Paradigm SHIFT is a project started in Jan’2004 that investigates solutions to increase capacity and maintain at least the same level of safety in order to target a global efficiency and to support a sustainable air transport business development.

Objectives are to take into account the interest of all actors dealing with ATM, like Airport, Airlines, Air Navigation Services,.... and to reinforce the co-ordination and co-operation between these actors, based on negotiated contract

The project is trying to optimize resources by reducing the uncertainty and aims at offering a new way of managing the process

The Paradigm SHIFT is proposing a collaborative approach, in a global system wide perspective, maintaining the adequacy of a tactical triangle : traffic demand, infrastructure and operations. The main goal is to increase the punctuality, by analysing and considering the potential disruptions in the Air Traffic Management system.

The first step of this project is to analyse the current ATM problematics, and their evolutions. The second step consists in describing an operational concept based on three major points:

- To consider the Air Navigation Services as a part of the Air Transportation System, with efficiency issues addressed with a global approach of this composite system.
- To increase co-ordination between actors based on negotiated contracts.
- To achieve operational excellence thanks to a local adequacy of a tactical triangle : traffic demand, infrastructure and operations.
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SHIFT proposes, through an analysis of the aeronautical system and ATM, innovative concepts for responding to safety, capacity and efficiency issues linked to the growth in air traffic in Europe after 2015. The scope of SHIFT does not aim at dealing with all aspects of ATM, but to focus its attention on the en-route part while maintaining a holistic approach, in particular by strengthening the interfaces with the other components of the air transport system.

There is a consensus to declare that the current air traffic management system has some limitations in order to cope with the challenges of future air transport system (ACARE, 2002; University Concept team, 2003; EUROCONTROL, 2004; Gate to Gate project, 2004). The initial work achieved in the Paradigm SHIFT project is in line with this vision, and identifies ATM key-features for proposing ways of evolution. ATM key-features identification has been raised from the analysis of Supersector project results and interviews of operational air traffic controllers and ATM experts.

The ATM key-features can be summarized in the following points:

• Air transport is a production system. The Air transport exists only because it meets cost-efficiency criteria. In this context, air navigation is a link in a chain of production which meets financial, safety and efficiency targets. ATM costs refer both to taxes charged on the airlines and passengers, and the consequences of ATM operations like delays, which penalize airline operations.

• The nature of future European air traffic demand is very difficult to establish. Economical, social and geo-political factors can quickly modify the demand and have great impacts on the air transport system. However, it seems reasonable to work on the following hypothesis: moderate growth of number of flights, complex network, main flows between north and south and between east and west, and high density central area.

• En-route Air traffic is a mix of climbing/descending and cruising aircrafts. Each of these categories has different characteristics in terms of throughput, disruptions, bulk, shape, complexity, and services, which require different solutions to apply. The task and responsibility sharing among ATM/ATC actors are based on geographical division where all traffic categories are combined. A better way to take into account the traffic characteristics in sector design and traffic organization is a fruitful way to have a more efficient task sharing between ATM/ATC actors.

• ATM/ATC are continuously subjected to disruptions. The uncertainty is currently one of the major factors that impacts the different entities sizes to face the growth of traffic. The management of the uncertainties is a key issue for the future. Uncertainty is the results of disruptive factors inherent in the aeronautical system. Disruptions can be classified into different categories: ad hoc events (meteorology, runway capacity, aircraft failure, etc.), constant imprecision (technologic inaccuracy, noise model), and system-wide problems generated by interfaces between ATM/ATC components (ATFM vs. ATC, and ATC vs. aircraft crew). The future Air Navigation system should not try to eliminate these uncertainties but have to live with. The system should not be constrained if this brings no operational benefits, otherwise it will be too rigid and therefore incapable to manage the inherent variability in the air navigation system.

• There is an operational continuity for airlines between ground and air operations. This continuity can be described as the operating cycle of an aircraft. In such a vision, landing time appears as a key factor for the airlines, and consequently a key challenge for the ATM/ATC to perform. The operating cycle of an aircraft integrates totally the approach developed by CDM-Airports for the ground operation side.
• There are strong relationships between the traffic to manage, the airspace structure and the ATCO operating method. The air navigation system operation modes need to be approached globally. They are the result of a complex compromise between the organisation of traffic (flight planning), the airspace structure (routes, navigation points, control units), and lastly, the operational working methods. The strong relationships between the three elements can be described as the "air navigation tripod". The balance between the axes of the tripod is performed to be locally efficient.

• Traffic demand continuously fluctuates. It is now acknowledged that, in order to manage heavy traffic loads, it is likely that more and more constraints will be associated to the navigation system. These constraints are only appropriate when loads are heavy and are disadvantageous on low density traffic. For this reason, air navigation must be envisaged in the shape of a flexible airspace which has the capacity to adapt itself to meet demand. Efficiency consists to reply to the demand in the frame of ATM/ATC resource management optimization.

Based on the here above key features, two majors concepts have been raised and define our approach of the ATM, the **Contract of objective** and the **Dual Airspace**. Those concepts are independent, they can be investigated independently and can lead to various sub-concepts.

The Contract of objective defines objectives applicable to a flight and links actors together through agreed interfaces. The respect of the Contract of objective, negotiate between the appropriate actors, is a way of managing organised traffic and conform the operations to planning. This Contract of objective is drafted during a negotiation phase involving all actors (airlines, airports, ANSP, military units...). This collaborative decision-making phase is known as the **Operational Plan**.

This global organization is driven by agreed objectives. This objectives assignment is based upon a breakdown of responsibilities in the ANS: the **decentralized ATM** organization appears as a new concept to increase ATM efficiency. Only local actors have the best view to optimize their organization

“Constraints must be as light as possible”. Disruptions are part of the ATM system. Putting constraints to insure safety and fluidity is necessary to manage the traffic. But over constraining close the door to the resilience face to uncertainty and is not cost-transparent The concept of **Target windows** is to define 4D windows as intermediate objectives for a flight, linking actors together and taking into account constraints and system capability to insure negotiations to reach global objectives.

The last main concept, **Dual Airspace** introduces a small number of continental highways conveying long haul cruise traffic to decrease the traffic pressure on local Navigation Services.

The contract of objective, the Operational plan, the target windows, the decentralized ATM organization and the Dual Airspace are the different innovative concepts proposed as guidelines for ATM evolutions.

The first stage of the SHIFT project is now finished and allowed to have an Operational Concept Document. The following stage will demonstrate the relevance and the validity of concepts in the frame of safety, capacity and efficiency issues linked to the growth in air traffic in Europe after 2020. For this, a **research agenda** was proposed for prioritising the studies and the resource use.
1 INTRODUCTION

This document constitutes the operational concept of the Paradigm SHIFT Project, launched in January 2004 within the Innovative Research (INO) Business Area of the EUROCONTROL Experimental Centre.

This project investigates solutions for increasing capacity while maintaining at least the same level of safety of the Air Traffic Management (ATM), and at the same time improving efficiency through a collaborative approach and the observations made on airspace and disruption management.

Thus, it proposes a new paradigm for air traffic management and control, to meet the challenges of the 2020s.

This document is the result of the working group comprising representatives from Steria, CS and the EUROCONTROL Experimental Centre, as well as interactions with operational controllers (French, Slovenian, Hungarian and Czech) and experts participating in the framework of the SHIFT Project.
2 THE PARADIGM SHIFT PROJECT CHALLENGE

The development of air transport means that its various component systems must constantly adapt. Airlines, aircraft designers, airports and air navigation services (to name only the key players) are therefore having to adapt on a day-to-day basis. The emphasis here is on "optimisation", either in isolation or in coordination with other areas, with this optimisation guiding all developments. However, if we look further into the history of air transport, several periods of development can be identified. [Bib 2] [Bib 16]

- When it first came into existence in the 1950s, the air transport system was characterised by a predominance of military aviation and the emergence of commercial aviation, both driven by developments in aeronautical technologies. Within this framework, air navigation defined and set in place an effective basis for air traffic management and control. This period may be described as the pioneering and creative phase.

- From the 1950s to the present day, the air transport system has been characterised by an explosive growth in commercial aviation worldwide and, as from the 1990s, by the appearance of "bottlenecks" at certain airports and in some areas of airspace. To cope with these changes, air navigation has developed Information Technology and is entering a professional phase, characterised by high performance levels in terms of both capacity and the safety/fluidity of air traffic.

- The years to come will see a phase of sustainable growth in the air transport system, which will be characterised by regular growth. This growth is viable only if it simultaneously takes account of quality, accessibility to the largest number of people, the environment, security, efficiency and, of course, safety. The organisation and operation of ATC must therefore be made more streamlined, combining professionalism and productivity.

The SHIFT Project was launched within the Innovative Research Business Area to meet the challenge of the years to come. SHIFT is one of the steps being taken by the ATM community with a view to proposing possible developments in air navigation. SHIFT is a forum for discussion, aiming to propose future concepts which should then be the object of more detailed study.

The starting points for SHIFT are en-route control and optimisation of the controller's working methods. Drawing on the experience gained from the Supersector project [Bib 18][Bib 20], the SHIFT Project considers the problems of en-route control in the broader context of ATM. This explains why it very quickly became necessary to look at capacity, fluidity and safety issues for en-route traffic from the perspective of the air navigation system. Consequently, a more general approach to en-route traffic was developed, not envisaged at the beginning of the study, and the scope of ATM was widened to include areas which may appear far removed from en-route control but which lead to a deeper understanding of the subject and suggest ways of improving it. This is why a large part of the discussions focused on airspace, an area where EUROCONTROL made a specific contribution.
2.1 POSITIONING

The Paradigm SHIFT Project developed here is to be seen within the context of the various research and development projects initiated at European level by the European Commission and by EUROCONTROL.

It is part of a “Top/Down” vision driven by an analysis of air navigation.

It also takes account of approaches developed by numerous projects dedicated to various support tools and the requirements of users, such as airlines.

These various approaches are represented in Figure 1.
3 AN ANALYSIS OF AIR NAVIGATION

3.1 AIR NAVIGATION AND AIR TRANSPORT

3.1.1 Air navigation in the air transport system

Air traffic management is part of the much wider context of air transport, the challenges of which go beyond simply transporting passengers, since it is also a market for employment, technological development and commercial development. [Bib 4].

The open nature of the transport market complicates the task of air traffic management in that it results in the optimisation of a process without the knowledge of the associated efficiency criteria. For there are as many business models as there are airlines (which are, moreover, not the only air transport operators), which need to be provided with optimal service while ensuring their safety.

The most fundamental component of traffic management, the one which ensures separation, is based on resolving a fundamentally local problem. However, the volume of traffic in Europe (approximately 30,000 flights per day in Europe at the start of the first decade of the millennium) forces the manager to focus on the allocation of resources, the availability of which is unable to match the rise in demand: runway slots and control capacity. Allocation cannot be effected on a local basis. The problems encountered involve flights from or to highly diverse locations, and every decision on allocation has repercussions for a substantial number of resources, with this chain reaction possibly jeopardising the profitability of a flight.

For this reason, the system of air navigation occupies a unique role in the air transport system. It is one of the essential elements in the performance and safety of air transport because it is an entirely integral part of air transport, forming one element of the complex jigsaw represented by airlines, airports, customers, services, aircraft manufacturers, etc. What, however, differentiates it from these other actors is the fact that it is not subject to such restrictive financial rules. Nevertheless, the direct and indirect costs of air navigation for air transport are important parameters in the viability of air transport.

The term "direct costs" refers to costs incurred in respect of the organisation and operation of air navigation. These result in charges which are billed to the airlines. The amount of these charges is a relatively stable parameter which the airlines can manage easily in their commercial strategies. Clearly, the lower the taxes, the easier it is for airlines to offer fares which encourage the development of air transport.
The term "indirect costs" refers to costs relating to the consequences of air navigation operations. These consequences may be reflected in traffic regulations, or indeed problems which penalise airline operations with regard to their organisation and operational strategies. As a result, airlines incur additional costs which are not easy to plan for and quantify, and which, quite apart from their financial aspects, cause customers to become dissatisfied with the services sold. These indirect costs do not encourage the development of air transport insofar as they contribute to the economic difficulties of certain airlines, particularly in a difficult context as is currently the case. Without wishing to stray onto purely financial ground, it is clear that the strong competition between airlines to develop market shares at the same time as resisting different organisational methods is encouraging greater visibility of the indirect costs incurred by air navigation. The impact of flight paths on the environment and their economic consequences are also factors which must not be ignored when considering indirect costs.

3.1.2 Air navigation and productivity

In the light of these constants, air navigation cannot shelter from the financial rules of air transport behind the safety argument alone. Air transport is a production system which exists only because it meets cost-efficiency criteria. In this context, air navigation is a link in a chain of production which meets financial, safety and performance targets. Being effective, as is currently the case in terms of safety, is not sufficient with regard to air transport operations. Better results in terms of capacity/fluidity and cost-efficiency must be achieved. These objectives will become all the more pressing as responses are sought to the growth trend in air traffic.

Air navigation must therefore give thought to introducing changes with a view to better integration of the criteria of performance, safety and cost-efficiency which govern air transport. In this context, direct costs (operating costs of air navigation bodies) fall outside the scope of the discussions conducted in the framework of the SHIFT Project. On the other hand, it would appear vital to consider the performance of the navigation system not only in terms of capacity constraints but also in terms of the costs incurred as a result of problems in responding to capacity requirements. All the discussions held and concepts advanced within the framework of the SHIFT Project have taken this into account. The performance criteria adopted for the navigation system are twofold:

- to meet the needs of the users, i.e. the airlines through the needs of the passengers;
- if this is not possible, to compromise the requirements of the users as little as possible and, in such cases, to have available the best possible prediction in relation to the changes made, in order to give other transport system operators enough notice to manage the resulting reorganisations to the best of their ability given their operational constraints and profitability requirements.
The mission of air navigation can therefore be summarised as follows: to organise and monitor air traffic effectively and safely in order to meet user requirements. Apparent in such a mission is a vital component of the transport system, namely user satisfaction. This is the approach adopted by the SHIFT Project on the basis of the performance criteria listed above. Optimising the way in which user requirements are taken into account in the air navigation system at the same time as taking account of the constraints to which air navigation is subject may lead the various navigation actors to take on different functions from those of today. It is along these lines that a development, or indeed a shift, may be envisaged in the paradigm for air navigation management and control.

Air navigation can therefore be described as an interface between the three components which are (Figure 2):

- the airspace in which the aircraft in flight operate, with all the uncertainty this entails;
- airlines representing customers (demand) and aircraft manufacturers (whose technological choices contribute to the definition of the operational framework);
- airports and all their support services: security, cleaning, fuelling, catering, etc.

![Figure 2: Air navigation: an interface at the heart of the aeronautical system](image)

The performance of the navigation system stems from its capacity to adapt in order to cope with the variability of these three components. We can therefore characterise air navigation as an opportunistic, anticipatory and reactive system:

- opportunistic because it must continually adapt to changing operational circumstances;
- anticipatory because it is not possible to design and manage a process without using a model. This model is important because it makes it possible to determine an operational framework for optimising resources and meeting a certain level of performance. The challenge for air navigation therefore lies in the validity of its anticipatory measures and in the ability to withstand instability factors;
- reactive so as to address the instabilities of the aeronautical system. Managing solely through "reactivity" is not in itself sufficient, however, owing to the risk of a spiralling of the resources required and a decline in performance.
3.2 AIR NAVIGATION

3.2.1 Air navigation today

The current air traffic management system is hampered in Europe by limitations preventing it from easily meeting users’ expectations for future years. Cost, punctuality, efficiency and flexibility are the criteria which define ATM in today’s context of increasing traffic. It is important to analyse the existing system in order to better understand its limitations and the potential areas for development.

The analyses of the limitations of the current air traffic management system are the subject of a consensus, to be found in several documents (ACARE, 2002 [Bib 2]; University Concept TEAM, 2003 [Bib 31]; EUROCONTROL, 2004 [Bib 15]; Gate to Gate, 2004 [Bib 17] ). This consensus is structured around the following points:

- Air navigation system capacity does not meet demand, yet the capacity theoretically available is not fully exploited. This can easily be explained by the operating arrangements at European level of the Central Flow Management Unit (CFMU). Since 1988, the CFMU has been the body responsible for coordinating air traffic at European level by managing aircraft flight plans. Its role is to draw up "load plans" for the different bodies involved in traffic management, taking account of their respective local constraints, and to organise traffic in such a way as to respond to these load plans. To this end, it works on forecasts of future traffic drawn up on the basis of the information at its disposal. The information to be processed, however, arrives continuously and may relate to both short and long time frames. The aeronautics environment, moreover, is unstable and a permanent source of disruption to the traffic management system. As a result, network capacity estimates are characterised by a high degree of uncertainty with regard to both planned traffic (on account of load variations not planned long in advance) and actual traffic (owing to "blurred" vision of the details of traffic distribution). The consequence is a "voluntary" reduction in planned network capacity in order to cope with this uncertainty in real time.

The action taken by the CFMU on aircraft management is of a purely restrictive nature; in other words, it consists of delaying take-off times. A lack of more direct links between the actual traffic, the state of the bottlenecks at en-route level, the runway capacity of aerodromes, which may vary considerably in the course of a day, and means of action more delicate and sensitive than simply delaying aircraft to control the traffic, limit the CFMU's impact when traffic volume is high. Paradoxically, it is at these peak times that the need for the CFMU is greatest. As a result, certain practices have arisen, not only among airlines (producing several flight plans for the same aircraft, failing to declare a delay before take-off, presenting the CFMU with a fait accompli, playing on the "first come, first served" principle) but also among aerodromes (managing take-off and landing sequences on the basis of aerodrome constraints alone and no longer on the basis of traffic distribution throughout the airspace) and control centres ("playing" on regulations in order to manage imprecision more effectively), which restrict the CFMU's role still further and mean that the global ATM system is operating below capacity.
European airspace is partitioned into areas of national airspace. Each of these has its own route network and working methods; this limits traffic capacity and flow, in particular at the level of the interfaces between networks. An integrated and global approach to traffic management at European level appears to be the only possible means of bringing about substantial change in terms of traffic capacity and safety. Functional and operational continuity between the various control bodies is vital if account is to be taken of the entire life cycle of an aircraft, thereby achieving a better understanding of air traffic as a whole. This partitioning is increased by military airspace, which, in the areas with the densest traffic, reduces the options for adapting the civil system.

Airport take-off and landing capacities constitute genuine bottlenecks, making it impossible to respond to an increase in air traffic. The largest airports are already operating at maximum capacity and only increased optimisation of the take-off and landing sequences will make it possible to cope.

Load plans are calculated within an en-route control unit on the basis of the maximum number of aircraft which can be controlled from a control position. This figure is specific to each control unit and corresponds both to an hourly throughput and to a snapshot of the number of aircraft at a given moment. Under the current model for controlling aircraft at control positions, controllers work in pairs, or in threes when traffic is heavy. This can be described as collective work to the extent that different tasks can be carried out by different people. A more precise analysis of relationships within a team of controllers working at the same control position, however, reveals that "executive" controllers' work is highly individual in nature since, although they can obtain the "planning" controller's help, they retain full responsibility for air traffic. They alone issue instructions to aircraft, and even if the "planner" prepares work for them or suggests solutions, it is they who eventually decide whether or not an instruction needs to be issued to an aircraft. This has serious consequences in terms of a control unit's load plan, for it is, in a sense, the lone "executive" controller's capacity to understand traffic which determines the control unit's capacity. Given current traffic organisation, the way in which it is controlled in 4D on the basis of the existing route network, "executive" controllers can understand traffic only if they have as complete a "picture" of it as possible. This means "knowing everything, everywhere and at all times". The explanation for this paradigm lies in the controllers' deliberate tendency to base their entire traffic management strategy on two points:

- an essentially reactive approach to conflict management;
- monitoring aircraft to satisfy themselves that the aircraft are doing what is required of them (i.e. that they are following the flight plan or instructions from control).

Persisting with this control paradigm within control positions would seem to be an insuperable obstacle to any increase in the number of aircraft to be controlled, owing to the attendant human limitations.

This control paradigm results in rigid route networks, meeting the controller's need for stable reference points to memorise the traffic, and a fragmentation of the control sectors into increasingly small sectors so as not to exceed the maximum traffic loads manageable by the human operator. Sector fragmentation means on the one hand that controllers abandon proactive traffic management in favour of more reactive management, and on the other hand that it is more difficult to ensure overall consistency for an aircraft flying through the large number of sectors it has to cross.
Poorly developed networks for sharing information between the various actors involved in the transport system result in a non-collaborative working method, despite the fact that the system must constantly adapt in order to cope with inevitable uncertainties.

Integration of new technologies in the operational process, both on the ground and in the air, is a slow process owing to their certification and the cost they represent for users.

Traffic demand is unevenly spread geographically and temporally, resulting in a major imbalance in traffic density across Europe, also depending on the time of day.

3.2.2 Air traffic components

Since they directly affect the performance of air navigation, it is important to better understand the various air traffic components, such as they are today.

One of the main obstacles to air traffic analysis is that it is easy to speak of a collection of aircraft seen individually, but very difficult to characterise a group of aircraft. The following description makes a distinction between three categories: airport traffic, climbing/descending airport traffic and cruising traffic.

3.2.2.1 Airport traffic

In the immediate vicinity of airports, highly sensitive problems arise linked to the management of runways and the critical take-off and landing phases, which are affected by specific disruptions (weather, ground system malfunctions, wake vortex, etc.) and subject to considerable environmental constraints (local residents, security, relief, etc.). This is not the place to discuss in detail the management of this phase, which is subject to specific management associated with a limited area of responsibility, the TMA.

3.2.2.2 Climbing and descending airport traffic

This traffic consists of aircraft climbing to their cruising level from their SID exit point and aircraft descending from their cruising level to their STAR entry point. This denomination combines climbing and descending traffic but, for many reasons, it would seem preferable to separate these flow patterns and their management.

3.2.2.2.1 Volumetrics

Climb and descent phases can be considered to relate to aircraft in a radius of less than approximately 150 nautical miles from their airport of departure or destination. Hence, the throughput of such traffic is measured by the number of movements. Of course, this number is identical to the number of runway movements at the airports served. Hence, demand for this type of traffic is limited by runway throughput. Regardless of the trend in demand in the medium term, a surge in this traffic would seem unlikely for TMAs already close to saturation (Paris, Frankfurt, London, etc.). The future situation will therefore probably be similar to that of the current situation of these major airports, where management is satisfactory, albeit apparently not sufficiently efficient. In the case of this traffic, the challenge to capacity will be unlikely to represent an insurmountable barrier.
Since throughput corresponds to the number of movements, no synergies are expected from annular segmentation around an airport. The natural allocation of tasks corresponds to angular sectors around the TMA. This type of sectorisation is applied around Paris.

3.2.2.2 Disruptions

Climbing and descending airport traffic is particularly prone to disruptions. This is an area subject to aeronautical events, since meteorological phenomena intensify both in frequency and size when approaching the ground. Uncertainties are similar in scope, but have greater consequences for the flight dynamics of aircraft moving vertically, particularly when climbing, where the flight domain is critically restricted. From the viewpoint purely of aeronautical disruptions, climbing traffic is subject to very few external disruptions, whereas the descent phase is exposed to the repercussions of disruptions affecting the entire flight.

3.2.2.3 Configuration

Climbing and descending airport traffic naturally moves in 4D. During climb or descent, vertical and longitudinal positions vary simultaneously, as do velocity and the flight envelope. Unfortunately, no standard profiles exist for these variations, which fluctuate considerably depending on the aircraft (type, engine power and weight) and the air mass status. These variations are particularly sensitive during the climb phase as opposed to the descent phase, for obvious reasons related to the flight mechanics.

Owing to its changing nature, climbing and descending airport traffic is both voluminous and complex. Because of the considerable uncertainties regarding route forecasting, each aircraft occupies a large amount of airspace in 3D, which makes conflict resolution all the more difficult in the case of aircraft with reduced manoeuvrability.

3.2.2.4 Service

A distinction needs to be made here between climbing and descending aircraft.

Climbing traffic originates from a runway in the area served. Its throughput is not aligned with the separation minima required in this phase. Control is therefore asked to separate aircraft and ensure their separation. This is made easier by the fact that traffic diverges towards several airports of destination, and therefore tends naturally to spread out into airspace. The main problems arise from the great diversity in aircraft performance, which brings aircraft closer together, and the 4D nature of traffic, which makes monitoring time-consuming because of the number of potential configurations. The task of ATC is therefore to provide a separation monitoring service tailored to each aircraft.

Descending traffic converges. It originates from various sources, and the task of ATC is to merge it into a single flow with a throughput corresponding to that of the landing runway. In order to achieve this, it makes aircraft perform manoeuvres allowing them to move on the temporal plane. The problem arises from the density of traffic, which results in available airspace becoming more congested.

3.2.2.3 Cruising traffic

This traffic includes all aircraft stabilised at a certain level for a significant period of time.
3.2.2.3.1 Volumetrics

Navigation of aircraft at cruising level does not vary in time or space, unlike in the climb and descent phases, which are dependent on spatial and temporal deadlines. It is possible to define a relevant throughput measurement: the quantity of radar plots, produced of the number of aircraft by their flight distance (or flight time). Management activity is therefore dependent on the distance flown and the number of aircraft (quantity of radar plots).

3.2.2.3.2 Disruptions

The cruising phase is only slightly affected by internal disruptions: the behaviour of high atmospheric levels is less turbulent than that of low levels, and the attitude of aircraft flying in a stable manner is easier to predict. Of course, the disruption factors as a whole may affect the smooth progress of such flights:

- events are more infrequent but do occur;
- route prediction is still prone to uncertainty;
- control may divert aircraft from their route in order to ensure separation;
- communications between control and the flight crew are still subject to inertia and uncertainty.

However, if control makes an effort not to divert aircraft from their planned route in order to "expedite traffic", it should be possible for the progress of traffic to be close to that expected. On the other hand, cruising traffic originates from climbing traffic, which is highly sensitive to disruptions.

3.2.2.3.3 Configuration

The mix of demand is the main obstacle to displaying cruising traffic, and even more so to managing it. This traffic consists of aircraft arriving from and leaving for all points of the compass. Expressed in terms of points of departure and arrival (city pairs), European traffic consists of 30,000 daily flights spread over 10,000 city pairs! However, long-haul flights contribute more to the quantity of radar plots than do medium-haul flights, and 1,500 city pairs account for half of the plots. This figure remains consistent and could jeopardise the frequent use of the term flow to designate cruising traffic: one aircraft every half hour is well short of forming a dense flow of flights. Flows do not result naturally from demand structured in the form of city pairs. They appear, of course, when demand is allocated over a network of routes, but attempts to construct a network responding "naturally" to demand have thus far not yielded any genuinely convincing results.

However, it might be very beneficial for control to organise cruising traffic in flows. Management of a flow is monodimensional. A flow is not very voluminous and takes up very little airspace, making it possible to envisage breaking down a flow into several corridors which are horizontally and vertically parallel in order to be able to process a higher throughput and have preset solutions making it possible to handle overtaking problems effectively. If flows are few in number, it might even be possible to separate them passively by allocating them different flight levels.
3.2.2.4 Service

Within a given flow, aircraft are able to head for a fairly broad spread of destinations. Furthermore, at a given route location, aircraft at cruising level still have on average 500 nautical miles to cover before starting their descent. There would therefore be little point in sequencing them precisely as in the approach phase. The regularity of flows is a useful management tool, but must remain second to punctuality. Cruising level is the best time to implement solutions which ensure that the aircraft arrive at the exit point at the scheduled time. The main obstacle to achieving this lies in the fact that cruising traffic is no more than a collection of traffic originating from airports which are totally desynchronised in relation to one another. Consequently, it is impossible to avoid the local formation of traffic bottlenecks. This situation necessitates the availability of a surplus capacity system which is able to go with the flow and handle adverse traffic configurations.

3.2.2.4 Summary

The categories of traffic described above are ideal models. They constitute reference situations reflecting actual situations to some extent, but occur only rarely in their pure form. However, it is useful to represent real traffic at a given location as superposed cruising and climbing/descending airport traffic.

3.2.2.5 Link with worksharing

The air navigation service requires a complex management system where responsibilities are shared by a large number of sub-systems. The sharing of responsibilities is currently based on a geographical delineation in European airspace. This method provides clarity, and ensures that two aircraft likely to enter into conflict are managed by a single and identified control authority, provided that the convergence points are sufficiently far away from sector boundaries. Sectorisation is therefore an exercise designed to share the workload between the various operators harmoniously.

The problem of sectorisation is algorithmically complex, since the evaluation of the workload requires a simulation of traffic progress, and the sectorisation of airspace in itself implies a coordination task. Furthermore, sectorisation and network are closely linked, and benefit from being considered together, which makes the task much more difficult. The development of effective airspace design tools represents one of the potential ways in which the capacity of the navigation system might be enhanced.

However, certain data suggests that the current paradigm does not present the problem of task allocation in the most beneficial way, since it is not based on a detailed analysis of the various categories of traffic and their specific characteristics. The congestion of the current en-route system would seem to be caused more by the fact that it mixes cruising traffic and climbing/descending airport traffic than by the intrinsic problems in managing traffic stabilised at a given level, which nevertheless accounts for 60% of radar plots.
3.2.3 The life cycle of an aircraft

The air transport system, and therefore the air navigation system, is based on the logic of production. The operationalisation of productivity in air navigation depends on setting an objective which is compatible with those of airlines (adherence to schedules in order to allow airline networks to function properly) and airports (optimisation of runway capacities and human resources), while respecting the environment.

Production in the air transport system is provided by the flights (destinations, frequency, timetables, etc.), but flights may be performed only by means of a complex logistical chain which includes the airlines, airports and air traffic. The quality of production is directly linked to the quality of this logistical chain, both in terms of complementarity and organisation. Addressing the role of air navigation in order to optimise its performance therefore requires an overview of the entire logistical chain and the ability to envisage its changes only in the context of changes to the other components and the interfaces with these components.

The work initiated as part of the Airport CDM projects [Bib 7][Bib 8][Bib 9] highlights an important notion which may represent a common theme for the two components, namely the aircraft’s "life cycle", i.e. the alternation between its two statuses (ground and air). Airport CDM assumes that taking control of an aircraft at an airport, and therefore predicting the off-block time, begins while an aircraft is still at the airport of the previous stage.

Although air navigation is concerned with the flight segment of aircraft, aircraft management cannot ignore or disregard their ground segment (aircraft management by the airports). Accordingly, a flight gains operational significance only in relation to its integration of two ground segments:

- The "departure" ground segment, which determines the moment when the management of the flight segment will begin;
- The "arrival" ground segment, which determines consistency and the operational validity of the flight with respect to the airline and its customers, but which can also determine the aircraft’s future flight segment if the aircraft’s ground management deadlines are insufficient. It would be worthwhile, at this stage, to introduce the concept of rotations, which is an operational concept for the airline, insofar as it represents both an operational approach (i.e. the means of achieving planned results) and continuity between the ground and flight segments of the aircraft.

It is nevertheless entirely possible to describe an aircraft’s life cycle as a loop divided into a "ground" part and a "air" part (Figure 3). In fact, between the "ground" part and the "air" part and vice-versa, an interface representing the taxiing stage must also be included. For an aircraft leaving the airport, taxiing is defined as the time between off-blocking and taking off, and for an aircraft arriving at an airport as the time between landing and on-blocking. Taxiing is a source of disruption, especially at major airports [Bib 24].
For the airport, knowing the aircraft’s off-block time at the previous airport is important, yet in an air navigation context it is equally important for airlines to be able to predict the on-block time for the airport of arrival. Bringing the arrival time into line with an airline’s flight schedules is an aspect of the system’s performance and efficiency, since sound management of hubs and aircraft rotation satisfies both the customers and the airline. Moreover, it also facilitates aircraft reception at airports of arrival and is therefore a point of entry for Airport CDM.

The loop makes it clear how important it is to increase consistency between the ground and air components of the life cycle, since the point of exit from one component is the point of entry into another.

One criterion for air traffic production is therefore adherence to aircraft arrival times at destination airports. This criterion may be added to the two existing criteria:

- capacity (a global criterion);
- safety (a local criterion).

ATM is therefore at the heart of the aircraft’s life cycle because:

- it is an aspect of negotiations and decision-making with airports and airlines as regards the “ground” component;
- it is a management and adjustment factor as regards taxiing;
- lastly, it constitutes the management and regulation factor in the “air” component.
3.2.4 Disruptions

3.2.4.1 Uncertainty or uncertainties?

Uncertainty lies at the heart of traffic management. Regardless of all efforts to reduce it, or even to eliminate it, it will always be an integral part of the aeronautical system. Now, therefore, a system must be envisaged whose aim is not only to reduce uncertainty, but above all to live with it – in other words, to lessen its impact. This observation prompts us not only to consider the role and impact of uncertainty in ATM, but also to attempt to analyse in detail the implications of the term "uncertainty" itself; above all, how can it be seen in the context of the aeronautical system so that it can be better understood and thus better managed?

Uncertainty is the disparity observed between traffic as planned and anticipated by those involved in air navigation on the one hand, and traffic as it actually develops on the other. It is the consequence of many different disruptive factors. Uncertainty is integral to the aeronautical system, but it is above all part of the ATM system. This means that it is accounted for in a proactive manner when action is taken by control. Reactive uncertainty management would leave ATM with too few solutions and too little room for manoeuvre. Uncertainty management, then, must be completely integrated into traffic management strategies in order to eliminate the element of surprise and avoid having a lack of solutions. In order to ensure that it is properly managed, therefore, uncertainty management requires leeway for adjustment and space for solutions, which must be left to the system if operating constraints are to be adhered to and performance criteria met. The system must be flexible enough to absorb the variations generated by disruptive factors without compromising its own coherence and operational capability in the process.

The impact of uncertainty may vary depending on the nature of the disruptive factors and the phase of the aircraft's life cycle during which disruption occurs. For this reason, it is vital to set in place a system which manages uncertainty in association with the operational requirements of safety, capacity and fluidity. This is because uncertainty management can be both necessary and highly restrictive for aircraft and control. The system can, on the other hand, deal with a certain proportion of uncertainty provided that its impact on the system is negligible or absorbed by other specific system components, such as the structure of the airspace.

The significance of uncertainty also depends to a great extent on the time frame involved. Traffic prediction criteria will therefore vary according to the time frames to which they are applied. Aircraft separation criteria, for example, have no operational relevance except when the uncertainty resulting from the anticipation process is less than the aircraft separation minima. If the uncertainty is greater than the separation minima, action by those involved in air navigation cannot be justified, since it could be much more costly than doing nothing.

Uncertainty can have three types of consequences for air traffic management, depending on how long it lasts and its operational value:

- no consequences at all;
- possible consequences, resulting either in proactive action, corrective action, or finally no action at all if the operator prefers to wait and see if the uncertainty decreases;
- unavoidable consequences, in which case corrective action is taken.
3.2.4.2 Disruptive factors

Disruptive factors characterise all of the discrete or continuous events which interact with the aircraft's life cycle and which may affect the way it is planned. These are the disruptions applying to all aircraft, i.e. air traffic disruption. Disruptive factors generate the uncertainty with which the air navigation system has to deal on a day-to-day basis. It is worth clarifying what these disruptive factors are, for the characteristics of each factor will give it a different status in terms of its impact on air traffic and, consequently, on ways of handling and managing it. The characteristics which make it possible to classify each factor in order to manage it better are:

- the period of advance notice: the period of time as from when it is known that disruption is going to take place and which makes it possible to take preventive measures;
- the frequency: whether a disruption occurs routinely or exceptionally. Whatever the frequency, all disruptions must be managed by ATM. The severity of the impact of managing the disruption to ATM procedures, however, will depend on how frequently it occurs;
- the extent in space and time: the scope of the disruption in space and time, on which the management of its consequences depends. The disruption may last only a few minutes, but its consequences may affect traffic for several hours;
- local or global impact on ATM: the extent of the consequences of the disruption on the ATM system. Some forms of disruption have local effects, affecting only one or perhaps two aircraft (as in the case of aircraft failure, for example), while others have a more global impact on one or two traffic flows (as in the case of thunderstorms).

The disruptions affecting air navigation from an operator’s point of view may be of two kinds:

- External disruptions. On entry, the traffic is not as planned. The cause of the disruption is exogenous, but the operator suffers the consequences. These disruptions may be aeronautical in nature, meaning that they originate from the internal functions of a different operational body. They may also be extraneous to the aeronautical domain, where an aircraft offblocks late;1
- Internal disruptions. These are the most interesting disruptions, since they make it possible to highlight the special nature of ATC. They can be subdivided into four categories.

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1 It is considered here that air navigation takes place between offblocking on departure and onblocking on arrival, and includes the taxiing phases, since these occur under the controller’s responsibility. This is of course a convention, but it allows this description to be linked to the analysis of disruptions on the ground carried out as part of the Airport CDM project.
3.2.4.2.1 Occasional events

Ad hoc events are discrete occurrences which punctuate day-to-day ATM. This category includes all those factors whose start and end can be clearly seen. These events may relate to a specific flight or resource (portion of airspace, runway, etc.). The seriousness of such events may vary considerably from one body to another, depending on their extent, duration and how far in advance they are identified. They may relate to a technical malfunction, meteorological phenomenon (storm, strong winds, turbulence), medical emergency on board, etc. Of course, these events occur with a frequency which can be identified at the planning stage.\(^2\)

They require no proactive treatment before they occur. They are managed reactively, for the most part, and their impact on ATM is most often global, calling unequivocally for the traffic situation and the planning thereof to be updated. The most frequent ad hoc factors are as follows (not an exhaustive list):

- Logistical delays at airports. These may be attributable to the airline or to logistical structures at the airport. The aim of Airport CDM projects is to manage these disruptive factors more effectively by promoting exchanges between the various partners in order to obtain information as early as possible on whether or not disruption is going to occur and, if it is going to occur, what the nature of the disruption will be.

- Runway capacities. These depend on the airport's logistical structures, the weather conditions and the type of aircraft involved.

- Meteorological phenomena such as thunderstorms, turbulence or high winds occurring during flight. These affect a great many aircraft and are characterised by the fact that although their existence can be predicted, their precise position, intensity and extent cannot. Preventive treatment of these phenomena may be more problematic than a single reactive treatment. Meteorological phenomena require the incorporation into the ATM system of margins for adjustment and flexibility if they are to be managed instantaneously and in relation to their consequences.

- Occurrences on board aircraft. These are infrequent, totally unpredictable and have a localised impact.

3.2.4.2.2 Permanent uncertainty

As their name suggests, these disruptions permanently affect the navigation system. They form the haze surrounding certain parameters, for two reasons:

- Measurement noise: regardless of the quality of the method and instruments used to ascertain the current status of the system (traffic and air mass), such measurement is subject to fundamental imprecisions.

\(^2\) For modelling purposes, each event corresponds to a traffic state seen as a system of discrete states.
- Model noise: most of the parameters which make it possible to forecast the progress of traffic change over time. Their dynamics are therefore simulated by a model, which only reflects reality to a certain extent. Depending on the qualities of the model used, the latter may be unbiased (the value it forecasts corresponds to the variable expectation) but, as regards most of the air mass parameters, dispersion around this value increases with the planning horizon (usually in linear fashion, in the case of additional noise). In the case of some situations (such as taxiing), no satisfactory forecasting model exists as yet.

All the system parameters are subject to uncertainty to some extent:

- The current aircraft position. Historically, this is one of the causes of the separation minima value. Current technologies using secondary radar have considerably reduced uncertainty in this respect.
- Aircraft performance, and in particular its flight domain (in order not to issue nonsensical orders), mass and consumption.
- Air mass properties: temperature, pressure and velocity fields. These parameters change in 4D according to a highly complex dynamic, and only very sparse and imprecise measurements of initial conditions are available. Nevertheless, these parameters influence the entire flight dynamic: envelope, velocity and consumption.
- Taxiing time.

Permanent uncertainties generate margins of error which the ATM system must accommodate. These errors are relatively minor and relate to local predictions. They require local modifications and adjustments. They do, however, require updates at global level if significant uncertainty is not to set in. Constant imprecision may relate to the position and speed of aircraft, their performance, physical characteristics of the air mass and taxiing time at airports.

3.2.4.2.3 Discrepancies peculiar to the system’s organisation

Factors caused by system-wide problems are generated at the interfaces between components of the ATM and aeronautical systems. They arise as a result of the different objectives of these components and from control loops which are not sufficiently adapted, especially in terms of frequency: either the frequency is too high, leaving operators with too little room for initiative or manoeuvre, or else too low, making it difficult to achieve final performance targets. The interfaces worst affected by system-wide air traffic management problems are:

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3 For modelling purposes, direct estimates result in a noise on the variable in question. For the dynamic models, it might be necessary to consider diffusion processes as differential stochastic equation solutions.
- the link between the management of the aircraft’s ground segment and its flight segment. This interface has to be synchronised with an eye to safety and efficiency, and quite simply in order to ensure realistic planning of the two systems. One system’s entries are the other’s exits, and vice versa. Take-off times shown on the flight plans are sometimes unrealistic in view of the airport platform’s operations, and an aircraft unable to find a block after landing is unlikely to be able to take off again on time if the time allocated to ground management is tight even at the planning stage;

- the interface between ATFM (Air Traffic Flow Management) and local ATC (Air Traffic Control). Although the global objective of both ATFM and ATC is to ensure that traffic is managed safely, it must be acknowledged that they put this objective into practice in different ways. This is because the two systems operate in an open loop, with information on the progress of operations not being channelled back to the other party. In the absence of such feedback, operators have to determine their own objectives, and nothing is able to get an operational situation back to the original plan. This allows the situation to drift, slowly but surely, causing planning to lose all credibility and effectiveness, since it is based on premises no longer valid. This situation is dangerous, since the system is sometimes forced to operate outside the safeguards which ensure effectiveness and safety, but above all because it undermines operators’ confidence in planning, which reduces their respect for this phase. The ATFM approach is based more on capacity while ATC accentuates safety. Their respective actions do not share a common approach, and as a consequence there is a lack of cohesion and functional continuity in traffic management. This is particularly clear at local level, where the control space is limited to the control unit (the sector, as a general rule, and occasionally the adjacent sector), but where there is no real perception of the logic underpinning the flight as a whole. This “encapsulation” at local level is reflected among controllers in individual performance criteria such as the elegance and quality of their “traditional” work, which are difficult to assimilate into global performance and which consequently cause disruption or even uncertainties relating to how traffic is managed. A management model in which the prediction of control measures is formalised will allow for better predictions and thus improve global system performance;

- the interface between ATM and aircrew representing the aircraft. As in the case of the previous interface, ATM and aircrew have different objectives. While ATFM is concerned with capacity and ATC with safety and compliance with aircraft separation criteria, aircrew give priority to compliance with a timetable linked to financial considerations. The lack of a common point of reference shared by all the actors may lead each component to favour options which are not necessarily ideal for the other components. In this management context, autonomy and dependence are the two notions underpinning the performance and flexibility required in order to respond to disruptive factors in ATM. Insufficient dependence or too high a degree of autonomy may also lead to irregularities which detract from the system’s global performance. Furthermore, it is the responsibility of the crew to implement a control order. The controller is not automatically a party to knowledge of the parameters for the execution of an order left to the pilot’s discretion. The controller is only able to acknowledge them after the event. It is therefore dangerous to base precise decisions on the outcome of the execution of the order before it has occurred.
3.2.4.2.4 The separation function

Control is based on the ability to change flight routes in order to prevent collisions. On a microscopic level, this is an insurmountable source of disruptions, regardless of the solution used to implement this function. Paradoxically, the more proactive a control tactic, the more it generates disruptions, since it applies to a greater number of aircraft and uses greater margins than do more reactive tactics because of the increase in permanent uncertainties with the spatio-temporal horizon. However, there are intrinsic limitations to this reactivity: the time taken to implement an order (time lag between controller and pilot), but also the reduced level of safety, because the advance warning needed to react to an unexpected event is no longer available, and the reduced performance of a controller placed under stress (as against the fact that he has fewer situations to handle).

Technological developments suggest that, in the near future, it will be possible to limit both the number of disruptive factors and the degree of uncertainty pertaining to each of them. In view of the random and hazardous nature of most of these factors, however, any new air navigation system must contain built-in properties to make it possible to manage them. These properties can be summarised as follows:

- It should allow adequate room for manoeuvre.
- It should adopt a level of uncertainty management commensurate with operational needs. The system should not be constrained if this brings no operational benefits, otherwise it will be too rigid and therefore incapable of managing the variability inherent in the air navigation system.
- It should make the system robust enough to deal with occasional disruptive factors.

3.2.5 Anticipation: a key process

As Garot & Ky point out [Bib 16] the complexity of the ATM system stems from the uncertainty of information and the imprecise nature of predicting air traffic movement. Air traffic is a continuous process involving aircraft which take part in rotations via life cycles. On this basis, each aircraft alternates between a “ground” status and an “airborne” status. This status and the aircraft’s intended movements can always be tracked using flight plans (filed or active).

The task for ATM is therefore to determine at a given moment (T0) what the status of air traffic will be at T0 + t in the future. Planning and anticipation are therefore spoken of in terms of the time span between T0 and T0 + t (Figure 4). Applied to all ATM actors, it becomes clear that this task is the same for ATFM or controllers at the control position. In the first case, planning can be carried out several hours, days, or even months in advance. In the case of controllers at the control position, action can be taken a few minutes, or possibly tens of minutes in advance. Depending on the extent of anticipation (short, medium or long term), the status of anticipated traffic will be determined on the basis of aircraft in flight or on the ground and/or information from either statistical forecasts or actual events as they unfold.
In terms of anticipation/planning, validating anticipated traffic is the key element of traffic management. It is here that all the disruptive factors between planned and actual movement combine to complicate the task of traffic management by introducing uncertainty into the prediction.

Traffic anticipation/planning is an essential stage in the traffic management process, yet the task of ATM does not stop there. It must also make a diagnosis of the anticipated traffic. Making a diagnosis means identifying whether the anticipated traffic is acceptable or not in terms of the relevant criteria. In an ATM context, the criteria will differ according to the anticipation time and the party making the diagnosis. At present, different criteria are applied by different actors. Controllers at the control position work with aircraft separation criteria. Parties earlier on in the process, such as the FMP (Flow Management Position) or the ATFM, work with traffic/volume criteria applied to flows, sectors, airports, or even to specific points along the route. It is possible to imagine that with different traffic management paradigms from those in use today, new criteria could be developed.

Once the diagnosis has been made, the final control task is to take action, if required by the diagnosis, in order to satisfy performance objectives. The action taken will differ depending on the actor involved in the traffic management process. Action can be taken as regards:

- the aircraft flight plan, either before take-off or during the flight (departure slot, arrival slot, airway, flight level, speed, route/heading);
- airspace, by exploiting its potential dynamic (collapsing or de-collapsing sectors, opening or closing routes or airspace, dynamic assignment of flight levels, deciding whether or not to use offsets);
- the staff, by adapting the manning of the control positions.
3.2.6 Modelling of air navigation

Although it is generally accepted that ATM must be understood holistically, it is more difficult to put this into concrete terms. Air navigation is a complex, dynamic system with numerous disruptive factors. It cannot be managed without planning in order to adapt resources to demand, but also, when there is no alternative, in order to limit demand in line with the resources available. The validity of planning is key to the air navigation system at both the global, strategic level and the local, tactical level. This planning, however, which generates uncertainty by its very nature, must allow for a high degree of reactivity, to enable it to adapt the system instantly to the desired performance and safety criteria.

3.2.6.1 Layer-based model

The relations between planning and adaptation are key to the air navigation system. Villiers [Bib 32] illustrates these relations with the aid of a model based on layers or filters. In this model, the air navigation system is described as a series of layers or filters applied to the chronological development of a flight between the strategic planning level located furthest upstream and the control unit at local level (Figure 5). The filters make it easier to handle traffic complexity and prediction by defining safety margins for each layer, depending on the level of uncertainty. The further upstream one is in the progress of the flight, the greater the tendency towards anticipation. The closer one is to the flight in real time, the greater the tendency towards reaction. The challenge, under this model, is for planning to be predictive enough for local, reactive adaptations to be in harmony with the overall planning and, most importantly, not to undermine it.

This model, by focusing on the limitations of ATM, describes a genuine “umbrella”, which protects front-line operators (i.e. the air traffic controllers). The objective is therefore not to exceed at local level, i.e. that of the control unit, the “limit” for the number of aircraft, in order to protect controllers.

![Figure 5: ATM “umbrella” model](image-url)
It is now considered that there is a lack of integration and information-sharing between layers in this model. There is no continuity between the predictive/anticipatory layers and the reactive/adaptive layers. In addition, this model approaches the air navigation system from the chronological perspective of a flight, whereas the system itself covers a set of aircraft all with a different status in relation to the ground and air components. Moreover, it does not envisage the interactions of the air navigation system with the other components of the air transport system.

3.2.6.2 Synchronised models

This is why all air navigation development projects use the terms "synchronisation" and "holistic approach" [Bib 31] [Bib 15] [Bib 19] to designate better integration between the various components of the system, both at the level of air navigation per se and between air navigation and the other components of air transport. Echoing the results of work carried out in the ground segment in the Airport CDM Project [Bib 7], the objective of which is to provide the most precise information possible on aircraft off-block times at airports through the sharing of information and cooperation between air navigation, airport and airline components, the recommendations of the Advisory Council for Aeronautical Research in Europe [Bib 2] and the conclusions of the Eleventh Air Navigation Conference [Bib 12] advocate the sharing of information and better cooperation between all the actors (air traffic bodies, airports and airlines) when decisions are taken.

The question, therefore, is essentially how do we structure and organise this synchronisation? Study of the literature and of many of the projects which deal with optimising the air navigation system reveals that the term "synchronisation" actually refers more to an attempt to optimise the current system than to a proposal for any genuine progress in integrating the various components of the transport system. Three general approaches to optimising the system may be identified.

The first consists in developing a system for predicting aircraft flight paths in four dimensions (for example a contract concerning a 4D tube corresponding to the envelope in which the aircraft has to operate - [Bib 28]). The selected paradigm is to develop traffic planning and prior traffic organisation to the extreme. The rationale behind this paradigm is that the reactive/adaptive human layer causes capacity constraints. Traffic capacity and aircraft safety are ensured predictively. It is thus possible to optimise the number of aircraft while respecting safety separation criteria by precisely predicting their positions. (Phase three of the Boeing ATM project [Bib 5]). The reactive layer has to be reduced to a minimum, leaving it to deal only with local situations which do not jeopardise planning as a whole. Responsibility for the reactive layer can be delegated to the ground or to the aircraft. The challenge under this approach is to give the aircraft a valid 4D contract and to update this contract during the flight depending on the disruptive factors encountered.

The limitations that might be pointed out in relation to such a system are that it involves overly-rigid predictions which would not appear to be entirely compatible with the complexity of the flight and its instability factors. Moreover, it can paradoxically result in less efficient routes by forcing aircraft to constantly compensate for variations in the flight conditions. Under this approach, knowledge of the precise positions of aircraft and the exchange of large amounts of data between the ground and the aircraft are the two technological prerequisites.
The second approach is the opposite of the first. Rather than making efforts to plan traffic before aircraft have left the ground, when one knows that all planning is subject to many disruptive factors, one will to some extent abandon the planning in order to deal with aircraft as and when they appear. The paradigm, then, is to organise traffic in relation to the estimated arrival times of the aircraft and the constraints of the destination airports. The earlier one is able to deal with the aircraft, the easier it is to organise the traffic precisely and productively. To an extent, air traffic is structured on the basis not of aircraft departures but of aircraft arrivals. This paradigm represents an extension to en-route control of concepts implemented for approach control (Maestro – Adagio). This system appears particularly well suited to airspace in which major flows of aircraft come into potential conflict with other flows to a greater or lesser degree. It is therefore particularly well developed in the USA for east-west flows and is under development in Australia, where links within the network are weak. At European level, trusting entirely to this paradigm does not appear suitable given the density of the network, since this system operates at a fundamentally local and independent level, namely that of the arrival airport. The greater the trend to deal with aircraft at an early stage, the more significant and further removed from local interests the interactions between the aircraft become, without any control of the network effect on capacity and safety. This paradigm would therefore appear to be satisfactory at local level but difficult to extend to a European-type network. Nevertheless, it could be suitable for specialised and specific airspace organisations.

All the projects which aim to plan as far ahead as possible [Bib 28] [Bib 29] or alternatively to organise arrival traffic with as much anticipation as possible depend on the development of technologies designed to reduce the uncertainties regarding the aircraft’s position and to share information between the ground and the aircraft (AFAS and MAFAS Projects, 5th PCRD-EC; Boeing ATM projects [Bib 5].

The third approach consists in better integrating the predictive/anticipatory level and the reactive/adaptive level by creating a coordination function. This coordination function is exercised in today’s control centres by the Flow Management Position (FMP). Much work, including the PHARE study [Bib 29] with the Multi Sector Planner, or FAM [Bib 14] with the FMP, has concentrated on developing and optimising this function. The fact that there is a need for this function to some extent reflects the weakness of the current system, since an interface needs to be added between the planning and adaptive levels. This is because the FMP in the current system is a protective filter which sends suggestions both downwards, towards the local level, and upwards, towards the global level. Under no circumstances, however, is the FMP called upon to have any direct involvement with traffic. It always acts via a decision-maker or enforcer who has a more precise and/or global view than itself. This raises the question not of the usefulness of this function, but of its place within the air navigation system and its interactions with the components of air traffic. The FMP is clearly an essential function for the synchronisation of air traffic management, but this function, if it is to be operational, must have the right means and resources at its disposal to deal with the challenges it faces with regard to traffic fluidity, capacity and safety.

3.2.6.3 Operational paradigms of air navigation

The many meanings of the term synchronisation are reflected in these approaches. This is why it is interesting to distinguish two types of air navigation management: asynchronous management and synchronous management.
Asynchronous management characterises the preliminary phase of air traffic management. It is used to define, allocate and mobilise the resources needed for a safe and efficient traffic flow. The data available during this phase is derived from forecasts, and the various processes implemented in this phase are intended to generate action plans. The phase could also be called the *a priori*, *off-line* or *back office* phase.

Asynchronous management is meaningful only if it is accompanied by synchronous management, during which short-term decisions need to be taken in the light of the actual traffic status within the framework of the predefined action plan. This phase could also be called the *real-time*, *on-line* or *front office* phase.

Far from being antinomic, these two methods of management are in fact complementary. They make it possible to improve the classification of the various operational paradigms, on the basis of the nature of the constraints placed on aircraft, their possible synchronous adaptation and, consequently, the resulting individual quality of service and capacity available. The following operational paradigms are analysed:

- 4D predictive,
- procedural control,
- free flight,
- free route,
- direct route,
- standard routes,
- highways.

Figure 6 shows that, as a general rule, the higher the quality of the service provided, the more difficult it is to meet capacity requirements. On the other hand, high-capacity systems cannot be managed without considerable constraints. This table is interesting because it highlights the issues connected with capacity and efficiency requirements. It also shows that there is no ideal solution and that the choice of how to organise the traffic will always be the result of a compromise between capacity and efficiency.
Moreover, the table puts into operation the ACARE 0 recommendations on the need for various operational methods (corresponding to various types of traffic and qualities of service, but also to various types of equipment) to coexist in European airspace. The working group identifies three main organisational categories in this connection:

- airspace with high traffic density;
- airspace with low traffic density;
- mixed airspace configurations where the transitions between the various operational methods will be made.

This third organisational category is particularly important in order to ensure the global cohesion and comprehensiveness of a unified navigation system. This means that, over and above local optimisation of air traffic through specific organisational measures, there must be a more general model for managing and organising air traffic, one in which local organisations retain their full relevance. One might think that many aircraft in the European area would be faced with only one type of air navigation organisation, because half of flights last less than one hour. This does not, however, take account of the radial linking of the European navigation network, which would probably mean that a large number of aircraft would have to cross the core area, which is very high-density airspace, on the way from and/or to much less dense airspace. Operational continuity for all air transport actors therefore becomes key to the viability of any future air navigation system.

### Figure 6: Operational paradigms of air navigation

<table>
<thead>
<tr>
<th>Operational paradigm</th>
<th>Service provided</th>
<th>Capacity available</th>
</tr>
</thead>
<tbody>
<tr>
<td>4D Predictive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asynchronous route and separation with servo-control</td>
<td>???</td>
<td>???</td>
</tr>
<tr>
<td>Procedural control</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asynchronous route and separation without servo-control</td>
<td>★★★★★</td>
<td>★</td>
</tr>
<tr>
<td>Free flight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Synchronous route – airborne self-separation</td>
<td>★★★★★</td>
<td>★★★</td>
</tr>
<tr>
<td>Free route</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Synchronous route – separation provided by the ground</td>
<td>★★★★</td>
<td>★★★</td>
</tr>
<tr>
<td>Direct route</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Personalised asynchronous horizontal route</td>
<td>★★★</td>
<td>★★★</td>
</tr>
<tr>
<td>Standard routes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard asynchronous horizontal route</td>
<td>★★</td>
<td>★★★★★</td>
</tr>
<tr>
<td>Highways</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard 3D and 4D asynchronous cruise route</td>
<td>★</td>
<td>★★★★★★</td>
</tr>
</tbody>
</table>
It is important to bear in mind that European airspace is naturally inhomogeneous in terms of demand: some zones are more attractive than others, flights are naturally concentrated in the central zone, and the airline’s operational policies based around central hubs create artificial areas of concentration. This variability is also temporal, since in the case of short and medium-haul flights it is strongly linked to the way the human activities are scheduled. In order to handle this diversity better, it would obviously be beneficial to adapt operational paradigms at local level. This would result in a European ATM system where the provision of navigation services would be based on varying operational modes dependent on location. This local tactical adaptation would seem more coherent and advantageous overall than the aircraft-by-aircraft adaptation which is sometimes mentioned. As regards the adaptation, although it is well designed spatially (each centre has its operational paradigm, with coordinated management of the interfaces), its temporal application gives rise to new problems. Clearly, night traffic is very different from day traffic in the core area: it is much less dense and largely comprises long-haul flights at cruise altitude. It would be highly advantageous to introduce a management system adapted to these parameters, which would of course be much more effective, in terms of routeings, than the system allowing the highly-dense day traffic to be handled in complete safety. However, the prospect of switching from one system to the other is much more daunting than the simple switch between geographical zones, where aircraft are handled individually. Moreover, a dynamic change in operational paradigms requires considerable adaptability on the part of staff.

3.2.6.4 The tripod of air navigation

The operational methods can only be approached globally, since they too are the result of a delicate compromise between:

- the organisation of traffic, i.e. planning flights in flows in relation to demand while taking account of the constraints and disruption generated by the network;
- the structure of the airspace both in the definition of routes and navigation points and in the delimitation of control units;
- lastly, the operational methods of the air traffic actors, which may develop on the basis of various continua such as anticipation versus adaptation, collaborative work versus individual work or industrialisation versus craftsmanship.

4 This type of local adaptation of the control rules on the basis of traffic density is routinely effected. It is done for example in the case of night traffic, or for centres located on the periphery of the core area, where aircraft are flying on direct rather than standard routes (some controllers deactivate standard route displays on their screens). However, such adaptations are currently left to the discretion of the operator, and they have not yet been systematised.
The difficulty of this compromise lies in the strength of the interactions and the interdependence of the three elements (Figure 7). All criteria relating to the capacity or safety of an air navigation system will thus depend directly on the quality of the compromise between the three pillars. The interdependence of the three pillars was demonstrated particularly clearly at the time of the Supersector study [Bib 20]. From radical manipulation of variables such as airspace, traffic organisation and controller working methods, it became clear that any given method of organising traffic was meaningful only in relation to a specific airspace structure. This meant that specialised working methods had to be designed. By monitoring working methods and airspace characteristics, moreover, it was possible to arrive at a different understanding of the capacity and safety criteria of the proposed air traffic system.

![Figure 7: The three pillars of air navigation](image)

The lesson of this study is that any approach to operational methods must consider all elements. Dealing with only one of the elements without considering the others makes little sense in operational terms. Any study the aim of which in trying to increase capacity and/or safety is merely to develop one or other of the three pillars will lose some its operational validity. It has to be said that many studies today consider only one of the three pillars. Admittedly, working in this way is easier at experimental and methodological level, but it remains very limiting with regard to the scope of the conclusions which can be drawn from the study. The only recommended course of action is to consider any new air traffic development concept in relation to all three pillars.
3.3 TRAFFIC DEVELOPMENT HYPOTHESES

Developing the air navigation system means responding to the challenges air transport will have to face in the future. These challenges must therefore be identified and defined. Whereas one of the main challenges of air navigation is to combine asynchronous and synchronous management, another is to define the best system of traffic organisation and management as regards this traffic. As we saw above in the description of the various operational paradigms, the service provided and air transport efficiency and capacity depend on the nature and density of traffic.

Currently there is a consensus that the existing air navigation system cannot cope with a consistent increase in traffic. But the real issue is to identify which qualitative and quantitative traffic increases air navigation will have to face and in what time frame.

Traffic forecasts predict an increase in traffic between now and 2020. At the end of the 1990s forecasts were optimistic in predicting a doubling or even tripling of traffic in the next 30 years, yet since the events of 11 September 2001 it has become extremely difficult to quantify traffic growth, especially within a set time scale. Each year since 2001 a series of events (war in Iraq, SARS epidemic, rise in oil prices) has forced a review of the various hypotheses put forward. It is therefore very difficult to obtain sufficiently valid and reliable forecasts with which to define the field of study of SHIFT. It therefore seems more reasonable to work with the scenario of a significant increase in traffic, which will necessitate a review of the organisation and operation of ATM within the aeronautical system. The working hypothesis adopted assumes a doubling of traffic, without specifying an exact date (2020 and beyond).

A second factor to be considered is the nature of this growth. At present, traffic poses a problem during peaks, when there is a surge in demand from users and airlines. This explains why only 20% of flights are subject to flow control measures. The growth in traffic could be absorbed by a more even distribution of traffic throughout the day without posing a real problem, but would this really meet the requirements of users? It seems not and it is therefore more appropriate to envisage traffic growth as an increase in current peaks.

The density of air traffic fluctuates over the course of the day, but it also fluctuates according to the day of the week and the season. The aeronautical system should therefore be sufficiently flexible and adaptable to be able to respond to the foreseeable and unforeseeable variations without being overwhelmed.

This becomes even more evident if we try to determine the type of flights that we will see in the future. Air traffic comprises commercial aviation, business aviation, private aviation and military aviation. If we confine ourselves to commercial and business aviation, the forms that air traffic may take in the next 30 years are manifold and far from certain:

- mass transportation (principle of large aircraft such as Airbus A380);
- “corporate” aviation for the business world (principle of flights given over to a professional sector, such as is currently offered to the oil industry by various airlines, or principle of direct “business” flights favouring comfort and speed for long-haul flights);
- aviation emphasising cost rather than service (low-cost airlines);
- regional aviation, which could be threatened by the development of multimodality (other high-speed means of transport such as the train), but which is also developing for inter-regional connections not covered by other high-speed modes of transport;

- international aviation, some of which may be rendered redundant by the new communication technologies.

All these elements or these uncertainties militate in favour of the development of an aeronautical and ATM system which is high-capacity, and safe, and above all is flexible and adaptable to these possible developments.

However, on the basis of current traffic, it is possible to identify certain characteristics which should influence future air traffic scenarios:

- 50% of flights cover distances of less than 330 NM and 75% of flights cover distances of less than 800 NM. These proportions should stay constant given that competition from other high-speed means of transport may justify closing down certain connections but cannot prevent the development of other connections.

- The “radial” European air network, which links the major airports, is also developing at inter-regional level with an increasingly dense network of flights.

- The arrival of large aircraft such as the A380 will perpetuate a radial network towards the airports accommodating these aircraft.

Smaller regional airports will develop in order to respond to customers' needs and avoid their having to travel via the major airports, which can waste time, incur additional costs and create congestion at these airports.

- The TMAs around major airports will increase in size and expand activities to include the smaller airports which will compensate for the constraints of the major airports. The TMA, grouping together several airports, should be the operational element for take-offs and landings with regard to en-route navigation.

- Airport movements are limited locally by the maximum capacity of an airport. Failing major changes in runway management or the acceptance by local residents of airport noise and pollution, the future situation will inevitably be fairly close to that seen today in saturated TMAs such as Paris, London or Frankfurt. As regards climbing/descending airport traffic, we will therefore probably be looking at an improvement in the current system, which is working, albeit with difficulty, rather than a major leap forward allowing us to overcome a hypothetical capacity barrier. Climbing/descending airport traffic is in fact protected by the management of the airports themselves: it is more vulnerable to traffic loads, but its management has nothing in common with aeronautical considerations.

- The major airlines, involved in global alliances, will build their networks around the hubs, which are central to their operational strategy.

- Faced with a service-focused business market, we should consider, via the low-cost airlines, a price-focused market which closely monitors the services provided in return for airport taxes and route charges.

- The industrialisation and sustainable growth of the aeronautical sector forces air service providers to work towards a maximum degree of regularity and punctuality, regardless of the system’s operational conditions, which is a real challenge if we consider the environmental (especially meteorological) conditions.
- The airlines' flight plans depend on the length of the flight and the type of aircraft used (jet engines or turboprops). Flight length distribution should maintain current proportions whereas the choice of aircraft is determined by operational costs (availability in the airline’s fleet, number of passengers and proportion of seats filled, price of kerosene and operational cost per seat/kilometre). This explains why, following a time when jet engines were in favour, airlines are increasingly advocating turboprop aircraft for connections over distances of less than 350 NM. An aircraft’s performance in relation to flight length is therefore becoming an important factor for determining the occupancy of airspace. To illustrate the role played by regional transport in the European system, 65% of flight time is below FL 300.

- The European network is characterised by an extremely dense network with a large number of “city pairs” and a demand that can be described as “everywhere to everywhere”. A look at current figures provides sufficient illustration. There are approximately 30,000 flights per day in the skies above Europe, broken down into 10,000 city pairs. The busiest city pair is Madrid-Barcelona, with 80 flights per day. The next busiest city pairs do not exceed 40 flights per day. Over half of all city pairs have less than 2 flights per day. The TOSCA (Testing Operational Scenarios for Concepts in ATM [Bib 23]) study showed that organising European airspace according to city pairs protected from the rest of the network (which can also be called “tubes”) would encompass only 35% of traffic, assuming the 300 most significant city pairs were included. The above data confirms the idea of an extremely complex network, lacking in structure. We should work towards a greater frequency of certain city pairs but also towards the creation of new city pairs which should give the future network the same characteristics as that of today.

- Besides this dense network, there are large traffic flows which, because of passenger demand, will not change (west-east and north-south flows). These traffic flows intersect over a European area called the “core area” which is at present a bottleneck for en-route traffic because of the complexity of traffic flying there. It is this area which is the focus for the CFMU flow control measures. Although this growth is diluted in European airspace, there will always be natural phenomena of local concentration towards the central area, currently already saturated, which lead us to believe that the current management system will be unable to absorb this future demand effectively. Any future growth in traffic will therefore affect the “core area” in particular. This reflects a major disparity within Europe in terms of traffic density, illustrated by the fact that 70% of traffic overflies 10% of airspace.
4 PARADIGM SHIFT

4.1 FRAMEWORK FOR CHANGE IN AIR NAVIGATION

4.1.1 A unifying framework

The SHIFT Project is part of the research and development drive initiated at European level by the European Commission [Bib 2][Bib 17] and EUROCONTROL [Bib 15]. It also incorporates the needs of the users, i.e. the airlines [Bib 3]. In other words, in order to establish a "sustainable development" phase for air transport, to improve the current performance criteria while coping with a regular increase in traffic, a number of recommendations must be respected, which can be summarised as follows:

- to press for a paradigm shift in the way in which the air transport system is designed and functions;
- to ensure that the punctuality and efficiency of air navigation are the explicit goals of productivity, as is already the case for safety;
- to press for a holistic approach to the air transport system with better integrated systems for sharing and exchanging information. Wider and more effective cooperation is required between the various actors, i.e. the airlines, airports and air navigation management and control bodies;
- to ensure maximum flexibility in low density areas and reduced flexibility in high density areas. Flexibility must also be envisaged when traffic density is not distributed evenly over time within a single airspace. There must be functional and operational continuity between volumes of airspace which use different operational methods to deal with different traffic loads;
- to review the role of the human operator within the wider ATM system (ATFM, ATC, airlines, airports, aircraft crews) with a view to developing automated aid systems. Humans will still occupy a central position but their role will develop towards a managerial role and the separation function could be shared between controllers and aircraft crews;
- to integrate local traffic management and organisation activities as part of an overall efficiency drive within the air transport system;
- to limit environmental risk factors and manage uncertainty factors more effectively. Better predictability of aircraft departure and arrival times is essential if punctuality and operational efficiency are to be guaranteed;
- to stress the need for any change to be valid only if incorporated from its initial phase, the transitional period between the current system and the future system.

On the basis of these recommendations and the analysis made in the first part of the document, it would seem appropriate to envisage an entirely new operational paradigm of aircraft management during the en-route phase, through a vision which takes account of:

- the entire duration of the flight, i.e. from airport to airport;
- but also the ground part.
This therefore involves defining an organisational system which lays down procedures both to carry out, use and manage planning and to control flights during all the flight phases, from block-to-block at airports. The advantage of this type of paradigm is that the flight is viewed in its entirety, with a view to operationality and productivity, while also taking into account all air transport components.

To put it simply, the Paradigm SHIFT aims to increase capacity and efficiency and reduce the cost of air navigation while maintaining or even increasing safety levels and reducing environmental impact.

To achieve these goals, the principles adopted are as follows:
- better cooperation between air navigation actors;
- better cooperation between the air navigation system and the other air transport actors;
- better planning thanks to more reliable and accurate data exchanges;
- better coordination between the ground and the aircraft, to improve airspace and airport capacity;
- local autonomy for those involved, within their areas of competence and responsibility.

Many air navigation projects are based on technological developments. SHIFT is to be seen against this background of technological developments but, at the present stage, it is not intended to be used as a tool. Its objective is to propose a set of concepts which, once validated, should lead to “feasible” developments in air navigation management. This is why Nicolaon’s recommendations [Bib 27] are intended to be used as a guideline for the development of an entirely new concept of air navigation:
- no change is justifiable unless it is essential, apposite, can be proved to work before being implemented and is operationally applicable so that it is accepted by all air navigation staff;
- efforts should be concentrated on improving traffic management in airspace where traffic density is high and in the most congested airspace;
- solutions must be pragmatic and provide answers to the most severe problems;
- change must be gradual, with an eye to a smooth transition. A "big bang" approach will give rise to resistance and grave doubts as to whether or not it is valid, for there is no way to certify a system prior to its being "tested" under real operating conditions;
- the solutions proposed or envisaged must make use of mature technologies which can be introduced in the short or medium term.

4.1.2 Prerequisites for future concepts

The definition of a future operational concept for air navigation must be envisaged within a well-defined conceptual framework in order to remain pragmatic and adhere to a credible timetable. SHIFT follows this logical approach to the letter, which is why it would seem important to specify the development hypotheses in accordance with which the study has been conducted.
4.1.2.1 Technology

As in all professional fields involving advanced technology, technology is one way of developing systems. Technology must not, however, be the only spur to development. It should rather accompany development, support it, make it possible or even initiate it, but under no circumstances must system development become a hostage to technological development. When confronted by major technological advances, one should always be able to ask oneself how useful such advances are in operational terms and what benefits may be expected from them, or else risk encountering problems of three types:

- the technological mirage: "there is no problem here, someone will find a solution";
- runaway technological progress, which always defers the feasibility and validity of the concept: "technology will always bring solutions to problems that cannot be solved today";
- costs which lose any relation to the original issues, even when the technological implementation is "perfect". All projects must be underpinned by an approach to costs which is compatible with the laws of the market.

In relation to these questions, Colin de Verdières [Bib 11] effectively sums up the problems of technological development by pointing out that for air navigation, for example, satellite-only technology for communication and navigation purposes was proposed in the 1990s without any proper definition of the initial aims. The "how" took priority over the "what" and, as a result, operational implementation did not follow. The definition of objectives and requirements must therefore guide manufacturers in the development of new technologies.

Despite these observations, it is nevertheless undeniable that technological developments will make it possible to envisage greater functionalities for the management of air navigation in the near future. Three main avenues must be considered:

- increased precision in locating aircraft and predicting their flight paths. These advances will depend on the development and optimisation of ground positioning system technology (the European Master Plan/SESAME), but also on systems such as the Flight Management System (FMS), which is to be found on board aircraft. Similarly, more precise meteorological models and greater allowance for wake vortices can but enhance the predictability of aircraft flight paths.

- a denser network of communications between aircraft, which will free traffic management from exclusive dependence on the ground segment (ADS-B (Automatic Dependent Surveillance Broadcast) technology).
- enhanced exchanges of information in real time between the ground and the aircraft. The decisive breakthrough in ground-air information exchange will come when it is possible to transmit one’s intentions to others. In terms of air-ground communications, this will mainly involve the transmission of data relating to the flight plan (whether it be an activated flight plan or a flight plan awaiting processing). For communications in the other direction, from the ground to the aircraft, a major field of investigation is clearly opening up for air navigation actors, one which is broader than safety per se. Irrespective of the direction of the transmission, significant developments may be discerned in the tasks of air transport actors in the future, insofar as shared knowledge regarding flight paths, or alternative flight paths, will make it possible to incorporate the time factor so as to move towards genuinely four-dimensional traffic management. Such developments are entirely feasible in view of the studies conducted within the framework of the AFAS (Aircraft in the Future ATM System) Programme, which relate precisely to the transmission of information between the aircraft and the ground, and the use of FMS data by air traffic controllers. Behind all this work and these applications, data-link technologies are developing.

4.1.2.2 Responsibility

The current traffic management model depends primarily, or even exclusively, on the ground segment, with one of two consequences:
- the capacities of the ground segment are exceeded when the traffic load is too heavy;
- conversely, the financial profitability of ground resources is low given the task to be carried out.

Whatever the hypotheses envisaged for traffic management in future, it is clear that consideration must be given to a redistribution of tasks between the aircraft and the ground. Whether it is supported by complete automation or by support systems, this question must be taken into account from now on. The studies conducted in the context of ASAS (Airborne Separation Assistance System) may not have explored all the operational implications of such a development (reference to the three-pillar model), but they have the merit of laying the foundations on which it must be envisaged. These questions are currently being raised in connection with the TCAS systems with conflict resolution, insofar as pilots have to follow the system’s proposals and controllers have to understand what is happening so that they can build up a "picture" of the situation and anticipate the consequences of the resolution advisory on future traffic [Bib 30].
In consequence, over and above the reapportionment of tasks, which will alter the roles of all concerned, the question of course arises of the actors’ responsibilities with respect to safety. To what extent can this responsibility be shared or ignored by an operator who might nevertheless have an "overview" of the traffic? These questions are far from being resolved because they not only demand a suitable legal framework but also require that the future tasks of air transport actors be taken into account in their entirety, both on the ground and on board aircraft. From a legal point of view, criminal liability is personal and individual. It cannot be collective. However, since several operators are required to interact in the same work space, it is appropriate to speak about joint liability. However, everyone is responsible for their own actions and therefore for their own mistakes, in proportion to the mistake made within the collective. Thus two, three or four operators may be held liable if it is proved that they each made a mistake. This means that the apportionment of tasks between operators has to be as clear as possible (who does what). Similarly, having access to another operator’s data may entail joint liability if it is established that normal procedures were not respected, taking into account the nature of the mission or the operator’s duties, areas of responsibility and also the authority enjoyed and resources available [Bib 25].

To return to the concept of airspace organised and managed on the basis of various operational methods, one can see the full extent of the flexibility which developments in ground-air responsibilities could bring to the cohesion and operation of such airspace.

4.1.2.3 The automation of tasks and the role of the human operator

One way of increasing capacity by overcoming human limitations is to make use of automation. Not so long ago, talk of the complete automation of air navigation provoked a lively response from professionals. It must now be recognised, however, that this course appears increasingly feasible. Projects such as PHARE [Bib 28] or work such as that done at the Global Optimization Laboratory, at the French National Civil Aviation Academy, show that such an approach is feasible in terms of the availability both of automation technologies and of the algorithmic approaches required in order to develop them. These approaches nevertheless raise a number of issues [Bib 27][Bib 34].

- They may require so much technological investment (satellite systems, aircraft equipment) that their final cost is no longer compatible with the laws of the air transport market, thereby invalidating them.

- Automation must be able to cope with emergencies or with unlikely, or even completely unforeseen, degraded situations. As things currently stand, it does not appear possible to automate such functions; the question which arises is therefore that of the role of the human who is to manage such a system.

- The transition between the existing system, in which the human operator plays a central role, and an entirely automated system. Automation can be envisaged only as the product of a gradual process during which the role of the human being is replaced by automated functions. The apportionment of tasks and skills between the human being and the automated system must therefore be very clear in order to avoid any confusion in managing aircraft.

- The last obstacle to automation is the question of who is responsible for safety. Will this responsibility be shared between several sub-systems, entrusted to an automated system controlled by a human operator, or entirely devolved to the automated system without any human intervention? The answers to these questions are far from obvious and are key to any automation process.
However, before considering complete automation, which nevertheless raises certain questions, numerous recommendations put forward the idea of a partial automation of air traffic management and control tasks.

In the wake of automation comes the question of how tasks should be apportioned or duties allocated between the support system and the human operator, with the related issues of apportionment of responsibility and monitoring by the operator of the support system [Bib 21][Bib 33].

Given the constraints of the air traffic control system, one of the challenges facing automation is how to reduce the controller’s workload to a level commensurate with his cognitive resources at times when the situation would otherwise leave him overloaded.

The aim is not to reduce an acceptable workload but rather to help the controller when he needs it – in other words, when he is no longer capable of performing his own task.

The assumption here is that any automation of the system must be envisaged not only in relation to the additional workload removed by automation but also in relation to the additional workload caused by implementing and monitoring the automated system. The workload reduction associated with a support system must free up enough time to allow the automated system to be managed. The greater the degree of responsibility – and thus the amount of surveillance and monitoring – assumed by the support system, the greater the workload demanded of the controller in order to work with it. Henceforth, therefore, support systems must be envisaged which enjoy as large a degree of autonomy as possible in terms of responsibility, and which are totally autonomous if possible. With such an approach, allocation on the basis of tasks seems a more suitable means of apportioning autonomy and responsibility than allocation on the basis of functions, which always leaves the human operator in the loop, monitoring the automated system.

4.1.3 Bases for future operational concepts

4.1.3.1 The airspace: disruption management tool

Structuring airspace appropriately is a means of managing uncertainty effectively by creating conditions under which uncertainty is no longer an issue or its consequences are limited. It is thus possible to envisage an airspace structured in such a way as to:

- minimise bottlenecks;
- reduce traffic complexity;
- reduce and even eliminate conflicts in some areas;
- modify controllers’ working methods, possibly involving actors in the aeronautical system other than controllers.

Many airspace-based uncertainty management solutions already exist in the current ATM system. However, the approaches adopted are local solutions which are not optimised over the network as a whole. A formal and system-wide approach applied to an integrated and coherent network must pave the way for the introduction of solutions to the problems of managing uncertainty and meeting capacity requirements.
4.1.3.2 Airspace flexibility

Traffic demand fluctuates in the course of a day, a week, a year, or in response to individual events. It is now acknowledged that, in the interests of managing heavy traffic loads, it is likely that more and more constraints will be placed on the navigation system. These constraints, however, are expedient only where loads are heavy and are disadvantageous when traffic loads diminish. It is for this reason that air navigation must not be envisaged in terms of rigid airspace but in terms of airspace which has the capacity to adapt to meet demand. This concept is compatible with, but different from, a system of air navigation organisation based on several operational methods. This really constitutes what might be described as dynamic and flexible organisation and management of airspace, i.e. organisation and management which is capable of adapting to demand.

In the framework of decentralised tactical management, it is still however crucial to ensure the systems’ consistency and interoperability in order for synchronous management to be problem-free. In engineering terms, this means that the passive and active resources must be based on the same equipment carried throughout Europe, and must use identical data models.

4.1.3.3 Managing uncertainty

The description of the current system for planning and anticipating traffic highlights the problem of uncertainty. This uncertainty is the result of disruptive factors inherent in the aeronautical system. Managing uncertainties stemming from these disruptive factors is a challenge on which the entire aeronautical community is focussed. Several approaches are envisaged:

- eliminating the disruptive factors. This, however, would seem unrealistic in view of the random and hazardous nature of most of these factors.
- reducing the uncertainty associated with each factor. This approach is one of the main initiatives envisaged – enhancing the performance of air traffic by exploiting technological developments. There must, however, be safeguards against any overconfidence, because this reduced uncertainty is also linked to improved performance. Today’s debate on the performance/uncertainty relationship, moreover, may continue in future, since a level of uncertainty will always exist, and this uncertainty will be proportionally just as great as it is today with regard to the performance or operating criteria used by the system.
a final approach involves creating loops for updating planning on the basis of actual information. An effective system for updating planning must be tailored to the specific requirements of air traffic – in other words, it must be continuous. It must allow traffic information updates to be collected and analysed continuously in order to update predicted changes. Its effectiveness relies on loops for circulating information, which can be used to act on and optimise traffic. Planning must be updated with a view to striking a balance between capacity and demand. The current approach is limiting since its only means of striking this balance is adjusting demand to fit capacity by delaying flights. Any optimisation of air navigation resources must also be envisaged in terms of adjusting capacity to meet demand. To this end, there are two essential prerequisites: “real-time” awareness of the status of traffic (both on the ground and in the air); and increased air navigation management flexibility in order to find the best compromise, in terms of safety, between capacity and air navigation constraints. It is thus possible to conceive of an air navigation system whose constraints become more marked as the demands made on capacity increase and vice versa, all within a contractual environment jointly defined by the partners in the aeronautical system.

4.1.3.4 Asynchronous and synchronous traffic management

The envisaged system organises the above concepts of asynchronous and synchronous air traffic management in a coherent way. It is based on management in two phases: an initial asynchronous phase, which organises and sets in place the resources to be used in the subsequent synchronous phase. The system is innovative as regards the organisation of the asynchronous phase and the link between the two phases.

4.1.3.4.1 Principles

Analysis

The ATM asynchronous phase must achieve two objectives:

- to define the optimal allocation of resources in the light of initial demand. It is possible that this allocation might not meet all the requirements identified, or might only meet them to some extent;

- to organise the resources needed to ensure smooth operations.

The setting in place of control resources is tactical by nature. Our use of the word tactical differs considerably from that traditionally employed in the ATM community, where it is used alongside the word “strategic” to distinguish between time frames (in particular within the framework of the layered model). The system proposed below reappropriates these terms along the lines of their military etymology in order to describe different levels of responsibility. The strategist defines large-scale objectives (continental in this instance) which he assigns at local level. The tactician organises resources on an operational scale allowing the strategic objectives to be achieved.

As is shown by the diversity of ways in which traffic can be controlled and the problems in identifying a satisfactory model for this, there is more than one suitable way of organising traffic locally. However, effective tactics in terms of cost and safety are necessarily consistently based on the tactical triangle (Figure 8):
The tactical triangle corresponds to the local customisation of the three pillars of air navigation. Consequently, the three vertices of the triangle have to be seen together. Concentrating on two vertices and ignoring the third will not result in a balanced system.

**Proposal**

In order to meet this requirement, we can imagine a system where traffic is globally coordinated as part of a strategic process, supported by a set of districts managed independently by tactical bodies. In this system, the tactical districts are both the partners, when strategy is decided (schedule preparation), and the local managers of the strategy’s implementation.

The current resource management system views resources as fixed and handles traffic accordingly. Conversely, one could equally naively consider the request to be sacred and subsequently identify the resources to accede to it. A compromise between these two situations needs to be found, based on a policy decision between free access and performance. Without attempting to pre-empt this decision, the architecture presented here makes the following assumptions regarding the organisation of routes in relation to the initial request:

- routes must take due account of airport constraints; if traffic is to increase radically, first and foremost runway capacity must be optimised;
- amending of strategic organisation in airspace is the exception. This means that, in the great majority of cases, a given flight relates to a fixed set of tactical units;
- amending of strategic organisation in time is marginalised in order to remain close to the initial request, which is deemed optimal in terms of punctuality;
- tactical organisation in airspace and in time is left to the discretion of the tactical level, provided that such organisation is within the framework of the strategic directives.

The aim of this programme is not to seek a global optimum of the metasystem (request + navigation system), in the absence of detailed information on that system. It is to produce a system which is cohesive, safe and efficient while remaining close to the initial request. Indeed, it would be pointless to seek a more explicit formulation of the requirements of the system users.

Consequently, the dialogue between the tactical manager and the strategic coordinator relates to traffic demand for a volume of airspace, expressed in terms of 4D entry and exit points, plus margins. The optimisation process is necessarily iterative: on the basis of the initial request, the district manager organises the control resources which will ensure that it is complied with, enabling him to make an initial estimate of costs and availability.

### 4.1.3.4.2 Role and responsibilities of the strategist

The formulation of a strategy ensures consistency between the various local adaptations made by the tactical managers, and their propagation throughout the system: ANS tactical managers and airline/airport operational managers.

The relevant strategic parameters are necessarily macroscopic.

In the asynchronous phase, the strategist never attempts to identify the resources used in detail: his knowledge is limited to the parameters transmitted by the tactician and allowing optimisation. In particular, concepts such as the detailed route of aircraft or load by basic traffic volume have no strategic relevance.

On the basis of the requirements for the system as a whole, which has to align ground management and airborne management of aircraft, the main factor influencing the strategic effectiveness of flights is punctuality\(^5\), i.e. compliance with the landing times requested by the airlines with the agreement of the airports. This parameter governs all of the following:

- runway occupancy;
- the organisation of aircraft processing resources (safety, refuelling, catering, maintenance, baggage and passenger handling);
- the commercial organisation of flights (passenger services, connections);
- airline fleet management (staff and aircraft rotation).

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\(^5\) Secondary processing of the arrival time by the current system is actually the major source of the criticism of that system. Currently, the CFMU’s usual response is to put back flights, generating substantial costs.
Without entering into the details of tactical management, its purpose is to ensure air traffic safety. Hence, in terms of capacity, the system in place is necessarily tailored to cater for the worst-case scenario. Since the system necessarily suffers from inertia to some extent in terms of time (once resources have been mobilised, it is impossible to demobilise them immediately), it is best to use all the resources available. This gives rise to the concept of regularity of access to resources as an indicator of the effectiveness of strategic management.

The strategic function as defined here is very different from that defined in the layered model. The aim is no longer to create a traffic regulation function in order to protect the control function against overloading\(^6\). It is to coordinate the various players and their problems. The overloading diagnosis is made at a more local level, thus maintaining tactical management autonomy.

4.1.3.4.3  Role and responsibilities of the tactician

In this decentralised system, the operators’ working methods and the infrastructure on which they are based are the responsibility of and dependent on the know-how of the local airspace manager. The preliminary organisation of the local operation of air traffic is a compromise between:

- the service provided individually to each aircraft. It can be measured in terms of cost in relation to the ideal Free Flight situation. Consideration must therefore be given to the direct cost of control (charges collected) and the various costs of the actual route (direct and environmental fuel costs, non-linear cost of delays);
- the available capacity, which can be measured in terms of volume (number of aircraft simultaneously controlled) or flow (number of new aircraft accepted).

The constraints affecting the decision include the progress of traffic, aircraft performance, operator competence, available technology and weather conditions.

This problem is indeed technical and local in nature. It is reasonable to expect the tactician to be able to arrive at an acceptable solution without having to negotiate with external partners, since it is he who holds all the cards.

4.1.3.4.4  All-synchronous or all-asynchronous

The system described above is based on the following two imperatives:

- Need for a synchronous approach: it is neither possible nor desirable to determine in advance the precise routes of aircraft.
- Need for an asynchronous approach: it is necessary to organise the system in advance.

This organisation of ATM into two complementary phases contrasts with two extreme visions of the future of ATC which need to be discussed here.

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\(^6\) This could be referred to as the umbrella model: the separation function governs the rest of the system which is intended to preformat its input, losing sight of the end purpose of the transport system.
All-asynchronous

In this vision, aircraft routes are determined in advance, and aircraft are servo-controlled using the 4D-predictive navigation aids incorporated in the latest-generation FMSs. Synchronous management is used only in exceptional circumstances, in order to respond to occasional unexpected events.

Unfortunately, things are not as simple as that. Planning flight routes in sufficiently fine detail to ensure separation at all times necessitates very close supervision of the work done by the crews, up to the point where they no longer have any autonomy. Furthermore, while this type of system seems at first sight to allocate better routes to aircraft, it will in fact be negatively affected by all the disruptions associated with air masses (wind, temperature, pressure) whereas a more opportunistic system could use this to its advantage.

Finally, this type of system does not seem sufficiently robust to provide the expected guarantees in terms of safety. While it would seem feasible to return to manual control (provided the qualifications of flight crews and controllers are kept up to date by means of the appropriate training) for isolated aircraft diverging from their flight plans, would it be possible to cope with an accidental and unforeseen incident simultaneously affecting a large number of aircraft? While the closure of a runway or appearance of an unexpected meteorological phenomenon are rare events, it is essential that they be taken into account when developing an ultra-safe system.

All-synchronous

The considerable advances made in conflict resolution algorithms, the possibility of transmitting data between the ground and the aircraft at high throughputs plus the low number of conflicts anticipated if traffic is allowed to organise itself along free routes all militate in favour of an opportunistic fully-automated ATM system. Such a system would seem particularly effective in terms of costs, since staff would no longer be required for ATC and flight routes, left to the initiative of airborne equipment and adapted in real time to environmental conditions, would be optimal.

However, the system would do away with human decision-making (controller and pilot). But, since it is not possible to guarantee the level of safety of an entirely automated system in the near future, a system has to be designed based on human responsibility. Since human intervention requires prior preparation, in order to define shift hours, working methods, etc., there needs to be an asynchronous component in management. Clearly, this would not be the case in a world where control capacity could be provided without prior notice at an acceptable cost.

4.1.3.4.5 Combining asynchronous and synchronous management

The various sources of disruptions have a decisive influence on the ATM system. They jeopardise the link between asynchronous and synchronous management, the system’s guarantee of safety and efficiency. A number of measures are required to strengthen this link and ensure that the system as a whole is robust.
Ignore the technological mirage
The ATM system has and will continue to have to co-exist with disruptions. In most cases, disruptions will not disappear at the stroke of a magic wand. A ploy often mentioned would be to make the synchronous progress of flights dependent on decisions taken asynchronously using 4D Predictive technology. This would be a very elegant solution to the problem of the divergence of intentions between planning, controller and pilot. It would delegate to the airborne system the management of disruptions resulting from uncertainties regarding flight parameters. From the control perspective, the problem would be resolved much more cheaply than by management through a controller. From the user's perspective, the gain is less obvious, since aircraft would be required to permanently resolve air mass disruptions. Moreover, the feasibility of a system of control by exception, where the operator would intervene only following an unexpected event, needs further study before being validated for operation.

Incorporate proactive management into tactics
ATC can justifiably envisage pre-processing of traffic in order to reach a nominal situation where traffic can be handled safely and effectively. It would be advantageous to formalise such pre-processing, since:
- it would help align planning and operations;
- its clarification would make it possible to use specific tools facilitating its implementation;
- this would allow its critical examination by all operators, who would thus be able to improve their know-how by ensuring “good practice” in a collective and consensual framework.

The necessary consistency between traffic, methods and the infrastructure provided and the tools allowing operators to implement them can be seen in the tactical triangle described above.

Improve knowledge of these disruptions
The above analysis of these disruptions does not in any way claim to be exhaustive. It attempts to move beyond simply noting the existence of disruptions by listing both their causes and effects. The intention is for it to be supplemented by suitable quantitative models, if possible. Taxiing is a preferred area of investigation.

Envisage simultaneous airborne and ground management
These two systems complement each other perfectly and consequently, internal disruptions have mutual implications.
Reject microscopic asynchronous management

Attempting to anticipate in detail the flight progress of an aircraft which has not yet taken off is tantamount to robbing planning of any credibility. This is because everybody will subsequently be able to see that what was forecast has not occurred. No meteorologist would attempt to predict the weather the next day above a specific location! In order to achieve its objectives, planning has to inspire confidence in those responsible for its application. A necessary stage comprises a criticism of the models used in the asynchronous phase in order to quantify the confidence which can be placed in the outcome of their operation.

Introduce retroactive mechanisms

In the same way as a controller, once he has issued an order, monitors its execution, it would be useful for the local work by ANS operators to be compared with the content of the instructions issued to them beforehand during planning. This retroactive mechanism would make it possible both to make operators aware of their responsibilities with a view to the nominal operation of the system, but also to be aware of discrepancies and to take the action required to remedy them while maintaining efficiency and safety.

This analysis and report could also be completed automatically and silently. For example, an aircraft which has just received an order could report on whether or not it has carried it out, which would release the controller from this task.

Finally, it would seem perfectly feasible to imagine closed-loop operations which would be more or less flexible but would still not short-circuit the ATC ground function.

Define explicit synchronous margins

This forms part of the development of a synchronous decision-making process. Once the nominal situation has been specified at the planning stage, it is possible to measure discrepancies if the current situation is known or future situation is predicted. A diagnosis of this discrepancy must then be carried out so that a decision can ultimately be taken. In view of the size and complexity of the system and the urgency of the decision, it would seem useful to synthesise the information on discrepancies in the form of a discrete-state indicator (such as a two-coloured or three-coloured traffic light). This presupposes the prior definition of tolerance thresholds. These thresholds have two advantages in principle:

- The information can easily be assimilated by the controller, whose processing might be expected to require fewer resources than the situation the information summarises. This should allow him to organise his work so that it does not affect the resources located downstream and may encourage him to remedy, insofar as is possible, a situation which is deteriorating, to the benefit of all.

- They make it possible to involve a higher level of responsibility in the context of operation by exception: green light – do nothing, red light – take action. This information potentially concerns all the downstream authorities in the flight logistics chain: subsequent districts, airport of destination. This mechanism makes it possible to predict the external consequences of a disruption.

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7 They would be better described as evaluations than as measurements, or values obtained by the function of observation of the forecast status of the system. In the jargon of data assimilation, the term measurement is reserved for information obtained from observation of the actual system.
The threshold value ideally depends on the flight in question and its position in the logistics chain, and should reflect as accurately as possible the constraints placed on downstream resources, by virtue of a propagation mechanism. This value must be specified in the asynchronous phase, but can be adjusted synchronously.

**Synchronisation based on arrivals**

For arrivals, it is important to organise the transition between the en-route part and the runway sequencing by synchronising aircraft with different origins before they commence their descent.

It is justifiable for airport management to seek to avoid traffic bottlenecks which it is unable to manage satisfactorily because of a lack of airspace or time. However, models based on traffic categories tend to indicate that it is counterproductive to seek to stagger cruising traffic since, at a given point in time, this consists of aircraft heading towards different areas, which would therefore make requests not mutually synchronised. Acceding to these requests, made on the basis of incompatible reasons, can only cause chaos in cruising traffic, which is sensitive in terms of capacity. It would be more logical to base this synchronisation function on a consistent system for managing climbing/descending airport traffic, which would keep an eye on all traffic heading towards an airport within a radius of 100-150 nautical miles.

Of course, asynchronous planning would be responsible for relaying the need to protect TMAs against overloading to the bodies supervising cruise navigation, but once the request had been taken into account (by a retrograde propagation method), synchronous management would cease to be involved, except by direct propagation.

**Draw up a risk management plan**

When a discrepancy is predicted or observed, decisions need to be taken accordingly. These synchronous decisions will question the asynchronous planning. In order to ensure that the decisions are both applicable and relevant, it is desirable for the decision to be accompanied, insofar as is possible, by a list of all of the parties affected by the discrepancy. This negotiation mechanism, which is cumbersome but effective, should only be used in exceptional circumstances. It is therefore necessary to adjust accordingly the sensitivity of the triggering parameter (the threshold value above which a discrepancy can no longer be handled solely at local level)\(^8\). In order to avoid this painstaking process, it might be a good idea to introduce standard measurements allowing the “expedited” processing of the most common situations.

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\(^8\) If, eventually, it proves possible to model problems sufficiently accurately, and the situation lends itself to this, it might be most useful to use risk cover strategies. Schematically, this involves combining situations where the consequences of uncertainties are correlated negatively.
It would seem worthwhile to process proactively certain situations resulting from an ad hoc event. For example, the system could respond to a storm by implementing a suitable plan. Of course, this plan could, insofar as possible, be based on the concept of consistency symbolised by the tactical triangle. It might also be possible to adapt the data collection and transmission resources and the display equipment to allow cloud masses to be displayed on the control screen in such situations.

4.1.4 Paradigm SHIFT

In order to put into operation all the concepts detailed in the previous chapters, the proposals concerning the Paradigm SHIFT have been grouped under three main concepts:

- The first concept is that of a European airspace where several operational methods for air navigation management and control exist alongside one another, according to the geographical area. This concept, originating from the ACARE recommendations, would seem essential to optimise traffic fluidity and capacity. Within the framework of SHIFT, flexibility and adaptation of these operational methods must be linked in order to reach the most effective compromise between demand, the resources available, the capacity criteria and traffic fluidity and safety.

- The second concept is that of functional and operational continuity in aircraft management, both on the ground and in the air, with a view to meeting safety and productivity objectives. Functional continuity has an airspace dimension (heterogeneity of European airspace) and a time dimension (from planning to implementation). To this end, it is proposed to bring together all air navigation components by means of a “contract of objective”.

- The third and last concept aims to resolve the issues concerning the overloading of certain areas of European airspace. This concept is that of a dual airspace in which the traffic management and control systems are divided into two, the operational continuity of the systems being ensured by the “contract of objective”.

The first concept is not exclusive to the Paradigm SHIFT although it is an important prerequisite of the project. To study it requires significant resources with which to model airspace, traffic and working methods at European level. Such a study could not be carried out as part of this phase of the work.

However, the discussions held to develop the two other concepts, which are considered in the remainder of this document, did not overlook the principle of a heterogeneous airspace from the viewpoint of these operational methods. They were defined in line with this principle and even make it possible to specify certain of its characteristics.

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9 Data can be obtained, using airborne meteorological radars, and the cumulo nimbus clouds are shown on the image restored by a primary radar, but they remain inaccessible to the controller because it is not possible to activate a specific datalink protocol, switch to a primary radar transmission mode and de-activate processing of the corresponding signal.
4.2 "CONTRACT OF OBJECTIVE"

4.2.1 Why a "contract of objective"?

Improving productivity while maintaining a high level of safety within the air navigation system requires better functional and operational continuity between the various actors, whether they be air traffic actors or those playing a more global role in the air transport system (airlines and airports). There must therefore be an operational link between all these actors identifying the role and the resultant redistribution of tasks for each actor, in relation to a clear, well-defined objective which is accepted by all concerned.

This objective is general, of course, and will be declined for each actor in accordance with the actor's specific characteristics and workload. It has the merit, however, of creating a certain amount of common ground between the actors which will enable them to interact and adapt to operational circumstances and constraints without losing sight either of the global objective, which ensures productivity, or of interactions with the other actors. The challenge, then, is to define a common operational minimum among the actors which is sufficient to strike the right balance between productivity and safety. Behind these recommendations one can discern the concept of the contract, which is increasingly common in the literature on the subject: one example is the four-dimensional contract suggested in the framework of the PHARE Project [Bib 28] and the ACARE recommendations [Bib 2]; another is shared vision for airports in order to predict airport departures as accurately as possible [Bib 7]. The contracts mentioned so far have a local dimension in that they involve only a limited number of actors rather than all the actors in the air navigation system.

For this reason, it is helpful to propose a global contract for the "flight" segment. This contract must facilitate functional and operational continuity between aircraft and the ground segment, since it is compatible with the objectives of airports, and also play a role in integrating the flight segment into the rest of the system, by creating bonds of reciprocal responsibility between the airline, the aircrew and air traffic components. The proposed name of this contract is the "contract of objective". The "contract of objective" is associated with a flight. All the "contracts of objective" for a given time window (for example, a day or half-day) are known as the final operational agreement. The final operational agreement is the result of a process of negotiation and refinement known as the operational plan. The operational plan brings together all the air transport actors involved in air navigation. The operational plan for a given time window lasts several months and requires the conclusion of interim agreements relating to the planning and management of the rotations requested by airlines. These interim agreements are known as operational agreements.

The organisations taking part in the operational plan are the actors. The actors are bodies which, during the implementation of the plan, will call on the services of operators, who will be directly answerable to the actors for their actions.

The "contract of objective" is intended first of all as a guarantee of results geared towards the satisfaction of air transport users on the basis of known constraints at the time when the contract is drawn up. The "contract of objective" is the result of a process of negotiation between the actors concerned, one which is initiated well before the flight. It is based on the following elements:
- gradual refinement of the objectives over time, leading to a final contract before take-off from the airport, thus guaranteeing as effectively as possible that the objectives will be implemented;

- negotiation of the continent-wide air navigation system at global level, with all known information made available (real-time information regarding the state of available resources, adaptation of resources to demand);

- incorporation of disruptive factors in the drafting and implementation of the "contract of objective";

- incorporation of appropriate room for manoeuvre to cope with disruptive factors (whether ad hoc, constant imprecision or caused by system-wide problems);

- management at the right level and using appropriate methods of air traffic constraints and the consequences of disruptive factors;

- a common overview of the flight and its development shared by the various actors;

- definition of each actor's objectives and of the information needed in order to achieve them;

- definition of each actor's responsibilities on the basis of the objectives and methods defined in the contract.

Over and above a commitment regarding the result, the "contract of objective" is a means of sharing the actors' intentions and thus of creating better synergy and communication among them, which will stimulate performance with a view to ensuring achievement of a shared result. Once the "contract of objective" is drafted, there is a commitment on the part of the entire navigation system, through its various actors (at tower, approach and en-route levels, but also at global level, for the planning of future traffic on the basis of what has already been negotiated) vis-à-vis the other actors, namely airlines and airports.

The "contract of objective" is linked with the aircraft's operating cycle and complements Airport CDM (Figure 9). Airport CDM predicts an off-block time; this makes it possible to refine the "contract of objective", the objective of which is not to adhere to a take-off time but to respect an arrival slot agreed with the airline and the airport. The arrival slot takes account of the following:

- runway constraints at airports;

- reception constraints and airline network and hub constraints;

- en-route control constraints.

![Figure 9: The flight within the aircraft's operating cycle](image-url)
The benefits for the airline of having a "contract of objective" are twofold:

- The navigation system must ensure that the aircraft lands at the destination airport at the scheduled time. Adhering to a flight schedule is no longer the concern only of the aircraft's crew. The control team and the aircraft's crew are able to work in synergy.

- Since it receives a guarantee relating to the aircraft's arrival time at the moment it departs, the airline can plan its resources for ground-based management of the aircraft and optimise the management of its hubs and operations. The same applies to airport resource management.

Through the "contract of objective", air traffic control is given the opportunity to go further in terms of service than "capacity and safety" alone. There is a commitment that a schedule will be adhered to at the destination airport. This means that ATC is responsible for managing traffic during the flight by allocating priorities among aircraft as appropriate in order to honour "contracts of objective". An information of the aircraft's final intentions, therefore, makes it possible to manage its room for manoeuvre earlier in order to deal with disruptive factors. ATC thus plays an active part in managing the flight by proposing solutions which meet airlines' operational targets and therefore the requirements of the crews.

For every operator associated with every actor which has negotiated "contracts of objective", contracts take the form of a service form, which is a specific version of the service contract for that operator. For the crew, the flight plan corresponds to a service form. For operators associated with air navigation service providers (ANSPs), the service form corresponds to the operational objectives they must fulfil and how to fulfil them. Some parts of the service form for ANSP operators also appear on the service form for aircrews. The information contained in both service forms thus becomes a shared frame of reference for the various operators involved in a given aircraft flight phase. ANSP operators can thus be informed of the aircraft's intentions in order to manage it on the basis of those intentions. Such information about the aircrew's final intentions makes it possible to manage the aircraft's room for manoeuvre earlier in order to deal with disruptive factors.

Since they take the form of service forms which are specific to each operator but share common elements, a common frame of reference is created for work, ensuring functional and operational continuity for the flight. These shared elements, moreover, constitute essential control loops linking the ground and the aircraft and guaranteeing that the final objective is attained without the possibility of sidetracking by disruptive factors. The control loops must be carefully distributed over time so that:

- They are not overly restrictive for crews and controllers alike, for, if this is the case, the loops will generate an additional workload which cannot be justified in view of the operational and functional challenges and reduce the leeway for managing disruptive factors. It might seem tempting to provide crews and control with a 4D flight path generated on the basis of a deterministic air traffic model. While this might be a temptation, such a system would seem to be totally unsuited to the specific nature of ATC and to the management of ATC-related disruptive factors in particular (see section 2.2.4).

- They are not too infrequent either, or they will not provide the structural framework guaranteeing that the objective will be met. Moreover, insufficient convergence points between the ground and the aircraft would give back too much independence to each actor, leading to the emergence of individual objectives, a cause of system-wide problems.
4.2.2 The principles behind the "contract of objective"

4.2.2.1 Description

The "contract of objective" is not a rigid framework within which aircraft have to operate. It contains built-in margins for flexibility and adjustment in order to manage disruptive factors. These margins are compatible with those of the other components of the aeronautical system. The contract is therefore a flight envelope defined on the basis of:

- The aircraft's room for manoeuvre ("commercial" flight envelope).
- Predictions relating to en-route control limitations.
- The objective to be attained. The closer one comes to the final objective, the smaller the room for manoeuvre becomes.

The "contract of objective" gives the controller and aircrew the means of managing the imprecision inherent in air traffic in accordance with their own objectives. The crews' objective, therefore, is to adhere to an arrival schedule; controllers, on the other hand, must ensure aircraft safety while keeping aircraft within the envelope defined in the contract, which guarantees that the contract's objective will be respected.

The diagram below illustrates a possible "contract of objective" with its built-in margins for manoeuvre and its links to the components of the aeronautical system (Figure 10).

Figure 10: The "contract of objective" and its envelope
The "contract of objective" is established on the basis of information received from ANSPs and Airport CDM within a time envelope commensurate with the inherent scope for uncertainties at off-block time and during taxiing, in order to adhere to the take-off time. Take-off time is determined with reference to the runway sequence laid down by tower controllers on the basis of runway capacity and the climb performance of the aircraft.

The "contract of objective" defines an arrival time envelope for the aircraft during approach; the envelope will be compatible with traffic prediction capacities at that moment. During this predictive phase, it is futile to speculate about conflicts, for at this stage the uncertainty regarding the aircrafts' position is greater than the separation margins between them. Maintenance of separation is a matter of local adjustment carried out by controllers at control units.

The climb phase generates uncertainty. The objective of air traffic control is to remain within the margins of the envelope guaranteeing that the arrival envelope is respected.

ATC's aim during the flight is to bring the aircraft into the arrival envelope at the start of the approach, subject to disruptive factors. ATC is aware at all times of the aircraft's position in four dimensions within its envelope. It is also aware of the disparity between this position and the flight path described in the service forms. This information allows it to manage disruptive factors while taking into account which aircraft have priority in terms of adherence to arrival schedules. Consequently, each ANSP operator manages aircraft on the basis of the information contained in his or her service form, and only this information is of interest to him or her.

The arrival envelope for aircraft in the approach phase must be precise enough to allow for organisation of the reception of aircraft at the airport. The flow of arriving aircraft is managed by ANSPs in order to optimise runway capacity and also to guarantee that the aircraft landing time envelope is the same as the envelope for arrival at approach. Approach control determines the precise touchdown time when working out its landing sequence.

If, in the course of the flight, the ATC system cannot honour the "contract of objective", either on account of "poor" traffic planning or because of ad hoc occurrences which cannot be managed within the margins laid down in the contracts, provision must be made for airlines, ANSPs and airports to renegotiate the contract during the flight.

The effectiveness of the "contract of objective" will depend on the capacity of ANSPs to deliver a "contract of objective" to aircraft a few minutes before off-block time, and on ANSP operators being able to apply this contract. One criterion for assessing whether the system is valid will be the number of "contracts of objective" renegotiated.
4.2.2.2 Implications for the activities of operators

For controllers, the incorporation of the "contract of objective" into their activities brings an additional task. It is clear that respecting the "contract of objective" is a key priority in their activities, but it is still secondary to safety. Safety is the controller's top priority. The addition of this new task poses the underlying question of controller workload. When traffic is heavy, will controllers be able to provide not only a safe but also a performance-related service? At present, it is not possible to answer this question. Interactions with the operational controllers taking part in the SHIFT Project would seem to indicate that they do not rule out the possibility entirely and feel that it is deserving of study insofar as better planning of traffic should make it possible not to overload controllers. Implied in this question, in fact, are the limits of an approach which seeks to address only one organisational aspect of the problem of air navigation without taking account of the other two of the three tactical pillars: working methods and airspace. Although the concept of the "contract of objective" represents one avenue for developing the air navigation system, it is clearly insufficient on its own and must be envisaged within the more precise framework of a volume of airspace and a set of working methods, in order to allow an assessment of the benefits it could bring. The choice of airspace and working methods will, of course, depend on which development hypotheses are selected in relation to the nature and quantity of the traffic.

Obviously, the introduction of an additional task making it possible to provide the service on which respecting the "contract of objective" depends will mean that operators will have to process additional information and communications. Relations with other air navigation actors, in particular with aircraft, will change, and this will require the development of tools, interfaces and appropriate working methods.

The "contract of objective" significantly alters the role of aircrew in the conduct of the flight. They are no longer the only persons responsible for adhering to the arrival time at the destination. They cannot, of course, question the "contract of objective" once it has been accepted by all the partners. As long as the flight takes place within the envelope defined in the contract, it falls to the controller to give orders to crews regarding safety and navigation. It goes without saying that under no circumstances can controllers pilot the aircraft. All orders from controllers are submitted for approval to and executed by the crew. This means that the crew has at its disposal on board the aircraft information telling it the "position" of the aircraft in the contract.

In technological terms, coordination between the ground and the aircraft requires the capacity to transfer data relating to "contracts of objective", and therefore to service forms, between the operators representing the various actors.
4.2.3 Drafting the "contract of objective"

4.2.3.1 The basis for drafting the "contract of objective"

The process of drafting "contracts of objective" is at the heart of the air navigation system, since this process will define the framework within which flights will be performed and the responsibilities which will apply to ATC actors.

The "contract of objective" is drafted on the basis of two sets of requirements:
- The individual requirements of the flight in question.
- The general or global requirements of the air transport system and all its partners. The individual requirements are a subset of the general requirements.

The drafting of the "contract of objective(s)" is done at strategic level through the operational plan. The aim of the operational plan is to reach an operational agreement for all flights within a given time window through a process of negotiation which achieves a balance between the demand, the resources and the solutions adopted. These negotiations are a long-term process and are optimised by refinement and update iterations.

This means that the process of drafting the contract depends on:

- the contract's origin, i.e. the initial request (which may be made anywhere from several months before the flight, as in the case of scheduled flights, to a few hours before, as in the case of "last-minute" flights);
- its end, i.e. the issue of the contract, which takes place a few minutes before off-block time at the airport (this time period is variable, but a limit of 10-15 minutes before the flight would appear compatible with the output of Airport CDM in the interests of ensuring operational continuity).

The aim of the operational plan is to manage the scarce resources represented by runway capacities and ATC bottlenecks. To this end, the aims of this approach to the drafting process will be:

- To adjust the resources available to fit demand. This adjustment is a two-way process, i.e. ATC resources are adjusted in accordance with user demands in the full knowledge that the resources are limited and will not be able fully to satisfy demand. This also constitutes an acknowledgement that for certain areas of airspace, it may not be possible to satisfy the whole of the demand. The system will, however, be optimised in order to satisfy demand as far as possible.
- To enhance cooperation between the various actors in air navigation in order to share and work on the most precise and up-to-date information.
- To minimise and/or attenuate global problems in order to encourage adjustments and limit the drawbacks.
- To reason at each stage of the drafting process with an appropriate level of granularity, which will depend on the precise information and the time remaining for the issuing of the final contract.
- To use "real-time" information as soon as it becomes available in order to increase the precision of the planning.

The challenge at the heart of the drafting process is therefore to build a system based on adaptive procedures and the sharing of considerable amounts of information.

### 4.2.3.2 The drafting process

The negotiation process or operational plan is conducted by a moderator and produces the operational agreement, which includes all the "contracts of objective" for a given time window. Within this time window, the "contracts of objective" relating to aircraft operating cycles may have one of two statuses (Figure 11):

- they may all be in the drafting phase and therefore anticipated;
- some of them may in the process of being implemented and may thus influence other contracts which are still in the drafting phase.

![Figure 11: The time window and the aircraft rotations](image-url)

**CURRENT TIME**

**Rotations**
- Rot 1
- Rot 2
- Rot 3
- Rot 4
- Rot 5
- Rot 6
- Rot 7

**REFERENCE TIME WINDOW**

**time**

- Historic
- Anticipation

**On ground**

**Airborne**
The drafting process comprises three phases, all centred on the assessment and planning of air traffic (Figure 12):

- Phase 1: airport resource management;
- Phase 2: resource management and anticipation of disruption.
- Phase 3: disruption management.

4.2.3.2.1 Phase 1: Airport resource management

This phase is initiated when the airlines express the demand. It relates mainly to flight requests submitted several weeks before the flight. It is, in fact, more useful to visualise flights using the concept of rotations. In operational terms, the rotation is a more useful element for airlines than flights because it is significant with regard to operations. The rotation is more complex than the flights associated with it because it takes account of constraints related to the aircraft and/or to flight sequencing, depending on whether the flights in question are short- or long-haul. The objective is therefore to identify which resources will be available at airport level by examining runway capacities, in order to bring the resources into line with airline demand on the date when the requested flights are to be performed. This is the first stage, for it involves management of the "scarcest" resource, namely runway capacities at airports.

This phase is refined by two factors:

- The operational expertise of air navigation actors who, from their wealth of experience, when faced with similar situations, will be capable of proposing by analogy a range of responses.
- Historical air traffic data, which make it possible to define the framework within which demand and resources will fluctuate. From this phase onwards, very general data relating to meteorological forecasts or the nature of the traffic are also taken into account.
At the end of Phase 1, it is possible to advance figures relating to runway capacities at airports, on the basis of which the navigation system as a whole will subsequently be adapted. Operational Agreement 1 is obtained in this way.

The actors during this phase are therefore the airports, the airlines and the moderator.

4.2.3.2.2 Phase 2: Resource management and anticipation of disruption

Phase 2 follows Phase 1 and differs from it in that a new actor intervenes in this phase, namely air navigation service providers, whether civil or military. Phase 2 is initiated on the basis of Operational Agreement 1. This Agreement makes it possible:

- firstly, to provide ANSPs with a basis for their work in preparing their strategies before the subsequent negotiation phase, which will produce Operational Agreement 2;
- secondly, to provide support to the actors involved in Phase 1 in order to incorporate, in the form of modifications, fresh developments relating to the predicted demand and airport resources.

Once the ANSPs have worked out their strategies on the basis of Operational Agreement 1, a phase of negotiations between all the actors enables the production of Operational Agreement 2. This Agreement intervenes before the end of Phase 2, since in this way it provides each of the actors with a basis on which to work at a sufficiently early stage for them to organise themselves and deploy enough resources (staff, maintenance operations, manning plan, etc.) at the appropriate level.

At this stage, however, the results of Operational Agreement 2 are likely to change, as the date on which the demand will appear is a long way off and numerous disruptions will still occur. Accordingly, predictions relating to disruption and developments in the demand are modified as appropriate by the actors.

This ongoing modification process makes it possible to introduce changes to the balance between demand and resources on the basis of the most recent operational developments. These iterative modifications must, however, lead to an agreement between all the partners, which intervenes at the end of Phase 2 and is known as the final operational agreement. The final operational agreement marks the end of Phase 2 of the process of drafting the "contracts of objective".

In the course of Phase 2, the negotiation process has two aims:

- to incorporate known or probable medium-term disruption (i.e. disruption known about or considered likely to occur approximately one month before the flight) as soon as possible;
- to enhance the predictions with the operational expertise of air navigation actors and historical data concerning the traffic and associated disruption.

Decisions are taken in consultation and after negotiations between the actors. The negotiations are conducted under the supervision of the moderator, which is one of the air transport system's central bodies.
During this phase, it is important to stress that the resources must match the demand. This is because it is during this phase that the role of the air navigation system changes in relation to the present model: since its function is to respond to demand, account must be taken of the fact that air navigation, via its ANSPs and management of its airspace, must attempt to respond to that demand. It is for ATC, by mobilising and using its resources, to find solutions which best respond to demand. It is at this level that the concepts set out in the sections relating to the balance between flexible and adaptive airspace (see above) will apply.

4.2.3.2.3 Phase 3: Disruption management

Phase 3 follows on chronologically from Phase 2. It is during this phase that the real traffic progress will be incorporated on the basis of the final operational agreement and that the transition will be made between a discrete planning system and a continuous system which will take account of the real traffic situation.

As soon as Phase 3 begins, certain flights covered by the final operational agreement, i.e. within the given time window, interact directly with flights which are already in progress, and are also confronted by disruptive factors which can no longer be dealt with at a purely strategic level. This means that data relating to the flight segments of the operating cycles of aircraft covered by the final operational agreement are taken into account when planning these flights. This leads to the definition of the "contract of objective", which is issued to all the actors involved in air navigation. The "contract of objective" is delivered a few minutes before off-block time. The "contract of objective" incorporates the most recent data on the aircraft's departure time, the state of the navigation network and any current disruptive factors which will affect future traffic. Since the "contract of objective" is issued shortly before off-block time at the airport, it enables air navigation actors to define the aircraft's predicted flight paths in order to establish the crew's service form, i.e. the flight plan. The crew will have sufficient time in advance to prepare their flight on the basis of the predicted flight paths received from air navigation actors.

This period requires central air navigation structures to have the capacity for constant awareness of the current traffic status and developments in order to refine its own planning. Since this period is also the subject of negotiations between the partners, geared towards bringing together asynchronous and synchronous traffic management, a real-time information-sharing system is required. Consultations and negotiations must be conducted using simplified and rapid procedures in order to comply with the time constraints within which decisions must be taken.

The "contract of objective" is drafted on the basis of criteria relating to traffic capacity, traffic fluidity and "global" safety. The drafting of the "contract of objective" does not take account of traffic safety "in detail", i.e. separation between aircraft. This responsibility falls to the control position, i.e. to operators associated with air navigation actors. The "contract of objective" or, to be precise, the "contracts of objective" relating to a given time window, create the conditions at global airspace level for control positions to perform properly their task of ensuring aircraft safety "in detail".
Phases 1 and 2 of the process of drafting the "contract of objective" are "preventive" phases, designed to forestall global questioning of the initial planning during Phase 3. This is why the updates, adaptations and refinements introduced during Phase 3 in particular must not be regulatory actions taken by aircraft but rather actions relating to aircraft flight paths. Until the "contract of objective" is issued, therefore, the air traffic management structure must be central and global. If the "contracts of objective" delivered in this way are relevant, there is no longer any reason for envisaging strategic actions during the flight aimed at modifying the flight path. Only tactical actions taken in order to maintain separation between aircraft are called for at control-position level.
4.3 FUNCTIONAL APPROACH

As mentioned above (see section 3.2.3.2), the operational plan (OP) supports the refinement mechanism which, as the process progresses, allows an increasingly precise assessment of demand and the extent to which it is in line with resources. It brings together the appropriate interlocutors (actors) for each phase and introduces enough of the requisite granularity, in accordance with the phase under consideration.

The principal actors considered in this document are: airlines, airports and ANSPs.

This process is based on two levels as presented in Figure 13:

- **Strategy:** at this level, objectives will be defined which must be achieved by all the actors involved in defining the traffic (i.e. the initial demand) and managing resources. As the deadline for the application of this strategy approaches, it is re-evaluated and the necessary refinements are introduced. Naturally, there is a need here to refine these objectives and ensure that they are not called into question any more than is strictly necessary.

  These objectives remain system-wide. They are thus large-scale objectives (i.e. significant granularity) which describe in a transparent manner each actor's obligations towards the others. In short, it is the strategic level which will make it possible to establish all the interfaces between the various actors in order to meet all of the demand expressed. For a given flight, the "contract of objective" (CoO) represents the final product at this level. The contract takes account of disruption affecting the real situation, whether exogenous (e.g. weather-related) or endogenous (e.g. linked to airport operations), and occurring up to the point when it is published.

  In order to avoid any kind of blockage in the process, a decision-making body of last instance, to be known as the moderator, will manage the strategic level. It will not only regulate in "authoritarian" fashion any disagreements arising between actors, but will also guarantee the proper functioning of the process and the consistency of the various operational agreements. It will ensure that the information required by each actor (operational agreements and "contracts of objective") is available, accessible and consistent. Lastly, it will also play a role in monitoring the smooth functioning of the operational agreement *ex post facto* (i.e. post-analysis) and will be able to take disciplinary action, if necessary, against actors who have not honoured their "contracts of objective".

- **Tactics:** at this level, the means required in order to achieve the objectives resulting from the strategy will be defined and organised. Although local (i.e. operational) objectives are assigned at strategic level, it goes without saying that tacticians will have provided strategic-level staff with information relevant to the negotiations. It thus becomes clear, in fact, that refining the strategic objectives also makes possible a similar mechanism at tactical level. The establishment at local level of a master plan for each actor will be refined in parallel and will make it possible to support the operational agreement.
The operational plan makes it possible to bring in line the scarce resources constituted by runway capacities and controllers (i.e. control capacity) with demand. It is on this aspect that the process will initially be focused. Subsequently, as the deadline for the envisaged real traffic approaches, disruption management will be added to this concern, the aim being to bring disruption management into line as much as possible with it until the "contracts of objective" are published.
Figure 14 illustrates the progress of the elaboration process (i.e. the operational plan) up to the activation of a "contract of objective".

It should be noted that this process is continuous over time and is constantly active, since it involves temporal anticipation.

At any given moment, indeed, one may simultaneously be, for example:
- in the disruption management phase for the operational agreement which will come into effect the following day;
- in the initial resource management phase for the operational agreement which will be active in a month's time.

The following paragraphs will detail the various stages of the global process by describing the various milestones (i.e. the rounds) and the role of each actor during these phases.

4.3.1 The operational plan

As already mentioned in this document, the resources to be managed are scarce. It has been acknowledged in this study that the resource which would in the first instance determine the dimensions of the system in relation to demand would be runway capacity.

The following figure illustrates the development of the operational plan.
Within this framework, the first “round-the-table” discussion (i.e. Round 1) will bring together airlines and airports. These negotiations are based, on the one hand, on the initial demand represented by all the rotations envisaged by the airlines, and on the other, on global runway capacity translated to local level for each airport or group of airports. Runways are the resource whose use remains most inflexible; it is therefore logical to take this limiting factor into account during the initial phase of the operational plan. This amounts to saying that, at least in Round 1, airspace capacity could be considered infinite and that, by extension, the same could be said for the capacity of ANSPs. This is, of course, far from being the case. One could also, however, see the initial demand as reflecting a real operational situation based on historical data and/or a "learning process" regulating any unacceptable demands on the part of the system.

The operational plan will then continue with Round 2, which will involve ANSPs. This will make it possible to produce Version 2 of the operational agreement, which will represent the first global agreement on the demand by all the partners (OA_{2}).

The third version of the operational agreement, which will also be the final one (OA_{3}), does not include any new actors but marks the end of the disruption anticipation phase and the start of real-time disruption processing. It therefore marks the cut-off point between a mechanism for making ad hoc modifications to the operational agreement and a mechanism for continuous modification within a closed loop by the incorporation of real data.
4.3.1.1 Resource management in the operational plan

This section is focused more specifically on the initial negotiations relating to the operational plan.

This phase is geared towards resource management.

It will be based on two stages, known as Round 1 and Round 2, which will provide Versions 1 and 2 of the operational agreement, respectively OA\(_{r1}\) and OA\(_{r2}\).

These two phases are illustrated in the following figures.

**Figure 16: Round 1 of the operational plan**

This first stage includes airports and airlines.

Airspace capacity will be taken into account at the next stage.
In addition to the initial participants in the previous Round, this second stage incorporates ANSPs, whether they be civil or military.

The objective here will be to strike a balance between traffic demand and control capacity.

At present, the rules governing airspace are established in advance by means of a slow process of minor adjustments, during which demand is regulated so as not to exceed the capacity of the equipment in place. By contrast, the process described in this document (see sections 3.3.1.1.3 and 3.5.1) is based on an almost virgin volume of airspace and imprecise traffic information, and seeks to provide specific information about both of these together, in a harmonious fashion.

4.3.1.1.1 Airports

Airports are the actors who manage one of the system's scarce resources: runway capacity, which represents the objective result of all the constraints imposed on airport management.

In the interests of precision, "runway sequencing" is a more accurate term than "capacity". This is because, although airports are at all events no longer responsible for aircraft operations on taxiways and runways, it is nevertheless the capacity of airports to guarantee logistics on the ground in accordance with planning which will determine whether or not optimum use is made of this resource.

Of course, this resource has a limit which cannot be exceeded. This limit will be fixed by whichever capacity is the most restrictive. In other words, the maximum capacity limit will be either the maximum runway throughput or the maximum throughput capacity afforded by the airport. In the remainder of this document, the term "runway capacity" will be deemed to refer to a consistent and thus realistic attempt to account for these two aspects at the same time as guaranteeing safety.
Obviously, the maximum runway capacity (i.e. the capacity limit) is an airport infrastructure constraint which is "unattainable" in the context of the operational plan. The robustness of the system in the face of exceptional disruption must systematically be taken into account, and a "reserve" must be maintained in order to manage such disruption.

Like most actors in the air navigation system, airports are engaged in a process of economic profitability which pushes them to optimise their operations. It is therefore important to come as close as possible to their maximum capacities while maintaining the level of safety and the demand from their users (e.g. airlines).

Environmental conditions (e.g. weather conditions and infrastructure maintenance) and demand change in accordance with the time of year under consideration. These conditions, however, generally follow a recurrent pattern which therefore allows a degree of anticipation. This anticipation will naturally be "approximate" at this stage of the operational plan (i.e. Round 1), but it is entirely commensurate with the refinement mechanism associated with the implementation of an appropriate level of granularity (the principle of minimal questioning of the previous phase).

In assessing the impact of these factors, the following may be particularly useful:

- The expertise and experience of operational staff at airports.
- The history of determining elements such as:
  - meteorological records;
  - statistics: passenger numbers, equipment failures or staffing problems (flu outbreaks are more frequent in winter).
- The various planning and working documents in their current forms, such as, for example, detailed preliminary drafts like in APD.
- On the basis of the estimated runway and satellite loads, it will be possible to use descriptive models permitting estimates of taxi times.

All of this will constitute the preparatory phase for Round 1.

4.3.1.1.1 Round 1

Once the airports enter the negotiations, it will become possible to speak about allocated runway capacities which will be "calculated" on the basis of the elements described above. These allocated capacities will have been compared with the initial demand (all rotations), which will have been circulated beforehand by the airlines.

During this round, airports and airlines will assess how well demand and allocated runway capacities have been brought into line. On the basis of contingencies arising in the course of their operations, airports, together with airlines, will establish flight arrival and departure lists. The notion of evolutionary granularity must not, however, be perceived as leading to uniformity in the margins associated with the objects manipulated during the various phases of the operational plan. Some of the lists mentioned here will be more limited than others (i.e. their margins will be more restricted) in order to take account of the actors' operational requirements. During periods when traffic load is low, for example, the margins associated with the various flights can be greater than during the morning rush; furthermore, satellite airports will have more room for manoeuvre, since traffic there is less dense.
These lists will be negotiated and it will, if necessary, be possible to modify the initial demand and/or allocated runway capacities.

These modifications might involve:

- Changes to a flight schedule.
- Reassessment (increase or reduction) by an airport of the proposed runway capacity. This is not, of course, a question of the maximum capacity, but rather of the initial assessment of the capacity proposed at the start of the round.
- Redefinition of a given rotation as two separate rotations.

All these amendments will, of course, be the result of a consensus between the actors or, in the event of disputes, will be decided by the moderator.

Version 1 of the operational agreement will be approved by all the actors involved and published by the moderator. It can be seen as an allocated airport capacity.

The airports will therefore have established departure and arrival lists compatible with the allocated runway capacities.

Pending the start of Round 2, the operational plan continues, and it is thus possible to make collectively-approved amendments if required, since the process is transparent and the moderator ensures that the various actors have the data at their disposal. Everyone will have these modifications at their disposal and will be able to consult them at all times. This mechanism also allows actors such as ANSPs, who were not involved in Round 1, to monitor and prepare the next Round.

4.3.1.1.1.2 Round 2

By the start of Round 2, therefore, the airports will have been able to refine their arrival and departure lists in conjunction with the airlines, if this has proved necessary. It should be noted that at this stage the airport departure list does not in any way constitute a slot allocation or means of sequencing flights on the runway. It should be seen more as a set of flights which will be provided to the airport flight segment within a given time window, with no bearing on the order in which they depart.

During Round 2, the arrival of the new actors, i.e. the ANSPs, does not alter the airports' logical imperative (respecting the allocated runway capacity) but may, as might more naturally be expected, impose constraints at the level of flight sequencing.

It is at this point, moreover, that the operational plan will enter a resource management phase which also involves anticipating disruption. Although the real traffic deadline is still a long way off, a degree of disruption may be known about or probable in the medium term, and can consequently be incorporated into the process of refining airport resources. Such disruption might include:

- Meteorological phenomena.
- Airport operations:
  - maintenance/repair due to an incident;
  - unavailability of staff (e.g. through strike action).

Version 2 of the operational agreement will be approved by all the actors and published by the moderator.

Airports will therefore have established sequencing slots (arrival/departure) which are compatible with the runway capacities refined during the round. As in the case of departure and arrival lists, this is not a form of runway sequencing. Slots will overlap in order to allow for internal reorganisation without calling into question the homogeneity of the flights involved in the time window under consideration.
4.3.1.1.2 Airlines

Airlines are the end-users of the air navigation system. They are therefore the actors who initiate the demand. This demand develops constantly because it is very sensitive to socio-economic factors. Examples of such factors are:

- the price of oil;
- the issue of safety, most commonly associated with dramatic events;
- seasonal fluctuations or changes in "fashion" affecting certain destinations;
- changing mentalities (e.g. the emergence of business flights);
- and, of course, the fierce competition between airlines.

All this means that it is necessary to make a considerable effort to show creativity and innovation in order to satisfy the customer, for this is the airline's true goal: satisfying customers, whether they be passengers or third parties who have entrusted the airline with freight.

On the assumption that safety will always be the top priority, the airline's main objective will therefore remain to ensure punctuality at the destination airport.

As stated above, the almost constant development of passenger expectations means that the purely repetitive aspects of current planning methods must be reconsidered in order to increase the adaptability and capacity to change of the demand.

In Round 1, airlines will therefore present their initial demand at the outset. This will be made up of a number of rotations. A rotation will be defined as a number of city-pair sequences (i.e. ADEP and ADES), constituting the flight segments. These are connected by ground segments which constitute the periods required for airport operations. At the beginning and end of each segment, there will be a time window in order to allow assessment by the airports.

As in the case of airports (see section 3.3.1.1.1), granularity must be large at this stage. In formulating this initial definition of rotations, the following may be particularly useful:

- The expertise and experience of airline operational staff.
- A history of determining elements such as:
  - meteorological records;
  - statistics: average duration of the flight, average fuel consumption and average stopover time at the airport under consideration.

Clearly, the initial global demand (i.e. all rotations of all airlines) must be structured. The reason for this is that the adaptive approach is ineffective when faced with the "all to leave at once" syndrome. Just as in the case of the "infinite" capacity of ANSPs, one could also see the initial demand as reflecting a real operational situation based on historical data and/or a "learning process" which will regulate any unacceptable demands on the part of the system.

Airlines are then prepared to present their initial demand during Round 1.

4.3.1.1.2.1 Round 1

As mentioned in section 3.3.1.1.1, Round 1 will make it possible to compare demand with allocated airport capacity as assessed by each airport.

These negotiations will make it possible to validate and refine the time windows of the rotations. Reorganising certain rotations may also be a possibility (see section 3.3.1.1.1).
The top priority, however, is, of course, to bring airport resources (i.e. runways) into line with demand. It is thus possible, at the negotiation stage, to allow airports to keep some capacity in reserve, creating margins for manoeuvre which are acceptable to all in order to take account of flights not included in the initial demand. This reserve would be available during the subsequent round in order to eliminate or at the very least minimise the "first-come, first-served" effect. Reserves such as this will be an integral part of the operational plan, i.e. they will respect the principle of transparency and the other actors will be aware of them.

Version 1 of the operational agreement (allocated airport capacity) will be approved by all the actors involved and published by the moderator.

The airlines will therefore have at their disposal a predicted demand which is compatible with the allocated runway capacities.

This predicted demand can be modified in conjunction with the airports pending the start of Round 2 and, as mentioned above, will be accessible to ANSPs in the interests of preparing for Round 2.

4.3.1.1.2.2 Round 2

Round 2 marks the first time that capacities directly related to the performance of the flight are taken into account. Although the impact on airports of the ANSPs' entry into the process was no more than limited, its effect with regard to airlines is much more significant. This is because the flight segments of rotations are reduced at this stage to their simplest possible form, a city pair.

Thanks to the operational plan's transparent cooperation mechanism, the ANSPs have been able to prepare a strategy and an initial assessment of the means which need to be set in place in order to comply as closely as possible with Version 1 of the operational agreement. They are able to propose various alternatives for their flights and negotiate them with the airlines.

These alternatives will consist in "strategic" flight paths which will make it possible to perform the flight for the designated city-pairs. These alternatives will make it possible to set in place a strategy approved by all the actors, which will not necessarily be based on the best or shortest route but which will ensure traffic regularity and fluidity at all levels.

A flight path may be considered in simple terms as a series of windows into and out of the airspace of the various ANSPs crossed in making the link between ADEP and ADES. These windows also mark the interface for coordination between the various ANSPs involved.

As in the case of airports, airlines will start to incorporate anticipation of disruption into their negotiation mechanisms. Such medium-term disruption may be of various types, including:

- Meteorological phenomena.
- Economic or political aspects:
  - inadequate predictions with regard to seat sales;
  - political instability in a country or region.
- Airline operations:
  - unavailability of aircraft;
  - unavailability of staff.

Version 2 of the operational agreement will therefore be published after taking account of the constraints of all the actors.
At the end of this round, airlines will therefore have an initial description of their planned rotations. Each rotation is divided into ground and flight segments determined by in- and off-block slots and the "overflight" path of the various ANSPs involved.

4.3.1.3 Air navigation service providers

ANSPs represent the second point at which the system's scarce resources are managed: airspace capacity.

While runway capacity remains easy to conceptualise, despite the dual nature mentioned above (section 3.3.1.1.1), describing airspace capacity involves a quite different challenge. This is mainly due to the interdependence and enmeshment of the characteristics of the airspace itself (i.e. its design), the use to which they will be put (i.e. traffic) and the result of combining them (i.e. complexity).

Rather than referring to airspace capacity at strategic level, therefore, the preferred term in the context of ANSPs is control capacity. Control capacity may be defined as a pattern of flows into and out of the airspace managed by the ANSP. Since each ANSP has control over its own tactics for ensuring the safety, regularity and fluidity of the traffic in its airspace, it will have all possible latitude in setting in place the organisation (e.g. free flight, route network) and means required in order to achieve its objectives.

The approach embodied by this process is an attempt to overcome the difficulty of constructing an effective organisational structure for airspace in the face of highly volatile traffic demand. While activity at an airport is closely related to activity in the area served by it, en-route traffic in a given area is composed of aircraft responding to very diverse socio-economic requirements which therefore develop much more quickly. It is therefore useless to try to force this traffic, which changes from one hour to the next, to use a network of air routes the development of which is better measured in terms of years.

This approach seeks to construct a functional representation of traffic, one that is consistent with the expected service and serves as a basis for human analysis. This approach is compatible with the establishment of a catalogue of solutions (i.e. of "playbooks"), since it makes it possible to identify the scenario corresponding to the demand, or to point out the emergence of a new situation requiring in-depth analysis (see section 3.5.1). This catalogue could then be gradually and continuously improved within the framework of a quality approach.

Like airports, ANSPs have to cope with environmental conditions which relate to the time of year under consideration and alter the control capacity. ANSPs will also be required, therefore, to assess the impact of these conditions in order to determine the control capacity which they will be obliged to guarantee when they enter Round 2 (their first participation in the operational plan).

In doing so, they will be able to draw on:

- The expertise and experience of operational staff.
- The history of determining elements such as:
  - meteorological records;
  - traffic records.

This will lead to the formulation of an initial approach to control capacity.
Since the ANSPs will participate only in the second round, however, they can already incorporate medium-term disruption and thus refine control capacities. Such disruption might include:

- Known meteorological phenomena.
- Internal operations:
  - maintenance/repair of equipment due to an incident;
  - closure/restriction of airspace (e.g. military areas, air shows);
  - unavailability of staff.
- External operations, such as VIP flights.

Moreover, this "late" entry into the operational plan also allows them access to Version 1 of the operational agreement and to any modifications made in the course of Round 1. This will enable:

- on the one hand, immediate comparison of demand with control capacities and thus, if necessary, fresh modifications to the latter;
- on the other, a "warm-up" which will permit ANSPs to pre-assess the alternatives which it might be useful to set in place in order to satisfy this demand and commence an initial synchronisation between neighbours in order to ensure the flow of traffic.

Although this upstream assessment of the demand remains internal to ANSPs (i.e. outside the operational plan's transparency mechanism), its aim is to encourage optimisation of the decision-making mechanism in Round 2 by providing relevant alternatives to the actors already engaged in the operational plan. It must not be perceived as a forced attempt to bring demand into line with control capacities.

Round 2 marks an important stage of the operational plan because it is the first time that all the actors are brought together and constitutes the "official" entry of ANSPs into the negotiation process.

As already mentioned in the preceding sections (sections 3.3.1.1.1.2 & 3.3.1.1.2.2), the incorporation of ANSPs will be particularly significant because of the resulting interaction with airlines. At this stage, the flight segments of rotations comprise only the ADEP-ADES pair. ANSPs will be able to propose flight paths to airlines, possibly with one or more alternatives for each flight segment defined in the rotations.

The "strategic" flight paths issued will have high granularity and will consist of windows marking points of entry into the areas of responsibility of the various ANSPs traversed during the flight (a point of entry into one area representing a point of exit from the previous one) (see section 3.5.1). These windows will represent a volume in four-dimensional space.

These flight paths will have been assessed not only on the basis of the constraints of ANSPs but also by taking account of technical and economic aspects such as:

- aircraft performance;
- kerosene consumption;
- airline overflight preferences.

Version 2 of the operational agreement (allocated navigation system capacity) will be approved by all the actors. The moderator will ensure that it is published.

The ANSPs will thus have at their disposal an assessment of the flows they are to manage. These flows will consist of portions of the flight segments (lying within the airspace controlled by each ANSP) of all the rotations applied for by the airlines.
As in the case of runway capacities, ANSPs will also be able to keep some capacity in reserve at the negotiation stage, in order to allow any additional "late" (i.e. supplementary) demand to be incorporated. This information will be made known to all the actors (in accordance with the principle of transparency).

As for Version 1 of the operational agreement, as the operational plan continues, amendments can be introduced through negotiations between the relevant actors. The transparency mechanism ensures that the latter are directly visible to the other actors.

4.3.1.2 Disruption management in the operational plan

This stage represents the last "round-the-table discussion" involving all the actors before facing real events. It will enable the publication of the final version of the operational agreement (OAf), relating to resource management. From this moment on, all cases of detection of disruption will be processed immediately in order to assess the effects caused, work out a strategy to resolve the situation and incorporate it into the operational agreement.

Notwithstanding the time span represented by the operational agreement, it is nevertheless possible to view this disruption management phase as simultaneous with real traffic as defined in one or more operational agreement(s) preceding the one under development. This means that events associated with current real traffic will represent potential disruption.

It is therefore necessary to set in place a sophisticated mechanism combining real-time data collection with a reactive negotiation process in order to assess and deal with any disruption detected.

This upstream disruption management phase will come to an end as soon as the operational agreement becomes active, i.e. when the time window begins and the final operational agreement (OAf) is activated. The phase of updating the operational agreement will then have begun.

4.3.1.2.1 Airports

Airports will have refined their runway capacities and sequencing slots at the beginning of this stage.

The start of the disruption management stage will particularly favour the integration of shorter-term demand (which it will have been possible to prepare for during the modification phase in Round 2). It is at this stage that the capacity reserves will be able to play their role. Since they are an integral part of the process and therefore known to all, any inordinately large demand can be rejected.

The final version of the operational agreement will be approved and published at the beginning of this phase.
As suggested in the first part of this document (section 2.2.5, Figure 4), traffic can be represented as an uninterrupted series of rotations. The potential will therefore exist for consistency between one active operational agreement and the next, since they will share common constraints (e.g. the departure and arrival of a flight are not covered by the same operational agreement). It is, in fact, highly probable that all of these common flights have already taken off and are consequentially governed by a CoO. Airports will therefore have at their disposal sequencing slots which will take account of the latest refinements to runway capacities, the incorporation of supplementary demand and the margins associated with those flights which are already active. Sequencing slots will always constitute spaces for adaptation (i.e. overlapping), thus enabling internal reorganisation; if this occurs, however, the number of aircraft associated with each airspace will be more limited. Moreover, the structuring of these slots will have been refined, taking account of the models and constraints of the ANSPs responsible for the flight segment, the airport, and the obligations which the airport will have assumed towards those CoOs which are already active.

Airports (like the other actors) will now begin to manage short-term disruption and real disruption. Such disruption may be either endogenous or exogenous.

Examples of endogenous disruption are:
- airport operations (e.g. bomb alerts);
- updates to the current OA (e.g. renegotiation of a CoO);
- disruption caused by the other "families" of actors (e.g. closure of airspace).

Exogenous disruption is associated with, for example:
- meteorological conditions (e.g. violent storms);
- communications infrastructure on the ground (e.g. closure of access routes).

Airports will receive data in real time in order to facilitate the disruption management process. This collaborative process will make it possible to assess disruption and inform the other actors of the corrective action taken. Initiatives such as Airport CDM [Bib 8][Bib 9] have already established platforms for assessing this process in the framework of the ground loop.

4.3.1.2.2 Airlines

In the interval between the publication of Version 2 of the operational agreement and the start of disruption management, airlines will have modified the demand in two ways:
- By introducing any modifications to the operational agreement.
- By preparing for supplementary demand relating to shorter-term contingencies. This will make it possible to turn to good account the mechanism set in place in the course of the two previous rounds (i.e. the reserves of capacity). Such preparation will be simpler and better optimised because the transparency of the process will enable airlines to adhere as closely as possible to the resources offered.

ANSPs will have refined their control capacities and enhanced the "strategic" flight paths and their possible alternatives in relation to the initial demand.

The negotiations relating to the supplementary demand will enable the airlines to shape the final demand on the basis of the other actors' constraints.
In its most propitious form, this final demand could represent the incorporation of the demand resulting from Version 2 of the operational agreement and the supplementary demand. It is also possible, however, for airlines to forgo certain rotations in order to favour the supplementary demand, or vice versa.

The final version of the operational agreement will be approved and published at the beginning of this disruption management phase.

Airlines will therefore have a final description of their planned rotations. As within the framework of Round 2, each rotation will be divided into ground and flight segments. They will be defined by departure and arrival slots and by a strategic flight path enhanced by various ANSPs.

This enhanced flight path will allow airline operators to make initial preparations for flights. For example, it could be given to crews in order to prepare for their flights.

Airlines, together with the other actors, will now enter the disruption management phase. Since the deadline for the activation of the operational agreement is close, the actors are increasingly affected as a group by short-term or real disruption.

Airlines will thus be clearly involved in the collaborative disruption management process described in the foregoing section.

### 4.3.1.2.3 Air navigation service providers

ANSPs will have put to good use the time between the publication of Version 2 of the operational agreement and the start of the disruption management phase in order to refine control capacities.

Given that ANSPs are responsible for the tactics to be applied in managing their airspace at local level, it is reasonable to think that, depending on the density of the traffic controlled by it, each ANSP will adopt a type of airspace management typical of itself, and that this type of management will be the most effective one in relation to this traffic [Bib 6].

The flight segment of a rotation will therefore be forced to cross volumes of airspace governed by different operational procedures. It might, for example, follow the following sequence type:

- sectorised with network of specified routes;
- free flight;
- "highways";
- lastly, sectorised with network of specified routes for the end of the flight.

This varying management structure means that refinements introduced at this stage of the operational plan will not lead to equivalent granularity for each element of the flight segment. For free flight airspace, this will correspond to refinement of the interface windows. For sectorised airspace with a network of specified routes, not only will this refinement of interface windows exist but the ANSP will be able to enhance it, for example by means of a list of interface windows between sectors, or even a set of alternative lists.

This refinement mechanism can be supported by a set of tools, including the following:

- fast-time simulations;
- complexity assessment calculations.

At all events, these refinements and the enhanced "strategic" flight paths will be macroscopic and will retain significant granularity. Under no circumstances will they constitute a 4D flight path which can be used by on-board equipment.
At the start of this phase, ANSPs will thus have refined the demand from Version 2 of the operational agreement and will have dealt with any modifications made to it during the intervening period.

The negotiations relating to the initial demand and the integration of supplementary demand will enable ANSPs to define their final control capacity. The negotiations will, of course, incorporate an assessment of any short-term disruption already known about.

The final version of the operational agreement (i.e. the planned traffic) will then be published.

The ANSPs will have the final plan for the traffic which they are to manage. Depending on the ANSP in question, this plan can more or less be detailed, on the basis of the methods and structure of the airspace used. They will all, however, have at their disposal a representation of those volumes of airspace with regard to which they must "coordinate" with their neighbours.

All of this will enable ANSPs to adapt their logistics and staff to the best of their ability in order to respond to traffic demand.

The disruption management phase is also about to start for ANSPs. As mentioned in the previous paragraph, they are affected, together with the other actors, by short-term or real disruption.

They will thus integrate quite naturally into the collaborative disruption management process.

4.3.1.2.4 Additional actors

At this stage of the operational plan, it is possible to envisage the participation of additional actors, such as bodies related to:

- meteorology;
- national or international security;
- the environment.

However, these possibilities will not be dealt with in this document.

4.3.1.3 Updating of the operational agreement

If the phase described in the preceding section marked the incorporation of real data into the operational plan, this phase marks the switch into the reality of the operational agreement.

The final operational agreement (OA) and the modifications made to it in relation to disruption management have therefore become active. It must now face the real situation, and the disruption which now appears has a direct effect on the rotations planned by it.

Although the operational agreement is active, this is not true of all the rotations which constitute it. A field remains open, therefore, within which those rotations or rotation segments which are still inactive may be negotiated.

In fact, even though the final operational agreement is no longer completely managed by the operational plan, it is always strategic-level staff who will carry out the negotiations. These strategic-level staff are the same or, at the very least, use the same means as those implemented during the disruption management phase described above because, at all events, the same rules are applied as previously, but in relation to a "reduced" part of the operational agreement.
4.3.1.3.1 Real data

Real data, being associated with the performance of rotations, is also of two types:

- ground data;
- flight data.

To be completely precise, a third type will also have to be introduced: data relating to the ground-flight interface (e.g. AOBT).

Ground data is related to all aspects of airport activity and represent activities associated with numerous different types of operators. They will not be described here. Presentation of these data and the tools associated with managing them will be dealt with by the ground loop (i.e. Airport CDM), as mentioned in section 3.3.1.2.1.

The flight data are associated with the flight segment of a rotation. They are therefore not limited solely to the flight phase per se but also to the whole of the aircraft's journey from the airport block to the runway and vice versa. These data will be exploited by the flight loop (see section 2.2.3, Figure 3). They will enable a global vision of current traffic (i.e. a continental vision) and its development in order, firstly, to refine the planning of the active operational agreement so as to allow optimal definition of the "contracts of objective" when they are issued (see section 3.3.2.1) and, secondly, to assess the repercussions (like a "what if" mechanism) during the disruption management phase.

4.3.1.3.2 Disruption management

The disruption which will need to be managed has a direct impact on the active operational agreement, whether it involves traffic which is already active or rotations which are still at the planning stage.

At this stage, however, it is helpful to distinguish between these types of disruption in order to find an appropriate level of treatment for each one.

The operational agreement and the "contracts of objective" which will result from it were drawn up in order to ensure traffic capacity and fluidity criteria by respecting a "global" safety level. They are by no means responsible for delivering conflict-free traffic to tactical-level staff. The responsibility for separation between aircraft (i.e. "detailed" safety management) still falls to each local operator (see section 3.2.3.2.3). This is because it is advisable to prohibit all forms of microscopic management at strategic level and such management will not, therefore, be dealt with by the staff mentioned in this section. In contrast, managing such disruption might have indirect effects which can be dealt with from a strategic perspective in order to eliminate or at least minimise the chain reactions which might ensue.

Similarly, some disruption will need to be resolved at local level for those aircraft directly affected. This same disruption will, however, be dealt with at this strategic level in the cases of inactive traffic and active traffic for which the impact deadline is still relatively distant. Aircraft directly in contact with major meteorological disruption, for example, will be dealt with at tactical level. Any decisions on re-routing a flow will be taken at this strategic level.

It will thus be noted that disruption whose management is envisaged here requires the involvement of a significant number of actors who are heavily involved in short-term resolution.
4.3.2 "Contract of objective"

As suggested in the first part of this document (see section 2.2.1), it is necessary, in a collaborative system such as the one described here, to achieve functional and operational continuity between the various actors. There must therefore be an operational link between all these actors, identifying the role of and allocating tasks to each actor in relation to a clear, well-defined objective which is accepted by all concerned. This is what the "contract of objective" represents.

The "contract of objective" is associated with the flight segment of a rotation and is issued on the basis of the refined information contained in the operational agreement.

The sections which follow will attempt to describe how the contract develops during the flight and the principles governing what happens when disruption recurs and calls the contract into question.

4.3.2.1 Life cycle of the "contract of objective"

The "contract of objective" results from the refinement process (i.e. the operational plan) which has led to the definition of the flight segments included in the operational agreement. A "contract of objective" will define the commitments undertaken by the various actors involved in this flight. It is adherence to these reciprocally-approved objectives which will ensure that the progress of each flight is planned and thus that related traffic is fluid and regular.

The ultimate aim of the "contract of objective" is to ensure that the flight arrives punctually.

The "interim" margins are defined in order to allow the various actors:
- to fulfil their part of the contract by supporting this global objective;
- to ensure coordination and cooperation;
- to detect any anomaly which would call this objective into question as early as possible, in order to take the requisite corrective measures (e.g. tactical development, renegotiation).

The life cycle of the "contract of objective" is structured around the contract's three statuses:
- published;
- active;
- terminated.

The following paragraphs will describe these three statuses.

4.3.2.1.1 Creation of the "contract of objective"

The creation of the "contract of objective" will be triggered $\Delta T$ before the off-block time which appears in the operational agreement. Its status will be "published" and it will then be created by the information system in the form of a complete and distinct object. It will be circulated among all the actors involved in this flight.

The information initially contained in the operational agreement will, depending on what type of information it is, be used to construct the "contract of objective" (i.e. the margins). It will also be circulated among the relevant participants at tactical level. The enhanced flight path, for example, could be provided to the aircrew and the various ground operators concerned with this flight.
This period before the effective departure from the airport will be short and has a twofold aim: firstly, to make it possible to refine the margins so that they fit the flight as closely as possible and thus take account of all the relevant parameters (e.g. current traffic, disruption); and, secondly, to allow the operators associated with the first actors involved to anticipate and possibly finalise the last remaining tactical aspects.

The "contract of objective" will be distributed to all the actors as soon as it is created. It will be their responsibility, on the basis of the tactics they will have set in place, to inform their operators when the time is right.

As already stated on many occasions in this document, the "contract of objective" is composed of the margins (i.e. the volume in 4D space) negotiated and approved by all the actors. These margins are based on the information contained in the operational agreement and associated with the relevant flight segment of the planned rotation. As previously stated (see section 3.3.1.2.3), the operational agreement may contain enhanced flight paths describing the routing in an actor's airspace in macroscopic terms. Those flight paths which have permitted tactical assessments by the actors will not form part of the "contract of objective" but will, as stated above, be distributed to the participants at tactical level.

From the moment it is published, the margins of the "contract of objective" will be rigid (i.e. will not allow for any more refinement of the contract) and will define the commitment of each actor to ensuring the final objective: punctuality at the destination airport.

4.3.2.1.2 Activation of the "contract of objective"

The activation of the "contract of objective" will take place as soon as the aircraft closes its doors (i.e. when it has left the terminal). Its status will then change to "activated".

This change of status will also mark the "contract of objective"'s shift to tactical level. The success of the flight is the responsibility of the actors' technical-level operators. These are the operators who will be responsible for the operational implementation required in order to respect the margin approved at strategic level (i.e. by the actor) while ensuring separation between aircraft.

The margins of the "contract of objective" form part of a "flight envelope" (see section 3.2.1) which takes account of the actors' various constraints (e.g. aircraft performance and en-route control limitations). Although the room for manoeuvre decreases as the final objective approaches, owing to the funnel effect (see section 3.2.2.1, Figure 10), it will not necessarily be possible to represent the "contract of objective" by means of such a rigid diagram, despite the fact that it is this approach which will have guided the negotiations. In particular, flights which are to cross volumes of airspace where traffic densities vary greatly should be included in this category (see Figure 18). This is because the constraints experienced by ANSPs managing high-density airspace (i.e. the core area) may lead them to negotiate more reduced margins. Since these will be more precise, they will encourage traffic fluidity and regularity, tending to minimise traffic peaks (i.e. bottlenecks).
From the moment of activation, the "contract of objective" is activated for all the actors involved in it. It will, however, follow the progress of the flight and will develop on the basis of the flight, in order to ensure that only current and future segments remain active.

4.3.2.1.3 Termination of the "contract of objective"

The end of the "contract of objective" will be signalled by the aircraft's arrival at the arrival terminal, i.e. its in-blocking. The contract's status will then change to "terminated" and it will no longer be available within the information system (i.e. the object will be destroyed). Recordings relating to its implementation, however, will be held on file for subsequent processing.

4.3.2.2 Renegotiation of the "contract of objective"

The "contract of objective" represents a contract of results approved and "signed" by each of the actors involved in it. These results are achieved by the margins that it contains, which link the actors to ensure that the plans are successfully executed. Failure to respect any one of these margins not only jeopardises the planned progress of the flight but also has more or less significant effects at the level of the operational agreement.

All these effects must therefore be assessed and corrective solutions must be found. A renegotiation mechanism must therefore be embarked upon.
Although the margins of the "contract of objective" incorporate the possibility of adaptation to take account of real disruption, exceptional disruption (e.g. emergency descent, sick person on board, hijack) will always exist and will destabilise planning. As stated above, moreover, ensuring aircraft separation is not one of the aims of the operational agreement per se. The effects of these factors on the "contract of objective" will therefore have to be taken into account and a new contract negotiated.

The quantity of such renegotiations will be a good indicator of the system's robustness and effectiveness.

In order to make effective management possible, the renegotiation mechanism must be implemented as soon as an actor anticipates that it will not be in a position to honour its contract, regardless of the disruption which has brought this about.

All the actors involved in the current "contract of objective" will participate in the renegotiation mechanism. The latter will thus be a strategic-level mechanism.

This mechanism will have to ensure, as far as possible, that questioning of the operational agreement is kept to a minimum, and will have therefore have to aim (in descending order of implementation):

- to try to respect the contract's final goal (i.e. punctuality at the destination airport);
- to have a minimal impact on other active "contracts of objective" (the "on-time, first-served" principle);
- to have a minimal impact on "contracts of objective" with "published" status;
- to limit chain reactions (i.e. the network effect) in the operational agreement.

This mechanism therefore requires the involvement of strategic-level staff, who have solid knowledge and wide experience of operations, in order to bring a solution into line as far as possible with operational contingencies.

An equivalent process to that in Round 3 will therefore be initiated but will be restricted, initially, to the actors directly involved in the "contract of objective" which has not been respected. If the renegotiations do not make it possible to respect the final objective, and if this affects other contracts, the process will gradually broaden to include those additional actors who are of use in resolving the crisis. Obviously, at the end of the renegotiation phase, the new "contract(s) of objective" will be published. It will be for each actor involved to inform its operators of any modifications relating to its own area of responsibility.

This process of renegotiation could be dealt with by the participants responsible for disruption management within the framework of the updating of the operational agreement (see section 3.3.1.3.2).

As stated above, the quantity of renegotiations gives an indication of the effectiveness of the system. It will therefore be advisable to study the events which have led to the renegotiations, in order both to allow the system to be improved/adjusted (e.g. by making the margins more flexible) and also, if necessary, to take "disciplinary measures" against the actor(s) responsible. This post-analysis will the moderator's responsibility.
4.4 DUAL AIRSPACE

4.4.1 Justification and expectations

4.4.1.1 A need for capacity at local level

The rising numbers of aircraft in our airspace are increasingly complex for controllers to manage. One solution to the problem of how to reduce this complexity, in particular at core area level, consists of exploiting the properties of the airspace itself. Several solutions may be envisaged:

- increasing the size of control units, thus making control actions more consistent by encouraging anticipation;
- avoiding crossing route intersections, to avoid having to manage convergence conflicts;
- not grouping aircraft together on the same axes, in order to facilitate understanding of the traffic distribution;
- building the separation of head-on traffic flows into the system;
- separating the various types of flight, i.e. climbs, descents and overflights;
- proposing parallel networks, with the aim of simplifying traffic within each network, since complexity is proportional to the square of the number of aircraft.

On the basis of these observations and the analysis of traffic characteristics in the core area, it is worth considering the concept of "dual airspace" combining flow-based traffic management and district-based traffic management.

The aim here is to propose an original air traffic management system which will make it possible to cope with the peaks in demand expected in the future. It is reasonable to suppose that the increase in demand will result in an increase in en-route traffic over the core area, which is already congested to the point where it gives rise to numerous regulations.

The management method described here does not claim to be universally applicable. Its aim is to increase available capacity by standardising aircraft flight paths. These constraints necessarily result in a loss of flexibility for air operators and a loss of efficiency in the flight paths. A system such as this could not therefore be applied at all times or in all places, but only under conditions where density is high; naturally, it has to cohabit and interact with other management methods. The interoperability of these various systems will be supported by a contractual management mechanism defined in the "contract of objective".
4.4.1.2 Fundamental concepts

The reasoning behind the creation of the system proposed here is based on several areas.

4.4.1.2.1 ATC efficiency

The air navigation monitoring and control system is subject to a phenomenon of saturation: doubling the number of aircraft quadruples the workload. Relieving a control unit of a small fraction of the aircraft for which it is responsible thus has a significant effect on its workload.

4.4.1.2.2 Traffic classification

Air traffic is not homogeneous in terms either of its volume or the demands it makes on ATC.

Traffic climbing from or descending to airports is directly related to the activity of the TMA served by it. Consequently:
- throughput is locally limited by airport operations;
- a strict cadencing is required, in order to best use the limited runway capacity.

Cruising traffic, stabilised at a given level, organises itself naturally into large flows which bring together aircraft flying from and to various points. This traffic naturally becomes concentrated above the core area, and requires improved supply in terms of capacity.

This description is deliberately centred on ATC rather than on individual aircraft, whose status changes during the flight.

4.4.1.2.3 Division of labour

Attempts to reform air navigation have often sought to relieve the operator of part of his or her workload by assisting him or her by means of automated systems. This approach would appear to founder on the problem of responsibility, with the operator ultimately responsible demanding to know all the ins and outs of his or her decisions. This obstacle can be overcome by introducing systems functioning in parallel and independently.

4.4.1.2.4 Control of the transition

Air navigation is a very sensitive field in terms of safety, and any innovation must be gradual and based on tried-and-tested technologies and practices. Dual airspace leaves room for innovation, which is essential for development, while drawing on current professional practice.
4.4.2 Description of the proposal

4.4.2.1 The principle of division

Within a high-density area, dual airspace is based on a functional division of traffic between two sub-systems:

- A small number of long-haul highways dealing with major traffic flows and conveying a large number of cruising aircraft using innovative navigation methods specifically adapted to aircraft stabilised at a certain level. The highway system is not organised with a view to connecting airports directly. It brings together flows corresponding to many city pairs.
- A partition of European airspace based in local districts, the purpose of which is to take aircraft from their departure aerodrome (SID exit point) to their highway, and from the highway to their destination aerodrome (STAR entry point). These districts also provide air navigation services to flights which do not make use of the highways, either because they are too short or because their route does not correspond to one of the main axes. These districts use tried-and-tested traffic control methods similar to those used today (Figure 19).

*Figure 19: Example of local organisation in a high-density area*

The division is implemented in such a way that both systems function independently, each one operating as a sealed black box for the other.
4.4.2.2 Physical introduction

Introducing this system of airspace organisation respects air safety, since it guarantees that aircraft located in two different sub-airspaces will never come into conflict. Cross-over points between the two systems are clearly identified and governed by clear and explicit rules. Introducing this system of airspace organisation respects air safety, since it guarantees that aircraft located in two different sub-airspaces will never come into conflict.

4.4.2.2.1 Horizontal organisation

Horizontally, the highway system may be described as a small number of ribbons (from one to six), each of which is a few dozen nautical miles across. Every ribbon contains two parallel clusters of flights, each cluster devoted to traffic travelling in the same direction. The division of each cluster into routes makes it possible to increase the capacity offered, and opens up new perspectives with regard to ATC.

The subdivision into districts enables effective traffic management between airports, and at highway entry and exit points. Districts contain enough airspace to allow complete climbs and descents to be monitored without the need for coordination. This requires approximately 150 nautical miles (Figure 20).

![Figure 20: Horizontal organisation of a highway ribbon](image)

4.4.2.2.2 Vertical organisation

It is the vertical organisation of the airspace which allows the two systems to coexist independently. The vertical airspace is subdivided into sections assigned alternately to one or other of the two sub-systems. Each system is thus sealed, without presenting an insuperable obstacle to the other. Aircraft are thus forced to remain stable at an authorised level all along the highways, where the systems overlap but never interpenetrate (Figure 21).
4.4.2.3 Operations

4.4.2.3.1 Highway system

The highway constitutes a privileged airspace with tremendous potential for innovation. The aircraft which make use of it are stable at a given level; they all move in a predictable manner, in the same direction and the same way. An aircraft flight path, then, is no longer three-dimensional but one-dimensional. The possible benefits of this situation are threefold and complementary:

- simplified traffic, making it possible to assimilate a larger number of aircraft;
- simplified ATC, through the use of a limited system of elementary instructions: change in speed and change of route (digital airspace);
- simplified displays, replacing the map backgrounds with synoptic tables.

The management of a highway is continuous over its entire length, and is not affected by national borders in any way. Aircraft flight paths are thus managed coherently in the long term, in order to achieve ambitious objectives in terms of punctuality.
4.4.2.3.2 Regional airspace

The control of regional airspace is based on tried-and-tested methods. Its purpose is to take aircraft between airports and highway access points efficiently.

Regional airspace is divided into autonomous districts for purposes of controlling operations. Each district is an independent tactical unit and organises control methods at local level: teams, procedures, tools and flight paths, depending on the specific traffic configuration. Each district makes commitments to the other air transport actors with regard to achieving results in terms of the punctuality of each flight.

Regional airspace should turn to its advantage the isolation of a significant proportion of cruising traffic:

- direct decrease in the volume of traffic;
- increase in the reliability of predictions;
- functional specialisation of districts (climb or descent);
- increase in available airspace.

4.4.2.3.3 Transitions

Points of entry from a district onto the highway and exits off the highway into a district need to be strictly codified. These transitions take place in clearly identified areas. Aircraft changing from one system to another apply a double-bayonet procedure. The system which the flight is leaving initiates the movement, which is completed with the agreement of the system receiving the flight. The regional airspace system supervises lateral movements while the highway system supervises vertical movements, which maintains opacity between the systems (Figure 22).
4.4.2.4 Disruption management

The airspace organisational structure described above is helpful in those cases, fortunately frequent, where aircraft do not experience any particular difficulty in accomplishing their mission. Furthermore, additional mechanisms make it possible to deal with unforeseeable factors.

4.4.2.4.1 External disruption

At sub-system level, this may be of three types:

- Aircraft supposed to enter the sub-system but not showing up. That does not cause any particular difficulty.

- Aircraft not supposed to enter the sub-system, but showing up. Examples include the case of a single aircraft having to leave the highway, or a major failure of the highway system. In both cases, scenarios will be established in order to deal safely with such events.

- Failure of an aircraft to be punctual. To be prepared for this eventuality, the highway system has a capacity reserve, enabling it to absorb traffic which is not punctual (and which can create a local load peak). It then adapts the speed of the aircraft to absorb this failure and deliver punctual traffic at the exit point.

4.4.2.4.2 Internal events

A distinction may be made between events which disrupt a limited number of aircraft, such as a failure affecting an aircraft or an airport, and events which require modification of the airspace itself. Bouts of turbulence, for example, require the closure of one or more vertical sections, while stormy weather can force the highway to divert to one side. Traffic in the affected sections is then moved towards an aeronautically stable section. A protocol for coordination between the two sub-systems is called for, and its terms will be stipulated in the interests of guaranteeing safety.

4.4.2.4.3 Interaction between control and crews

For various reasons, control may decide to modify aircraft flight paths. In order to guard against the oversights and failures to understand which can blight this type of communications, control positions and/or on-board navigation systems will be equipped with a mechanism guaranteeing separation between highway airspace and district airspace.

4.4.3 Matters outstanding

This document describes the basic principles of dual airspace organisation. A number of matters are still to be discussed with regard to the arrangements for applying the concept, its feasibility and its usefulness.
4.4.3.1 Arrangements for applying the concept

The highway system constitutes a broad field of investigation. The principal questions relate to the volume of traffic envisaged and the control methods; they require an in-depth analysis drawing on related studies. The model's geometrical parameters require delicate adjustment:

- vertical division of the airspace, and the number and nature of the sections;
- positioning of the highways;
- number of routes and their functions.

4.4.3.2 Feasibility

The control methods envisaged in the context of the highways and the development of regional ATC given the existence of the highways must be examined from the operational perspective of acceptance by the operators and air safety. It is therefore essential to validate the usefulness of the highways system by means of an experimental protocol based on full-scale simulations.

4.4.3.3 Efficiency

Arrangements for applying the concept must be established, in the interests of maximising its efficiency in terms not only of flight paths but also of capacity and accessibility. These criteria must be assessed by means of a validation process which can be supported by arithmetical simulations.
4.5 TECHNOLOGICAL AND LOGISTICAL SUPPORT

The concepts described in this document are only conceivable if they are supported by suitable infrastructure and working methods which allow each participant to be sure of reaching its objectives.

The paragraphs which follow are an attempt, brief and with no claim to being exhaustive, to outline the technological and human support which would make it possible to implement these concepts and put them into operation.

The three main avenues to be pursued in the following paragraphs relate to:

- The adaptive approach to airspace, which will complement the operational plan due to its evolutionary granularity. This will make it possible to define the objects handled during the various phases of the operational plan with increasing precision and without calling previously-made choices into question.
- The global cooperation infrastructure, which will have to allow full availability of all data handled, in particular during the operational plan, in order to ensure that the process is transparent and efficient.
- The allocation of objectives between the strategic and tactical levels, together with the objects which will make it possible to ensure that all the participants receive consistent information, and thus to set up an appropriate management structure.

4.5.1 Adaptive airspace

Prior to the procedures described in this section, European airspace has been divided into districts, for each of which an ANSP is responsible. The tactical authority of an ANSP is absolute within a district. This authority is based on expertise relating to the specific configuration of the district, rather than to a global model. The ANSP adapts control methods, active and passive, on the basis of the services that it undertakes to provide.

The functional coherence of the districts (FBAs) is a factor affecting the performance of the proposed system. In order to improve the conduct of navigation operations, it is advisable for the sub-division to be based on operational and functional considerations. Each TMA must therefore correspond to a single district (but a single district can serve several TMAs). The process of sub-division must preserve the coherence of principal airport traffic flows.

This involves organising airspace in a constructive way, starting with a clean sheet and endeavouring to meet the needs expressed during the initial phase of negotiations between airlines and airports.

This process will consist of:

- Sub-dividing the airspace into districts. This sub-division will not be modified during the negotiation phase.
- Allocating strategic routes. Traffic demand will initially need to be dealt with at district level. To this end, each city pair is allocated a strategic route made up of a series of districts, beginning with the district serving the departure airport and ending with the district serving the destination airport.

10 Whenever the series of districts crossed by the flight does not appear to be clearly univocal, alternative strategic routes may be considered. These alternatives complicate the process but do not profoundly alter its nature.
Establishing the directional load plan. This approximate flight definition makes it possible for each district to establish its directional load plan. This is composed of three lists:

- a list of climbs from the TMAs served by the district, laid out in accordance with the district receiving the flight;
- a list of descents into the TMAs served by the district, laid out in accordance with the district where the flight started;
- a list of overflights, laid out according to both the district where the flight started and the district receiving the flight.

Ideally, the overflights correspond to cruising traffic stabilised at a given level.

This load plan is expressed in local terms, being based only on the relations between neighbouring districts. It provides a minimal, district-centred description of the traffic, by describing the exchanges between a district and its neighbours.

This allocation entails dividing the border of each district into sections on the basis of which neighbour is on the other side, and classifying flights in accordance with the borders they cross. For climbing and descending traffic, then, this allocation involves sub-dividing the district into angular sectors centred on the TMA.

Estimating times and propagating the margins from Round 1. To accompany this spatial process, the time constraints agreed by airports and airlines (take-off and landing windows) are incorporated using an ad hoc propagation mechanism. The traffic demand is thus expressed locally at the level of each district, in the form of space-time entry and exit windows.

A tactical outline. On the basis of local demand, each district sets in place its main tactical provisions:

- form of control;
- manning of positions.

This tactical plan is accompanied by indicators enabling tacticians to estimate the development over time of the saturation of the various elements set in place.

Negotiating the margins for Round 2. This constitutes tactical refinement. In order to absorb load peaks, districts can impose horizontal, vertical or time constraints on certain aircraft. These constraints particularise the margins already approved by the actors: this is a process of refinement.

The constraints originate in the most restricted systems and are then transferred to those with more room for manoeuvre. They are then evaluated by the strategic actors involved by means of a "what if" phase. The refinements implemented will therefore seldom impinge on those approved previously. Naturally, these strategic refinements lead to tactical developments.

With regard to cruising levels, these negotiations are multilateral, bringing together all districts and airlines.

With regard to times and points of entry to and exit from districts, negotiations are a priori tripartite, involving the two districts and the airline concerned\(^{11}\).

\(^{11}\) It will be feasible, in the interests of simplifying matters, to replace the airline with a cost model representing the loss of flight path efficiency brought about by the turning point.
The final agreement. At the end of Round 2, all the actors have a tactical organisation allowing them to guarantee all the missions regarding which they have made commitments. Laying these missions end to end ensures that the traffic is taken care of.

4.5.2 Collaborative infrastructure

The concepts described in this document attach much importance to collaborative mechanisms and real-time availability of a considerable amount of data (e.g. aircraft positions and intentions, meteorological information). It will therefore be necessary to have a communication system which is not only powerful but also interoperable, with a large number of heterogeneous data sources.

While it seems reasonably likely that the communication system will be global, the question of whether the processing system will be unified or heterogeneous, at least within the framework of a family of actors (e.g. ATCC systems) remains open. The fact remains, however, that interoperability with the information system supporting the operational plan will remain essential.

Studies relating to these concepts of global information system architecture (SWIM [Bib 22]) and common data storage/processing space (CAISS [Bib 10]) are already under way. The aim of this document is not to give a detailed description of requirements or data models, but rather to outline the prerequisites for the concepts presented.

Determining whether the system which will support the operational plan will be centralised or shared (e.g. centralised or shared DBMS) is not the central concern at this stage. That system will, however, have to ensure:

- Complete geographical accessibility.
- Global availability at all times and for all participants (i.e. actors or operators), and therefore failure tolerance mechanisms (e.g. redundancy).
- Controlled access to data, related to the very nature of that data. In other words, transparent consultation of all data but only suitable participants are allowed to modify them.
- Data presentation which distinguishes the data associated with the current phase of the process from the rest (i.e. present the data associated with the current level of granularity).
- Use of the most relevant source (i.e. that which provides the most precise data) or a fusion mechanism for multi-source data.
- Assessment mechanisms (e.g. "what if") which give the same results regardless of which participant initiated them and independently of the system used by the participant.
- Interoperability with equivalent systems.

The information system must use the most relevant data. The same information can be provided or accessible via a number of different sources (sensors or other computer processing systems). The shared data must therefore be identical for each participant involved in the transparent collaboration process. Either the best source or else a fusion mechanism for each piece of data presented must therefore be selected.

This will be the case particularly in the context of the tactical management of the "contract of objective", where the ability of the pilot and controller to arrive at a coherent awareness of the situation in the air depends on their receiving identical, relevant and coherent information.
Within this framework, the ground/air data link (e.g. the ADS-B and/or ADS-C data link) should play an important role. The fact that the aircraft's intentions are available on the ground will allow better anticipation for the controller and may even constitute a decision-making aid. It goes without saying that on-board equipment (e.g. 4D FMS) will also have to support these capacities, in particular by providing data of the best possible quality.

It may also help the flight to adapt better to the real situation, since it provides a means of refining the information provided on the crew's service form by means of direct real-time updates (i.e. uplink messages refining the "strategic" flight path). It will, however, be advisable to define:

- The scope in time of the data transmitted, which will condition the frequency of the updates. If a section of the flight path is too short, it will involve overly-frequent updates and extra work for the crew in order to take into account and assess the acceptability of the solution.
- The period of notice for these updates. In other words, the time lag between the transfer of data and the effective implementation of that data, which will enable the crew to do its job under acceptable conditions.

Another area in which the ground/air data link could be useful relates to the use of aeronautical equipment data to complement information which does not directly concern the flight path. One might, for example, envisage using meteorological information known to the aircraft to complement traditional sources. This will allow greater knowledge of local conditions (e.g. characteristics of the air mass or of storms) encountered by aircraft.

4.5.3 Organisation and management

As already stated in this document (see section 3.3), the whole challenge facing the system is to foster a refinement mechanism (i.e. to minimise the calling into question of the results of the previous phase) and provide the final operator with a clear representation of his or her objectives within a system for managing scarce resources.

While the incorporation of strategic and tactical levels defines an organisation which allows everyone to concentrate on their own tasks, these levels must of course communicate and complement each other.

The air navigation system can be understood from two different but nevertheless complementary perspectives:

- an axis relating to a single rotation, which might be termed the "longitudinal axis";
- an axis relating to the entire infrastructure enabling aircraft to perform their rotations, which might be termed the "transverse axis".

These two perspectives must, of course, be coherent and enable all the participants to share necessary and relevant information so that they can do their respective jobs effectively.

The concept of strategic and tactical levels as proposed in Figure 13 does not imply a "black box"-type organisation, for it is quite clear that actors will have to depend on their respective tacticians in order to conduct realistic and effective planning. This section constitutes a high-level approach to the managerial organisation of the system.
First of all, let us consider the transverse axis. When each actor participates in the operational plan, it must know the "acceptable limits" within which it is authorised to negotiate. These may be presented as a master plan (MaP) which will identify the resources at the actor’s disposal. This plan will, of course, be the result of the tactical adaptations which will support the actor's strategy, and thus of an internal dialogue with its tacticians. The plan will also, however, provide support to tactical-level staff, who will be able to plan the implementation of the required means. This master plan will be refined in the light of the operational plan.

Each master plan will of course incorporate the data resulting from the operational agreement and some data specific to each actor (e.g. organisation of a control room).

As for the tactical level, it will depend on the information contained in the master plan to define and eventually set in place appropriate means. At the level of operators, this will take the form of a service plan (SeP) which will define the flights for which it will be responsible.

These flights will be described by service forms (SeF). The service form is a version of a "contract of objective" which is specific to a given actor and which will establish the means allocated to it. This contract of means, however, allows for a certain amount of flexibility and/or adaptation with respect to the real situation and to each operator's own constraints.

Within the framework of this transverse perspective, flexibility will nevertheless continue to depend on respect for the interfaces defined between neighbouring actors (e.g. respect for the margins between one sector and another). Accordingly, this will also be a contract of results vis-à-vis the next operator in line. Compliance with the margins associated with the service forms of all the operators involved in a flight ensures compliance with the margins laid down in the "contract of objective" accepted by the supervising actor.
The following figure illustrates this approach.

Turning our attention to the longitudinal axis, we note that the perspective is that of a single rotation. In fact, what follows will be even more restrictive and will deal only with the "reduced" view of a flight (i.e. as the elementary air component of a rotation). For issues related to the ground segment, the reader should consult Airport CDM Project documents [Bib 7][Bib 8][Bib 9].

A flight performed by an aircraft and its crew will cross the areas of responsibility of various actors (i.e. ANSPs). It will be governed by the "contract of objective" published on the basis of the operational agreement.
The following figure illustrates this approach.

Figure 24: The longitudinal axis of a flight segment

A flight represents part of the demand. Unlike the operator associated with the resources (in this case the controller), the associated operator (i.e. the crew) will not have a service plan in its possession, but only a service form. To draw a parallel with today's terminology, this service form would be similar to a flight plan.

It will constitute the specific version of the "contract of objective" for the crew, and will consist, amongst other things, of a compilation of all the flight information (i.e. information relating to the flight path) contained in the service forms of all the other operators involved in this flight. The crew's service form differs from the controller's service form, however, in that although it also describes a contract of means, the contract of results will not be directed at operators but at the actors involved in this "contract of objective". The final objective is, of course, punctuality at the destination airport.
4.6 EXPECTED BENEFITS

On the basis of the recommendations made by ACARE, EUROCONTROL and Gate to Gate, and taking user requirements into account, the SHIFT Project proposes an entirely new paradigm for managing aircraft in the en-route phase (see section 3.1.1).

The objectives are, obviously, to increase capacity and efficiency and reduce costs globally while maintaining and even enhancing levels of safety.

**Costs and efficiency**

The overview envisaged by the SHIFT Project makes it possible to take account of the interests, preferences and constraints of all the actors involved during the various phases of the negotiations, in order to work towards global but also mutual benefits. Each actor will bring to the various phases of the negotiations not only its requests but also its socio-economic constraints and its own global operational model. The solution negotiated will unquestionably be the best possible compromise for all. This is a real step forward for ATM.

The primary aim of implementing the "contract of objective" is to work towards real punctuality in aircraft arrivals at and departures from airports. The financial component aims not only to satisfy airline requirements but also to enable, in global terms, the most cost-effective organisation possible for all the actors. It is therefore through the financial constraints of these actors, whether they be airlines, airports or navigation bodies, that the user will reap the benefits, via the fare price inclusive of tax.

These same "contracts of objective" also allow all traffic management operational methods, which are bound up with the specific characteristics of the various types of traffic and local areas, to become truly adaptable.

By means of the link represented by the CoO, this functional and operational continuity makes it possible to increase the productivity of the whole system (see section 3.2.1).

The implementation of dual airspace, with flow-based traffic management, allows a real increase in capacity, moves away from national borders and simplifies traffic, how it is displayed and therefore how it is controlled. Dual airspace therefore allows a sharp increase in productivity linked to a reduction in operating costs. It is not difficult to imagine a reduction in air navigation management costs using this scheme, achieved by setting automated systems in place or by delegating responsibility for separation to the crew on board the aircraft.

Another real step forward suggested by this operational concept resides in the fact that traffic management is no longer based on planning constraints reflected in delays imposed on aircraft on the ground. Thanks to the various phases of negotiation between actors and to the adaptability of the airspace, capacity can be more closely aligned with demand, with real management of the resources of all the actors concerned, which will have undeniable repercussions on the cost and efficiency of the system as a whole.

**Safety:**

The issue of safety remains the SHIFT Project's primary concern.

Better collaboration between all the actors and better planning supported by appropriate data exchanges can only be helpful in this regard.
The tactical level, as has been stated several times in this document, is always responsible for ensuring that separation between aircraft is observed. Nevertheless, incorporation at strategic level of the methods specific to each actor, combined with better knowledge of disruption, should allow the controllers to anticipate traffic more realistically, thus enabling them to avoid having to manage situations where risks are likely.

The implementation of dual airspace (see section 3.4.2) makes it possible to de-saturate local districts by relieving them of stable cruising traffic flows, which results in a workload reduction for controllers in local districts.

Similarly, such dual airspace management makes it possible to minimise bottlenecks, reduce the complexity of traffic while making it more "specialised", and manage uncertainty more effectively (see section 3.1.3.1), which has a very important impact on that same controller workload and therefore on safety.

**Flexibility**

The type of airspace management proposed in this document and the implementation of "contracts of objective" allow local districts to adapt completely to control operating methods, on the basis of their traffic and local problems.

Depending on the traffic density, the modular nature of the adaptive airspace solutions proposed in section 3.5.1 will obviously allow a very high degree of flexibility.

Managing uncertainty as outlined in section 3.1.3.3, by taking account of the various types of disruption described in section 2.2.2.2.2 using the margins of the "contracts of objective" and also the airspace’s margins for adaptation, renders our system more robust in the face of, for example, meteorological phenomena.

It might also be pointed out that, since the "contract of objective" is a contract of results, the operator will also find a certain amount of flexibility in performing his or her tasks, as long as he or she respects the contract’s margins, i.e. the achievement of the results specified in it (see section 3.5.3).

**The environment**

Air transport, like many other fields, has an obligation to consider the impact of its activity on the environment.

Respect for the environment, in particular efforts to reduce noise around airports and the fight against air pollution, are legitimate community demands.

The possibility, proposed by this project, that local districts be permitted to set in place their own operating methods, on the basis, naturally, of the inherent requirements of the traffic they are responsible for managing and also of their specific environmental characteristics, allows their individual pollution and noise issues to be effectively taken into account, which constitutes a step towards a real sustainable development policy. Adaptive airspace makes it possible to adhere more closely to the operating procedures which are most respectful of communities, because it is managed locally.

Aircraft punctuality, a major concern of the Paradigm SHIFT Project, also allows greater respect for all airport-related noise restrictions and cuts down on pointless waiting, which of course has an effect on gas emissions.

Taking account of all the air transport actors' constraints when the contract of objective enables airlines to give satisfaction as much as possible in terms of fuel consumption and to reduce emissions.
These negotiations are, in fact, a search for the right balance between the requirements and the constraints of the various actors, in the interests of ensuring transparency.

*Transition*

This Project does not by any means recommend a revolution, a "big bang". On the contrary, the approach put forward here makes it possible calmly to envisage a reduction in costs through increased respect for punctuality and the implementation of the "contract of objective"; it also proposes a resolutely capacity-based solution, that of the implementation of dual airspace.

While these two elements constitute an innovative proposal, they also leave room for the progressive implementation of the negotiation mechanisms and the introduction of the highways. As has been repeated several times in this document, the local districts remain entirely responsible for the means they will implement in order to achieve their final objectives.

The SHIFT Project is in step with technological progress but does not require revolutionary or immature technologies. We are keen to maintain the place of the human operator in the system.

By considering the flight as a whole, including the linking elements between flights, for both operational and productive purposes, and by taking account of all the components of air transport, the SHIFT Project makes it possible not only to envisage real benefits for all air transport actors but also to clarify roles and responsibilities for each of them in the interests of transparency.
5 CONCLUSION

This document is a summary of the work conducted throughout the first part of the SHIFT Project.

It provides a frame of reference, the Paradigm SHIFT, for developing air navigation and the working methods of its various actors in order to meet traffic performance and safety constraints in future. The solutions proposed, the "contract of objective" and dual airspace, were worked out on the basis of the preliminary analysis of the problems of air traffic which constitute the subject of the first part of this document.

This document should be considered more as a basis for reflection in evaluating and defining the main avenues of research and for further analysis in the future.

The concepts described by Paradigm SHIFT represent acknowledged developments for the air navigation system. At present, these concepts require further theoretical and operational analysis. They raise many questions, which will be listed in the form of a research agenda.
REFERENCES


[Bib 28] PHARE. http://www.eurocontrol.int/phare/


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ANNEXES

A.1 Definitions
A.2 Glossary
A.1 DEFINITIONS

1.1.1 Actor

A participant in the process of negotiating and developing the operational plan (OP). It has a responsibility towards the other actors for the results of the "contract of objective" (i.e. it must respect the margins associated with the contract). It will therefore be responsible for the smooth functioning of the service plan to be implemented by the operators for whom it is responsible.

Examples of types of actors include:
- an airport (such as ADP);
- an airline (such as United Airlines);
- an ANSP (such as SkyGuide).

A.1.2 Moderator

The arbitrating authority (i.e. the final decision-maker in finding a consensus) of the operational plan.

It guarantees:
- optimum conduct of the negotiation and development process;
- the coherence of the operational plan (i.e. of its various agreements);
- accessibility of the data to the various actors and their operators.

It has the role of publishing the "contract of objective".

It will also carry out post-analysis of the operational agreement and monitor its smooth running (i.e. compliance with the "contracts of objective" by the various actors). As such, it also takes on the role of disciplinary authority.

A.1.3 Operator (TO)

The persons responsible to the actor supervising them for the successful execution of the service plan and the implementation of the associated means.

Examples of operators include:
- the crew of an aircraft;
- a team of controllers;
- a refuelling crew.

A.1.4 Rotation

A set of flights, defined by an airline, which follow on from each other in time and impose relational constraints in the logistical chain.

It is an airline's basic operational unit.
A.1.5 Initial demand

This term designates all the rotations proposed by the airlines.

A.1.6 Operational plan (OP)

The operational plan represents the process of negotiation involving all the actors and which leads to the refinement of the initial demand.

It is conceptualised and approved at the end of each phase of the negotiations in the form of a version of the operational agreement.

A.1.7 Operational agreement (OA)

An image of the operational plan which has been fixed and approved by all the actors.

It comprises all the planned rotations for a given time window.

A.1.8 "Contract of objective" (CoO)

The "contract of objective" is associated with a flight and results from the operational plan.

It is extracted from the operational agreement and is finalised $\Delta T$ before the planned start of the flight (i.e. $\Delta T$ before OBT).

It constitutes the contract of results associated with a flight for all the actors involved in that flight. It should therefore be regarded as fixed from the moment it is issued.

It defines the objectives (i.e. the margins accepted and negotiated by the various actors) from OBT, the moment when the aircraft disconnects from the departure terminal, until IBT, when it connects to the arrival terminal (i.e. G2G perspective).

A.1.9 Margin

The basic unit of the "contract of objective".

It results from the global refinement process (i.e. the compromise between actors) which has led to the publication of the "contract of objective".

It constitutes the definition of the interface between two actors associated with a flight. It can be viewed as a compromise with regard to the specific constraints of each actor involved.

It defines a window or a volume of 4D airspace into which an actor will "receive" or "deliver" a flight.

The principal criteria taken into account are:

- flight constraints;
- airline preferences;
- available means implemented by the actors;
• cost;
• strategic safety indicators ([Bib 6] sections 1.3.2 and 1.3.3.3);
• adaptability with respect to disruption.

A.1.10 Renegotiation

This process is initiated as soon as an actor anticipates that it will not be able to fulfil the terms of the "contract of objective", i.e. that it will not be able to respect its margin.

It involves the actors who are still associated with the progress of the flight and has two main guiding principles:

• an attempt to respect the final objective (i.e. punctuality at the destination airport);
• minimal impact on other flights in progress.

A.1.11 Service form (SeF)

The service form represents the specific version of a "contract of objective" for each operator concerned.

It defines the contract of means allocated to an operator. However, it allows the operator a degree of flexibility and adaptation with respect to the real situation and its own constraints.

In the case of ground operators – for example, those within an ANSP – this flexibility will nevertheless remain conditional on respect for the interface defined with the operator's neighbour.

The service form will therefore also define a contract of results between this operator and the next operator in the chain; the cumulative effect of these contracts will be to ensure that the margin accepted by the supervising actor is finally respected.

A.1.12 Service plan (SeP)

The service plan represents for a given operator all the aircraft that he/she/it will have to deal with.

In material terms, in fact, it comprises all of this operator's service forms.

It must be noted, however, that aircrew will constitute an exception since they will not receive a service plan but only a service form, as stated in section A.1.13.

A.1.13 Flight plan

In the accepted terminology, this term actually refers to the service form published for the aircraft operator (i.e. the crew).

It represents a compilation of the flight information (i.e. a portion of the flight path) contained in the service forms of all the other operators involved in this flight.
A.1.14 Strategic level

The strategic level defines global objectives (i.e. on a continental scale).

It makes it possible to federate and guarantee the global coherence of the system (i.e. regular access to resources) and will be based on the parameters transmitted by the tactical levels.

Although the strategic level takes as its basis "information" provided by the tactical level, it takes into account only "macroscopic" aspects of the system in order to ensure that it functions smoothly (i.e. in order to ensure fluidity and homogeneity).

Consequently, the strategic level will be concerned only with the interfaces between actors in the system (i.e. the planning of results), leaving to the tactical level the task of implementing the means and of understanding the system at "microscopic" level in order to achieve these results.

Typically, the "contract of objective" is part of the strategic level.

A.1.15 Tactical level

The tactical level, unlike the strategic level, will define local objectives. In other words, the tactical level will comprise the internal process set in place by each actor in order to support the strategy defined in the operational plan.

It will set in place and organise means at local level in order to achieve the objectives defined at strategic level. These tactical means will be either "passive" (e.g. the airspace structure) or "active" (e.g. the control position).

It is also engaged in a process of refinement which will make it possible to adhere as closely as possible to the real situation.

Typically, the service form is part of the tactical level.

A.1.16 Round

A round represents the temporal space associated with:

- the negotiation and publication of a version of the operational agreement approved by all the actors involved in this stage;
- the modification mechanism which will follow the publication of the operational agreement and function until the next version of the operational agreement.

The modification mechanism will ensure the refinement of a limited part of the operational agreement in accordance with current granularity, in order to ensure optimal resource management without calling the foundations of the agreement into question.

It will have meaning, therefore, only in the resource management phase.
# A.2 GLOSSARY

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<tr>
<th>A</th>
<th>Definition</th>
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<tbody>
<tr>
<td>ACARE</td>
<td>Advisory Council for Aeronautics in Europe</td>
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<tr>
<td>ADEP</td>
<td>Aerodrome of Departure</td>
</tr>
<tr>
<td>ADES</td>
<td>Aerodrome of Destination</td>
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<tr>
<td>AFAS</td>
<td>Aircraft in the Future ATM System</td>
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