>
</tr>
<tr>
<td>Int</td>
<td>114</td>
<td>84</td>
<td>75</td>
<td>88</td>
<td>68</td>
<td>65</td>
</tr>
<tr>
<td>TOTAL</td>
<td>285</td>
<td>187</td>
<td>192</td>
<td>238</td>
<td>166</td>
<td>166</td>
</tr>
</tbody>
</table>

From the table above, these comments can be made:

- The number of conflicts goes down by 35% from A3 to B3.
- The number of conflicts goes down by 30% from A4 to B4.

The number of conflicts is similar between organisations B and C with the 2 traffic samples. Some points like Rolex where many conflicts were recorded in organisation A were no longer places of high conflict density in the RVSM organisations.

3.5. Conclusion

In this chapter, the incidence of 2 different ways of applying RVSM have been analysed: In organisation B each flight level above 290 was in the opposite direction to the level above and below, in organisation C, 2 superimposed flight levels were in the same direction above FL290. The figures contained in this chapter have been obtained with a preferential radar resolution for conflicts detected in the simulation.

With the modifications applied to the vertical split of the sectors, no major influence has been recorded regarding the distribution of flights per sector. The only difference was found for sectors UR and UY where the split was at FL340 in the reference organisation.

The influence of applying RVSM on the distribution of the working times has shown for the proposed organisation B a global reduction of 8% in both traffic samples simulated. This reduction was of 10% in proposed organisation C with 2 flight levels in the same direction. This reduction was mainly affecting the radar tasks of the controller where the reduction was of 30% from organisation A to organisation B. The reduction in the radar tasks has been found higher with both traffic samples with organisation C.
4. RESULTS OF RVSM IMPLEMENTATION WITH PROCEDURAL CONFLICT RESOLUTION

4.1. Introduction

In the previous chapter, we have analysed the results of the 2 different ways of implementing RVSM in a continental airspace with radar conflict resolution. In other words, almost all the conflicts (except those where the tracks of conflicting aircraft were in the same direction) detected during the simulation were required to be resolved by a radar manoeuvre, the flights remaining at their original flight level. In this chapter, another type of conflict resolution will be analysed, the conflict resolution by flight level change of one of the conflicting aircraft in the case where both aircraft in conflict were in a cruise attitude.

This type of resolution was originally tested with organisation C where 2 superimposed flight levels were in the same direction and which was operationally easy to apply. In order to have results analytically usable, it was decided by the working group to simulate this kind of conflict resolution in both proposed RVSM organisations.

A total of four exercises were simulated with this type of procedural conflict resolution:

AG01B3P, AG01B4P, AG01C3P, AG01C4P

4.2. Distribution of traffic

The split between the pairs of superimposed sectors had been designed in order to keep the maximum of coherency between organisations A and proposed organisations B and C.

As a conflict was detected by the Airspace Model, the priority levels given by the model were in the same sector as the original level. For that reason, it can be noticed from the chart below that very few changes have been recorded between radar and procedural conflict resolutions.

---

**DISTRIBUTION OF TRAFFIC**

Proposed B & C Organisations Radar / Procedural Resolutions

---

**Morning Traffic 2000**

**Afternoon Traffic 2000**

---

Org. B3
Org. B3P
Org. C3
Org. C3P

---

28 RVSM procedural conflict resolution
4.3. Distribution of working times

On the chart below, the distribution of working times is indicated for the 2 ways of resolving the conflicts in the simulation. The top chart shows figures for the morning traffic sample, the bottom one for the afternoon traffic sample.

In both traffic samples, the procedural resolution applied to proposed B organisation gave rise to a global reduction in the total working time of about 3%. This reduction was slightly less in the proposed organisation C where the decrease was of only 2%.

As this global reduction is not very significant, the figures per task categories need to be analysed in more detail.

Category Radar - In the B organisation (one flight level each direction) a decrease of 28% was recorded with the morning traffic sample, and 26% in the afternoon traffic sample.

Category R/T - In the four exercises simulated with this type of conflict resolution, 8 extra minutes were recorded. This represents the tasks necessary to advise the aircraft to change level and the necessary acknowledging and reports from the pilots.

Category C/S - An increase in conflict search tasks was recorded in the 2 traffic samples. This value of 7 minutes was the same for the 2 proposed organisations in the morning traffic while it was higher in C organisation with the morning traffic sample.
Category Coordinations - The global value from radar to procedural resolution goes up in both proposed organisations. In fact there is no change for external coordinations, the difference coming from internal coordinations. In the case of Reims control centre, the internal coordinations are performed automatically by the system if there is no change on the predicted profile of the traffic. The only internal coordinations recorded are in the case where an aircraft was due to arrive in a control sector in certain conditions and that for air traffic control reasons, this predicted profile cannot be performed. This kind of situation can also appear when a control sector cannot accept a flight in the predicted conditions. The airspace model records in that case a transmission/reception of request to the previous/next sector for reclearance of an aircraft before transfer of control. With the procedural resolution of conflict there were many more occurrences of level change before transfer of control which triggered a higher number of this kind of coordinations.

Category flight data - No significant change was recorded by the model.

4.4. Distribution of workload

The distribution of workload of the radar controllers through the simulated sectors is shown for the 2 different types of conflict resolution on the chart below:

The general tendency of the controller workload over 3 hours is to go down from radar to procedural resolution of conflicts. This difference is nevertheless very small between the 2 methods. The reduction recorded on the working times has a minor impact on the percentage of workloads. This is due to the fact that almost all of what is gained on radar tasks is compensated by R/T, Conflict search and coordination increases.

The work to perform in the 2 kinds of conflict resolution is in fact very different: where a conflict has to be resolved by radar, the activity of the controller is related
to radar vectoring while when procedural resolution is preferred his activity is in the field of frequency management.

From an airspace user point of view, the procedural resolution with more flight level changes would certainly present disadvantages to radar conflict resolution. In the morning traffic sample, the number of flight level changes from radar to procedural was recorded in the proportion of 1 to 3. In the afternoon traffic sample, this value was from 1 to 2. This preferential flight level change would be operationally more acceptable in the proposed C organisation where the vertical change is 1000ft compared to the 2000ft of the B organisation.

4.5. Conclusions

In this chapter, the second method of conflict resolution has been analysed in the proposed organisations simulating an RVSM scenario. The influence of radar or procedural method has been found insignificant in term of distribution of traffic. This was due to the fact that fewer conflicts than in the reference organisation were detected and that a level change procedure tried to leave the aircraft in the same sector as on its original profile. The influence on the working times has been recorded as a minor global reduction. The main interest relies in the detailed analysis of this reduction: it was composed of a decrease in the radar tasks category associated to an increase in the conflict search and R/T tasks. From workload and The best method to implement would be the determined by the degree of assistance which can be provided to the radar controller by the tools he uses to perform his work.

From a user point of view, the proposed organisation C with 2 flight levels each direction seems more appropriate to a procedural conflict resolution method than proposed organisation B with one level each direction due to the smaller vertical change to request from the aircraft (1000ft instead of 2000ft).
CONCLUSIONS AND RECOMMENDATIONS

The main objective of this first study in a series of fast time simulations on continental RVSM was to assess controller workload when RVSM levels were introduced. Different flight level orientations and conflict resolutions were applied to the simulation exercises. The area of the simulation was Reims ATCC.

Two traffic samples, one morning and one afternoon, were simulated both at 1994 levels and at the level of traffic forecast for the year 2000. These were references without RVSM levels. The simulation of year 2000 traffic led to very high workloads throughout the simulation area.

The 2 further organisations which used RVSM levels were then simulated in each FL orientation and by using both radar conflict resolution and then procedural conflict resolution rules.

The first RVSM organisation (Org B) simulated an extension of the current alternate FL orientation from FL 190 to FL 410. The global workload was 8% lower than that of the reference organisation when radar conflict resolution was used and a further 2% lower when procedural resolution was used.

The second RVSM organisation (Org C) simulated the current FL orientation up to FL 290. FL’s 300 and 310 were then paired in the same direction with the next 2 levels paired together in the opposite direction. This pairing of levels continued to FL 410. The global workload was 11% lower than that of the reference organisation when radar conflict resolution was used and a further 3% lower when procedural resolution was used.

The traffic was modified from the reference samples to those using RVSM levels by an equal distribution to the new RVSM levels. An intuitive conclusion and conformed to the theoretical model of K. Hurras (ref. 1B112-91/05, of DLR Braunschweig), could be that this reduced the conflicts for cruising traffic by 50%. The airspace of the simulation also contained a large number of arrivals and departures form adjacent airports but the reduction in workload for this traffic was not so apparent.

The theoretical approaches to the study outlined above could also consider that flights in conflict at their original levels could also be in conflict at the new level.

It can be concluded that:

- A further study should be made regarding the orientation of the flight levels taking into account the optimum cruise level for aircraft. This may trigger a higher concentration of flights on particular levels and generate special requirements or recommendations on the use of the available RVSM levels. The reduction recorded in the number of conflicts in the present study may prove to be less important.

- The simulated airspace had various splits between superimposed sectors. It should be considered in further studies that there is a homogeneity between sectors in their bottom and top levels.
• The flight level orientation of Organisation B provides a coherency to the present system throughout the vertical limits of the airspace. The orientation used in Organisation C however, produces a structure which is different above and below FL 290. This could be a source of errors.

• The decrease in radar workload when RVSM is applied is directly related to the number of conflicts. This indicates that as the traffic increases then so will the proportional reduction in workload.

• Organisation C recorded better performances than B in terms of workload with both radar and procedural conflict resolutions. In the case of procedural conflict resolutions the vertical change in Organisation C was half of those encountered in Organisation B.

• In the simulation all FL’s were considered usable for civil traffic. Military flights were not considered for their potential use of those levels.

• There are in Europe 2 main semi-circular rules for the application of FL’s which apply the magnetic route of the flights to determine the direction. One has an axis from North to South and the other West to East. Another application which would be interesting to simulate would be a quadrant system also applying magnetic routes where 2 of the quadrants would each be coherent to the 2 current systems. In such a study it is envisaged that the number of conflicts would go down compared to the Organisations simulated in AG01.

The author wishes to express his thanks and gratitude for all the help and assistance given to him by the personnel from DED4, Headquarters, EUROCONTROL, who participated in this airspace model simulation study.
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