Controlling air traffic

Air traffic needs to be controlled. The first step is to know where all aircraft are. CNS is important here. Next to this, flights also need to be managed properly, both by air crew and ground crew. This chapter discusses several aspects of these subjects.

1 CNS

1.1 What is CNS?

CNS stands for **communication, navigation and surveillance**. It consists of three parts. These are, surprisingly,

- **Communication** – Ensuring that the telecommunication necessary for the safety, regularity and efficiency of air navigation are continuously available. An important communication system is the **aircraft communications addressing and reporting system** (ACARS). Currently, aircraft communication systems are low-bandwidth, expensive and local.
- **Navigation** – When airborne, determining your own position and velocity. This usually done by following beacons. But another possibility is **area navigation**, also known as **random navigation** (RNAV). Now, the aircraft still uses beacons for navigation, but flies in a straight line to its destination. This is much more efficient.
- **Surveillance** – Determining the position and velocity of an airborne vehicle. To do this, we often use **radar: radio detection and ranging**. In fact, radar is the primary means of **air traffic control** (ATC) for surveillane. The only places where radar can not be applied is in oceanic regions and other remote areas. On these places we use **procedural voice reporting**: roughly every 30 minutes, the pilots must report their position to air traffic control.

Two types of radar systems can be distinguished: **primary surveillance radar** (PR) and **secondary surveillance radar** (SSR). We will examine PR first. After that, we go into depth on SSR.

1.2 Primary surveillance radar

Let's look at what a PR system does. First, it sends pulses for $4\mu s$ in a certain direction. (This is the **pulse width**.) It then starts to listen for $2496\mu s$. In that time, the pulses will be scattered back by the aircraft that are in the neighbourhood. From the signals that come back, the distance and heading of the aircraft, relative to the radar, can be derived.

Note that there is a cycle of $2500\mu s$. Thus, 400 **pulses per second** (PPS) are sent. And, since light can travel only 400 nautical miles $2500\mu s$, the **maximum range** of the radar is $200NM$. The **minimum range** depends on the pulse width. Another interesting thing is the accuracy of the radar system. Let's suppose that the **antenna beam width** is $1.8°$. A radar can only measure whether a signal is reflected back. It can not measure where in that $1.8°$ the aircraft actually is. So, if the aircraft is $200NM$ away, then the size of the aircraft will appear to be 1 nautical mile.

1.3 Secondary surveillance radar

SSR systems works slightly different than PR systems. When using SSR, there has to be a **transponder** on the aircraft. When this transponder receives a radar signal, it automatically sends a signal back. The exact message, which is sent by the aircraft, depends on the SSR mode. There are three important SSR modes.

- In **SSR mode A**, the transponder replies with the **aircraft identification code** (ACID), which is defined by ATC. This message consists of only 12 bits. Thus, $2^{12} = 4096$ possible ACID codes are possible. (SSR Mode A is used, when the interval between the P_1 and P_3 pulses is $8\mu s$.)
- In **SSR mode C**, the transponder replies with the aircraft **flight level** (FL) (being the pressure altitude in feet, divided by 100). So, when using SSR, you can find out which aircraft have which heading, distance and altitude. (SSR Mode C is used, when the interval between the P_1 and P_3 pulses is $21\mu s$.)
- In **SSR mode S**, a unique 24-bit **Mode S address** is assigned to each aircraft. Thus $2^{24} \approx 17$ million IDs are possible. Using the mode S address, aircraft can be unambiguously identified worldwide. (This mode is relatively new, and might replace mode A one day.)

An SSR system sends three pulses: P_1, P_2 and P_3. P_1 and P_3 can be seen as the most important signals. The interval between them determines the interrogation mode. However, when transmitting P_1 and P_3, a lobing pattern will occur: there will be one main lobe and several side lobes. When the aircraft comes close to the SSR beacon, it may start reading the side-lobes. This so-called **side-lobe interrogation** is undesired. To prevent it, we use a signal P_2. This signal is omni-directional. It is stronger than the side-lobes, but weaker than the main lobe. Thus, an aircraft will only reply to an SSR if the P_1 and P_3 signals are somewhat stronger than the P_2 signal.

Sadly, there are a couple of problems with SSR. First of all, aircraft transponders might become **over-interrogated**, when multiple SSRs are around. Also, problems may arise when two aircraft have the same distance from an SSR system. In this case, the signals from the two aircraft may become merged, such that they lose their meaning. This is called **garbling**.

2 The flight management system

The **flight management system** (FMS) is the center of the avionics system. It helps the crew in the planning and execution of the control, monitoring and management of the flight. How did it come into existence?

In the 1970s, the oil crisis forced airlines to fly as efficiently as possible. This led to the development of **aircraft operating manuals** (AOM). This manual contained data on fuel consumption, as a function of cruise altitude, trip distance, and more. The crew then needed to find the optimal flight. Not only was this a lot of work for the crew. But the AOM also didn't take into account other data, like fuel prices, crew salary, etcetera. Thus, the flight management system was developed.

The FMS consists of three important subsystems. The **flight management computer** (FMC) performs the important calculations, the **flight data storage unit** (FDSU) contains almost all data that is necessary and available, and the **command/display unit** (CDU) is the interface of the FMS with the crew. (Although the FMS can display data on the PFD and the ND as well.) The FMS also has three main tasks.

- **Flight planning** – The pilots enter the initial position, the destination, and some other data into the FMS. Next to this, the FDSU also contains data on airports, airways, beacons, waypoints, and so on. Based on this data, the FMS plans the flight of the aircraft.
- **Navigation and guidance** – The FMS takes data from various sources (INS, GPS, etc.) to find the best possible estimate of the aircraft position and velocity. It also computes the ground speed, the wind direction and velocity and much more. In this way, the FMS can provide navigation and guidance for the aircraft.

- **Flight optimization and performance prediction** – The FMS has knowledge on the aircraft type, the aircraft weight, the engine types, the aircraft CG position, the wind properties, the flight plan constraints and so on. Based on this data, it can calculate an optimal flight plan. Next to this, the FMS can also predict the performance, like the fuel usage, the altitude at waypoints, the arrival times, and more.

3 Air traffic control

3.1 Air traffic services

The present **air navigation system** (ANS) provides **air traffic services** (ATS) for civil aviation. The purpose of ATC is to accomodate air traffic. It should enable aircraft operators to stick to their planning as well and as safely as possible. Air traffic services can be split up into three parts:

- **Flight information service** (FIS) – Collect and handle information to assist pilots. An example system is the **automatic terminal information service** (ATIS). It provides data like wheather reports, the QNH, the transition altitude, and more.
- **Alerting service** (AL) – Initiate an early search and rescue activity for aircraft in distress.
- **Air traffic management** (ATM) – This again consists of three subparts.
  - **Air traffic control** (ATC) – Maintain a safe distance between aircraft and obstacles. (By the way, this is mostly only necessary for IFR. In VFR, pilots are often responsible for separation theirselves. But (almost) all commercial flights are IFR flights.)
  - **Air space management** (ASM) – Maximize the use of airspace. (For example, based on dynamic time sharing.)
  - **Air traffic flow management** (ATFM) – Ensure an optimal flow of aircraft through busy regions.

3.2 Splitting up airspace

There are a lot of **flight information regions** (FIR) around. Such regions can generally be distinguished into two categories. In **uncontrolled airspace**, no ATS is provided. On the other hand, in **controlled airspace** there is ATS. But you do need clearance from the ATC to enter controlled airpsace.

Near an airport, there are always several regions. First, there is the **control zone** (CZ), having a radius of only $r = 5NM$ and a height of $h = 3000ft$. (These values can differ a bit per airport though.) Around it is the much bigger **terminal control area** (TMA). It starts at a height of $1500ft$ (below that is lower airspace, where free flying is allowed) and ends at a height of $10500ft$. Around the TMA is the **control area** (CTA), which is up to roughly $19500ft$. Above this is the **upper control area** (UTA). In this area, control is often done over bigger regions (e.g. Eurocontrol). Airports also have a **waiting stack**, where airplanes wait before they can land. In this stack, airplanes fly a holding pattern on an assigned altitude.

Next to air regions, there are also **ATS routes**. These 'highways-in-the-sky' often go from beacon to beacon. Most airways are **dual airways**: they have two lanes to separate aircraft. Less busy airlines often have **separation by altitude**.

3.3 Controlling aircraft near airports

There are three important types of control centers on an airport.

- The **area control center** (ACC) controls incoming/outgoing airport traffic and en-route traffic that flies through the CTA. It uses a **long-range air-route surveillance radar** (LAR).
- The **aerodrome control** (TWR) controls air traffic in the CTR (so very near to the airport). Also, taxiing aircraft are controlled by the TWR. The TWR uses both **airport surface detection equipment** (ASDE) and visual inspection (binoculars) for surveillance.
- Finally, the **approach/departure control** (APP) forms the link between ACC and TWR. It controls the approach and departure of aircraft in the TMA. The APP uses a **terminal area surveillance radar** (TAR).

When aircraft leave from an airport, they often use a **standard instrument departure** (SID). These are procedures (defined by APP) that make use of beacons. They connect the aircraft departure with an ATS route. Similarly, arriving aircraft use **standard terminal arrival routes** (STARs). SIDs and STARs are defined for three main reasons: to separate incoming and outgoing traffic, to reduce noise around the aircraft and to reduce the necessary communication between the pilot and the controller.

To improve the control possibilities of aircraft, the aircraft crew must develop a **flight plan** before every flight and hand it to ATC authorities. This plan must consist of (among others) aircraft data, whether IFR or VFR is used, what navigation equipment is present, what TAS and cruise altitude is planned, what the origin and destination of the flight are, which departure time and route are planned, how much fuel and people are on board, and so on. The flight plan is then sent to all relevant ATS units through the **aeronautical fixed telecommunications network** (AFTN).

3.4 Airplane noise and safety

ATC has three priorities (in this order): safety, noise abatement and efficiency. To reduce the amount of noise, we can do several things. There are technical measures (more silent engines), political measures (reduce night flying) and operational measures (e.g. defining SIDs and STARs well, or using specific runways).

To ensure safety, **separation criteria** are used. For airways, a **lateral separation** of 1 to 6 nautical miles is used. For **longitudinal separation**, this is doubled. (So 2 to 12 nautical miles is used.) For **vertical separation**, often $1000 ft$ is used (or sometimes $2000 ft$ at higher altitudes).

Next to this, relatively big aircraft also must have an **airborne collision avoidance system** (ACAS). This system autonomously prevents mid-air collisions of aircraft. The most-used ACAS system is the **traffic alert and collision avoidance system II** (TCAS-II). This system interrogates SSR transponders of nearby aircraft and looks for possible conflicts. 40 seconds before the **closest point of approach** (CPA), it issues a **traffic advisory** (TA): where is the 'dangerous' aircraft and what is its heading? The pilots can then look for a solution. If they don't, then 25 seconds before CPA, the system will give a **resolution advisory** (RA): it shows a vertical escape manoeuver (e.g. 'go up' or 'go down') to avoid a collision.

4 The future air navigation system

4.1 Necessity of a new system

In 1983, the ICAO noticed several shortcomings of the ANS system. Routes and airways are often very indirect and have inconsistent procedures. Widely different aircraft use the same high density traffic area, causing great complexity in traffic flow and control. SIDs and STARs are fixed, which results in very little flexibility. And, in general, insufficient use is made of all the technological possiblities. Thus, improvement was necessary.

The ICAO therefore formed a committee to investigate **future air navigation systems** (FANS). This resulted in ideas for a new **FANS CNS/ATM** system. Ideas for communication, navigation and surveillance were all present. Let's have a look at these ideas.

4.2 Communication

The goal was that airplanes could communicate **around the world**, including remote and oceanic regions. Quite likely, digital data links would be used for this. For this, we could use VHF data links: ground stations are quite cheap and already widely available. Next to this, also SSR Mode S is a possible option; although this may not interfere with the primary task of SSR, being surveillance.

However, these two options both use line-of-sight communication. The third option is developing an **aeronautical mobile satellite service** (AMSS) system. This would ensure high-quality global communication, except at the poles. Also, ground stations are not required. But sadly, this system would be rather expensive. These three systems together could then form an **aeronautical telecommunications network** (ATN).

4.3 Navigation

For navigation, it would be nice if there is one system, providing adequate navigation **all over the world** for **all phases of flight**, for **all users** in **all meteorlogical conditions**, without having to follow beacons. A **global navigation satellite system** (GNSS) like GPS, combined with RNAV, can approach this ideal. However, currently, such systems are not always accurate and integer enough.

Luckily, there are methods to reduce these problems. With **receiver autonomous integrity monitoring** (RAIM), the receiver autonomously monitors the integrity of the signal. Also, **local/regional aera augmentation systems** (LAAS/RAAS) are ground-based systems that monitor the status of the GNSS system. The resulting information is then sent to the aircraft to increase the on-board accuracy and integrity.

4.4 Surveillance

For **surveillance**, we can use **automatic dependent surveillance** (ADS). This is an on-board avionics system that automatically transmits (via a digital data link) various aircraft data. In **ADS-Broadcast** (ADSB), aircraft periodically transmit data, like their position, velocity, altitude and other kinds of data.

When such a system is in place, we might actually achieve the possiblity of **free flight**. In this case, aircraft can choose their own path and speed in real time. All ATC needs to do is make sure that the traffic flow in a region is not exceeded, and ensure separation. The latter is done based on a **protected zone** and a smaller **alert zone** around the aircraft. These zones must always stay clear of other aircraft.