**TITLE:**  
AIR TRAFFIC FREEWAY SYSTEM FOR EUROPE

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<th>Authors</th>
<th>Date</th>
<th>Pages</th>
<th>Figures</th>
<th>Tables</th>
<th>Annexes</th>
<th>References</th>
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**Abstract:**

Europe is a very special airspace with extreme dense traffic concentrated in the western part, the core area. This core area includes seven airports out of the 30 busiest world airports. Its airspace is highly congested and creates major traffic delays. Controllers’ workloads have reached generally accepted limits. Estimated traffic increase for the next decade cannot be absorbed from the current ATM system. New concepts are required.

The paper proposes a dual airspace concept to split the air traffic in dense traffic areas accordingly to ATC issues (short haul – airport traffic, long haul – cruise traffic). The resulting airspace consists of a district airspace (similar current airspace) and new Freeway airspace.

Freeways are independent, isolated airspace at high altitude with special rules. They shall absorb major parts of Core-Europe’s intercontinental traffic and parts of European’s long haul domestic traffic. A Freeway interconnects multiple areas. The proposed Freeways follow, the main European traffic flows and ends at the current intercontinental connection areas. The Freeways shall accumulate long haul traffic with the same direction, but the destination may be different. Freeways will free district airspace from parts of the long-haul traffic and create therewith-new capacity for the future. Freeways are operated with advanced techniques and concepts by an unique non-national organisation, the ‘Freeway Control’ (FC). The capacity of the Freeways is adaptable and they reduce pilot’s workload caused by the multiple sector changes, too.

Freeways represent an early step towards a ‘Single European Sky’.
# TABLE OF CONTENTS

REFERENCES .......................................................................................................................... VIII

1. INTRODUCTION ................................................................................................................ 1  
   1.1. EUROPEAN SITUATION ......................................................................................... 1  
   1.2. EUROPEAN AIR TRAFFIC ..................................................................................... 3  

2. STATE OF THE ART .......................................................................................................... 5  
   2.1. SINGLE EUROPEAN SKY INITIATIVE .................................................................... 5  
   2.2. FREE-FLIGHT CONCEPT ....................................................................................... 5  
   2.3. TUBE CONCEPT ..................................................................................................... 5  
   2.4. PARADIGM-SHIFT CONCEPT .................................................................................. 6  

3. FREEWAY SOLUTION ......................................................................................................... 7  
   3.1. FREEWAYS GEOGRAPHICAL LAYOUT ..................................................................... 7  
      3.1.1. Freeway Route ................................................................................................. 8  
      3.1.2. Freeway Flight Levels ...................................................................................... 9  
      3.1.3. Freeway Intersections ..................................................................................... 10  
   3.2. FREEWAY MANAGEMENT ....................................................................................... 11  

4. DISCUSSION OF THE FREEWAY CONCEPT ................................................................... 13  

5. CONCLUSION .................................................................................................................... 15  

## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1</td>
<td>European Situation on Air Transportation</td>
</tr>
<tr>
<td>Figure 2</td>
<td>European Air Traffic by Destination</td>
</tr>
<tr>
<td>Figure 3</td>
<td>European Air Traffic Distribution by Flight-Level/Distance</td>
</tr>
<tr>
<td>Figure 4</td>
<td>European Freeways</td>
</tr>
<tr>
<td>Figure 5</td>
<td>Freeway - One-Way Route</td>
</tr>
<tr>
<td>Figure 6</td>
<td>Freeways 'Blue'</td>
</tr>
<tr>
<td>Figure 7</td>
<td>Freeways 'Blue' - potential Flight Levels – e.g.: FL (n+2) activated</td>
</tr>
<tr>
<td>Figure 8</td>
<td>Freeways Intersection</td>
</tr>
</tbody>
</table>
REFERENCES


1. INTRODUCTION

The European airspace is highly congested and generates major delays. Controllers’ workloads have reached generally accepted limits; therefore many so called ‘hot sectors’ are object of traffic restrictions/regulations during many hours a day.

Predicted traffic increase requires new innovative methods to overcome these bottlenecks.

This paper presents first the current air traffic situation and its special characteristic of traffic followed by the state of the art with a discussion on proposed solutions and develops then a new proposal for the problem.

1.1. EUROPEAN SITUATION

Europe is a conglomeration of historical independent states with different languages and cultures. High effort is spend to become an European Union.

Economically, considerable progress was made. Today, the landside borderlines mainly no more exist, but in the air control sector boundaries follow beside other opportunities mainly national frontiers. Approximately 65, mainly national, Air Traffic Control (ATC) centres handle the European upper airspace. In the USA with a similar surface, only 19 ATC centres exist [1].

Furthermore, in Europe local national mentalities see air carriers still as national prestige and so resulting hubs are not economically distributed or optimised over Europe.

The historical development of the European continent is inhomogeneous. Natural barriers (mountain chains, rivers, …) culture, climate, economical constraints are so various and result in the current situation. Western Europe represents economically the core area of Europe. This core area can be seen as a circle (Figure 1) delimited by a radius of about 450nm representing about one hour of cruising distance for an aircraft. Inside this core area, seven out of the first 30 busiest passenger airports of the world [2] are located (2x London, Frankfurt, Paris, Amsterdam, Madrid, Rome). In core Europe, the density of the population reaches nearly 150 citizen/km² (Europe total 66 citizen/km², USA 29 citizen/km²; about same surface).

In 2005, the Europe of the 38 member states of the European Civil Aviation Conference (ECAC) will reach nearly the number of 30 000 air movements per 24 hours (e.g. 14/5/05 28 823). A major part of these movements take place in the core area.
A small zone (Figure 1) – red filled area, ~200nm) inside this core area is much more crowded. EUROCONTROL’s Upper Area Control Centre at Maastricht controls a part of this zone and handles over 4000 aircraft movements per day. In this zone, one finds the four major European airports London LHR, Frankfurt, Paris, Amsterdam, which are under the nine busiest world airports. These airports are so close, that high-speed trains (existing or planned) can connect these places in about 2 hours. Today connection flights between these airports still exist, whereas high-speed trains connect city centres (Paris- London ~2 h), only. In future, planned high-speed trains could interconnect specific airports and so reduce air congestion in this area. In example, already today for an Air France connection flights between Paris and Brussels a high-speed train (Thalys) ticket is handed out.

Intercontinental air traffic to and out of Europe is due to geographical and economical constraints focused on four major flows indicated in Figure 1 by four large arrows:

- North-west: northern America
- South-west: southern America, West-Africa
- South-east: southern Asia, Oceania, East-Africa, Australia
- North-east: northern Asia

These intercontinental flows associated with the local ECAC domestic flows create important crossing flows in the airspace of the 4 busiest European airports (Figure 1), too.
1.2. EUROPEAN AIR TRAFFIC

Data of the EUROCONTROL Central Flow Management Unit (CFMU) indicate about 25000 movements per day for 2004. Out of this year, six traffic samples have been selected in an arbitrate manner for a simplified statistical analysis. The presented information is part of an internal study of the EUROCONTROL Experimental Centre from K. Belahcene [3] for the ‘Paradigm Shift’ [4] project. Each movement represents one flight of an aircraft with departure, cruise and arrival. For this paper especially, the classification of the traffic by departure and arrival airport seems to be from interest.

![ECAC Air-Traffic](image)

**Figure 2: European Air Traffic by Destination**

Figure 2 presents the results for the Europe of the ECAC states. Following classifications are used:

- Departure and arrival airport in Europe (domestic traffic)
- Departure and arrival airport outside Europe (transit traffic)
- Departure in Europe, arrival outside Europe (departure traffic)
- Departure outside Europe, arrival in Europe (arrival traffic)

The 25 000 traffic movements in Europe represent about 40 000 flight hours with nearly 700 million passengers [5]. Flight hours are directly proportional to the flight distance. Figure 3 shows a correlation between flight distance and the requested cruising flight level. For better understanding, the measures of dispersion in form of a box-plot graphic are used. The lower graph of Figure 3 indicates the sample size distribution of the box-plot graph above.
Figure 3 shows a dependency between the requested flight levels (RFL) and the flown distance for flights up to a distance of 600nm. This can be explained by a more or less parabolic flight profile of short haul flights. Companies prefer for economical reasons high flight levels (> FL300). To reach these economical flight levels, an aircraft needs approximately half an hour. During this time it flies about 150nm. The descending phase is similar in time and distance. For medium and long haul traffic, a correlation exists no more between flight level and distance travelled.

In conclusion it can be said, the current route-system is used from a highly inhomogeneous traffic. Aeroplanes with quite different performances (propeller, turboprop, jets), short and long haul traffic in different flight phases use this common route structure and create therewith capacity reducing complexity. Separating the traffic by classes of performance in specific airspace could be one method to reduce the complexity for the human operator and create therewith new capacity.
2. STATE OF THE ART

The European Commission estimates for Europe an air traffic grow of 4% a year during the next 15 years, leading to a nearby doubling of traffic by 2020 [6]. The European network is able to absorb the current traffic. But the estimated traffic increase for the next decade cannot be absorbed with the current system. New concepts are required. Several concepts have been presented in the past; some of them are described thereafter.

2.1. SINGLE EUROPEAN SKY INITIATIVE

Europe eliminated most of the ground frontiers with the 1985 single European market. It dismantled economic frontiers with the 1990 economic and monetary union. It is a view widely held that borders in the sky should not exist. So, in 1999 the European Commission lunched the ‘Single European Sky’ [6], [7] initiative. The Single European Sky initiative represents a legislative approach to solving issues that currently affect air transport as well as enabling ATM to cope with future demands and was drafted with the following objectives:

- to restructure European airspace as a function of air traffic flows, rather than according to national borders;
- to create additional capacity; and
- to increase the overall efficiency of the air traffic management system.

At the end of last year, the European Commission and EUROCONTROL signed a cooperation paper to enhance their synergy. Recently EUROCONTROL launched the program SESAME (Single European Sky Air-traffic Management).

The proposal of this paper supports this strategy.

2.2. FREE-FLIGHT CONCEPT

Our current ATC system is base on a route network. The network becomes more and more crowded and highly constraints the traffic. Beside the crowded routes the remaining huge airspace is unused. So the idea was born to suppress the route network and airplanes fly freely the direct way from the departure to the destination airport to overcome capacity constraints.

In theory, global airspace is big enough to absorb the air traffic without constraint. But, as the distribution of the global population isn’t uniform, the resulting air traffic density will be concentrated over some regions. EUROCONTROL experiments showed the advantage of a route-system for dense traffic areas while regions with less traffic might use a free-route system [8], [9].

The main advantage of a route system is to reduce the traffic complexity for the human operator. Core Europe can be seen as dense traffic area where a route system is mandatory.

2.3. TUBE CONCEPT

In 2004 Arash Youseefi et al. [10] proposed ‘High-Volume Tube-shaped Sectors (HTS)’ for the USA airspace with its long distances between the interoperating carrier hubs. The basic idea of such a tube concept is to interconnect city-pairs. The air traffic in a tube is isolated from the surrounding traffic and may be controlled separately. Estimations predict for the tube concept a workload reduction for controllers and pilots, and a capacity increase for the overall system.

The airspace structure of core Europe is different. Distances between hubs are very little and they work mainly independently from each other. J.P. Florent presented in TALC [11] a tube concept adapte to the european airspace. The highest frequency for an European city-pair in is about 70 connections per day (Madrid – Barcelona; high-speed train under construction). Reserving tube shaped airspace between city-pairs would absorb about 1-2% of the European traffic (<30000 movements /day), only. Benefits from a tube concept for Europe seem limited, especially as between most of the potential city-pairs high-speed train connections are under construction.
2.4. PARADIGM-SHIFT CONCEPT

The predicted traffic increase for Europe requires new operational concepts for this area. A group of multidisciplinary researchers from ‘Innovative R&D’ of the EUROCONTROL Experimental Centre are developing such a new concept called ‘Paradigm Shift’. The ‘Paradigm Shift’ concept [4] proposes for Europe strong collaboration for a contract of objectives and the creation of a dual airspace.

The contract of objectives is based on the existing operational plan with its target windows for a flight and has a decentralized design. The concept links the air- and ground-phase of a flight together and defines the applicable objectives for all actors. The objectives are permanently negotiated and updated through commonly agreed interfaces. This creates flexibility and allows coping with uncertainties.

The dual airspace concept splits the air traffic in dense traffic areas accordingly to ATC issues (short haul – airport traffic, long haul – cruise traffic). The dual airspace consists of a district and new motorway airspace. District airspace represents the current airspace with its concepts and a new totally separated, but restricted airspace the motorways.
3. **FREEWAY SOLUTION**

The author of this paper is a part-time member of the ‘Shift’ team and presents therewith a specific part vision of Shift’s dual airspace concept. This technical oriented vision of this new, separated airspace is called Freeways in this paper. The proposed Freeway concept is based on practical observations of natural realities to give Freeways user as match freedom as possible.

Freeways are based on the following assumptions: Controller Pilot Data Link Communication (CPDLC), Airborne Separation Assurance System (ASAS), aircraft satellite navigation, 4D Flight Management System (FMS) are operational and the operational concepts of the carriers prioritise safety and the predictability in time (in contrast to the economical aspect of fuel saving).

Freeways represent independent, isolated airspace with special rules. Freeways shall absorb major parts of Europe’s intercontinental traffic and parts of European long haul domestic traffic. A Freeway will interconnect multiple areas. These areas are part of the district control with several airports.

The concept is based on the idea to collect and guide parts of the traffic with common performance and similar direction (e.g. intercontinental) on a Freeway through congested district airspace. The Freeway is isolated from the district airspace - only at defined intersection areas, Freeway and district airspace are interconnected.

3.1. **FREEWAYS GEOGRAPHICAL LAYOUT**

There are two Freeways proposed for Europe, which follow the main traffic flows in the region. The endings of the Freeways are identical with the currently used intercontinental connection areas:

- **Freeway Red:**
  - North-west (Ireland): to/from North-America
  - South-east (Turkey): to/from Australia, South-Asia, East-Africa
- **Freeway Blue:**
  - North-east (Baltic Sea): to/from northern Asia
  - South-west (Spain): to/from West-Africa, South-America

Commercial aircrafts reach the cruising flight level mainly within 30 minutes after take off. During the climb phase (~25…30 minutes) they fly a distance of about 150nm. The descend phase is similar. So, in Figure 4 a 150nm circle was drawn around the shown airports to indicate the potentially flown distance during this climb or descend from or to the airport. Freeways trajectory tries to pass through or as close as possible of these circles and ends close to the known intercontinental connection points.

Intersection areas for the district are placed on the Freeway in a cruising distance of about one hour. Logically the Freeway traffic of a specific airport will use the intersection closest to the direction of the destination to avoid major detouring.
Airports, with at least 2/3 international traffic (ECAC and intercontinental) are shown in blue (Figure 4) as they potentially generate more Freeway traffic as airports in grey with a higher part of national domestic traffic.

The Freeways have no crossing with any kind of traffic. Freeway ‘Red’ and ‘Blue’ use different flight levels.

3.1.1. Freeway Route

A Freeway consists of a longish airspace volume with a rectangle shape. The vertical height of the Freeway volume is one flight level. Inside such a Freeway volume there are two or more horizontal safely separated, independent lanes in parallel (same flight level). The lanes define the 3D (3 Dimensional) trajectory of the aircraft on the Freeway.

Any Freeway is used in a single direction, only. An aircraft may not change the lanes during its trajectory on a Freeway. Figure 5 shows in a sample the shape of Freeway ‘Blue North’ with three lanes. The Lanes are numbered from left to right (flight direction).

A Freeway is represented by several 3D trajectories, one for each lane (e.g. Freeway ‘Blue North L2’). These entire 3D trajectories with the associated safety margins (horizontal, vertical) represent the reserved airspace of a Freeway.

The Freeway for the opposite direction is left hand side in parallel. Distance between both Freeways has to be large (e.g. 20…30nm) to support manoeuvring of the district traffic. Figure 6 shows on the left Freeway ‘Blue South’ and right the Freeway ‘Blue North’ with potential extensions up to five lanes for each direction.
To increase Freeway’s capacity, new lanes may be added at the right hand side seen in flight direction (e.g. 5 lanes). The capacity of the Freeway is depending on the number of independent parallel lanes and the minimum time distance (safe separation) between the aircrafts in trail. In example Freeway ‘Blue North’ with 5 lanes and 3 minutes of time distance between aircraft’s in trail would have a mathematical maximum capacity of 100 aircraft per hour for this unique direction.

3.1.2. Freeway Flight Levels

Local meteorological events should not influence the Freeway traffic. ‘Weather’, which may influence air traffic occurs in the lowest earth’s atmospheric layer called troposphere. Tropopause is the boundary region between troposphere and stratosphere. Clouds and most of the terrestrial weather turbulences end in Europe just below the tropopause. Therefore Freeways are located in the tropopause or above. Over Western Europe the tropopause is mainly located at 10 - 12km altitudes (FL330 – FL390). The altitude of the tropopause varies, mainly with the seasons.

For one Freeway several Freeways are defined distributed over consecutive flight levels. The defined flight levels covers the potential levels of the tropopause. Figure 7 shows the altitude association for this defined Freeways block. Only one out of this defined flight levels is activated for the Freeway a time. All other defined, inactive Freeways are available for district traffic.
3.1.3. Freeway Intersections

At defined areas, a Freeway has intersections with the district traffic. Intersection areas represent reserved airspace associated with the Freeway. An intersection consists of a connection-airspace and a junction-airspace. Traffic, out of the district to join the Freeway, uses the connection-airspace (entry). Traffic, leaving the Freeway for joining the district airspace, uses the junction-airspace (exit). Inside the connection and junction airspace, 3D trajectories are defined between the Freeway lanes and the handover points with the district airspace. These handover points represent agreed rendezvous points for the aircraft at a given time. All intersections have an equal layout and consist of a connection and a junction who are reserved airspace associated with the Freeway.

These intersections are based on specific rules and procedures borrowed from military formation flights. A military aircraft, entering or leaving a formation, executes a climb action (visibility from cockpit). Freeways have the same rule. To leave the Freeway (FL n) the aircraft has to climb into the junction airspace (FL (n+1)). In the junction airspace, the aircraft turns right on a defined trajectory towards the junction exit point (3D). At this point, the handover from Freeway to the district traffic takes place.
To join the Freeways the aircraft enters the connection airspace (FL (n-1)) at the connection entry point (3D) flying straight ahead until the assigned Freeway lane can be reached by a left turn. Now flying in parallel with the Freeway lane, but below, integration is done by a climb to the Freeway flight level (FL n).

Intersections shall not disturb the Freeway traffic flow. A ‘horizontal’ intersection (same flight level) would disturb the Freeway traffic. In this case an aircraft would have to cross other lanes flows to reach the lane assigned to enter or exit the Freeway. These critical changes of lanes could not be done under ASAS conditions on the Freeway. The proposed vertical intersection (exit to higher – entry from lower flight level) does not disturb the traffic flow on the Freeway.

Figure 8 shows intersection airspace for the Freeway ‘Red West’ with 3 lanes and 2 optional lanes. The dotted line at lane L1 shows the trajectories for an aircraft leaving through the junction and another one entering the Freeway at the connection of this intersection.

The oncoming Freeway traffic is located left-hand. The horizontal distance between Freeways will be large enough to allow safe aircraft manoeuvring as connection for both Freeway directions is done from in between the Freeways.

3.2. FREEWAY MANAGEMENT

The Freeway represents activated reserved airspace. This airspace is safely isolated from other airspace by separation rules. In this airspace the Freeway traffic is organised, coordinated and monitored by an unique non-national organisation called Freeway Control (FC).

Each Freeway is organized as one longish sector handled by one FC unit. Standard air-ground communication is done via CPDLC (Controller Pilot Data Link Communication). For emergencies, voice communication is available.

Freeways have one-way flows on horizontal safely separated independent lanes (no lane change). Separation between aircraft in the same Freeway lane is based on time (e.g. 3 minutes) defined by FC.
The responsibility to follow a defined 3D Freeway lane and the time separation between aircraft in the same lane is transferred to the pilots (ASAS). The FC is monitoring the Freeway for save separation only.

An aircraft has to use the intersection airspace to join or leave the Freeway.

Emergencies on the Freeways are handled in a conventional manner:

- In extreme serious cases, like de-pressurisation, pilots secure first the aircraft and inform the FC, which contacts the district ATC centre to redirect other traffic. For other emergencies, the pilot informs the FC. On a case-by-case base, an exceptional leave of the Freeway (between junctions) may then be agreed in collaboration with the district ATC services.

Intersection areas (connections, junctions) of the Freeways are controlled by the FC. The aircraft starts its Freeway trajectory at a 3D connection entry point and ends at a 3D junction exit point. For the intersections, FC collaborates with the district ATC centre:

- For any connection to the Freeway a 4D (3D + time) rendezvous is fixed at the connection entry point of Freeway connection airspace. The 4D rendezvous is agreed between district ATC, FC and aircraft. It is FC’s responsibility to assign to a connecting aircraft a specific lane. FC has to arrange this assignment in a way that the connecting aircraft can be integrated safely in the traffic flow on the assigned lane and the connecting aircraft is able to guarantee its separation to the preceding aircraft with non or minimal constraints in speed.

- Aircraft leaving the Freeway agrees during its trajectory in the lane with the FC a 4D rendezvous at the junction exit point. For multiple aircraft in the junction area the FC has to guarantee separation in the junction area towards the junction exit point by moderating the 4D rendezvous. FC has to coordinate the junction flow with the district ATC.

Freeway 'Red' and 'Blue' have to be at different flight levels. It is the responsibility of the FC to activate flight levels for the Freeways in appropriate manner. The activation of the flight levels is based on meteorological predictions (tropopause, jet streams). Flight level changes of a Freeway require specific procedures. These changes can take place during the low traffic period at nighttimes, only. During changes, two flight levels may be assigned for the same Freeway for a short period of hours.
4. DISCUSSION OF THE FREEWAY CONCEPT

Freeways will absorb intercontinental traffic and long haul domestic flights inside Europe. The introduction showed that about 21% of the ECAC traffic is intercontinental. Hypothetically, major parts of this traffic could use a Freeway. Further, more than 1/3 of the ECAC domestic flights are longer than 600nm. Parts of these long haul domestic flights could use a Freeway, if flight routing corresponded with a Freeway routing.

Freeways will accumulate traffic with the same direction but the destination may be different. The proposed concept absorbs and distributes these traffic flows at defined intersections points. These intersections serve all the airports in a large area around the intersection.

Freeways are located in or over the tropopause. In Europe, ground weather influence onto the tropopause does mainly not exist. Therewith no specific weather dependent rerouting procedures are required. Winds (jet streams) at this altitude are influenced from air pressure of large areas and influence all aircraft ground speeds in a homogeneous manner. This represents no safety issue. The flight level of each Freeway can be adapted to the metrological constraints on a day-by-day base. The FC selects the active flight levels for all European Freeways.

Freeway traffic is separated in time (e.g. 3 minutes) under responsibility of the pilots (ASAS). The FC is monitoring the traffic on the Freeway and controls the intersections. Commercial aircraft in the tropopause have very similar performance. The average air speed of these aircrafts varies very little (~450 mph ±5%, very few exceptions). So, flying miles in trail on the Freeways will represent a negligible problem, especially as different Freeway lanes may be temporarily associated with different speed ranges or a larger time distances (>3min.) can be used for catch up.

For monitoring aircraft separation in time on the Freeways, new time-based tools have to be developed.

Freeway’s presence may constrain the district ATC services. A Freeway represents a large horizontal band (e.g. 5 lanes ~30nm) of reserved airspace. This can be seen as large impermeable horizontal ceiling for the district sector. A large space in between the Freeways of the different directions (except in the connection areas) helps to prevent and reduce this district disturbance. Short and medium haul district traffic mainly uses flight levels below the Freeways in the tropopause (Figure 3: e.g. 400nm⇒90% <FL340; 600nm ⇒50% <FL340).

Freeway intersections disturb the district traffic. An intersection requires a large volume of reserved airspace and it creates supplementary traffic for the district. The intersection serves for all airports in an area within ~150nm. The traffic will be star-shaped concentrated at the 3D connection and junction points. These 3D points are at different flight levels and far away from each other’s.

Freeways create supplementary economical effort for the user. Using the Freeways may constraint users in different ways. The trajectory may become slightly longer (rerouting to intersection), flying miles in trail and the carriers have to invest in specific equipment (ASAS, CPDLC, ...). To counterbalance these constraints for the carrier, a route charge modulation for the Freeways should be foreseen.

Freeways are reserved, isolated airspace. The Freeways are managed by a non-national organisation: the FC. Each Freeway represents a longish sector and is handled by one FC unit, only. Therewith pilot’s workload caused by multiple sector changes is reduced. The FC represents a first step of the ‘Single European Sky’ initiative with one Pan-European Freeway system.
Freeway's capacity can be increase with the traffic demand. - By adding right-hand side new lanes to an existing Freeway, its capacity will automatically increase. A five lane Freeway has a theoretical maximal flow capacity of 100 aircraft per hour (3 minutes separation). In practice, probably at least 50% can be estimated as flow capacity.
5. CONCLUSION

The Freeway concept interconnects multiple European areas; it shall cumulate their long haul intercontinental traffic and medium/long haul ECAC traffic.

The ‘Paradigm Shift’ project evaluates controller’s work in a district including Freeways. The explorative simulation takes place in October 2005. Further simulations are planned: district with an intersection and Freeway capacity evaluation.

The overall capacity of a dual airspace system, as seen by the ‘Paradigm Shift’ concept will increase with Freeways. Therefore, parts of the district traffic are shifted to the new Freeways airspace, which is managed with advanced concepts and technologies. Freeways will reduce the traffic of the district control centres. Constraints caused by the presence of a Freeway for the district control should be negligible (hypothetically).

Freeways are reserved airspace with ASAS rules. The Freeway traffic can be seen as an isolated flow, where a single element of the flow (aircraft) requires no specific observation effort.

Freeway’s favours the predictability in time for the aircraft trajectory. Pilots will be freed from multiple sector changes on the Freeway as it will be operated by an unique non-national organization. So, Freeways will reduce pilots’ workload and free capacity in the district control centres.

The Freeway concept could be an early step towards a ‘Single European Sky’.