PARADIGM SHIFT:
THE DUAL AIRSPACE EXPERIMENT

EEC Note No. 08/06
Project INO-1-AC-SHIF

Issued: March 2006
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<th>Reference: EEC Note No. 08/06</th>
<th>Security Classification: Unclassified</th>
</tr>
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<td>TITLE: PARADIGM SHIFT: THE DUAL AIRSPACE EXPERIMENT</td>
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<td>INO-1-AC-SHIF</td>
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<td>Distribution Statement: (a) Controlled by: Marc BROCHARD Deputy of INO</td>
<td>(b) Special Limitations: None</td>
</tr>
<tr>
<td>Descriptors (keywords): Dual airspace, ATM, functional division of traffic</td>
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SUMMARY

The entire ATM community highlight the fact that current air traffic management system cannot cope with the challenges of future air transport system. The aim here is to propose an original air traffic management system which will enable to cope with the peaks in demand expected in the future. The paradigm of Dual Airspace aims at increasing the en-route traffic by introducing a functional division of the traffic. This concept is based on separation of traffic patterns and creation of two kinds of control units: the Highways and the sectors. This paper presents the first results obtained after a proof of concept experiment, assessing the impact on one en-route control sector of a highway passing through the sector. It represents an initial assessment of the concept, in terms of capacity and efficiency, while also maintaining a high level of safety, which should allow its operational relevance.
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1. INTRODUCTION

By taking into account the current and future features of ATM, Paradigm SHIFT project [1] started in January 2004, proposes two major concepts as the backbone for the shift of control paradigm from the current to the future: Contract of Objectives and Dual Airspace. These two paradigms could be independent but could also be combined together because there is no contradiction in their mode of operations.

It is admitted that the sharing of responsibilities in the current ATM system is based on a geographical delineation of the European airspace. However, the current paradigm does not present the problem of control task allocation in the most beneficial way, since it is not based on a detailed analysis of the various traffic patterns and their specific characteristics. It would be beneficial to introduce a system which would separate responsibility for managing cruising traffic and climbing/descending airport traffic where traffic is very dense.

As proposed in the Paradigm SHIFT project, the concept of Dual Airspace aims at increasing the en-route traffic capacity by introducing a functional division of the traffic, based on its nature (i.e. climbing, descending, cruising). The objective would be to have two operational modes of traffic management cohabiting in the same geographical area for coping with the peaks in demand expected in the future. It is an innovative proposal for task sharing in ATM.

The concept of Dual Airspace introduces a small number of continental highways conveying long haul cruising traffic in complement to all-included sector-based traffic (district) as of today. This purpose of this paradigm is to release the pressure on local air navigation services by separating the long-haul routes from the current routes.
2. CONCEPT

The Dual Airspace principle is founded on the division of traffic not on a geographical basis (sector segmentation) but rather on a functional separation of flows. The functional separation of flows in common airspace is based on:

- Independent and autonomous traffic flows, except in precise and well-defined exchange areas.
- The possibility of different operational control modes for each flow.
- For air traffic controllers, total "airtightness" between flow management modes.

Dual airspace as defined in SHIFT is characterized by:

- A limited number of highways on a continental scale, crossing the core area. Highways are located in the upper airspace and are defined in order to respond to the major traffic flows overflying Europe and the core area. They do not link directly airport terminal areas (TMAs) to other airport terminal areas. They receive aircraft from and hand them over to other volumes of airspace. The aircraft using the highways are steady at the flight levels allocated to the highways. The levels allocated to highways are defined in accordance with a flight level allocation system (FLAS) in order to minimize interactions between highways and enhance safety.

- A route network similar to that currently in existence, the objectives of which will be to ensure the transfer of aircraft from TMAs to highways and vice versa, and to safeguard cruising traffic with no access to a highway. The route network will be divided into sectors, like today's airspace. Within the sectors, working methods will be similar to today's. Outside the highway cohabitation areas, sectors will be managed as they are today or as they might be in the future once new operational control methods are introduced.
3. PURPOSES OF THE SIMULATION

A Human in the Loop experiment will enable to validate the hypotheses which have led to the definition of the dual airspace concept and its operationalisation in a given volume of airspace.

The capacity gain expected as a result of the introduction of dual airspace is based on the fact that the sector will no longer have to manage any of the aircraft allocated to the highway. The potential gain is thus in two areas:

- In the sectors, since more aircraft can use the flows crossing those allocated to the highway.
- On the highway, since the similarity between aircraft flight paths opens room to envisage a much higher-capacity operational control mode, thereby allowing a response to the growth of traffic in the major flows overflying Europe.

Dual airspace operationalisation in the Paradigm SHIFT project raises a certain number of questions:

- The first set of questions relates to the definition of the two types of airspace and the interface between them.
- The second concerns the operational feasibility of the concept in terms of working methods and operational continuity.
- The third seeks to evaluate the impact and gains of such a system.

The aim of the October 2005 experiment was not to find ways of responding to all of these questions but, to evaluate the impact of a highway volume crossing a control sector, not only in capacity but also in operational and safety terms. It was a local approach to the concept of Dual Airspace.

Questions associated with the highway's internal structure, working methods relating to the management and control of aircraft on the highway, and the airspace and operational modes which will ensure the operational continuity of aircraft moving from sectors onto highways and vice versa, were not envisaged in this experiment.

The aim of the experiment was to find ways of responding to the following problems:

- Shapes of highway meeting the needs of highway traffic and acceptable for operational and safe traffic management in the sectors crossed.
- Impact of the volume occupied by the highway on the work of controllers in the sector (comprehension, decisions, possible actions, workload).
- Constraints imposed by the highway on the definition of the airspace in the sectors crossed (volume, routes, beacons, convergence points, etc.).
- Working methods of controllers responsible for traffic management in the sectors crossed by the highway.
- Definition of the control position and control support tools for the sectors crossed by the highway.
- Capacity gain in terms of the traffic load in the sectors crossed by a highway system.
- Impact of traffic load on traffic safety in the sectors crossed by a highway.
4. EXPERIMENT OBJECTIVES & HYPOTHESES

The aim of the "Human in the Loop" experiment which took place at the EUROCONTROL Experimental Centre on 21-28 October 2005 with four en-route controllers was to carry out an operational assessment of the concepts developed within the SHIFT study on Dual Airspace. It represents an initial assessment of the concept, which should allow its operational relevance to be evaluated for the purpose of:

- refining the concept;
- extending the concept to transitions between sectors and highways;
- enabling more general studies to be initiated into the concept of Dual Airspace at the level of its pan-European and regional organization and efficiency;
- developing the work on the internal organization and management of the highway system.

The hypotheses are as follows:

- to assess the impact of Dual Airspace within a sector by comparing airspace with a highway to airspace without a highway;
- to assess the impact of the configuration of the highway in relation to the volume it occupies in the sector; this volume depends on the airspace occupied on both the horizontal and vertical planes;
- to compare the previous hypotheses (with and without a highway) based on varying traffic loads;
- to compare, for a given traffic load, the impact of the solutions adopted at highway level in order to deal with meteorological turbulence requiring aircraft present in the highway to change flight level;
- to assess support tools and aids to facilitate the work of controllers in the sector.

The expected results of the experiment were an assessment of:

- the potential gains in capacity to be made from the Dual Airspace concept within a high-density control area;
- the efficiency of the control method in conjunction with the changes introduced by the presence of the highway within a control sector;
- the preservation of a safety level compatible with air traffic operational targets;
- the working methods of the controllers in the control sector;
- the potential development of the controller working position in terms of support tools and aids to facilitate the controller's task;
- the design principles for a volume of airspace which unites within a single geographical area "sector" airspace and "highway" airspace.
5. **ENVIRONMENT OF THE SIMULATION**

The measured scenario is based on an operational framework structured around the following elements:

- A control sector.
- A highway.
- Air traffic.

### 5.1. CONTROL SECTOR

The control sector is a volume of airspace *80 nautical miles long by 60 nautical miles wide*, oriented north-west/south-east. It extends vertically from FL 290 to FL 430. It is surrounded by four sectors (feeders) playing the role of entry or exit sectors.

The sector is composed of beacons (Figure 1) and a network of routes (Figure 2).

![Figure 1: Control sector and beacons](image-url)
The routes allow for the transit of even and uneven traffic flows and run in all directions. There is no hypothesis governing the organisation of the route network or the position of the beacons. The following elements have, however, been taken into consideration:

- For the reference scenario without a highway, routes must exist which allow for the transit of a flow of aircraft simulating at least the flow of aircraft which might transit on the highway.
- There are no route convergence points in the highway area.
- There are no beacons in the highway area (Figure 3).
5.2. HIGHWAY

The highway represents an obstacle to traffic management in the sector it crosses, since it is a no-go zone just as military areas can be today. The shape of the highway therefore represents an important variable affecting the impact it can have on traffic management.

The volume occupied by the highway must meet two criteria:

- It must meet aircraft demand in terms of flight levels and capacity at these flight levels. If the highway does not meet a demand, it becomes less attractive and useful.
- It must be minimised in order to reduce the highway's impact on traffic management in the sector crossed. This impact will depend on a number of factors:
• The number of flight levels occupied;
• Whether or not these flight levels are contiguous (one or more vertical blocks);
• The vertical height of the contiguous flight levels;
• The width of the highway;
• The possibility of modifying the selected configuration in order to deal with meteorological events constituting disruptive elements (horizontal modification for thunderstorms and vertical modification for turbulence).

The number, contiguity and height of the flight levels have a direct impact on how the traffic is managed. This impact will be all the greater since the aircraft will be operating in the vertical plane and will need to be stabilised at a given level in order to cross the highway. The impact will be increased by the existence of highway crossing area convergence points at varying intervals.

Points of aircraft entry to and exit from the highway are not simulated.

5.2.1. Horizontal Structure

The highway runs in a straight line and is 22 nautical miles wide. It crosses the sector along its longitudinal axis and approximately along its centre line. In the definition of the highway volume, it has been decided to minimise the possible impact of highway width. Accordingly, only the calculated minimum width will be studied, no matter what the vertical configuration of the highway. The width defined is 22 nautical miles.

![Figure 4: Horizontal structure of the highway](image-url)
5.2.2. Vertical Structure

The levels occupied by the highway will vary depending on the scenarios. The highway will in all cases occupy three flight levels. In order to respond to vertical meteorological variability factors (turbulence), the highway may be moved vertically on the basis of scenario events and thus occupy more levels. Vertical extension solutions are also scenario-specific.

For the purposes of the experiment, two highway configurations will be studied:

- Configuration A, in which the highway comprises three independent flight levels (370, 330 and 310);
- Configuration B, in which the highway comprises three flight levels, one of which, 370, is independent, while the other two, 330 and 320, are contiguous.

The number of flight levels and the levels themselves have been selected in order to meet traffic demand. The expression of traffic demand is formalised in the EEC Note entitled “Segmentation stratégique du traffic et de l'espace aérien”[7].

The difference between Configuration A and Configuration B lies in the vertical height of the contiguous flight levels. In Configuration A, the flight levels are independent; this means that there are 1000-ft no-go zones which must be avoided by traffic in the sector crossed. In Configuration B, it has been decided to study the impact of a 2000-ft-high no-go zone.

5.2.3. Vertical Adaptation to Turbulences

Turbulences are source of traffic disturbances. The aim of integrating turbulence into the scenarios is to assess the feasibility of vertical modification of the highway configuration and to evaluate the impact of such a modification on traffic management in the sector concerned.

Two solutions of vertical modification of the highway configuration are possible:

- Solution 1, in which "airlocks" are opened for descending and climbing between various nearby but not contiguous highway flight levels, i.e. 2000 or 3000 ft apart (Figure 5).

- Solution 2, in which the highway shifts downwards by 2000-3000 ft. (Figure 6).
It is clear from a consideration of the two modes of vertical configuration of the highway previously described that each of the two solutions proposed here corresponds particularly well to one of those configurations. Solution 1 is thus adapted to Configuration A and Solution 2 to Configuration B. Each solution will be assessed during the experiment at the same time as the vertical configurations of the highway.

5.2.4. Horizontal Adaptation to Thunderstorms

Horizontal adaptation of highway to thunderstorms will be not simulated during the experimentation.
6. EXPERIMENT VARIABLES

On the basis of the hypotheses listed above, the following variables were set or measured.

6.1. INDEPENDENT VARIABLES

6.1.1. Existence or Absence of a Highway

The highway represents an obstacle to traffic management in the sector it crosses. So the first independent variable will be the existence or not of a highway in the measured sector.

It's why a reference scenario, without any highway has been created.

6.1.2. Configuration of the Highway

For the vertical volume, two configurations were assessed Figure 7.

- Highway 1 (H1), where the highway occupies three distinct and separate flight levels, namely FL 370, FL 330 and FL 310;
- Highway 2 (H2), where the highway also occupies three flight levels, two of which are adjacent, namely FL 370, FL 330 and FL 320.

For the lateral volume, following discussions held during the previous stages a constant width of 22 NM was proposed for the two vertical configurations.

![Figure 7: Vertical configurations of the highway](image)

6.1.3. Traffic Density

Two density levels were set: a medium traffic load and a heavy traffic load. These levels were determined according to the declared capacities of the operational sector chosen as a reference for the definition of the experimental airspace. They then had to be adapted to the limitations on controllers' tasks caused by the experiment platform, i.e. on one hand the lack of coordination with adjacent sectors and on the other hand the fact that the interactions with aircraft were carried out solely via the radar interface with no radio communication. Moreover, instructions given to aircraft were carried out immediately and flawlessly by the latter. As a result, the controller's workload was reduced, necessitating an increase in air traffic density to ensure equivalence with what happens in the Ops room for medium and high-density traffic loads. Traffic adjustments were made and validated with two operational controllers.
Traffic load is defined by two parameters: capacity per hour and instant capacity. These two parameters reflect the difficulty involved in defining traffic, because of its variability. This is why the traffic used in the experiment was defined and rated on the basis of an average instant capacity, in this case over a 15-minute time period. The two traffic levels were therefore as follows:

- medium traffic density: average instant capacity of 9.5 – 9.65 aircraft;
- high traffic density: average instant capacity of 11.2 – 11.35 aircraft.

It is interesting to note from these figures that the perception of traffic density is not linear with respect to the number of aircraft but sensitive to a threshold above which one quickly passes from a comfortable level (medium density) to a level requiring considerable mobilization of cognitive resources (high density).

6.1.4. Response to Disruption due to Turbulence

In the context of the concept of *Dual Airspace*, the proposed system should be resistant to disruptive factors. Rather than entering into an exhaustive assessment of all the possible disruptive factors which can affect a flight (for which see the "Paradigm SHIFT Operational Concept"[1]), only the "meteorological turbulence" disruptive factor was assessed.

Meteorological turbulence refers to meteorological phenomena which oblige all aircraft to request a change in flight level. This differs from stormy weather, which in general results in a horizontal and not vertical change to an aircraft's flight path.

Since highway levels are pre-determined flight levels, any request from aircraft navigating in the highway system to change flight level because of turbulence must be feasible within the proposed system. It was decided in this experiment to assess the highway adjustment mechanisms on the basis of aircraft requests following turbulence phenomena.

Two adjustment mechanisms for the vertical configuration of the highway were defined, each corresponding to a vertical hypothesis for the configuration of the highway Figure 8:

- For Highway 1, the adjustment mechanism involves including in the highway an extra flight level between FL 330 and FL 310. The highway thus occupies FL 370, FL 330, FL 320 and FL 310.
- For Highway 2, the adjustment mechanism involves bringing the two adjacent flight levels down two levels. The highway thus occupies FL 370 and FLs 330 to FL 300.

![Figure 8: Highway turbulence-adjustment mechanisms](image-url)
6.2. DEPENDENT VARIABLES

6.2.1. Dependent Variables relating to Controller Activities

The purpose of these variables was to objectify controller traffic management activities on the basis of independent variables monitored in the simulation exercises. The operationalization of these variables was achieved by measuring the workload, the traffic situational awareness or "picture", instructions given to aircraft by controllers, and lastly the opinion of controllers after they had carried out the simulation exercises.

Workload

The workload was assessed by means of a self-assessment questionnaire using a scale of 1 to 6. The questionnaire was based on NASA-TLX and SWAT questionnaires.

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<td>Phase posing no difficulty. Is completed practically without thinking.</td>
<td>Phase which feels easy but during which certain things require thought. Cannot be completed &quot;with one's eyes closed&quot;.</td>
<td>Phase requiring sustained concentration but during which there are no difficulties.</td>
<td>Dense phase with much to do. One feels that it would be difficult to do much more of this.</td>
<td>Very dense phase in which one feels that it is impossible to do anything more.</td>
<td>Phase during which one feels out of one's depth.</td>
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Figure 9: Workload self assessment questionnaire

Situation awareness

Situational awareness was assessed by means of a self-assessment questionnaire using a scale of 1 to 6. The questionnaire was based on the concepts of situational awareness developed by Endsley[6], Grau & all [8].

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<td>Phase in which it is easy to understand everything with the desired precision.</td>
<td>Phase in which one understands everything but would like a little more time to clarify certain points.</td>
<td>Phase in which one would like better anticipation.</td>
<td>Phase in which one ensures safety above all.</td>
<td>Phase in which one feels one has understood everything but is not sure.</td>
<td>Phase in which one is sure that one does not understand everything.</td>
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Figure 10: Situation awareness self assessment questionnaire
Control orders

The instructions given to aircraft are an objective reflection of the controllers' cognitive activity when managing the traffic. They do not represent all the aspects of this cognitive activity since a controller's understanding, reasoning and decisions are not necessarily all translated into by an instruction given to an aircraft. However, they make it possible to assess the decisions taken to:

- organize the traffic and make it compatible with the cognitive resources available in line with the constraints of the current and expected situation (flight plan constraints and sector constraints);
- resolve conflicts;
- manage avoidance of the highway.

To quantify the given orders, an "instruction given" parameter was defined which corresponded to the average number of instructions given by the controller to each aircraft for each scenario phase corresponding to the setting of monitored variables.

Post-simulation interviews

The post-simulation interviews allowed us to find out the controllers' views on their activities. They were recorded and a content analysis was carried out. Lasting around one hour per controller, the interviews were carried out using open and closed questions and a semi-structured interview format.

6.2.2. Dependent Variables relating to Safety

Safety became an issue in the experiment where there was a loss of separation between aircraft and/or where an aircraft entered highway airspace. To avoid this and warn the controller before one or more aircraft became a safety risk, the control position was equipped with two alarms, a short term conflict alert (STCA), and an area infringement warning (AIW) which identifies the imminent intrusion of an aircraft into the highway envelope.

The activation of these alarms during the simulation exercises was considered a security issue even though there remained sufficient time for the controller to act immediately and reactively to avoid loss of separation. In all cases, the alarms reflected a lack of anticipation on the controller's part in managing aircraft flight paths in relation to other aircraft or the obstacle presented by the highway.

This is why all the alarms (STCAs and AIWs) which were triggered were accounted for and recorded for each scenario phase corresponding to the setting of monitored variables. However, the triggering of these alarms is the result of an algorithmic calculation which does not take controllers' intentions into account. This is why the alarm may have been triggered in certain circumstances even though the controller was aware of the situation and was capably handling the separation between aircraft and/or with the highway. To deal with this limitation, all the alarms were reclassified according to the context (controller's opinion and observations of the person running the experiment) and only "real" alarms were taken into account.

There are two types of safety data:

- the number of times the STCA alarm was triggered;
- the number of times the AIW alarm was triggered.
6.2.3. Dependent Variables relating to Performance

Alongside safety, which was the top priority, air traffic control performance was also assessed through the criteria of capacity, stability and efficiency.

**Capacity**

Capacity was evaluated in the experiment using the hypotheses taken for the construction of traffic samples on the basis of density. Since the traffic density calculation takes into account the limitation of the controllers' tasks, the experiment's conclusions on capacity will be expressed in relative and not absolute terms.

**Stability**

Stability is an index characterizing instructions given by control to aircraft in the sector. This dimension is the same as that defined to objectify controller activities.

**Efficiency**

The term "efficiency" denotes the traffic variability induced by the sector, its route network and the working methods used by controllers to manage the traffic. Knowledge of this variability makes it possible to quantify the impact on traffic of the highway passing through the sector. This is important in order to determine how variability may be acceptably allocated within the network, especially in the context of the contract of objective as it is envisaged in the Paradigm SHIFT Project.

One way of quantifying this variability is compliance with aircrafts' scheduled flight plan parameters on leaving the sector. The efficiency index takes account of divergences from predictions made when aircraft enter the sector concerning the time and the distance needed to cross it. These divergences are calculated for each aircraft and expressed in the form of an average time and distance per aircraft.

In order to assess control efficiency, the following data were gathered:

- average time divergence per aircraft calculated as the difference between the flight duration and the predicted flight duration in the sector;
- average distance divergence per aircraft calculated as the difference between the real distance flown and the planned distance flown in the sector.
7. **CONDUCT OF THE EXPERIMENT**

The experiment took place over six days with four en-route controllers from three air navigation operational centres: one Czech controller, one Slovenian controller and two French controllers.

The airspace and traffic scenarios were designed on the basis of a real-life situation. However, so that all the controllers began on an equal footing in terms of any prior knowledge of the circumstances, the airspace and traffic were changed to make them anonymous.

For each controller, the experiment was conducted as follows:

- One day to present the concept, the experiment, the platform and training on the platform with scenarios of the same difficulty as those to be measured.
- One day to carry out three 70-minute scenarios, each followed by a post-simulation interview.

### 7.1. **STRUCTURE OF THE SCENARIOS**

The scenarios carried out by the controllers were built around the idea of independent variables testing the experiment's hypotheses. Each scenario was built around five phases:

- Phase 1 – warm up, to start the scenario and put the controller in situation. This phase lasted 15 minutes.
- Phases 2,3 and 4 – the measured phases. They each lasted 15 minutes.
- Phase 5 – finishing the exercise. This lasted 10 minutes.

Phases 1 and 5 were not taken into account in the results analysis.

The traffic in the scenarios was made up as follows:

- 70% steady traffic;
- 30% climbing and descending traffic.

### 7.2. **THE THREE EXPERIMENTAL SCENARIOS**

The three scenarios are as follows: Reference scenario (R), Highway 1 scenario (H1) and Highway 2 scenario (H2).

#### 7.2.1. **Reference Scenario (R)**

The R scenario has no highway. The three measured phases are as follows:

- Phase 2 with a high-density traffic load;
- Phase 3 with a medium-density traffic load;
- Phase 4 with a medium-density traffic load and turbulence.
7.2.2. Highway 1 Scenario (H1)

The H1 scenario introduces Highway 1. The three measured phases are as follows:

- Phase 2 with a high-density traffic load;
- Phase 3 with a medium-density traffic load;
- Phase 4 with a medium-density traffic load and turbulence necessitating the application of the H1 adjustment (vertical enlargement of the highway at FL 320).

7.2.3. Highway 2 Scenario (H2)

The H2 scenario introduces Highway 2. The three measured phases are as follows:

- Phase 2 with a medium-density traffic load;
- Phase 3 with a high-density traffic load;
- Phase 4 with a medium-density traffic load and turbulence necessitating the application of the H2 adjustment (vertical enlargement of the highway at FL 300 and FL 310).

7.3. TOOLS TO FACILITATE THE WORK OF CONTROLLERS IN MANAGING VERTICAL CONSTRAINTS

Four specific tools were developed for this experiment in order to facilitate the work of controllers in managing the vertical constraints inherent in the presence of the highway in the control sector. These tools are as follows:

- highway level filter to display aircraft on the same level as the highway flight levels;
- alarm to signal imminent incursion of an aircraft into highway airspace;
- dynamic vertical representation of the overall traffic situation in the sector;
- static representation of the vertical flight path of a pre-selected aircraft and its potential changes of level based on its performance.

7.4. AUTOMATED MANAGEMENT OF VERTICAL CONSTRAINTS LINKED TO PENETRATION OF THE HIGHWAY

The vertical constraints imposed by highway crossings generate an additional workload for the controller. Since these constraints are fixed and permanent, it has been suggested that they could be managed automatically and systematically in the flight plan. It would therefore be left to the aircraft to respect the constraints automatically where programmed into the aircraft’s flight management system. In the experiment, constraints were declared and respected in the flight plan and the process was therefore automatic. The integration of the vertical constraints into the flight plan meant that the controller did not need to take any action with regard to aircraft flight plans; no aircraft could penetrate the airspace at the entry point of the highway.

The corollary of this choice is that aircraft spontaneously climb or descend in the vertical plane without receiving control instructions but in conformity with the flight plan. This means that the controller must memorize the spontaneous movements of aircraft to avoid being surprised when they happen. Similarly, he or she must integrate these movements in the event of a change of aircraft flight path for traffic management or conflict resolution purposes, since these flight plans are not conflict-free.
8. RESULTS

8.1. CRITERIA FOR ANALYZING THE DATA COLLECTED

8.1.1. Average Values

The results obtained from the four controllers thus enabled trends and approaches to be identified on the basis of the confirmation or rejection of the hypotheses used in the experiment. The data obtained cannot be processed statistically and at this stage of the investigations into the concept of Dual Airspace, to do so would be meaningless.

For the purpose of the results analysis, we will present only the average values for all controllers Figure 11.

<table>
<thead>
<tr>
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<th>Phase 4</th>
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</tr>
<tr>
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</tr>
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<td>1.50</td>
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<tr>
<td></td>
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<td>0.75</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>AIW</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>ATCO's orders</td>
<td>1.29</td>
<td>1.32</td>
</tr>
<tr>
<td></td>
<td>Delta time(s)</td>
<td>-2.75</td>
<td>-1.50</td>
</tr>
<tr>
<td></td>
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</tr>
<tr>
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</tr>
<tr>
<td></td>
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<tr>
<td></td>
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</tr>
<tr>
<td></td>
<td>Picture</td>
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<td>2.75</td>
</tr>
<tr>
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<td>STCA</td>
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<tr>
<td></td>
<td>AIW</td>
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<td></td>
<td>Delta dist. (1/10 NM)</td>
<td>-4.50</td>
<td>-5.75</td>
</tr>
</tbody>
</table>

Figure 11: Summary of the average values for the data gathered in the experiment
8.1.2. Subjective Assessments (Workload and Picture)

Subjective assessments of workload and situation awareness (picture) were made on a scale of 1 to 6. Some controllers tended to make low assessments and others high assessments. For each controller, however, the assessment varied according to the level of traffic density and the complexity of the situation to be controlled. The differences between the controllers’ assessments favoured an analysis based on average results.

The small number of controllers meant that significance tests could not be carried out on the results obtained. It was therefore considered that a difference existed between the analyzed results where the divergence exceeded 0.75 (15%). This figure may seem high but it takes into account the low number of controllers and the consequent variability of the results while also making it easier to judge whether there is a similarity or discrepancy between the data obtained for the "outliers". We are aware that using this method meant that the analysis criteria were fairly crude but they were nevertheless compatible with the experiment objectives, i.e. to identify strong trends in order to continue developing the concept.

8.1.3. Given Orders (ATCO’s orders)

The unit defined for instructions given is the average number of instructions given per aircraft. Since we had no reference by which to qualify controller activity using this value in relation to traffic density or complexity, we arbitrarily decided that a difference of 1 was significant. In the results analysis, it will be possible to see whether this choice was justified or whether it should be refined.

8.1.4. Safety Criteria (STCA and AIW)

The selected safety criteria were the triggering of alarms. As their name indicates, the alarms leave the controllers time to act reactively in order not to infringe the minimum separations between aircraft or the minimum distances from the highway. This means that the alarm is not exceptional, even if it represents a lack of anticipation on the controller's part. Moreover, we acknowledge that there is a "simulation" effect on the number of alarms observed in the sense that the alarms are triggered more regularly owing to reduced involvement of the controllers in traffic management because a simulation can never reproduce the real context [3].

This is why a minimal value of 0.50 was retained as a safety significance criterion for all controllers, which corresponds to a difference of two alarms for all four controllers.

8.1.5. Traffic Management Efficiency Criteria (Delta Time and Distance)

As with the instructions given, it was proposed to objectify traffic efficiency using units defined for this experiment, namely the average difference in sector-crossing time and distance for each aircraft between what was scheduled in planning and the actual time/distance flown during the scenario. Since we had no experience on how to use or value this data, we purposely refrained from defining significance criteria. The results analysis will make it possible to identify more precisely the relevance of such criteria for operationalization choices made.
8.2. AIRSPACE AND AIR TRAFFIC DENSITY

8.2.1. Medium Traffic Density

With medium air traffic density Figure 12, there is no difference between the three scenarios for the activity carried out by the controllers (workload, number of given orders), the safety level achieved and the traffic management performance.

This means that the highway has no impact on traffic management in the sector, whichever highway configuration is envisaged (H1 or H2).

<table>
<thead>
<tr>
<th></th>
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<th>Highway1</th>
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</tr>
<tr>
<td>ATCO instructions</td>
<td>1.32</td>
<td>1.76</td>
<td>1.28</td>
</tr>
<tr>
<td>Picture</td>
<td>1.50</td>
<td>1.75</td>
<td>1.50</td>
</tr>
<tr>
<td>STCA</td>
<td>0.00</td>
<td>0.25</td>
<td>0.00</td>
</tr>
<tr>
<td>AIW</td>
<td>---</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Delta time(s)</td>
<td>-1.50</td>
<td>0.75</td>
<td>-3.00</td>
</tr>
<tr>
<td>Delta dist. (1/10 NM)</td>
<td>-2.00</td>
<td>0.00</td>
<td>-4.50</td>
</tr>
</tbody>
</table>

Figure 12: Comparison of medium-density airspace

8.2.2. High Traffic Density

For high traffic density Figure 13, there was a change in the variables in all scenarios, reflecting controller activity in relation to medium traffic density. This change took the form of an increase in perceived workload and reduced situational awareness of the traffic. The latter did not, however, affect safety. The change in situational awareness seems more significant than that in workload. However, there was no change in the average number of orders given to aircraft by the controllers.

As regards safety, more STCA alarms were triggered in the three scenarios. This increase is completely consistent with the perceived increase in workload and perceived decrease in situational awareness. The consistency between these three variables shows that the traffic density played out in the scenarios put the controllers in a situation where they had to apply safety strategies. Above all, the controllers no longer had adequate cognitive resources to apply "elegant" solutions [4]. However, these results also show that they never reached the point of breakdown, entailing loss of control of the situation and thus loss of safety.

It should also be noted that the changes observed were similar for the three scenarios, from which we can conclude that there is no difference between the reference scenario and either of the highway scenarios.

As regards safety, the only alarms observed were those concerning aircraft separation, regardless of the scenario and the traffic density. No alarm was triggered signalling loss of separation with the highway. This result is promising within the framework of the concept. However, it must be seen in the context of the experimental conditions, because the decision was made to automatically schedule aircraft to avoid the highway. Any alarms triggered would therefore have resulted from flight plan changes aimed at conflict avoidance. In the event, no alarms sounded. However, this shows that the controllers were able to manage conflict avoidance between aircraft in the context of the constraints imposed by the highway.
8.2.3. Traffic Management Strategy

The “average number of given orders” variable leads us to conclude that no difference can be observed between the scenarios, even with different traffic densities. In fact, observing traffic management strategies shows us that the controllers were using different strategies from one another and also from one scenario to another. The terms “strategy” and “traffic management” are used to mean interventionism or a certain degree of anticipation in the instructions given. We can thus observe highly anticipatory and interventionist strategies where the controller structures the traffic very early on as he/she sees fit on the basis of future constraints or wait-and-see strategies where the controller prefers to wait until the last moment before giving instructions only when they are essential. This variability in behaviour shows that the “average number of instructions given” variable depends more on controller behaviour than on traffic density or airspace structure factors (with or without a highway). One way of allowing this variable to be analyzed would be to ask the controllers to standardize their management strategies. However, this would still need to make operational sense in relation to a real-life situation. There are certainly tendencies among controllers which should be thoroughly reviewed and they should be asked to do in the simulation what they do in the control room.

This variability in traffic management strategies affects the analysis of the traffic efficiency criteria which we defined. In fact, the aircraft sector-crossing times and distances are also linked to the traffic management strategies used by the controllers. Thus, as shown by the negative times in the reference scenario, the controllers instinctively use direct routes which reduce the average crossing time and therefore the distances travelled. The tendency to use direct routes further intensifies in periods of high traffic density, as shown in the results. Moreover, in high traffic density the crossing times and distances are lower in the two highway scenarios than in the reference scenario.

In order to explain these results we can suggest that in medium traffic density the controllers have the cognitive resources allowing them to apply strategies without seeking a genuine saving or to optimize these resources. In high traffic density, the need for savings is more urgent because we are approaching the controllers’ maximum capacity. In this case we observe the implementation of strategies favouring whatever is most efficient in terms of safe traffic management.

In the medium-density scenarios the controllers can adopt whichever strategies they wish, which might explain the increase in the crossing times and distances observed in the H1 scenario. In the high-density scenarios the controllers strive to perform their activities as efficiently as possible. They use the simplest solutions and direct routes are part of this. This is why we observe more significant reductions in time and distance for the highway scenarios.
Although these results are consistent with a cognitive logic of traffic management, they nevertheless differ from what we were expecting. Indeed, they show that the denser or more complex the traffic - i.e. where the constraints on controllers are tighter - the shorter the crossing times and distances. We might have expected traffic complexity to necessitate less fluid management strategies penalizing the traffic, but this is not the case judging from our observations in the experiment.

8.2.4. Dual Airspace and Capacity

The results obtained from the medium and high-density scenarios were particularly interesting for the increase-in-capacity hypothesis. In fact, even if we note a difference in the controllers' activity and traffic safety between the medium and high-density scenarios, these differences do not demonstrate an effect linked to the sector structure. This means that the highway, regardless of the configuration under assessment, does not reduce sector capacity in comparison with a sector without a highway. It is thus possible to maintain the same traffic capacity in a sector with a highway as in a sector without a highway. Knowing that while maintaining the same capacity, we increase the capacity of the flows crossing the flow which is integrated into the highway, we can potentially increase the capacity in a geographical airspace structured with Dual Airspace.

8.3. Configuration of the Highway and Turbulence

The highway must be resistant to disruptive factors including those linked to turbulence, which forces aircraft to change their flight level. For each type of highway a way of vertically expanding the highway was assessed. For H1, expansion meant the creation of an airlock for descending and climbing between two highway flight levels. For H2, expansion meant bringing the two adjacent highway flight levels down two levels.

8.3.1. H1 Configuration and Climb or Descent Airlocks

In the light of the data collected on medium-density traffic we can see that there is no difference for the H1 highway between a situation with and one without activation of the airlock Figure 14. Whether in terms of controller activity, the safety level achieved or the traffic management performance, similar values are noted for the two experimental conditions.

<table>
<thead>
<tr>
<th></th>
<th>Normal</th>
<th>Turbulence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workload</td>
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<td>2.50</td>
</tr>
<tr>
<td>ATCO instructions</td>
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</tr>
<tr>
<td>Picture</td>
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<tr>
<td>AIW</td>
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</tr>
<tr>
<td>Delta time(s)</td>
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</tr>
<tr>
<td>Delta dist. (1/10 NM)</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Figure 14: Highway H1 turbulence-adjustment mechanism
8.3.2. H2 Configuration and Bringing Down the Two Flight Levels

Unlike for H1, with H2 we can see a significant change in the values for the controller activity and the safety level achieved upon activation of the two flight levels Figure 15. Where there is medium traffic density, equivalent or even slightly higher values are observed than those for the controller activity in high-density traffic. As regards safety, a significant increase can be seen in the number of STCA alarms triggered, exceeding the number without activation albeit in a high-density traffic situation, and above all we note that AIW alarms were triggered, which was not the case in any of the other scenario phases.

![Figure 15: Highway H2 turbulence-adjustment mechanism](image)

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Workload</td>
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</tr>
<tr>
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<tr>
<td>Delta dist. (1/10 NM)</td>
<td>-4.50</td>
<td>-3.75</td>
</tr>
</tbody>
</table>

8.3.3. Summary of the Two Adjustment Mechanisms

Clearly, bringing down two flight levels and thus blocking four adjacent flight levels creates a wall which disrupts controller activity. In the H1 hypothesis only three adjacent flight levels are blocked, which seems much more acceptable to controllers.

This may seem like stating the obvious, since blocking four levels is clearly a more penalizing measure than blocking three. Beyond this simple observation, however, it is especially interesting to see that a limit seems to exist in terms of blocked flight levels after which the control task is objectively penalized. Moreover, this limit seems to be genuine because we pass from a situation where the results are similar for one, two and three flight levels to an objective deterioration for four flight levels.

Beyond the fact that the H2 solution seems problematic in the event of adjustments for turbulence, which is not the case for the H1 solution, the comparison between the two experimental situations makes it possible to set a maximum number of adjacent flight levels operationally acceptable to controllers. This figure of three is important to take into account when determining the height of the highways but also the highway adjustment mechanisms in order to deal with disruptive factors.

The average number of instructions given to each aircraft is slightly higher in the adjustment situation than under normal conditions. This is entirely logical and represents the additional instructions given by controllers in order to avoid the new flight levels which had not been declared in the flight plans.

Regarding traffic management efficiency, it is difficult irrespective of the highway configuration to identify any particular trend between the situations.
8.4. HIGHWAY AND WORKING METHODS

On the basis of the interviews conducted with all the controllers following the simulation and an assessment of the data, the consensus is that the presence of a highway in a sector does not change current control methods. The controllers acknowledged that they managed the aircraft in the same way as they currently manage them in the control room, and this posed no particular problem with regard to the constraints imposed by the highway. They made the same observation during the H1 and H2 scenario phases when the highway adjustment mechanisms for turbulence were activated.

However, the automatic management of aircraft vertical constraints linked to the penetration of the highway was strongly criticized by the controllers. Rather than help them, automatic management of vertical constraints increased their workload, since it was difficult to know what each aircraft would do and, above all, when and how it would do it. They unanimously preferred to have steady traffic, and to control its movements on the basis of their own constraints. Before any instruction has been given, it is clear what the aircraft is doing. It is easier to know that the aircraft are in level flight and to manage their movements than to have to always be wondering what they are going to do and when, or be waiting until they perform manoeuvres.

The controllers are not, however, against traffic planning which takes highway-crossing into account. This means that vertical instructions may be introduced into the flight plan. These instructions would serve as a framework for the controller but it would always be the controller who gives the instructions. By giving these instructions, he/she is sure of the aircrafts' movements and, in particular, of controlling future flight paths thus facilitating their memorization.

When asked whether they could nevertheless envisage a system where controllers did not have to give all the instructions since such instructions increase the interactions with the aircraft, they all underlined that in this case there would have to be improved visibility of the flight plans and of the spontaneous movements of aircraft. Nonetheless, for that to happen they realize that much more formalized rules governing aircraft movements would have to be drawn up (the existence of a fixed point before the highway to change the flight level for example). Paradoxically, however, establishing rules penalizes the system because we are more often forced to adapt to the values of the least efficient variables. Such a system exists for SIDs and STARs, but it seems difficult to extrapolate this for en-route flight without reducing capacity. Moreover, the use of pre-established flight profiles or patterns would mean the controller having to carry out considerable surveillance activities. The role of the controller hinges on these alternatives; in the first case he/she is active and manages the traffic, in the second the task is primarily centred on surveillance.

The controllers quickly integrated the flight-level constraints on leaving the sector into the management of the vertical constraints linked to the highway. They thus adopted strategies early on to avoid flight levels occupied by the highway, taking into account exit flight level. A corollary of this attitude is the desire they expressed for aircraft flight plans to be as consistent as possible in terms of the highway vertical constraints and constraints on leaving the sector so as both to facilitate highway-crossing and to simplify coordination with the adjacent sectors.

8.5. CONTROL SUPPORT TOOLS AND HUMAN-MACHINE INTERFACE

Four control support tools were developed specifically to support traffic management in a sector crossed by a highway.
8.5.1. Vertical Representation of the Traffic

This display, located to the bottom left of the radar screen, was considered useless by the controllers. The first criticism made against it was that it was too small to allow a clear picture of the traffic, even if the scroll bars to zoom in on and centre the image were very intuitive and useful. Moreover, a horizontal rather than a vertical display would better warrant a tool for analogue visual identification of flight levels in relation to one another. Horizontal lines marking the reference flight levels would seem to be essential. Although the logic adopted for the projection in the vertical plane was considered the only viable one (projection axis perpendicular to the highway axis), the controllers did not use this tool because they were perfectly able to construct a vertical representation of the traffic without additional support. Vertical representation or, more to the point, spatial representation of the traffic requires know-how which is developed and acquired through training and experience. It is constructed using 2D analogue radar data and the alphanumerical information presented on the radar and/or paper strips. Since they already have this know-how, a 2D vertical representation does not help the controllers in any way. They have this aptitude: it is one of their skills and to be frank they do not understand how anyone could doubt their ability to construct a correct spatial representation of the traffic.

8.5.2. Aircraft-Centred Vertical Representation

This display, located to the bottom right of the radar screen, was hardly used. Initially thought to be on a par with the vertical representation of the traffic, i.e. useless, the controllers revised their opinion because it allowed an aircraft's chosen vertical flight path to be displayed and therefore made it possible to anticipate the aircraft's future position in relation to the highway. This function was seen as useful for organizing the traffic entering the sector, in particular the aircrafts' vertical constraints were entirely managed by controllers, as they would like. Used in this way, the display has two functionalities:

- assessing the correct crossing of the highway on the basis of the flight plan;
- helping the controller give instructions for movements in the vertical plane, on the basis of aircraft's performance as shown in the display.

These functionalities were not implemented by the controllers as part of the experiment and should be the subject of further study in this specific area.

8.5.3. Highway-level Filter

The level-filter linked to the levels occupied by the highway was unanimously seen to be particularly useful for anticipating flight-level problems arising from crossing the highway. Used for entry to the sector, it helps the controller construct a spatial representation of the traffic. In fact, it acts more to back up the controller's own spatial representation than really to help construct one. The level filter allows the controller to check that he/she has properly understood the traffic, not in fact all the traffic but only the potential traffic problems caused by highway-crossing. The complexity of the level-filter tool depends on the extent to which the flight plan data is integrated. Either it functions according to the aircraft's flight level when the filter is activated, which is already satisfactory for the controllers, or it integrates the flight plan and functions according to the aircraft's anticipated flight level when it crosses the highway.
8.5.4. Area Infringement Warning (AIW)

This tool is very similar to the STCA. Like the STCA it acts as a "safety net" and as such is totally endorsed by the controllers.

8.5.5. Human-machine Interface

The main comment concerned the visual display of the highway in the radar image. Even if what was presented was entirely acceptable, the controllers would have liked the highway to be represented in a more "alarming" way and requested, in particular, a reminder on the radar image of the flight levels occupied by the highway.

8.6. AIRSPACE

The Human in the Loop experiment made it possible to confront controllers with the sector's design rules and those of the highway which crosses it.

8.6.1. Sector

The size of the sector as proposed in the experiment (80 NM x 60 NM – FL 290 to FL 430) was deemed satisfactory by the controllers, although two of them would have preferred a larger sector to allow better anticipation of traffic management and to reduce coordination with adjacent sectors.

It was acknowledged that the choice of the size and configuration of the sector was the result of a compromise which took into account:

- the width of the highway;
- the density and nature of the traffic crossing the sector;
- the position of the convergence points in the sector in relation to the highway, in order to manage highway-crossing;
- the position of the route's convergence points in relation to the sector entry point, to anticipate as far as possible the management of potential conflicts.

The main comment from controllers concerned the lack of equal status for routes in the sector. Equal status would have made their work easier regarding the proposed convergence points.

The most contentious issue was of course the positioning of the highway in the sector. The ideal airspace according to the controllers would include:

- a central highway;
- points of convergence at a minimum distance of 20 to 25 NM from the highway in order to anticipate highway-crossing. This implies that there should be no route parallel to the highway at less than 20 NM distance;
- no route crossing across the width of the highway;
- no converging routes at less than 20 NM from the sector entry point;
- routes with equal status.
The problem with this ideal airspace is its size, which, in high-density traffic areas, is no longer compatible with controller resources in terms of capacity. It emerged from the interviews that it was difficult to define a strict framework for designing sector airspace. Each sector will be a special case and will need to be optimized on the basis of local constraints. The solutions assessed in the experiment are relevant and must be adapted to the local context.

Alongside this sector-by-sector approach and specific sector design, it was unanimously acknowledged that the highway must in no way be shared by adjacent sectors owing to the risk of confusion on handover and controller responsibility for aircraft.

Another intermediate solution would be to situate the highway at the edge of the sector. This would make it possible to liberate as much airspace as possible in the sector to anticipate the crossing of the highway by traffic flows coming from the opposite side of the sector to that on which the highway is positioned. On the contrary, for flows arriving from the sector next to the highway, any anticipation and management of traffic crossing the highway would therefore have to be done by the entering sector. The controllers think that this solution may be feasible since very precise rules exist for the sharing of tasks and responsibilities between the various operators.

To summarize the issue of sector airspace, we can say that the SHIFT experiment made it possible to better identify operational needs and thus define design rules. However, it is clear that beyond the local level of acceptability assessed here, airspace can only be envisaged and defined at global level. Although airspace has to accommodate the application of the Dual Airspace concept, it must above all respond to air traffic demand with all the related constraints on punctuality and cost-effectiveness. On this continental scale, new constraints would certainly appear that are impossible to perceive at this stage.

Building on the results of the experiment, subsequent steps for developing design rules for Dual Airspace at sector level should now be the subject of specific studies on airspace at continental level and be based on designing airspace models.

### 8.6.2. Highway

The highway should occupy as little space as possible in the sector. This comment is a "creed" stated by the four controllers. Alongside this comment, however, a reality principle should be taken into account, namely the service that the highway must provide in terms of traffic demand. This of course has consequences for the horizontal and vertical size of the highway as well as for its geographical position.

In the horizontal plane, the design rules used for the concept (width of 22 NM) have been accepted and leave almost no room for manoeuvre to reduce the width of the highway. Moreover, all the controllers found this width to be entirely acceptable, and not detrimental to efficient traffic management in the sector. Admittedly, finding an acceptable width for the highway also depends on the sector's size, as detailed in the previous chapter. This also shows that an operational model is relevant and Dual Airspace can only be designed at a more global level. It is at this level that assessments must be made, with all the peculiarities that will arise. From this perspective, the experiment that was carried out was an initial step, indispensable but not sufficient for the process of designing Dual Airspace.

In the vertical plane it is also necessary to determine the number of flight levels occupied by the highway in terms of traffic demand. The decisions made in the experiment in both the vertical and horizontal planes are deliberately focused on capacity. On the basis of more refined studies of potential traffic demand scenarios, it would be entirely possible to adapt the number of flight levels.
In the context of the experiment, the distribution of flight levels in the two highway configurations was considered acceptable. Nevertheless, in the analysis of the two hypotheses H1 and H2, opinion was divided. For some, it would be preferable for traffic to have flight levels which alternate with the free flight levels, as is the case in H1. This imposes fewer constraints on the management of traffic crossing through by not creating a wall and by limiting the scope of the instructions which may be given. Others felt that a single free flight level between the flight levels occupied by the highway (H1) was insufficient because it was too restrictive and not very practical at operational level. This flight level is trapped between the other two and is difficult to work with.

In the light of these results, blocking three adjacent flight levels is acceptable, but this is not the case with four flight levels. This means that any adjustment to the dual system to deal with turbulence must not exceed three adjacent flight levels. If this cannot be done as part of a limited adjustment to these three flight levels, additional adjustment solutions must be envisaged, probably on a more global scale, such as action taken on traffic organization and density.

### 8.6.3. Independent Sector and Highway

In the definition of the *Dual Airspace* concept, sector and highway are completely hermetic which means that the controllers of each system do not see the traffic in the other system. This was the hypothesis assessed in the experiment.

The controllers consented to this way of working but drew attention to degraded or critical situations (emergency descent for example). These cases were represented in the operational concept of *Dual Airspace* in the following way: as soon as an aircraft declares itself to be in a degraded situation (switch to Emergency), it displays a transponder code which makes it visible in airspace other than that in which it finds itself but with which it may have to interact. From this moment on, the controllers of each volume of airspace concerned can make use of means of communication (datalinks, radio communication, etc.) suitable for optimizing the management of this aircraft depending on its intentions. Faced with this kind of situation we move away from a nominal operating framework to function in emergency mode. This operating mode was defined in order to take into account firstly the controller's workload in a nominal situation and secondly the controller's area of responsibility. It should be remembered that under the current legal framework, each controller has a responsibility vis-à-vis the information he/she can access [5]During the role-plays in the experiment scenarios, even where this was not one of the experiment's objectives, it emerged that some controllers would like to be able to visualize traffic in airspace which they are not controlling. To this end, they suggest display on request rather than permanent display of information. They would prefer this solution to the hypothesis proposed in the concept, because they feel that an overview of traffic in other airspace is important in order to best manage the emergency situation. This alternative will require on the one hand an examination from a legal point of view of whether a controller can be deemed not responsible when displaying information from another airspace, and on the other hand a clear definition of what we mean by an emergency situation and who establishes criteria defining such a situation. These hypotheses must be assessed in future developments of the *Dual Airspace* concept.
9. CONCLUSION

The general feeling on the concept is positive. Both the opinions of the controllers and the analysis of the data obtained indicate that the Dual Airspace concept presents a potential axis for increasing traffic capacity in geographical areas with high traffic density. For controllers, therefore, the concept is perfectly "workable" and deserves to be developed in this type of experiment. To support this general feeling, we can summarize the results of the experiment via an analysis of the experimental hypotheses:

- The presence of a properly designed highway within a sector, in whatever configuration (H1 or H2), does not affect capacity, safety or efficiency in comparison with the same sector without a highway.

- The presence of the highway does not affect the controllers' workload or their understanding of the traffic.

- A sector's capacity is maintained when the sector is crossed by a highway. Therefore, if we add the sector capacity to that which can be managed in the highway, it is possible to increase the capacity of a single geographical area by using the Dual Airspace concept. This is possible because the principle of traffic sharing between controllers is no longer geographical but based on a functional separation of traffic.

- When the highway is modified to deal with disruptive factors such as turbulence, the vertical wall created should not exceed three adjacent flight levels. The adjustment solution assessed via the H2 highway configuration, occupying four adjacent flight levels, proved too problematic in terms of safety and workload and was therefore unacceptable.

- The hypotheses for the design of the highway and sector are a coherent foundation for continuing work on the Dual Airspace concept.

- The working methods for traffic control and management are not fundamentally different from those currently in use. The controllers unanimously rejected the principle of automatic management by aircraft of the vertical constraints linked to the highway. They would prefer complete control of the vertical constraints in order to ensure optimum management of traffic anticipation and organization.

- Concerning the support tools offered to controllers and integrated into the control position, only the AIW and the highway-level filter were considered of operational interest. The vertical representation of traffic is irrelevant and the aircraft-centered vertical representation could be useful in the framework of complete management by controllers of the vertical constraints.

To sum up, we can therefore conclude that the answers provided to the questions posed on Dual Airspace as assessed in the "proof of concept" experiment enable us to state that the concept is operationally acceptable to controllers and that it allows the capacity of a geographical area with high traffic density to be safely increased.
10. FURTHER STUDY

Even if these initial results confirm the relevance of the Dual Airspace concept and the steps taken to define it, they are only a first stage in the validation process. They demonstrate that the concept deserves further examination. Equally, the issues tackled in this experiment do not cover all aspects of the concept. It would therefore be useful, following this experiment, to:

- develop concepts for aircraft entry and exit between the sector and the highway;
- define the functioning of an highway;
- refine the definition of the rules governing airspace design, working methods and support tools;
- define at continental level, for both the highway and the sectors, an airspace structure which integrates local constraints;
- lastly, assess the Dual Airspace concept using a real-time, full-scale simulation platform in order to integrate operational consistency between sectors, between sector and highway and with aircraft.

Throughout this definition and validation process, it is important to stress the leading role to be played by the operational controllers. They must be included as full partners in the various stages of the process.
REFERENCES


