The Context of Air Traffic Management

This chapter is a short introduction to the air traffic management operational context.

1.1. Introduction

The aim of this chapter is to present clearly and concisely the current air traffic management (ATM) system, so that readers who are not familiar with it can understand the problems being addressed in this book. More detailed information on the rules and organization in ATM can be found in specific documentations such as [INT 01, INT 08], published by the International Civil Aviation Organization (ICAO).

ATM covers a wide range of activities, including air traffic control (ATC) in which ground-based controllers monitor aircraft and issue instructions to pilots in order to avoid collisions. Between the moment passengers board the aircraft and the moment they arrive at their destination, a flight goes through several phases: push back at the gate, taxiing between the gate and the runway, takeoff and initial climb following standard instrument departure procedure, cruise, final descent following standard terminal arrival route, landing on the runway and taxiing to the gate. During each phase, the flight is handled by ATC organizations: airport ground control, approach and terminal control and en route control. These control organizations provide services ensuring a safe and efficient conduct of flights, from departure to arrival.

The ATM system is highly complex. It handles a huge number of flights and involves many actors: airlines, air navigation service providers (ANSP), airports, national and international regulatory authorities, etc. In 2013, the ATM system controlled 9.6 million flights operating under instrumental flight rules (IFR) in

Europe and 15.1 million in the United States. The Federal Aviation Administration estimates that its National Airspace System is in charge of 4,000–6,000 flights simultaneously[1] during peak hours.
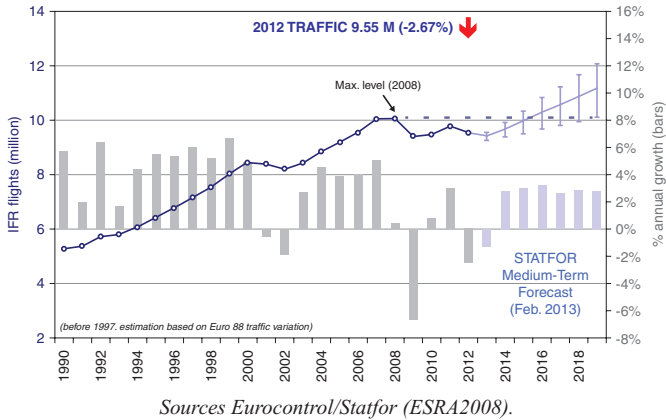

Sources Eurocontrol/Statfor (ESRA2008).

Figure 1.1. *Air traffic forecast in Europe*

In terms of future evolutions, the Asia-Pacific region is anticipated to undergo a rapid growth in traffic volume. In North America and Europe, the growth rate is expected to weaken. However, the global trend still points toward a traffic increase, as shown in Figure 1.1.

1.2. Vocabulary and units

The aviation community uses specific units and a specific vocabulary that needs to be introduced before describing the ATM system. An index of acronyms can be found at the end of the book.

Altitudes are expressed in feet (ft), or in flight levels (FL), with 1 FL = 100 ft. There are several definitions of altitude, but the most widely used is the geopotential pressure altitude, computed from the static air pressure p measured onboard the aircraft. FL are defined in reference to the isobar surface $p_0 = 1,013.25$ hPa.

Distances are expressed in nautical miles (NM), with 1 NM = 1,852 m. Velocities are expressed in knots (kts), with 1 kts = 1 NM/h.

The aircraft speed in the air is measured through dynamic pressure sensors. The true airspeed (TAS) is the actual aircraft speed in the air. The calibrated airspeed

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1 http://www.fly.faa.gov/Products/Information/information.html.

(CAS) is the TAS that would be necessary at mean sea level to obtain the same dynamic pressure than that measured onboard the aircraft. If we neglect the instrument errors, the CAS is the speed used by pilots when operating their flight, together with the Mach number, which is the ratio of the TAS and the speed of sound in the air. Typically, a climbing aircraft will follow several climb segments at constant CAS, followed by a climb segment at constant Mach number, at high altitudes.

Aircraft fly in the air, and the air is in movement above the Earth's surface. We also define velocity relative to the Earth's surface, called the ground speed, expressed in knots.

1.3. Missions and actors of the air traffic management system

The objective of ATM is to ensure safe and efficient flights, from departure to arrival. This mission is carried out by a number of national or international organizations that provide different services to the airspace users.

There are different kinds of airspace users. General air traffic includes commercial flights, private flights for leisure or for affairs, special flights for geographic data collection, meteorological studies or any other scientific study, drones, gliders, aeromodelling, etc. Military air traffic includes flights with specific missions such as flight combat training, surveillance and in-flight refueling, and other military missions.

Several kinds of services can be provided to the users:

– ATC services: 1) prevent collisions between airborne aircraft; 2) on the ground between aircraft and obstacles; 3) organize and expedite air traffic flows;

– flight information services provide useful information and advice to ease safe and efficient traffic;

– alerting services notify relevant organizations regarding aircraft in need of search and rescue aid, and assist such organizations as required.

While information services are not responsible for trajectory separation, control services are. Therefore, air traffic controllers issue instructions to pilots to maneuver the aircraft laterally, vertically or by adjusting speed or rate of climb/descent. When only the flight information service is provided, pilots take charge of collision avoidance.

The control, information and alert services are provided to users by ANSP. There are many actors interacting with one another in the ATM system: airports, air traffic

control centers (ATCCs), airline operators, national and international regulatory authorities, military control centers and authorities, meteorological services, etc.

In order to avoid airspace or airport congestion, it is necessary to organize and regulate the traffic flows. This continental-scale network management is carried out in Europe by the Eurocontrol Network Management Operations Center (NMOC) that enforces air traffic flow management (ATFM) regulations when required so by ATC units anticipating overloads. In the United States, this regulation takes the form of ground delay programs (GDPs) concerning each one or several airports in a same area. These GDPs are coordinated by the Air Traffic Control Strategic Command Center (ATCSCC). Similar organizations exist in other parts of the world where the traffic is dense enough to require such flow regulations.

1.4. Visual flight rules and instrumental flight rules

Flights can be separated into two categories, depending on the level of equipment of the aircraft and level of qualification of the pilots. A flight may operate under visual flight rules (VFR) or instrumental flight rules (IFR).

Under VFR, the pilot must maintain a sufficient distance to the neighboring clouds and obstacles. He/she can fly only if the meteorological conditions are compatible with VFR, especially concerning the visibility. These flight rules are designed for light aviation, where the basic "see and avoid" principle is applied to maintain separation from other aircraft.

IFR are less hampered by degraded meteorological conditions. Because IFR flights are allowed to fly in low visibility conditions, they are generally controlled by an ATC unit that is in charge of ensuring separation from other IFR or VFR flights.

1.5. Airspace classes

Several classes of airspace (from A to G) determine which services are provided to which types of flight. For example, only IFR flights can fly in Class A airspace, where the ATC service is provided to all IFR flights. In Class B airspace, IFR and VFR flights are admitted. The control service is provided to all flights and separation from other aircraft in ensured for all flights (IFR and VFR). Both IFR and VFR flights are allowed to fly in Class C airspace. However, separation from other aircraft is only ensured for IFR/VFR or IFR/IFR pairs. VFR flights are separated from IFR flights, but they only receive flight information relative to the other VFR flights and must ensure their own separation from these VFR flights. The following classes are similarly defined, with less and less services provided to flights. In Class G airspace, only the flight information service is provided and only for the flights that request it.

1.6. Airspace organization and management

1.6.1. *Flight information regions and functional airspace blocks*

Flight information regions (FIRs) are managerial divisions of the airspace into large regions where the air navigation services (control, information, alerting) are provided to airspace users. FIRs cover the totality of the Earth's atmosphere. In some countries, there is only one FIR covering all the airspace within their borders. This is not always the case, however. Some countries may have their national airspace included in a wider FIR covering neighboring countries. Other countries have divided their airspace into several FIRs. This is the case in France, for example, where the national airspace is divided into five FIRs. Figure 1.2 shows the airspace partitioning into FIRs in Europe.
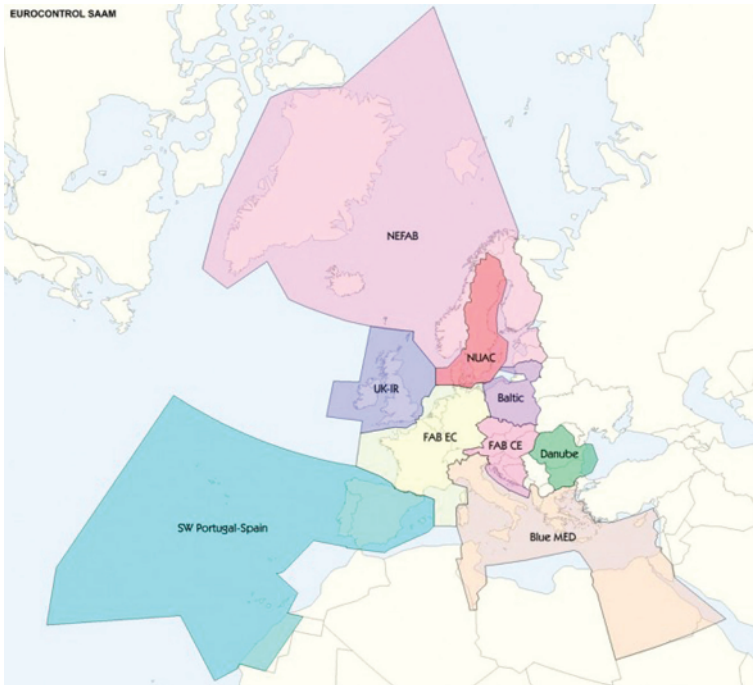

Source Eurocontrol

Figure 1.2. *FIRs in Europe*

The FIR boundaries are designed by the national authorities. Some FIRs are split vertically. In such cases, the lower part keeps the name FIR whereas the upper part is called an upper information region (UIR).

As a consequence of Europe's history, a great number of FIRs cover the European territory. The Single European Sky legislative package aims at harmonizing the ATM

system, making it less dependent on the national boundaries. For that purpose, FIRs covering different national airspaces are grouped into larger units, called functional airspace blocks (FABs). Figure 1.3 shows the FABs in Europe. For the time being, the different FIRs within an FAB are not fully integrated yet, but there is a closer coordination of the ANSP within a same FAB.

Source Eurocontrol

Figure 1.3. *Functional airspace blocks in Europe. For a color version of the figure, see www.iste.co.uk/durand/atm.zip*

1.6.2. *Lower and upper airspace*

In Europe, the airspace is split vertically, defining a lower airspace and an upper airspace. The boundary between upper and lower airspace is usually at FL 195, which means a pressure altitude of $19,500$ above isobar $1,013.25$ hPa. However, in some countries, lower and upper airspace may be divided at a different FL. For example the UIR of the Maastricht control center, which is in charge of the airspace above Belgium, Luxembourg and the north west of Germany, starts at FL 245. In France, there is only one UIR, above FL 195, and five FIRs below FL 195, although in practice

the portion of upper airspace above each FIR is controlled by the ATCC in charge of this FIR. In the United States, there is no UIR but the upper airspace sectors start at FL 240.

1.6.3. *Controlled airspace: en route, approach or airport control*

In the airspace where control services are provided to users, some volumes are dedicated to aircraft flying in the vicinity of airports, and some others are dedicated to en route flight between departure and destination.

The airspace volume around the airport is a control zone (CTR) for aircraft flying at low altitude, close to the airport runway. Above the CTR, a larger zone called terminal maneuvering area (TMA) in Europe or terminal control area (TCA) in the United States is dedicated to aircraft following arrival or departure procedures. It may cover several airports, in dense areas. Figure 1.4 shows the Paris TMA, as an example of such zones, with top and side views illustrating the airspace classes for each volume of airspace in the TMA.

The TMA (or TCA) is a transition between airports and the network of airways defined in the en route airspace. To summarize, there are different types of control activities, depending on the airspace volume being controlled:

– airport control, which includes tower control for runway operations and ground control for aircraft taxiing on the airport surface;

– approach control, for departure and arrival procedures;

– en route control, for flights following airways from departure to destination.

These three kinds of control activities are illustrated in Figure 1.5, where some radio-navigation aids, radars and communication equipment are also shown. A control tower and an en route ATCC are also represented. The control tower is in charge of aircraft separation in the neighborhood of the runway. It sequences takeoffs and landings, and prevents collisions of aircraft taxiing between the gates and the runway. The ATCC is in charge of en route traffic. The approach control service can be provided by an ATC unit located on or near the airport, for big airports, or the regional ATCC center, for small airports.

1.6.4. *Air route network and airspace sectoring*

Aircraft flying in the lower or upper en route controlled airspace follow predefined airways. The air route networks might be different in the upper and lower airspaces. Aircraft can deviate from their intended routes when instructed so by air

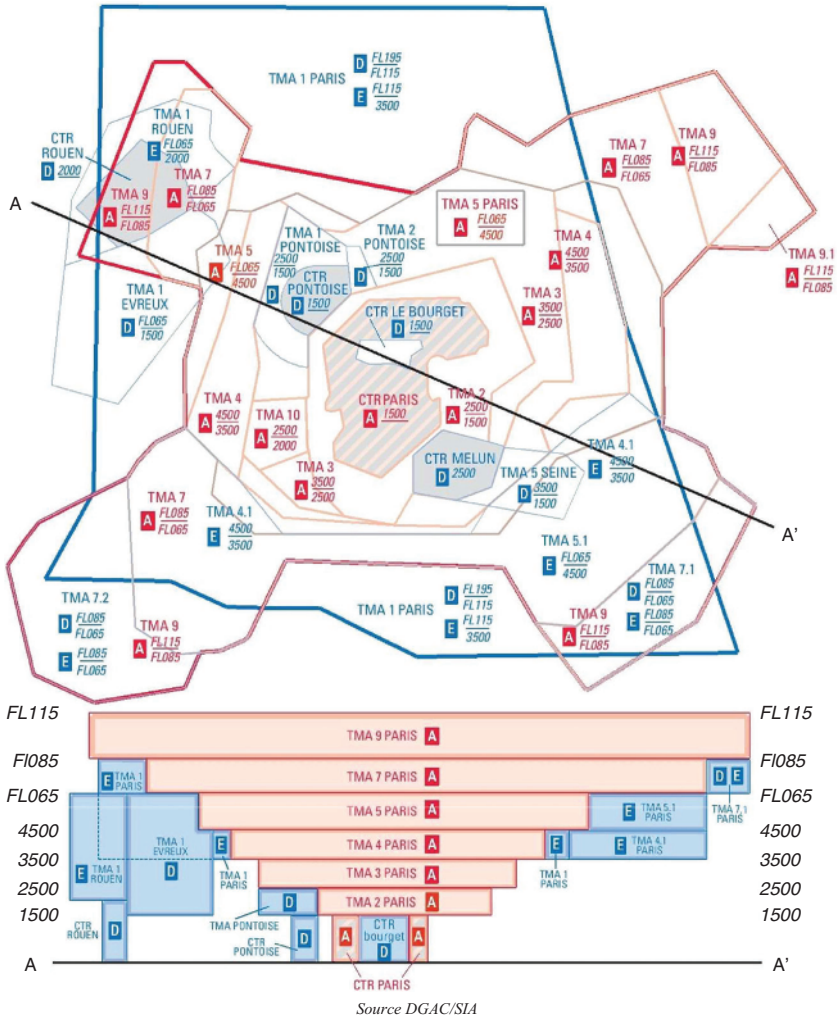traffic controllers, in order to keep separation with other aircraft or to avoid convective weather.


Source DGAC/SIA

Figure 1.4. *Top and sectional view of Paris TMA (2011). For a color version of the figure, see www.iste.co.uk/durand/atm.zip*

As a human controller can only handle a limited amount of traffic, the airspace is divided into sectors, which can be seen as the smallest airspace unit. An air traffic controller is only in charge of the traffic flying through the airspace sectors assigned to its working position.
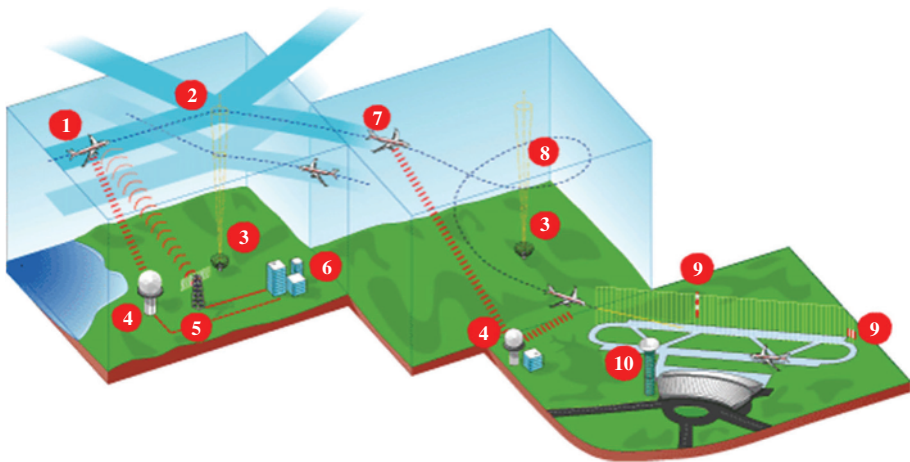
1 Aircraft entering an en route sector	**6** ATCC
2 Airway	**7** Aircraft entering an approach sector
3 Radio-navigation aid	**8** Holding stack
4 Mono-pulse radar	**9** Instrument landing system (ILS)
5 Two-way radio transmitter	**10** Control tower and ground radar

Figure 1.5. *En route, approach and airport control. For a color version of the figure, see www.iste.co.uk/durand/atm.zip*

Figure 1.6 shows both the air route network and the airspace sectors in Europe, in the upper airspace.

1.7. Traffic separation

1.7.1. *Separation standard, loss of separation*

One of the core tasks of the air traffic controller is to avoid collisions between aircraft. For that purpose, he/she must make sure that all aircraft are separated at all times by a distance greater than a given distance, called the separation standard. Any pair of aircraft must maintain a lateral separation of at least δ_ℓ, or a vertical separation of at least δ_z. These separation standards can take different values, depending for example on the radar and radio coverage in the airspace where the aircraft fly.

Typical values for the radar separations in the European en route airspace is 5 NM laterally and $1,000$ ft vertically. These separations, which may look large, consider the position uncertainties due to radar detection, the navigation errors and the delays in the processing of the radar information, between the actual radar detection and the position display on the controller's screen.

Losses of separations are critical events in ATC. When they occur such events are analyzed by the authorities, with the aim to improve the ATC system and procedures. As an example, the French ANSP publishes every year two indicators, "HN70" counting the separations below 70% of the separation standard and "HN50" for separations less than half of the separation standard. In 2012, the HN70 was 0.64 per 100, 000 controlled flights, and there was no loss of separation below 50% of the separation standard.
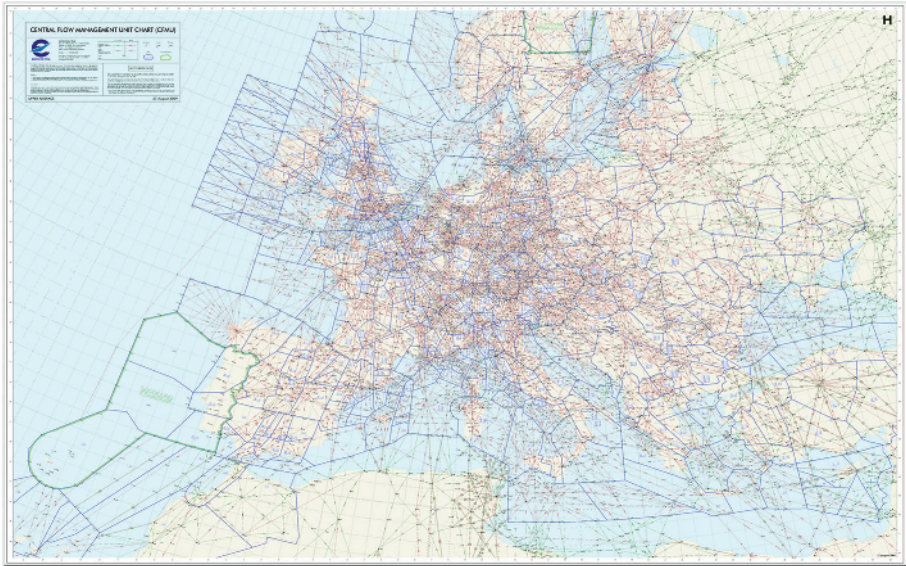
Source Eurocontrol

Figure 1.6. *Routes and airspace sectors in Europe (2009), in the upper airspace. For a color version of the figure, see www.iste.co.uk/durand/atm.zip*

Safety culture is widespread in the civil aviation environment.   When they consider that the safety of a flight has been put at risk, controllers or ground-based agents can file a report. Pilots can also file "airprox" reports. These incidents are systematically processed and analyzed by the authorities in order to continuously improve the procedures and the air traffic safety. In 2012, the French ANSP reported 1 airprox per 100, 000 flights, involving at least one IFR flight and no military aircraft, and 0.3 airprox per 100,000 flights, involving a military and a civil aircraft.

1.7.2. *Conflict detection and resolution*

In order to avoid losses of separation, air traffic controllers monitor aircraft trajectories and give instructions to pilots to maneuver the aircraft when they anticipate a loss of separation. A conflict can be defined as an anticipated loss of separation between the future trajectories of two aircraft, as illustrated by Figure 1.7. Mathematically, two aircraft i and j are in conflict when $\exists t$ such that:

$$d_\ell(i, j, t) \leq \delta_\ell \quad \wedge \quad d_z(i, j, t) \leq \delta_z$$

where δ_ℓ and δ_z are the lateral and vertical separation standards (e.g. 5 NM laterally and $1,000$ ft vertically).
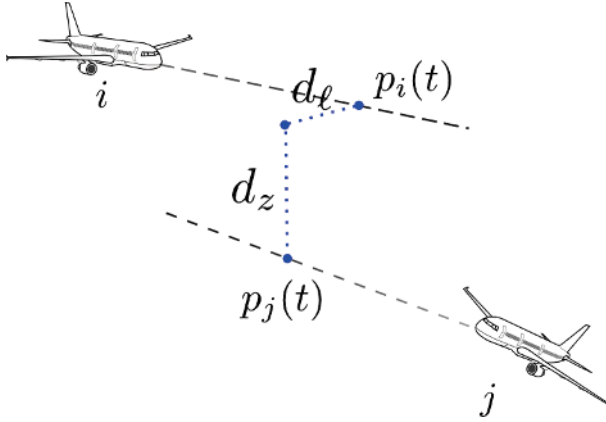

Figure 1.7. *Aircraft conflict*

In practice, the notion of conflict can cover traffic situations involving more than two aircraft (see Figure 1.8), for example when an aircraft is in conflict with another, which is itself in conflict with a third aircraft. Such situations are called n-aircraft conflicts, assuming n is the number of aircraft involved. Such extended conflicts can be formalized as closures of the relationship "is in conflict with". In some publications, the term conflict denotes only a potential loss of separation between two aircraft, whereas the "n-aircraft conflicts" are called clusters, so as to make a clear distinction between the two notions.

The maneuvers instructed to pilots by controllers can be of several types: heading or altitude change, climb/descent interruption at an intermediate level, speed regulation, holding pattern start at a given position, etc. These instructions are transmitted to pilots by radio.

1.7.3. *The distribution of tasks among controllers*

The "radar controller" (R-side) monitors aircraft trajectories on a "radar display" and gives instructions to pilots. He is also called "tactical controller", or "executive controller". He/she is assisted by a "planning controller", or "data controller" (D-side), who predetects potential conflicts between incoming flights and coordinates flights with adjacent sectors.
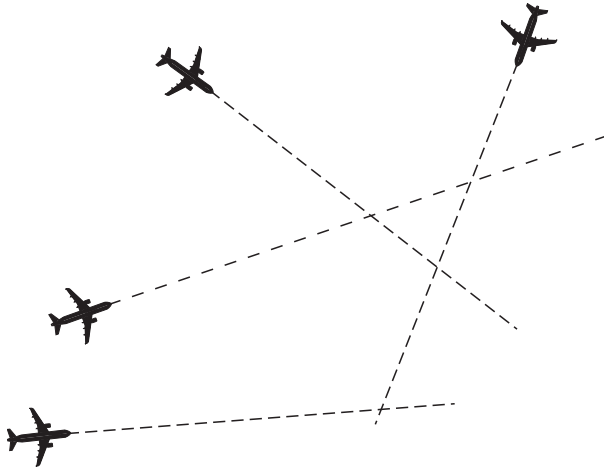

Figure 1.8. *An example of 4-aircraft conflict (cluster)*

In several countries, radar and planning controllers operate in tandem on the same ATC sector. With the emergence of new technologies and new computer-assisted control tools that are being developed, a new distribution of tasks is being discussed in the European and American modernization programs of the ATM/ATC systems. One of the possibilities being discussed is to introduce a "multisector planner" that could either act as a planning controller for several radar controllers or organize the traffic in advance for the benefit of several ATC sectors, using short- to medium- term traffic and workload forecasts.

1.7.4. *The controller tools*

The controller uses a number of tools to perform his/her tasks. One of them is the radar screen where the aircraft positions and velocities are displayed, together with the sector boundaries, routes and other relevant information. Controllers also use strips containing all necessary information relative to a flight: departure and arrival airport, route, times over waypoints, etc. Former paper strips are now being replaced

by electronic strips or stripless environment. The other equipment that can be found on a controller working position are radiocommunication and telephone equipment, some input/output devices allowing the controllers to receive, display and modify flight data and screens displaying meteorological data and other relevant information.

A radio frequency is allocated to each airspace sector. Telephone lines and radio frequencies can be switched from one controller working position to another, allowing the control room manager to dynamically assign airspace sectors to controller working positions.

1.8. Traffic regulation

A key issue for air traffic safety is to avoid overloading air traffic controllers. The traffic level in any opened ATC sector should remain acceptable for a human being. This constraint determines the capacity of the ATM system to accommodate the traffic demand in a given environment (meteorological conditions, level of equipment, type of traffic, etc.). In this section, we briefly introduce the different measures and procedures that aim at avoiding overloads while trying to match capacity and demand as much as possible.

These measures and procedures are applied in advance, before the aircraft enter the ATC sector that might get overloaded, with an advance notice depending on the type of measure being taken. Strategic planning is mostly concerned with the route network and airspace design, and takes place well in advance. Pre-tactical planning, such as staff changes and flow regulation measures, usually takes place one or two days before, or a few hours in advance. Tactical measures such as flight rerouting due to severe weather are decided in real time.

1.8.1. *Capacity and demand*

Capacity and demand are defined as follows in the ICAO documentation [INT 08]:

– *Capacity*: The maximum number of aircraft that can be accommodated in a given time period by the system or one of its components (throughput).

– *Demand*: The number of aircraft requesting to use the ATM system in a given time period.

With these definitions, capacity and demand can be quantified in a number of different ways, depending on the context. The mathematical expression of the capacity will not be the same when considering the ATM subsystems at various

geographical scales (airspace sector, FIR, FAB) and with different time periods (e.g. one hour, one day or one year). As a consequence, there is a multitude of formal definitions for capacity, depending on the context and purpose.

Among the multiple uses of this rather vague notion of capacity, let us cite the strategic design of airspace sectors and FABs, or the performance evaluation of ANSP. In pre-tactical applications, the notion of capacity can be used to regulate the traffic flows by allocating delays to departing aircraft so as not to exceed capacity in airspace sectors. The ATCC capacity can also be adapted to better match the demand by modifying the staff roster. Capacities can also be used and adjusted in real time, for example when an airport capacities (arrival and departure rates) are decreased due to bad weather.

These few examples show the diversity of objectives, of geographical and temporal scales, in the use of the notion of capacity. A direct consequence of this diversity is that there is no unique mathematical definition of capacity.

The same remark is true for the traffic demand, which can be quantified in many ways: density (number of aircraft within the sector boundaries at time t), entry counts (number of aircraft entering the sector in a given time period), occupancy counts (number of flights occupying the sector in a given time period), number of repetitive flight plans over a year, number of aircraft requesting takeoff, or landing, etc.

At the beginning of this section, we have outlined the need to avoid overloading air traffic controllers. However, the notion of workload is not explicitly mentioned in the ICAO definition of capacity, although we can guess that there is a relationship between the workload perceived by controllers and the maximum number of aircraft that can be accommodated, as mentioned in the ICAO definition. The reason why workload is not explicitly mentioned is related to the difficulty to quantify the actual controller workload. We shall see in section 1.8.2 that several factors, such as the traffic complexity or the sector complexity, impact the controller workload. Considering these factors when estimating workload and capacity has been a recent development in ATM research, with the aim to introduce more accurate metrics. Currently, very simple metrics are still being used in operations to roughly adjust the traffic variable to the capacity constraints.

The ATM organizations in charge of traffic flow regulation use declared capacities, provided by the ATCCs or airports, to enforce ATFM measures (in Europe) or GDPs (in the United States). Such measures consist of delaying departing aircraft or rerouting some flights so as to avoid to exceed the capacities declared by the ATC units. This declared capacity can be seen as an acceptable compromise between the delays imposed to the airlines and the workload incurred by air traffic controllers.

1.8.2. *Workload and air traffic control complexity*

Capacity is related to a workload threshold that should not be exceeded by air traffic controllers. Controller workload can be defined as the amount of physical and mental work done by the controller to perform his/her tasks [MAJ 02]. In this same publication [MAJ 02], Majumdar and Ochieng wrote that the term "controller workload" is subject to confusion, and to a multitude of definitions, models and metrics proposed in the literature.

In practice, the controller workload can vary significantly, for a same number of flights, depending on dynamic factors related to the traffic and static factors related to the sector geometry and route network. An additional factor is the operational procedures that air traffic controllers must follow when handling the traffic in their sector.
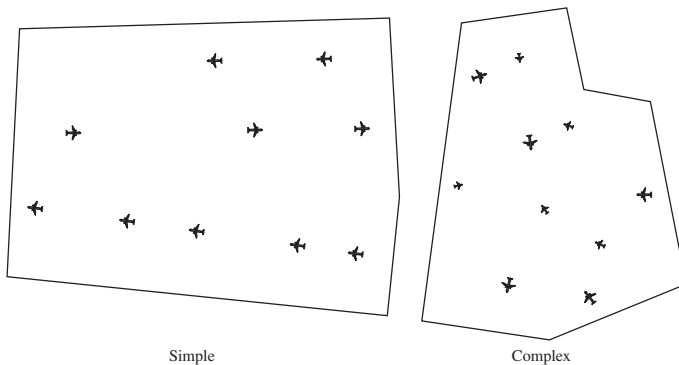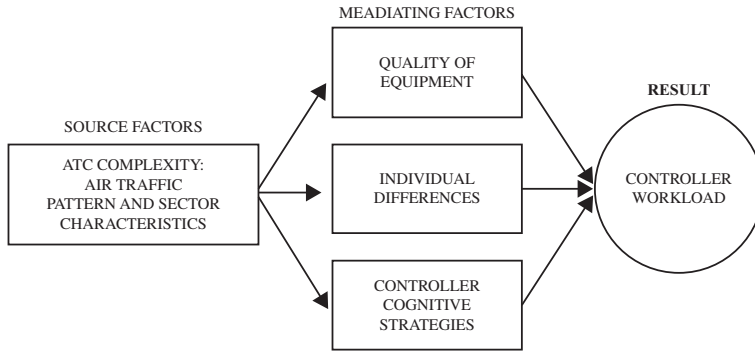

Simple   Complex

Figure 1.9. *Intuitive approach of ATC complexity*

The influence of traffic and sector complexity is illustrated in Figure 1.9, assuming the aircraft size in this figure is related to its speed. Intuitively, we can expect the traffic situation on the left, with aircraft at the same speed following routes that do not cross, to be much easier to handle than the traffic situation on the right, with various speeds and many crossing trajectories. Adding the vertical dimension, we can also have all flights cruising at separate constant FL, or we can have many climbing or descending aircraft that cross other traffic cruising at a constant FL.

Other factors related to the human operator and its environment can impact the controller workload. Figure 1.10, taken from [MOG 95], shows how controller workload is affected by source factors related to ATC complexity and mediating factors related to the controller and its equipment. Mogford *et al.* [MOG 95] defined ATC complexity as "a multidimensional construct that includes static sector

characteristics (sector complexity) and dynamic traffic patterns (traffic complexity)".
The reader can refer to [MOG 95, HIL 04] and their bibliography for a literature
review on ATC complexity.

MEADIATING FACTORS

SOURCE FACTORS

RESULT

ATC COMPLEXITY:
AIR TRAFFIC
PATTERN AND SECTOR
CHARACTERISTICS

QUALITY OF
EQUIPMENT

INDIVIDUAL
DIFFERENCES

CONTROLLER
COGNITIVE
STRATEGIES

CONTROLLER
WORKLOAD

Source Mogford et al. [MOG 95]

Figure 1.10. *Factors impacting the air traffic controller workload.*

1.9. Airspace management in en route air traffic control centers

1.9.1. *Operating air traffic control sectors in real time*

Several adjacent airspace sectors can be grouped together and assigned to a
controller working position. Depending on the context, the term "sector" is used in
the ATM community with different meanings: it may refer either to an "airspace
sector", which is an elementary unit of airspace, or a "control sector" (or ATC
sector), which is a volume of airspace made up of one or several airspace sectors and
operated on a controller working position.

Controllers can alleviate their workload, when it becomes excessive, by
transferring some of their airspace sectors to another working position. This sector
splitting can be done either by opening a new working position or by merging some
of the airspace sectors of the initial ATC sector with a neighboring ATC sector that is
less loaded. This is possible only when the initial ATC sector is made up of several
airspace sectors, and when there is enough staff to open a new position, if necessary.
Conversely, when workload is low, the control room manager can decide to merge
several ATC sectors that are under loaded and assign them to a single working
position.

These sector merging/splitting operations give some flexibility in the capacity to
accommodate the traffic demand, in real time. Of course, when an ATC sector is made

up of only one airspace sector and when this ATC sector is overloaded, some other measures must be taken (traffic reroutings, for example).

Dividing the airspace sectors into even smaller sectors can alleviate the workload. However, there is a lower limit to the size of airspace sectors that can be actually operated as ATC sectors. If the sector is too small, the radar controller has not enough time and space to maneuver the aircraft, and the coordination workload of the planning controller becomes excessive.

### 1.9.2. *Anticipating sector openings (France and Europe)*

The duty roster and the provisional sector opening scheme are usually built in advance. They can be adapted in real time by splitting or merging sectors as explained before, but it is essential to anticipate as much as possible if staffing will be sufficient, or if some overloads are expected. Anticipating such situations well in advance allows the traffic flow managers to prepare and take preventive measures, such as delaying departing aircraft or rerouting flights, if necessary.

In order to better understand the choice of metrics that are still being used nowadays to evaluate the traffic demand and capacity in this context, it is useful to go back in time. Before 1995 in France and in other European countries, the pre-tactical planning phase used to take place one or two days in advance, in each ATCC. It consisted of collecting the list of repetitive flight plans filed by the airlines, manually counting the flights entering any given sector to estimate the traffic load in a given period of time (one hour or half-an-hour). Candidate sector configurations were then compared, and the sector opening scheme that seemed to best fit the traffic demand was then transmitted to the organization in charge of traffic flow management. At the time, it was a national flow management team, which was soon replaced by the Eurocontrol Central Flow Management Unit (CFMU), now baptized NMOC.

After 1995, when CFMU became fully operational, the preparation of sector opening schemes was done by the flow management positions (FMPs) installed in each European ATCC. Some computer tools replaced the pen and paper that were used before. The Human Machine Interface (HMI) of a prototype of such tools is shown in Figure 1.11. This HMI displays a table where the columns are time slices of one hour, and the lines are ATC sectors. There are two numbers in the cells associated with ATC sectors that are planned to be opened: the number of flights entering the sectors in the hour (left) and the sector capacity (right).

Actually, Figure 1.11 does not show a provisional sector opening scheme. It matches the sector openings that actually occurred that day with the initial traffic demand. The first two lines of the table show the number of controller working

positions that were actually opened (first line) and the number that was planned in the provisional sector opening scheme (second line) transmitted to the CFMU. We can observe that there are big differences between these numbers. If we look more closely at the colored cells representing ATC sectors that were actually opened, we can see that several of them are red or black, which indicates that the traffic demand, expressed as the flow of aircraft entering the sector within the hour, exceeds the declared sector capacity, which is a threshold value that should not be exceeded, in theory. This comparison shows the difference between what was planned and what actually occurred on that day. It questions the quality of the prediction that was made concerning the sector opening scheme based on the incoming traffic flows and sector capacities.
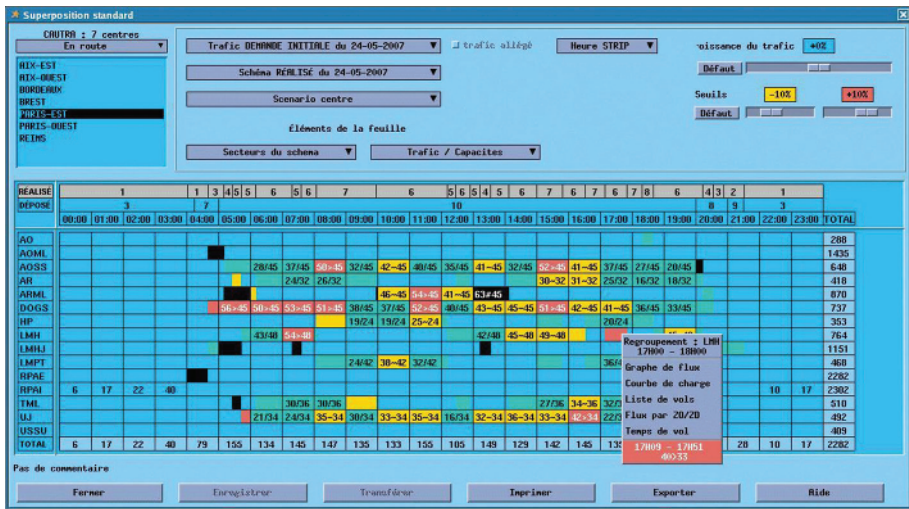
Source DGAC/DSNA

Figure 1.11. *Example of an HMI displaying sector opening schemes. For a color version of the figure, see www.iste.co.uk/durand/atm.zip*

Since 2011, a few other metrics have been introduced in the new tools for short-term ATFM used by the FMP operators. In addition, instead of a unique capacity, there are now several monitoring values representing different kinds of thresholds (peak, average, etc.), as shown in Figure 1.12 for the occupancy count.

This recent evolution is probably just the consequence of the recent awareness that incoming flows and sector capacities are poor indicators of the actual controller workload. This is well known by air traffic controllers. This may also be the result of a slow dissemination of the research works on ATC complexity and air traffic controller workload.

However, the current method to build sector opening schemes remains manual, although it is assisted with some computer tools. The FMP operator still chooses the successive ATC sector configurations among a small number of predefined configurations. Figure 1.13 gives an example of a provisional sector opening scheme for the ATCC of Zagreb (Croatia), which is made up of such predefined configurations. The FMP selects the configurations on the basis of his/her previous experience of similar traffic situations and considering the duty roster constraints.
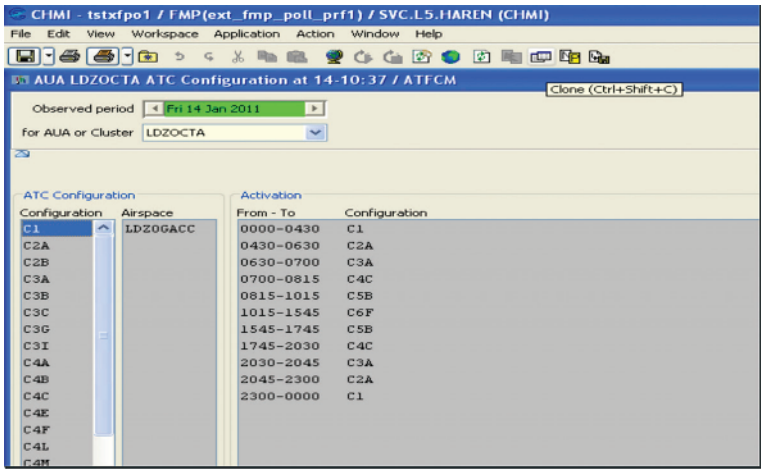

Source Eurocontrol

Figure 1.12. *"Monitoring values" for the "occupancy count" metric*

1.10. Air traffic flow management

In Europe, ATFM consists of delaying departing aircraft or rerouting flights in order to satisfy the capacity or flow constraints that have been enforced in congested areas. These traffic regulations are requested by ATC units so as to stay below the runway capacity of congested airports, for example, or to remain below the capacity of overloaded en route ATC sectors, when the workload cannot be alleviated simply by splitting or merging sectors (see section 1.9).

To be efficient, such measures must be taken well before the flights enter the areas where congestion is anticipated. They are enforced at the European level by a single actor, the European NMOC, in coordination with the FMPs of each ATCC. The network managers use the capacities declared by the ATCCs and the airports to regulate the traffic. These capacities may change across the day, depending on weather conditions, military activity, equipment failures, etc.

Source Eurocontrol

Figure 1.13. *Eurocontrol CHMI/CIFLO interface for FMPs*

Historically, in Europe, the en route airspace was subject to more congestion than airports. This was due to the scattering of the European airspace into a number of national airspaces, subject to a number of constraints (national borders, military areas, etc). In the United States, congestion was mostly observed at the airports whose capacities can be highly impacted by convective weather, in the airspace around the biggest metroplex. These differences can explain that researchers in Europe and in the United States sometimes focus on different subjects. This also explains why, in the United States, traffic flow management is more centered on GDPs that concern each a specific airport or terminal area, these different GDPs being coordinated by the ATCSCC.

Since the 1990s, however, these differences between Europe and the United States have tended to fade away, as airports have also become congested in Europe. The European air route network and en route airspace also follow a continuous process of harmonization and optimization, impulsed by the Single European Sky legislation, making the en route airspace comparatively less congested than it was before.

1.11. Research in air traffic management

1.11.1. *The international context*

Two major programs have taken the lead in the worldwide modernization of the ATM system: NextGen in the United States (also called NGATS for Next Generation

Air Transportation System) and SESAR (Single European Sky ATM Research) in Europe. These programs define new operational concepts based on 4D-trajectory management. They aim at harmonizing and modernizing the ATM systems, at a continental scale. They introduce new concepts such as the "business trajectory" that would be negotiated between ATC and pilots, enabling a more flexible and efficient use of the airspace while maintaining or improving the current level of safety of the ATM system.

In the proposed operational concept (see [CON 07] and [SWE 06]), the 4D-trajectory is defined as a contractual 4D-volume in which the aircraft would be free to fly, which would be negotiated between the ground control and the airline operators and pilots. The concept does not say how such conflict-free trajectories can be computed.

The implementation of this 4D-trajectory concept and other operational concepts is mainly an opportunity to involve all the actors (airlines, ANSP, industrial partners, regulatory authorities) in discussions on how to improve the current ATM system, and in the specification and development of the future tools to be deployed in the ATCCs and NMOC. In this context, scientific research on ATM problems is a marginal activity, carried out mostly in work package E "Innovative research," for the SESAR program.

1.11.2. *Research topics*

Through the quick description of the ATM system made in this chapter, we have introduced a number of topics that can be addressed as optimization problems: route network design, airspace sectoring, takeoff slot allocation, airport traffic optimization, conflict resolution.

These problems are complex and not always easy to formulate explicitly for the ATM actors, for several reasons. First, all these problems are related to one another, and ideally they should all be answered at once. For example we can avoid airspace congestion by smoothing the traffic (e.g. by delaying departing flights), but we can also address this by dynamically reassigning airspace sectors to working positions or by addressing both problems simultaneously. This gives us three different formulations for the same general problem (airspace congestion). Second, ATM relies on complex systems involving many actors from different domains, operating at different temporal horizons. Airlines, ANSP, and airports conduct different activities on the short, medium or long term. Finally, these activities undergo many uncertainties: predicting an aircraft trajectory is difficult because of errors generated by uncertainties on the weather, pilot intents and aircraft parameters. Before departure, missing luggage or passengers can generate unexpected delays on takeoffs. Dealing with uncertainties requires complex models that must be robust and reactive.

Modeling ATM problems is a difficult task in this context: if the model is too simple, it cannot handle realistic hypotheses, if it is too complex, it becomes impossible to optimize. Furthermore, when problems are correctly modeled, they are often hard to solve with exact methods because of their huge sizes.

For all these reasons, metaheuristics are generally good candidates to answer many ATM optimization problems. We will see in some examples that, sometimes, they can be less efficient than exact methods, and in some other examples that they are the best known methods.