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Human Performance

Version 2

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040 HUMAN PERFORMANCE

01

PRINCIPLES

Human factor principles

01 HUMAN FACTORS IN AVIATION

1.1 Introduction to human factors

In all large technical systems, safety has recently become a key issue. From nuclear energy specialists to aerospace engineers, all work together in concert to improve safety conditions in their area of activity. Air transportation is no exception to this impetus toward increased safety.

In order to meet this objective, significant efforts have been made in both the technical domain and in regulatory affairs. In recent years, "Human Factors" that were long seen to be the cause of certain problems are now viewed as areas with a great deal of potential for improvement.

However, what do we mean when we refer to "Human Factors":
"Human Factors applies knowledge of how human beings perceive, sense, learn, understand, interpret, process, remember and use information, and also applies knowledge of how to measure human performance and its effects within a functioning system" *(ICAO Circular 241, p.3)*.

Human Factors training has the following objectives:

- To provide knowledge on human functioning to the flight crew;
- To make flight crews aware of their own behaviour in the cockpit;
- Finally, and on the basis of the first two points, to give them the tools they need to ensure that they are able to change their own behaviour in the cockpit towards even safer behaviour.

The human factors field is multidisciplinary. It uses sources of scientific information to solve practical, real world problems. The disciplines that highlight human factors are physiology, psychology, sociology, and ergonomics.

Physiology is the science that studies the functions ensuring the maintenance of life in living beings, as well as the physical and chemical factors and mechanisms involved. It analyses the interactions of these functions with the environment.
The main physiological systems are the cardiovascular, respiratory, nervous (perceptive and motor), digestive, and reproductive systems.

Psychology is the scientific study of human behaviour with all of its mental aspects, including both normal and pathological behaviours. The goal of psychology is to understand the structure and general laws associated with mental and behavioural functions.
Psychology explores the major human intellectual functions, such as motivation, personality, perception, memory, understanding, decision-making, learning, personal relationships, errors, alertness, workload, etc. It allows human limits and abilities to be described.

Psychosociology studies the relationships that exist between persons within a group. It is concerned both with personal interactions within the group and with group phenomena. Topics include communication, teamwork, and group processes.

Sociology is the study of social interactions and their products: ideologies, beliefs, communities, societies, cultures, habits, traditions, etc. It investigates social norms and seeks to understand the cause of the phenomena and social transformations observed. Sociology is useful in understanding

the profession of the pilot, including interprofessional relationships in the company, and within the air transportation system.

Ergonomics is a discipline that aims to define the characteristics of work situations as they are adapted to their users, so that the users can perform their activities with maximum efficiency, safety, satisfaction, and well-being, with a relatively short adaptation phase. Ergonomics draws its fundamental knowledge from other human science disciplines, and adapts them to the study of the work situations at issue.

The field of ergonomics is varied. A distinction is generally made between:

- The physical ergonomics of work stations (the dimensions of work spaces, accessibility, positioning of supports, the forces required to manipulate controls, etc.);
- Physiological ergonomics (protection against hypoxia, vibrations, acceleration, etc.);
- Cognitive ergonomics (information processing in connection with interactions between people and with other work situation components, such as modes and controls, help systems, etc.);
- Organizational ergonomics (optimization of socio-technical systems, including their organizational structure, rules, and mechanisms); relevant topics, including communication, collective resource management, work schedules, cooperative work, organizational culture, etc.

1.2 - Becoming a competent pilot

ICAO defines pilot proficiency as the combination of the knowledge, skills and attitudes required to perform a task safely to a specified standard:

- Knowledge comprises stable items of information that are formalized and internalized by a person. It is represented by a conventional code (language, writing, image, posture, gesture, etc.) and can be stored, processed or sent through communication. It is acquired through training and experience.
- Skills are the know-how that allow a task to be carried out. Many skills are the result of putting knowledge into practice. They are developed through practice. Skills are sensory-motor (perceiving, acting, etc.) and/or mental (reasoning, managing a workload, etc.).
- Attitudes are relatively stable, mental dispositions based on experience that affect our reactions to situations or people. They allow the managing of situations encountered in flight as well as interactions between people.

Knowledge, skills and attitudes are typically referred to as technical skills and soft skills. Technical skills include everything that makes a flight possible, i.e. knowing your aircraft and its equipment, how to use it, how to carry out a flight operation, etc.

Soft skills are directly related to how to behave individually and collectively when faced with a situation. They include personal aspects such as personality and emotions, interpersonal components, i.e. social or psychosocial and cognitive components relating to information processing.

Aviation history has shown that crew performance depends on both technical skills and soft skills. For this reason, crew training in soft skills is essential. It begins in initial training, as in the ATPL with

the 040 to acquire knowledge about human behaviour, and continues throughout the operational career with Crew Resource Management (CRM) training, which focuses more on skills and attitudes.

ICAO breaks down knowledge, skills and attitudes into eight fundamental or core skills. These skills are:

- Application of procedures,
- Communication
- Aircraft flight path management with automated systems,
- Aircraft flight path management in manual piloting mode,
- Leadership and teamwork,
- Problem solving and decision making,
- Situational awareness,
- Workload management.

These eight basic skills are both technical skills (application of procedures, managing the aircraft's flight path with automated systems and in manual piloting mode) and soft skills (communication, leadership and teamwork, problem solving and decision making, situational awareness and workload management).

1. The application of procedures involves, using the appropriate knowledge, identifying and applying procedures in accordance with the operational instructions and regulations in use. This involves:
    - Identifying the source of operational instructions,
    - Following operational procedures unless a high-level safety issue requires an appropriate deviation,
    - Identifying and following up all operating instructions in a timely manner,
    - Properly using aircraft systems and associated equipment,
    - Complying with applicable regulations,
    - Applying relevant procedural knowledge.

2. Communication involves effective oral, non-verbal and written communication in both normal and abnormal situations. This involves:
    - Ensuring that the receiver is both ready and able to receive the information,
    - Knowing in a relevant way who to communicate to and what, when and how to communicate,
    - Delivering clear, precise, concise messages,
    - Ensuring that the receiver has correctly understood the relevant information,
    - Knowing how to listen and showing what you understand when you receive a message,
    - Asking relevant, effective questions,
    - Using standard phraseology and radiotelephone procedures,
    - Accurately reading and interpreting company and flight documents,
    - Reading, interpreting, formulating and responding accurately in English to "datalink" messages,
    - Providing accurate reporting as required by operational procedures,
    - Properly interpreting non-verbal communication,
    - Using the look in the eyes, body movements and gestures consistently with verbal messages to reinforce them.

3. **Aircraft flight path management with automated systems** involves controlling the aircraft's flight path with the automated systems, including the appropriate use of guidance and flight management systems. This involves:
    - Controlling the aircraft through the precise, fluid use of automated systems according to the situation,
    - Identifying deviations from the desired flight path and taking appropriate action,
    - Maintaining the aircraft within the normal flight envelope,
    - Managing the flight path for optimum operational performance,
    - Maintaining the desired flight path during the flight using automated systems while managing other tasks and distractions,
    - Selecting appropriate automation modes and levels in a timely manner depending on the flight phase and workload,
    - Effectively monitoring automated systems, including engagement and automatic mode transitions.

4. **Aircraft flight path management in manual piloting mode** involves manually controlling the aircraft's flight path, including the appropriate use of guidance and flight management systems. This involves:
    - Controlling the aircraft in manual piloting mode with precision and fluidity according to the situation,
    - Identifying deviations from the desired flight path and taking appropriate action,
    - Maintaining the aircraft within the normal flight envelope,
    - Controlling the aircraft safely using only the relationships between aircraft attitude, speed and thrust,
    - Managing the flight path for optimum operational performance,
    - Maintaining the desired flight path in manual piloting mode while managing other tasks and distractions,
    - Selecting appropriate flight guidance system modes and levels in a timely manner depending on the flight phase and workload,
    - Effectively monitoring flight guidance systems, including engagement and automatic mode transitions.

5. **Leadership and teamwork** involves demonstrating effective leadership and teamwork. This involves:
    - Understanding and accepting the crew's roles and aims,
    - Creating an atmosphere of open communication and encouraging crew participation,
    - Taking initiatives and giving advice when necessary,
    - Admitting errors and assuming responsibilities,
    - Anticipating and appropriately responding to the needs of other crew members,
    - Carrying out the requested instructions,
    - Communicating relevant concerns and intentions,
    - Giving and receiving feedback in a constructive manner,
    - Taking action in complete confidence when it is important for safety,
    - Demonstrating empathy and showing respect and tolerance for others,
    - Involving others in planning and allocating tasks fairly and appropriately according to capacity,
    - Addressing and solving conflicts and disagreements in a constructive way,
    - Maintaining self-control in all situations.

6. Problem solving and decision making involves accurately identifying risks and solving problems, and making use of appropriate decision-making mechanisms. This involves:
    - Seeking accurate and relevant information from appropriate sources,
    - Identifying and checking what has happened and why things are not going as planned,
    - Using appropriate problem-solving strategies,
    - Persevering in solving problems without reducing safety,
    - Using appropriate and timely decision-making mechanisms,
    - Setting priorities appropriately,
    - Identifying and considering options effectively,
    - Monitoring, reviewing and adjusting decisions as necessary,
    - Identifying and efficiently managing risks,
    - Improvising in the face of unexpected circumstances to find the safest solution.

7. Situational awareness is about perceiving and understanding all relevant available information, and anticipating what might happen and what might affect operations. This involves:
    - Accurately identifying and assessing the condition of the aircraft and its systems,
    - Accurately identifying and assessing the aircraft's vertical and lateral position and intended flight path,
    - Accurately identifying and assessing the environment, in particular to understand whether it may affect operations,
    - Maintaining an awareness of time and fuel,
    - Maintaining an awareness of the status of personnel involved in or affected by operations, and their ability to perform their tasks as planned,
    - Anticipating precisely what could happen, planning and always being ahead of the situation,
    - Working out effective contingency plans based on potential threats,
    - Identifying and managing threats to the safety of aircraft and people,
    - Recognizing and responding effectively to information that shows a drop in situational awareness.

8. Workload management involves the effective management of available resources to prioritize and complete tasks appropriately based on the time available under all circumstances. This involves:
    - Maintaining self-control in all situations,
    - Efficiently planning, prioritizing and scheduling tasks,
    - Managing time efficiently when performing tasks,
    - Offering and accepting support, delegating when necessary, and asking for help before it is too late,
    - Carefully reviewing, monitoring and checking the actions taken,
    - Making sure that tasks are completed until the expected result is achieved,
    - Effectively managing and recovering from interruptions, distractions, deviations and failures.

02 FLIGHT SAFETY CONCEPTS

2.1 - Threat and error management model

The model for the management of threats and errors - Threat and Error Management model (TEM model) - was developed by the University of Texas (Robert L. Helmreich and Ashleigh Merritt, Ph.D., Psychology Department - The University of Texas Human Factors Research Project (UT) - Austin) from the analysis of air incidents and accidents. The ICAO now recommends describing and diagnosing the relationship between safety and human performance in the operational context.

The use of the "TEM" model is most often associated with the safety analysis methodology "Line Operations Safety Audit (LOSA)".

In the LOSA, the observation of current operational activities is made using the "TEM" model, in order to identify systemic threats and errors, manage them and their consequences for safety purposes.

The "TEM" model is an approach that takes into account the dynamics and complexity of operational situations. Its purpose is to improve safety by providing a methodology for the management of crew threats and errors in flight.

The "TEM" model focuses on three components:

- Threats (threats),
- Crew errors (errors)
- Undesired aircraft states (undesired aircraft states).

2.1.1 - Threats

Threats are events (environment or aircraft) or errors (other aircrafts, air traffic controllers, maintenance personnel, commercial personnel, etc.) that occur independently of crew actions conducted on the aircraft. They are not caused by the crew. Threats increase the complexity of the operational situation, because they have the potential to negatively affect flight operations by reducing safety margins.

Some threats can be anticipated as they are known or expected by the crew (e.g. thunderstorm area). Other threats are unexpected or unpredictable, such as a sudden failure without prior warning.

If some threats are obvious to identify, others are much less so and require a more extensive analysis on the part of the crew. These threats are called latent, by contrast with those that are easily identifiable, called active. Latent threats may be improperly managed, even ignored by the crew, to the extent that it has not identified or incompletely identified them. Latent threats are:

- Equipment design problems;
- Database navigation errors;
- Optical illusions;
- Layover durations too short;
- Maintenance errors;
- Etc.

Threats can be classified into two categories:

- Environmental threats;
- Organizational threats.

Environmental threats occur due to the environment in which air operations take place. They can be anticipated or occur in unpredictable ways, but in any event, they must be managed in real time by the crew. Environmental threats are diverse:

- Weather: thunderstorms, turbulence, icing, wind shear, crosswind, high or low temperatures, etc.;
- Air traffic control: traffic congestion, TCAS RA/TA, air traffic controller error, non-standard phraseology, runway change, etc.;
- Airport: contaminated runway, confusing signage, complex taxiing procedures, airport construction, closed runway, unfamiliar airport, etc.;
- Terrain: mountainous, lack of ground features, "black hole", etc.;
- Other: similar call signs, etc.

Organizational threats can be controlled by organizations at their source. They are general latent regulations. Organizational threats are diverse:

- Operational pressure: delays, late arrivals, etc.;
- Aircraft: malfunction, automation-related event, MEL/CDL, etc.;
- Cabin: flight attendant error, cabin event, sick passenger, cabin door security, etc.;
- Maintenance: maintenance error, etc.;
- Ground operations: de-icing, baggage, refuelling, catering, ground agent error, etc.;
- Dispatch: error, incomplete document, etc.;
- Documentation: manual not updated, error in a document, on a map, in a database, etc.;
- Other: crew planning, etc.

2.1.2 - Crew errors

Crew errors, as defined by the ICAO in the TEM model, are crew actions or non-actions that result in a deviation from the original expectations or intentions of the crew or organization. Errors are considered to reduce safety margins by increasing the likelihood of adverse events occurring. Errors may or may not have negative consequences on safety and some errors may have no consequences.

The effect of an error on safety depends on the ability of the crew to detect and manage this error before it leads to an undesired aircraft state, and then to a potential safety issue.

The "TEM" model describes three types of errors:

- Aircraft operation errors,
- Procedural errors, and
- Communication errors.

Aircraft operation errors

They occur when the crew interacts with the controls, automation systems and/or aircraft systems. For example, aircraft operation errors are:

- Manual handling and flight controls: vertical/lateral trajectory deviation, speed deviation, incorrect position of flaps or airbrakes, incorrect thrust reverser or engine settings, etc.;
- Automation: incorrect steering and navigation settings, incorrect mode, etc.;
- Systems: incorrect radio frequency, improper use or neglect of de-icing, altimeter, fuel management, speed bugs, etc.;
- Taxiing: turning down wrong taxiway, taxiing too fast, etc.

Procedural errors

They occur when the crew is working with procedures:

- Standard Operating Procedures (SOP): Not cross-checking the parameter inputs, etc.;
- Checklist: omitted, forgotten item, late checklist, unverified response, memory checklist, etc.;
- Announcements: omitted or incorrect, etc.;
- Briefings: omitted, items missed, etc.;
- Documentation: incorrect weight and balance, fuel information, airport information (ATIS), misinterpreted items on paperwork, incorrect application of the Minimum Equipment List (MEL), etc.

Communication errors

They occur when the crew interacts with other people (air traffic control, ground crew, other crew members, etc.):

- Crew to external: missed calls, misinterpretation of instructions, incorrect read-back, wrong clearance, taxiway, gate, or runway, etc.;
- Within the flight crew: miscommunication, misunderstanding between crew members, etc.

Aircraft operation errors, procedural errors and communication errors may be involuntary or result from wilful non-compliance of procedures, regulations, or work methods.

To explain the voluntary or involuntary nature of the errors, the "TEM" model identifies two subcategories of errors:

- Intentional non-compliance errors, which are voluntary deviations for operating regulations and procedures;
- Competence errors, which result from a lack of knowledge or sensorimotor skills.

There are three types of crew responses to errors committed:

- Trap the error: The error is properly detected and managed by the crew before it becomes consequential;
- Exacerbate: The error is detected, but the crew's action (or inaction) leads to a negative outcome for safety;
- No response: The crew does not react to the error committed, either by failing to detect it or choosing to ignore it.

There are three types of responses to crew behaviour toward errors committed:

- "No importance", because the error has no effect on flight safety, or it was properly handled by the crew to avoid any impact on safety; this corresponds to most errors in an aviation system designed to tolerate or resist human errors;
- "Additional error", where the crew commits another error following the first error committed; there is a very close link between the two errors committed;
- "Undesired aircraft state", where the aircraft is not necessarily placed in a compromising situation that creates increased safety risks.

2.1.3 - Undesired aircraft states

Undesired aircraft states are the differences in the aircraft position, speed control, poor application of flight controls, and incorrect configuration of systems resulting in reduced safety margins.

Off-center landing, excessive approach speed, and a long landing on a short runway are undesired states.
Often considered as the point of becoming a near miss or accident, undesired aircraft states must be handled by the crew.

In the "TEM" model, undesired states may be grouped into three categories:

- Aircraft handling: aircraft attitude, vertical/lateral deviation, speed deviations, unnecessary weather penetration, unauthorized airspace penetration, unstable approach, continued landing after unstable approach, landing (long, hard, or off-center), etc.;
- Ground taxiing: Proceeding towards wrong taxiway or runway, wrong taxiway, ramp, gate or hold spot;
- Incorrect aircraft configuration: systems, flight controls, automation, engines, weight and balance, etc.

There are three types of crew responses for handling undesired aircraft states:

- Mitigation: The active response of the crew after the occurrence of an undesired state allows for risk reduction and return to a safe flight;
- Worsening: The response of the crew (action or inaction) after detection of an undesired state leads to an additional error;
- No response, either because the undesired state is not detected, or because the crew chooses to ignore it.

Consequently, there are three possible crew responses to an undesired aircraft state:

- Recovery: the risk has been eliminated;
- Additional error: action or inaction of the crew leads to an additional error following the previous error; there is a very close link between the two errors committed;
- Final state: the consequences of which can be more or less severe and lead to an incident or an accident.

2.1.4 - Countermeasures.

In the normal exercise of their operational functions, the crews apply countermeasures in order to limit reductions in safety margins due to threats, errors and undesired aircraft states.
Countermeasures require actions by the crew.

Some countermeasures have a systemic origin and are based, for example, on checklists, briefings, training, SOPs, alarm systems (i.e. Ground Proximity Warning System (GPWS) or Traffic Collision Avoidance System (TCAS)), etc.

Other countermeasures are based on the pilot's direct contribution to safety. These countermeasures are individual and collective:

- Planning countermeasures, for managing anticipated and unexpected threats: established and shared action plan, work load distribution, management of priorities and emergencies, etc.;

- Execution countermeasures, for detecting and responding to errors: monitoring and crosschecks, workload management, automation management, etc.;

- Review countermeasures, for managing the changing flight conditions: evaluation and modification of action plans, questioning the validity of current action plans, removing doubts and affirming its views, etc.

2.2 - "SHELL" model

The "SHELL" model describes the various components of a socio-technical system in which humans occupy the central place. It is the model advocated by the ICAO to explain human performance and error sources.
In 1972, Edwards was the first to propose a model that he called "SHEL", acronym of the initials for the English component names making up his model. Therefore, SHEL means that the socio-technical safety system for air transportation can be described through the interactions of four elements:

- "Software" (S), i.e. the information present in the system, documentation (procedures, symbols, software, etc.);
- "Hardware" (H), i.e. the technical component of the system, the hardware;
- "Environment" (E), i.e. the conditions under which the transportation system must operate;
- "Liveware" (L), i.e. the human component: size and physical condition, physiological needs and tolerances, perception, information processing, decision making and action, communication, etc.

"SHELL" model (Hawkins). 1975

Thereafter, Hawkins enriched the model by introducing another human component to model ("L"), human social interactions present in any collective work. The "SHEL" model thus became the "SHELL" model.

Safety is considered in the model on two levels:

- For each element of the model: the safety system involves a high level of each of its elements;
- For the interfaces between the model elements; the quality of coupling between the elements is critical to safety, poor coupling may be a source of error.

The "SHELL" model is focused on the human being. For optimum efficiency of the socio-technical system, the other aspects of the model must be adjusted to and harmonized with this central aspect.

2.2.1 - Model interfaces

a) L-H Interface (Liveware-Hardware)

It is the most widely known interface when we speak of human-machine interfaces. It covers the fields of investigation as varied as the design of cockpit seating, display surfaces and information presentation, or aircraft and system controls.

b) L-S Interface (Liveware-Software)

It is the interface between the pilot and non-physical aspects of the system: procedures, operating manuals, checklists, symbols, meaning of information, tree navigation or presentation of information, software, etc.

c) L-E Interface (Liveware-Environment)

The environment is the operational environment in which the flights are made: physical, meteorological, but also operational and economic environment (pace and working conditions, air navigation, traffic, economic constraints and pressures of the company, etc.).

d) L-L Interface (Liveware-Liveware)

This is the interface between people. The analysis of the accidents in the Everglades (1972) and in Tenerife (1977) pointed to a poor distribution of tasks between the crew members in the first case, and leadership not using all of the crew resources in the second case. Management of the human-human interface is just as important for performance and safety as technical skills alone. Human-human interfaces refer to the collective work within the crew and with the other operational actors outside the cockpit.

2.2.2 - Harmonization of elements

The basis for the "SHELL" model is to establish harmony within the levels of interface between the different elements of the model. However, it is necessary to take into account the fact that any socio-technical system is constantly developing: both in the model elements and interfaces. This means that harmony is a dynamic process of control between the elements of the system, which takes into account the limits of each element.
The system design, regulations, and procedures create a safe equilibrium between the system elements. This equilibrium has been defined according to past experience (reporting) and risk analyses for future situations.

During operation, the system can be confronted with situations for which it was not designed and planned. Or it may then present limitations that had not been envisaged (e.g. a failure or a "bug"). When a change, development or limitation is observed, and especially if this calls into question the safety equilibrium between the elements of the socio-technical system, balance must be restored. The new balance must be sought at the relevant interface. In some cases, this is not sufficient due to the limitations of each element. It is then necessary to find balance through readjustments of other interfaces, even if these interfaces were not directly involved in the cause of the balance breakdown.

For example, we discover a bug in a computer system. Either we know how to correct it, and it restores balance within the "Hardware" element. Or we do not know how to correct it or its correction incurs a cost that we assessed as too high; in this case, we will act on other elements, such as the environment (operating conditions) or information (training or documentation). It then acts on the interfaces to recreate harmonization.

03 SAFETY CULTURE

3.1 - Introduction to the safety culture

Air transport is a globalized system that employs millions of people. In 2018, it carried 4.3 billion passengers and 58 million metric tons of freight on scheduled flights (source ICAO). In Europe, there are more than 30,000 IFR flights on average per day in 2018. A peak was reached in June 2019 with 37,228 IFR flights controlled in one day (source: Eurocontrol).
The centre is organized around three main entities:

- national and international regulatory authorities (ICAO, IATA, JAA, EASA, Eurocontrol, FAA, DGAC, CAA, etc.);
- professional organizations (IATA, IFALPA, IFATCA, etc.), which defend the specificities of each profession in the aviation industry: airlines, flight crew, cabin crew, maintenance staff, air traffic controllers, etc.;
- airlines with management, commercial departments, administrative departments, training and monitoring departments, flight crews, maintenance, etc.;
- other aviation industries, including air traffic control, airports, manufacturers, equipment and service providers, etc.

Air transport safety and performance are the result of the functional, financial and operational complementarity between all these entities. Individual aims may be contradictory and a source of conflict. The system works through compromise, with financial and political considerations playing a major role.

For years, safety involved reviewing accidents by analysing the activity of the front-line players (pilots, air controllers, etc.). If an error caused an accident, it was a flight crew error. The question of whether or not the conditions under which the crew were working (cockpit ergonomics, procedures, regulations, training, operational requirements, economic requirements, etc.) had an effect on their activity was not asked. The crew had to adapt to the situation regardless of the working conditions. If the crew made a mistake, it was obviously because they did not do the right thing.
This model was satisfactory for designers and managers because it did not call them into question.

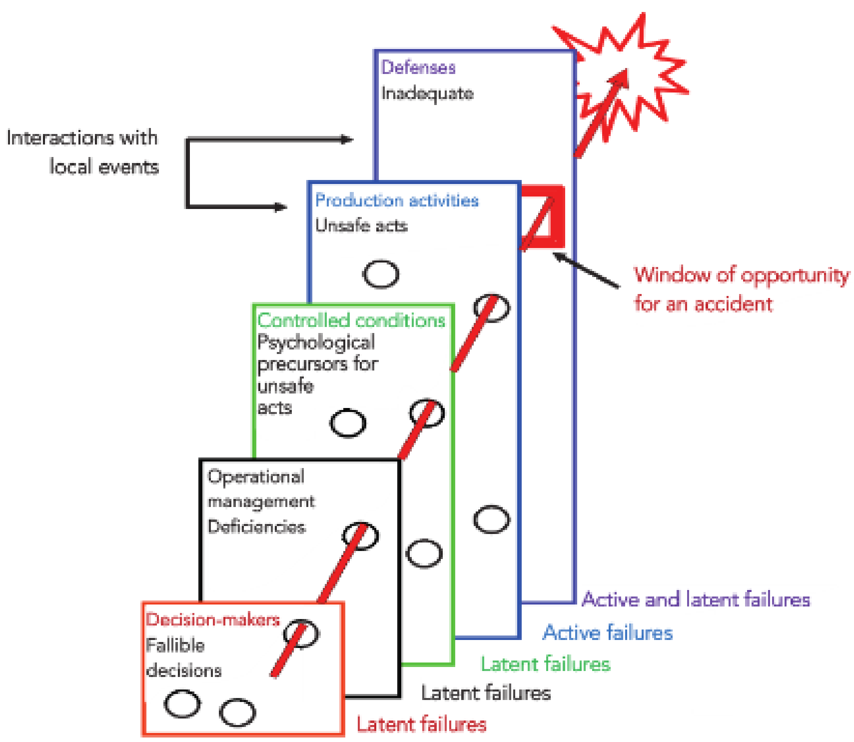
The approach aiming at broadening the spectrum of safety investigations is contemporary to a series of disasters that have occurred since the late 1970s, such as "Three Mile Island" (nuclear power plant in the USA in 1979), "Challenger" (space shuttle in the USA in 1986) and "Chernobyl" (nuclear power plant in Ukraine in 1986) accidents.
Using the data contained in these investigation reports, James Reason proposed a model of accident causation at the level of organizations: "layered security" model or "Swiss cheese" model.

3.2 - "Swiss cheese" model by James Reason

Safety is the result of coordinating numerous human and technical elements. Their operation requires protections or safeguards. Accidents result from a combination of factors, each of them being necessary but not sufficient on its own, to undermine the effectiveness of safeguards.

The model by Reason explains how failures on various levels of a complex organization can lead to an incident or accident.
It provides a cross section of the organization in successive layers with each one representing a hierarchical or functional level.

At the peak of a company, there is upper management, the executives (or policy makers). On the one hand, policy makers have the responsibility of setting goals and, on the other hand, to manage available resources to achieve these goals safely and efficiently (adhering to passenger schedules, budgetary constraints).
Another element of the system is represented by operational managers, who are in charge of implementing the decisions made by policy makers. Operational managers thus define the required conditions to achieve them as well as the production activities. For example, equipment must be reliable and powerful, crews must be properly trained and motivated, and organizational conditions must be safe (planning, rest periods, etc.).
The final element is represented by defenses. They are established in order to protect people and equipment against negative unexpected consequences and prevent incidents or accidents involving safety or the production of the system, and which could not have been anticipated by policy makers, operational managers, production activities or required conditions.



"Layered security" model still called the "Swiss cheese" model by J. Reason.

Any complex system has inherent failures. These failures vary in their root cause and may or may not manifest themselves. When they have immediate consequences after their production, these

failures are classified as active. They are generally attributable to primary actors, such as pilots, air traffic controllers, mechanics, etc.

When their consequences manifest themselves at a distance from the time they were produced, we refer to them as latent failures. Latent failures are the prerogative of actors located upstream from the work situation (directors, managers, procedure editors, designers, etc.), but they may also be produced by frontline actors (an error inserting values that will manifest itself several minutes or hours later when the function will be engaged).

In human-machine, human-regulation or human-human interfaces, the frontline personnel inherit system failures. It creates the conditions in which latent failures may occur. We are referring to windows of opportunity for accidents.

Most latent failures result from the errors of policy makers. Even in the best-led organizations, a number of decisions prove to be dangerous, because they are made by human beings and are therefore subject to bias and their own limitations. Then we are referring to fallible decisions.

Some of these decisions endangering safety could be avoided, but it must be possible to detect them in order to reduce the harmful consequences. It is the role of the operational managers. However, they can make improper choices, because they are also human beings. These deficiencies will generate requirements for psychological precursors of unsafe acts, and activities producing unsafe acts.
At this level, unsafe acts produce active failures.
Defenses are then the last lines of protection to avoid windows of opportunity for an accident.

3.3 - Principles and characteristics of the safety culture

The concept of the safety culture is used in the industries at risk to describe the way in which safety is managed. It reflects attitudes, beliefs, perceptions and values shared by the personnel of an organization in terms of safety. The culture results as much from the safety policy from management as the way in which it involves all personnel.
The safety culture of an organization is the result of various influences, including national culture, professional culture and organizational culture.

National culture differentiates the national characteristics and value systems of different nations. In aviation, some aspects of national cultures have been identified that may be critical to flight safety:

- The distance with regard to power characterizes the way in which power is exercised. The greater the distance, the more autocratic decisions are accepted by subordinates, who are confined to an implementing role.
- Individualism versus its opposite, collectivism. This dimension reflects the way a nation values either individual initiatives or collective initiatives.
- Masculinity versus its opposite, femininity. Masculinity conveys competition, performance, and ambition, while femininity conveys modesty and attention. Some nations are more masculine or feminine than others.
- The avoidance of uncertainty reflects the attitude of accepting uncertain, ambiguous or unknown situations. Nations that accept uncertainty are more open to original solutions and adaptation. Nations that avoid uncertainty establish standards and strict rules that govern situations.

Professional culture differentiates the characteristics and value systems of a profession. Through selection, training, experience, and work characteristics, professionals develop similar behaviours to those of their peers.
For example, they can develop the feeling of invulnerability or may not be affected by their personal problems.

Organizational culture differentiates the characteristics and value systems of different organizations. Each organization has its own culture based on its history, sector of activity, management, personnel and objectives.

Within the same airline, there are different professional cultures (pilots, mechanics, ground agents), but there can also be find different national cultures (pilots from different countries), as well as different organizational cultures (personnel coming from other companies or those with a military background, subcontractors, temporary employees, etc.).

One of the important characteristics of the safety culture is the sharing of safety information within the organization and entire air transportation system.
We refer to open culture to classify the attitude of an organization that promotes safety-related information, their analyses and sharing of these analyses, whether it be within the company or the professional aeronautics community.

Developing an open culture, in contrast to a closed culture, means admitting that deviations occur (errors, violations), whether they are known by the organization and they are analysed without fear of sanctions or reprimands for their authors.

This also means that the organization is able to go back to the root causes that produce them, in order to challenge them to be able to advance toward safer operating rules.

An open culture is accompanied by a just culture. In the 1990s, the development of concepts related to safety and human error were at the root of approaches promoting feedback on dangerous acts, and particularly unintentional errors and thus hardly reprehensible.
Therefore, the need arose to establish the concept of a non-punitive culture, without sanctions against actors who report dangerous acts, in contrast to a punitive culture. However, this approach has quickly shown its limits, due to the impunity granted to certain acts and permissiveness that it could generate among frontline actors.
That is why a middle road, the "just culture", was introduced between a punitive and non-punitive culture. Today, the just culture is considered to be a new and improved safety method to satisfy the need to know about dangerous acts falling within the scope of human errors, and penalizing acts falling within behaviour deemed as non-professional.

Since its origin, safety has been a priority in aeronautics. "Safety First" is the adage used to express the importance of safety in the air transportation system and the efforts that should be allocated to it.

Safety is not just for when there is a near miss or accident. In speaking of "Safety First", the company must demonstrate that it places risk analyses and strategies for managing these risks at the heart of its decision-making process for production objectives.

Through this behaviour and transparency, the company provides the setting in which it expects that its frontline actors (aircrews, mechanics, air traffic controllers, operators) to also conduct themselves.

The safety culture is promoted by a number of factors that it must endeavour to develop in any company or organization providing air services:

- A clear policy and safety objectives known by all in the company; this involves a willingness to analyse malfunctions as well as their individual, collective and organizational components;
- Visible commitment by management in defining and implementing the company safety policy;
- A safety organization in the company, clearly identified by its financial, material, and human resources, its managers and its reference documents;
- Procedures for threat analysis, which leads to defining risk management strategies;
- Reporting and audit systems that ensure safety within the company and identify new threats;
- Communication tools and training for risk management of the company;
- Transversality between operational services of the company is an ongoing concern.

3.4 - Five components of a safety culture

James Reason worked on the characteristics of the safety culture. He identified five components of a safety culture:

- Information and knowledge culture: Those who manage and lead the organization have a good knowledge of the human, technical, organizational and environmental factors, which determine the safety of the organization as a whole.
- Feedback or "reporting" culture: The organization establishes a climate of confidence where all personnel are ready to report their errors and near misses.
- Just Culture: The organization creates a climate where the personnel are encouraged (even rewarded) for providing essential information on safety. However, there is also a clear line that establishes limits between acceptable and unacceptable behaviour.
- Flexibility and adaptation culture: A culture where an organization is able to reconfigure itself during high-tempo activities or certain types of danger; to be able, when it is necessary, to shift move from a conventional hierarchical operating mode to a more functional and operational mode.
- Learning Culture: The organization must have the willingness and competence to draw the right conclusions from its safety information system along with the desire to implement necessary reforms.

3.5 - Safety management system (SMS)

Aviation safety managed is now organized in air transport through the Safety Management System (SMS) concept.

A safety management system is a structured approach to safety management that encompasses the required organizational structures, responsibilities, policies and procedures.

All air service providers such as airlines, maintenance workshops, aircraft airworthiness organizations, aerodrome operators, air traffic services and training centres are required to have an SMS.
National organizations, or supranational organizations in Europe such as EASA, are required to have a safety programme to achieve an acceptable level of safety in air operations. The safety programmes are supported by the state air service providers' SMSs, and in turn, the state safety programme makes recommendations for safety management at individual air service provider level.

The objective of an air service provider's SMS is to ensure the consistency and completeness of safety actions to provide the accountable manager (the person who is responsible to the authorities for the means used in their company to achieve the acceptable safety level) with the safety information required for decision making within the company. The SMS provides a tool for identifying and managing safety priorities.

The SMS aims to go beyond regulatory compliance (safety is judged in terms of regulatory compliance) to establish means-based compliance, i.e. the implementation of an effective risk

management and safety maintenance process, and results-based compliance, i.e. achieving an acceptable level of risk through the continuous assessment of the company's safety level.

SMS is characterised by the involvement of all hierarchical and functional levels of the air service provider by incorporating human factors in risk management.

In practice, the SMS uses quality tools for the benefit of aviation safety management. These tools involve the following: say what is done, do what is said, check the adequacy of the results against the aims and adjust. As a result, each air service provider's SMS is established on the basis of four pillars.

Pillar 1. Air service provider's safety policy and aims

The safety policy and aims describe the following points that are implemented within the company:

- Commitment and responsibility of management and supervisors to apply a positive safety culture (fair culture without punishment of errors to encourage voluntary, non-mandatory feedback), identify lines of responsibility, define acceptable safety aims and means of safety assessment;
- Definition of the SMS organisation within the company and appointment of personnel assigned to SMS-related functions;
- Plan for identifying and managing emergency responses to crises;
- Establishing of documents that can be consulted by all and that describe the SMS, its operation and its results.

Pillar 2. Risk management

Risk management is the process by which the air service provider maps its risks by identifying threats or hazards to the safety of its operational activities and assessing the risks associated with the consequences of these threats. Risk assessment is carried out using a risk acceptability matrix that defines three levels of risk based on the severity of the consequences and the frequency of occurrence of threats: acceptable, tolerable or unacceptable.

Risk management then involves implementing strategies to control, monitor and mitigate risks when they are unacceptable or intolerable so as to make them as acceptable as possible or, if not possible, as tolerable as possible. Risk control strategies must be documented to assess their actual effectiveness on the safety of operations. The choice of risk control strategies is the responsibility of the accountable manager for whom the SMS organization has provided all the information needed for decision-making.

The knowledge of threats and the identification of risks is largely based on feedback from front-line players. This is only possible if the organization has developed a high-performance safety culture that is based on trust between all the players in the company, and transparency in analysis and decision-making processes to manage and improve safety.

Pillar 3. Ensuring and maintaining safety

Ensuring and maintaining safety is the process by which the organization's safety level is checked by comparing the safety aims defined by the safety policy against the actual results achieved in terms of safety of operations.

This process requires the definition of safety indicators and sources of information for the collection of these indicators.
The assessment of the organization's safety level then allows the planning of a continuous safety improvement process.

The impact of changes in the organization or operations on safety are also considered in the ensuring and maintaining of safety pillar. For any significant change that modifies the operations as defined and assessed for safety in pillar 2, a safety impact assessment is required. A significant change is, for example, the opening of a new line, the introduction of a new aircraft type, a regulatory change regarding training, the introduction of electronic documents, etc. The safety impact assessment follows the same process as safety management, i.e. identification of new threats, assessment of the risks associated with these new threats and a strategy to control the risks if necessary.

Pillar 4. Promotion of safety

The promotion of safety has two aspects: training and communication.

Training involves giving each member of staff involved, whether directly or indirectly, in operational activities, regardless of their hierarchical or functional level, the level of training that enables them to fully fulfil their role in the operation of the SMS within the company. There are several levels of training: operational staff, local managers, the accountable manager and top managers and the people responsible for coordinating and operating the SMS.

The purpose of the communication is to disseminate information from the SMS to all company personnel. The aim is to transparently inform staff about "critical" information related to the safety of operations, explain risk management decisions, explain changes and disseminate "essential to know" information. For this purpose, all appropriate means of communication should be used such as meetings, newsletters, notes, dedicated websites, e-mails, working groups, etc.

040 HUMAN PERFORMANCE

02

PHYSIOLOGY AND HEALTH OF THE AVIATOR

Physiology and health of the aviator

01 FUNDAMENTALS OF AERONAUTICAL PHYSIOLOGY

1.1 - Terrestrial Atmosphere

The terrestrial atmosphere is defined by its pressure, composition and temperature. Throughout the altitude range used in aeronautics, only the pressure and temperature vary with the altitude; the chemical composition of the atmosphere remains constant.

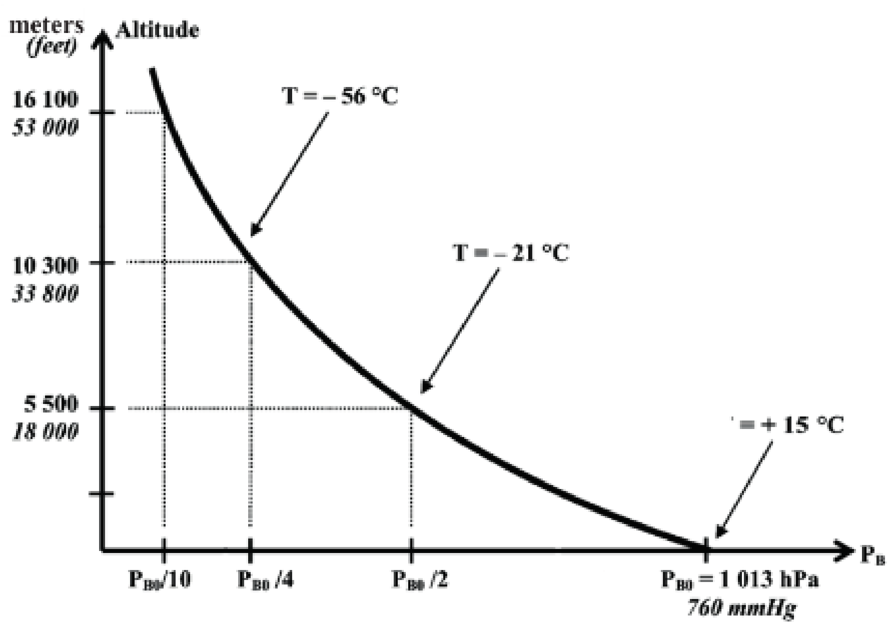
1.1.1 - Pressure Units

Pressure is expressed in pascals (Pa) in the metric system; other pressure units are commonly used, such as bar, "mercury units" or Imperial units. The equivalences are as follows:

- 1 bar = 10^5 Pa = 1000 hPa
- 1hPa (hectopascal) = 1 mbar (millibar)
- 1013.25 hPa = 760 mmHg (millimeters of mercury)
- 1 psi (pound per square inch) = 68.95 hPa
- 1 bar = 14.5 psi

1.1.2 - Barometric Pressure

Atmospheric pressure, or barometric pressure (Pb), varies with the altitude according to an approximately exponential law. At the average sea level, the barometric pressure (P_{B0}) is equal, on average, to 760 mmHg, or 1013.25 hPa; it varies between 960 and 1040 hPa.



Graphical representation of barometric pressure
and temperature as a function of altitude.

1.1.3 - Chemical Composition of the Atmosphere

The chemical composition of the terrestrial atmosphere is constant throughout the range of altitude encountered in aeronautics (up to 30,000 m, or 100,000 ft., at least), with the exception of water vapor and a few minor elements of the atmosphere.

Table below shows the composition of the air, by limiting it to a few rare gases only. Most water vapor is encountered in the lower layers of the atmosphere. Ozone is essentially located in the stratosphere.

Gas	Chemical symbol	Fraction	Comments
Nitrogen	N_2	78.101%	Constant
Oxygen	O_2	20.946%	Constant
Water vapor	H_2O	2%	Highly variable
Argon	Ar	0.917%	Constant
Carbon dioxide	CO_2	0.033%	Variable
Ozone	O_3	0.00005%	Highly variable

Composition of the atmospheric air up to 100,000 ft. (at least).

1.2 - Respiration and Blood Circulation

1.2.1 - Ventilation and Respiration

a) Definitions

- Ventilation. Ventilation is the function that ensures the gas exchanges between the lung alveoli and the surrounding atmosphere. This function is ensured by the lungs
- Respiration. Respiration is the set of mechanisms that lead the oxygen from collection via inhalation to its use in the cells.
- Metabolism. The metabolism is a word used to designate the chemical activity inside the cells (e.g. lipid metabolism).
- Energy Metabolism. It covers all the processes for supplying the necessary energy to the cell.
- Aerobic Metabolism It is the component of energy metabolism that strictly depends on the intake and use of oxygen.
- Basic Metabolism. It is the value of energy metabolism necessary for the maintenance of the life under the minimum conditions of strict rest. Its value is often known by its energy intake from required food sources, or 1,800 kcal/24 hours (kilocalories per 24 hours). In metric units, this value corresponds to 87 Watts (87 W). We will consider that the value of basic metabolism is between 85 and 90 W.
- 1 kilocalorie (kcal) = 4.18 kilojoules (kJ)
- 1 watt (W) = 1 J/s
- 1,800 kcal = 7,524 kJ
- 1 day = 86,400 s
- 1,800 kcal/day = 7,524 kJ/86,400 s = 0.087 kJ/s = 87 W

b) Anatomy

The ventilator system (or respiratory system) consists of a network of gas ducts, a surface of exchanges between the blood and gas and a mechanical system, which ensures the transport of gases by generating pressure differences.
The network of ducts consists of the upper airway (nose, mouth), the pharynx and then the larynx, where speech is formed and which is extended by the trachea, then the bronchi, right and left, which are progressively subdivided into smaller bronchi, then the bronchioles and finally into alveolar ducts.

The blood transported in the lung blood capillaries between in contact with the gas present in the alveoli across the alveolocapillary membrane, whose thickness is on the order of one micron. This membrane delimits a potential exchange surface of 60 to 70 m^2.

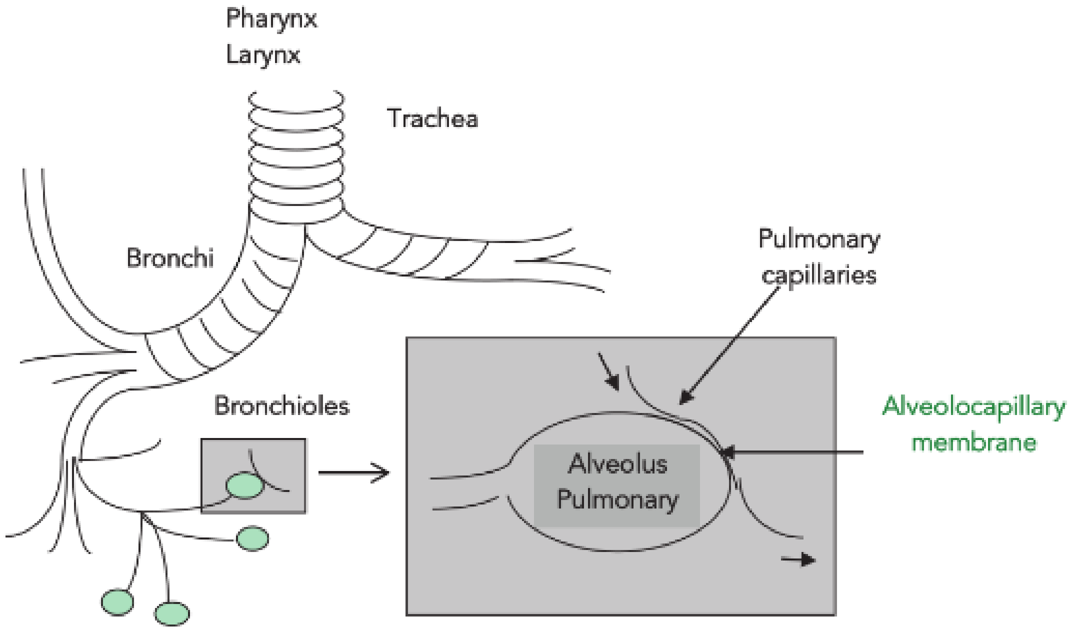


Diagram of the ventilatory system.

The mechanical ventilatory system is constituted as a semi-rigid musculoskeletal cage.

The skeleton of the thoracic cage is composed of:

- To the rear: 12 dorsal vertebrae, to which are attached as many pairs of ribs;
- In the front: the sternum (flat center bone on the front part of the thorax);
- Twelve ribs on each side; the first ten ribs are related to the front of the sternum (directly or through the intermediary cartilage) and the last two are not directly attached to the breastbone (“floating” ribs).

The skeleton of the rib cage is moved by the respiratory muscles: intercostal muscles, diaphragm and muscles that connect the rib cage to other structures, allowing a deformation "outside" of the rib cage.
The deformation of the rib cage causes variations in volume, and thus pressure, which ensures the movement of gas.

c) Role of the Lungs in Respiration

The lungs are where the exchange of gases between the external environment and the inside of the body take place. Pulmonary ventilation brings in fresh air and eliminates the air used.

Gas exchanges across the alveolar membrane respond to a mechanism for gas diffusion, which is exclusively dependent on the differences in partial pressure between gases.

Figure on next page identifies some concepts and useful terms. It establishes the major principles of circulation and gas exchanges. Oxygen and carbon dioxide are exchanged between the blood and the air in the lung alveoli.

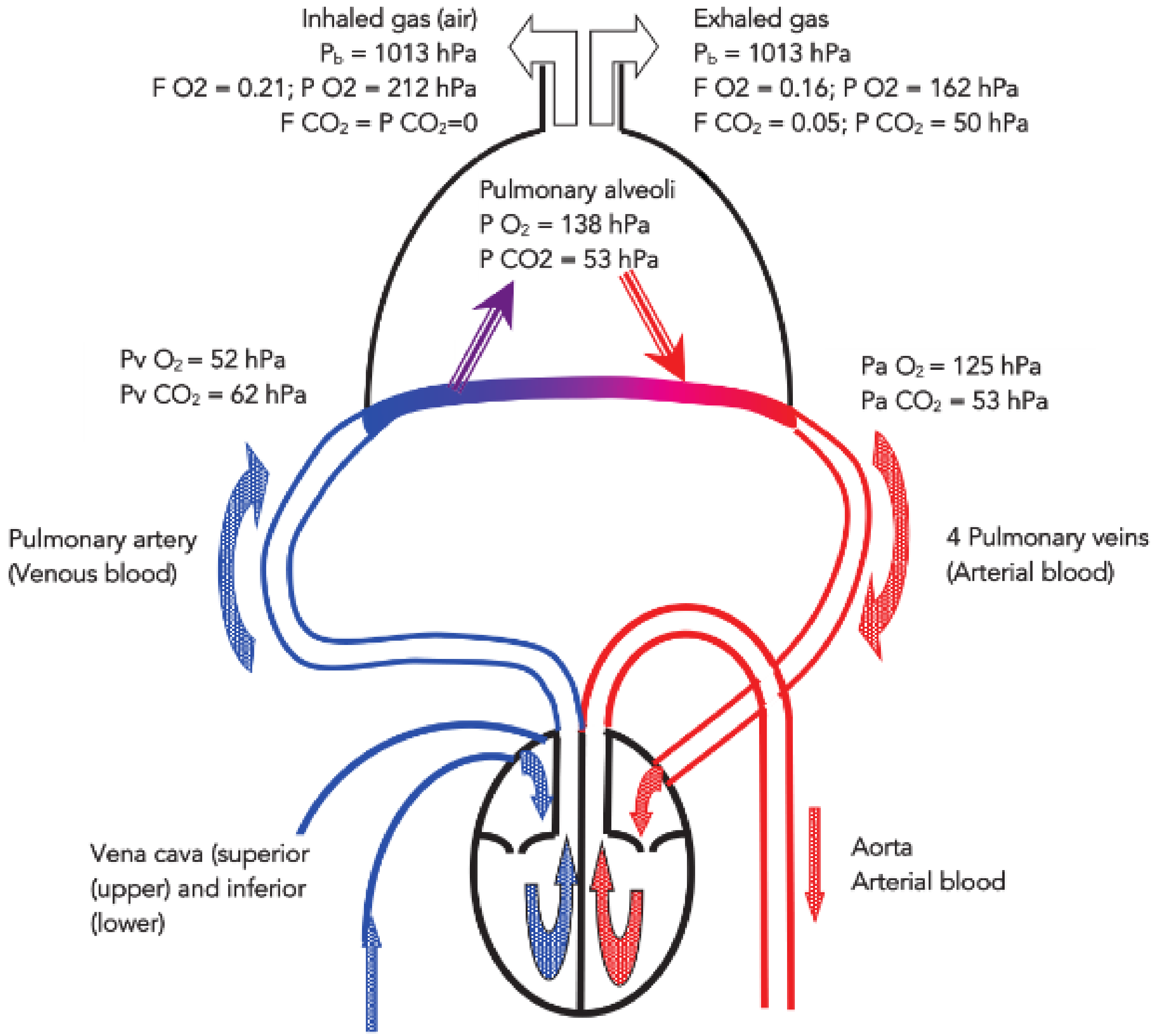
At this level, it involves a pure diffusion mechanism; gases diffuse as a function of their partial pressure, from the highest partial pressure to the lowest partial pressure.
In this case, the blood that arrives in the lungs is at 52 hPa for O_2 and 62 hPa for CO_2 in humans at rest. The alveolar gas is at 138 hPa for O_2 and 53 hPa for CO_2; the O_2 thereby diffuses the alveolar gas into the blood and CO_2 in the reverse direction.

The difference in partial pressure is very different for these two gases: exchanges are nevertheless balanced by the fact that the diffusion of CO_2 is much more rapid than that of O_2.

The adjectives "arterial" and "venous" applied to the blood refers to the "overall" circulation and not to pulmonary circulation. The "arterial" blood circulates in the arteries of the circulatory system and in the pulmonary "veins". Venous blood circulates in the arteries of the circulatory system and in the pulmonary arterial network.

Under normal conditions, gas exchanges in the lungs only involve O_2 and CO_2.
Other gases in the atmosphere, such as nitrogen, are exchanged in very low to zero quantities under usual conditions. CO (carbon monoxide) also exchanges very well in the lungs, but it is a highly pathological situation.

In the tissues themselves, the process of gas exchanges is complex. Let us simplify, looking at these comparable mechanisms for diffusing gases in tissues with a lower partial pressure of O_2 and a higher partial pressure of CO_2 than in the blood.



Overall diagram of blood circulation and pulmonary gas exchanges.

d) Volumes and Average Flow Rates

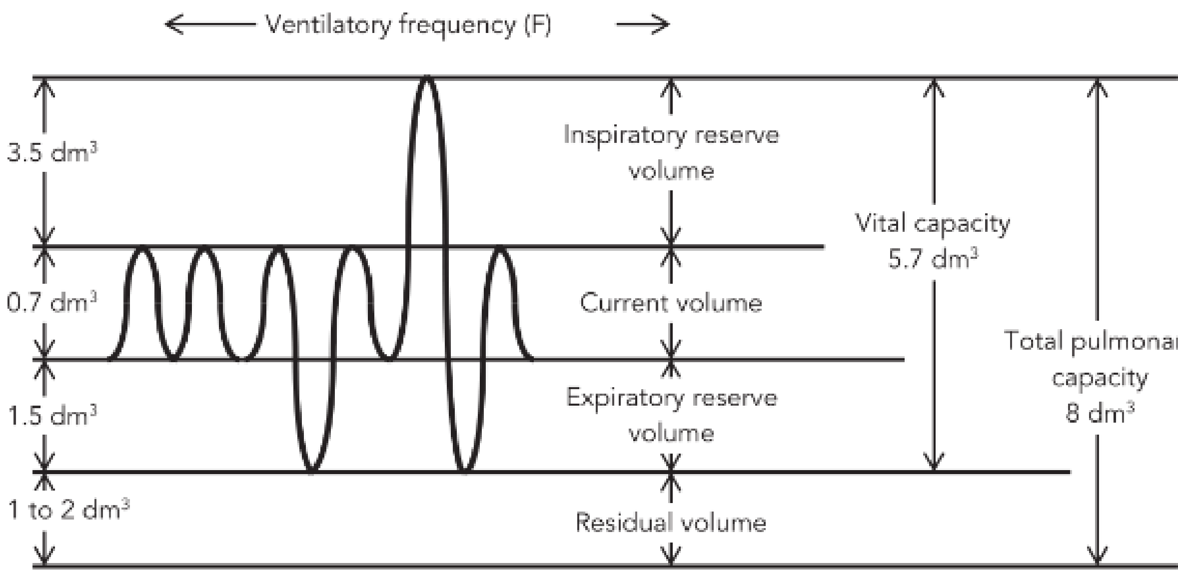
Lung volume characteristics are presented through the representation of the spirogram (Figure in the next page). The current volume (VT) is the volume ventilated in each ventilatory cycle. The initial part of this volume reaches the pulmonary alveoli; this is the alveolar volume (V_A). The final part of the current volume does not reach the alveoli and does not contribute to the gas exchanges; this is the dead volume (VD; ''D'' for « dead »).
The ventilatory frequency (F) is expressed in cycles per minute (c/min); the product of the current volume and the ventilatory frequency determines the ventilatory volume per minute (V_E), or average ventilatory flow rate.

The current volume (V_T) is supported by the reserve, inspiratory and expiratory volumes; these volumes are used for increasing ventilation during physical exercise. Finally, the forced exhalation does not eliminate all the gas from the lungs; this volume of gas is known as residual volume.

The "vital capacity" corresponds to the volume mobilized between the forced inhalation and forced exhalation (maximum mobilisable volume of gas); the "total lung capacity" is the sum of the vital capacity and residual volume.
In figures:

- Ventilation (average ventilatory flow rate): 5.5 to 8 dm^3/min (liters/minute);
- Current volume : Between 0.5 and 0.8 dm^3;
- Ventilatory frequency, or respiratory frequency: 12 to 16 cycles/minute;
- Vital capacity : 4.5 ± 0.5 dm^3 (women), 5.5 ± 0.5 dm^3 (men);
- Oxygen consumption of a subject at rest: 0.27 dm^3/min (STPD).

In aeronautical data banks, the "normal" ventilatory frequency is generally estimated at 16 cycles/min. This figure is relatively high for a subject at rest.



Representation of different spirometric variables (volumes and average flow rates). The figures shown are from aeronautical data banks (young subjects, in good health and, historically, male). There is existing data from other populations.

The term "regulation of ventilation" is as common as it is inaccurate. In reality, the ventilation is not regulated. On the contrary, it is the manipulated variable of two regulated variables, which are the partial pressure of oxygen and carbon dioxide in the arterial blood (respectively P_AO_2 and P_ACO_2). And ventilation being the manipulated variable of two separate regulation loops does not simplify the question from a theoretical point of view or a didactic point of view!

e) Influence of Oxygen on Ventilation

The "influence of oxygen on ventilation" (traditional term) reflects the response of the ventilation at different values of the partial pressure of O_2. This influence is moderate, and she is varied greatly from one subject to another.

- Ventilation increases substantially (approximately 50%, with wide variations) when the inhaled pressure of O_2 decreased by half, i.e. in terms of altitude at 5,500 m (18,000 ft.).
- Due to hypoxia alone, ventilation increases on average by a maximum factor of 4, with a significant variability from one subject to another (1.5 to 7).

f) Influence of Carbon Dioxide (CO_2) on Ventilation

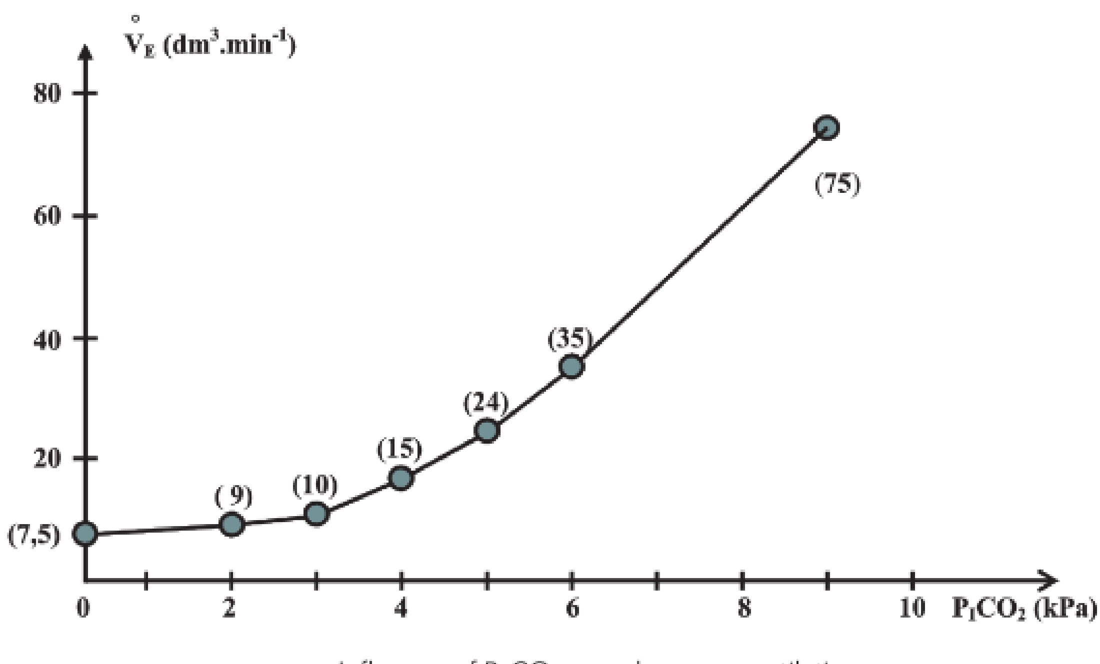
The influence of carbon dioxide on ventilation is much more powerful than that of O_2.
It is represented in Figure below, which shows the influence it has on ventilation during inhalation of mixtures enriched with CO_2.

The body is sensitive enough to a small increase in partial pressure of inhaled carbon dioxide (P_ICO_2, up to 3 kPa); by contrast, for higher values of P_ICO_2, ventilation is powerfully stimulated; inter-individual variability in sensitivity to carbon dioxide is less than O_2.

In reality, ventilation is controlled by the pH of the cerebrospinal fluid (liquid in which the central nervous system is immersed); it is very closely and very quickly dependent on the partial pressure of CO_2 in the arterial blood, itself being a function of $P_ICO_2$on which, from a practical standpoint, it is more convenient to act.

- We recall that the body powerfully to variations in P CO_2.
- This regulation is adaptable, which means that, in the face of a prolonged modification of P CO_2, the body cancels the corresponding stimulus in one or more weeks.
- Sensitivity to CO_2 is found in cells located even within the central nervous system.

The control of ventilation in healthy humans is, in the short term, mainly dependent on P_ACO_2 (partial pressure of carbon dioxide in the arterial blood).



Influence of P_I CO_2 on pulmonary ventilation.

1.2.2 - Blood Circulation

The total volume of blood contained in the heart and blood vessels is on the order of 4.5 dm^3 in the normal adult.

a) Anatomy

Heart

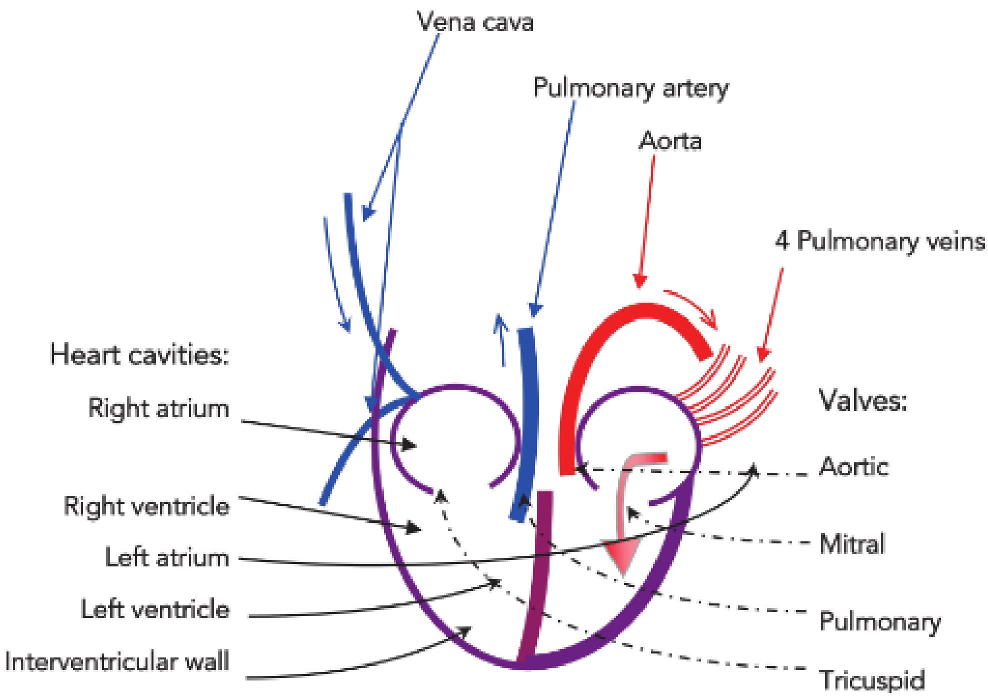


Diagram of the heart.

The heart is a hollow muscle, divided into four cavities; these cavities are grouped two by two, constituting two functional entities, the right heart and the heart left, each consisting of one atrium and one ventricle.

During the cardiac cycle, the period of contraction by the muscle is called systole. The period of release is the diastole, during which the heart cavities are filled.

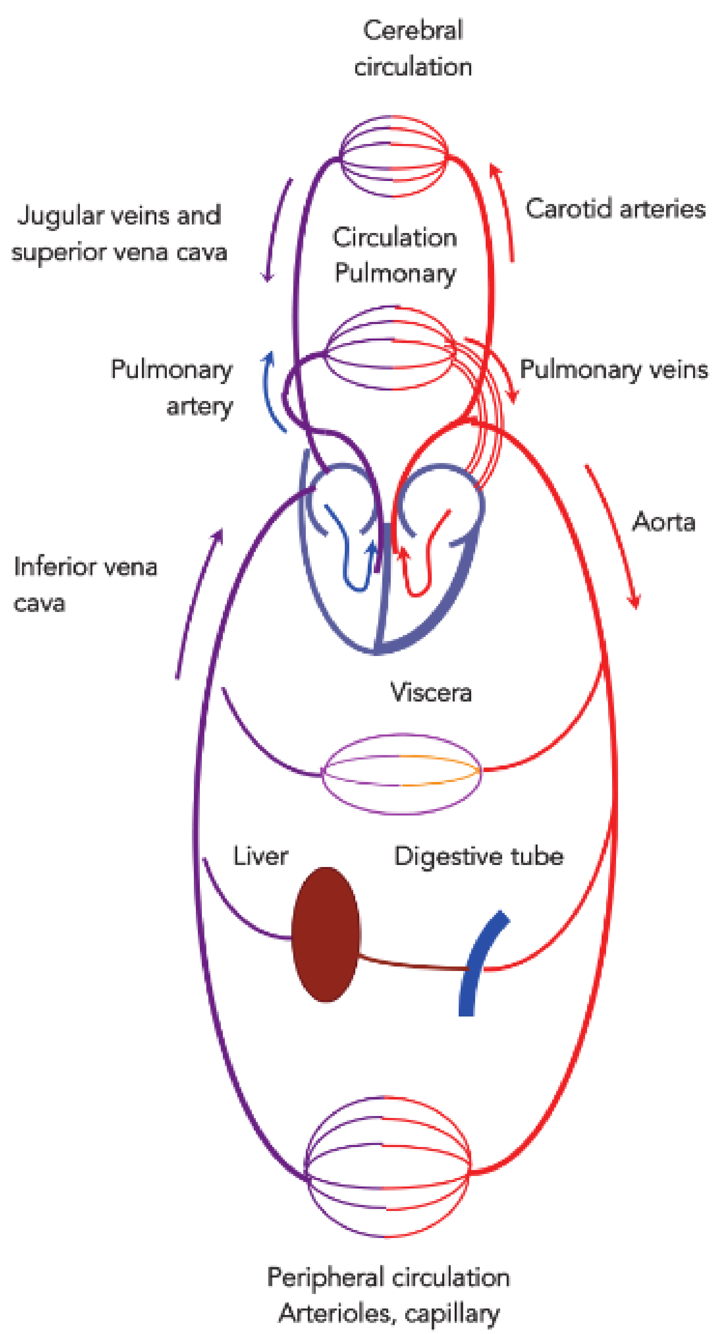
The contraction of the ventricle allows the ejection of the blood to the corresponding artery; aorta for the left ventricle and pulmonary artery for the right ventricle.

The right heart and the left heart are synchronized in frequency, but have no direct circulatory connection.

Blood circulation

The overall plan of blood circulation is described in Figure below.

Let us determine the origin of the circuit in the left ventricle in systole; the blood is expelled under pressure in the aortic artery, through the Sigmoid valve.
The aorta quickly forms several branches: the coronary arteries (See Figure "Details of the cardiac anatomy" next page), responsible for supplying the heart muscle itself, then the carotid arteries going to the head, and the subclavian arteries going to the upper members.
At its arch, the aorta bifurcates 180°; it takes a downward direction and irrigates the trunk and lower limbs.



Overall plan of blood circulation.

b) Physiology

Heart Rate and Blood Flow

Blood flow is defined as the volume of blood ejected by each ventricle in one minute. At rest, it is on the order of 4.5 to 5 $dm^3.min^{-1}$. It reaches 30 $dm^3.min^{-1}$ at maximum physical exercise.
The heart rate is 60 to 65 cycles/minute at rest; it reaches 180 to 200 cycles/min under maximum conditions.

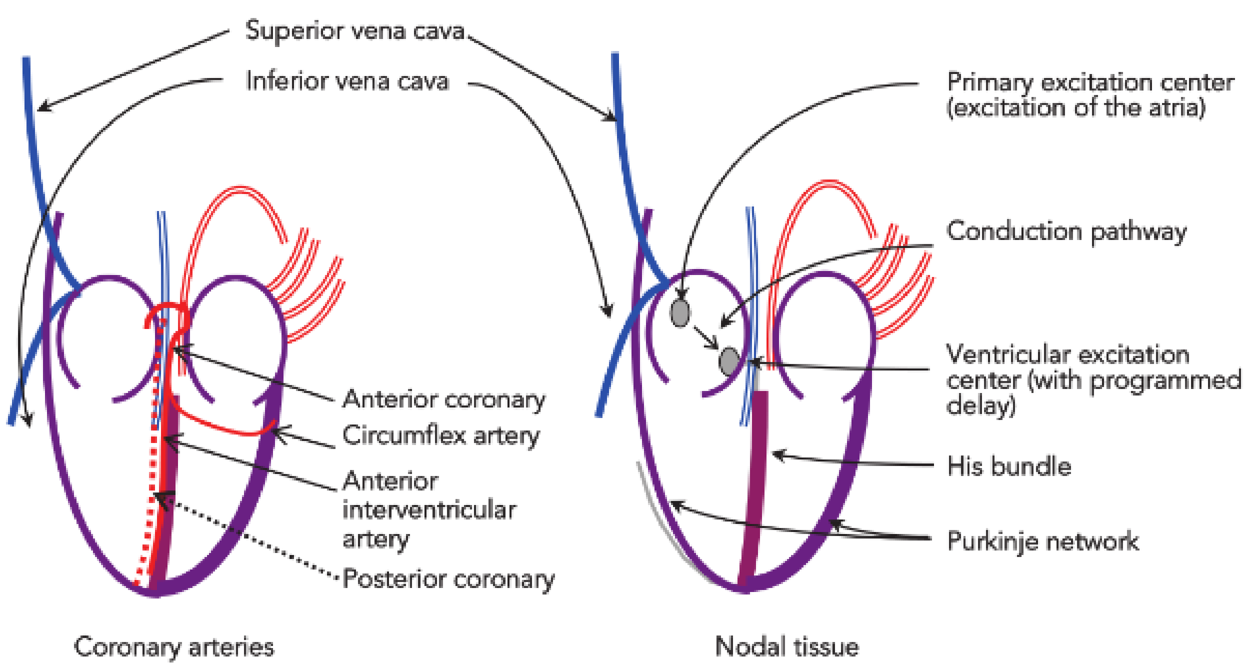
We have already found the figure of 4.5 to describe the total blood volume. This is a coincidence. In young adult subjects in good health and at rest, the blood volume is about 4.5 dm^3 and the blood flow is about 4.5 $dm^3.min^{-1}$ (the blood circulates completely in approximately 1 minute).
We emphasize the identity of these two digital values, because it could pose a problem on the day of an exam

Blood flow is the product of the systolic ejection volume by the heart rate.

The systolic ejection volume is the volume of blood that is ejected by the left ventricle during each contraction (systole).

In humans at rest, the ventricle contains approximately 120 cm^3 of blood at the beginning of the contraction, and it ejects approximately two thirds (80 cm^3). With physical exercise, the two basic factors, heart rate and systolic ejection volume, increase simultaneously, by a factor of 3 and 2 respectively. Therefore, the cardiac flow increases by a factor of 6.
For a normal subject at rest,

Heart Rate : 60 to 80 cycles per minute
Cardiac Output: 4.5 to 5 l/min.
Total Blood Volume (reminder): 4.5 dm^3



Details of the cardiac anatomy.

To the left: Diagram of the blood flow to the heart (coronary arteries); coronary arteries circulate on the surface of the heart. The left coronary artery circulates on the front of the heart and the right coronary artery on its rear surface (it is represented here by the dotted line). Coronary circulation is recovered by the coronary veins, not represented here.

Heart Cycle

The heart muscle, or myocardium, functions alternatively, succession of contraction periods (systole) and relaxation (diastole). The role of the atria is to collect blood from the veins and fill the ventricles before their own systole.

Heart Automatism and Nodal Tissue

The heart is an automatic organ integrated into the body. Isolated, but properly fed, oxygenated and maintained at a proper temperature, it can beat indefinitely without any external intervention. Individually, all cardiac cells are automatised.

However, a group of specific cells have a beat frequency higher than others and leads to the contraction of the entire heart; these are pacemaker cells.
All of these cells are grouped under the term of nodal tissue (Figure above). The normal cardiac contraction follows a specific diagram: the excitation originates in the right atrium and extends quickly to both atria; then it stops for approximately 1/10 second, which allows each atrium to fill the corresponding ventricle; it then extends to the ventricles by causing their contraction from peaks to lows.
This temporal architecture of the cardiac contraction is very identifiable in the electrocardiogram (ECG).

It is weakened in certain circumstances: pharmacological damage of the heart tissue (a pharmacological agent otherwise known as caffeine), exposure to an unusual factor in the environment, such as hypergravity (takeoffs + G_Z of long duration; refer to Paragraph 1.8), congenital anomaly or pathological damage acquired in the course of life.
An extrasystole is a cardiac contraction that originated somewhere other than the normal location; a myocardial fibre of high excitability resulted in the contraction of all myocardium. In general, this contraction is rarely effective or ineffective from the standpoint of blood circulation. It is sometimes felt and described as a "palpitation".

Too many and/or polymorphic extrasystoles result in aeronautical unfitness until evidence is provided for their safety (EU Regulation No.1178/2011 MED B.010 e).

Cardiac Workload and Blood Pressure (Arterial "Pressure")

The work of the heart muscle is expressed by ejecting under pressure a certain volume of blood. In current English language, in the doctor's office, blood pressure is also referred to as "arterial pressure". Its value is usually expressed in centimetres or millimetres of mercury.

- It is generally measured in the arm.
- Blood pressure increases with cardiac output and peripheral vascular resistance.

During systole, blood is pumped through the aortic valve, which closes at the end of the systole. During this phase, the pressure is therefore identical in the ventricle and all of the arterial network.

However, the artery is an elastic duct; after the closure of the aortic valve, there is still a residual pressure in the arteries, which allows for the continuity of blood flow to the organs.
Thus, blood pressure is measured by two figures: the higher corresponds to the pressure in the systolic phase and the smallest to the residual pressure in diastolic phase. In the normal state, the blood pressure is equal to 12 cmHg (16 kPa) during systole and to 7 cmHg (9.3 kPa) during diastole. Expressed in cmHg, "blood pressure" is 12/7; this traditional notation obviously does not express a fraction.

c) Regulation of Cardiovascular Functions

The body is able to adapt various components of cardiovascular function to different situations encountered. An excellent example, in the world of aeronautics, was given by the adaptation to takeoffs + G_Z of long duration, that we will examine in this course.
Since adaptation focuses on the cardiac function itself, the body can change the heart rate, the volume pumped in each systole and ejection pressure. With blood vessels, the body can adapt resistance.
These regulatory actions are relayed by the nervous system and the hormonal system.

Concerning blood pressure, it is dependent on:

- Blood flow, the product of the pressure of ejection by the heart rate;
- Blood viscosity;
- Blood volume;
- Flow resistance, vasomotor function.

Blood pressure therefore increases when, within the limits of physiological conditions:

- Heart rate increases;
- Systolic ejection volume increases;
- Blood viscosity and/or blood volume increases;
- Flow resistance increases (vasoconstriction condition).

d) Blood Pressure, Normal or Pathological

There is a relationship between the systolic and diastolic values of the blood pressure; the diastolic pressure is equal to half of the systolic + 1: $P_{diast} = ½ P_{syst} + 1$. For example, 12/7. For higher values (systolic greater than 16 or 18), replace the 1 with a 2: $P_{diast} = ½ P_{syst} + 2$. For example, 20/12.
Clinically, it is diastolic pressure that is the most used to assess the state of health of a patient (as a "risk factor").

Blood pressure may increase with age (but it can be slow); high blood pressure (hypertension) is a strong cardiovascular risk, particularly with regard to coronary disease (see Paragraph 1.2.4) and risk of stroke.

Regulatory texts give the blood pressure limits within which medical fitness can be declared, as well as the principles for treating a possible hypertension, compatible with medical fitness (EU Regulation No. 2019/27 MED B.010 c)

We will note here that being medically unfit may be pronounced either because of the pathology itself, or due to the side effects of the treatment prescribed.

e) Hypertension, Hypotension

Hypertension is the increase in blood pressure beyond its normal value. It can long remain asymptomatic (silent), but it involves the vital long-term prognosis, because it is a high risk factor for vascular disease (predisposition to health-related accidents, such as myocardial infarction or stroke).

Hypotension is a decrease in blood pressure below its normal value and it often has no clear cause. It causes a feeling of faintness (feeling of malaise, loss of imminent consciousness), and sometimes a real loss of consciousness. Apart from the immediate consequences of the loss of consciousness, hypotension is not bad in terms of risk factors for future health. But It can be incompatible with being a pilot.

Therefore:

- Arterial hypertension: High risk factor for vascular disease, incompatible with the status of pilot if it is not treated or not treated satisfactorily.
- Arterial hypotension: Incompatible with the status of pilot, due to the risk of loss of consciousness.

Treatment is available for high blood pressure (arterial hypertension). The treatment is not necessarily innocuous. Even if it is recognized as compatible with the task of piloting, it must be undertaken outside of aeronautical work in order to assess tolerance.

1.2.3 - Blood and its Functions

Blood is composed of plasma (liquid component) and three types of formed components: red blood cells, white blood cells and blood platelets.

- Plasma carries the dissolved elements.
- Red blood cells carry O_2.
- White blood cells are the vectors of immunity.
- Blood platelets support coagulation.

The blood carries various physical, chemical or informational elements, from one point to another in the body; the concentration of some of these elements is subject to regulation on the part of the body. Without going into all details it includes:

Physical Elements Heat

The body produces heat, due to cellular metabolism, and it dissipates in heat exchangers (skin, lungs); the blood carries heat from one point to another in the body.
This function and its importance are not very well known to the general public; it is nevertheless essential knowledge.

Chemical Elements

- The O_2, which is transported by the hemoglobin of the red blood cells from the location of its capture (lungs) to the locations of use (all tissues of the body);
- Carbon dioxide (CO_2), from its place of production to its sites of elimination (lungs in gaseous form and kidneys in the form of bicarbonates);

- Various nutrients, transported from the recovery location (intestines) to the transformation (liver) and storage (e.g. fats in the body) locations and/or use.

Informational Elements

Hormones, are transported by the blood and are signal molecules for activating remote organs.

Others

Let us add the body's defense elements (white blood cells and antibodies), and the coagulation agents that include blood platelets, etc.

And we recall the transport of gases (O_2 and CO_2) by the blood.

a) Oxygen Transport by the Blood and Role of Hemoglobin

O_2 is a gas that slightly dissolves in water, about 0.3 cm^3 STPD for 100 cm^3 of water, at 37°C and normal partial pressure of O_2; this amount is not sufficient to supply the body.
Thus, aerobic organisms have developed another mode of transport for O_2, of a chemical nature.

Under normal conditions, human blood carries approximately 20 cm^3 of O_2 to 100 cm^3 of blood, in the form of a weak chemical combination with a dedicated molecule, hemoglobin, which is contained in red blood cells.

Red blood cells are presented as small flattened disks of 7 μ (microns) in diameter and 2 μ in thickness. Their average number is 4 to 4.5 million per mm^3 of blood.

Hemoglobin is a protein whose nucleus contains one atom of iron. Its connection with the O_2 molecule is represented by the symbolic form: $Hb + O_2 \leftrightarrows HbO_2$.
This is the partial pressure of CO_2 which, at least in part, regulates the affinity of the hemoglobin molecule for O_2; in contact with the alveolar gas, in the lungs, at low partial pressure of CO_2, O_2combines with the hemoglobin molecule (reaction above from the left to the right); in the tissues, at higher partial pressure of CO_2, it is the opposite that takes place.
It is common to express the quantity of O2 transported by the blood as saturation of arterial blood oxygen ($S_a O_2$), the quotient of the quantity of O_2 transported at the theoretical maximum quantity for transport.

$S_a O_2$ is the easier criterion to measure. Everyone knows that arterial blood is bright red and venous blood is dark red; this change in color corresponds to a variation of the absorption spectrum in the red and near-infrared depending on the oxidised state of the molecule.
This optical property of the hemoglobin molecule is used to measure the $S_a O_2$; this measure is possible through the skin, without blood sampling; these are the "oximeters", and in their current version, ''pulse oximeters", also referred to as
''saturometers".

The relationship that unites $S_a O_2$ to $P_a O_2$ is represented graphically by a characteristic curve (Figure next page). Various factors can change the hemoglobin dissociation curve, including the $P\,CO_2$ (see above) and temperature.

b) Various disorders causing a decrease in the amount of oxygen transported by the blood

Transporting a sufficient quantity of O_2 in the blood requires several conditions:

- A sufficient mass of blood: a hemorrhage or, more commonly, a donation of blood, temporarily restricts the amount of O_2 transported; it is typical not to pilot an aircraft hours after blood donation;
- A sufficient P O_2 in the inhaled gas (this is the problem in altitudes);
- A satisfactory pulmonary function; some patients are actually unfit for flight;
- A satisfactory circulatory function, because the blood must enter into the different organs; in addition to diseases that obstruct the arteries, takeoffs + G_z of long duration decrease cerebral blood flow (refer to paragraph 1.8);
- The blood must be able to transport O_2, that is, the O_2carrier must be of sufficient quantity, and operational.

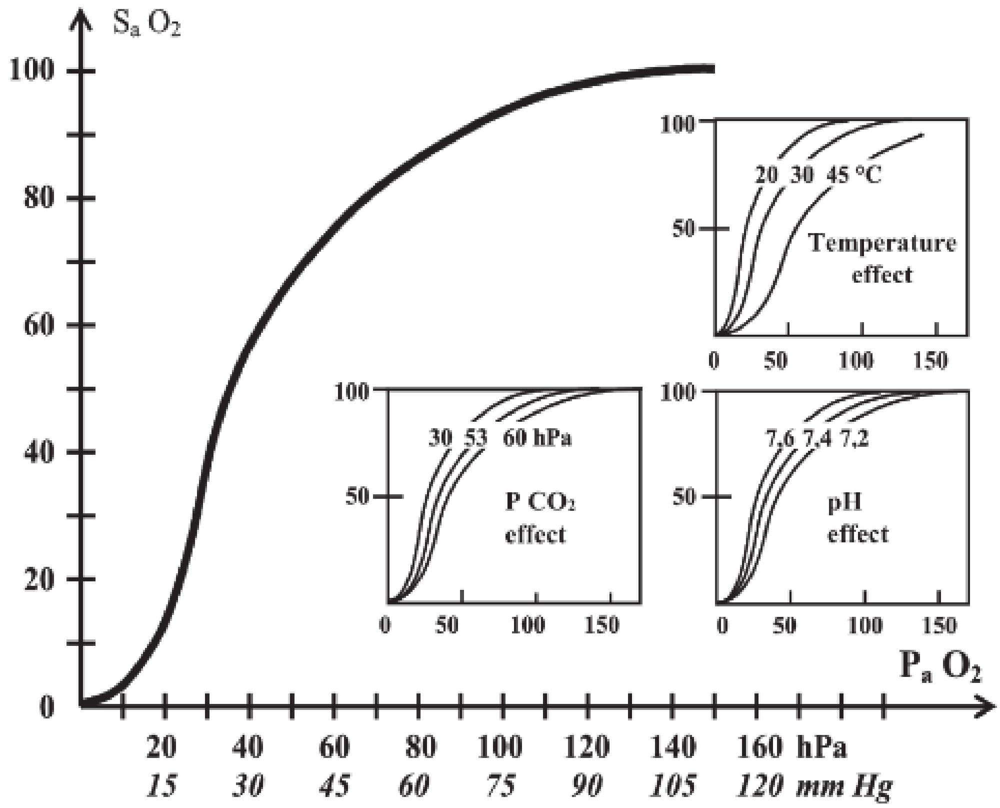
Let us discuss this last point in more detail; it involves anemia and the risk of carbon monoxide poisoning.

A blood donation comprises a collection between 350 and 450 ml, or 10% of the total blood volume. It decreases the transport capacity of $O_2$by the blood, and it causes a decrease in the mass of blood present in the blood vessels, which can cause hypotension. It is the risk of hypotension that is restrictive. The decrease in the transport capacity of O_2 by the blood is not very significant, because the system is designed for maximum physical exercise; there is therefore a large margin, even at the maximum altitude authorized without O_2.
This issue is referred to in the "OPS" (EU Regulation No 965/2012) in a clearly imprecise way: The crew member shall not perform duties on an aircraft until a reasonable time period has elapsed after following blood donation.

In this regulatory text, we like the adjective "reasonable"!

In the military field, the applicable text is the NATO STANAG 3474AMD regulation, which prescribes a flight ban of 36 hours after blood donation.

Anemia is a "lack of blood". The word "hypemia" (blood deficit) in some English language publications is more accurate.



Hemoglobin dissociation curve: Relationship between the saturation of arterial blood oxygen ($S_a O_2$) and the partial pressure of oxygen ($P_a O_2$). This relationship depends on the temperature, pH and partial pressure of carbon dioxide in the blood. Partial pressures of gas are expressed in hPa.

Beyond the deficit observed in blood (e.g. after a hemorrhage), anemia refers to the deficit in hemoglobin and, by extension, the deficit in functional hemoglobin.

When it comes to a deficit in hemoglobin, the person is pale, because the color of the skin comes from the hemoglobin - but this is more easily recognizable in those with fair skin.
Deficit in functional hemoglobin? We understand that hemoglobin exists, but it is inappropriate for the transport of O_2. The pallor is then absent.

We will discuss only two major causes of functional hemoglobin deficiency: genetics and toxicity.

The genetic cause is common in Africans; it is a chemical anomaly of hemoglobin, known as sickle cell anemia. It can remain imperceptible and reveal itself only under certain conditions, such as hypoxia or physical exertion.
The malformation of hemoglobin is identifiable using certain laboratory analyses. It can only be partial; depending on its severity, it can lead to the unfitness of aircrew personnel to perform their duties.

c) Carbon Monoxide Poisoning

Due to the importance of this subject, we discuss this in a paragraph dedicated to the topic.
The most frequent toxic cause of anemic hypoxia is carbon monoxide poisoning (CO).

It was a historical cause of accidents in commercial aviation; in this context, the certification regulations and their application have helped to eliminate these accidents.

Carbon monoxide poisoning remains a general concern in aviation. The poisoning mechanism is still the same; pollution through exhaust gases from the air conditioning or heating system in the cabin, either as a result of cracks in the exhaust systems, or due to the porosity of CO in some metals or alloys above a certain temperature.
In addition, fires with fuel and a number of combustions, with or without flames, can generate CO; CO poisoning is therefore a concomitant of other accidents.
Finally, we do not ignore production of CO through cigarettes (800°C).

CO is an odorless, colorless, tasteless and non-irritating gas, thus impossible to detect by oneself.

CO is produced during a number of combustions. Actually, any combustion, including at high temperature, does not necessarily produce CO_2 from carbonaceous fuels. CO, a product of incomplete combustion, is itself likely to ignite.

Symptoms of CO poisoning are obvious to the subject himself or his entourage.
Headaches are probably the most characteristic symptom. Then, feelings of malaise, loss of balance, sometimes nausea begins to appear. The patient can lose consciousness in this setting with minimal effort (e.g. call for help).

The role of CO on the transport of O_2 is twofold. First of all, CO is a competitor of O_2 for binding sites with hemoglobin; it forms a stable connection with hemoglobin, which then becomes HbCO (carboxyhemoglobin).

The affinity of CO for hemoglobin is approximately 240 times higher than for O_2; this means that, in a gaseous mixture containing one part of CO for 240 parts of O_2, the HbO_2/HbCO distribution is 50/50; in normal atmosphere, this distribution is reached for a CO concentration near 0.9 per 1000.

Since the color of HbCO is the same as HbO_2, the patient has no reason to present the characteristic paleness of anemia, any more than the patient is cyanotic.

The presence of CO induces another effect on the hemoglobin molecule; it alters the chemical properties. In the presence of CO, the binding of O_2 to the remaining sites of hemoglobin is much more stable, which means that the O_2 remains in the blood and is no longer released into the tissues.
In the blood, measuring the amount of O_2 may still reveal a satisfactory value, since nothing is consumed; but this measurement in no way corresponds to the gas exchanges within the cells. This is a formidable pitfall in emergency medicine. In case of severe CO poisoning, the blood saturation measurements in O2 usually indicate a normal figure.
The term functional anemia describes the loss of capacity of the blood to transport O_2. Physically, there is blood, but it becomes improper to assume the function of O_2 transport. Functionally, it is as if there was no more blood (anemia).
In addition, we have previously seen that ventilation depends essentially on the partial pressure of CO_2, much more than on the partial pressure of arterial O_2, which remains normal (this is the amount of transported O_2 that decreased, not the partial pressure of O_2). This is how people can lose consciousness without ever having any symptoms of hyperventilation. This is a formidable pitfall.

CO only eliminates itself very slowly from the body (several days). To accelerate this elimination, the specific treatment for CO poisoning is hyperbaric O_2. Conversely, we understand that there is a very strong potentiation between CO poisoning and altitude hypoxia. There is a CO/hypoxia crossover danger in two aeronautical circumstances: smoking and accidental toxic releases in flight.

Smoking 1 pack per day causes a blood HbCO level of about 5 to 8%.
This poisoning, at normal altitudes in a pressurized cabin, is considered to be equivalent to an exposure of 3,000 to 5,000 additional feet.

Accidental toxic risk is due to the fact that CO is a small molecule that is found in all release of fumes, by fire or by combustion in the cabin.
The CS-25 and the FAR 25 [§831.(b)(1)] indicate, as a maximum permissible concentration in the cabin of an aircraft, the value of 1 part for 20,000 or 50 ppmv (part per million by volume). However, the regular measurements made in the cabin, under normal flight conditions, only show that CO rates vary between 1 to 2 ppmv.

1.2.4 - Coronary circulation and coronary artery disease (angina pectoris, myocardial infarction)

a) Coronary Circulation: Definition

The heart is an organ whose activity is - as everyone knows - uninterrupted during life. It calls for a regular supply of O_2 and nutrients.
To this end, it requires a regular supply of blood. It is led by the coronary arteries so-called due to its path that leads and distributes them in a "crown" pattern on the surface of the heart. Then, the blood is recovered by the veins of the same name.

b) Mechanism of Coronary Artery Disease

The arteries of the body are sensitive to the risk of degeneration; they become rigid and their section narrows, with irregularities on their wall; more or less rigid plates form the interior of the artery wall, which may break, migrate downstream, and block it as soon as their diameter becomes greater than the section of the artery, interrupting all or part of the circulation.
Then, a clot forms at the blockage and completely obstructs the section of the artery; subsequently, the clot consolidates in a rigid, final form.
As in the case of arterial blockage, areas downstream from the obstruction are no longer being supplied with O_2 and soon cease to function. They die if the obstruction is not quickly removed. If the patient survives the initial accident, these areas eventually become scarred, inactive areas.

Coronary artery disease corresponds to the appearance of these anomalies in the coronary arteries.

c) Coronary Artery Disease

The coronary artery disease presents two modes of expression: angina pectoris and myocardial infarction (MI).

- Angina pectoris
- Angina pectoris is the consequence of a partial obstruction; it corresponds to the fact that the heart, or a part of the heart, is under-supplied and is no longer able to provide required effort; the symptom of this is a very characteristic pain, which appears during physical exertion or environmental stresses, such as cold, requiring a higher capacity of adaptation.
- A classic circumstance of triggering the pain of angina pectoris is walking in the cold against the wind. Generally, there is a constricting chest pain; it can radiate, or sometimes be present almost exclusively in the jaws or arms, sometimes up to the wrist. The pain lasts a few minutes and then suddenly stops. Obviously, the patient has ceased exertion. Ingesting trinitrine makes it disappear.
-
- Myocardial Infarction
- Myocardial infarction (MI) is the acute accident. It presents a risk of death, immediate or delayed. MI is the result of a complete arterial blockage, which leads to the stop of O2 supply and nutrients in the territory served by the artery, downstream of the obstacle. This area loses its function (loss of its motor power), and then dies, leaving non-functional scar tissue. Sometimes, the myocardium ruptures.
- The MI can occur in a patient who has already had episodes of angina pectoris, but it can also occur without warning as the first manifestation of the disease.
- MI is recognised 80% of the time by the pain, quite similar to what is described for the angina pectoris, but without disappearance of the pain.
-
- Some curative treatments are available for MI in hours following its occurance.
- There are several types of treatments: drugs dissolving the blood clot, dilation and/or internal unblocking of the artery (by endoarterial route), open heart surgery to unclog or replace an artery flap, transplant of a healthy artery in close proximity to the coronary network, surgical repair or consolidation of the heart, etc.
- All these treatments must naturally be applied within a reasonable period of time, fairly quickly.
-
- In the current terminology, "MI" is replaced by “acute coronary syndrome," the latter only becoming a "myocardial infarction" if the unblocking could not be performed within the time limits required.

d) Special Case: Heart Rhythm Disorders and Defibrillators. (Semi-) Automatic

MI can disrupt the organization of cardiac activity, at the origin of rhythm or cardiac conduction disorders (disorganization of the transmission of the contraction order to different parts of the myocardium). These disorders can cause a major myocardial inefficiency - in practice, a dramatic interruption of the circulation of blood.

However, this disorder may be reversible in its initial phase. A calibrated electric shock is able to stop the episode of rhythm disorder, thus providing time to treat the cause, either by drugs or surgery.

The words fibrillation and defibrillator respectively refer to this disorder and the device delivering the electric shock to stop it.

Principle: Fibrillation presents a very characteristic sign to the electrocardiogram (ECG), which recognizes it automatically. Some devices have been developed and are available: they collect ECG data for automatic control.
They are referred to as semi-automatic defibrillators (SAD) or in a more recent automatic version (AED, for automatic external defibrillator). They have been available for the widest possible deployment in public places, including airports and commercial passenger aircraft.
These devices are designed to be used outside of any medical setting, by trained persons, but not necessarily physicians.

e) Screening for Coronary Artery Disease

The "coronary" patient presents, either permanently or at the time of the crises, very specific disorders in the ECG. If the ECG at rest is normal, the stress test reveals disorders; this exam is very sensitive, which means that, when it is performed correctly, it shows a very low rate of false negatives.

If only 80% of MI cases involve pain, what about the others? The answer is simple: this is discovered with the systematic ECG, interviewing the patient and sometimes emphasizing a previous episode of "major fatigue". Sometimes the lesion is too old to be treated. However, the prognosis is exactly the same, whether the MI was "silent" or not; prognosis decides whether a pilot may fly.

f) Developing Coronary Artery Disease

"The life expectancy of the heart patient is between 30 seconds and 30 years" (Gallavardin, Lyon (France), 20th century). Since this time, therapy has made spectacular progress; a number of heart patients can even be considered cured (with monitoring). However, untreated coronary artery disease exposes the subject to the risk of sudden death, within the totally unpredictable time period stated above.
The author had to deal with such a patient, a young airline pilot in his 40s. In the course of a routine semiannual visit to the Medical Center, the ECG showed MI scar tissue, in its "severe" state with an obstruction of the anterior interventricular artery. The patient did not remember anything very specific in terms of health issues. No therapeutic possibility remains for this totally healed lesion, dating back at least 2 months. Common risk factor: Smoking. Definitive unfitness. Appeal denied. He attempted to fly under other skies, considered to be more lenient than those who are under the guardianship of the Medical Council of French Civil Aeronautics. This patient died suddenly at the age of 46.

Coronary artery disease is responsible for 50,000 sudden deaths every year in France.

g) Coronary Artery Disease, Aeronautical Ability, and Prevention

For pilots: Coronary artery disease poses a serious risk and a major risk of sudden incapacity in flight. No impasse is possible with respect to flight safety. However, when the disease is caught in time with an effective strategy for eliminating risk factors and treating lesions, the patient shows a significant possibility of being sufficiently stabilized, until recovery of one's aeronautical fitness. Therefore, the question must be considered with an open mind.

Three major risk factors contribute to vascular disease: smoking, high blood pressure and metabolic disorders, of which diabetes is the foremost. Adding to this list is and individual's sex (male) and genetic predisposition: family medical history. Sports (moderate) is a strong factor in maintaining the performance of the heart.

Thus, we will recall the following prevention factors:

- Moderate participation in sports;
- Elimination of any smoking;
- Controlling metabolic functions, normalizing deviant functions (cholesterol, lipids, uric acid), with a special reference to controlling glycemic balance (preventing diabetes or controlling early diabetes);
- Screening and treating high blood pressure.

1.3 - Hypoxia

To introduce the subject: the Boeing 737 accident of Helios, near Athens, on August 14, 2005 - 121 deaths.
As a result of a poorly controlled maintenance operation, the aircraft was never pressurized. It was on automatic pilot with an altitude setting at FL 340. Two powerful alarms had been issued with the passage of FL 120 and then 180. They were confused with other alarms from the crew.
The crew did not understand anything (usual effect of hypoxia). They asked for advice from the ground, in an obscure series of questions and answers. The captain lost consciousness in front of his breaker panel behind his seat and the pilot officer in front of his instrument panel.
The pilots never acknowledged the lack of pressurization and did not use their oxygen masks.

1.3.1 - Definitions

Hypoxia Deficiency of oxygen.

Anoxia No oxygen.

In altitude, barometric pressure decreases, but the fraction of O2 remains constant, as well what we have previously established (see paragraph 1.1.3 - Chemical Composition of the Atmosphere "The chemical composition of the atmosphere,").

We deduce that the partial pressure of O2 in the blood decreases at altitudes; this is hypoxia. Hypoxia can be described according to two criteria: its duration of application and its type.

a) Hypoxias classified according to their duration of application

Hyperacute or fulminant hypoxia occurs within a few seconds, through a sudden and total loss of cabin pressure or by an abrupt interruption of the O2 supply at high altitudes, with no cabin pressure or insufficient cabin pressure; it is responsible for an initial syncope (= without prior symptoms).

Acute hypoxia occurs within a few minutes, by slow exposure (in a few minutes) at an average altitude, between approximately 4,000 to 6,000 m; it is responsible for all types of psychological disorders and all levels of severity.

Prolonged hypoxia extends over several hours, for altitudes of approximately 2,500 to 3,500 m; the major symptom is fatigue.

Chronic hypoxia extends over several days, months or years, or even one's entire lifetime; these are states encountered during trips to or living in mountainous regions and during which physiological adaptations appear. Chronic hypoxia is not a concern in aeronautics.

b) Hypoxias classified according to their type

Atmospheric hypoxia is caused by a decrease in the P O_2 of ambient gases; it is encountered at altitudes or during administration of gaseous mixtures at sea level, where F_IO_2 is < 0.21. It is also called hypoxic hypoxia.

Anemic hypoxia or hypemic hypoxia is due to a decrease in the capacity of the blood to carry O_2 (e.g. hemorrhage, CO poisoning).

Circulatory hypoxia is observed when the blood does not arrive in sufficient quantity to be perfused by body organs. In aeronautics, this is one of the problems posed by takeoffs + G_z of long duration.

1.3.2 - Subjective Symptoms

Hypoxia causes two inconsistent characteristic symptoms: shortness of breath sensation ("dyspnea") and headaches, increased by physical exercise and sleep. A subsequent state of fatigue over the next few hours after an exposure to hypoxia.
Shortness of breath is the subjective translation of hypoxic hyperventilation (see the paragraph 1.2.1 - Ventilation and Respiration, e) "Influence of Oxygen on Ventilation"), which varies greatly from one subject to another. Hyperventilation, a feeling like "shortness of breath", can therefore be linked to hypoxia - but it "may" be gradual. Shortness of breath is therefore a possible symptom of hypoxia.
Regarding fatigue, despite the ordinary and vague nature of this concept, its importance should not be minimized at any cost after exposure to hypoxia. Hypoxia causes a residual fatigue that can lead to an accident.

Example: As an infraction in the rules of use for O_2 at altitudes, glider pilots have remained several hours at high altitudes (actual figures are unknown). They have struck rugged terrain while descending from altitudes of less than 2,000 m. They were out of the "hypoxic" zone at the time of the accident. Clearly, these accidents must be attributed to "post-critical asthenia," a state of intense fatigue that follows exposure to hypoxia at altitudes. Although indirectly, it can be stated that ~~que~~ these accidents were due to hypoxia.

1.3.3 - Effects of acute altitudinal hypoxia on major vegetative functions

In common terms, vegetative functions are the stewardship functions of the body, ventilation and circulation being first and foremost.

a) Effects on Ventilation

Acute altitudinal hypoxia leads to an increase of about 20% in average ventilation (hyperventilation) at 4,500 m, approximately 50% between 5,500 and 7,000 m - actually nothing very spectacular.

b) Effects on the Heart

Heart rate and blood flow increases moderately to less than a factor of two. The reason is simple: Under hypoxic conditions, the heart no longer has the energy resources to work better…Hypoxia reveals rhythm or cardiac conduction disorders.
During exposure to hypoxia at high altitudes, the electrocardiogram can be altered, sometimes very significantly.

A passenger with coronary heart disease, stable under normal barometric pressure conditions, may present symptoms higher than 2,000 m of altitude.

c) Cyanosis from Hypoxia

It is traditionally described as cyanosis from hypoxia. The word "cyanosis" means a bluish or purplish coloration of the skin and mucous membranes. It is particularly noticeable in the lips. Cyanosis is observed in severe and prolonged hypoxic states, such as those resulting in death.
It is described in reports of criminal experiments performed at Dachau in 1942. The constant experience of a high-altitude chamber or in-flight testing does not show this symptom, which is also well identifiable as in Caucasians.

The presence or the absence of cyanosis, is important to know. In certain circumstances, it can be generated by a hypoxic situation (e.g. paratroopers before a jump at high altitude) and personnel receive the instructions to monitor each other.
After what we have just mentioned, they must know not to wait for cyanosis to recognize hypoxia.

1.3.4 - Effects of Hypoxia on the Relational Functions

Individuals can make contact with the outside environment. Using:

- Motor function;
- Sensory functions;
- Psychological functions;

These functions are particularly sensitive to hypoxia.

a) General Effects of Hypoxia on the Nervous System

The nervous tissue is very sensitive to hypoxia. Two simple concepts should be remembered.

In high altitudes, the body has no convenient oxygen reserve, because our natural reservoir is intrapulmonary gas, with the partial pressure of O_2 at sea level; in high altitudes, the partial pressure of O_2 is very low, which makes this reservoir disappear (in terms of O_2 mass - even though volumes are maintained).

The nerve cells do not contain any O_2 reserve; in humans, when they are in severe O_2 deficiency conditions;

- The most sensitive nerve cells cease to function only 5 seconds after the interruption of the O_2 supply, which causes loss of consciousness;
- Irreversible nerve lesions are likely to occur after only 3 minutes, resulting in permanent brain lesions.

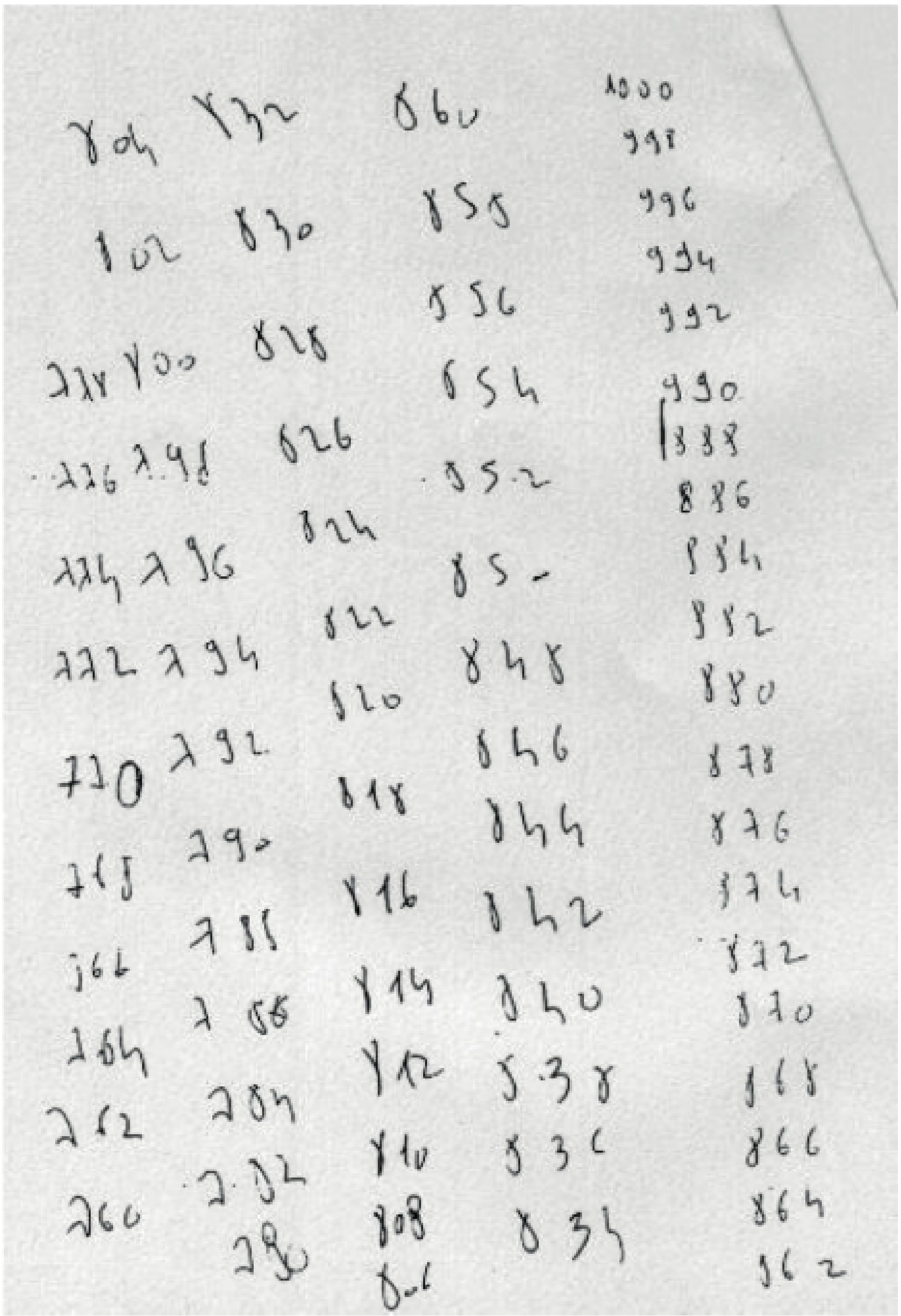
b) Brain Function

Brain function is altered by hypoxia; tremors appear at about 4,500 m, before motor incoordination and a state of paralysis if the hypoxia is advanced.
Movement is deeply affected, without the subject realizing it. The subject may become incapable of performing a gesture, even though the will to carry it out remains.
Several hypoxia tolerance tests are based on the study of motor coordination by writing tests. They show that the subject is completely ignorant of both the considerable deformations of his writing (motor deficiency) and the nonsensical nature that is sometimes noticed in the writing process (psychiatric disorders). The first damage appears at 3,500 m. An example of a writing test was given as an illustration shown under "*Personal document of the author*".

For pilots: Performing pilot functions is slow and imprecise, with difficulty concentrating and reading instruments; delays, inaccuracies and errors in the read back of radio messages are common. The voice drawls and is shaky. Several rescues have been made due to this symptom; either the controller or, in rare cases, the pilot, noting a real "muddling through" in performing the instructions, suddenly recalls the instruction received and corrects the situation by a rapid descent - and a saving act!

Changes of voice are often the first sign perceived over the radio by the one listening to the pilot. Sometimes a well-instructed pilot realizes this anomaly in himself. In an approach to flight safety, it is crucial to recognize and inform on this symptom.

Incident reports have been written or announced where their authors (aircraft passengers, air traffic controllers or pilots themselves) explicitly state that because they were clearly informed about this symptom they have saved the situation.



Personal document of the author.
The test starts at 15,000 ft and the altitude progressively increases towards 20,000 ft. The instructions are to start at 1000 and decrease in steps of 2 digits. The straying from these instructions, the gradual change in writing, the errors (990 → 888), never detected, can be seen as well as the strange reversal in the overall direction of the writing, from right to left - given that the subject was a French native speaker).

c) Sensory Functions;

Hearing is particularly resistant to hypoxia. This fact is essential to know and to inform others. Many crews owe their life to this because voice communication is the only means of communication remaining with a pilot, who is the victim of a severe hypoxic accident.

In contrast, vision is altered by hypoxia. Changes in night vision are observable as low as 1,800 m, and the deficit increases with the altitude. Seeing colours can start to deteriorate between 2,500 and 3,000 m.

Deterioration of visual performance in a subject equipped with night vision binoculars at 3,000 m (10,000 ft.) is currently a topic of special attention. The deterioration of visual acuity itself has never been highlighted as a hypoxic topic.

Let us summarize the effects of hypoxia on vision:

- The perception of light is diminished (the scene is darkened); this consequence of hypoxia is perceptible in the opposite sense when, in a hypobaric chamber, it restores O_2 to the subject: within a few seconds, the atmosphere then appears much brighter. However, except for having past experience with this type of situation, initial darkening always passes totally unnoticed;
- Night vision is deteriorated between 1,800 to 2,000 m (5 to 6,000 ft.);
- Color vision is deteriorated between 2,500 to 3,000 m (8 to 10,000 ft.);
- Narrowed visual field (tunnel vision), seems to have a central effect rather than peripheral;
- By contrast, visual acuity is maintained; it only deteriorates above 6,000 m;
- Hypoxic visual deterioration cannot be perceived by the subject who has already reached the state.

d) Psychological Functions

Depending on its severity, hypoxia is reflected by two types of symptoms: loss of consciousness and behaviour disorders. Loss of consciousness may begin or be preceded by behavioural disorders.

Initial loss of consciousness is observed in the case of hyperacute hypoxia. The subject loses consciousness within a few seconds, without a precursor symptom. An inexperienced subject does not feel anything before the loss of consciousness and has no recollection of the situation.
Sometimes, instead, one keeps a hallucinatory memory associated with the loss of consciousness, in the form of noise (noise of bells) or coloured spots (kaleidoscope impression). If reoxygenation is fast enough, the loss of consciousness regresses in approximately 20 seconds.

Psychological disorders are due to acute hypoxia, with a link to behaviour and cognitive disorders. These disorders result in severe and very diverse symptoms. Some of them are very noticeable.

- These disorders may be remembered by the subject, but memory is inconsistent.

- Altitude and onset of these disorders are unpredictable. For a similar person, they may vary from one day to the next; thus, a pilot cannot check himself for hypoxic risk. The concept of an "identity card" for hypoxia is not reliable.

- The psychological symptoms of hypoxia cover all types of behavioural disorders: excitation, aggressiveness or, on the contrary, characteristic depression or antisocial behaviour. Fights have been observed, but the quarrels were pacified by the administration of oxygen to the individuals involved.

- Under its most common depressive form, hypoxic crisis is characterized by the suppression of one's drive. The subject is able to correctly analyse the situation, but does not draw any practical conclusion, including one's own survival. One may declare that "nothing can be done" (this is an extremely common theme during the hypoxic crises), have no reaction, or present a frankly inconsistent reaction, leading to the execution of an act totally contrary to logic.
- A flagrant example of this last type of behaviour was given by the observation of a fighter pilot who, after announcing an actual failure of oxygen, depressurized the aircraft.

- Cognitive disorders are constant; difficulty in reasoning and complete inhibition of the capacity for self-criticism. The subject is incapable of handling simple arithmetic problems (very simple!) and the errors are consistent and significant (see Figure "Personal document of the author" under Paragraph 1.3.4; the subject performs his test in a completely mechanical way; even very obvious errors may not be seen by the person.
- In terms of flight safety, this total absence and early detection of cognitive feedback on the task that is being executed is to be taken seriously.
- Simple arithmetic operations start to pose a problem such as fuel calculations or trajectory calculations (cap-route-drift).

- The memory capacity is quickly reached, at 10,000-12,000 ft., with a decrease in learning capacity.

- Erosion of the concept of safety is very characteristic. In the experimental situation, the subjects were instructed about the necessity to use oxygen if they observed the need for themselves. In the experience of the author, these instructions were never executed.

- A summary of these observations involves describing ''tunnel'' vision. Actually, the person was totally focused on the task that he was performing (poorly) and did not see anything else.
- In more modern and quite familiar language, we would ideally describe this state as "putting one's nose to the grindstone".

- The course of the hypoxic crisis is also remarkable. It frequently occurs in the form of a particularly characteristic euphoric period.
- Euphoria is found in the spontaneous accounts of pilots who, whether they were aware of the risks involved or not, broke the rules that protect against hypoxia.
- In the latter case, the situations described were particularly dangerous, because the euphoria experienced was pleasurable; these pilots seem to have sought to experience these sensations again; this is genuine behaviour of addiction to hypoxia

- Finally, the disorders due to hypoxia may not reveal a latent personality disorder. They only express a pathological functioning of the central nervous system. It would be ludicrous to consider hypoxia as a form of truth serum.

In summary:

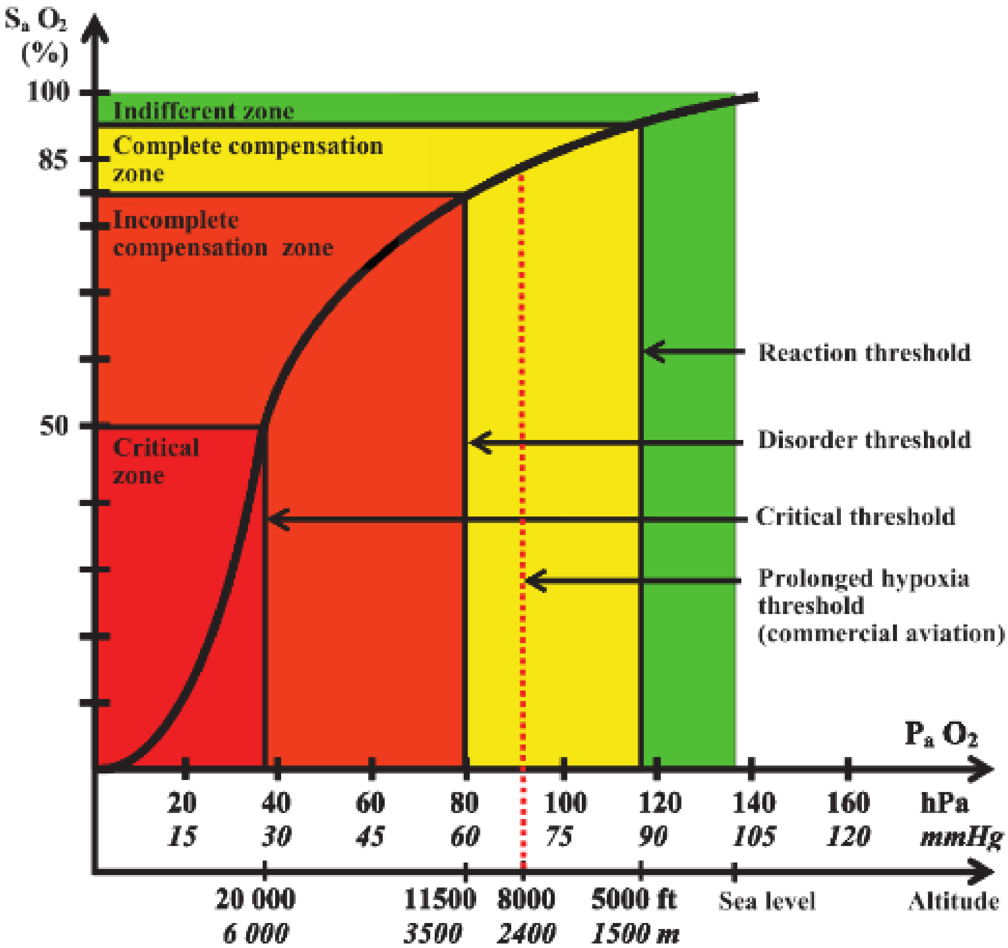
- Hypoxia introduces a serious risk for aircraft crews. It is good to inform and be informed, by insisting on the relative preservation of hearing, which may be the only sensory way for a third party to assist in the rescue of a pilot in distress.
- Although it happens, it is unusual that a pilot is saved alone. The purpose of the instruction in hypoxia is first to raise awareness about the reactions of others, and to perceive in others one's own reactions.
- It is crucial to make the same statement, and with the same care, to all those involved in the aeronautical field in contact with the pilot in flight, particularly air traffic controllers.
- The instruction for all personnel regarding the risk of hypoxia should include personal experience in the altitude chamber (in a stimulation center, inhaling oxygen-depleted mixtures with a mask can, at lower cost and risk, replace entering into a high-altitude chamber).

1.3.5 - Hypoxia Tolerance at Altitudes

The previous presentation outlines the symptoms of hypoxia under their qualitative form. The next question concerns the corresponding quantitative values: What are the altitude values, and what are their time limits?
In the situation of so-called acute hypoxia, the limiting factor is the altitude reached. In the situation of hyperacute hypoxia, the limiting factor is the duration before a redhibitory degradation of psychomotor performance.
Before giving precise figures, or having regulatory values, the wide variability of data should be recalled; variability from one subject to another and, for the same person, variability from one day to the next. Regulatory values must be able to cover the entire population concerned.

The variability of disorders means that, most of the time, the regulatory values can be violated without extremely adverse consequences. However, the tolerance is a random risk, and any violation of it is criminal. Protection against the hypoxic risks at high altitudes almost always wastes a little oxygen; this is the cost of safety.

Hypoxia tolerance as a function of the altitude reached is described from the dissociation curve of the haemoglobin (Figure below) It describes four segments, the values indicated being valid for an aircrew population (medically "fit"), with the lower limit of probable values.



Hypoxia tolerance zones as a function of altitude.

• Indifferent zones are between 0 and 1,500 m (0 and 5,000 ft.); no physiological response to hypoxia manifests itself.

• Complete compensation zones are between 1,500 and 3,500 m (5,000 and 11,500 ft.); the body compensates hypoxia through adapted cardio-respiratory reactions. However, two functions are not compensated:

- Night vision;
- Learning ability.

In addition, necessary physiological reactions may create a certain fatigue.

- Incomplete compensation areas are between 3,500 m and 5,500 to 6,000 m (between 11,500 ft. and 18,500 to 20,000 ft.). It is characterized by the risk of psychological disorders, typical of acute hypoxia.
- The critical zone is located beyond the 5,500 to 6,000 m (18,500 to 20,000 ft.). It is characterized by the risk of hypoxic syncope, which occurs much more rapidly as the altitude becomes higher. Without correcting the hypoxic situation, syncope ends in death.

The main threshold values of hypoxia tolerance at high altitudes recognized by the major regulatory texts are:

- 5,000 ft. for normal flight without any physiological impairment;
- 8,000 ft. for the prolonged hypoxia threshold without excessive fatigue; this threshold is retained for civil aviation (CS-25.841);
- 12,000 ft. for the threshold to use oxygen under any conditions. The threshold of 8,000 ft. applies to civil aviation. The threshold of 12,000 ft. applies to military regulations (OTAN: STANAG 3198 AMD).

Regulations are very complex. As concerns safety, we will recall a simple rule.

The EASA has recently clarified the question of the altitude at which the use of oxygen is required. This regulation supersedes all less restrictive national texts and applies without distinction to all types of flights, all types of aircraft and all operating conditions:
Flight crew members (pilots) must use (rather than *have available*, as in previous texts) oxygen above the cabin altitude of 10,000 ft unless the time of exposure at an altitude between 10,000 ft and 13,000 ft is less than 30 minutes (first 30 minutes of flight between 10,000 ft and 13,000 ft only). Above 13,000 ft, the use of oxygen is mandatory, regardless of the time the aircraft remains at this altitude. Pilots must have sufficient oxygen available for the flight time at altitudes above FL 100. The responsibility for compliance with these rules lies with the aircraft's captain. This is the cabin altitude, regardless of the aircraft's pressurisation status (para. CAT.IDE.A.235 and 240).
Passengers must be provided with oxygen above FL130, with an adequate supply of oxygen throughout flight at altitudes above FL130.

From a practical standpoint, let us summarize some of the concepts outlined above.

Physiological equivalence between exposure to altitude without the use of oxygen and exposure to altitude with the use of pure oxygen? The calculation uses the laws of the physics of gases, as well as specialized calculations of intra-pulmonary gas exchanges. This calculation is complex; only the results are shown below:
The calculation involves the equation of alveolar gases and the application of Dalton's Law. This calculation is complex and only results are indicated.

Breathing in the air	S.L.	5,000 ft.	8,000 ft.	12,000 ft.
Breathing in pure oxygen	34,000 ft.	36,500 ft.	38,000 ft	39,000 ft

It necessary to clearly distinguish the response threshold and threshold of disorders.

- At sea level (SL) to 5,000 ft. without additional O_2, and 34,000 ft. to 36,500 ft. with inhalation of pure O_2, the body is impervious to altitude hypoxia. Actually, it is not even hypoxic, since the specific properties of the hemoglobin molecule ensure that saturation of the blood with oxygen remains close to 100%.
- From 5,000 to 12,000 ft., without additional O_2, and 36,500 ft. to 39,000 ft. with inhalation of pure O_2, the body finds appropriate physiological reactions to compensate for most hypoxia.
- Beyond 12,000 ft. without additional O_2, and at b39,000 ft. with inhalation of pure O_2, these physiological reactions are insufficient to compensate for hypoxia.
- 5,000 ft. without additional O_2 and at 36,500 ft. with inhalation of pure O_2 are the response thresholds.
- 12,000 ft. without additional O_2 and at 39,000 ft. with inhalation of pure O_2 are the disorder thresholds.

Note: The value of 40,000 ft. is often used in place of 39,000 ft.

1.3.6 - Hyperacute Hypoxia Tolerance and Time of Useful Consciousness

On October 25, 1999, a Learjet took off from Orlando, FL (USA). Passing FL 230, the aircraft was authorized by air traffic control to climb to FL 390; this was the last radio contact.
Fighter jets intercepted it, but frost covering the windows did not allow them to see inside the aircraft. It crashed after its fuel was used up.
The six occupants died. The investigation concluded the oxygen supply of the pilots failed after a loss of pressurization, without knowing the cause.

The risk of hyperacute hypoxia is extremely significant, because it requires safety measures within a few seconds of a rapid depressurization of the cabin.

The most serious hypothesis considered is that of an engine burst at the cruising altitude, with projection of fragments through the cabin and depressurization within a few seconds. Loss of consciousness can then be very fast, within a few seconds.

Let us present the problem from a specific hypothesis, which would be rapid depressurization of the cabin of an Airbus A320, flying at FL 390 (PB = 197 hPa) and a cabin pressurized for 8,000 ft. (PB = 753 hPa) - see Figure "Variations of P_A O_2 after a rapid decompression" under Paragraph 1.4. We note that this type of accident has never occurred on an A320. At 8,000 ft., the O_2 partial pressure of alveolar gases (PAO_2) is equal to 96 hPa and 40 hPa for venous blood.

Decompression is defined by the decrease in P_B of 753 hPa at 197 hPa, or a decrease of pressure in a ratio close to four. With the airways open, the total intrapulmonary pressure follows the same rate of change.
There are four intrapulmonary gases (O_2, N_2, CO_2 and H_2O), but they do not all follow the same law of decrease P_A H_2O maintains a constant value and P_A CO_2 only decreases by a factor of two.
$P_A O_2$ and $P_A N_2$ thereby decrease by a factor of 6, which brings $P_A O_2$ to a very low value, approximately 15 hPa, a much lower value than P O_2 for venous blood.

The body is then in an original situation, where the partial pressure of O_2 is lower in the intrapulmonary gases than in the venous blood. It is the venous blood that leads to desaturation in the pulmonary alveoli; from the moment it is totally desaturated, blood that leaves the lungs to return to the left chambers of the heart and to irrigate the body organs.

The blood that leaves the lungs reaches the brain four seconds later and, from the moment where the brain is deprived of oxygen, 5 seconds later the loss of consciousness occurs. Loss of consciousness can therefore occur 8 to 10 seconds after the initial event.

We now recognize that the pilot must immediately put on the oxygen mask (which is stocked with "100% oxygen" by a mechanical device). Loss of consciousness does not result in a stop to breathing, since neurons of ventilatory control are much less sensitive to hypoxia than neurons of consciousness.
Consequently, even unconscious, the subject continues to ventilate (for approximately 15 minutes). With each ventilatory movement, the subject rejects gas containing nitrogen and replaces it by pure oxygen. $P_A\ O_2$ returns within approximately 1 minute to a target value close to 90 hPa, which allows for the return of consciousness.

Remember: During rapid decompression of a pressurized cabin at high altitudes, the pilot has only 5 seconds to protect himself against hypoxia.

The time limit between the initial event and loss of consciousness has been tabulated; this is the concept of Time of Useful Consciousness (TUC), and is useful to know for the pilot at the controls (Table below).

Decompression at the Altitude of	Time of Useful Consciousness (calm subject)
6,000 m - 20,000 ft.	30 min
9,000 m - 30,000 ft.	1 – 2 min
10,500 m - 35,000 ft.	30 – 90 seconds
≥ 12,000 m - ≥ 40,000 ft.	15 - 20 seconds

Time of useful consciousness (Data: LO 2018).

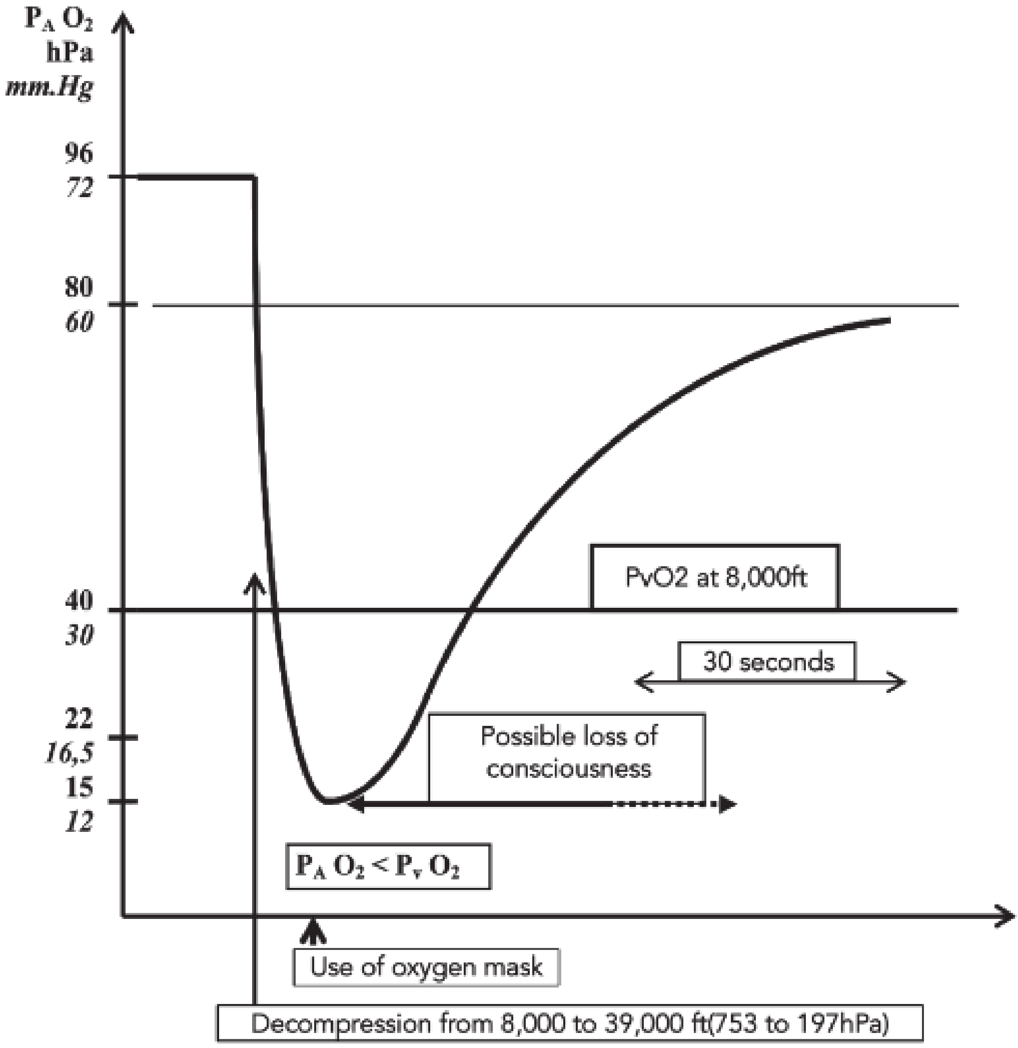
To be specific, the loss of consciousness, which is the issue here corresponds to the "loss of situational awareness", i.e. when the pilot is no longer able to exercise his tasks. There are a lot of different figures to describe the TUC.

Measurements are relative; conditions vary according to the situation. Calm subjects (in the altitude chamber) breathing pure oxygen and unfastening their mask differ from an airline pilot at the controls of his plane who is a victim of rapid decompression while he was not wearing an oxygen mask.

The value of the TUC then varies in a ratio of 1 to 4. The author prefers to describe the second situation instead of the first, which is the most commonly cited (e.g. defining a TUC of 20 to 30 s at 30,000 ft. instead of 2 minutes found in certain texts).
In the 1980s, a TUC of nearly 20 s was observed by the author in a test flight at 28,000 ft.

This is not "loss of consciousness" within the meaning of syncope, but it is the state described, for example, in Figure "Personal document of the author" under Paragraph 1.3. In this example, psychomotor deterioration was triggered even before arriving at 20,000 ft.

For the altitude of 39,000 ft., the author of this text preferred to use a value of 8 to 10 seconds, much more realistic than the 15 to 20 seconds announced. Let us not forget that safety is based on taking into account the most pessimistic figures, and not the average values.



Variations of $P_A O_2$ after a rapid decompression.
The oxygen mask must be in position within 5 seconds.

1.4 - Decompression Sickness

1.4.1 - Description

Decompression sickness from altitude is linked to nitrogen. This gas is dissolved in the body as a function of its partial pressure. When the barometric pressure decreases rapidly, nitrogen is in supersaturation in the tissues of the body.

Nitrogen is five to six times more soluble in human fats than in water. The body of a young adult, lean and male, contains approximately 1 dm^3 of nitrogen, of which 70% are stored in the fat; nitrogen can only escape to the atmosphere outside through dissolution in the blood, where this gas is poorly solubilized.

In addition, any diffusion processes of nitrogen from one compartment to another in the body is a slow process, which explains that the symptoms do not always appear instantly; they sometimes even appear after a delay in the physical changes in the environment.

Decompression sickness for the diver is not fundamentally different from the aviator. However, the diver is confronted with variations in pressure which are more significant than the aviator. That is why symptoms of decompression sickness are much faster and more severe in the diver then in the aviator.

1.4.2 - Symptoms

The symptoms of decompression sickness can be classified into two groups:

- "Mild" symptoms (at least, if taken care of without delay);
- Severe symptoms.

Milder forms are by far the most common:

- Joint pain, often called the "bends", gradual appearance, affecting one or more joints and are aggravated by movement;
- Skin symptoms, often referred to as "creeps": tingling or stinging, sometimes urticarial eruptions; they are due to the release of nitrogen contained in subcutaneous fat;
- Non-painful joint manifestations are rarer; gaseous collections in the joints and tendon sheaths are painless.

These symptoms disappear spontaneously in the descent.

Serious forms are rare in aeronautics. They are considered as neurological, pulmonary or cardiac disorders (in order of frequency). These serious forms are potentially fatal.
They can be pronounced by severe joint pain. They are caused by the migration of gas bubbles in the arterial circulation; these bubbles block the terminal vessels (capillaries), determining, on the one hand, hypoxia of tissues located downstream and, on the other hand, biochemical complex phenomena, including blood coagulation in the very abnormal interface between the blood and a gas bubble.
The delayed forms can appear several hours, or even several days after exposure to high altitudes; they are often of a neurological type - quite similar to a stroke - and vary in severity.

1.4.3 - Risk Factors for Decompression Sickness

- Speed of the rise in altitude: No risk if the speed of the rise remains less than 1 $m.s^{-1}$ (200 ft./min).

- Altitude reached: From sea level, the risk of decompression sickness appears above 5,500 m, but only becomes really significant, at around 7,000 to 7,500 m. It becomes a major concern above 9,000 m.

- Time spent at high altitudes: There is a delay of several minutes before the onset of the first symptoms. However, if accidental depressurization occurs in the cabin, the emergency descent must go to an altitude ≤ 25 000 ft. in less than 3 minutes. Under these conditions, the risk of decompression sickness can be neglected.

- Age, with a sudden increase of risk around 40 years.

- Obesity and fat mass.

- Scuba diving before an exposure to altitude.

- Apart from a few rare observations on board a non-pressurized aircraft flying at high altitude, flying after scuba diving has been the only significant cause of cases of decompression sickness in recent civil aeronautics.

- Prevention is based on a simple rule: Always observe an interval of 24 hours between the end of scuba diving and a rise in altitude.

1.4.4 - Risk Prevention in Civil Aeronautics

The principal means of preventing decompression sickness is based on cabin pressurization and on emergency descent procedures after a depressurization accident.
In practice, under current conditions for commercial passenger aircraft (certified FAR or CS-25 aircraft), the maximum altitude in the cabin is 8,000 ft. This altitude is lower than the threshold for triggering decompression sickness, except for personnel who have scuba dived just before a long flight (at least 8 hours).
In accidental depressurization of the cabin, the aircraft must be able to descend quickly enough so that the symptoms of decompression sickness do not have time to appear (US text FAR 25.841(2)).

When protection can be ensured through pressurization (e.g. non-pressurized aircraft used for aerial work), prevention is based in the inhalation of pure oxygen, for a sufficient period before exposure to altitude.
This period may be measured in hours. It depends on the exact conditions of exposure to altitude, including the characteristics of the person (age, sex, fat mass, scheduled muscle activity, etc.). This is a heavy technique.

1.5 - Hyperventilation at High Altitudes

Hyperventilation is the first cause of malaise among commercial aviation passengers.
Well-documented medical observations of syncope by hyperventilation in the aeronautical community are extremely rare. We observed one of them during an experiment in the altitude chamber, with indisputable physiological recordings. It is reported below.

1.5.1 - Example

a) Incident Circumstances

A human test was performed at the altitude of 5,500 m in the decompression chamber. The experimenter was in a laboratory setting, aged 38, and very accustomed to physiological tests. During the test, a doctor accompanied him inside the chamber.
The test was to last two hours but it didn't. It included, in 30-minute increments, various physiological recordings, including recording of ventilation and measurement of arterial blood oxygen saturation. Between the measurements themselves, recorders were moving slowly, which allowed a posteriori to restore the initial conditions & data of the incident.

b) Description of the Incident

Around the 40th minute, this subject had a state of hypoxia with slight hyperventilation, completely normal in such cases (approximately 11 $dm^3.min^{-1}$). After a few minutes, the subject began to hyperventilate, voluntarily and excessively, with the goal of compensating for his hypoxia. Then, he had a growing discomfort with very abundant sweating on his face, tingling and numbness of the extremities and then all of his members. He was in anguish with cramps and widespread, intense muscle pain. The almost total loss of consciousness came quickly, leaving sensations of violent muscular pain.

The clinical picture was that of a tetany crisis with all its symptoms. The saturation of arterial blood oxygen, measured continuously, was greater than 95%. The ventilation reached a very high value, approximately 40 $dm^3.min^{-1}$ (at the least, because the recorders were saturated!). The ventilatory rate was very quick, approximately 40 to 45 cycles/min.
The administration of oxygen by the accompanying doctor did not change his symptoms; his ventilation remained stuck at this level. The crisis was only resolved after emergency recompression of the chamber and appropriate therapeutic measures.

1.5.2 - Physiological Mechanisms

Under physiological conditions, it is the partial pressure in CO_2 that determines the ventilation. With physical exercise, the amount of CO_2 produced by the metabolism increases and ventilation increases to eliminate the excess CO_2. This is a perfectly regulated physiological hyperventilation. This is the normal functioning mode of the terrestrial aerobic organisms.
It is not the same for what is commonly called "hyperventilation", or implied "pathological hyperventilation". When ventilation increases for a reason other than the increase of partial pressure in CO_2, there is a release of an exaggerated quantity of CO_2 and decrease of its partial pressure (hypocapnia). Various circumstances encountered in flight can be responsible for hyperventilation with hypocapnia as its consequence.

Therefore, it is appropriate to distinguish "physiological" hyperventilation, regulating the increase of CO_2 production, "hyperventilation" without further details, implied "pathological", and which is the subject of this chapter.
The disorders observed are consequences of hypocapnia. Some explanations: CO_2 combines with water to form carbonic acid (H_2CO_3). H_2CO_3 dissociates into H^+ ions and HCO_3^-; HCO_3^- ions enter the entire assessment, complex, of bicarbonates in the body.
With respect to H+ ions, their measurement is expressed by the pH of the blood. Any change of partial pressure in CO_2 of the body causes a change in the pH of the blood and other fluids of the body. Yet, the function of excitable cells (nerve cells, muscle cells) is very dependent on the pH of the medium in which they are immersed.
Any disturbance of the acid-base balance of the bodily fluids thereby seriously affect the functioning of these cells and, generally, the organs that they compose, the nervous system and particularly the muscle system.

The crisis of hyperventilation is therefore characterized by a profound disruption of the entire neuromuscular system.
Hyperventilation syndrome is characterized by hypocapnia, which leads to an increase of blood pH, i.e. its alkalinity. In strictly equivalent terms, hyperventilation leads to a decrease in blood acidity.
Hyperventilation with hypocapnia is therefore the source of various serious disorders, which culminate in a tetany crisis.

One component of the hyperventilation crisis is particularly extreme during a tetany crisis, the central nervous system disorders are such that even normal ventilation regulating mechanisms are lost, in favor of a totally pathological process.
Instead of responding to hypocapnia by hypoventilation, powerful hyperventilation is observed, creating an internal hypocapnia-hyperventilation chain; in terms of automatisms, it is a positive feedback system. The situation becomes blocked and can only be resolved through an outside intervention.
It is this situation that was observed in the experience described earlier.

1.5.3 - Symptoms

The symptoms felt by the persons are identifiable. In a preliminary stage, it is a disorder often expressed as "vertigo"; a sensation of malaise. The person may experience a few visual disorders. Then, very quickly, the following symptoms are observed.

- Sensation of Growing Malaise. This malaise may appear quickly, but never abruptly, as may be the case with acute hypoxic syncope.
- In contrast with hypoxic syncope, which is often accompanied by a feeling of indifference or even euphoria, malaise by hypocapnia is always accompanied by a sensation of intense anguish, sometimes a feeling of imminent death.
- Actually, even under its depressive forms, hypoxia usually leaves the subject in a calm and resigned state, or committing numerous errors, including that nothing can be done.
- This difference between the subjective signs of hypoxia and those of hypocapnia are very characteristic, and somewhat paradoxical. Hypoxia is potentially lethal in a very short time, but leaves the subject relatively indifferent.
- Hypocapnia is not in itself fatal immediately, but it causes a particularly intense anguish of imminent death.

- Sweating of the face and extremities is very frequent and sometimes very abundant.
- Tingling, stinging and numbness of the extremities is very characteristic and constitutes excellent signs of the beginning of the crisis. They become more and more intense and can extend to any member. The same sensation can be felt in the lips.
- At the beginning, muscle cramps or involuntary contractions appear in small muscle groups, which are difficult for the subject to detect by himself. At most, muscle cramps can lead to an extremely painful generalized contraction, despite the change in consciousness.
- This is what was observed during the incident reported previously, with a typical tetanus crisis, major hyperventilation and sedation only through specific medical treatment of the tetany crisis.

All of these symptoms show overall change of neuromuscular function.

Causes of the hyperventilation syndrome in flight are:

- Motion sickness can multiply ventilation by a factor of 3 to 5, which is considerable; in this case, hypocapnia is constant;
- Anxiety;
- Genuine hypoxia, produces hyperventilation; it is common to find hypocapnic components in the symptoms described by a pilot, who was a victim of a hypoxic crisis;
- Sometimes wearing an oxygen mask is too restrictive for inhalation and expiration.

Let us point out a few items to obtain sedation in flight during a hyperventilation crisis. It is necessary to correctly identify the cause of the disorders, by eliminating the other causes of malaise in flight. In addition, on board a single-pilot aircraft, the pilot victim of such an incident is both a patient and therapist, which is not a comfortable situation.
Other causes of malaise in flight must be mentioned. Two of them must be remembered: hypoxia and intoxication of the pilot by a toxic emanation inside the cabin.

1.5.4 - What to do

Sedation of disorders is based on a simple principle: it is alright to let the body fill itself full of CO_2. It is easier to say than to do…
Let us examine the most restrictive case, the pilot of a single seater fighter jet. In flight, sedation of the crisis can be done only through the behaviour of the pilot. As for any treatment, it must treat the presumed cause without ignoring another cause of malaise.
If there is an interaction with the oxygen equipment, a good solution would be to quickly reach a cabin altitude lower than 10,000 ft. and unfasten the oxygen mask (fighter jet). However, this procedure is not recommended, because it is only correct if the diagnosis is sure
Therefore, it seems more appropriate to propose the following procedure (pilot of a fighter aircraft):

- Immediately interrupt the mission and descend to the altitude of oxygen safety (< FL 100);
- Check the oxygen system;
- Tighten mask;
- Regulator of pure oxygen ("100% O_2").

These precautions eliminate the risks of hypoxia and intoxication from the cabin. Poisoning in flight through pollution of the oxygen system now seems to be quite rare. Pure oxygen is not toxic and

the traditional term "drunk on oxygen" has never actually occurred as described…hyperventilation. In case of malaise by hyperventilation, oxygen is neither beneficial nor dangerous, but its systematic use allows one to overcome the misdiagnosis.

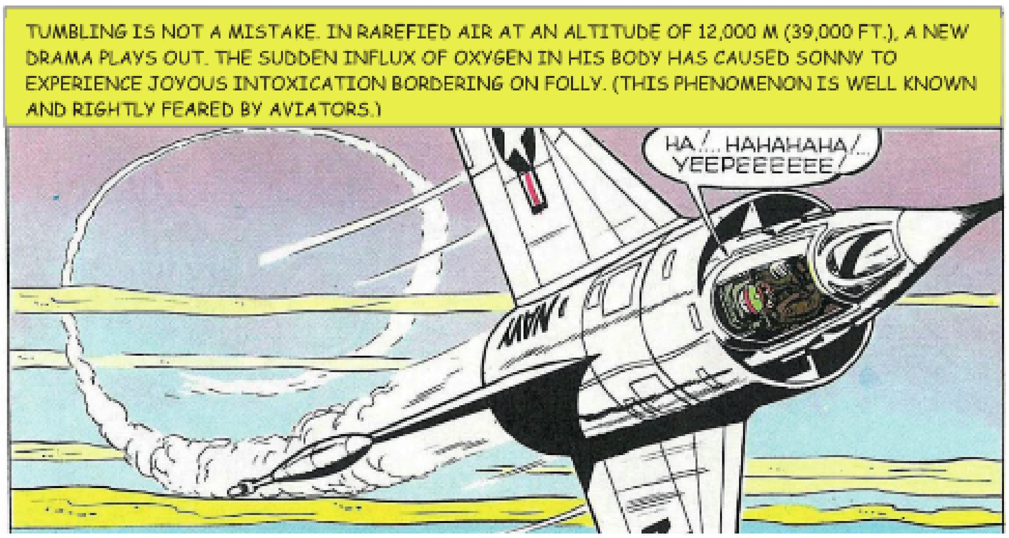
It is necessary to apply the specific procedure that, in flight, can only be strict control of ventilatory behaviour, either by observing short periods of apnea, or by controlling the ventilation rate, using the chronometer on board. Two techniques are possible:

- Holding one's breath for 20 seconds each time;
- Timing one's breathing to inhale every 6 to 7 seconds, this latter technique appearing to be much more realistic to propose to pilots.

In the case of a passenger, after having eliminated a serious cause of malaise on board, the malaise by hyperventilation is treated in a simple way:

- Calm the anxiety and motion sickness if applicable;
- Then treat the hypocapnia, either by controlling the ventilation or by the breathing for a reasonable time in a closed bag; this latter technique allows the subject to recycle his own CO_2 and eliminate the hypocapnia. The Cabin crew of commercial aviation are generally well-prepared for this…

However, returning to this tenacious myth: "drunk on oxygen". What can complicate the argument… are comics!



When a misconception is popularized by a famous comic and is "well-known", it becomes indestructible. It is the origin of a tenacious myth, such as the use of oxygen at an altitude at risk. For the reader to be satisfied: at 12,000 m, only pure oxygen will save someone.

1.6 - Toxic Hazard Onboard

1.6.1 - Introduction

A report published in 1987 by authorities in the United Kingdom identified, between 1966 and 1985, 74 air accidents in which 8,623 persons had been affected by the toxicity from fires, resulting in 2,688 deaths.
Among these accidents, four of them caused the death of all these persons (42, 45, 248 and 301 dead), fourteen caused between 75 to 100% of the deaths, and fourteen others between 50% to 75% of the deaths. This hazard does not decrease with time.

a) Example

On July 11, 1973, a B707 of the Brazilian company, Varig, departed from Rio-de-Janeiro and was approaching Paris-Orly from the West for 26, stable at FL 080. At 13 h 58 min 20 s, the crew contacted the approach for a "problem with a fire onboard". An emergency descent was requested. At 13 h 59 min, they were cleared to descend to 3,000 ft. for a direct landing in 07.
The situation worsened onboard; smoke penetrated into the cockpit and passengers were asphyxiated. Clearance to descend to 2,000 ft. was granted at 14 h 01 min 10 s. The crew used their oxygen masks, but the smoke made the instruments unreadable. At 14 h 03 min, the crew decided to make an emergency landing 5 km from the runway threshold, landing gear retracted and flaps deployed. The aircraft approached with a nose up and a little tilt to the left. The aircraft was partially dislocated, but the fuselage remained intact. Ten occupants (10 crew members of 17) evacuated the aircraft. The firefighters arrived 6 minutes later, without finding any signs of life. They evacuated four passengers, who were still alive but unconscious; only one of them survived. The accident left 11 survivors out of 134 occupants.
Probable cause: fire in the restroom. It is possible that the fire had been caused by a negligent passenger (a poorly extinguished cigarette butt).
Comment: In mechanical terms, it was possible to survive the emergency landing. The persons died due to poisoning (CO and other toxic gases).

b) Hazard of a Closed Environment

The cabin of the aircraft is a closed environment in which the space assigned to each person is reduced beyond what is commonly encountered under normal conditions of life. To give an example, the overall volume of the A330 and A340 cabins is roughly 800 m^3. This cabin is likely to accommodate up to 440 passengers. It is obviously impossible to escape from the cabin while in flight.
Toxic hazards are first risks linked to fire. Other possible causes of toxic poisoning are real but rare, if not exceptional at the present time; these are malfunctions of the cabin conditioning systems.

There is a risk of fire or accidental combustion onboard the aircraft. The causes are numerous, including these three:

- Smoking in flight, with fire or starting a fire in the lavatory of the aircraft, due to a discarded cigarette butt not having been extinguished.
- Electrical fire: By overvoltage and then overheating of the electrical conductors, followed by combustion, with or without flames, near coatings and materials. These, of a synthetic nature, release sometimes very toxic gaseous compounds by pyrolysis.

- The accident of a Swissair MD11, which crashed into the ocean on September 2, 1998, 1 h 15 min after takeoff from New York, is attributed to this cause.
- The presence of a large quantity of fuel onboard the aircraft. Fire appears to be a frequent concomitant of in-flight incidents or accidents. Intoxication by smoke is often thought to be the cause of incapacity of personnel to evacuate the aircraft and dangerous areas. Example: The accident of a B737 on takeoff from Manchester in 1985, due to an engine explosion, which then spread the fire to the fuel after takeoff. The death of 53 persons has been attributed to intoxication of fumes.
- All enclosed spaces pose the same risk. Two fires in night clubs, in France and in Spain, remained notorious for this reason, as well as the fire of the Mont Blanc Tunnel, in 1999.

1.6.2 - Risk Analysis

Chemical analysis of the gases released during the fires show the frequent presence of:

- Carbon dioxide;
- Carbon monoxide;
- Hydrochloric acid;
- Hydrocyanic acid;
- Nitrogen oxides;
- Hydrocarbons and their degradation products.

a) Carbon dioxide

CO_2 is produced during the combustion, at the same time that O_2 is consumed. CO_2 acts:

- As an asphyxiant, replacing O_2;
- As a powerful ventilatory stimulant, which increases ventilation, thereby allowing other toxic gases into the pulmonary alveoli;
- As a toxic substance when its partial pressure exceeds 10 kPa, with a lethal risk up to 30 kPa.

b) Carbon monoxide

Refer to Paragraph 1.2.3; c) Carbon Monoxide Poisoning.

c) Hydrochloric acid

Hydrochloric acid comes from the combustion of chlorinated compounds, such as polyvinyl chlorides. This gas, when it is inhaled, dissolves in the mucous membranes of the respiratory tract, where it is at the origin of serious lesions, because it destroys lung tissue.

d) Hydrocyanic acid

Hydrocyanic acid comes from the combustion of natural (silk, wool) or synthetic (polyurethanes, polyamides, etc.) nitrogenous materials. Hydrocyanic acid is based on cellular systems that use O_2 and blocks them. Death is very fast. This gas is extremely toxic, death occurs within 10 min for a concentration of 180 ppm, with an all or nothing law (death, or survival without sequels).

e) Nitrogen oxides

Nitrogen oxides are represented by nitrogen monoxide and nitrogen dioxide. The action of nitrogen monoxide on the body is close to that of carbon monoxide, by forming a stable compound with hemoglobin, unfit to transport oxygen. The action of the nitrogen dioxide is close to that of the hydrochloric acid, with serious chemical damage to the lungs.

f) Hydrocarbons

Hydrocarbons are less toxic than most of them. In its volatile form, these increase the risk of fire.

1.7 - Specifics of Flying at High Altitudes

We turn now to a few very minor problems for persons onboard the aircraft.

1.7.1 - Ozone

Ozone, or triatomic oxygen (O_3), is produced by the bombardment of ultraviolet rays on the upper atmosphere. Ozone is a very powerful and very unstable oxidant.

A complex balance is established in the atmosphere between ultraviolet (UV) rays, which is actually absorbed, and mono/di/tri-atomic oxygen (ozone) and various products of chemical recombination after dissociation of ozone, including nitrogen oxides. Absorbing the ultraviolet radiation, the upper atmosphere protects the lower atmosphere by generating an "ozone layer". This stops nearly all of the UVB rays and allows the UVA rays to pass (much less dangerous).
The stratosphere contains 90% of the atmospheric ozone, which is mainly divided between 12 and 50 km of altitude (an altitude range sometimes referred to as the ozonosphere), with a maximum level at approximately 30 km of altitude; 10 ppmv (parts per million by volume). The concentration of ozone is no more than 1 ppmv at 12,000 m and 0.03 ppmv at sea level.

Ozone is a powerful oxidant and can be used medical disinfection (e.g. surgical blocks) or industrial disinfection (e.g. water treatment).
However, this oxidizing power also gives it toxic properties, starting with an irritation of the respiratory mucous membranes (symptom: cough). At higher doses, it destroys the lungs. Inhalation of ozone is lethal from 10 ppmv and above.
From a strict aeronautical standpoint, ozone is not a major problem, because the air allowed in the cabin, taken from the engine compressors, is warmed by the compression, which is sufficient to destroy ozone molecules.
Nevertheless, specific ozone filters are installed in the air conditioning systems. The "ozone" risk is taken into account in the certification regulations (FAR 25 and CS-25, §832):

> "(a) The airplane cabin ozone concentration during flight must be shown not to exceed –
> (1) 0.25 part per million by volume, sea level equivalent, at any time above flight level 320; and
> (2) 0.1 part per million by volume, sea level equivalent, time-weighted average during any 3-hour interval above flight level 270".

1.7.2 - High Altitude Radiation

The biological effect of radiation is measured in sieverts (Sv) or in millisieverts (mSv). Under natural conditions at ground level, the average dose received by humans is from 1 to 5 mSv/year, including 10% from extraterrestrial origin.

a) Effects of Radiation on Living Organisms

The words "rays" or "radiation" cover a very heterogeneous group. There is electromagnetic radiation of all wavelengths (including "visible" radiation), as well as particulate radiation of all energies. Therefore, the biological effects depend on the nature and energy from these rays:

- Purely thermal effects: The most well-known example is none other than the microwave oven. In aeronautics, the (rare) accidents known involve persons inadvertently exposed to a close radar beam.
- Chemical effects: These effects begin within the range of electromagnetic radiation to "visible" radiation. It is good that they are visible, since perception is based on the excitation of photoreceptor cells in the eye. These chemical effects can be highly desirable. For example, these originate from photosynthesis; through chlorophyll in plants or, in humans, photosynthesis of vitamin D3 takes place by the skin exposed to the sun.
- Effects on the cell genome: "ionizing" radiation penetrates deep into the cells of the body. They release their energy, at least in part, by causing molecular destruction. Some of them (most) cause cell death. The aim to destroy cells is used in the course of cancer radiotherapy, or for disinfection. Other cellular lesions related to the cell core and bearer of the genetic heritage of the cell, carry a risk of cancerous degeneration.

In practice, the main risk related to cosmic radiation is the increased risk of cancer and in pregnant women, the risk of fetal malformation.

b) Cosmic Radiation: Origin and Composition

The radiation at high altitudes comes from space.
Cosmic radiation includes a solar component and a galactic component, modified by the magnetic solar activity, which trap the galactic radiation within the solar magnetic field; the dose of galactic radiation received by the earth varies in inverse proportion to the solar activity.
Solar activity is not constant: With a regular emission cycle of around 11 years. Solar eruptions (infrequent events) add another component - they occur during the peaks of solar activity.

Cosmic rays arriving in the vicinity of the earth are to a large part trapped by the earth's magnetic field, which confines them in a high density radiation area, by Van Allen's belts. These cover several hundred kilometers of altitude, about 2/3 of the globe, centered on the equator and leaving the polar ice caps uncovered. The cosmic radiation is therefore distributed differently, more the poles and less at the equator - on average with 2 μSv/h at the Equator and 6 μSv/h beyond the 60° latitude at FL 350; these doses are multiplied by 2 between FL 500 and FL 600.

c) Assess the Cosmic Radiation Received in Flight

The doses of cosmic radiation received in flight are estimated, either by embedded detectors or by published algorithms, they indicate the dose received in each part of the airspace that is crossed. On average, each person receives less than 1 mSv per year:

- For 200 flight hours at 35,000 ft. on a typical Europe-North America route;
- For 400 flight hours at the same altitude on an equatorial route.
- In Europe, the Directive 96/29/Euratom is applicable to Aeronautics; in its standards, it requires:
- Monitoring When exposure exceeds 6 mSv,
- When exposure exceeds 1 mSv/year, an evaluation of the dose received, with specific attention to pregnancy. As soon as pregnancy is declared, a woman may not be subject to conditions that will expose her to radiation of more than 1 mSv in the year.

d) Importance of "Radiation" Hazards in Aeronautics

We have noted that the medical risks of high altitude radiation are cancers and fetal malformations Remember that humans live in an environment that always contains a little radiation; they adapt to levels of radiation, with the process of cellular repair that ensures the sustainability of species; as a result, the dose/effect ratio for radiation clearly presents a threshold effect.
The doses specified by the Euratom directive give levels of threshold. In commercial aeronautics, it is appropriate to consider that the risk linked to radiation is o very low.

There is no "fatigue" related to radiation, at least in the doses received under conditions of commercial aviation. Fatigue related to radiation is observed in medicine, during radiotherapy. However, these are doses and exposure conditions have nothing to do with the foregoing.

1.7.3 - Hygrometry

a) Measuring Hygrometry: Absolute Humidity, Relative Humidity

In absolute value, the amount of water present in the air is assessed by mass per volume of air (e.g. mg or g per m3), either in terms of partial pressure of water vapor or in the dew point; temperature at which the atmosphere would be saturated for the quantity of water present; this concept is well known to pilots.

Relative humidity can be measured as the ratio between the actual quantity of water present and that which would saturate the atmosphere, at its current temperature. The relative humidity is in relation to the risk of fog in the atmosphere, and with the comfort perceived by the body.

Example

Air temperature = 23°C; quantity of water saturating at 23°C is 20.6 g/m3.
Quantity of water present this day in the atmosphere (example): 10.3 g/m^3, or 13.6 hPa (Dew point = 11.5°C).

Answer

The relative hygrometry is = 10.3/20.6 = 0.50 (50%).

b) Hygrometry in the Aircraft Cabin at Cruising Altitude

In the aircraft cabin during the flight at altitude, humidity is almost zero, because the air in the cabin is taken from outside the aircraft. At the cruising altitude of the aircraft, the air is very cold; however, even at -56°C, the air is saturated with 31 mg of water per m^3, regardless of the pressure.

At 23°C, thermal comfort is assured when the relative humidity is at least equal to 40 or 50%, or about 10 g of water per m^3. Warming up the outside air does not lead to additional water; the relative humidity of the cabin is therefore almost zero. Note that the water vapor brought into the cabin by human presence is negligible, taking into account the conditions of ventilation in the aircraft cabin.

c) Dry Air and Human Tolerance

The dryness of the air causes local and general consequences in the body.

The local consequences can be described as a sensation of dry mucous membranes (oral and respiratory mucous membranes, conjunctiva) and sensation (light) of cold in the skin. The only objectively troublesome consequence in this enumeration concerns the conjunctiva (mucous membranes that coat the eyes), when the subject wears contact lenses.
Repeated flights under such conditions require some precautions for wearers of contact lenses.

The general consequence of the dryness of the air consists of a theoretical risk of dehydration.
Often mentioned, this risk can be calculated, knowing that the loss of water is both from the skin and lungs. Between a dry atmosphere and an atmosphere at 50% relative humidity, at 23°C, the calculations indicate that an average adult loses 42 g of water per hour at 50% of relative humidity, and 59 g of water per hour in a dry atmosphere. This difference is very low; it corresponds to an additional glass of water for a flight of 10 hours!
The cabin air is dry and, even if it can be subjectively a little uncomfortable, it does not do much harm.

d) "Economy Class Syndrome"

For the culture of the reader, we here introduce an outside subject in relation to the required knowledge, but it is an important topic. It is linked to the preceding subject (dehydration).

The "economy class syndrome" is a phlebitis of the lower limbs ("thrombophlebitis" to be exact), which may lead to a pulmonary embolism; the pulmonary embolism may itself lead to a sudden death.

This syndrome corresponds to a fairly general problem in the body; when blood circulation is poor, it may coagulate and form a clot. If, for whatever reason, the circulation is recovered again, the clot can fragment or release, and then migrate during circulation, until a bifurcation or division of the blood vessel prohibits its passage.
It then blocks it, interrupting the circulation downstream. In this case, a venous clot migrates through the vena cava, passing into the right heart cavities, and then in the pulmonary artery; it blocks in the first subdivision of lower diameter in the chest.

A large clot can thus block all the pulmonary circulation; this is complete circulatory arrest, and death.
Phlebitis is one of the possible consequences and common in all prolonged immobility situations; this is a nightmare for the sick or injured who require prolonged bed rest. In the case of the air traveler, the clot forms after several hours of immobility.

The pulmonary embolism is observed when the clot detaches, either at the time of landing or at some time after the flight (between a few hours and a few days).

What you need to know:

- This disorder has nothing to do with the economy class, because it seems to be observed with the same relative frequency everywhere in the aircraft;
- No physical factor of the environment can explain it and the aircraft is not specifically responsible;
- Actually, it is a disorder related to prolonged immobility, observed in all similar circumstances (e.g. transportation by bus over long distances); simply, the aircraft concentrates the cases in the same place and at the same time;
- The hazard depends on the duration of the flight, appearing anywhere from 6 to 8 hours of flight and becoming significant from 10 to 12 hours of flight; for obvious reasons, the night flight is more "productive" than the day flight.

Why link this presentation to the one on dehydration? Because mobilizing people is the best way to prevent the formation of blood clots (move the passengers). Yet, for the passenger to drink a little more than necessary (but water, only!), obliges one to go to the toilet in before the time required to form clots.

The author agrees that this approach is not very reliable scientifically. However, it ensures effective prevention of a serious risk. Of course, the subjects at risk will also receive helpful advice and preventive measures from their physicians, who are familiar with the subject.

1.7.4 - Thermal Problems

The true thermal problem in civil aeronautics is survival after accident, with two major circumstances: survival in the hot desert and survival at sea (cold!).

a) Physiological Responses in Humans Exposed to Heat

In the hot desert, remember a single figure, which is the amount of water that humans can lose by sweating: 1 liter of water per hour during the hot hours of the day. If the personnel are not immediately recoverable on the ground, the amount of water that it is appropriate to provide is approximately 10 liters per person per day.
We will consider the problems facing people during their stay in a hot climate in the "Hygiene" section.

b) Physiological Responses in Humans Exposed to Cold

Exposed to cold, the human body maintains its temperature by using muscle as a generator of heat. Remember that muscle is a thermal aerobic machine, which transforms chemical energy, by low temperature combustion of fuel with oxygen, into mechanical and thermal energy.

Under the usual conditions of muscle activity, the thermodynamic yield of human muscle is approximately 15 to 20%, i.e. at least 4/5 of the energy consumed is transformed into heat. In the cold, a specific activity develops; it involves making the muscle work at a thermodynamic yield of zero, that is, all energy is transformed into heat without production of mechanical energy. This activity occurs in the form of muscle twitching, the "thermal shiver".

The thermal shiver is the mechanism used by human beings to produce heat when it is exposed to duress by the cold. It is a muscle activity devoted solely to the production of heat. The maximum muscle power developed by the thermal shiver is limited, about five times the base metabolism during a short time period.

The human body develops another physiological response to fight against the cold: peripheral vasoconstriction. The blood vessels in the skin constrict, thereby reducing blood flow, which limits the cooling of the body.

Physical consequences of exposure to cold

In the cold, the following two physical concepts should be remembered:

- Heat exchange is made by convection in the surrounding fluid; at the same temperature, they are 26 times higher in water than in air; even if the air is cold, it is urgent to get out of the water;
- They are strongly increased by the relative displacement of the body in relation to the fluid.

We recall that:

- 90% of the bodies of water on the planet are at a temperature less than 25°C;
- From the standpoint of tolerance by an average subject immersed in water for a short duration, the water is cold below 28°C.

Physical consequences of exposure to cold: Hypothermia

Hypothermia appears when the heat loss is greater than the heat the body can produce. It occurs in two privileged circumstances of wrecks: in water or in the mountains.

Hypothermia is gradual. After a stable phase, the temperature begins to decrease, more and more quickly. Thermal shivers are maintained at their maximum level until a central temperature of about 35°C and then, if the cooling continues, it rapidly decreases until the body temperature reaches 30 to 33°C and disappears. It is replaced by muscular stiffness, which continues up to 27°C.

Hypothermia is accompanied by a significant cardiac and neurological symptomatology. A risk of serious heart rhythm disorders appears below 33°C. Consciousness is altered between 35 and 34°C. Unconsciousness appears around 30-31°C. In the strict sense, the hypothermic subject passes away.

Operational data

- To have the best chances of survival, you must get out of the water as soon as possible.
- The role of the life raft (in aviation transportation, this role is played by the evacuation slides) is not to prevent drowning, this is the role of the life jacket, but to prevent hypothermia; even if the air is cold, the loss of heat in the air is always less than what it is in the water.
- Cover yourself with all available layers of clothing.
- If you cannot get out of the water, your best chance of survival is absolute immobility; if you are stranded with several others, group yourself and tighten yourself against each other to minimize the heat exchange surface with the water.
-

"Stay motionless": let us comment on this point, which goes against some of our a priori; swimming considerably increases heat loss; the heat it provides comes of metabolic energy, i.e. muscular activity is inevitably limited in the time for a given force.

All calculations and all observations show that, without even considering the hypothesis of muscle exhaustion, swimming negatively impacts the heat balance of the subject in comparison to immobility.

Summarizing how to deal with the risk of immersion:

- If you can, clothe yourself with all available clothing before entering the water;
- In the water, especially, do not swim (except if you are absolutely certain that you have only a few meters to go);
- As soon as possible, get out of the water (life raft or whatever is available).
-

1.8 - Takeoffs

1.8.1 - Definitions

The displacement, speed and acceleration are the magnitudes of the mechanical systems oriented in space. They are represented by vectors. The displacement is the basic data, the speed is the derivative of the displacement compared to the time and acceleration (γ), the derivative of speed.
If the displacement (X) is expressed as a function of the time, the successive derivatives are expressed by:

$$x = f(t) \qquad v = \frac{dx}{dt} \qquad \gamma = \frac{dv}{dt} = \frac{d^2x}{dt^2}$$

1.8.2 - Units

The units used are, as always, a mixture of units from the International System (SI) and units used in the aviation culture. The most frequently used are indicated in Table below).

Physical Size	Displacement	Speed	Acceleration
International System (SI)	Meter (m)	Meter per second ($m.s^{-1}$)	Meter per second, per second = meter per second squared ($m.s^{-2}$)
Common Units		km/h, mph	
Aeronautical Units	Nautical mile (NM)	Knot (1 NM/hour)	"G" (= 9.81 $m.s^{-2}$ = 32.2 $ft.s^{-2}$)

Principal units of measure.

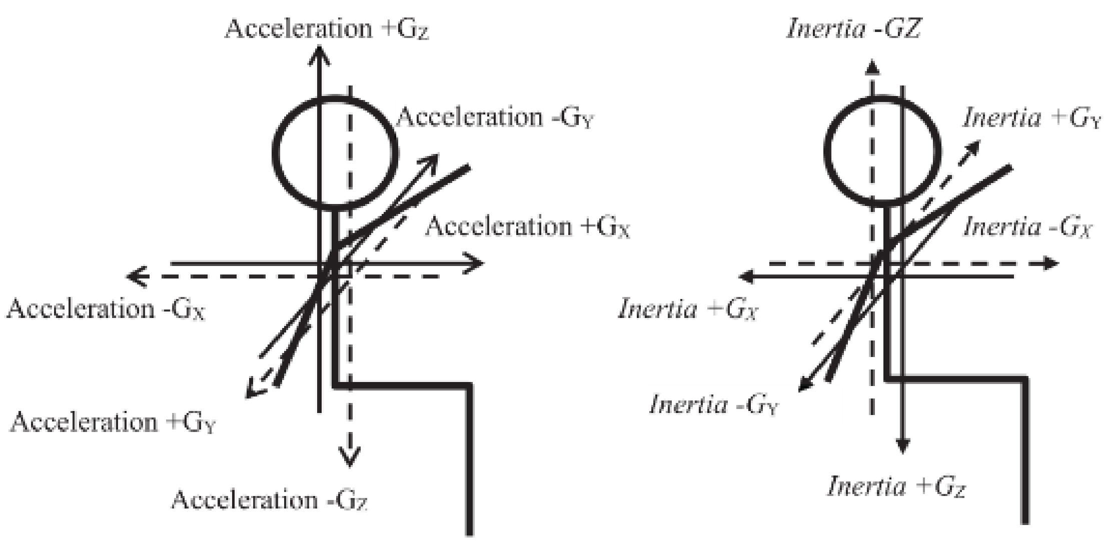
About the "G". The legal unit of acceleration, $m.s^{-2}$ (meter per second, per second, or "meter per second squared"), is not very intuitive. The practice is made to compare the acceleration of something movable to that which is due to the Earth's gravity, which we are familiar with in our everyday lives.

It is referred to as "1 G", and its measurement, in the International System, is equal to 9.81 $m.s^{-2}$. The figure of 9.81 is often rounded to 10: **1 G = 10 $m.s^{-2}$.**

1.8.3 - Classifications

Takeoffs encountered in aeronautics and space can be classified according to their axis, type, duration and speed of application.

a) According to the Application Axis: X, Y, and Z axes (Figure below)



Definition of acceleration and forces of inertia according to their axis of application. Note that the force of inertia is brought by the same axis as acceleration, but it is in the opposite direction.

- The major axis of the body (axis of the vertebral column) is designated by the letter Z; acceleration G_Z is positive when it is exercised in the direction of the headrest; the forces of inertia are exercised against the headrest. In humans, the G_Z vertical axis is also the one with large blood vessels.
- The lateral axis of the body is designated by the letter Y. The acceleration G_Y is positive when it is directed in the left-right direction.
- The anteroposterior axis of the body is designated by the letter X. The acceleration G_X is positive when it is directed in the back-front direction.

b) According to the Type: Linear, Angular or Radial

Linear Acceleration Applied according to a straight line (all vectors are collinear); it is typical in the takeoff/landing of the aircraft.

Angular Acceleration Body rotation; some tight aerobatic maneuvers, or tumbling after ejection (spinning of aerodynamic origin), causing this type of acceleration.

c) According to the duration of application: Long or short duration

Acceleration of short duration. Acceleration in which the duration of application is less than one second.

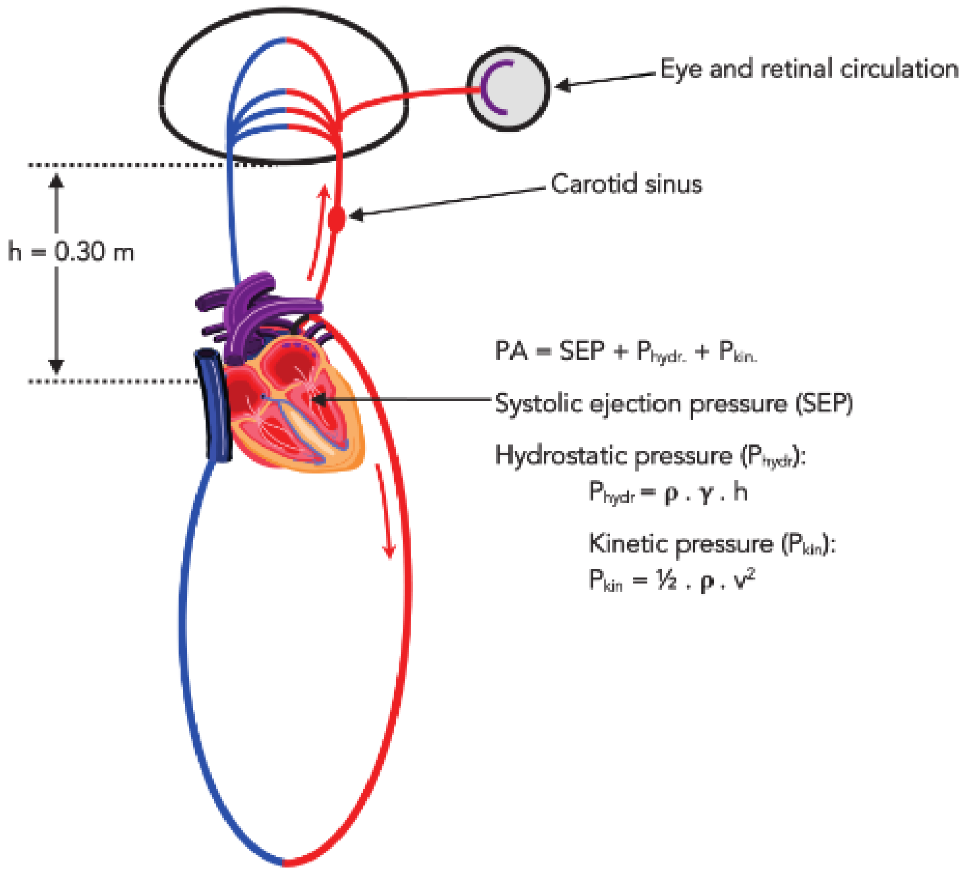
Acceleration of long duration. Acceleration in which the duration of application is greater than 5 seconds.

1.8.4 - Subjective effects of acceleration + G_Z

At 1 G: Usual sensation of terrestrial gravity.
At 2 G: Sensation of moderate compression on the seat, sensation of heaviness of the head and members, difficulty in moving.
At 3 G: Sensation of great heaviness of the members and body, the inability to walk; between 3 and 4.5 G: possible appearance of the gray veil.
Between 4 and 5.5 G: appearance of the black veil.
Between 4.5 and 6 G: risk of losing consciousness.
From 6 G: it is no longer possible to mobilize the head; it should therefore have been placed in the desired position before the application of acceleration;
From 8 G: it is no longer possible to move the members; only the extremities retain acceptable mobility.
Due to the forces of inertia, soft tissues are stretched in the direction of the forces of inertia. Facial deformation is characteristic.

1.8.5 - Cardiovascular effects of acceleration + G_Z: Hydrostatic hypothesis and its consequences

The description of the main effects of acceleration (gray and black veils, loss of consciousness) is based on the diagram of Figure below.



Very simplified functional diagram of the blood circulation.
Two vascular loops from the heart; one irrigates the upper part of the body, including the brain and eyes, and the other irrigates the lower part of the body.

At any point along an artery, the total pressure of the blood inside the artery (blood pressure: P_A) is described as the sum of systolic ejection pressure, hydrostatic pressure and kinetic pressure.

a) Systolic Ejection Pressure

The systolic ejection pressure (SEP) is provided by the contraction of the myocardium. This is the usual arterial pressure ("blood pressure"), which is expressed in pascals for consistency in calculations. Its average value is 16 kPa (12 cmHg).

b) Hydrostatic Pressure

Hydrostatic pressure (P_{hydr}) involves the column of blood, between the output of the heart and the brain. It is calculated as the product of three terms: fluid density (ρ), gravitational acceleration (g) and height of the hydrostatic column (h).

If all the values are expressed in SI units, the pressure is expressed in pascals.

Under normal gravitational conditions on Earth, the density of blood is similar to water, approximately 10^3 kg.m^{-3}, gravitational acceleration is 10 m.s^{-2} and the height of the heart-brain blood is 0.3 m; the difference of hydrostatic pressure is thus equal to 10^3 x 10 x 0.3 = 3 000 Pa = 3 kPa.
In aeronautical practice, this figure is multiplied by the load factor.

c) Kinetic Pressure

The kinetic pressure (P_{kin}) is due to the speed of the blood inside the vessel. It is equivalent to the "Badin" effect in the air. Under the normal conditions of resting blood circulation, its value is less than 1 kPa and can be disregarded. In contrast, it is important in the case of strong cardiovascular stimulation, which is the case under a high load factor.

Toward the lower part of the body, the blood mass moves in the direction of the forces of inertia and blood accumulates in the veins of the lower limbs.
It results in a decrease in the return of blood to the heart and a concomitant decrease in the pressure of systolic ejection, which results in a decrease (undesirable here) of cardiac activity.

Under a load factor, despite the cardiac inhibition due to the decrease in venous return, the heart is stimulated by powerful reflexes. It results in a significant increase in heart rate and blood pressure, quite similar to that observed during physical exercise.

In terms of aeronautical fitness, the exposure to acceleration + G_Z of long duration is equivalent to a maximum stress test (or physical exertion).

1.8.6 - Gray veil, black veil

The gray veil ("gray-out") is interpreted as the restriction of blood flow to the periphery of the retina and its decrease in the central part.

In terms of symptoms, due to the disappearance of circulation and the peripheral retinal function, results in a narrowing of the peripheral visual field; the subject no longer sees throughout the normal field of vision.

We observe, due to the alteration of circulation and central retinal functions:

- A decrease in the chromatic sense (color vision), ranging to its total loss; the subject then sees in black and white; this is the "gray veil'' concept;
- A decrease in visual acuity (fuzzy scene);
- A decrease in light perception (darkening of the scene).

These different symptoms are summarized by the image of the tunnel filled with fog (narrowed field of vision; blurred, darkened and discolored vision).

The black veil (" black-out") describes itself very simply; it accompanies the complete restriction of blood flow to the retina, with the entire loss of vision.

1.8.7 - Consciousness disorders and loss of consciousness

Consciousness is altered by the decrease in cerebral circulation. At the most, it is the loss of consciousness, thus: disorders or loss of consciousness.

a) Consciousness Disorders

Consciousness disorders are described as the appearance of a state of "confusion", involving a certain degree of spatial disorientation and impairment of judgment. In the English language, they are described under the name of A-LOC (Almost G-Loss Of Consciousness, "quasi-loss of consciousness").

b) Loss of Consciousness

The loss of conscience due to acceleration + G_Z, or "loss of conscience under load factor", occurs on average at 0.5 G after the emergence of the black veil when acceleration is established slowly, or without prior symptoms when the acceleration is established quickly. Its characteristics are the following:

- It occurs after the gray or black veils, or without prior symptoms;
- It *can* be totally ignored by the subject, who may have no recollection of it;
- On the contrary, it *can* leave the memory with visual or auditory hallucinations (ringing sounds, bright spots in the field of vision);
- The subject may have convulsive movements of the members or head (but this is not epilepsy);
- The episode of loss of consciousness *can* be followed by a period of anterograde amnesia (amnesia of the minutes, or even hours, preceding the loss of consciousness).

During a sudden acceleration, the loss of consciousness is defined by several phases:

- A latency phase, for approximately 5 seconds, explained by the fact that the neurons can continue to function for a few seconds after the interruption of the oxygen supply;
- Then, an unconsciousness phase in the strict sense (absolute incapacity), during an average of 15 seconds (extreme values are between 5 and 20 seconds);
- Finally, a phase of relative incapacity, characterized by a state of temporal and spatial disorientation (in plain language, the subject no longer knows where he is), including the average duration is also approximately 15 seconds, with values ranging between 1 and 50 seconds.

c) Tolerance of accelerations + GZ of long duration

Tolerance is based on passive untrained subjects according to Table below.

	Gray veil	Black veil	Loss of consciousness
Average value	4.1	4.7	5.4
Minimum value	2.2	2.7	3.0
Maximum value	7.1	7.8	8.4

The thresholds of appearance for the gray veil, black veil and loss of consciousness.
Note the significant deviation between the extreme values.

The physiological state of the subject modifies his tolerance to accelerations, particularly all the factors that mobilize the blood volume. It is necessary to give greater importance to three of them:

- Heat: The fight against heat requires a strong increase in the blood flow of the skin, largely conflicting with that used under acceleration;
- Dehydration, which decreases the circulating blood volume;
- Digestion, which moves a part of the blood flow toward the digestive tract.

Hypoxia experienced at high altitudes aggravates the cerebral hypoxia of a circulatory origin. This combination is uncommon in sports and recreational aviation, but it was observed in fighter jet aviation.
From an applied standpoint, note the incompatibility between digestion, the fight against the heat and the tolerance to acceleration + G_Z of long duration. Actually, any of these three factors require a specific circulatory adaptation, which the body may not necessarily be able to handle at the same time. This combination is responsible for fatal accidents.

1.8.8 - Protective Measures against Acceleration + G_Z

The protective measures against acceleration + G_Z are composed of active methods (manoeuvres, centrifuge training for personnel) and passive methods (anti-G equipment, tilt of the seat, overpressure respiration).
Military aviation takes into account the protective measures to counter acceleration. The doctrine of civil aviation is non-existent in this area. We will therefore only describe the methods available in civil aviation (recreational or competitive aerobatics).

a) Musculo-Respiratory Maneuvers

Head turned into the shoulders and leaning forward, lower limbs raised (to decrease the height of the hydrostatic column), voluntary contraction of the muscles of the abdomen and lower limbs (to increase the return of venous blood to the heart), rapid and deep inhaling and then heavy exhaling, either with a semi-closed glottis (grunting), or with a closed glottis (so-called Valsalva manoeuvre to voluntarily create an intrathoracic overpressure); the ventilatory component of the manoeuvre must be repeated every 3 seconds. The protection provided is approximately 2 ± 0.5 G.

1.8.9 - About the physiological effects of acceleration – G_Z

Acceleration - G_Z is relatively poorly tolerated, but this is not the essential. Actually, they cause a reverse cardiovascular adaptation for what is required to tolerate the acceleration + G_Z. Therefore, the problem that they pose is successive accelerations - G_Z and then + G_Z (in this sense); this is the push-pull effect (handle action; nose down / nose up).
During the minute that follows an acceleration - G_Z, loss of conscience can be observed as early as + 2 G_Z.

02 NEUROSENSORY SYSTEM IN HUMANS

2.1 - General Information, Definitions, Anatomy Basics

2.1.1 - Neurosensory System

The neurosensory system acquires information from the outside world, transmits it to the nervous system and processes it within the nervous system itself. The nervous system sends a response back to the outside world, generally in the form of a motor system action.

The motor system action is regulated; the motor action resulting from the order of the nervous system is measured by a feedback loop, with a view to its fine adaptation. This means that the motor system is itself also a sensory organ.
At the risk of being a little complex, we cannot overlook this return action, because it contributes to the genesis of certain sensory illusions.

2.1.2 - Senses of the Human Body

The traditional teaching speaks of "Five Senses"; it is a bit simplistic. The analogy with the number of fingers on the hand probably has something to do with it. These "Five Senses" are well known: Sight, hearing, touch, taste and smell.

This list is not complete, because leaves out the entire group of functions related to orientation in the field of gravity. In addition, these functions are complex and cannot be summarized in a single word; for example, touch includes sensitivity to pressure, temperature, local gradients of these different perceptions, etc.

Let us go into a little detail in particular with equilibrium, itself complex and "somesthesia" (in Greek: soma (body) + aesthesia (perception); "sensory perception of bodily feelings"), a function that consists of sensors located in the skin, muscles, tendons and joints.

2.1.3 - Nerves

Nerves are nerve extensions that connect:

- Nerve centers on the periphery (sensory nerves or efferent nerves);
- Or the periphery to nervous centers (motor nerves or afferent nerves).

Note that, in reality, this distribution is not pure. Only a few very specific nerves are purely sensory or purely motor. In general, a "nerve" is a common duct, which brings together various sensory and/or motor contingents.

2.1.4 - Neurons, nerve impulses and synaptic transmission

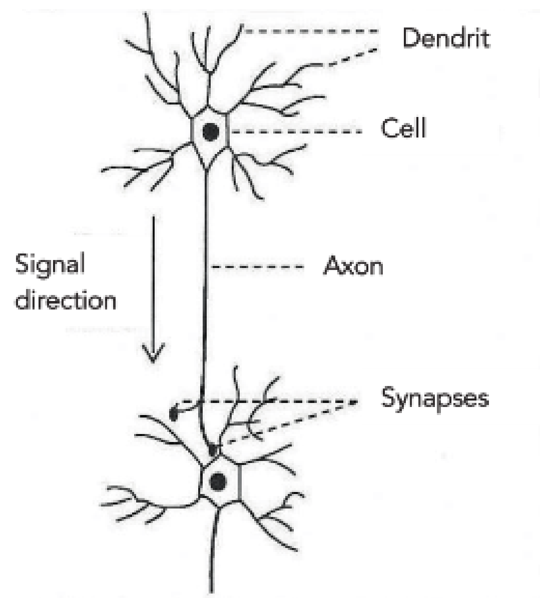
Neurons are the functional cells of the nervous system, central or peripheral. The nervous system contains other cells, but these have only one role of logistic support.

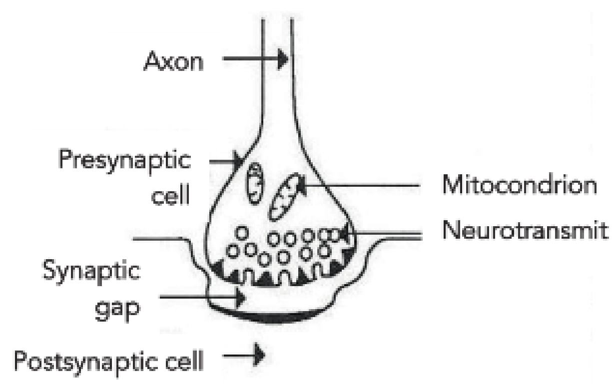
The neurons are excitable cells. They are composed of a cell body and several ramifications.

One of these ramifications, which may itself be subdivided, is the path of neuron; it is referred to as an axon. Other ramifications are called dendrites; the walls of the cell body and dendrites receive the information transmitted by the axons from other neurons.

With few exceptions, the transmission of information from one neuron to another does not take place electrically, but chemically. The neuron upstream is separated from the neuron downstream by a space, the synaptic gap.
It releases a small quantity of a specific chemical substance, the neurotransmitter, which causes a change in the receptor membrane downstream. Some of these neurotransmitters, or products similar to the neurotransmitters, are well-known; they are used in human therapeutics, e.g. for the treatment of Parkinson's disease. Others are subject to a less desirable use, because they are the basis of combat gas or illicit narcotic drugs.

The following two figures (extracted from the book *Physiologie humaine* (in English, Human Physiology), edited by Hervé Guénard) represent the neuron and the synapse (Figure below).





Neurons and synaptic transmission.

The function of the synapse on a chemical mode, confers to the transmission of information the character of polarized transmission; the latter can only be made in one direction.

Each neuron receives a large amount of information. Within the central nervous system, the unit stimulation of a neuron is generally not enough to excite it. Among the stimulation received, some are exciters, others are inhibitors, and still others are "facilitators". The release of each neuron therefore corresponds to the integration of multiple stimuli.

The transmission of information to the muscles is made according to the same process: a "motor" axon from a large neuron of the spinal cord comes in contact with a muscle fiber. The excitation is then direct, and always in chemical form. Curares suppress synaptic transmission of the axon to the muscle. They lead to paralysis of the muscles, and death by paralysis of the respiratory muscles.

The synapse is a real chemical micro-factory, which requires energy. Note in the right part of Figure "Neurons and synaptic transmission" under Paragraph 2.17, the presence of mitochondria.
These intracellular organelles, present in all living cells, are specialized in providing energy to the whole cell, through a strictly aerobic chemical process.

The absence of oxygen immediately degrades the energy of neurons and synaptic transmission processes; we have an immediate connection with the study on the consequences of human exposure to altitudes.

Nerve impulses

The excited neuron emits a signal in the form of propagated changes to the structure of the cell wall.
The nerve impulses correspond to a sudden change in the chemical structure of the cell wall.

From the excitation area, the impulses spread gradually with a variable speed according to the neurons, from approximately 1 to 30 m/s.
After the passage of nerve impulses, the wall is replenished using an aerobic energy process.

2.1.5 - Reflex concept

Position a subject seated on the edge of a table, legs dangling. Tap on the patellar tendon with our "reflex hammer" (just below the knee joint, in the hollow between the tibia and kneecap) and we will observe an almost instantaneous contraction of the quadriceps
The percussion of the patellar tendon was perceived by the body and triggered an automatic reproducible response. Fundamentally, the reflex is the physiological mechanism that is technically known as "regulation". These two concepts, reflex to biology and regulation in engineering, are isomorphic.

In the case (single) of the patellar reflex that we have described above, the percussion of the tendon causes its sudden elongation, not desired by the central nervous system; the latter restores the structure to its programmed length through a rapid contraction. This is one of the most simple elements, a vast set of regulating elements intended for the maintenance of posture and the preparation of the body for movement.

We previously discussed other "reflexes": those for maintenance of P_aO_2 and P_aCO_2 (p. 30), or maintenance of blood pressure.

The body perceives information (e.g. chemical, mechanical, thermal…). This information is compared to a regulation, fixed or adjustable according to the circumstances. The nervous system deduces an error correction in the appropriate form.

Therefore, we also speak about "reflex" to describe both the lengthening of muscles (the patellar reflex described above) and regulation of blood sugar (rate of sugar in the blood), temperature, or large quantity of hormones. There is a very broad group of regulations for the body, which allows it to maintain its optimum state of functioning, both under static and dynamic conditions.

For the reader: Awareness of these regulation mechanisms date back to the 19th century, with the decisive contribution from the great French physiologist Claude Bernard. He defined the concept of ''internal environment'' (''milieu intérieur" in French), a sort of inner sea, specific to each body, in which the cells of the body are immersed.

Our regulations constantly maintain the chemical characteristics of the inner environment within the acceptable limits, regardless of the characteristics of the "external environment". They enable the functioning of our various organs. The aeronautical environment is an excellent example of the "external environment", which can exceed the adaptation capacity of our regulations. The concept of the internal environment joins homeostasis.

2.1.6 - Basic Neurosensory Functions: Sensitivity, Threshold Effect and Adaptability

The various sensory systems show common functioning characteristics, referred to in the title of this paragraph: Sensitivity, Threshold Effect, and Adaptability.

a) Sensitivity

Sensitivity is the relationship that exists between the physical input signal and sensory perception, with the same meaning as when this word is technically used (physical sensor sensitivity).
The sensitivity figures will be indicated for each sense studied. The sensitivity of a physiological sensor is often expressed on a logarithmic scale of base 10; Weber-Fechner Law, set out in the middle of the 19th century (for acoustics) indicates that perception increases to one when the physical power of the signal is multiplied by 10. Based on this law, the concept of bels and decibels became well known not only in physiology, but also in many technical fields.

b) Threshold Effect

The threshold effect characterizes a number of sensory perceptions. It may be very limiting (including: possible sensory illusions).
In the same way that a physical sensor (e.g. altimeter) may remain at zero as long as the signal has not reached a certain value - a characteristic of non-linearity -, a physiological sensor may not issue any information to nerve centers as long as the stimulation remains below a certain value.

Examples of threshold effects:

- Auditory perception starts at a power of 10^{-16} $W.cm^2$ (this is the zero of the logarithmic scale for auditory perception, i.e. the audiogram);
- Light perception;

- Perception of rotations by the vestibule (inner ear); the threshold effect can be at the origin of dreadful sensory illusions (we will develop this subject in the corresponding chapter);
- Skin perception;
- Etc.

c) Adaptability

Adaptability is a characteristic of certain nerve centers.

d) Other Properties

Our body is mainly sensitive to the derivative of a signal: Actually, what we perceive as better, this is not the stabilized value from stimulation, but from its variation in time and/or space.

Example: Auditory perception
We perceive a continuous noise; unless it is totally deafening, we "erase" it fairly quickly.
To compensate for this "erasing", emergency vehicles are equipped with sirens that modulate both the frequency and intensity; it is impossible to "erase" them and thus they maintain their alerting power.

A more common example of this nervous system property in aeronautics is the perception of rotations, which can fade. The risk of sensory illusions is major.

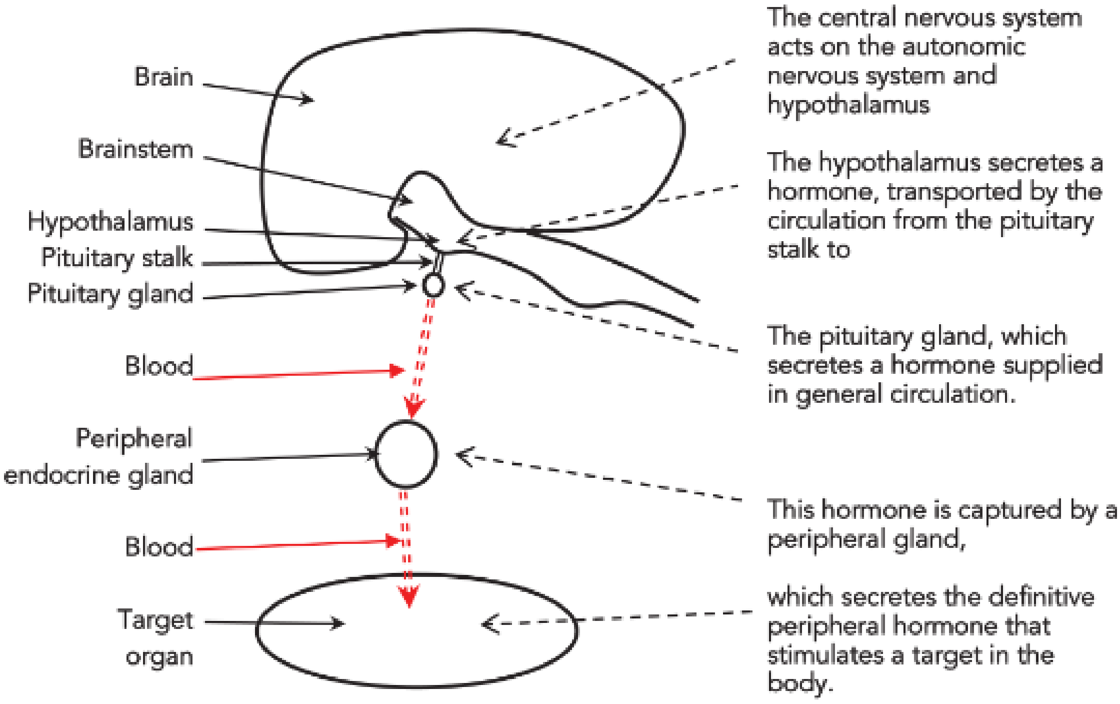
2.1.7 - Neurohumoral System

The discovery of physiology was made in stages. The 19th century witnessed the description of two major integration systems of the body: the nervous system and the endocrine (or hormonal) system; the link between the two was not established, until the second half of the 20th century.

Recall the concept of hormones and the endocrine gland: an "endocrine" gland delivers its secretion inside the body. This secretion is a "hormone", which has signal value to stimulate other organs.

The most well-known endocrine glands are the thyroid, located at the front of the neck and which secretes thyroxine, the adrenal glands, positioned above each kidney and which secrete cortisone between one another, the endocrine portion of the genital glands, ovaries and testes, the endocrine portion of the pancreas, which secretes mainly insulin and glucagon (regulation of blood sugar - rate of sugar in the blood).
The neurohumoral system involves the endocrine system from the central nervous system.

In the center of the head, there is a specific area of the brain called the hypothalamus, which is directly related to an endocrine system gland, the pituitary gland (hypophysis). The pituitary gland has two types of secretion, the endocrine ones intended for all of the body, and others specifically intended for other endocrine glands.
In this latter case, the pituitary gland plays the role of amplifier relay between the central nervous system and endocrine system (Figure below), with regulation at each stage of amplification.



Functional diagram of the neurohumoral system.

For the reader: Without this presentation of one of the greatest discoveries of the late 20th century… and the official program seems to be "zapped". Our body has not two but three major integration systems, the third being the immune system. Having been discovered in the 1980s, receptors located on the immune cells, sensitive to a number of hormones, particularly those that are produced by the adrenal glands.

Therefore, we have a series of two links:

- Nervous system → endocrine system;
- Endocrine system → immune system.

2.1.11 - Homeostasis

The endocrine system plays an essential role in maintaining homeostasis, i.e. maintaining set values for a number of parameters of the body. The word homeostasis means "maintaining at a constant value".

Each of the endocrine glands delivers its secretion according to the parameter value in question. For example, the pancreatic endocrine system secretes two hormones: one is the insulin, which causes a decrease in the rate of glucose in the blood, the other is glucagon, which causes the opposite action. The secretion of these two hormones depends on the rate of glucose in the blood. This is a complex controlled system, because the glucose is a fuel for the body and its flow must be instantly adapted to the needs.

2.2 - Vision

Vision is a sensory function, which includes a sensor, the eye, and an information processing organ, the brain. Therefore, vision is not limited to the model of a photographic camera; it is an intelligent system, which captures information and processes it according to the context, past and present.

In this "image processing", a part of the process is local, in the eye itself, and the rest is distributed within the nervous system. Since the conditions of the environment change, software may no longer be suitable; the passage from the terrestrial surface environment to the aviation environment can generate serious errors in mental representation of the image.

2.2.1 - Physical reminder: convergence, divergence, and measurements in diopters

A lens is the convergence of light rays on a specific point. The power of convergence is expressed in diopters. The diopter is expressed as the inverse of the distance of convergence: If the convergence occurs at a distance of 1 meter from the optical center of the lens, the power of the lens is 1 diopter. If the convergence occurs at ½ m (50 cm), the power is 2 diopters, at 1/3 m (33 cm), 3 diopters, etc.
Unlike a converging lens, a diverging lens makes an image appear from the infinite as if it came from a specific point, located behind the lens. The measurement of this lens in diopters is based on the same principle.
The power of a converging lens is expressed by a positive number of diopters. The power of a diverging lens is expressed by a negative number of diopters.

The purely optical portion of the eye has been excellently modeled by the photographic camera, which include various concepts that can be used in analyzing the optical part of vision. For this purely optical part of vision, the whole point is to bring the exact image from the outside world to the photoreceptor (retina), regardless of the distance of the stationary object.
The eye that correctly fulfills this function is called emmetropic ("for proper measurement"). In the opposite case, it is called ametropic ("without measurement").

2.2.2 - Anatomy Reminders

The visual system is comprised of two eyes, information conduction pathways and nerve centers. The eyes are animated by their external muscles.

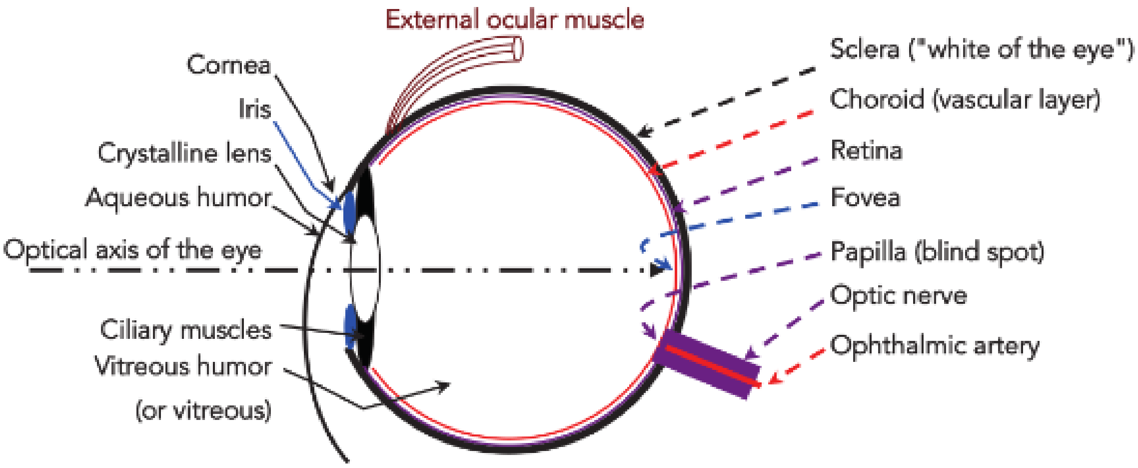
The photosensitive part of the eye (Figure below) is composed of a thin membrane of specialized nervous tissue, the retina, which lines the back of the eye. The latter consists of several parts:

- The protective shell of the eye is the sclera, better known by its common term, the "white of the eye";
- The sclera is open toward the front by a surface transparent to rays, the cornea;
- The choroid is an internal membrane in the eye; it ensures circulation to the retina, as well as a black pigment that gives the eye its dark room characteristic;
- Behind the choroid is the retina.

In the axis of the cornea, we find:

- The iris and, in its center, the pupil, through which the light rays penetrate;

- Then the crystalline lens, which is a lens with adjustable convergence; It is therefore equipped with its own muscle; under tension by the ciliary muscles, the crystalline lens is the organ of accommodation, whose function allows the optical system of the eye to focus on the image, regardless of its distance (in a well-defined range); the function of the crystalline lens of the eye is fulfilled by the autofocus of a camera.



Anatomy of the eye, cross-sectional view.

The cavities of the eye are filled with transparent substances: aqueous humor between the cornea and the crystalline lens, and the vitreous, or vitreous humor, which fills the posterior chamber of the eyeball.

The eye is sensitive to light radiation of a wavelength between 397 and 723 nm (0.397 and 0.723 micron).
The converging power of the eye is provided mainly by the cornea and by the aqueous humor, for approximately 48 diopters. The total diopter power of a normal eye is 60 ± 2 diopters on average. The accommodation of the crystalline lens allows for a gain of 10 to 12 diopters.
The amount of light that enters the eye is regulated by the diameter of the iris (this is the function of the diaphragm of a camera). In addition, the neurosensory system itself can adapt its sensitivity to the quantity of light received. All of these mechanisms, mechanical and neurophysiological, constitute adaptation.

The visual information is collected and undergoes a first processing in the retina itself, which issue from the fibers collected within the optic nerve.
The eye receives its blood circulation from the ophthalmic artery, which penetrates in its posterior chamber. The ophthalmic artery is a branch of the internal carotid artery. After penetration into the eye, it assumes the name of central retinal artery. Then, it is divided progressively and concentrically to the periphery of the retina. Conversely, the blood is collected by the veins according to a symmetric diagram.
At the inside of the eye, the common emergence of the artery and nerve is made in the papilla; devoid of retinal tissue, it constitutes a blind spot (also called a Mariotte blind spot). In binocular vision, there is no blind area which is why, under normal conditions of life, piloting included, the existence of this "blind spot" has no importance.

Highlight the blind spot:

Close your left eye and focus on the cross (only the cross) with your right eye, and then bring this page to approximately 30 cm from your face and move it gradually closer. There is a certain distance at which you will no longer see the circle. Continue to move the sheet closer to your face, and then the circle will reappear. This time make the symmetry observation with your other eye by focusing on the circle; you will observe the temporary disappearance of the cross from your field of vision. External ocular muscles surround the eye and ensure its mobility in the horizontal and vertical planes, as well as a certain degree of mobility in axial rotation.

2.2.3 - Retina

The retina is a thin sheet that lines the internal face of the envelope of the eye. It receives the light information and transforms it into nerve impulses, in the direction of the brain.

The retina is composed of a large number of photoreceptors, of which there are two types, designated according to their appearance in the microscope: cones and rods.

- The cones number between 5 million to 7 million. Most of them are located in close proximity to the optical axis, in a narrow area of the retina, called the fovea. Their sensitivity to light is not very high, but their density is high, which allows you to perceive details.
- There is a specialization of the cones according to the colour. The perceived colours are red, green and blue. The fovea is the central area of vision, during the daytime; it provides visual acuity and perception of colours.
- The rods number approximately 130 million. They are almost absent from the fovea and are divided up to the periphery of the retina, with a maximum density at 20° of eccentricity. After adaptation, they are very sensitive to light, which allows perception under low light conditions, or during nighttime. By contrast, they do not provide a proper differentiation (nighttime visual acuity is poor, with colour blindness).

Transmission of visual information to the brain

Light information captured by the retina is subject to an initial processing - the retina is therefore not only a photoreceptor plate as in the example of a camera. The information is collected by the optic nerve. The left and right optic nerves join at the base of the skull, behind the eyeball area. They form the optic chiasm, designated as such due to its X-shaped structure (the Greek letter Chi). The optic chiasm receives information from the two retinas, then distributes outgoing information according to their laterality; the two right halves of each retina are directed to the left cerebral hemisphere, and the two left halves of each retina are directed to the right cerebral hemisphere. Then, the information travels in a complex way toward the occipital lobes of the cerebral hemispheres, in the extreme rear part of the skull.

2.2.4 - Visual functions

The functions of the central retina (cone area) are visual acuity, on which reading depends, depth perception (in part) and colour vision.

The peripheral retina allows lateral vision (peripheral) and nighttime vision.

a) Visual Acuity and its Disorders

Visual acuity is the separating power of the eye. It allows us to distinguish objects at a distance separated by a certain angular distance. Applied to complex objects, it allows us to distinguish them from one another and recognize them.
Visual acuity is a function of the central part of the retina, the fovea, from which we derive the equivalent denominations of central vision or foveal vision.

There are several methods of measuring it. It is morphoscopic visual acuity that is the most commonly used. It is measured using optotypes: letters, numbers, drawings. It enables the expression of visual acuity from 0.1 to 1.2 (in France), with this scale being derived from historical data.
TFP professionals must have a minimum acuity of 7/10 in each eye, and 10/10 in binocular vision, with required optical correction, where applicable (EU Regulation No. 2019/27 MED B.070 c).
Foveal vision ensures precise vision on an opening of 1 to 2° around the central point. At a normal distance from the passenger transport aircraft cockpit, this provides on the cathode ray tube screens a clear circle of vision of 2 to 3 cm in diameter.

Ametropia. Refraction disorders. In ametropia, the dioptric power of the eye is not a perfect match with the geometry of the eye. The image does not form exactly on the retina.

Emmetropia. Eye of normal optical power.

Myopia. The image forms in front of the retina; the optical power is too high; optical correction is obtained with divergent glasses.

Hypermetropia. The image forms in back of the retina the optical power is too low; optical correction is obtained with convergent glasses.

Astigmatism. The eye is not perfectly spherical (flattened on one of its planes). Necessary optical correction is obtained from toric lenses (toric = curve volume where the curvature radius varies depending on the axis; the Earth is a torus, flattened at the poles and inflated at the equator).

Presbyopia. Decrease, linked to age, of the optical performance of the eye. The crystalline lens is a flexible and adaptable lens, deformable under the effect of its specific muscle. The standard crystalline lens for the emmetropic adult allows adaptation between 20 cm and infinity. Aging is accompanied by a stiffening of the crystalline lens, which loses its flexibility. This process annoyingly appears on average at the age of 45 years. Presbyopia is corrected by a set of corrective glasses: bifocals or trifocals, progressive lenses; it usually focuses up to 2 to 3 diopters.

Of course, the same subject may have myopia, astigmatism and presbyopia… Correction of ametropia is made using appropriate optical aids (glasses, contact lenses). The ametropic pilot must always have a backup set of corrective lenses on board (emergency glasses in the cabin).

Some additional details:

- The most recent European texts are complex (EU Regulation No. 2019/27 and AMC-GM to Part MED).
- Beyond the limits defined in these texts, recognition of fitness is made after a fitness "assessment" by the Authority (in France: Medical center of the Directorate General for Civil Aviation (DGAC)).
- The word "derogation" has disappeared from the official vocabulary.
- If necessary, the medical certificate bears a restriction or a limitation in the form of a trigram corresponding to the situation (VDL, VML, VNL - means of optical correction for farsightedness/midsightedness/nearsightedness). This restriction imposes by law, without it having to be specified, the obligation to have an additional pair of glasses in the cabin, and of the same power as the principal means of correction; the latter can be "normal" glasses or contact lenses.

- About Contact Lenses.

The optical correction provided by the lenses is good, except for presbyopia. The only problem posed in flight (commercial) for contact lenses is the dryness of the air during the flight at high altitudes; the cornea remains very dry under the lens and may cause unpleasant sensations. Suitable lenses or instillation of artificial tears are the means to mitigate this inconvenience. It may also be relevant not to wear the lenses continuously, in particular to remove them for sleeping.
Please note: There are contact lenses intended for presbyopia. Their use is not authorized for a TFP in flight.

Refractive surgery aims to modify the curvature of the cornea. It can give excellent results, but can also weaken the eye. With good results, it is compatible with fitness.

- Empty Field Myopia

Empty field myopia would be a tendency of the eye to return to a resting position, with a short distance focus (1 to 1.5 m). This concept has been used to explain the imperception of distant objects, traffic conflicts in the civil aviation or hostilities in military aviation.
In typical civil aeronautics practice, the field of vision is not empty; the instrument panel is sufficiently complex to stimulate vision.
By contrast, what is true is that the eye requires a few tenths of a second to go from one distance to another. After a phase of intensely focusing on the instrument panel, the perception of a distant object is not immediate - and vice versa. The same observation is true inside the cockpit, when the collimation distances are very different. For example, on a fighter aircraft going from reading head-down screens to head-up displays (HUD), which is collimated to infinity.
In the case of commercial aviation, the imperception of a distant object is probably not due to a history of "empty field myopia", but simply the time taken for the eye to adjust from viewing the optical systems to viewing a different distance.

b) Depth Perception, Distance Vision, and Binocular Vision

The estimation of depth and distance call for physical, physiological and cognitive mechanisms. It is realized in the course of landing.

Binocular vision is one of the modes to estimate distances. Both eyes are offset in the frontal plane and do not perceive the same image. The brain compares the two images received and derives information from a distance, relative or absolute.

The parallax movement may supplement binocular vision; an eye movement in the frontal plane changes the image, which the brain then interprets as before. The estimation of distances by parallax movement no longer calls for two simultaneous images, such as in normal binocular vision, but successively acquired images.

Accommodation is a mode of distance estimation. The focusing of the eye on an object cancels its blur. The effort of accommodation is measured by the nervous system, which calculates the distance. As a result, contrary to a received idea, the monocular subject (in current French: borgne…) is not necessarily a significant handicap in perceiving distance and terrain.

Binocular vision can be affected, either by using specific instrumentation, or because the physiological mechanisms of binocular vision are not satisfactory.
Under the term "specific instrumentation", we understand that there are various vision aids available to pilots, mainly night vision aids. Environmental information is captured and then transformed into a visible signal on a screen. Since humans focus their vision on the screen and not on the actual target, the accommodation is obviously lost.

Binocular vision is also lost on most of these devices; this last assertion is true, even when using "night vision binoculars," because the two night vision tubes are evidently not controlled by the natural movements of the eyeball. Moreover, if this equipment is used in a helicopter, while hovering at night, the parallax movement is also lost.

This function was studied during the recognition process of pilot fitness [EU Regulation No. 2019/27 MED B.070].

Cognitive mechanisms of distance estimation

- Effect of Perspective In a natural scene, the distance of objects is accompanied by two changes in their perception: the foot of the object rises in the visual field depending on its distance (its height increases in the visual field) and its size decreases.
- Colorimetry In a natural landscape, the colorimetric method gives a strong indication of distance. In the European atmospheric environment, at low altitude, the atmosphere is always more or less saturated with water vapor. The water vapor absorbs a portion of visible radiation and the distance of an object always leads to a degradation of its color, which fades into bluish colors with the distance (Illustration below). In other very dry environments, the purity of the colors of landforms can be seen at a great distance, which lead to large errors in the representation of distances.

Observe the gradual shading of colors in the blue-grays depending on the distance of the various planes.

Brightness and perception of details

An object of less brightness or blurrier than normal can be perceived as being at an excessive distance. This mechanism can be at the origin of illusions of distance in the fog or when the brightness of an object is less than normal. For example, if at night the runway is not as bright as usual, it may appear further than it is in reality.

The interpretation of shadows: In the natural environment, light sources are in a higher position. Under unusual conditions of illumination or position, these can generate interpretation errors for volumes. Note also that the images obtained from systems using night vision can cause this type of error.

The same image, rotated 180°. In one of the images, try to recognize the interpretations of the terrain that you could see in the other…

c) Color Vision

The cells of the retina called cones allow seeing in color. Three types of cones encode the three basic colors: red, blue and green.

Color perception overflows from the central vision and extends to the periphery. It does not spread in a homogenous way, which was shown by measuring a visual field for each color of the spectrum.

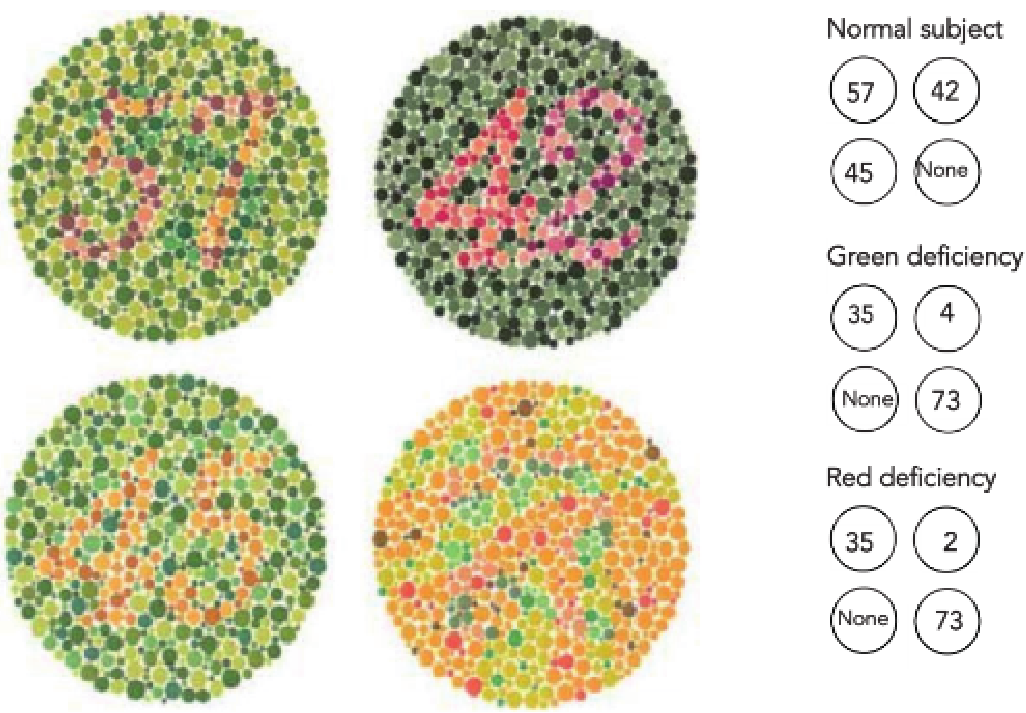
Color perception depends on the brightness of the object. At low intensity, any color is perceived as white, except the color red which remains red, hence its interest in signage.

Color vision disorders are known by the scientific name of dyschromatopsia or by its more popular name of Daltonism (named after the English chemist, John Dalton, who observed this disorder in himself).

Actually, there is a whole range of dyschromatopsias, according to the type of deficient cones and the significance of the deficiency.

Many tests have been devised to detect dyschromatopsias. In the aviation industry, the basic test is an Ishihara test.
This test consists of recognizing shapes; the shapes are composed of basic colored units in the middle of a page composed of colored elements. Those with a color vision disorder cannot distinguish the shapes at the bottom of the board (next figure).

Other tests exist that we will not discuss here; they allow possible retesting for pilot candidates who have failed the Ishihara test.



Examples of Ishihara vision test boards and their interpretation.

The "trick" is fairly simple to understand. Let us make the assumption about a subject who is totally deficient in perceiving the colour green. Let us fill three frames (Figure below); one with pure red, one with equal parts of red and green (which gives yellow) and the last one with pure green. Only seeing red, the subject will see the first two frames as identical in terms of colorimetry and thus could not distinguish them, and he will see the third frame in black and white.

Objects viewed by a normal subject — or by a subject withdyschromia (Green colorblindness)

- Wearing tinted glasses, including those with variable filtration, can change the perception of colors, as well as the ability to distinguish between certain colors. Pilots of aircraft with cockpits based on "glass-cockpit" technology must be aware of this problem.
- The tint of some lenses is light-adaptive according to the brightness of the environment. These glasses can also have a corrective function for those with ametropia; therefore, the pilot cannot do without them. However, the cockpit windows have their own filtering system for solar radiation, and in some cases, they do not reduce the rays as the pilot would like, either in time or in intensity of absorption. Their use requires basic common sense.

Do not forget that if the pilot must wear glasses, on the medical fitness record, he must have an extra pair of glasses in the cabin. If the light-adaptive glasses do not meet the desired form, the pilot always has the possibility to change glasses... Recommendation: The "extra pair of glasses" may be the most neutral and ordinary pair possible!

d) Glare

The photoreceptors in the retina, cones or rods function by transforming a specific chemical molecule under the effect of light. This means that each cell must continuously replenish its stock of chemical substrate. After exposure to a high intensity light, the cells may be unable to immediately resume their function; this is glare.
Glare is a global phenomenon. However, everyone also knows the phenomena of partial glare: stare at a bright object for a certain period of time in a dark environment, and then look at another scene. Then you will observe that your light field is reduced where it was exposed to the bright object, which is somehow seen as negative.
In everyday life, observing a television or computer screen can provide a good example of this mechanism. If the object viewed was very colourful, the scotoma (visual field deficit) appears in the complementary colour of the one that was viewed.

In aeronautics, the prolonged observation of a very bright object in the central vision can lead to a central scotoma, thereby reducing the perceptive ability of the eye. This effect is obviously very embarrassing in perceiving the environment.

Adaptation of the eye to ambient brightness: pupillary reflex
The eye has an effective and rapid, but not immediate, mechanism for modulating the amount of light entering the eye: the pupil. It dilates or contracts, under physiological conditions, depending on the amount of ambient brightness. This action is a reflex (regulation): pupillary reflex.

If multiple objects of very different brightness coexist in the visual field, adaptation is made according to the most luminous object. An object placed at a low angular distance from the sun cannot be perceived. This the typical tactic of fighter pilots: positioning oneself with one's back to the sun to blind the opponent when approaching head-on.

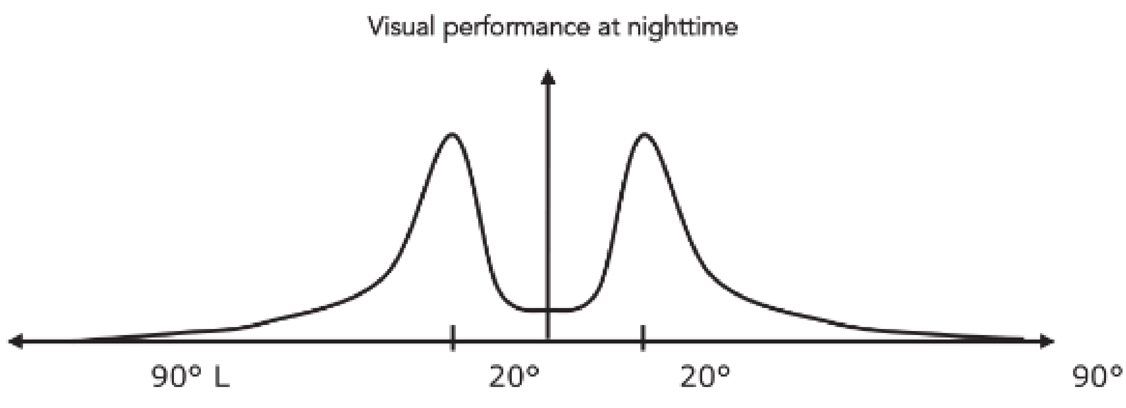
However, this does not only occur with fighter jets. Let us read the following experience, which requires no further comment. It is an extract from the BEA website.

In-flight collision, at 15:29 UTC, 23 July, between Geneva and Chambery.
[…] The D-EIBH flying with a heading of 225°, and the HB-CLW with a heading of 185°. Neither the student nor the instructor of the HB-CLW saw the D-EIBH on their left. There had been no avoidance maneuver […]. The sun was at azimuth 261, either at 36° to the right of the axis of the D-EIBH, for a height of 37°. It is likely that the height of the sun was low enough to obstruct the pilot […]
The D-EIBH crashed - two dead. Damaged, but flyable, the HB-CLW landed in Geneva.

e) Peripheral Vision and the Visual Field

The peripheral part of the retina occupies the greater part of the retina. The receptor cells of the peripheral retina are the rods. At approximately 130 million in number, their distribution is very characteristic (Figure below).
They are practically absent from the central part of the retina (fovea); their density increases rapidly to reach a maximum at 20° of eccentricity in relation to the optical axis of the eye, then their density decreases gradually up to the peripheral limit of the retina.

In addition, the number of rods connected to the same neuron increases with the eccentricity in the retinal field.
Visual acuity decreases very significantly with eccentricity. When visual acuity is 10/10 in central vision, it is 5/10 at 3° of eccentricity, 2/10 at 10°, and 1/10 at 30°.



Distribution of rods on the retina.

Peripheral vision is a vision for warning. It is particularly sensitive to *movement*. Side vision is a biphasic vision: the peripheral retina indicates a warning; the subject then directs the gaze to absorb the information in the central vision and analyse it in detail.

The visual field is the cone, centered on the eye, inside of which vision is possible. One can define a visual field eye by eye, as well as a visual field called "binocular", centered over all of the head.

It is not the same for white light and for each of the fundamental colours (the visual field specific to each colour is included in the visual field for white light).

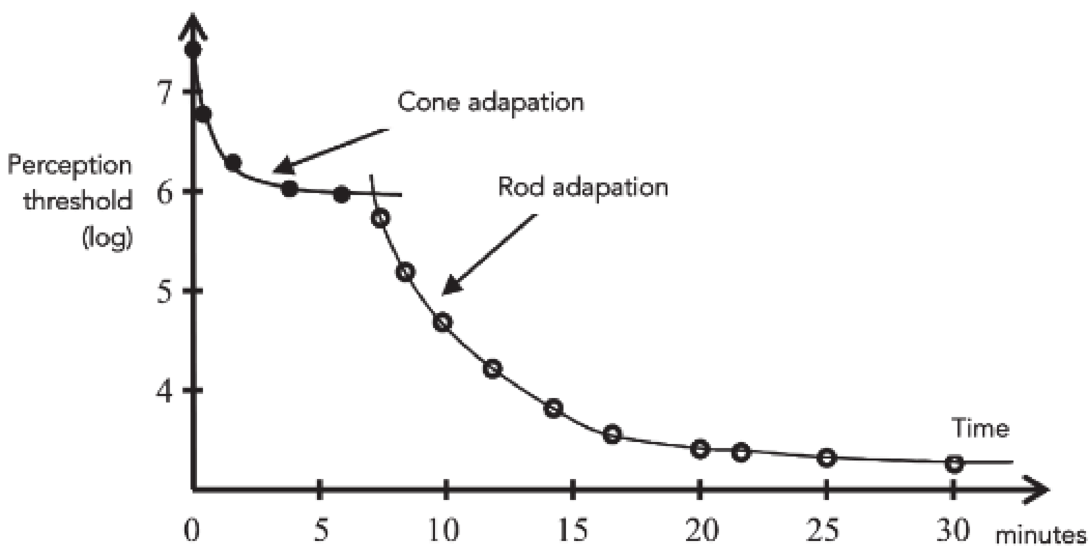
Alcohol and Peripheral Vision Peripheral vision is very quickly degraded by even a relatively low alcohol rate. Therefore, alcohol causes both a reduction of the peripheral visual field and the familiar overconfidence of different alcohol levels.

f) Nighttime Vision

The rods are only sensitive to light intensity, which means that they do not distinguish the colours ("at night, all cats are gray"); by contrast, after adaptation, they are sensitive to a very small amount of light, which makes them particularly suitable for nighttime vision.
Nighttime vision presents several characteristics.

- Adaptation

Is linked to the fact that the transduction of light signals into nerve impulses is made by degradation of a specific protein, rhodopsin. Light degrades rhodopsin and, to be able to see at night, this molecule must be resynthesized, apparently after arriving in the darkness.
This synthesis requires vitamin A.
The curve of Figure below shows the kinetics of adaptation: first the adaptation of the cones, then the rods. The time necessary to experience the best performance in nighttime vision from daytime vision requires approximately 30 minutes.



Adaptation curve for nighttime vision after 3 minutes of exposure to intense light.

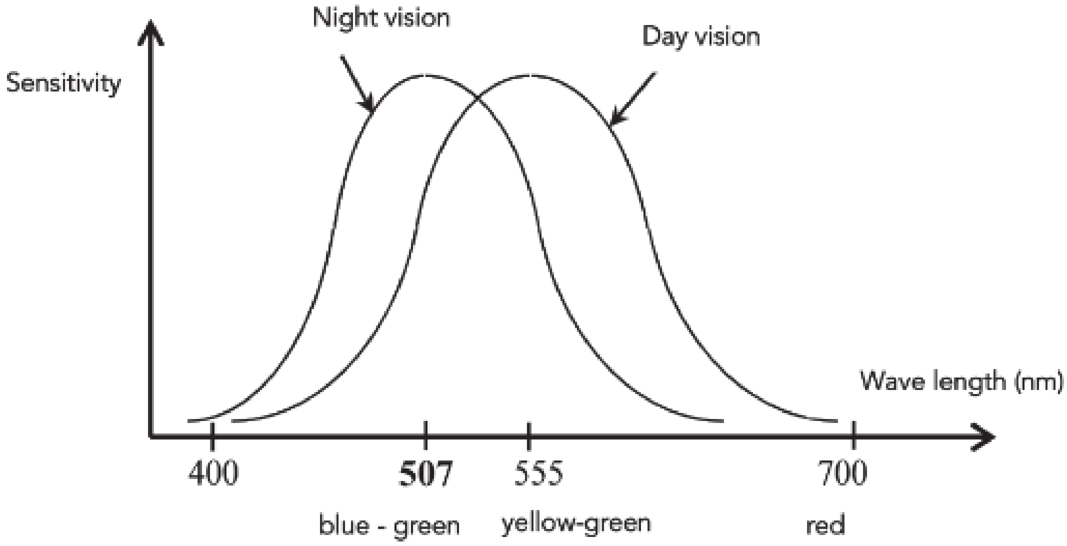
The existence of this adaptation mechanism in flight can pose a problem.
The view of the instrument panel lit up puts the eye in conditions of daytime vision. Even if, at night, the light from the instrument panel is decreased, adaptation to external vision is necessary, even if it is less than what is described in Figure above.
This means that the pilot only perceives the outside environment effectively after a few minutes. When this vision is necessary (e.g. helicopters in rescue missions), working as a crew is required, with strict sharing of viewing conditions.

- Eccentricity of the best nighttime visual acuity

We have mentioned that the density of the rods is optimal at 20° of eccentricity in relation to the visual axis; this means that there is an optimum for nighttime visual acuity, around 20° of eccentricity for the viewing direction.
Experiencing it during a clear night, especially without the moon; a faint shining star may only be perceived slightly in the side vision and disappear when you try to establish it in the central vision. In addition, let us recall that side vision is particularly sensitive to movement.
Hence, in night flight, the best visual performance is obtained when the pilot regularly scans his field of vision; it is then that the details at low light are optimally perceived.

- Purkinje effect

There is a sensitivity curve for the retina as a function of the wavelength of light; all radiation does not impress the retina with the same intensity. The cones and rods do not have the same response curve (Figure below).
Therefore, if one compares the overfly by day to the overfly by night of the same landscape, these are not the same structures on the ground that, according to the colour, appear in the most intense manner. There is a risk of error during night overfly of a landscape known in daytime conditions.



Sensitivity of the cones and rods as a function of the wavelength (Purkinje effect). This curve shows the shift from 555 to 507 nm for maximum perception. Note that the two curves have been reduced to the same graphic scale, but they correspond to absolute levels of light perception different from several orders of magnitude.

2.2.5 - Ocular pathology

a) Glaucoma

The liquids of the eye are not static but, on the contrary, they are secreted and reabsorbed continuously, which allows the eye to regulate its pressure. This pressure is known, in current language, as ocular tension. This pressure allows the eye to maintain a constant shape.

Glaucoma is an increase in the intraocular pressure, quite often observed during aging. The increase in pressure exerts a counter pressure on the retinal blood flow, which, in the long term, can cause atrophy of the retina and, ultimately, blindness. It starts from the retinal periphery (loss of the peripheral visual field).

Glaucoma is curable by drugs, general or local administration, or by surgical treatment. However, it remains for a long time without causing detectable symptoms to the patient himself, because it is a very slow and very gradual restriction of the visual field.
Its systematic screening is thus essential (measurement of eye pressure, measurement of the visual field). Without this screening, the diagnosis is only made when the patient consults for a significant loss of side vision and a degradation of central vision. The diagnosis is then too late and, at this stage, the lesions are irreversible.

b) Cataracts

Cataracts is a gradual clouding of the crystalline lens. The patient progressively loses vision. Cataracts can originate either from aging or an eye trauma. Surgical techniques are now well developed, allowing the ablation of the opaque crystalline lens and its replacement by an artificial lens.
The pilot with cataracts is obviously unfit; if the operation goes well, fitness is granted.

2.2.6 - The role of environmental factors on vision

Hypoxia degrades vision:

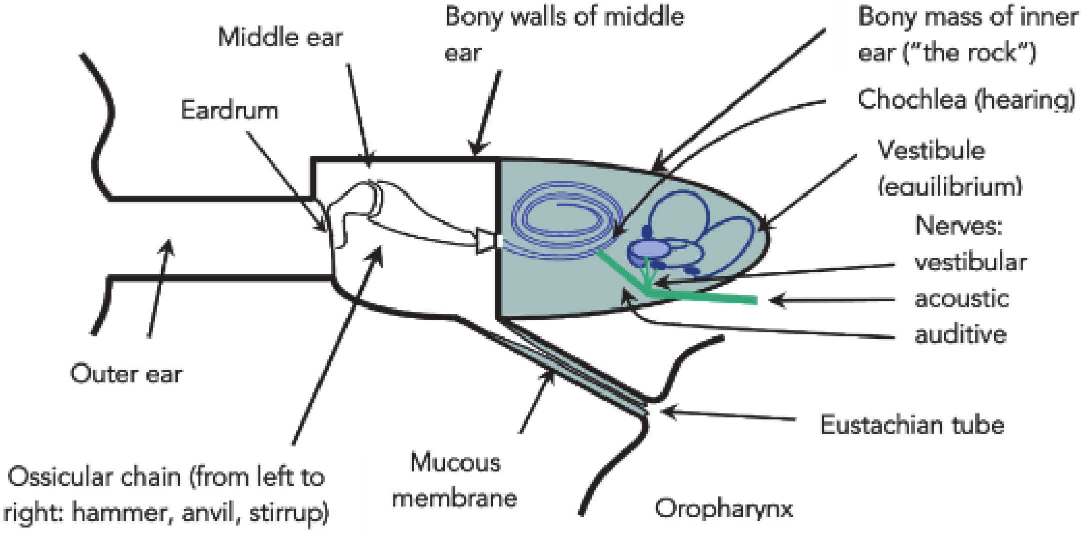
- Nighttime vision decreases above the altitude of approximately 2,000 m (6,000 ft.);
- The perceived intensity of light decreases, as if the scene is extinguished;
- Some subjects reported a very significant reduction of the visual field, with a tunnel effect - without knowing whether this observation was due to the retina or the nerve centers.

The effects of acceleration on vision has already been mentioned. Refer to the paragraph 1.8.3.

2.3 - Hearing

2.3.1 - Anatomy

The ear is composed of several parts.



Schematic representation of the outer, middle and inner ear.

a) Outer Ear

The outer ear is composed of the pinna and ear canal (external auditory meatus). Its role is to capture sounds.
The eardrum separates the outer ear from the middle ear.
The eardrum is a thin membrane stretched between the external environment and a semi-closed cavity, which balances slowly with the external environment through the Eustachian tube.
The eardrum thus acts as a highly dynamic differential pressure sensor; it perceives sound vibrations well.

b) Middle Ear

The middle ear is a recess in the skull. Its volume is approximately 1 to 2 cm^3.

It contains the ossicular chain, which is a set of three small bones that transmit sound vibrations from the eardrum to the hearing organ.

This anatomical description suggests two types of pathologies:

- Either a deficit in the equalizing of pressure between the middle ear and outer ear, due to an obstruction of the Eustachian tube; large variations in barometric pressure observed during climbs and descents of the aircraft may be the source of barotraumas; aggravating factor: any "flu-like" states;

- Or a change in articulation between the ossicles: the ossicular chain stiffens and transmission of sound vibrations is impaired, causing a "hearing loss". An infectious disease or aging can cause this type of deficit.

c) Inner Ear

The inner ear is a complex organ, which is made up of different channels and cavities that form the labyrinth. The labyrinth is comprised of two major subunits: cochlea (hearing) and vestibule (equilibrium). The sensors of the labyrinth are immersed in the same liquid, called endolymph.

The cochlea, or cochlear channel, is the auditory sensor. It presents itself in the form of a channel wrapped around itself, with a progressively decreasing radius of curvature, like the coils of a snail, from which a number of pictorial terms describing this organ are historically derived (e.g. "cochlea"). The number of windings is about 2.5.

The channel contains a carrier membrane of sensory cells generally assigned to distinct sound frequencies (low frequencies at the entrance of the channel, high frequencies at its end).

The sounds are transformed into nerve impulses in the cochlea, and then transmitted to the central nervous system by the auditory nerve, which, after merging with the vestibular nerve, becomes the acoustic nerve.

Deafness of "transmission" is a defect of the outer or middle ear; deafness of "perception" is a defect of the inner ear or nerves that issue from it.
Possible pathology: The inner ear is immersed in an incompressible fluid. A brief violent sound (gun) or a sudden atmospheric pressure variation can be transmitted without weakening the fragile sensor of the inner ear. Generally, such damage is permanent (risk of sudden and permanent deafness).

Presbycusis is a hearing loss linked to aging, often without a clearly identifiable cause. In its initial phase, it affects the high frequencies.

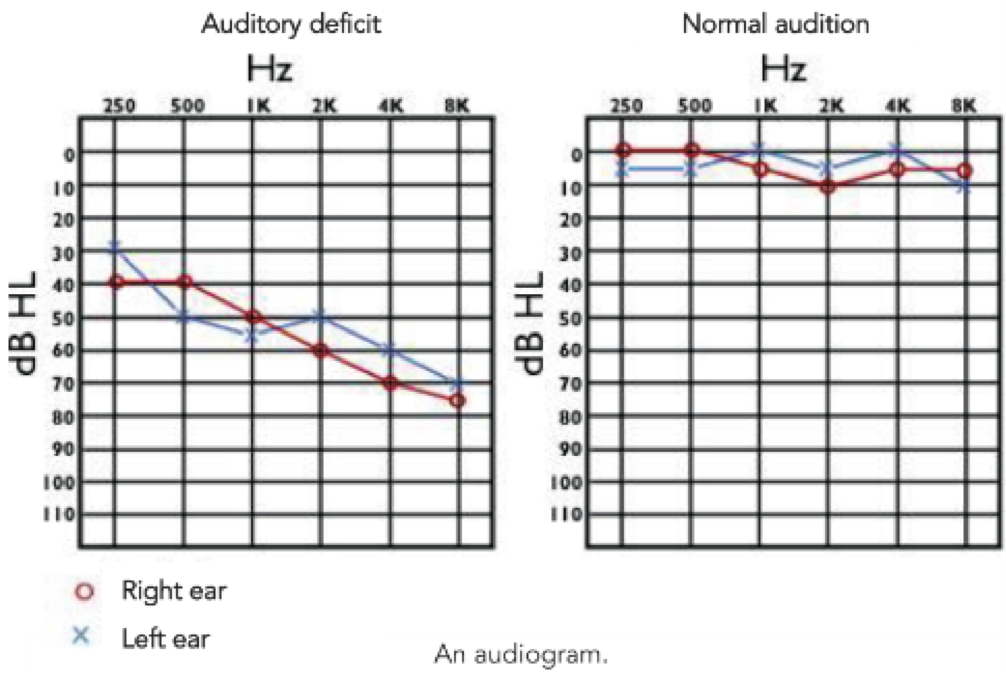
Regardless of the cause, hearing loss is often accompanied by tinnitus, which is an intermittent or permanent ringing or buzzing that is sometimes very annoying in everyday life.

2.3.2 - Auditory Perception

The sensation of sound is produced by vibrations transmitted through a fluid. No sound is transmitted if it is empty. The limit of frequencies perceived by children is between 20 and 20,000 Hz (20 Hz and 20 kHz). The upper limit decreases with age.

The perceived intensity is proportional to the logarithm of the strength of stimulation (Weber-Fechner law), from a threshold value. Acoustic perception is expressed in bels.

The audiogram is the test performed, based on frequency, at the minimum perceived power. It is expressed in a graph (Figure next page). It makes up part of the basic functional exploration of each aircrew member. It explores the quality of the auditory sensor. This is tonal audiometry.



An audiogram.

However, it is only the performance of the sensor. Performance also involves the processing organ, the brain, which is responsible for analyzing sounds.

A more general test takes into account the ability to recognize phonemes; this is speech audiometry. The latest published texts state that "In an examination for extension or renewal, an applicant with a hearing loss greater than these values must demonstrate satisfactory functional hearing ability". It may be a voice test or a cockpit test [EU Regulation No. 2019/27, AMC1 MED.B.080(a)(2)].

2.3.3 - Hearing loss prevention

Exposure to noise generates various disorders: basic fatigue, overall decreased performance, up to varying degrees of temporary or permanent hearing impairment. It is hearing loss caused by noise. It may appear as low as 90 dB. Some exposure limit values can be proposed: 8 hours of exposure at more than 90 dB, 2 hours of exposure at more than 100 dB, 1/2 hour of exposure at more than 110 dB, no exposure at more than 120 dB.

The sources of noise in aeronautics are well known: engines take first place. On the aircraft without a cabin air conditioning system, the noise from the engines is heard in the cabin.
On the aircraft equipped with a cabin air conditioning system, some of them maintain relatively high ambient noise levels in flight between 80 and 85 dB. These are either from residual engine noises (e.g. on turboprops with an insignificant amount of low frequency noise) or noises related to the air conditioning system and operating embedded systems.
Finally, even if they are not pilots, let us include the ground personnel working near the runway, on engines, or in boiler room workshops.

Hearing loss prevention is related to noise passing through the protection. It involves wearing helmets that limits the transmission of ambient noise to the ear.

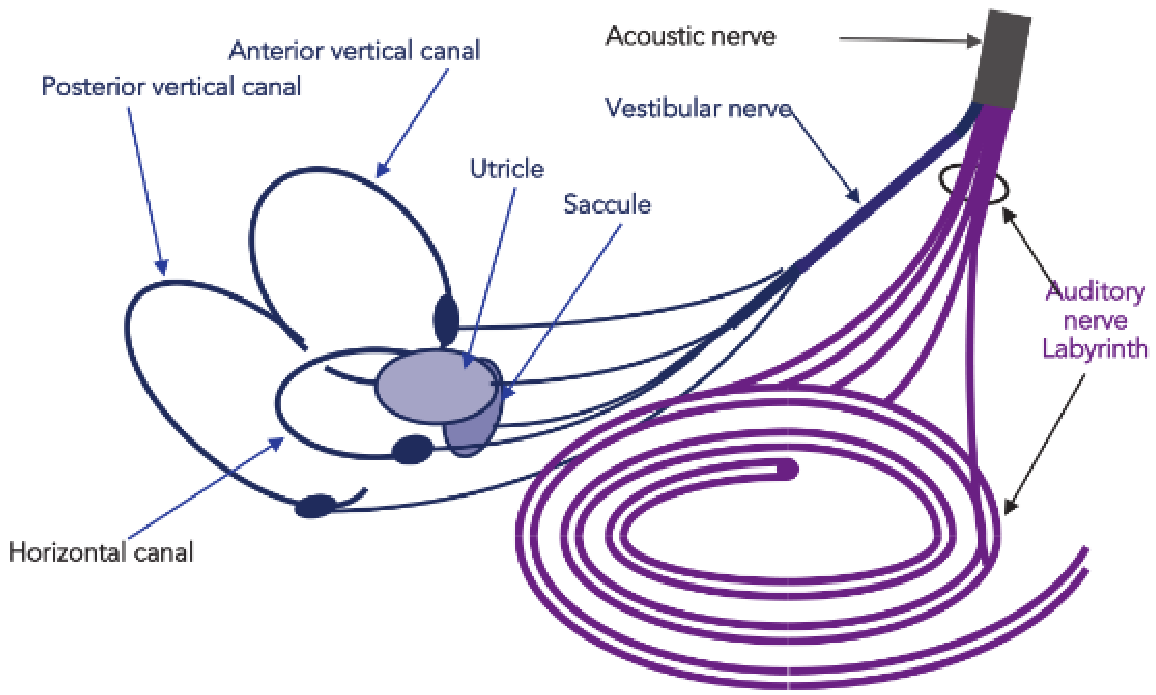
2.4 - Equilibrium

What is commonly referred to as the vestibule, or vestibular apparatus, is an organ located in each inner ear (below). The vestibule is one of the components of the "rock"; it is also part of the "labyrinth".

The equilibrium organ is complex, because it is able to detect two types of information:

- The direction of the gravity vector and its variations by the otolithic apparatus;
- The angular movements by the semicircular canals.

Each semicircular canal includes an "ampulla", at one of its ends.



Anatomical diagram of the inner ear (labyrinth), auditory apparatus and vestibular apparatus.

From a didactic viewpoint, the various vestibular functions should be presented separately. In reality, they are partially nested together.

Each ampulla, as well as the utricle and saccule, emits a nerve branch, whose meeting forms the vestibular nerve. The latter joins the auditory nerve to form the acoustic nerve (eighth cranial nerve).

2.4.1 - Otolith organs

The otolithic apparatus, sensitive to gravity, is composed of two small cavities:

- Utricle;
- Saccule.

They are both filled with endolymph. The otolith organs function as an accelerometer, measuring the intensity of the gravito-inertial field.

This mechanism is a formidable source of sensory illusions in flight, because it has much information regarding perceived gravity.
According to a principle stated by Einstein, the different forces of inertia are indistinguishable from each other, regardless of the sense used; Einstein probably had only physical senses in mind, but the physiological senses obviously obey the same physical laws.
Therefore, the body only measures the resultant in the presence of inertial forces. Without vision, you can easily confuse the direction of the resultant vector and direction of terrestrial gravity; hence a misrepresentation of vertical. It is a frequent and dreaded disturbance mechanism of spatial orientation in flight.

a) How do the senses function?

The utricle and saccule each contain a sensitive plate, the macula, whose cells are equipped with cilia (Figure below). The cilia are embedded in the otolithic membrane, a small weight whose density is higher than endolymph. The otolithic membrane moves under the effect of inertial forces (including gravity). The cells of the macula are sensitive to deformations of the cilia. Therefore, they are at the source of gravity information.

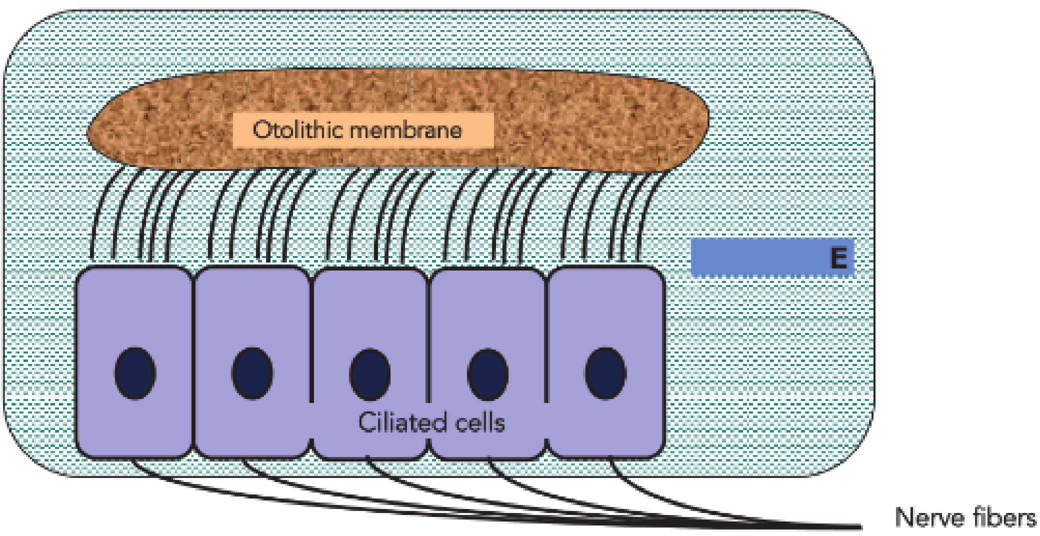


Diagram of the macula.

The saccules measure the lateral movements of the head and the utricles measure the anteroposterior movements. These senses are sensitive to both the absolute values and their derivative with respect to time. The combination of this data allows the central nervous system to be informed regarding the inertial forces exerted on the head.

b) Perception of Linear Accelerations: The Threshold Effect

The otolith organs present a threshold effect of approximately 0.06 $m.s^{-2}$ (6.10^{-3} G) in the horizontal plane and 0.1 $m.s^{-2}$ (or 10^{-2} G) in the vertical plane.
The threshold of 0.1 $m.s^{-2}$ in the vertical plane is significant. In the sense of G_Z, exceeding this threshold is perceived as a "air hole". The pilot, concerned for the well-being of his passengers, thus performs his attitude dip by slowly pushing the yoke, in order to maintain acceleration – G_Z within the comfort limits (acceleration – G_Z subthreshold). Passenger transport aircraft with electrical

flight controls include an autopilot function for descents, under the constraint of this threshold effect ($\gamma \leq 0.01$ G).

These aircraft are very comfortable for passengers, because the air hole sensation does not occur during descents. However, if passengers do not feel the acceleration, then pilots even more so do not feel it, which deprives them of basic sensory information. This automated system is legitimate only to the extent that the ergonomic design of the instrument panel restores sensory information to the pilot, at least as powerful as the information that he was deprived of. Not being able to perceive the descent, or its true value, is one of the explanations for certain air accidents involving collision with the terrain while the pilot is at the controls, including in France in the recent past.

c) Perception of the Head Position

The stimulation of the otolithic apparatus is the source of conscious awareness of the head position in relation to the field of gravity. Under normal conditions of life, this is the field of the terrestrial gravity; under other conditions, especially when visibility is obstructed, the body interprets perceived information as the normal vertical (sensory illusion). This perception is also at the root of reflex movements of the eyes, head, torso and its members.

d) Otolithic Reflexes

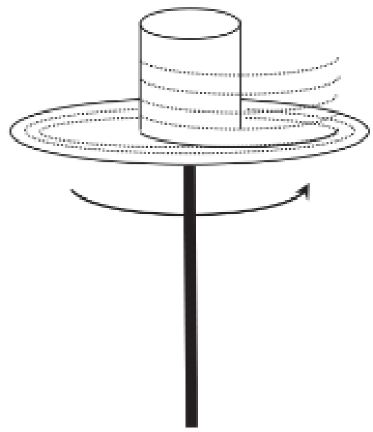
The perception of gravity is not an end in itself. It serves several major functions among which we will distinguish:

- Maintaining a Fixed Gaze Vestibulo-ocular reflexes, in their otolithic component, permit one to maintain their gaze on a fixed target, regardless of the movements of the body and/or the platform that the body is on. Example: You are riding in a public transport vehicle and you see the "pub" on the wharf. Whatever the movements of the platform, your gaze remains focused on what you are seeing. Explanation: The information from movements is captured by the otolith organs, the origin of vestibulo-ocular reflexes; these reflexes are responsible for general eye movements in the space of the head, which allows one to maintain a fixed gaze.
- Maintaining Posture Vestibular postural reflexes maintain the stability of the body, regardless of the movements of the body and/or the platform that the body is on. Consider the same example: You are still in the same public transport vehicle; when changing direction and/or speed, you can reasonably maintain your grip on stationary objects. Regardless of the movements of the platform, your posture adapts in order to maintain your center of gravity in the support polygon. Explanation: The information from movements is captured by the otolith organs, the origin of vestibular postural reflexes; these reflexes are responsible for movements of muscular adaptation, which allows one to maintain posture.
- Maintaining Cardiovascular Function Let us return to the cardiovascular adaptation model that we used to show the effects of accelerations (see paragraph "Accelerations" including). A set of reflexes was recently discovered that allows the cardiovascular system to instantly adapt to gravitational changes.

2.4.2 - Semicircular canals

The three semicircular canals (Figure below) are located in almost orthogonal planes. For the simplification of this presentation, consider the three semicircular canals of each inner ear as placed in the classic horizontal and vertical orthogonal planes. They work in pairs. Each canal only moves in one direction.

Let's illustrate the threshold effects, remanence, and adaptation. A semicircular canal is a loop filled with a liquid, endolymph, which is almost like water. A small solid element is immersed in this liquid. Technically, it is a force sensor.



Let's imagine a glass of water on a potter's wheel. We place a force sensor on the inner wall of the glass; if there is a relative movement between the container and its contents, this force sensor measures the friction from the water. Let's turn the potter's wheel.
First, the glass turns but, by inertia, the water remains stationary. Although the movement of the glass has become stabilized, the sensor perceives the information over a certain period of time (remanence). Then, gradually, the water turns with the glass at the same speed; our sensor no longer measures anything (adaptation).

Now let us imagine that the rotation is made at a very low speed;
the water will still turn at the same speed as the glass and the sensor will detect nothing (threshold effect).

a) Function of the Sensor

Each canal is composed of an arch and an ampulla; the ampulla is a swollen area, located near the utricle. With a structure similar to what has been described for the utricle and saccule, the ampulla represents the sensitive area where perception originates.

Let's rotate a canal. At the beginning of rotation, the inertia of the liquid (endolymph) does not allow it to rotate as quickly as the canal that contains it. Therefore, there is a relative displacement of endolymph in the canal. This movement generates a frictional force on the sensor, which causes its stimulation. Then, the speed of the endolymph joins the canal; the stimulation disappears.

b) Threshold Effect, Remanence and Adaptation

A very slow rotation results in the joint movement of the canal and endolymph; this is the threshold effect of the sensor, which only detects rotational acceleration in so far as they have a sufficient value.
When the rotational speed is stabilized, perception continues for a few seconds; this is the phenomenon of remanence.
Then, when rotation is maintained at a constant speed, the feeling disappears; this is adaptation.

Stopping the rotation results in symmetrical observations.

Finally, it should be noted that rotational acceleration is perceived by a semicircular canal, not to be confused with the rotation of the whole head.

The rotation of the head in a rotating assembly causes the change of the plane and rotation speed of two (at least) of the semicircular canals, to the right and to the left. The illusions, dizziness and motion sickness that result from it can be very powerful.

The demonstration is very easy: during a steep turn (45 or 60°) and while you are a passenger, turn your head completely to the side and observe… Before doing this exercise, make sure that you have the airsickness bag handy, and open!

c) Vestibular Reflexes (Semicircular Canals)

In the same way that the otolith organs are the source of eye or posture reflexes, the semicircular canals emit same type of information. A perceived rotation causes the gaze to shift, as well as the muscles for posture.

If the shift of the posture muscles does not seem to have a much relevance to our subject, the eyes may be responsible for sensory illusions during the flight in poor visibility (the gaze deviation reflex can give false information on the position of an outside object - e.g. another aircraft).

2.4.3 - Role of skin and somatic proprioceptive receptors in spatial orientation

The term "proprioceptive receptors" refers to physiological sensors distributed throughout the body, which are sensitive to various information. We also find receptors in different parts of the body.

- In the muscles. The muscles have control elements where information is returned to the nervous system; the stretch and length of muscles are known to the nervous system, and muscle contractions are adjusted in terms of force, length and speed of movement.
- In the tendons. The Golgi organs are receptors housed within the tendon insertion of the muscles. They act as force sensors, one of the roles of which is to inhibit muscle contraction, if the latter reached a rupture value (this function is well demonstrated in some animals; however, it is less clear in humans).
- In the joints. The sensors provide information on the position of joints and their variations.
- In the skin. We find a rich set of touch receptors, receptors that are sensitive to pressure, vibration, temperature, as well as various receptors, such as those associated with hair follicles (hair).
- The force of gravity gives rise to pressure and contact sensations, whose distribution provides information on the position of the body relative to its support, thus in relation to the field of gravity.
- These pressure and contact receptors are adaptable. They are mainly sensitive to variations of information and first detect changes. This is how the hand, resting on a neutral structure, no longer quickly perceives contact (adaptation), but fully perceives the initial contact or loss thereof, or even the change of position of the structure.

2.4.4 - Relationships between various receptors: Multisensory perception of space

The perception of space requires him multiple sensors, coordinated in a complex way, from which the term "multisensory perception" is derived. This is at the root of the perception of body position in space, through a chain of sensory organs. The general pattern includes the perception of head position, and then the perception of other body segments in relation to the head.
In humans, the position of the head is first known by vision. On the one hand, vestibular information intervenes when vision is lacking and, also under normal visual conditions, such as in planning for movement.
Various sensors are coordinated between them. We have examined the principle of the vestibulo-ocular and postural reflexes. We emphasize again that these normal and expected reflexes may be the source of powerful sensory illusions in flight. This naturally leads us to the following paragraph…

2.5 - Spatial disorientation and sensory illusions in flight

2.5.1 - Definitions, general information and statistical data

Orientation of humans in space requires multiple sensory receptors. It uses vision and the equilibrium system, as well as less well-known non-specialized sensors, distributed throughout the body, in the skeleton, tendons, muscles and skin.
These sensors supply the central nervous system with information concerning posture, support and relative positioning of different body segments in relation to one another. Other sensors may also play a role, such as hearing.

Under normal conditions of life, the most powerful orientation sensor is vision, completed or supplemented by the other sensors. All these sensors are coordinated between them, which means that spatial disorders may originate from multiple and complex sources; they may either be disorders of an individual function or disorders resulting from coordination mechanisms of various sensors between them. Finally, the disorders may result from the conscious or unconscious interpretation of the information collected by the central nervous system. Spatial orientation disorders can also result in motion sickness (travel sickness) and dizziness.
Let's comment on the concept of "sensory illusion". Sensory illusion may take on various forms. It may involve perception of the attitude of the aircraft or its movement. In both cases, it may be the lack of perception of what exists, the misperception of what does not exist, or a decorrelation between perception and reality. In addition, the illusion may or may not be recognized by the subject, but be debilitating to varying degrees.

Statistical Data
It is difficult to obtain a statistical assessment of the responsibility of spatial orientation disorders in air accidents. Various available sources put the figure at somewhere between 10 and 45%, a widely varying proportion depending on the piloting conditions (private aviation, fighter jet aviation, commercial passenger transport aviation, etc.).

An interesting statistic was published in 2000 by U.S. military aviation. It shows that spatial disorientation was responsible, for approximately 25% of accidents. Unquestionably, it also shows another interesting result, which is the risk of an accident (fatal) by spatial disorientation regardless of one's experience; the risk remains the same throughout one's career.

Sensory illusions of visual origin	By physical deformation of information		
	By lack of information		
	By erroneous physiological perception of information	Errors of movement	Autokinetic illusion
			Apparent movement
			Consecutive movement
			Induced movement
		Distance errors	
	By cognitive interpretation of information errors	Horizontal plane errors	
		Vertical orientation errors	Illusions of horizontal tilt in roll and pitch
		Various errors	Confusion of light sources
			Improper interpretation of shadows
		Errors by diversion of perception from indicators on the ground	
		Distance errors	
Sensory illusions of vestibular origin	By physical deformation of information	Coriolis effect	
		Changes in semicircular canals	
	By lack of visual information		
	By erroneous physiological perception of information	Errors related to threshold effects	Tilt illusion
		Errors related to the adaptability of sensors	Somatogravic illusion of tilt when turning
	By cognitive interpretation of information errors	Somatogravic illusions	Nose down or nose up
			Inversion
			Tilt in roll or pitch
		Somatogyral illusions	Death spin Death spiral
Sensory illusions of mixed origin		Oculogravic illusions	
		Oculogyral illusions	
Spatial orientation disorders of cognitive origin		With altered pilot capacities	
		Without altered pilot capacities	

Classification of main sensory illusions.

2.5.2 - Sensory illusions of visual origin

Spatial disorientation of visual origin is due to:

- A deformation of the physical signal;
- A lack of information;
- A misperception of information by the sensor;
- An erroneous processing of information by the central nervous system.

a) Illusions by physical deformation of information

Heat, rain or snow can alter the optical properties of the air and deform visual information. At high speed, these diopter effects can be due to gaseous flows on aircraft surfaces. These illusions do not seem to major. In the same vein, flashing lights can create a risk of disorientation or dizziness when they are used in clouds.

b) Spatial disorientation by lack of information

In this case, one lacks a component of vision. The most characteristic example is a helicopter pilot hovering at night, while using night vision devices (NVD). NVD have limitations: Their definition is low and they only provide a mediocre visual acuity (approximately 1/10); the projected image in front of the eyes is a "2D" image, which does not allow depth perception. While hovering, there is a motion parallax (see p. 30). Accurate positioning becomes impossible.

c) Illusions by erroneous physiological perception of information

Errors of movement

- Autokinetic illusion

Extract from a report published in the "Bulletin d'information sur la sécurité des vols d'Air-France" ("Information Bulletin on Air France Flight Safety" in English) (No. 46, Sept. 2000, p.12 et seq.), recopied in telegraphic language.

- 1990, a B747 was taking off from Djibouti to the Seychelles, at night. Prior to takeoff, air traffic control announced: "Traffic from Mogadishu, coming from the south, not yet in contact, altitude unknown." After takeoff, at 1,000 ft, turn right toward the south. The PNF (on right side) looked outside and searched for the other aircraft. The traffic was spotted right in front. The OP announced: "Aircraft just in front of us, at our height." The pilot in command (pilot flying) immediately began an avoidance manoeuvre by reversing the direction of the turn and putting the aircraft into a rapid descent.
- The pilot in command later said: "Actually, nobody had seen the plane. What had been taken for a plane was in fact a very bright light (certainly a boat). However, with the tilt of the turn, this unique light (very dark night, no other point of light) wobbled, and seemed to be exactly at our height and moving right toward us. [...] Actually, it took a few moments to realize it, because the similarity was very high [...]. The aircraft reported by the tower was never identified. "
- FDR Data Analysis: At about 1,500 ft., starting descent toward 3,500 ft./min, Vi= 238 kt (>VFE 10°). GPWS Alarm for 7 s, resource at 1.35 G.

Comment: Double illusion. An autokinetic illusion accompanied by an illusion of cognitive origin ("ball in the middle, the plane of my wings indicates horizontal - everything that is in the plane of my wings is the same height as me").
The autokinetic illusion has been described by astronomers who observe the stars; everyone believed the star moves, but in a completely random way; in addition, the different observations, shared in common, were inconsistent with one another. This illusion was the cause of considerable difficulties in holding the position in night training flights, during bombing raids of the Second World War; it should also be noted that some of these pilots were relatively inexperienced. In the same context of war, drivers of land vehicles driving in convoys with minimal lighting experienced similar difficulties.

Autokinetic illusion occurs at night. It consists of the misperception of movement from an isolated, low-intensity light source against a dark background. After a delay of a few seconds to a few tens of seconds, the latter seems to move in slow motion with irregular oscillations.
Explanation of this illusion. The gaze only remains fixed on an object when its size or brightness is sufficient. A faint light in a dark scene does not allow the eyes to maintain a constant focus, which fluctuates around the middle position of the gaze; the image of the bright point on the retina moves accordingly. As we have no perception of these eye movements, we interpret the displacement of the object image on the retina as the movement of the object itself.

This illusion is exaggerated by fatigue or a prolonged fixation on the bright spot. It decreases or disappears in the presence of other stimuli in the visual field. Increasing the light level in the cockpit decreases and consciously shifts the gaze to make it disappear. The increase in the number of runway edges and centerline lights, or the use of flashing or rotating lights also makes it disappear.

In night flight, both to improve nighttime perception and to avoid autokinetic illusion, it is essential to continually visually scan the scene.

- Illusions of apparent, consecutive or induced movement (relative movements)

The illusion of apparent movement is caused by ignition of two similar alternating light sources, located a short distance from each other in the visual field (e.g. runway entrance lights). The illusion is a single light source, which moves from one point to another.

The illusion of consecutive movement is caused when, after the prolonged observation of a surface in movement, the eye fixes on a stationary point. It then appears temporarily mobile.
The illusion of induced movement is well described by a common observation: (false) perception of the movement of the moon relative to the clouds.

It seems that both the illusions of consecutive movement and induced movement impede pilots, flying at high speeds and low heights in poor weather conditions, with rapid transition between visual flight and instrument flight. Besides visual illusions, they are also responsible for motion sickness.

Distance errors
Helicopter accidents have been attributed to distance errors during night flights, while using night vision devices. Known as the Pulfrich effect, the erroneous estimation of distance appears when the object is perceived with a different light intensity in each eye.

It has been shown that, when light intensity is not the same for each eye, the fusion of the two retinal images, right and left, leads to an error in the perception of depth and distance. This error is even more significant than when the light intensity is different for each eye and the overall light level is low. Night flights with an NVD requires an adjustment of the NVD before each flight to obtain an equal brightness on each tube.

d) Illusions by cognitive interpretation of information errors

Learning allows one to organize and understand sensory input, to develop a mental representation of space.
In an unusual context, some perceptual input, while correct from the physical point of view, can lead to sensory illusions through interpretation errors.

Horizontal plane errors

Learning and conditioning the human body leads to identifying any wide flat or approximately flat surface as horizontal. Very large representation errors are attributable to this mechanism. These errors are observed in visual flight; some reference points are clearly identified, but wrongly interpreted as horizontal.

- Illusion of horizontal tilt (in roll). The latter may appear during a flight above or on the edge of an inclined cloud layer, in a weather front. The upper surface of the clouds provides a very definite visual reference point. It can be tilted to 10° or more. In the absence of a geographic horizon, the pilot has a tendency to align with this false horizon, which is the cause of untimely turns. Without examining the flight instruments, the pilot perceives the existence of this illusion. However, the latter may be very powerful and cause some piloting difficulties.
- Illusion of horizontal tilt (in pitch). Some topographic configurations can create a "false horizon", on which the pilot may attempt to align: gently sloping hills, flying in a valley when the ground is steadily rising, flying over a glacier. This illusion of horizontality is aggravated by "white" time, snowy ground and sky being partly confused. This illusion is especially dangerous, because it can cause the pilot to fly over terrain with a slope that is greater than the ascending capabilities of the aircraft.

There are other comparable illusions, such as takeoffs in mountainous sloping terrain. With the ground being used as a horizontal reference, both the horizontal and vertical speed settings may be completely inadequate.

Vertical orientation errors

It is the misperception of the "high" and "low". Under the natural conditions of life, like day and night, "high" is always more luminous than the "low". While flying at high altitudes results in the natural distribution of brightness, night flights reverse this process. These errors occur either in air combat at night (military), or in the case of implementing an unusual position.

Errors by confusion of light sources

In the course of flying over sparsely populated areas at night, the rare ground lights can be confused with stars.
In night flight at high altitude, the stars and the moon may appear below the real horizon.
In a milky sky, approaching a coastal shoreline, the sun can be veiled by clouds and be reflected in the sea at the same time; it is the reflection that is perceived as the sun, in a setting of deteriorated visibility.
These errors may lead to flawed actions on the part of the pilot.

One very particular error has caused many surface collision accidents; these accidents occurred while flying over bodies of water at low altitude, in somewhat foggy weather, while the moon was low on the horizon, when the pilot looked for the moon in its natural position relative to himself, above the cockpit.

Distance errors

The estimation of distances is a complex function involving not only binocular vision, but also a certain amount of monocular information, based on the interpretation of perceived forms and their spatial relationships.
The laws of perspective play an important role in depth perception (object of smaller size and higher position in the visual field). These natural reference points were lost during the flight. The most characteristic illusion is the misperception of altitude and approach slope, either on a runway of unusual geometrical dimension or with a rising or falling slope.

Another distance error is related to the unusual lighting conditions in night flight. Observing allows for the assimilation of a certain light intensity in the distance. The perceived light intensity may be lower than normal and the pilot will perceive the runway as further than it really is, or vice versa if the lighting is too powerful.
We will approach this illusion mechanism of the so-called black hole, which makes the runway appear as too distant compared to its actual position. In urban settings (and it is often the case of airports…), the environment is often brightly lit up, which makes the runway and associated taxiways appear as - far away - the darkest area of the region. Therefore, the pilot must "plunge" in this obscure hole. In visual flight, this lack of brightness, aggravated by the contrast with the environment, can induce errors by the pilot.
Fog and the blurred vision that results from it may be the source of the same illusion of excessive distance.

Distance errors can be enormous under certain environmental conditions. This is the case when flying over mountains or in the desert at low altitude. Two examples are characteristic:

- In the mountains. The aircraft flies in the middle of rocky walls and gives the illusion that the wings are going to touch the wall. A known reference point is the size of a man. Imagine a man was climbing this wall and an observer in the air suddenly becomes aware that there is actually a climber; this only occupies a very little angle of his visual field. The rock wall is several hundred meters.
- In the desert, at very low height. Each irregularity of the surface can become a mountain, or at least an obstacle of significant size. The pilot can then fly at an exaggeratedly low height, until the accident occurs.

Errors by diversion of perception from indicators on the ground

The illusion comes from a real "theft" (in the sense of "thief") of sensory perception. In more technical terms (but perhaps more obscure…), we will refer to them as visual attractors. By way of example, consider the following situation: A narrow and short runway, located close to a large landmark, such as a wide, straight road over a long distance. This small runway is, in addition, a little skewed in relation to the road. The pilot will have a strong tendency to align with the axis of the road. The gaze is attracted by the large size of the landmark. Subjectively, sensory perception of the small landmark seems to be "diverted" or "flown" by the larger landmark.

This illusion can be very strong in night flight; in approaching land, lights that are lined up (train, highway, coastal roads) could be confused with runway lights, resulting in catastrophic landings. At night, airports in urban areas are often - always - the darkest area of the visual scene. It is not natural to move toward this dark area.

Runway errors

We are now moving on to the work of monitoring… The student has established a link between the apparent length of a normal runway in one's visual field and the distance from the runway threshold: when the runway is short, the distance is overestimated; when it is long, the distance is underestimated.
Similarly, a wide runway appears shorter. Depending on the flight attitude, the height is underestimated if it is nose down and overestimated if it is nose up.

During the approach, the pilot must position the aircraft according to a path whose angle of descent is defined, usually 3° (5%). Let's assume that the approach is made visually. The pilot is trained to follow precise visual reference points (Figure "*Visual* perception *of the runway according to its length and width*").

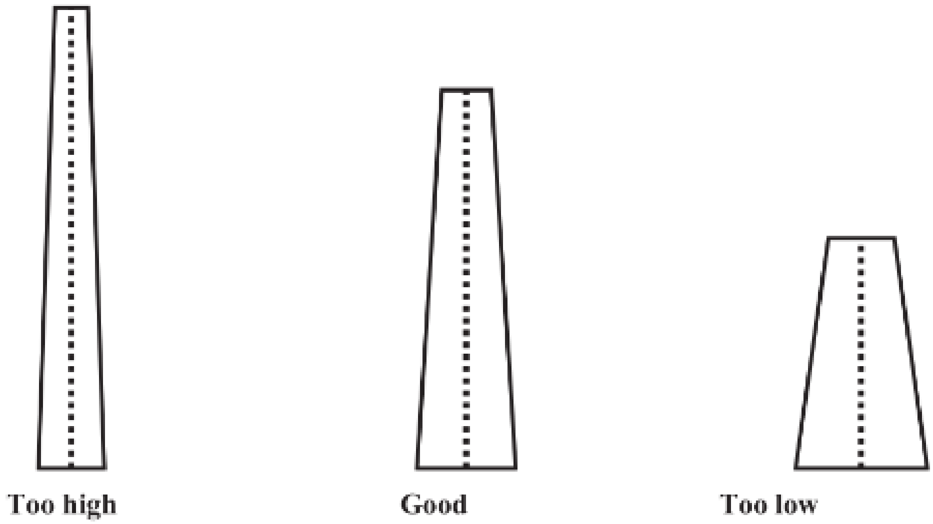
One can then be a victim of estimation errors (Figure "Perception of a "normal" runway according to the angle of approach");

- An error due to the link between the apparent length of the runway in the visual field and the distance from the runway threshold: when the runway is short, the distance is overestimated; when it is long, the distance is underestimated;
- Error due to the link between the relative dimensions of the runway: a wide runway appears shorter;
- Error due to the link between the perception of the runway from the cockpit and its distance: when the aircraft has an unusual flight attitude, the height is underestimated if it is nose down and overestimated if it is nose up.

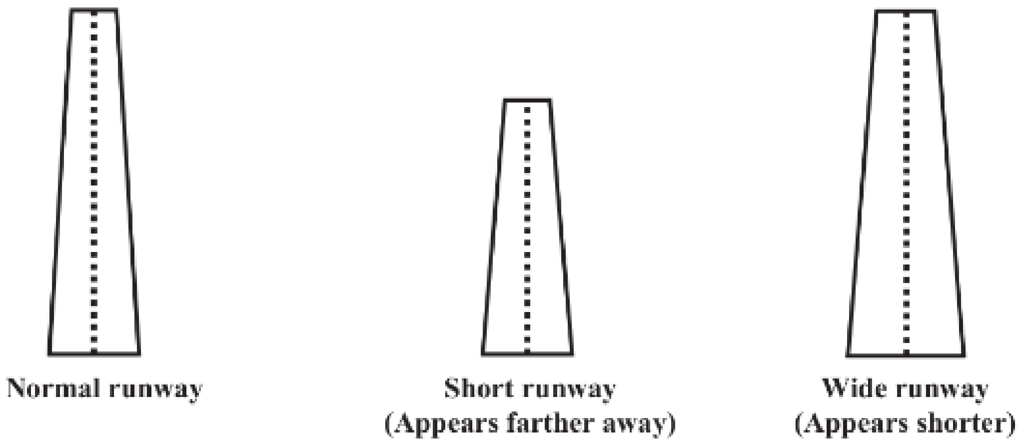
Specific problems of horizontality

If the ground that precedes the runway rises upward, or if the runway itself is raised, the height is overestimated in relation to the actual height. The illusion created is an approach with too steep of a slope, corrected intuitively by the pilot using an overly flat approach. The consequences are reversed in the case of flying over terrain with a downward slope before the runway, or in the case of a descending runway (Figure "*Visual perception of the runway according to its slope*").

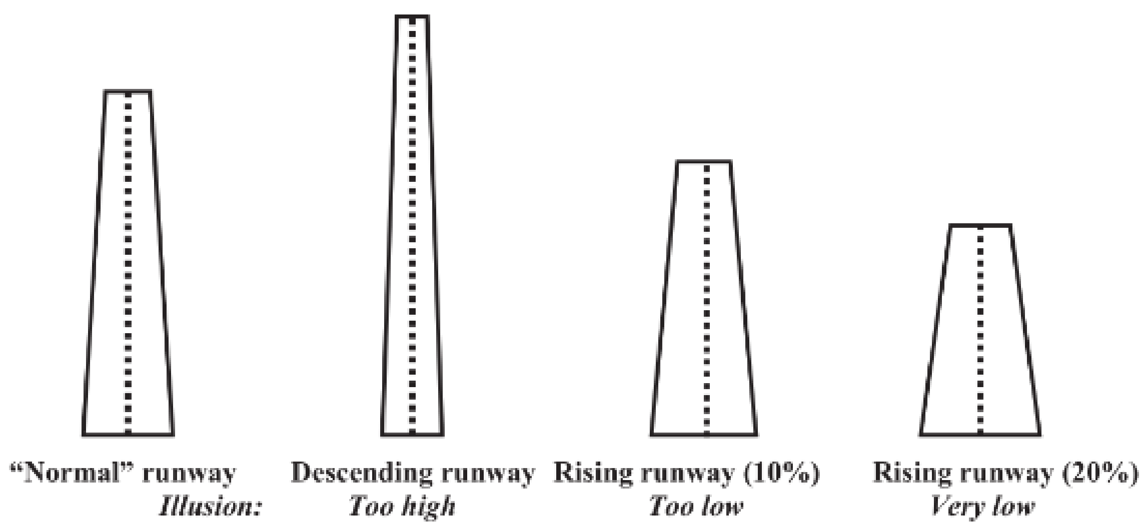
The illusion due to the raised runway creates all the difficulty of landing in the mountains on a high-altitude runway. The training is specific and requires the issuance of a special qualification.



Visual perception of the runway according to its length and width.



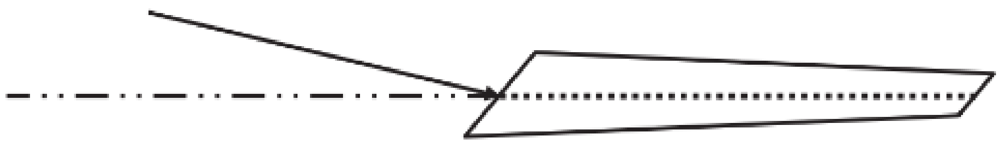
Perception of a "normal" runway according to the angle of approach.



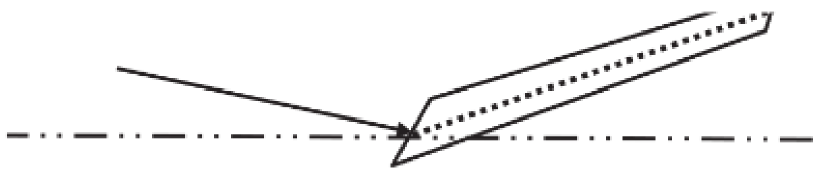
Visual perception of the runway according to its slope.

Let's review the illusion mechanism with a geometric side representation of the situation. A proper approach is made according to the surface at 5% slope *(Figure "Normal approach path: slope of approach at 5% (3.3°). The runway surface and geographical horizontal plane are confused"). With a rising runway, the pilot must adhere to the same slope of approach in relation to the geographical horizontal (Figure "Rising runway, correct approach path (5% compared to the geographical horizontal plane").*

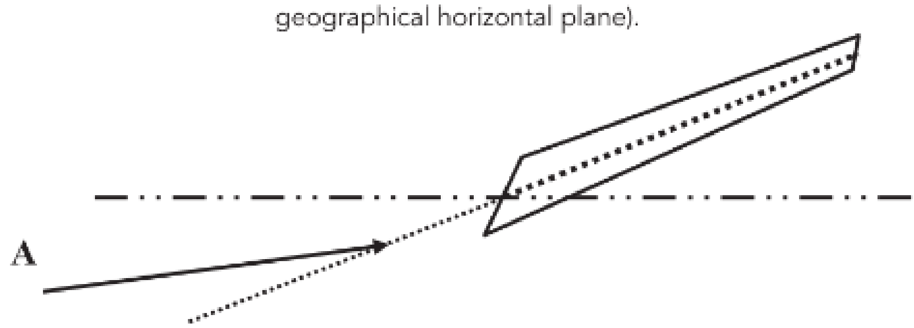
A particularly dangerous case is of the pilot, misled by a runway with a sharply rising slope (Figure "Very incorrect approach path: rising runway, the pilot has been the victim of the illusion from being too high on the plane. He is positioned too low. Being very close to the ground and at low speed, the half-turn is no longer possible. Accidents become inevitable.") seeking to assimilate the runway surface with the geographical horizontal; he then takes his slope of approach in relation to his visual perception, and not in relation to the geographical position of the runway threshold.



Normal approach path: slope of approach at 5% (3°).
The runway surface and geographical horizontal plane are confused.



Rising runway, correct approach path (5% compared to the geographical horizontal plane).



Very incorrect approach path: rising runway, the pilot has been the victim of the illusion from being too high on the plane. He is positioned too low. Being very close to the ground and at low speed, the half-turn is no longer possible. Accidents become inevitable.

To summarize:

- On a raised runway (or if the ground rises in front of the runway), there is an illusion of being too high;
- On a descending runway, there is an illusion of being too low.

2.5.3 - Sensory illusions of vestibular origin

Spatial disorientation of vestibular origin is explained:

- By the physical characteristics of the signal;
- By the non-linear nature of the physiological perception of the physical signal;
- By interpretation errors of the physical signal.

a) Errors related to the physical characteristics of the signal

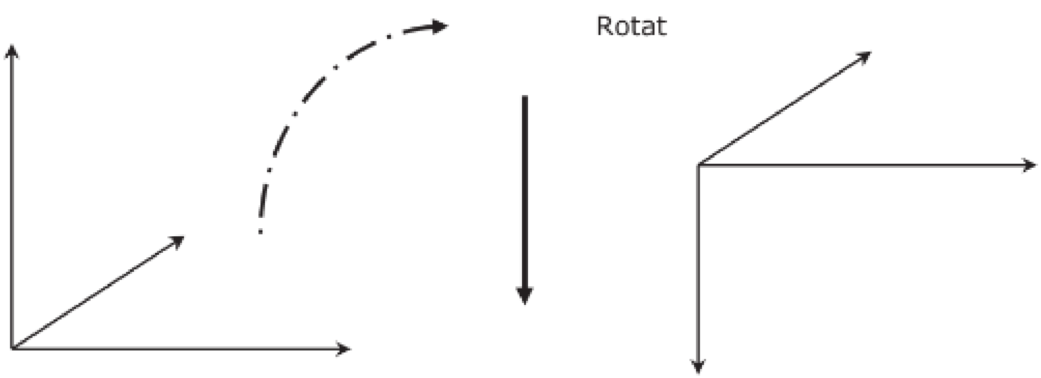
Coriolis effect

Representation of Coriolis effects.

The Coriolis theorem applies to complex movements and describes the forces involved when an object moves in relation to a repository itself in motion.
Figure (left): Application to linear movement in relation to the earth. Figure (right): Circular motion in relation to a repository, itself in circular motion; Coriolis acceleration then depends on the mobile position on its relative path and instantaneous speed vector.
In aeronautics, Coriolis accelerations can have devastating effects. They are observed in the sensors of the vestibular system when, mobility is changing, the subject turns his head. They are the source of very strong illusions of tilt.
"Oculogyral" illusions may appear during the Coriolis effect. We have described the vestibulo-ocular reflexes, which causes eye movement when the vestibule is stimulated (see paragraph "Relationships between various receptors: Multisensory perception of space").

This is what happens during a situation with Coriolis acceleration. The image on the retina of a point fixed objectively moves, giving a misperception of movement

Role of changes in semicircular canals
The representation of this factor is simple (Figure below). It is sufficient to represent the three semi-circular canals as a triaxial sensor and to rotate it, e.g. around the axis (Z):



Changes in semicircular canals

This principle applies in the case of an aircraft making a stabilized turn. After some time stabilizing, due to their adaptability, the sensors of the semi-circular canals no longer provide information on the tilt of the aircraft and the feeling disappears.
Turning the head: Each semicircular canal changes direction in relation to the space and between in a new cycle of excitation. In general, you will perceive a rotation around a third axis. However, you may also be the victim of the sudden triggering of an episode of motion sickness (airsickness). This mechanism combines well with Coriolis accelerations. Your passengers are particularly sensitive to all of this (Illustration below).

Here is an example: The pilot proposes to his passenger a flyover of the Château de Chambord. He performs a low-speed circle around the Château; the wings are tilted at 40°.
Two hypotheses are possible: In the first hypothesis, the pilot informs the passenger of the existence of the illusion and explains to him that he must maintain his view on the Château, which the pilot carefully maintains at the end of the wing; the passenger will also have been instructed about the need to have his camera prepared before the manoeuvres and the need to manipulate the head position without changing it. Everything goes well. In the second hypothesis, the pilot does not warn the passenger and, to give the "TP" greater impact, proposes to the passenger some current manoeuvres, tuming around to pick up the camera in the backseat, while looking at the Château and the hot air balloon that flies nearby (which is common at Chambord), etc. A normal passenger does not finish the complete tour of the Château, and the photos are missed!

The photograph of Illustration above was taken at 1,100 ft. QNH, when flyovers of the Château de Chambord were not yet prohibited at this altitude.

b) Errors related to the non-linear nature of the physiological perception of the physical signal

Illusions of tilt are errors related to the threshold effects.
Illusions of tilt are explainable by the existence of a sensitivity threshold for semicircular canals. These illusions are frequent, powerful and dangerous. They are observed during flights with poor visibility or no visibility. They can be intense enough that the pilot, although being aware that it is only an illusion, actually looks for or relies on a side wall of the cockpit to "keep his balance". Training teaches the pilot ignore these sensations and only fly using his instruments.

The illusion of tilt is observed during a gradual motion of the aircraft in roll at a subthreshold speed (below the threshold), followed by a suprathreshold inverse manoeuvre (above the threshold): this illusion is classic. It occurs in instrument flight (IFR), when the pilot has not perceived the slow drift of his aircraft in roll. When he becomes aware of the aircraft's attitude, he corrects it using a suprathreshold motion. This can then give him a strong illusion of tilt in the direction of the correction.

From an operational point of view, this Illusion tends to oblige the pilot to maintain the erroneous attitude in turning, with the tilt of the aircraft.

An inverse illusion of the previous one can be observed when a rapid rolling motion is introduced (e.g. turbulence followed by a slow return to the horizontal position). It is the first movement that is perceived, and not the second. The pilot continues to feel the first tilt, and then it no longer exists.

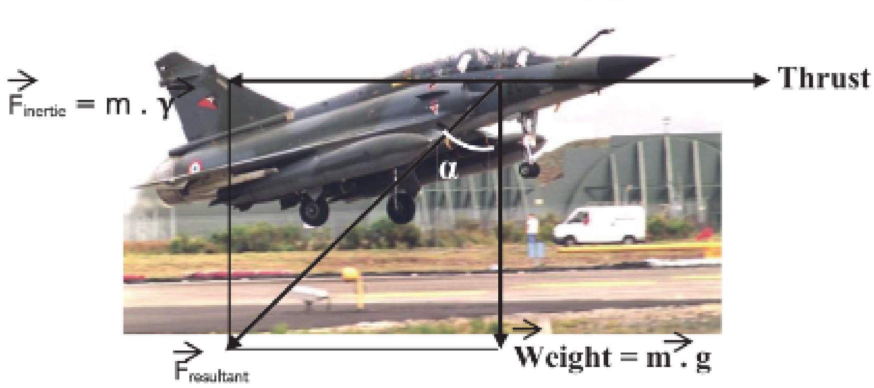
c) Interpretation errors of physical signals

The physical signals perceived and interpreted by the body can give false indications; these are the somatogravic illusions of nose up, nose down and inversion, as well as the somatogyral illusions of rotation or tilt.

Somatogravic illusions of nose up, nose down and inversion
One accident occurred (1988), during which an insufficiently experienced pilot on a powerful aircraft departed under poor weather conditions (the base of the cloud layer was at 350 ft.). He had the aircraft's nose too high. Probably the victim of an inversion illusion, he manually adjusted and struck the ground at the end of the runway after a desperate recourse. The hypothesis of sensory illusion was retained to explain this accident.

The otolith system as well as somesthesia only detects the apparent direction of the gravity field and not the direction of geographical gravity. Various movements of the aircraft can cause this type of disturbance. Figure below shows an example, taken from military aviation. The resulting vector can then be erroneously considered as a reference of verticality, causing a poor perception of body orientation in space.

In practice: The illusion of a wheelie is observed on high-performance aircraft during takeoffs assisted by rocket, or catapulted, in poor visibility. In the absence of external visual reference points, the pilot feels the illusion as the aircraft's nose rises and may give an inadvertent order to point the nose down. Ultimately, it is the inversion illusion: The pilot has the feeling of falling backwards. The illusion of a nosedive is observed by the sudden braking; in military aviation, it is dangerous during flight patrol; the patrol slows abruptly and the illusion of a nosedive may cause an erratic action to pull the nose up, risking a collision with another aircraft.



Vector composition of the forces of gravity during the takeoff of an aircraft.

On Figure "Vector composition of the forces of gravity during the takeoff of an aircraft", the resulting field of gravity is the sum of terrestrial gravity, obviously always present, and inertia of the pilot in relation to the aircraft (i.e. during takeoff, the pilot is pressed backwards against his seat).
In the absence of visibility, the resultant can be taken for the terrestrial gravity vector only; the corresponding illusion is the nose lifting up. Conversely, a vigorous deployment of the speed brakes in flight, possible on this fighter jet, causes a strong illusion of a nosedive.

Somatogyral illusions
Somatogyral illusions are illusions affecting the perception of rotating movements. The cause of these illusions lies in the functional adaptability of semicircular canals. They appear preferentially when visual information is lacking. However, they are so powerful that they can also manifest themselves in the clear sky. They are responsible for disasters.

- Illusions of rotation in a spin, extremely serious in flight. During a spin, functional adaptation of the semicircular canals leads to a disappearance of the sensation of rotation, under conditions where observing the instrument panel can also be difficult. When the pilot performs maneuvers to pull out of the spin, he perceives the rotation in the opposite direction, and it is likely, to correct this sensation, putting the aircraft in the previous spin. This is the death spin.
- Illusions of rotation during a spiral. With an illusion similar enough to the previous one, otherwise the aircraft is not in a situation of loss of control or aerodynamic stall. The consequences are the same for the death spiral as they are for the death spin.

2.5.4 - Complex sensory illusions of mixed origin, vestibular and ocular

Some illusions are due to the existence of vestibulo-ocular reflexes. These reflexes are interpreted as an anticipation of eye movement, so as to ensure the stability of the focused gaze, regardless of the movement to which the mobile platform of the head is subjected.
Let's give an example. You are on a motorized lawn mower and your gaze is pointing toward the clump of grass to be cut. During your ride, an irregularity in the surface causes an acceleration. This is perceived by your vestibule and vestibulo-ocular reflexes, thereby locking your gaze on the objective.

You are now in your aircraft and you look at your instrument panel. Turbulence occurs. It is not possible to neutralize your vestibulo-ocular reflex. Therefore, the reflex causes a deviation of the eyes. As there is no displacement between your head and the instrument panel, eye movement causes a displacement of the image of the instrument panel on the retina, which you can interpret as a movement according to the pitch axis.

Oculogyral illusions. It is the apparent shift of an object placed before a subject, which undergoes an angular acceleration. The vestibulo-ocular reflex is triggered by rotation. This illusion is easily highlighted: Prepare the swivel chair with a bright point set along the axis of vision, and then sit a subject on this chair in the dark and turn him, while asking him to focus on the bright point. While the chair rotates, the light appears to move in the same direction as the rotation, with an amplitude that can reach 30°. After stopping, it appears to move by saccades in the other direction and with an amplitude that can reach 60°.
In flight, this type of illusion appears when there is only one light or a single star in an empty visual field. The apparent motion from the isolated light may persist for many seconds, or even several minutes.

2.5.5 - Spatial orientation disorders of cognitive origin

There is a category of spatial representation disorders, without any particular movement of the body, related to mental representation that makes him pilot of his position in space. Although not documented, these disorders seem quite real. They are reported both by the pilots as well as their monitors.
The actual position in space and the perceived position are different; from one actual example. With poor nighttime visibility, the pilot was preparing to move from the downwind leg to the base leg, by a turn of 30° bank angle. He looks at his artificial horizon and finds that he is already tilted at 30°. Therefore, no change of attitude needs to be made to the aircraft. Yet, he feels a violent sensation of dizziness for a few seconds, leading to a severe restriction of is piloting ability.

Positioning in geographical space; this difficulty is observed in two main circumstances. The first is starting navigation, just after takeoff. The second is alignment on a navigational axis, after flying over a turning point or a series of changes. Some pilots experience a real difficulty in intuitively viewing the navigational axis that they must rejoin. They have the very powerful illusion of having to place their aircraft in a direction, which has nothing to do with what is indicated on the card.
This illusion can lead to serious navigation errors during visual flight. Even when it does not lead to a direct error as a pilot, it induces a heavy work overload.

2.5.6 - Conclusions

Sensory illusions are a serious risk in flight. Flight without visibility (instrument flight) or with reduced visibility outside is a formidable factor in sensory illusions and accidents. However, sensory illusions are not confined to only sensory perception disorders.
Generally, they include any mental representation disorders that the pilot makes with the surrounding space. The prevention of sensory illusions is complex, involving multiple actors, to teach the different mechanisms of sensory perception and their limits, to demonstrate the reality of illusions in the simulator and in flight, and finally to train pilots in instrument flight.

It is appropriate that pilots, and generally any air safety actors, are convinced that sensory illusion is a physiological, deterministic, and inevitable process. This is in no way a "weakness" on the part of the pilot, or an admission of failure. It is an unavoidable physiological consequence of flight; instruction, training and availability of relevant equipment serve to mitigate this disorder.

2.6 - Motion sickness

Synonyms: Motion sickness, travel sickness, airsickness.

2.6.1 - Description

All modes of transportation are likely to lead to a set of symptoms grouped under the term motion sickness or travel sickness. Motion sickness (sometimes also referred to as "travel sickness") may also occur during movements only suggested by vision, such as in the simulator. During aircraft movements, the highest generating vibration frequencies of motion sickness are between 0.5 and 2 Hz.
Motion sickness occurs only when the vestibule is intact. Statistically, the frequency of motion sickness is low before the age of two (2) years, increases between two (2) and 12 years, and then decreases; then the frequency increases after 60 years. It is traditional to claim that women are more susceptible to motion sickness than men (this is probably not true…).
The frequency of motion sickness varies with the mode of transportation used. By aircraft, the frequency varies greatly depending on the size of the aircraft. Historical statistics indicate that the incidence is approximately 1% in commercial passenger aircraft and 8% in aircraft used for tourism; in fighter jets, approximately 50% of navigators and 40% of pilot students experience motion sickness during their initial training.

The pilot is usually not prone to motion sickness (which is good news!), unlike the passenger. However, a pilot flying as a passenger can be affected; this last remark is not without importance, due to the change of systems, the pilot can become the passenger of his own aircraft. Modern autopilot systems and, even more, ground monitoring systems at very low height in military aviation are technical improvements.
Many psychological and environmental factors have an impact on the frequency of motion sickness. In addition, heat, odors, noise and anxiety promote the occurrence of the symptomatology.
Motion sickness leads to hyperventilation. Hyperventilation syndrome (see p. 30) and motion sickness are highly promoted or aggravated by anxiety; we have here the most frequent cause of passenger discomfort in commercial aviation.
The symptoms of motion sickness are well known: drowsiness, sweating, hypersalivation, pallor and nausea; then, vomiting. Subjects who experience motion sickness are often despondent and indifferent.

2.6.2 - Prevention and treatment

There is a need to restrict the movements of the head. Closing the eyes may be beneficial. Desensitization programs based on training or biofeedback techniques have yielded interesting results.
Treatment of motion sickness with medication remains quite disappointing. The number of molecules tested is significant, with varied results. Currently, the reference product is scopolamine, marketed in the transdermal form (patches) under the name of SCOPODERM TTS. Other product categories have antinaupathic properties, particularly MARZINE™ or TRANSMER™. Any products used cause a decrease in vigilance and have some contraindications of a medical nature. Thus, they are not always usable. It is possible to combine them with stimulants for mitigating hypovigilance, but the dosage is complex.

Other molecules have been proposed, such as cinnarizine and flunarizine. These products have antinaupathic properties without side effects, at least conventionally used doses.

Therefore, motion sickness treatment is still inadequate at the present time, which makes it useful for prevention:

- Avoid turbulence (choose proper flight levels - whenever it is possible);
- Position sensitive passengers of large aircraft near the center of gravity of the aircraft;
- Fly to avoid nausea-generating manoeuvres; for example, by avoiding accelerations - G_Z due to a nose down action being too abrupt (rising runway landing or descending runway landing); remember that the perception threshold of acceleration - G_Z is 10^{-2}G;
- Instruct the passengers: During a VFR flight of discovery, inform them that, during the turn at 30°, they will have to keep their head fixed in relation to the aircraft; prevent them from moving at the beginning and end of the turn (see Illustration 2.3, p. 30);
- Discourage passengers from becoming agitated;
- Prevent their distress (by talking);
- Eliminate additional risk factors, such as consuming alcoholic beverages.

03 HEALTH AND HYGIENE

3.1 - Circadian rhythms, vigilance and sleep

3.1.1 - Definitions and reminders

Definition of words used

The word Circadian means "approximately 1 day" (from Latin, circa = approximately; diem = day).
The words nycthemeron and nycthemeral refer to the day-night cycle (from Greek, the words meaning day and night).
Chronobiology is the study of biological rhythms of living organisms.
Jet lag is due to rapidly crossing time zones, where the legal and social time of arrival is different from the time of departure.

Shift work is characterized by varying work schedules (e.g. work shifts of "3 x 8 hours" in an industrial environment).
Sustained operations, a term often used by the military, are operations of a duration that significantly exceeds the amplitude of the normal working day. Sustained operations may extend continuously over two to three days.

On long-haul flights, the professional activity of the aircrew in commercial aviation is a mixture of jet lag, shift work and sustained operations.
Circadian rhythms are biological rhythms, of about 24 hours.
Numerous experiments have shown that, without a time measuring device (independent experiences), the human body has a spontaneous rhythm whose period is about 24.5 - 25 hours.

The most powerful rhythm of the environment is obviously the day/night cycle due to the rotation of the Earth itself. This sets the human rhythm to 24 hours under natural conditions.
Being put in a "timeless" situation, with rigged clocks, has enabled us to show that the human body can synchronize in a maximum interval between 21 hours and 28 hours. Rhythms of less than 21 hours are called "ultradians"; rhythms greater than 28 hours are called "infradians".

This gives us a first indication of human capacity to tolerate jet lag. As long as humans have traveled by surface means, the apparent duration of the nycthemeron varied a fraction of time and disorders linked to jet lag were not observed.
By contrast, aviation has introduced the rapid crossing of several time zones, with the possibility to observe inversions of rhythm (12-hour difference at the end of a 20-hour journey). The nycthemeron period of the body is then temporarily included in the 21-28 hour interval and "jet lag" symptoms appear.

The word jet lag refers to the set of disorders that the human body feels when subjected to a time difference greater than its capacity to adapt.

To explain the existence of circadian rhythms, it is typical to theorize the existence, in the vegetative areas of the central nervous system, of a biological clock or a "pacemaker".

3.1.2 - The main circadian rhythms of the body

The functioning of the body integrates a rhythm component. The most known is obviously the sleep-wake cycle. Other body functions are involved depending on the time of day. Two of them are remarkable: body temperature and cortisol rate.
We will describe three of the main rhythms of the body.

a) Thermal rhythm

The average body temperature of a calm subject varies between 36.5 and 37.2°C during the nycthemeron period, with the minimum at the end of the night, around 5:00 a.m. The exact form of this rhythm then varies according to the activity of the subject.
Body temperature is a complex function, which integrates multiple components of the body (several sources of heat production and several systems of heat dissipation).
Thermal function can therefore be divided into several subsets, each one having a very marked rhythm, but generally the rhythm of body temperature may serve as a marker to study the rhythmicity of the body and its disturbances.

b) Hormonal rhythms

The main hormonal rhythm is corticosteroid production. The secretion of this group of hormones, containing cortisol, is controlled by hypothalamus cells, with relay in the pituitary gland. The cortisol secretion rate is much easier to measure than the hypothalamic activity; it is thus a good indicator of the pacemaker activity.
With the role of cortisone in a large number of cellular functions being very pronounced, this hormone serves as a "delegate" synchronizer to pace the activity of different parts of the body.

c) Vigilance rhythm

The vigilance rhythm appears as a consequence of all of the numerous rhythms of the body.
We will remember that it presents two minimum characteristics:

- One with a strong tendency to sleep in the early afternoon (siesta time);
- The other with a very sharp decrease in performance, at the end of the night, around 4:00-5:00 a.m.

3.1.3 - Adaptability of circadian rhythms of the body

When the body is placed, as a result of a transmeridian air travel, in an environment in which the local time of arrival is not identical to the time of departure, how does the body reset itself?
We have indicated that experiments in an isolated environment with rigged clocks showed that body rhythms can adapt to a 21-28 hour interval. Therefore, we have described the limit of adaptation for transmeridian travel.

In practice, we observe:

- That the journey from east to west (Europe → to North America) is better supported than travel in the opposite direction from west to east (Europe → to the Far East);

- That, from east to west, the resetting takes place at a rate of 3 hours per day and, in the opposite direction, at a rate of 2 hours per day.

We can admit that, for very significant time differences, close to the inversion (between 9 and 12 hours), the complete resetting only occurs at a rate of 1 hour per 24 hours.

However, these are very average values. Every rhythm of the body does not resynchronize in phase with each other, which seems to be a significant source of fatigue.

3.1.4 - Sleep

A number of scientific works have demonstrated the bad effects on crews with reduced sleep cycles, because of lack of restorative rest or changes in the architecture of sleep.
All of this creates real risks for the pilot: periods of drowsiness, lack of vigilance in monitoring processes, decreased performance of cooperative crew work, decreased ability to integrate incoming information and decreased ability to make cognitive decisions in case of machine malfunction.
Beyond a certain level of sleep deficit, crews are victims of involuntary microsleep episodes, even during crucial periods in flight (descent, until landing; a case was observed).

Sleep can be explored by recording the electrical activity of the brain, this is an EEG (electroencephalogram). This analysis is completed by recording the electrical activity of some muscles, particularly the muscles of the neck and chin, as well as the motor muscles of the eyes. We then speak of polygraph or polysomnographic recordings. The plots had different stages of sleep which could to be recognized.

a) Description of states and stages of sleep

Two main states of sleep are usually recognized: "normal" sleep, itself subdivided into four stages, and "REM" sleep.

Wakefulness During wakefulness, EEG activity is rapid and desynchronized. By and large, each area of the brain works, and it results in a quick random, low voltage average surface activity.

Stage 1 sleep. The electrophysiological plots resemble those of the awakened subject, and then slow down. Slow movements of the eyes occur. It is an intermediate state between wakefulness and sleep: The subject remains aware of changes in the environment and vocal messages can be perceived. If the subject is awake at this stage, he denies being asleep; he does this in good faith, because he is not aware of falling asleep. This state is obviously dangerous from the standpoint of flight safety. Such transitory states may be identified as microsleeps. Note that they are common in subjects who watch television in the evening. In flight, microsleeps are the source of significant losses of vigilance in performing the tasks of a pilot.

Stage 2 sleep. During normal sleep, stage 2 appears after 5 minutes of stage 1. It is maintained for 10 to 20 minutes.

Stages 3 and 4 sleep (stages of deep sleep). They are characterized by EEG rhythms of low frequency and large amplitude (SWS, Slow-Wave Sleep). They are differentiated by EEG analysis. It is more

difficult to wake up a subject in deep sleep than it is a subject in stage 1 or 2. In addition, the subject removed from deep sleep may take several minutes before recovering all faculties of wakefulness, which defines the concept of "sleep inertia".

Recall the concept of "sleep inertia": time that it takes the subject, after imposed awakening, to recover a state of total vigilance and mental performance.

REM sleep. It intervenes after 30 minutes of stage 4, therefore 1 to 1 1/2 hours after falling asleep at night, but it may appear very quickly during the afternoon siesta, or after a long deprivation of sleep. The EEG of REM sleep looks like the EEG of wakefulness and eye movements are rapid. In contrast, the postural muscles of the subject become very relaxed and it is difficult to pull him out of his sleep.

The term "REM sleep" comes from this dissociation: behaviour of the subject in deep sleep, EEG of wakefulness and dissociated muscular activity, awakening for some muscle groups and deep sleep for others. If the subject is awakened during an episode of REM sleep, he frequently recounts a dream and, conversely, the vast majority of dreams occur during REM sleep.
The qualifiers "paradoxical" or "rapid eye movements" reflect the same perplexity of the researchers who first observed these symptoms… and who were a little "dry" on their interpretation. These qualifiers have been retained.
We will note two concomitants of REM sleep: secretion of a specific hormone, of pre-pituitary origin, which is the growth hormone and, in men, the erection.

Distribution of sleep stages during the night Sleep is not constant during the night. Sleep cycles of approximately 1 1/2 hours are observed, 5 to 6 on average, during alternating stages 2, 3, 4, 2, and then REM stage. Episodes of stage 1, or even awakening, interrupt this alternating during the night, after an episode of REM sleep. At the end of the night, the "REM sleep" phase ends more frequently by awakening, of longer or shorter duration.
The normal duration of sleep among adults is 7 to 8 hours per day, with interindividual variations ranging from 5 to 6 hours up to 9 to 10 hours. It is said that this duration decreases with age.

b) Acute pathophysiological consequences of sleep deprivation

Under the operational conditions of sleep deprivation, i.e. when this is due to an imposed activity, the sleep that follows is richer in stages 3 and 4, which intervene much earlier after falling asleep. The same is true of REM sleep.
These very specific kinetics of sleep after deprivation are significant in considering whether "naps" should be authorized in the course of professional activity, after a long period of activity. Authorized microsleeps occur immediately in the form of deep sleep with a significant inertia; consideration must be made as to whether the subject is expected to resume control or command at the end of this microsleep.
In the long term, sleep deprivation causes mood disorders.

c) Relationship of sleep with other circadian rhythms of the body

Sleep is much better when it is in phase with the fundamental rhythms of the body, well-evidenced by the rhythm of body temperature. If sleepiness occurs only out of phase with other rhythms, the restorative quality of sleep decreases.

Sleep disturbances Sleep can be disrupted by factors of the environment: noise, light, heat or cold, uncomfortable body position, without mentioning the neighbor or spouse who snores…
The causes of sleep disturbance of medical origin, psychoemotional origin, anxiety, etc., are not restricted to aeronautical personal and are the responsibility of the usual therapist and aviation medical specialist (who will have to check the compatibility of the disorders and their treatment with aeronautical activity).

Finally, a number of medicinal or equivalent substances contain stimulants. These substances may be listed as benign; for example, various over-the-counter pain medications. However, they may contain significant doses of caffeine or ephedrine, which are central nervous system stimulants. Do not forget that the pilot does not operate only in France and that, outside France, there are over-the-counter substances that the French do not usually issue without a prescription. Thus, there is a significant risk of sleep disorders, related to self-medication practiced in good faith and ignorance.

3.1.5 - Management of circadian rhythm disruptions in aeronautics

The disruption of circadian rhythms in aviation can be managed by several means, pharmacological or otherwise.

a) Non-pharmacological management of circadian rhythm disruptions

Instruction of personnel and procedures adapted to improve the tolerance to circadian rhythm disruptions.

Instruction
Personnel must know that a reduction of 1 to 2 hours of sleep per day decreases psychomotor skills.

They should also know that:

- A pilot's motivation for his work, training or willingness does not prevent this deterioration;
- A given individual is not a good judge of his own level of performance;
- Interindividual variability is high;
- There is no miracle solution adaptable to all for combating these, other than sleep itself.

We reproduce here an English document (J. Caldwell, "The good sleep habits", in Ernsting's Aviation Medicine, 2006):

"Allow some time for waking up and plenty of sleep time each day of the week, if possible;
Only use the bedroom for sleep and sexual relations (in other words: do not use it as an office);
Resolve daily problems outside of the bedroom;
Your sleep rituals must be respected as much as possible;
Establish and maintain physical aerobic exercise habits;

Establish calm and comfort around your rest area;
Use an eye mask to isolate ambient light;
Use ear plugs to isolate ambient noise;
No coffee or caffeine within 4 hours before scheduled sleep time;
Do not use alcohol as a sleeping aid;
Do not smoke before going to sleep;
Do not sleep during the day if you have trouble sleeping at night (this last instruction does not apply to short naps taken during a long period of intentional wakefulness). "

Procedures

- Sleep on board Sleeping on board, outside the cockpit, is authorized for civilian or military flights when there is an augmented flight crew (at least three pilots) and rest facilities are available on board.
- In the United States, augmented flight crews are mandatory for long-haul flights of more than 12 hours. On some military aircraft, such as the American B-2, specific provisions are planned, taking into account aircraft characteristics and potentially very long missions. Although the quality of sleep on board is not like normal sleeping conditions, there is an undeniable advantage in being allowed to sleep, regardless of its quality, compared to a continuous state of wakefulness over a very long duration.
- Cockpit naps ("short snoozes in the cockpit"). Currently, it is possible to allow the pilot to take short periods of sleep at his post, while the other pilot is at the controls of the aircraft.
- NASA studies have validated this procedure for airline pilots, observing sleep periods of 30 minutes as being a safe and effective method to improve performance. Naturally, this procedure can only be applied with effective crew cooperation. The rest period should allow 30 minutes for sleeping and 20 minutes for recovery.
- However, the operational use of "naps" should not make us forget that, if "naps" are taken in a context of sleep deprivation, the sleep of the "nap" may then immediately become a deep sleep, SWS (stage 4), and present a significant inertia when awakening. All this should be carefully weighed.
- Controlled rest. During night flights, short periods of rest, with movement in the cabin, reduces uncontrolled episodes of drowsiness. The periodic change of posture, in the sense of a more upright posture, also goes in the same direction. The recommendation is that, during night flights, each pilot moves around in the cockpit or cabin for a few minutes every hour.
- Proper planning of schedules. It is often a pious wish… The activity of aircrew is supervised by a national, international, or regulatory body, without forgetting the operational constraints (transporting passengers on time …).
- Taking this into account, the chronobiological needs are often neglected by necessity or by ignorance, in flight planning.
- Retraining through light, food and exercise. These three factors are very powerful synchronizers of social life and circadian rhythms. If the layover is long, the subject will quickly readjust to the local time; if, instead, the layover is short, it will be better to remain at one’s original time. Light, eating times and exercise will greatly help
- In some cases, it is possible to anticipate the time difference; outside the world of the aircrew, this may be the case of sports teams brought to compete in distant locations.

Before the trip itself, a strategy may be proposed, including a progressive phase shift to the new time, and using the three factors of the environment cited above (light, food and exercise).

- Retraining to the local time or not? We have just discussed this subject. When the time difference exceeds 6 hours, the common opinion is the following:
- For inbound stays of less than 2 days: Do not attempt to retrain and live as much as possible according to the time of departure. One management element is important: the choice of hotel, which if it is an establishment of sufficient standing, will offer a calm atmosphere to its customers (and possibilities for flexible local dining times);
- For inbound stays longer than 4 days: Synchronize as quickly as possible to the local time during your stay, and then manage your sleep by any means available to arrive on the aircraft without sleep debt for the next flight.

b) Pharmacological management of circadian rhythm disruptions

Certain medicinal substances help the subjects to sleep at the appropriate time and to be awake and efficient when they are at their workplace.

- Melatonin. Unproven …
- Sleep inducers. Short-acting benzodiazepines: These drugs have as their leader Diazepam (VALIUM®), whose duration of action is greater than 24 hours; for this reason, this molecule is not usable as a sleep inducer. Derivatives of Valium have been synthesized, with a short duration of action. In particular, these include Temazepam (in France: NORMISON®), Lorazepam (TEMESTA®), Bromazepam (LEXOMIL®), Flunitrazepam (ROHYPNOL®, whose use is currently very limited because of its side effects). The hypnotic effect of these tranquilizers wears off after a few days of administration, but for a very limited use over time (one or two nights), their hypnotic effect is very interesting.
- Zolpidem (STILNOX®, USA: ABIEN®), Zopiclone (IMOVANE®), Zaleplon (SONATA®, STARNOC®) was introduced more recently. They present interesting alternatives to the usual benzodiazepines.
- To maintain wakefulness Modafinil (MODIODAL®) was extensively studied in the years 1980-1990; used in sleep pathology, it currently seems to be less used to maintain wakefulness. Caffeine, in its extended release form, is an interesting substance, without significant side effects, used by the military aviation industry. Amphetamines are interesting stimulants, with few side effects. The U.S. Army has often used them. In France, amphetamines are classified as narcotic drugs; as a result, their detention and use are illegal.
- Induce sleep and maintain the wakefulness: General precautions for use. Naturally, these pharmacological methods have been tested under neutral conditions before their use under operational conditions (in practice: during a period of rest).
- In addition, some of these substances may randomly present some side effects from one subject to another; prescribing and monitoring should obviously be personalized, under the supervision of a specialist doctor in aviation medicine.

All of these substances formally prohibit the use of alcoholic beverages.
Reason: They are active substances on the central nervous system (CNS), in the same way as alcohol. Active substances on the nervous system have severe enough results. All hypnotics interact with alcohol on the CNS.

3.2 - General problems of the aviator

3.2.1 - Barotraumas

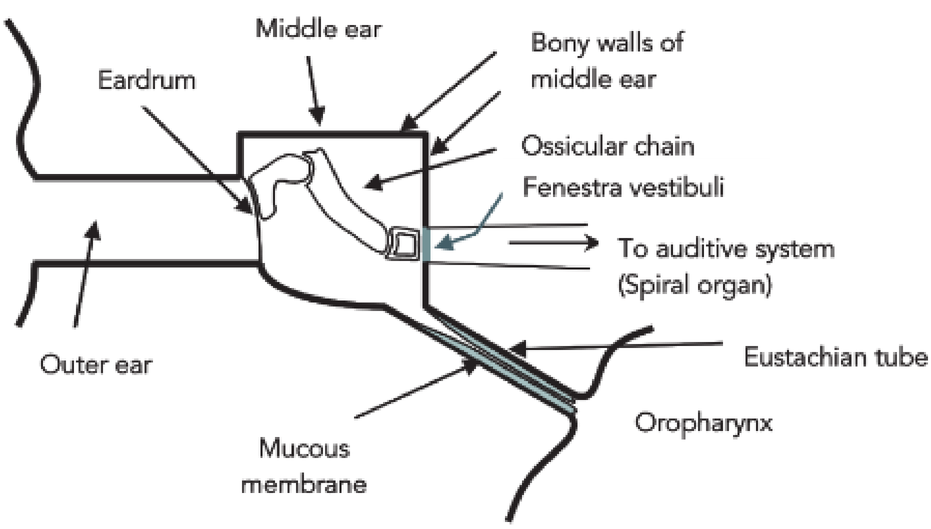
Barotraumas (sometimes called dysbarisms) are the mechanical consequences of human exposure to altitude. They are due to the direct application on the body of Boyle-Mariotte's physical law. Gases are contained in free form in closed or semi-closed cavities of the body. Pressure variations lead to changes in volume. However, the walls of body cavities are not freely distensible. Gas expansion is limited by the elastic characteristics of the walls, whose distension can be very painful before possible rupture.

It should be noted that the symptoms are comparable to what is observed in the course of scuba diving. These traumas due to pressure, or barotraumas, primarily affect the ENT (ear, nose & throat) cavities and digestive tract.

a) ENT barotraumas

ENT barotraumas affect the ears and sinuses. Figure below represents a diagram of the outer and middle ear. The middle ear is a bone cavity closed on its external face by a thin membrane, the eardrum. The middle ear cavity communicates with the outside through a very winding duct, dug into the bone; this is the Eustachian tube.

The Eustachian tube communicates with the back of the mouth. It is lined with a respiratory mucous membrane that, with its orifice pointing outward, may result in thickening. In practice, this mucous membrane may behave as a true one-way valve, only allowing gas to pass by in one direction, or generally for their evacuation.



Schematic representation of the outer and middle ear.

Barotraumas are due to the valve effect. While climbing in altitude, the barometric pressure, decreases, the volume of gas contained in the middle ear increases and the excess volume drains easily. In the descent, the Eustachian tube remains closed; a gas deficiency is formed in the middle

ear, causing a pressure difference on either side of the eardrum. This may be the location of various lesions (distension, maceration, perforation) and/or a sharp pain.

A single barotrauma with an isolated eardrum lesion, and well-treated, generally heals without sequels. In contrast, repeated barotraumas can produce a hearing impairment (deafness).

In rare cases, the consequences of otitic barotrauma are much more serious, reaching the inner ear, in the form of sensorineural hearing loss, sometimes immediate, total and irreversible. It should be noted that this phenomenon is not symmetrical; this deafness affects only one ear. In addition, the damage can spread to the other nearby sensory organ of the inner ear, the labyrinth, which is the organ for equilibrium.
The barotrauma of the inner ear may account for deafness and/or an equilibrium disorder (major).

The sinuses are cavities in the thickness of the cranial bones. They are filled with gas and communicate with the outside world through narrow channels, whose structure is comparable to the Eustachian tubes. Only slightly opened to the exterior, these cavities become infected easily. Their infection constitutes sinusitis. Barotraumas of the sinuses respond to the same mechanism that has been described for the middle ear; they cause sharp pain, generally in the frontal sinuses, above the orbits.
ENT barotraumas (ear infections and sinusitis) occur mostly in the descent. They are very aggravated by any respiratory tract condition (flu, "cold", etc.).

In civil aviation, they represent a common cause of temporary or indefinite unfitness of commercial aircrew personnel. Their prevention is based on the medical tests, the prohibition of flying with an inflammatory ENT infection or a genuine sinusitis, and the prevention of seasonal ENT disorders.
In commercial aviation, ENT barotraumas are the main consequence of accidents or incidents of accidental in-flight depressurization. The depressurization phase itself does not typically pose a major problem, even if the rise is rapid. By contrast, the descent can produce several ENT disorders. In press reports published as a result of such events, any "injured" refer to persons with ENT barotraumas.

b) On-board treatment of ENT barotraumas

Preventive action: Do not fly.

Curative actions:

- Mechanical methods: Valsalva manoeuvre. Inhale, pinch the nose with the fingers, close the mouth and make an effort to exhale. Under normal conditions, you can feel the overpressure in the eardrums. In case of blockage of the Eustachian tube or similar canals that communicate with the sinuses, this operation can force the passage of air.
- Pharmacological methods: local instillations of vasoconstrictors can unblock the ENT ducts, through a contraction of blood vessels in the mucous membranes (e.g. ATURGYL®, DETURGYLONE®). A painful otitic barotrauma may benefit from a local anesthetic (OTIPAX®). Pay attention to the fact that we only refer here to palliative care methods, treating the pain on board for a few hours. We do not discuss substantive or curative treatments; for example, local anesthetic to ease the pain of otitic barotrauma,

which leaves the potential infectious risk created by the eardrum intact. Consult with a physician on arrival.

c) Aerodontalgia

Dental pain due to the rise in altitude (in medical language, aerodontalgia) are due to small lesions of bacterial fermentation in the dental pulp. The rise in altitude causes the volumetric expansion of these gaseous microbubbles, which can lead to severe pain of the dental pulp. These pains appear to the rise and disappear during descent. The pain can be very intense within the limit of the syncope.
Healthy or properly treated teeth are never the source of such disorders.

d) Barotraumas of the digestive tube

Barotraumas of the digestive tube are very rare in civil aviation. They are reflected by pains in the stomach and intestines. These can contain several hundred cm^3 of gas (swallowed air, gas from intestinal fermentation, etc.).

In altitude, these gases undergo a volumetric expansion, which is limited by the distensibility of these viscera. The corresponding disorders range from simple abdominal discomfort to very sharp, incapacitating pain. After protective measures against hypoxia, it is probably the most common altitude disorder; they usually appear at an altitude of 5,000 to 6,000 meters and affect about 1/3 of subjects at 12,000 meters. These symptoms completely regress in the descent.

Strict food hygiene is required to prevent these disorders; avoid soft drinks, fermentable foods and irritants. We note that it is above the altitude actually observed in the cabin; when it is pressurized, the altitude to be taken into account for this risk is, obviously, the cabin altitude and not the flight altitude.

3.2.2 - Common fever and flu-like conditions

Do not forget that fever, whatever the cause, is a strong factor in the reduction of psychomotor performance.
By itself, it renders the pilot unfit to perform his functions. In addition, fever may:

- Reveal a serious disorder; or
- If it is an infectious problem, be due to a condition that can spread to other persons present in the cabin (we are talking here of both the aircrew and passengers).

This said, the pilot may be tempted to fly, even if he has slight flu-like symptoms, and to do this by treating himself.

We will cite a few drugs according to both their chemical name and brand name in France. At the risk of increasing this text, it is necessary to indicate the names of the chemical molecules, because brand names are not the same everywhere in the world. Brand names are often followed by the marking ® or TM (Trademark).

Note: To decrease the symptoms of these minor viral conditions, or those of a simple cold, a large number of medications contain substances that interfere with vigilance.
Actually, the substances that help reduce inflammation of the upper airway belong mostly to the class of antihistamines, substances which all present side effects in the form of vigilance disorders. All instruction leaflets for these drugs also contain a warning message specifically for drivers of motor vehicles or operators of systems.

These drugs are over-the-counter, sometimes in France and very often in countries outside of France. Among them:

- Triprolidine and dextromethorphan (opiate) (ACTIFED®);
- Clocinizine combined with a morphine, pholcodine (DENORAL®);
- Pholcodine (morphine) only (HUMEX®);
- RINUTAN®, which is combined with three molecules;
- and many others.

The pharmaceutical industry now offers antihistamines without hypnotic effects. In chronological order, the first among them is loratadine (in France, CLARITYNE®); this product is compatible with the functions of a pilot. It is the same for cetirizine (in France, ZIRTEC®).

These are not behaviour modifiers; anti-inflammatory drugs with an ibuprofen base (BRUFEN®, ADVIL®, NUROFEN®). This product is distributed in France and abroad under dozens of brand names (or trade names). It can cause heartburn; it is to be taken with or just after a meal; heartburn is effectively relieved by MAALOX® (mixture of aluminum hydroxide and magnesium), which may be taken preventively without inconvenience.

We should not forget aspirin (acetylsalicylic acid), particularly in its form as lysine acetylsalicylate (ASPEGIC®), significantly less harsh on the stomach, unlike paracetamol (DAFALGAN®, DOLIPRANE®, EFFERALGAN® - among others).
CODOLIPRANE® contains codeine (morphine).

None of these products are compatible with consuming alcoholic beverages.

Some details, outside of the EU OPS, but useful:

- Even aspirin may interact with alcohol;
- Do not forget the anticoagulant action of aspirin;
- Concerning the products that we have qualified as morphine (opioids): they are derived directly from a modification of the morphine molecule; they have lost the astounding features of morphine, but they have kept other properties, such as being excellent cough suppressants and minimizing motion sickness; but they have kept also two problematic characteristics of the morphine molecule: they are strong sedatives and, based on chemical analysis, they appeared to the analyzers as if they were morphine; therefore, obviously, they should not be used in flight or before the flight and always be able to justify having used such a product In the event of positive screening for opiates, in France or abroad; the proof may be a prescription, or simply the empty bottle; also think about it before a medical appointment at a Specialist Center for Aviation Medicine ("CEMPN" or "Centre d'expertise médicale du personnel navigant" in French).

3.2.3 - Gastrointestinal disorders

a) Description

Gastrointestinal disorders are represented in flight by transit disorders, diarrhea, production of intestinal gas, and sometimes vomiting (related to causes other than motion sickness). The origin of these disorders is most often infectious disease. It either results from common viral infections ("stomach flu"), which can be treated by general medical care or, more specifically, food-borne illnesses.

Food-borne illnesses are due to bacterial contamination of food or drinks. They require specific preventive measures. Their risk of occurrence is relatively high and their consequences can be serious.

Two major types of food-borne illnesses can be observed.
In the first of these types, the microorganism in question has already secreted its toxin (toxin = poison), and this is what causes the symptoms in a short period of time: 30 minutes to an hour after ingestion of the contaminated food. The microorganism in question is often a staphylococcus.
In the other type of poisoning, the bacterium in question, often of the genus Salmonella, must undergo a multiplication stage in the digestive tract before triggering the symptoms; this will then appear within several hours after ingestion of the contaminated food.

The symptoms of food-borne illnesses are digestive pain and diarrhea, sometimes violent and urgent. Of course, if all meals come from the same chain of preparation and/or distribution, the probability that all guests will experience the same symptoms simultaneously is high. In the limited cabin space of a passenger transport aircraft, the situation quickly becomes uncomfortable, even unbearable.

b) Prevention

For pilots, the meal trays must come from two different sources; the two operating pilots may not eat the same menu item. Even if these instructions do not seem to be very user-friendly, during the layover, both pilots should not eat at the same restaurants in the hours preceding the flight.

For both the CAP (commercial aircrew personnel) and passengers, extreme vigilance must preside over the preparation of loaded meal trays; the airlines must know how to manage the provision of meal trays that they serve to passengers. For some destinations, the meal trays for the return flight are preloaded before the outbound flight.

3.2.4 - Obesity

Obesity is defined as an excess of fat mass. Its relationship with food is complex; all persons are not equal as regards their risk of obesity. Therefore, we will clearly divide the problem of obesity and consider the matter of balanced food intake. Excessive or inadequate food intake *can* be a cause of obesity.

Obesity can be measured by the Body Mass Index (BMI): m/T^2, where m is the mass of the body (in kg) and T is the size (in m). The correspondence between BMI and weight status is the following:

- Men: normal weight for a BMI between 21 and 25 kg/m²;
- Women: normal weight for a BMI between 19 and 23.5 kg/m²;
- Emaciated: BMI < 18.5 kg/m²;
- Starvation (anorexia nervosa): BMI < 15 kg/m²;
- "Overweight": BMI > 25 kg/m²;
- Moderate obesity: BMI > 30 kg/m²;
- Severe obesity: BMI > 35 kg/m²;
- Massive obesity (morbid obesity): BMI > 40 kg/m².

Like any global index for a population, the BMI has certain limitations and can provide basic information in line with its intended use. It is applicable to a population in standard physical condition, between the ages of 18 and 65 years. For example, it is not applicable to a muscular athlete.

Multiple diseases are associated with obesity.

- Disease is part of the metabolic disorders of obesity: diabetes.
- Diseases resulting from metabolic disorders of obesity: arterial diseases. These diseases are serious and incapacitating. Smoking greatly increases the risk.
- Debilitating diseases or conditions, aggravated by excess weight; venous disorders (varicose veins of the lower limbs), joint degeneration and arthritis of the lower limbs (obese individuals with osteoarthritis must first lose weight…).
- Debilitating diseases or conditions, aggravated by excess body fat; fat infiltration of the lungs may drastically reduce necessary lung volumes… in a person whose weight requires a surplus of aerobic energy to move!

From a strictly aeronautical viewpoint:

- Those who are obese do not handle accelerations well;
- In case of exposure to the risk of decompression sickness and taking into account the high capacity of fats to dissolve nitrogen, obesity represents a strong risk factor (see paragraph "Decompression Sickness", p. 30).
- Musculoskeletal disorders associated with overweight.
- We will not omit the fact that a number of aeronautical standards (e.g. strength of seats structures) have been enacted under the assumption of a subject of standard weight; in commercial aviation, the weight of the pilot considered for certification is 77 kg [CS-25 §785(g)]; the highest standard in terms of the weight of the occupant seems to be glider pilots: weight between 50 and 110 kg, including parachute (CS-22 §25).

Finally, obesity can contribute to difficulties in social relationships: mockery, up to exclusion of some jobs… including discussion of aeronautical fitness (AMC-GM to Part MED, §AMC2 MED.B.025(b)).

3.2.5 - Diabetes

Diabetes is a metabolic disease, which is characterized by an elevation of blood glucose (rate of glucose in the blood). This rate is normally around 0.8 g/l or 4.6 mmol/l.
Glucose is a fuel that is rapidly exchangeable in the body, which is able to store/unstore and be consumed very quickly according to dietary needs or intakes. Despite everything, its rate in the blood compartment, which is the intermediate compartment of transport, has remained remarkably constant, due to the secretion of adapted hormones. These hormones are hypoglycemic hormones (decrease the rate of blood glucose), insulin, and a series of hyperglycemic hormones, of which the best known are glucagon and adrenaline. Insulin and glucagon are secreted by the pancreas.

Diabetes is an imbalance in the regulation of blood glucose, or hyperglycemia. There are two types of diabetes. Type 1 diabetes corresponds to a destruction of insulin-producing cells. It may only be treated by substitutive insulin injections, and not without difficulty. Type 2 diabetes, or fat from diabetes, is generally a diabetes founded in middle-aged or older adults, often (but not always) in overweight or obese subjects. Most patients with type 2 diabetes can be treated by a combination of diet and oral drugs. Some of them resort to insulin treatment (injection).
The forms of diabetes requiring treatment with insulin are generally not compatible with aeronautical fitness, which excludes those with type 1 diabetes from this study. The short-term visible consequences of type 2 diabetes are unfortunately lacking, except those that can be linked to certain treatments.

We deliberately used the word "unfortunately" above; it is because type 2 diabetes can be ignored and/or neglected over the long time, which allows for the development of long-term complications.

In the short term, the main disadvantages of diabetes remain its treatment through diet and medication. Insulin, as well as some oral antidiabetic drugs, such as Gliclazide (DIAMICRON®), run the risk of hypoglycemia. Hypoglycemia can lead to a loss of consciousness, sometimes during an epileptic seizure. Aeronautical fitness is then essential. Finally, note that if treatment by insulin cannot be replaced, it is sometimes possible to replace oral hypoglycemic agents by antidiabetic drugs compatible with flight. Therefore, relevant advice should be given to pilots with early and/or mid-stage diabetes. Finally, it should be noted that a change is under way concerning the medical fitness of pilots treated with insulin, which may be restored, but under significant restrictions (personal data of the author of this text).

In the long term, diabetes is a high risk factor for cardiovascular disease, affecting both the large vessels and microcirculation of tissue. Concerning large vessels: impairment of the aorta, coronary arteries, arteries of cerebral circulation, renal arteries, etc. The corresponding disorders are called dissection of the aorta, coronary artery disease, stroke, etc. The microcirculation disorders of the tissue affect mainly the retina and kidneys; untreated diabetes is one of the main causes of blindness and end-stage renal failure.

3.2.6 - Food hygiene (quantity, composition, quality)

Here it is no longer the risk of food-borne disease, discussed above ("Gastrointestinal Disorders," p. 30). Food hygiene is based on a balance between intakes and energy expenditure, as well as on the intake of vital substances.

Expenditure of energy:

- Base metabolism corresponds to the functioning of body systems at rest; the corresponding energy expenditure is 1,800 kcal / approximately 24 hours (in metric units: 87 W);
- Metabolic expenditure induced by the absorption and processing of food;
- Physical exercise.
-

Food contains several classes of substances: substances to supply energy and substances necessary for the structure of the body; the distinction between these two classes is not absolute.

- Proteins (or protides). They are required for the building or maintenance of the body structure, but they can also serve as energy support. They are of animal or plant origin. Ideally, they must take in 8 to 15% of the food ration. 1 g of protein provides 4 kcal.
- Lipids They provide some structural materials, serve as a vector for other liposoluble compounds (this is the case with some vitamins) and are mainly an energy source, at the rate of 30 to 35% of the daily energy consumption. 1 g of fat provides 9 kcal.
- Fats are usually distributed according to one of their chemical characteristics, which is the degree of hydrogen saturation in the carbon chain of which they are composed;
- Saturated fats: considered dangerous for the arteries, they are from animal origin (beef, lamb, pork, dairy products) or vegetable origin;
- Poly-unsaturated fats: from cold water fish and vegetable oils (corn, sunflowers or soybeans); these fats can reduce cholesterol levels, but they tend to increase body fat;
- Mono-unsaturated fats: from olive oil and peanut oil, they are considered to be the best dietary fats.
- Carbohydrates (or sugars). They provide energy with rapid or semi-rapid availability in the body. Fast sugars are short-chain carbohydrates, immediately or very quickly available in the body. Slow sugars are long-chain carbohydrates (polysaccharides), which require a process of digestion before release of simple sugars; a food supply based on slow sugars allows for a continuous intake and extended energy to the body. Carbohydrate intake ideally represents 50 to 62% of total food consumption. 1 g of carbohydrates provides 4 kcal.
- Fiber. This are fermentable substances in the large intestine. Thus, they produce gas. In addition, they promote intestinal transit. They are attributed with other virtues: reducing absorption of cholesterol, and limiting the emergence of certain pathologies, such as tumors or hemorrhoids.
- Trace elements. These elements are found in small quantities in the body, in very specific functions, such as iron (central component of the hemoglobin molecule) or cobalt (component of vitamin B12). Let us add copper, magnesium, iodine, fluorine and zinc. Red meat, fish and chocolate each provide some of these substances.
- Vitamins. So named, because the first substances identified of this type belonged to the chemical class of amines; "vitamin" is the contraction of vital amine. Many substances

fall within the class of vitamins, with widely varying biological actions; let us cite the consequences of some deficiencies:

- Vitamin C deficiency (provided by citrus fruit): scurvy;
- Vitamin D deficiency: rickets;
- Vitamin A deficiency: vision disorders;
- Vitamin B12 deficiency: anemia.
- Mineral salts. Sodium, potassium, calcium, magnesium, and phosphorus are necessary, because they contribute to various functions, body structure (Ca, P) and/or electrolyte balance, and resulting in the functioning of cellular membranes (functioning of any neuromuscular system depends on this adjustment).
- The intake of mineral salts is approximately 1 g/day under normal conditions of life. When transpiration is very abundant, as during a stay in a humid subtropical environment, these intakes should be significantly increased (if concomitant water intake).
- Water. Water needs are highly dependent on the physical activity and climate. We will detail in the next paragraph ("Water Needs of the Body").

Some tips for pilots
We consider the temporal irregularity of one's activity.

- Preflight: Avoid foods with fiber, soft drinks, and digestive stimulants. Choose the more digestible slow sugars (pasta, rice) and proteins (chicken, fish, ham).
- In-flight: Pilots in command use of meal trays from different sources; both pilots should not consume the same meal.
- Avoid various "snacks" and nibbling.
- During layovers: There is a risk of food-borne illnesses. Ideally, the pilots of a crew must not eat in the same restaurant within the 12 hours preceding the flight. Of course, avoid local drinks and consume only bottled water from safe sources.

3.2.7 - Water needs of the body

What is the water balance in the body? Water intake is from beverages and, to a lesser extent, solid food. Actually, even the combustion of solid food produces water; let's take the example of glucose combustion ($C_6H_{12}O_6$):

$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$

Water is expelled through urine, breathing, and sweating. They correspond to physiological or physical necessities; urinary water dilutes and eliminates waste from the body.
Lungs, saturated in a humid environment, automatically reject water through exhaled gases.
With regard to water discharged by the skin, it is due to 2 factors. The first is the evaporation of water from the hydrated medium, that is, the skin in a dry atmosphere; this necessary evaporation of water produces a slight cooling, without great significance, even if it is well perceived in the very dry setting of the aircraft cabin.
The second fraction of water discharged by the skin is through sweating; the evaporation of water produced by sweat is the only active means that humans possess to release excess heat. We will note that regulating the temperature is the highest physiological priority of the body; humans sacrifice all other regulating functions to maintain temperature.

The body regulates its quantity of water both by regulating their volumes and their osmolarity. Excess water is eliminated by the renal route. Water deficiency triggers the sensation of thirst.

Water needs. In the basal state, a daily quantity of 1.5 liters of water is sufficient. During intense physical exercise and/or in a very hot climate, the loss of water may reach 1 liter per hour (calculating 12 liters per person per day in case of survival in a very hot desert climate).

We have previously indicated that it is necessary to think of the risk of dehydration in flight at high altitude (see paragraph "Hygrometry,").

3.2.8 - Intoxication and addictive behaviors

Let us treat in the most objective manner possible this very sanctimonious… and sometimes controversial chapter. We will clearly distinguish between harmless addictions (coffee), regulated addictions, otherwise authorized by the law (smoking, alcohol), addictions by illicit drugs (by definition repressed by the law), and self-medication, which is more often just a simple case of not knowing the risks and the risk of accidental poisoning.

a) Caffeine

Caffeine addiction is common. It also depends on what each person and/or each culture calls "coffee".

Beneficial effects of caffeine: It increases vigilance and shortens reaction time. It decreases or delays sleep.
Adverse effects of caffeine: It decreases or delays sleep (stage 4, REM sleep). It increases the risk of high blood pressure and cardiovascular disease in susceptible individuals. It can cause extrasystoles of the heart or increase their frequency. It may favor the appearance of abnormal tracings on the electroencephalogram (EEG), with waves that may resemble epilepsy.

Absorbed on an empty stomach, caffeine passes through the bloodstream within 10 minutes, peaks in under 30 minutes and persists for 2 to 4 hours. The adverse effects of caffeine appear from absorbing a dose of 200 mg. A common dosage of caffeine is 50 mg/100ml (standard coffee), 65 mg (an espresso), 30 mg/100 ml (tea, coca).
Caffeine is present in a number of medications, to counter the effects of drowsiness from certain active ingredients. To indicate how long the list of these medications can be and how varied their nature, we cite CÉPHYL® (common pain medication), GURONSAN® ("fortifying"), GYNERGÈNE CAFÉINÉ® and MIGWELL® (migraine therapies), LAMALINE® (strong pain medications), MERCALM® (motion sickness medication), and many others… In some countries (e.g. United States), caffeine tablets are sold over-the-counter, usually dosed at 200 mg.

b) Smoking

Tobacco smoke contains three substances or groups of substances: carbon monoxide (CO), nicotine and tars.
The issue of CO was discussed previously (see p. 30). Remember that smoking 1 pack per day causes an HbCO blood level of about 5 to 8%; this poisoning, at normal altitudes in a pressurized cabin, is considered to be equivalent to an exposure of 3,000 to 5,000 additional feet.

Nicotine stimulates the production of adrenaline and stimulates vigilance. However, nicotine causes addiction. The addiction to tobacco thus comes from the "nicotine" of the smoke. The harmful effects of tobacco come from the "tars". The tars cause irritation of the mucous membranes. In the most benign case, they promote the occurrence of chronic bronchitis.

The risks linked to chronic tobacco abuse are:

- Risk of lung cancer (at least 95% of lung cancers occur in smokers);
- Risk of pulmonary changes of any type (lung tissue itself, bronchi), leading to chronic respiratory insufficiency (debilitating);
- Risk of cardiovascular disease with its consequences, especially coronary artery disease (see paragraph "Coronary Circulation and Coronary Artery Disease", p. 30), risk of stroke and arteritis of the lower limbs.

When smoking is associated with other addictions, such as alcoholism, this list of risks is complemented with the risk of digestive cancers (i.e. tongue cancer, esophageal cancer) and bladder cancers.

Let's talk about your passengers. "Non-smoking" flights were developed based on cost reduction issues. Actually, the tars clog all: Air recirculation filters, pressurization valves, as well as all systems located above the passenger seats (e.g. oxygen systems).
The economic rationale of non-smoking flights is thus fully in line with public health aims; this fact is rare enough to be mentioned.

However, smoking is an anxiolytic (decreases anxiety and fear) and there is no doubt that many passengers are afraid of flying. In short, non-smoking flights have sometimes become flights with much more alcohol, consumed during and often before the flight. The resurgence of unruly acts on board is explained in part by this cause, and it is also viewed as a manifestation of anxiety. The next step could be non-smoking flights without alcohol… then the anxiety of passengers will need to be treated.

c) Alcohol

News story (among others…)
According to a report published by the ''Bureau d'Enquêtes et d'Analyse'' (Bureau of Investigation and Analysis) (www.bea-fr.org).

Event: Landing before the runway threshold during flight training, collision with the ground.
Identified causes: Overconfidence, focus of attention.
Contributing factor: Impaired judgment skills after consumption of alcohol.
Consequences and damage: Aircraft heavily damaged.
Aircraft: Robin DR 400-120.
Operator: Club.
Location: Uncontrolled aerodrome, unpaved runway 02, 1,030 m x 50 m, LDA: 910 m.
Nature of flight: Aerodrome circuits in training.
Persons on board: Instructor + student.
Titles and experience: Instructor, 53 years, PPL, CPL, FI, FE, 4,304 flight hours including 300 on type and 38 in the previous three months including 4 on type, 2,900 in instruction; pilot-trainee, 58 years, 30 hours of all dual control flight including 2 on type and 9 in the previous three months.

Weather conditions: Assessed at the accident site, wind 010°/4 kt, CAVOK, temperature 10°C, QNH 1,024 hPa.

Circumstances: The student and instructor flew together for the third time. The instructor explains that he was temporarily replacing the usual student instructor.
A few hours earlier, he agreed with a friend pilot that, during his instruction session, they would fly in close formation in the aerodrome circuit.
The student and instructor take off at 14:45 from the Valréas airfield. After a pattern, the student performs a touch-and-go landing on runway 02.
During the initial climb, the instructor hears the tailwind integration message for runway 02 from the pilot of the Jodel, registered F-PPPD. On the one hand, he requests the student whether he wants to be close to this aircraft to initiate the flight training and, on the other hand, to the pilot of the Jodel whether he is still in agreement to complete the aerodrome circuit by flying in close proximity to one another. The student and the pilot of the Jodel accept.
The instructor suggests to the student to position the DR 400 slightly lower and approximately five meters behind the right part of the empennage of the Jodel.
The pilot of the Jodel decides to adopt a low angle of descent and land before the offset threshold to benefit from a greater rolling distance during the touch-and-go landing. The instructor resumes the controls of the DR 400 during the finale. He does not notice that the final trajectory of the Jodel is low. The DR 400 touches the ground thirty meters before the beginning of the runway. During the rolling, the front and main axles break on the shoulder of a road.
The instructor applies the full power and the aircraft rises a few meters. After flying over the first third of the runway, the instructor decides to land. The aircraft slides for approximately 300 meters and then stops on the runway.

The instructor specifies that during the training flight, he focused his attention on maintaining constant spacing between the two aircraft. He had not given specific instructions to the pilot of the Jodel, who was focused only on his own trajectory. The pilot of the Jodel had flew in formation with this instructor on several occasions. He thought that this last time would interrupt the approach during the finale, as he had announced it.

The blood alcohol level of the instructor revealed a rate of 0.36 mg of pure alcohol per liter of exhaled air, and then 0.31 mg per liter of air, 1 hour 35 minutes and 2 hours 7 minutes respectively after the accident. The instructor confirmed that he consumed alcohol during his lunch, approximately two hours before the flight. Extending the reaction time and inhibition reported were compatible with these measures.

Commentary. The figures provided by the BEA can be interpreted as follows: There is a close connection between the 2 alcohol levels in mg/l of exhaled air and the blood alcohol level in g/l of blood.

Thus, the two results above correspond to 0.72 and 0.62 g/l of blood alcohol levels. The work performed away from the event.

We will discuss the validity of Widmark's formula below, but in the first approach, we will apply a rate of decrease in blood alcohol level of 0.15 g/l per hour. It is easy to infer that the blood alcohol level of the instructor could have been between 0.9 and 1 g/l at the time of the accident.

Aeronautical precision. In "googling" the registration of the Jodel, it appears that this aircraft is a D119. This aircraft does not have flaps; in landing, it presents a strong ground effect that can make the touchdown of the wheels considerably farther than the normal visual landing point. As a result, it may be relevant to view a landing point located upstream from the runway threshold if one really wants to land on the entrance of the runway. Naturally, the pilot controls the gas.

In the case of this accident, the instructor on board the DR-400 chose to fly his plane in patrol until landing with the D119. It is likely that the DR-400 was in landing configuration, with its flaps extended, perhaps even the full flaps. In this case, the landing point and touchdown point of the wheels were very close to one another. Moreover, the instructor stated having positioned the DR-400 *"slightly lower"* than the D119.
A normal landing trajectory for a D119 is totally unsuitable for a DR-400 and the flight patrol in the landing was not possible. He had to be drunk to imagine such a scenario.

Issue of alcohol on board

In France, alcohol concentration is measured in grams per liter of blood (g/l). The European regulation "OPS" expresses the blood alcohol level in units "per thousand", which is the same. Anglo-Saxon data is expressed in %. Consequently, we believe that it is g/100 ml of blood with a factor of 10 between this expression and the French expression: 0.05% = 0.5 g/l.
There is an ancient basic rule: "Any member of the crew must refrain from exercising his functions as soon as he [...] is under the influence of alcoholic beverages [...]", which can be found in the decrees repealed by Transportation Minister of November 5, 1987 (§ 6.1.2) and July 24, 1991 (§ 3.1.4.1).

Apparently, this particular rule was actually made vague on purpose, because it is difficult to clarify exactly what is meant by *"being under the influence of an alcoholic beverage"*. Let's discuss this concept.

In terms of metrology, the rate "zero" does not exist, because there is always a background noise in the measurements; on the other hand, common fruit juice always ferments a little and thus produces a little alcohol; as a result, the absorption of a significant quantity of fruit juice can reveal a low rate of alcohol in the body, approximately 0.10 to 0.12 g/l.
In the strict sense, slight traces of alcohol in the blood do not necessarily mean taking a drink as "alcoholic beverage" is defined and may not be used as an interpretation in this sense. In addition, blood alcohol levels of those who come to be cited do not really produce any detectable effect.

It seems that one can establish a value for the blood alcohol level without embarrassing psychomotor impact. Since 1991, American authors have published their works on this subject. It is only from 0.30 g/l that significant psychomotor effects can be measured, which can induce errors in the pilot. The aviation industry has settled the debate with a smaller margin and has retained the rate of 0.20 g/l as the upper admissable limit for a pilot in command [Regulation (EU) No. 965/2012, AMC-GM to Part CAT, §AMC1 CAT.GEN.MPA.100(c)(1)(b)]. This value formally eliminates all the false positives and it is lower than the threshold of risk. Scientifically, this rule is irreproachable. However, make no mistake about it: a rate < 0.2 g/l imposes abstinence of any drink considered alcoholic.

Recall that the legal limit for driving an automobile is 0.5 g/l, "indisputable" impairment threshold; but the European aeronautics industry is more stringent than the world of automobiles, or the American aeronautics industry, which sets the threshold at 0.4 g/l.

All databases have perhaps not yet incorporated this regulation. We can check the right answers to the questions:

- Question: "What is the threshold for impairment in aeronautics?", The correct answer is 0.3 g/l (0.03%);
- Question: "What is the maximum level authorized by the European Regulation?", The correct answer is 0.20 g/l (0.02%).

Question: What is the rate of decrease in alcohol for the body? It concerns the one who has been drinking and who would like to predict when he will again be in possession of his faculties, as far as he can tell, and who would like to know, based on a measurement performed in time ("t"), what his real blood alcohol level was at the time.

This is Widmark's formula, published in the 1930s, which indicates that the blood alcohol level decreases by 0.15 g/l per hour in the blood (0.015%/h).

This formula has a statistical value, with limits in its application: validity of 2 1/2 to 3 hours; original blood alcohol level of approximately 1 g/l; white population ("Caucasian"). For example, it is known that Asians have an alcohol elimination curve that is much slower than Europeans, without anyone knowing the reason. Therefore, Widmark's formula should be applied with caution.

What is almost completely ignored is the exact role of certain factors associated with ethyl alcohol intoxication, such as hypoglycemia. Actually, hypoglycemia is both a consequence and factor increasing the effects of ethyl alcohol intoxication. However, this factor is difficult to evaluate.
What some assume, and which seems realistic, is the residual role of alcohol when every trace of alcohol has disappeared from the bloodstream. Canadian authors have shown that psychomotor impairment may persist, even after disappearance of the alcohol in the bloodstream (i.e. zero blood alcohol level), without being able to clearly identify the reasons for it.
In practice, it is the description of a "hangover". In other words, the disappearance of the blood alcohol level does not necessarily mean its complete disappearance from all tissues of the body, even when the blood alcohol level has returned to zero; it is possible that the central nervous system still remains disrupted for a certain time afterwards.

The operational rules concerning the consumption of alcohol may be summarized as follows:

- A crew member may not:
- Consume alcohol less than 8 hours before performing in-flight service or other crew duties,
- Present a blood alcohol level greater than 0.2 g/l at the time of departure or while performing crew duties,
- Consume alcohol during the flight or layover, or while performing crew duties,
- The pilot in command has the right and duty to prohibit access on board, or to disembark any personnel, crewmember or passenger, who would appear to be under the influence of alcohol or a psychotropic substance.
- The operator shares this last prerogative with the pilot in command.

Alcohol and autopsies after an air accident
This issue is important. Body tissues contain sugars, which ferment after death and produce ethanol; indiscernible of ethanol that would have been ingested before the accident. The risk of attributing an accident to a supposed illicit consumption of alcoholic beverages by the pilot is therefore great, except for very specific forensic procedures that are not always available.
In practice, after an accident, if the field investigation does not eliminate the hypothesis of an external source of alcohol, the surviving flying pilot (FP) or operator risks serious consequences. In addition, in the case of very high profile accidents, the press always ends up uncovering these facts, and are more than happy to comment on them.

The responsibility of all actors of the flight (aircrew, operators) is that there can be no ambiguity concerning the source of this alcohol.

Let's summarize the key statistics concerning alcohol:

- Apparent psychomotor deterioration due to alcohol: 0.5 g/l (maximum legal limit for driving an automobile in France);
- Measurable psychomotor deterioration due to alcohol: 0.3 g/l;
- Maximum blood alcohol level threshold retained by EU No. 965/2012: 0.2 g/l;
- Maximum blood alcohol level threshold retained by the American authority (FAR 121.458): 0.4 g/l;
- Technologically, the rate "0" does not exist; the threshold of 0.2 g/l retained by EU No. 965/2012 is a proper measurement, which avoids any contentious discussions over the interpretation of metrological background noise, which still remains < 0.2 g/l;
- No consumption of alcohol less than 8 hours before the flight or performing crew duties;
- No consumption of alcohol in flight, during layovers or while performing crew duties;
- The pilot in command has the right and duty to prohibit access on board or to disembark any crew member who would not respect these rules, as well as any passenger whose state of intoxication would threaten flight safety and/or the serenity of other passengers.

Acute alcohol intoxication

We have already mentioned it, but it bears repeating. All combinations:

- Alcohol and medications;
- Alcohol and hypoxia;
- Alcohol and all neurotropic substances (acting on the central nervous system), medications or illicit drugs;

Cause an intensifying of both components in these combinations.

Furthermore, the consumption of alcohol causes the following changes:

- Decrease in sensory performance, including vision and hearing;
- Decrease in psychomotor skills: e.g. decrease of hand-eye coordination (imprecision in steering), increase in reaction time, imprecision of gestures;
- Decrease in monitoring performance of a task;
- Decrease in mental performance, with decrease in cognitive abilities and difficulty recalling memorized items;
- Decrease in capacity for self-criticism, particularly with an overestimation of personal abilities and excess self-confidence;
- Removal of inhibitions and excessive risk-taking;

- General physical condition impaired, increasing fatigue or making it appear more quickly;
- Sleep disturbance, then hypovigilance and drowsiness in a state of wakefulness;
- Increased risk of equilibrium disturbances and probability of dizziness or spatial orientation disorders and sensory illusions;
- Metabolically, increased risk of hypoglycemia;
- Potentiation with psychomotor deterioration from hypoxia.

In other conditions, alcohol increases the likelihood of an accident with heat and the risk of developing symptoms of decompression sickness.

Alcohol addiction (chronic alcoholism)

The maximum quantity of alcohol that can be metabolized by the body is approximately 100 g/day; it produces approximately 700 kcal, which should be included in the energy balance of food intake. However, unlike all other nutrients, alcohol cannot be used in the body as an element of structure. Beyond the production of 700 kcal/day, alcohol cannot be used by the body and must be eliminated as such, or after deterioration by the liver

This maximum quantity of alcohol corresponds to 1 standard bottle of wine per day (0.72 l). Beyond this amount, the consumption of alcohol is excessive. Repeated, it is considered to be chronic alcoholism.

And to respond to one of the items of the official program, there is no difference between the maximum quantity per day and the maximum quantity per week ("maximum daily or weekly intake of alcohol"); in other words, the body cannot store alcohol on Friday evening to be consumed during the following week.

Chronic alcoholism, in its most benign form, is a trained, social, mundane alcoholism. In its severe form, it is a symptom of a personality disorder. Alcohol is an anxiolytic. In the face of alcohol addiction, two therapeutic attitudes should be undertaken at the same time, the treatment of the cause and the treatment of the symptom, that is, alcoholism, which has become a disease in its own right.

As an organic disease, chronic alcoholism affects two organs, the liver and central nervous system. Its screening requires clinical data (patient examination) and biological data, which serve as markers for intoxication.

Alcohol addiction is a cause of medical unfitness for the functions of aircrew personnel

3.2.9 - Self-medication or therapy established outside of the supervision of a physician specializing in aeronautics

Almost everything has already been said on the subject. In the face of benign illnesses, a fortiori layover in countries where regulations authorize the issuance of drugs without a medical prescription, it is natural and legitimate to seek to heal oneself in the simplest way possible.

However, there are cases where the aircrew member is tempted not to declare anything to his expert physician…

Personal anecdote: One of my patients, a fighter pilot, was being treated - discreetly - by a "non-aeronautical" friend; in accordance with the therapeutic protocols of the time, the friend had prescribed Atropine, a substance that could be considered common, except that…

My patient came to see me one morning, sheepishly and still in an emotional state. He was out on a night flight; the approach ramp remained on "full alert" during his approach.

However, the Atropine caused a mydriasis (maximum dilation of the pupil). The glare effect was extremely intense and, at the controls of his Mirage 3 (approach speed of 185 kt), this pilot was completely blinded and almost got himself killed! Therefore, he remained unfit for flying for as long as the treatment by Atropine was necessary, and his fitness was returned to him afterwards.

In theory, any drug therapy renders one unfit to fly. In real life, treatment is often necessary. It is necessary to achieve a compromise between flight safety and the health of pilots; we all know that the total prohibition entails a risk of concealment and potentially dangerous self-medication and that, conversely, total permissiveness is not possible.

The major classes of adverse side effects for aircrew personnel focus on:

- Vigilance;
- Neurosensory receptors;
- Cardiovascular system.

We will add some side effects for the digestive system (pain, diarrhea) and urinary tract.

The major rules to be observed require common sense:

- Take only necessary treatments, but without delay due to the flight;
- Choose the minimum dosage;
- Know the pharmacokinetics (duration of action in the body) and side effects;
- Avoid new products;
- Begin treatment on the ground, during a rest period - or temporary unfitness;
- Refuse clearly dangerous medications.

Some drugs are incompatible with flight, whereas the pathology that is the reason for their prescription is not. These drugs are few in number. We will cite:

- Two classes of antidiabetic drugs, insulin and sulphonylureas; we have already established (para; 3.2.5, p.138) that these drugs cause unfitness due to the associated risk: a hypoglycemic crisis that may result in loss of consciousness, sometimes even an epileptic seizure;
- Some antimalarials, like LARIAM® (neurological risk);
- Anticoagulants (risk of bleeding, including cerebral), and also the reason why they are prescribed may also be a cause of unfitness;
- Anxiolytics and, generally, central nervous system drugs (antiepileptics, antidepressants, antipsychotics), and the disease itself may also be a cause of unfitness.

Beta-blockers are not compatible with strong physical exertion or with tolerance of accelerations + G_Z, but they may be allowed in flight outside of these conditions.
Treatments for high blood pressure may be compatible with flight. A period of observation on the ground at the time of initiation of treatment is still welcome. Beta-blockers (α-blockers) are not authorized.
Among the treatments for more common illnesses, predominantly ENT - cough suppressants, various pain medications, migraine drugs, anti-inflammatory drugs -, we will turn our attention to the risks regarding vigilance, because a number of drugs recommended for any other condition

contain substances that act on the central nervous system. Generally, these are side effects of active ingredients; we have already mentioned cough suppressants, antihistamines, additives put in the products above and which contain caffeine to counter the hypnotic effects (i.e. drowsiness), anti-inflammatory pain medications - acetylsalicylic acid (aspirin), non-steroidal anti-inflammatory drugs (NSAIDS), etc.

Most of these drugs are incompatible with alcohol and interact with hypoxia.

An anonymous survey recently carried out in France had the following results: painkillers-fever reducers (60%), antihistamines (23% - 5% of pilots take ACTIFED, an opiate-based cough suppressants, and three-quarters fly with them), homeopathy (13%), antibiotics (13%), anti-inflammatory drugs (7%), antispasmodics (6%), cough suppressant (6%), antimalarials (3%), anxiolytics (2%).

In short: Regardless of the type of treatment, take the time to consult with a physician experienced in aeronautics.

3.2.10 - Accidental exposure to toxic risk

The toxic risk under accidental conditions (fire-fumes) was discussed in the paragraph "Toxic risk on board" (p. 30). Under normal flight conditions, the list of potentially toxic products to which aviation personnel can be exposed is very long. We will recall:

- Hydrocarbons;
- Fuel additives; Oxidation inhibitors (amine or phenol derivatives), anti-knock compounds;
- Deicing fluids;
- Power boost fluids (methanol);
- Corrosion inhibitors;
- Lubricants;
- In some applications, specific propellants, such as extremely toxic hydrazines; hydrazine is sometimes used in emergency auxiliary power units (APUs), like in the F-16 fighter jet; the triethylamine-xylidine combination was used as the ignition module of the high-altitude rocket with NO_2/kerosene from the Mirage 3; UDMH is a derivative of hydrazine and is often used in rocket fuels.
- Exhaust gas, with a particular mention for CO;
- Extinguishing agents.

3.3 - Tropical diseases

The risk for the aircrew in contracting tropical diseases is the same as for the frequent traveler. Tropical pathology takes on two forms: climate adaptation disorders and infectious risk.

Malaria is the parasitic illness that still kills European aircrew personnel, because of their professional activity.

3.3.1 - Disorders and accidents in adapting to hot climates

a) Physiological responses in humans exposed to heat

Exposed to heat, humans have two ways of maintaining body temperature, cutaneous vasodilation (dilation of the blood vessels that irrigate the skin) and evaporation of water. With cutaneous vasodilation, blood is used like a heat transfer fluid, from the deep organs where heat is produced to the skin, where it is dissipated in the environment.

Sweating is the secretion of water to the surface of the skin. The secreted water is evaporated from the surface of the body, which cools it (2.46 kJ per g of water evaporated). Only evaporation cools the body.
In an environment totally saturated with moisture, sweat trickles and is lost from the point of view of heat loss; this corresponds to the concept of the evaporative power of the atmosphere.

We must then distinguish the physiological mechanism (sweating) from the physical mechanism (evaporation).
This discussion is only academic: In a hot humid environment, the body responds to excess temperature by sweating, which is ineffective if the water does not evaporate. The body can thus lose considerable quantities of water and salts through sweat, without the slightest benefit in terms of maintaining its temperature.

b) Accidents due to heat

Accidents due to heat can be the consequence of the thermoregulatory reactions described above, or result from a failure of these thermoregulatory reactions or simply be characterized by a gradual decrease in performance, often called acute heat failure.

Accidents due to heat, consequences of thermoregulatory reactions
This group of reactions to heat is quite heterogeneous and it brings together various causes. Cutaneous vasodilation, as well as the loss of water volumes through sweat, can lead to a risk of hypotension, which results in a tendency toward syncope or an actual syncope.
Loss of water and electrolytes by sweating, under sometimes anarchic conditions, results in ion concentration imbalances in the body (sodium, potassium, chlorine).

The risk of syncope is very significant in aeronautics. It is aggravated by accelerations + G_Z of long duration. It is more frequent among the non-acclimated subject. It is very aggravated by consumption of alcohol.

The syncope is manifested by a loss of consciousness, sometimes total. At the time of the incident, the arterial pressure ("blood pressure") is abnormally low.
The risk of syncope is major during aerobatic competitions, organized during the summer for climatic reasons.
Heat, accelerations, fatigue related to repeated flights, and sometimes dietary errors associated with a festive atmosphere: the risk of accident is high.

Water-electrolyte balance disorders are the consequence of abundant sweating, with loss of water and electrolytes. According to the respective portion of water or electrolyte losses, they may cause various disorders, commonly referred to as heat edema, dehydration fatigue or hyponatremia fatigue (sodium deficiency).
As symptoms, we can experience: fatigue, dizziness, headaches, anorexia, nausea, vomiting, GI motility disorders, muscle cramps, syncope.

The exact nature of these disorders are identified through laboratory analyzes, which also guide their treatment. These analyzes are not very complex, but they are indispensable. These various disorders are sometimes intricate, with common symptoms. It is not always easy to distinguish them without laboratory examinations.

Skin lesions may appear after a few days of stay. They cover different types; they can be secondary infections and eczema. They quickly change after returning to a temperate environment.

Accidents by thermoregulatory reaction failure: Heat stroke

Heat stroke stops sweating. It is an extremely serious t condition with an increase in core temperature at 40.5°C or more.
It includes central nervous system disorders, coma or epileptic seizure and it leads to rapid death, unless emergency treatment is received. Obesity, consumption of alcohol or a febrile illness are highly predisposing factors. It is an absolute medical emergency.

Acute heat exhaustion

Acute heat exhaustion becomes manifest as a gradual deterioration of physical and psychomotor performance, without an apparent cause or well-identified symptoms. It is no less real and quickly changes after returning to a temperate environment.

Prevention (water and salt)

Arriving in a hot and humid tropical environment, an individual who is not acclimated may sweat profusely, with significant water and salt loss. This loss varies greatly from one subject to another. A simple principle of prevention is a healthy body is able to eliminate excess water and salts - these are our basic regulation mechanisms. By contrast, it cannot create them.

Upon arrival in a hot and humid environment, the simplest way is to administer a sufficient quantity of water and salt. Traditional “moisturizing tablets" are nothing other than sodium chloride. Do not take *only* water or *only* salt, because you would then risk the disorders described above (exhaustion through water or salt loss, heat edema, etc.).

3.3.2 - Infectious risk

In hot environments, the infectious risk is widespread, and it is impossible to exhaustively expose it. It includes various risks, related to modes of transmission and contamination. It is serious.

a) General information: Infectious agents and anti-infective treatments

Different types of "microbes"

There are three major classes of infectious agents: viruses, bacteria and parasites.

- Viruses They are only formed from genetic material, more or less encapsulated in a protective shell. The virus diverts the metabolism of the host cell for its own reproductive needs.
- In doing so, its metabolic chains are those of the host, and there are no substances acting specifically on the viruses; in terms of curative treatment, we are very poorly armed against viruses, even if there has been progress on some diseases, such as herpes, AIDS, some types of hepatitis or human papillomavirus (HPV), responsible for cervical cancer.
- In terms of prevention, some viruses are susceptible to vaccines (smallpox, yellow fever, polio, influenza (flu), etc.), other are not (AIDS).
- Bacteria. They represent the easiest case. The structure of the bacterial cell is very different from the more developed body cell, and it is possible to develop substances whose specificity is sufficient to address metabolism or the structure of the bacterium without (too much) reaching humans. These drugs are antibiotics. Much of the bacteria can also be susceptible to the vaccination.
- Parasites are organisms, unicellular or multicellular, whose biological structure is closer to that of higher species, including humans. Their cellular organization become similar to humans, and it is much more difficult than for bacteria to find specific substances, which adversely affect the parasite and not the human body. For the same reason, there is no vaccine against parasites.

Anti-infective treatments

- Disinfectant kills the infectious agent by direct action, chemical or physical. All infectious agents do not present the same resistance.
- The methods are either chemical (oxidants, alcohols, solvents for the bacterial cell wall, etc.) or physical, of which heat is foremost. Some disinfectants are usable on the human skin (ethyl alcohol, oxygenated water, quaternary ammonium compounds (QACs), iodinated compounds, etc.).
- Chemoprophylaxis (word and concept that we will use below) involves administering a general anti-infective drug for prevention purposes, usually used to treat the declared disease. In the absence of something better, this can be a solution if not ideal, at least not the worst. For example: Prevention of malaria. The mode of administration is most frequently oral, and sometimes by injection.
- Vaccination, or rather the vaccinations Historically, it is clear as a mild infection, the vaccine protects effectively against a very serious infection, smallpox; hence Jenner's

idea, promoter of the method at the end of the 18th century, to inoculate healthy subjects with the vaccine ("vaccinate"), to protect against smallpox.

- Then, the word "vaccination" ("immunization," in English) had success that we know of, even though this technique of inoculating a disease to protect another disease remained unique. In its modern generality, vaccination involves stimulating the body to produce antibodies to fight against the target infectious agent.
- Having stated this principle, the difficulty is to isolate a fraction of it (antigen) from the infectious agent, harmless but able to stimulate the production of antibodies. Subsequently, if the body is contaminated by the infectious agent, the antibodies will destroy the infectious agent.
- Ideally, neither the antigen nor the antibody exhibits adverse consequences for the body to be protected.
- Without claiming to be exhaustive, these include:

An ideal vaccine, the tetanus toxoid vaccine; the tetanus agent acts through a toxin, which spreads in the human body before it destroys the microbe; it is possible to cultivate this toxin and alter it, to make it non-toxic while giving it a strong antigenicity; after contamination of a vaccinated subject, the antibodies destroy the toxin and the body has time to destroy the microbe;
Other ideal vaccine: the polio vaccine;
Good vaccine, against a whole group of diseases (e.g. typhoid): a fragment of bacterium or virus is isolated and detoxified; after contamination, the antibody products destroy this part of the infectious agent, thus the infectious agent is itself destroyed; sometimes, the effectiveness remains only relative, but better than an unideal vaccine that is not a vaccine at all;
Since they are not devoid of side effects (e.g. rabies), the use of vaccines should include weighing up advantages vs. disadvantages.
There is no universal recipe for manufacturing a vaccine. Some diseases remain without a knowing vaccine at the present time: malaria and AIDS are the most well-known.

b) Infectious diseases, classified according to their mode of transmission

We will distinguish:

- Diseases transmitted by insects;
- Diseases transmitted by water and food (dysentery);
- Diseases transmitted in the water;
- Diseases transmitted by large animals;
- Diseases transmitted by humans; Diseases transmitted by insects

Malaria is transmitted to humans through the bite of the female Anopheles mosquito. The infectious agent is a microscopic parasite, Plasmodium, of which there are several variants, not all sensitive to the same therapeutic agents. The mosquito bites at the end of the day, at dusk.
There is no vaccine for malaria; in contrast, there is a possibility of prevention by systematically taking antimalarials, varying according to the area visited and the intensity of exposure to risk. Reported malaria is not necessarily treatable, even in a wealthy European setting. Annually, it is believed to be responsible for 2 million deaths worldwide.

Recently, two pilots of a French aerial work company contracted malaria during a mission in the Gulf of Guinea. It was reported after their return to mainland France. One of the two pilots died

and the other was only released after much suffering. This is only one of the anecdotes on the matter.

Even if a pilot has not visited a malaria zone recently, remember:

- Any unexplained fever is, a priori, a case of malaria, until proven otherwise. Strongly emphasize this to your doctor.
- The “febrile gastric embarrassment" is, a priori, a severe form of malaria. The common "turista" does not cause fever.
- Any disorders of consciousness or unexplained coma in aircrew personnel is, a priori, a cerebral malaria, until proven otherwise - and your loved ones should be informed.

Sleeping sickness (common name of trypanosomiasis) is also a parasitic disease transmitted by the bite of the female tsetse fly (Glossina), also at dusk. Sleeping sleep is susceptible to curative treatment, but it can only be applied in a specialized hospital setting and may have side effects. Personal prevention (avoiding the risk) and collective prevention (sanitation in residential areas) remain the standard practice.

Filariasis is a disease caused by threadlike parasitic roundworms. Threadlike roundworms of various sizes (up to 1 m), which are transmitted to the human body and develop there:

- Lymphatic filariasis, due to the Wuchereria bancrofti roundworm, affects 120 million individuals worldwide; it is transmitted by a mosquito;
- Onchocerciasis or river blindness, is caused by the Onchocerca volvulus, which is a worm transmitted by the black fly into the eye area; this disease affects at least 20 million patients throughout the world, even leading to blindness; it is present in sub-Saharan Africa and the Americas (Central America and northern South America), more recently, it has been observed in the southern part of the Arabian Peninsula, probably related to population transfers;
- Loa loa filariasis, caused by the Loa loa, is transmitted through the bite of a horsefly, genus Chrysops, and characterized by migrations of the worm under the skin and conjunctiva.

Note: All figures regarding the number of patients worldwide are to be used with reservations. When these figures involve pathologies of poorer countries, the count or statistical estimation may not be exact. In addition, these figures vary in time according to the programs for eradication, themselves fluctuating depending on the generosity of donors and political stability of the countries in question.

In other countries, yellow fever is also transmitted by a mosquito, Aedes aegypti. This disease is very serious. It is effectively prevented by vaccination (single injection, validity of 10 years).

Visceral leishmaniasis (kala azar) or dermal leishmaniasis (the Oriental sore) is transmitted by the female sandfly, insect bite at twilight. This disease is very widespread: 12 million people are infected worldwide, including 1.5 to 2 million new cases every year.

Further, in keeping up with the news, chikungunya is an epidemic that struck the islands of the Indian Ocean and India itself, and which is spread by a hydrophilic mosquito (several millions patients infected in India). The only solution is prevention behaviour. This virus is close to dengue hemorrhagic fever, primarily found in the Pacific Ocean.

Diseases transmitted by water and food – dysentery

Diseases transmitted by water and food cover all types of infectious agents, viruses, bacteria or parasites.

The word "dysentery" is often the generic name of these pathologies. These are also the "diseases of dirty hands". Some of them are well known.

- Bacterial diseases, in the category of food-borne illnesses.
- Cholera. Its dangerousness comes from the speed with which it develops and the violence of the symptoms, along with very significant and rapid dehydration. In the environment of a strong economic power, cholera should be cured without sequels. Cholera was partially prevented by a vaccine, removed in 2007.
- Typhoid is also a disease transmitted through the digestive tract. It is actually a group of diseases, in which there are also "paratyphoids", due to a variant of the same microbe.
- These infectious agents belong to the large group of salmonella. There is a vaccine for typhoid and some paratyphoids. The typhoid treatment has greatly benefited from the development of a now well-known antibiotic, ampicillin.
- Parasitic diseases, including amebiasis, which is certainly the most familiar. Historically, amebiasis was dangerous to treat and it left deep scars in the digestive system. The introduction of metronidazole (FLAGYL®), in the late 1960s, has radically altered (and simplified) its treatment.
- A still present parasitic disease, the filaria of Medina, or Guinea worm, is caused by the Dracunculus medinensis worm (Guinea worm). It is transmitted through contaminated drinking water by the presence of a microscopic crustacean, in the genus Cyclops.
- Viral diseases Among them, we include polio, which has been responsible for dreadful epidemics. The polio vaccination is 100% effective.
- A still present viral disease: Hepatitis A (there is a vaccine).
- Without forgetting the very familiar turista, common gastroenteritis, responsible for diarrhea, sometimes abundant, with a slight fever, various abdominal pains... but responsible for an obvious inability to ensure a pilot for the return flight!

Concerning the mode of transmission for most of these diseases, we speak in plain language rather than using sophisticated elegance. A number of infectious agents mentioned here are eliminated in the stool (cholera, salmonella, amoebas, turista agents, etc.).

If they are contagious, they pass from the stools of one to the food of another, through contamination, flies, food delivery, and first and foremost our hands.

This is the reason why we have used the term "diseases of dirty hands".

In addition, one of the problems posed by the commercial aviation lies in the rapid dissemination of certain germs from one point of the planet to another. The recent spread of cholera has thus been fully traced back to the airline "hubs".

We simply conclude: Prophylaxis of these diseases is based on risk avoidance and water hygiene.

Diseases transmitted in the water

Diseases transmitted in water (distinguished from diseases transmitted by water) are due to parasites, which in a larval form can pass directly through the skin and then, by a more or less complex circuit, develop in certain sites of the body.

These diseases affect a very large number of humans; they are generally contracted in the course of their work activity (e.g. work in the rice fields) or recreational activity (e.g. swimming in polluted water). Among these diseases, there are different types of bilharzia (at least 200 million persons infected throughout the world, 500,000 deaths per year).

Diseases transmitted by large animals

Among the diseases transmitted by large animals, we will recall rabies. The only known animal species that serves as a chronic virus reservoir for rabies (without being fatally affected) is the bat. The risk of rabies contamination exists in and around caves, sheltering these bats. Annually, rabies is the cause of 50,000 deaths worldwide, which is most often the result of an infection by a rabid dog.

The plague is a bacterial disease transmitted by rats, particularly through rat-human transfer through flea bites. Its infectiousness is very high. It is curable by antibiotics, but the vital risk remains high. It is still present, mostly in very poor countries.

According to the sources, tetanus affects between 1 and 5 million people annually throughout the world, of whom at least 100,000 to 200,000 are newborns, with a very severe prognosis. In France, there are less than 50 cases per year. The tetanus virus reservoir are the intestines of horses (in France).
The bacterium responsible for tetanus is strictly anaerobic, but during its time in the open air, it protects itself using a resistant shell. When it is completely sheltered from air, it separates from its shell and begins to develop. Tetanus is thus transmitted through a deep contaminating sting, which buries the bacterium deeply inside the body.
The typical example of the common contaminating prick is the rose thorn. The tetanus vaccination is ideal (totally harmless and 100% effective). Prophylaxis by anti-tetanus serum in an unvaccinated subject (within a reasonable time period) is also very effective. The existence and systematic application of these prophylactic methods explain the rarity of this disease in an economically favored environment.

Diseases transmitted by humans

In the group of diseases transmitted by humans, we will recall sexually transmitted diseases (STD). Everyone knows the modes of prevention. In terms of public health in some African States, 80% of blood samples for transfusion must be rejected, if they are carried out in the general population, due to contamination by one or more of the following three diseases: malaria, AIDS or hepatitis C. Sexual contamination is generally multiple in personnel at risk: medical records frequently report, at the time of the AIDS diagnosis, a history of syphilis, hepatitis C, tuberculosis, without speaking of more benign conditions, such as gonorrhea or soft canker sores. A basic prophylaxis should avoid these horrors.

Meningitis, of different types, are also transmitted from human to human, through air. There is a possibility of vaccination for this risk, but it may not cover all possible types of infectious agents (usual meningococcus vaccines are for types A and C).

3.3.3 - Prophylaxis for infectious risk

The prophylaxis (prevention) for infectious risk is based on various methods, whether individual or collective.

a) Individual prophylaxis

Individual prophylaxis is based on methods applicable to persons themselves.
These are procedures to be respected and pharmaceutical substances to be administered.
The procedures are derived from the observations made on the modes of transmission:

- Hygiene of water and food: do not eat salads or raw vegetables, always peel any fruits, only consume properly prepared food, and avoid ice;
- Avoid transmission exposure by insects: do not go out during the hours at risk, primarily at dusk and after nightfall, wear protective clothing, sleep under mosquito nets, avoid wetlands, Avoid swimming in contaminated water;
- Vaccination against the diseases where possible;
- Take an appropriate chemoprophylaxis (e.g. against malaria);
- And, regarding the very common turista, do not forget, before departure, to bring ERCEFURYL® (intestinal disinfectant) and IMODIUM® (intestinal transit regulator).
-

About Vaccination Do not forget that systematic vaccination against certain diseases is certainly an attitude of individual prevention, but it is also an altruistic attitude of collective prevention. It blocks the human step of transmitting these diseases.

b) Collective prophylaxis

From the collective point of view, prevention depends on the eradication (if possible) of living and reproductive vectors: drying marshes, destruction of vector agents, etc. From a historical standpoint, the political will of drying Pontine Marshes, around Naples (Italy), in 1922-1923, allowed for the eradication of malaria from the Italian peninsula. When it is possible, this action is effective. Without altering the environment, sometimes the destruction of vectors is possible. The extensive campaigns of spraying DDT after the Second World War and in the 1950s was effective, until the Anopheles developed an almost total resistance to this insecticide (at the same time that Plasmodium developed its own resistance to antimalarial drugs).

Targeted actions are also possible, such as destroying breeding sites of vector larvae. The current insect vector control of chikungunya is a good example.

c) International Health Regulations

The International Health Regulations (IHR) was enacted by the World Health Organization (WHO); this is not a specifically aeronautical regulation. The 2014 version is currently in force.

The object and scope of the IHR involves "preventing, protecting against, controlling and responding to the international spread of diseases through a proportionate and limited public health action as it presents risks to public health, by avoiding the creation of unnecessary barriers to international traffic and trade".

These activities are conducted in respect to other rules of international law and international agreements; the regulations must be implemented "by fully respecting the dignity of persons, human rights and fundamental freedoms" and by being guided by "the concern of its universal application in order to protect the entire population of the world from the international spread of diseases".

Generally, the IHR defines public health events to which it applies, in order to increase the chances that all events of this nature could have major international implications, being detected and promptly reported to WHO by Member States with a view to assessing them. The regulation provides a legal framework in which the Member States and WHO can lead a concerted action to prevent, detect and control risks to public health at their source before they spread beyond the borders.
The Member States of WHO therefore undertake to implement the necessary means for the supervision of their territory and to report any threat to WHO that could affect other States. The restriction by operation of law for air traffic and establishment of quarantines are part of the precautionary measures that the States may be directed to take.

Compared to the earlier version of the IHR, which specifically set forth the threats to take into account, the later IHR was drafted in a more general way, that takes into account new contagious diseases, such as SARS in the early 2000s or, in current events corresponding to the date of revision of this text (2020), the steps taken to combat the "Covid-19" pandemic due to the Sars-Cov-2 Coronavirus.

3.4 - Risk of in-flight incapacitation

Two types of in-flight incapacitation are recognized: sudden in-flight incapacitation and subtle in-flight incapacitation. Sudden in-flight incapacitation is easy to define and identify: The Pilot is no longer able to assume his functions. He is unconscious, or then a victim of such disorders that he is aware of his incapacity.

By definition, subtle in-flight incapacitation is much more difficult to identify; it corresponds to a deterioration of performance. The causes of in-flight incapacitation are due to a factor of the environment or a personal factor, linked to the pilot.

3.4.1 - In-flight incapacitation of environmental origin

In commercial aeronautics, you only recognize two causes: hypoxia and toxic risk.

Unfortunately, hypoxia has not disappeared, because it was involved in the accident of the B737 from Helios (see p. 30), near Athens (Greece), on August 14, 2005, causing the death of all passengers on the aircraft (121 persons). Of course, it was a sudden total incapacity in this accident. However, more insidious hypoxic situations have been observed, leading to complex discussions on the origin of the accident.

Toxic risk has been observed in the past when air conditioning systems in the cabin have poisoned crews through carbon monoxide coming from the hot parts of the engine. The crew has no way to detect such pollution by a colorless odorless gas. The prevention of these accidents seems to be

effective. Still remaining are the accidents through onboard aircraft combustion, these are recognized by the pilots, who have the means to protect themselves.

In military aviation and in civil acrobatic aviation, accelerations + G_Z can cause a loss or alteration of consciousness (G-LOC, A-LOC: See paragraph "Consciousness disorders and loss of consciousness," p. 30).

Sudden in-flight incapacitation can also be physiological in nature, due to a state of spatial disorientation; it was discussed in the paragraph designated for spatial orientation disorders.

In a slightly different vein, it is rare that a pilot is affected by motion sickness, but the case may arise, particularly when the flight is very turbulent and the aircraft is maintained by automation; the pilot is only a passenger of his own aircraft and can be affected by motion sickness. The case is familiar in military aviation during certain flights operated with ground tracking systems, at high speed and low height. The monitors can also present motion sickness problems.

We will also point out the risks related to jet lag and work shifts outside of the normal hours of the sleep-wake cycle. Some accidents clearly occur when people are much more vulnerable (between 2:00 and 4:00 a.m.), this finding is also not specific to the aeronautics.

3.4.2 - In-flight incapacitation of personal origin

Sudden in-flight incapacitations of personal origin are either due to a disease not diagnosed by an expert in Aviation Medicine or a condition from an unexpected occurrence.

There are various statistics, indicating a trio of disease groups involved in this risk:

- Cardiovascular disease, first and foremost damage to the myocardium;
- Gastrointestinal diseases, from the hemorrhagic ulcer that bleeds in flight up to common gastroenteritis with pains, diarrhea and vomiting, and through digestive tract pains of all types;
- Neurological and neuropsychiatric conditions with in-flight anxiety attacks - not to mention proven cases of suicide or suicide attempts in flight.

Other causes of sudden in-flight incapacitation are classics, but they have become very rare with adequate prevention, such as hypoglycemia; unfitness declared with regard to at-risk pilots, with appropriate dietary measures and advice.

Fever is common. It obviously diminishes psychomotor performance. When declared before the flight, it is a cause of unfitness for the pilot.

03

FUNDAMENTALS OF AVIATION PSYCHOLOGY

01 PROCESSING OF INFORMATION

The human operator, and particularly the crew, develop in a dynamic and unpredictable environment. Information from the outside world, the flight panel or other actors (other crew members, air traffic controllers, etc.) is continuous. However, one must know how to collect, interpret and understand information at any time to make proper decisions, in relation to the flight objectives.

The mechanisms that characterize the mental work of the crew are called the "information processing mechanism" or cognitive mechanisms. The term cognitive qualifies all that relates to knowledge, whether it is the processing of information from the environment or using it to act.
Knowledge of cognitive mechanisms is important firstly for understanding, then for human performance and the sources of error that they can generate causing real safety hazards.

If perception, memory, understanding, decision-making and action are the cornerstones of information processing, we must not forget that all of these mechanisms are subject to factors that will directly or indirectly influence them.

These factors are attention, vigilance, fatigue, stress and motivation.

1.1 - Attention and Vigilance

1.1.1 - Definitions

Attention and vigilance are two concepts that are often confused. Distinguishing them is important, even if they are strongly interrelated:

- Attention is a psychological mechanism;
- Vigilance is a physiological mechanism;

Attention can be defined as the ability to direct one's activity, i.e. cognitive resources, to a specific task. It is a matter of controlling and directing activity. Attention allows one to focus on specific information or a task to receive it, understand it, make a decision or act on it (e.g. during takeoff, we focus our attention specifically on the acceleration of the aircraft and its speed).

Vigilance reflects an active state of the central nervous system, i.e. a state of awareness. The level of activation is linked to the electrical activity of the brain, which varies depending on the level of alertness. The activation state of the brain can be determined by means of electrodes placed on the scalp; this is an electroencephalogram (EEG). The levels of brain alertness will range from active waking to deep sleep. Each level of vigilance can be associated with a type of electrical wave.

Consequently, alertness means that one must be constantly monitoring. However, just because one is monitoring does not ensure that one is alert.
Through the activated states of the brain, one sees that it is possible to define the levels of monitoring (also called vigilance) and states of hypo-vigilance.

Hypo-vigilance refers to the difficulty to stay awake, or maintain a state of vigilance. Hypo-vigilance is a natural phenomenon marking the entry into sleep. It occurs at the end of the day and at the beginning of the afternoon after lunch, due to natural circadian variations in vigilance (also called biological rhythms of vigilance).
It is also dependent on the level of fatigue accumulated by the operator. In such a case, it can occur at any time during a task.

1.1.2 - Attention

a) A Limited Resource

Attention is a limited resource. This means that it is not possible for the human being to pay maximum attention to everything that surrounds him. It is necessary then make choices on how to divide the attention one has on all information or tasks that one must perform. One can distinguish two types of attention: selective attention (*focused attention*) and switching attention (*divided attention*).

- Selective attention is mobilized when one must focus on a single stimulus among several. For example, this is the call sign of its aircraft heard in the flow of en-route control messages, while the crew is performing another task.
- Switching attention is mobilized when attempting to process several stimuli at the same time.
  For example, during takeoff, the pilot at the controls looks at the runway to steer the aircraft and at its flight panel instruments to monitor the critical parameters. Even if it seems that several tasks can be performed simultaneously, it actually involves going from one task to another very quickly. In effect, the human being can only manage to be attentive to two new and/or complex tasks at the same time.

b) Impaired Attention

The attention level of a person may be affected by various factors: hypo-vigilance, distractions, interruptions, time pressure, repetitive steps, professional concerns not directly related to flying, extra-professional concerns, decreased motivation, stress.

1.1.3 - Vigilance

a) Factors Affecting the State of Vigilance

The factors that affect the state of vigilance are numerous: sleep deficit, accumulation of fatigue, certain drugs (now there is a special logo on the boxes), heat, continuous noise, duration in one work position (long-haul flights, sequence of steps), hypoglycemia, alcohol, large meal, monotonous task, reduced workload, and lack of information.

b) Effects of Hypovigilance

A series of manifestations occur.

- Physical Manifestations. Yawns, stinging eyes, heaviness of limbs and head, discomfort, greater sensitivity to sensory illusions, fight against sleep, episodes of drowsiness, micro sleeps.

- **Mental Manifestations.** Memory gaps or excessive confidence in one's abilities to memorize, slowness of reasoning, increased reaction time, difficulty concentrating, reduced attention, decreased ability to make decisions (less assumptions, stuck on one aspect of the problem), slowness of actions, less precise gestures, increased tendency to take risks, appearance and increase in the number of errors (omissions, repetitions, confusion, misunderstandings, etc.), decreased ability to accept criticism, doubts or conversely overconfidence, decreased motivation.
- **Manifestations on Collective Work.** Changes in mood (irritability, anxiety, passivity), withdrawal, decreased communications, increased non-professional communications, loss of rigor in professional language (phraseology), complacency and overconfidence in another crew member or in the systems (fewer cross-checks).

c) Management of Hypovigilance

To avoid or delay the manifestations of hypo-vigilance in flight, it's important to be aware of several factors:

- Have balanced meals before and during rotation, no alcohol;
- Refresh yourself (fresh air, movements, take a few steps in the cabin, conversation, stay busy with tasks);
- Take stimulants, such as coffee or tea, but not too much (no more than three to four cups per day, because beyond this, the side effects may outweigh the benefits in terms of vigilance);
- Crew communication, an increased awareness with possible variation of tasks and cross-checks between the crew members;
- Do not seek to do exceptional things, keep it simple (basic, standard) and familiar (procedures);
- Take a nap during the allotted time slots on a long-haul flight with an augmented flight crew

1.2 - Perception

Perception can be defined as the mental mechanism by which humans take in knowledge of the world around them. Traditionally, five senses have been established: sight, hearing, touch, taste and smell. These senses are associated with specific receptors: the sense organs. The sensor enables the transformation of a physical signal into a nervous signal.

1.2.1 - Properties of Receptors

- **Bandwidth.** This is the range that delineates the stimuli to which the sensor is sensitive. Thus, humans only see the light rays ranging from infrared to ultraviolet or only hear the sounds with a frequency between 20 and 20,000 hertz.
- **Sensory Threshold.** It is the smallest intensity of a stimulus in the physical environment, which causes a sensory organ reaction.
- • **Sensitivity.** It is the smallest difference in the intensity of the stimulus that can be detected by the sensory organ.

- Adaption or Habituation. When a stimulus is continuous, the receptor adapts and the its reaction decreases with time, or may even disappear altogether. Then the stimulus may no longer be perceived in the bandwidth of the receptor.
- Habit has two consequences:
  - It enables the organism to not be "bombarded" continuously by stimuli that have been perceived in the environment.
  - To be sure that a stimulus is perceived in time, it should not be continuous; it is for this reason that, in the cockpits, visual emergency alarms flash or they use modulating sounds.

In the retinas of our two eyes, we have approximately 250 million receptors, divided into cones and rods, which send the information to the brain through the optic nerve, which is made up of approximately 1.6 million nerve fibers.
Therefore, the optic nerve is not able to transmit all of the information received by the two retinas to the brain. This means two things:

- On the one hand, the information must be pre-processed in the receptors before being transmitted to the brain;
- On the other hand, certain stimuli will not be transmitted to the brain, because it does not have the physiological capabilities to do so.

There is evidence of the first limitation of the perceptual system related to the characteristics of the senses and the ability to transmit information perceived by the senses to the brain.

1.2.2 - Processing of Data-Driven and Concept-Driven Information

The mechanism of perception depends on both data-driven processing and concept-driven processing.

a) Data-Driven Processing

The processing mechanism driven by data is a bottom-up system, i.e. it goes from the senses to the brain (*bottom-up*). The whole issue of data processing is that the information reaches the brain, and this despite the limitations outlined above. For this reason, the stimulation must be sufficiently outstanding from others.

b) Concept-Driven Processing

The processing mechanism driven by concepts is a top-down system, i.e. that goes from the brain to the sensors *(top-down)*.
It is common knowledge that humans are not able to perceive everything and certain things can escape our perception. Accordingly, we will channel perception to perceive what is considered useful to achieve the task.
In other words, Humans search for information that fit into the schemas that they already have in mind and enable them to act in accordance.

In reality, data processing and concept processing are usually complementary. Each processing mode contributes to the overall analysis. That is why perception is described as an active mechanism.

c) Perception and Knowledge

Concept processing introduces another significant factor, namely knowledge of the subject. Therefore, assumptions related to the concept are directly dependent on knowledge of the operator. This has two consequences:

- perception is never complete and is only an image of reality;
- perception is personal and therefore subjective.

d) Learning to Perceive

These potential deficiencies are mitigated by:

- Design of interfaces, whose objective is to make the most salient information relevant to the crew;
- Training and experience, which allow aircrew to develop true perceptual strategies according to requirements and constraints specific to each flight phase.

However, these strategies are effective because there is complementarity and interaction between the crew members, and thus synergy. Being two in the cockpit allows for greater perception by perceiving more information, ensuring that the information received is well identified, avoiding identification errors through mutual confrontation, and promoting awareness of the occurrence of sensory illusions.

e) Factors that Influence Perception

There are multiple factors that influence perception:

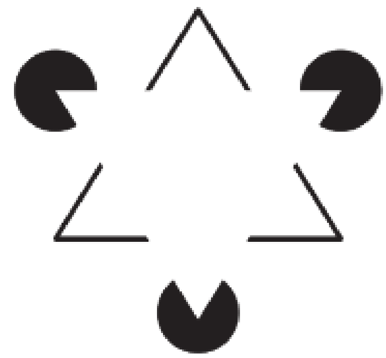
- Quality and properties of the sensor (e.g. bandwidth of the sensor, reduced visual acuity or colour blindness);
- Physical characteristics of the stimulus, which can vary depending on certain conditions (e.g. illumination, quality of communication media, etc.);
- Knowledge that enables the pilot to have a record of cumulative experience;
- Mode of processing by data or by concepts;
- Individual perceptual strategies, developed through training and experience;
- Flight and event dynamics, which influences expectations and crew objectives;
- Collaborative strategies of perception within the crew.

f) Daydreaming

By putting knowledge at the centre of the perception mechanism, strategies are established to surpass the anatomical, physiological and functional limits of the human sensors.

However, knowledge acts continuously on perception, and sometimes without our consent. They lead us to collect information and make identifications that do not correspond to reality. They even add to the information that is not present in the original stimulation, without being fully aware of it.

It seems that figure represented on the side, is composed of two overlapping triangles, which is not the case. There are three circles, which is lacking a section, and three V's. As it stands, this information has no immediate meaning. Accordingly, the brain has taken these pieces of information, and has used its knowledge to invent, on the one hand, a triangle passing through the three circles and, on the other hand, a triangle from the three V's.



To make this even clearer, the brain adds colour; the triangle on top seems whiter than the one on the bottom. Therefore, what is seen is a mixture of what is represented and what the brain has added.

Applied to the field of aeronautics, these illusions can be sources of danger, because they can lead the pilot to:

- Perceive things that do not exist;
- Perceive different things from the same stimuli;
- Only perceive an i entity and remain focused on this entity.

1.2.3 - Perception and Multisensory Integration

Perception of the environment is made with our five senses. The information from these senses are not processed independently in our brain, but are integrated. We are talking about multisensory perception.

Multisensory perception is important for several reasons:

- It allows comparing several sources of information to confirm or deny a perception;
- It accentuates the perception of certain stimuli when these stimuli are complex and they transmit information using several sensory functions;
- It also allows sensory functions to combine to be more effective in the performance of a task.

Multi-sensoriality is at the root of human performance, but it can be deeply flawed when there is a conflict between perceived information through different senses or when there is predominance, voluntary or not, from one sense to another. The consequences are often of perceptual illusions.

Despite its limitations and pitfalls, human perception is a very powerful tool due to its flexibility and variety of registers, qualities that are not available today in artificial perception systems.

In aeronautics, perception is central to safety in all phases of flight, whether they be visual or on the instruments. Vision provides adequate information on the environment in the flight phases near the ground. It also provides knowledge of the state of the aircraft through information on the cockpit instruments (attitude, engine, navigation, etc.).

The vestibular apparatus, the organ for balance, allows the head to know its position in three dimensions. With the visual, tactile and proprioceptive senses, it participates in the perception of the body's position in space.

It should not be forgotten that the olfactory sense is capable, of detecting any unusual odours, like a burning smell, and before a physical sensor detects it.

Perception, beyond its formidable capabilities, has limitations due to the anatomy and psychophysiology of its organs. Perception is learned in order to make the best use of perceptual capacity according to situational constraints. However, perception is never complete.
Proper perception allows access to pertinent information for task objectives to be accomplished. In these adaption strategies, perception may be erroneous.

Whether individually or collectively, it is necessary to be wary of one's perception. Do not hesitate to doubt and use systematic scans of information to avoid false perceptions. Unfortunately, several accidents due to sensory illusions serve as reminders that perceptual pitfalls are present daily and can affect crew individually or collectively.

1.3 - Memory

Speaking, reading, listening, understanding, decision making and acting are all activities that are only carried out by an operator if this one's brain can encode, store and recall information.
Memory is a complex mechanism. According to the duration of information retention in the memory, there are three memory registers described:

- Sensory memory;
- Short-term memory/working memory;
- Long-term memory.

1.3.1 - Sensory Memory

The sensory memory maintains a precise and complete enough ''image'' of sensory information to reach a receptor. A specific sensory memory exists for each receptor.
The persistence of this "image" is of very short duration, ranging between 200 milliseconds and 1 second according to the receptors. It is a memory that retains a high proportion of present information, but very briefly. It functions outside of any conscious control. It enables the receiver to maintain an "image" of the stimulus, while the stimulus has disappeared to perform the first steps of perception. The sensory memory is particularly important and useful to the short-term stimuli or when the time available to perceive the information is also very short.

1.3.2 - Short-Term Memory/Working Memory

Theoretically, short-term memory and working memory are two slightly different concepts. However, they have, on the one hand, common properties (quantity and duration of information storage) and, on the other hand, the information contained in the short-term memory is part of the information in the working memory. It is for these reasons that one likens short-term memory to working memory in the professional world.
The working memory is the structure that stores information necessary for performing tasks. This memory retrieves information directly and quickly when the pilot needs it.

The working memory stores three types of information:

- Information from the sensory memory;
- Information from the long-term memory, where all the knowledge of the pilot is stored, and useful for the current task;
- Information produced by the crew as a result of reasoning on the current situation.

a) Properties of the Working Memory

Working memory presents properties that explain how its use shifts from real management:

- It is finalized, i.e. it includes knowledge useful for implementation of the current task; its content changes depending on the tasks;
- It is limited; its maximum capacity is approximately 5 ± 2 items or units of information; if it seeks to retain more than 5 ± 2 items, the additional items will be automatically lost;
- The duration of the working memory is short, since it is generally several seconds; beyond this, information is lost;
- Finally, the working memory is sensitive to interruptions during the retention phase; if an interruption occurs within 30 seconds after information has been stored in the working memory, the probability that it will be forgotten is much higher.

b) Management of the working memory

This is why it is useful to write ATC clearances or ATIS's on paper when the number of items to be retained may be higher than 5 ± 2.
In referring to the limited capacity of the working memory, we spoke of an ''item''. This ''item'' concept deserves to be developed. It explains that it is ultimately possible to retain significant amounts of information in the working memory, whereas this number must not exceed 5 ± 2.
The ''item'' (or "chunk") is here defined as a significant unit of information for the operator, for use as part of the realization of its task. Thus, the item can be a simple figure or word, but it can also be a sentence, a number and even a concept with all its properties (e.g. processing of a malfunction).

To increase the capacity of the working memory, it is possible to combine multiple pieces of information into a single unit of information, which represents only one item. Two mechanisms can thus be described:

- Association or ''chunking'', which consists of grouping information. Each group then becomes an item. For example, this mechanism is used to remember a phone number. "06 66 91 45 59" is easier to remember than "0666914559".
- Grouping information in categories that share common properties. The items are then categories and, in referring to the categories, their content is recalled.

One could also mention mnemonics among the ways to improve the retention capacity of the working memory. For example, the phrase "Men Very Easily Make Jugs Serve Useful Needs Perhaps" allows one to remember the position of the planets in relation to the Sun: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, Pluto. The sentence is an item.

For information, the working memory is the entry door to the long-term memory. For this reason, the information in the working memory must be repeated and processed in order to increase their print and avoid forgetting before they are transferred to long-term memory.

1.3.3 - Long-Term Memory

The long-term memory is the structure where all knowledge of an individual, whether it is professional or not, is permanently stored. The retention capacity and duration in long-term memory is unlimited.

Memorizing information in long-term memory includes three steps: encoding, storage and recall (or recovery).

a) Encoding

Encoding aims to give meaning to information relative to information already stored in long-term memory. The depth of encoding, and the organization of information, will determine the ease with which it can be retrieved.

The encoding process also makes reference, not only to the information, but also to its environmental, cognitive, and emotional context. This is very important for recall, because a way to have access to the information stored is also to remember the circumstances in which this information has been produced, used or encoded. Once the context is recalled, it creates a real Ariadne's thread leading to the information sought.

The information can be encoded verbally, visually, or audibly. Individual preferences exist on how to encode information.

This shows that proper education must combine various means of presenting information, to satisfy all of the trainees and also promote connections between the different forms of encoding.

b) Storage

Storage is the active process that makes memorized information less vulnerable to loss since amnestic traces naturally have a tendency to weaken. This strengthening requires two mechanisms:

- Consolidation, which transforms and integrates information with knowledge already stored. Consolidation consists of creating associations between new and old knowledge.
  Consolidation explains the differences in memorization between the recollection of recent events and the recollection of the old facts. Recent events are more fragile than old facts, which is associated with a greater amount of already established knowledge.
  It is during sleep, and especially REM sleep, that the review and repetition of information acquired during the day allows for an effective consolidation. Any suppression of REM sleep lowers memory and, consequently, learning.
- Reconstruction, which consists of reshaping existing knowledge based on new information.

Consolidation and reconstruction are part of long-term memory, which is constantly changing and reorganizing.

In long-term memory, we typically distinguish between two types of memory: declarative memory and procedural memory.

- Declarative memory is the memory of knowledge (concepts, facts, events).
  It is conscious and explicit, because we can describe it verbally. In a lecture, we learn declarative knowledge (jet operator, anticyclone characteristics, VHF omnidirectional range).
- Procedural memory is the memory of know-how (skills).

It corresponds to the know-how required to use the knowledge of the declarative memory. It is implicit memory, because it is hardly verbalizable.

c) Recall

Recall or retrieval is the result of activation, voluntary or involuntary, of knowledge in long-term memory.

Recall will use the encoding mechanisms to retrieve the information sought. That is why the more information is coded, developed, organized, or structured, the easier it is to retrieve. Similarly, the closer the recall context is to the encoding context, the easier it is to retrieve information.

The inability to retrieve information or knowledge stored in long-term memory can be caused by misfires at each of the three memorization stages:

- Poor encoding;
- Insufficiently consolidated trace;
- Retrieval difficulty.

d) Memory Lapse

The memorization mechanisms in long-term memory are complex. The main difficulty is knowing how to retrieve the information that one wishes from among all stored knowledge. The access time to retrieve information can be very long, or even be incompatible with flight dynamics or beyond temporary stops, for which a decision must be made. In extreme cases, it is possible that one no longer knows how to retrieve the information. One can then consider that it is forgotten, but this is not completely true. In reality, it is always stored, but it has lost the keys or the path to access it.

It is for this reason that before any flight, it is important to reactivate, i.e. to make the knowledge of the long-term memory more available, which will be or could be useful for the flight. That is the purpose of flight preparation.

Memorization is affected by certain factors:

- Level of vigilance, attention and concentration;
- Emotional value attributed to the information to be memorized, as well as the degree of emotion of the operator;
- Interest, motivation, need or requirement are all factors which, when they are high, contribute to better memorization;
- Expectations direct an operator's attention and interpretations on particular facts, which will be stored to the detriment of others;
- Being continually reorganized and reconstructed, knowledge can either be distorted or enhanced over time, to keep only the positive aspects; this problem is particularly present in testimonies;
- Inference and suggestion; due to the associations between knowledge, one can improperly think that information was present since it is usually associated with other information; for example, if an aircraft speed was 350 kt, and no change in speed has been made or noticed, two minutes later, it was still the same; in fact, two minutes later, it has not been observed, but if one asks what the speed was, one knows the answer.

1.3.4 - Amnesia

If the memory lapse is associated with encoding and difficulty retrieving information or knowledge, amnesia is an excessive loss of memory due to a brain injury or psychological trauma.

1.4 - Selection of Responses

1.4.1 - Learning Principles and Techniques

Learning is the acquisition of new knowledge and know-how.

There are three approaches to guide learning:

- Behavioural approach, also called the ''behaviourist'' approach (from the English word "behaviour");
- Cognitive approach;
- Model approach.

a) Behavioural Approach

The behavioural approach was inherited from the works of Pavlov and then Skinner on the subject of packaging. It consists of establishing a connection between a stimulus and a response. The answer is the behaviour that one wishes to see. Therefore, the strength of the learning connection depends on the strength between the stimulus and the response.
The instructor uses either positive or negative reinforcement to achieve the expected result. The trainee is viewed as a well-trained individual, who possesses an array of mechanized behaviours. The learning of emergency procedures or failure management are examples of learning where one seeks to mechanize the behaviour of the crew.

b) Cognitive Approach

Learning builds on the meaning given to information for learning and the way in which they are stored in memory. Learning comes before any problem resolution by discovering an appropriate solution through the restructuring of situational elements.
It involves discovering and establishing new relationships between elements, which until then were seen as isolated. For this reason, the subject must be active in an understanding-resolution process. "Insight", which describes what is "right in front of our eyes", translates the psychological phenomenon occurring as a result of a new organization of situational elements when understanding occurs.

The instructor is responsible for guiding the trainee and creating the conditions that will promote discovery of the new organization. Thus, the error or trial-and-error can be useful in order to demonstrate the current dilemma, and make a new meaning "emerge". Learning by discovery is at the heart of cognitive learning.
Behind the cognitive approach, there is the adage: ''One only remembers well what one understands well".

Cognitive learning is particularly well suited for the learning of "know-how" or skills. For example, in learning how to handle stalling, the natural tendency is to pull on the yoke when one feels the aircraft is diving. It is necessary to leave this reference setting to adopt another, in which one must restore the speed to come out of the stall. Insight is the moment when one understands that the recovery of speed is more important than the desire to resist diving. One should be tested in a situation to be convinced.

c) Model Approach

Learning by model or by imitation involves benefiting from the experience of others to teach oneself. The most classic model of instruction is the instructor who shows an exercise and requests the trainee to perform it. Learning by imitation must be preceded by necessary information so that the trainee can take full advantage of the model by the instructor. Imitation mainly involves learning know-how.
Learning by imitation is a teaching between the behavioural approach (learning a sequence of actions) and the cognitive approach (performing a sequence of actions to understand it).
The limitations of learning by model are:

- Each situation is different, and what is learned in one situation is not necessarily adapted to another;
- The model of the instructor can be imperfect and, beyond the desired knowledge, imperfect knowledge can be transmitted.

d) Learning Factors

The learning process is influenced by various factors:

- Trainee's motivation to want to learn (intrinsic motivation);
- Trainee's abilities;
- Trainee's mental health;
- Trainee's awareness of learning issues;
- Level of alertness;
- Training programme defining the pace of learning;
- Teaching aims (level of learning, overlearning, mechanisation, general view, etc.);
- Selected teaching methods such as the use of practical exercises or repetition to encourage memorization;
- Instructor's competency both in terms of teaching and professionally;
- Quality of the relationship between the instructor and the trainee;
- Instructor's motivation;
- Process of taking into account the trainee's difficulties.

When learning, there are two possible ways to improve memorization: 1) mnemonics and 2) memory training.

- Mnemonics
  These methods aid in memorization. For example, the list of actions to be performed before a flight phase can be summarized by the first letters of each word in a phrase.
  Thus, before landing, the phrase "Fais Ton Métier Pour Vivre Entier et Heureux" (French version) allows one to remember the actions and checks to be performed without forgetting it: Freins, Train, Moteur, Pas, Volets, Essence, Huile (French checklist).

- Memory Training
  Training the memory involves using more complex techniques requiring a real workout:
  - Word association or "chunking";
  - Categorization;
  - Methods of association involve creating associations between already-possessed knowledge and new material to be memorized; in this method, for example, a well-known location (one item) is associated with each new item to be memorized; storage of new material will be made by association with this existing knowledge structure; and for recall, it will suffice to recall the places in order to remember the items of the newly memorized material;
  - Understanding and formalization of knowledge, when their learning facilitates storage;
  - Recalling by referring to the contexts.

e) Learning Skills

A skill is an ability, generally learned and acquired by training, which allows one to perform actions to achieve a desired result. Skill is the more operational stage in the acquisition of knowledge.
There is a distinction between motor skills and mental skills.

To understand the process of skills development, we will refer to the Anderson model of learning. Anderson distinguishes between three learning phases: cognitive stage, associative stage and autonomous stage.

- The cognitive stage involves the acquisition of declarative knowledge (knowledge). This is a long phase of discovery, where new knowledge must be understood. It is characterized by many errors.
- The associative stage corresponds to the transformation of declarative knowledge into procedural knowledge (know-how). Knowledge is reinforced through practice according to a dual mechanism of compilation and composition. Compilation associates knowledge, makes connections between them, and creates shortcuts. Composition enriches compiled knowledge to make it more applicable to various settings of use. The associative stage develops knowledge specific to the field of application.
- The autonomous stage is a consolidation step and reinforces procedural knowledge. Consolidation is concerned more with the autonomy of the procedure than its enhancement. Procedural knowledge wins out in speed, precision and resistance over disturbance factors. This is how skills are acquired.

Among the many skills possessed by an operator, two are particularly important for the pilot: 1) motor programs and 2) mental schemas.

f) Motor Programs

Motor programs are sensorimotor skills that provide rapid and precise responses of varying complexity (e.g. controls and inspections).

g) Mental Schemas

Mental schemas are mental representations, particularly useful for understanding, reasoning and acting. The mental pattern is a structure of knowledge organized for a purpose. It is composed of

concepts, actions, reasoning, potential incidents and of associated solutions, as well as checks and inspections. The pattern consolidates useful information for the achievement of a goal and has it immediately available when the pattern is activated. However, the pattern is generic. This means that it is necessary to customize it for the current situation.

For takeoff, the pilot has a mental pattern describing the takeoff sequence, along with the actions, checks to be performed and behaviour in case of incidents. However, to be operational, the pattern must be adapted for takeoff conditions, i.e. the airplane mass, QFU (magnetic bearing of the runway), length of the runway, weather conditions, etc.
The schemas are developed during training and enriched through experience.

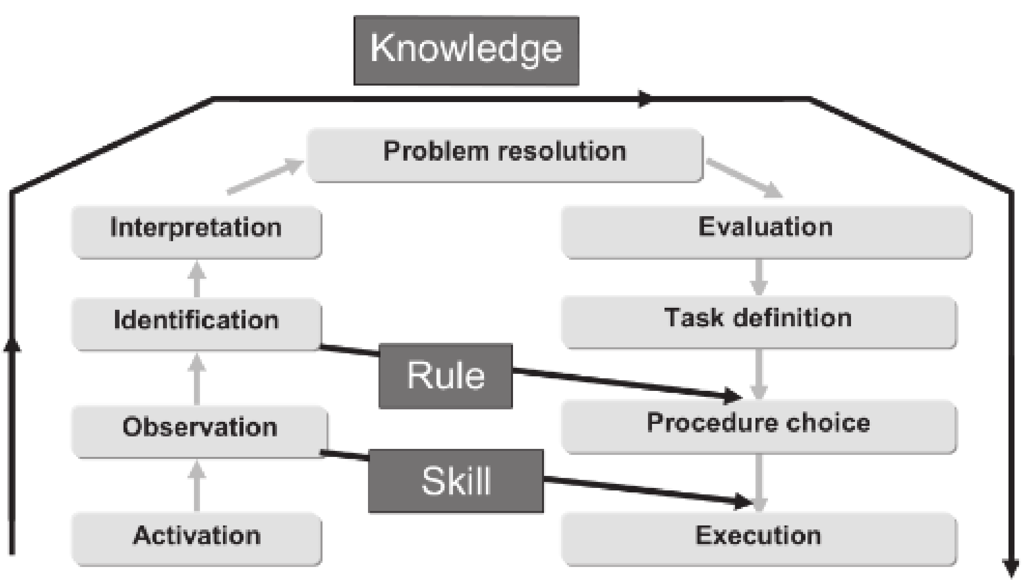
The benefits of mental schemas are to facilitate understanding, anticipate, guide perception more easily through processing directed by concepts, pre-activate knowledge in long-term memory in order to better manage the working memory and prepare decisions and responses in advance.

In summary, the schema controls the situation instead of being controlled by it. It is through the schemas that one can anticipate, and therefore pilot the aircraft.

The disadvantages of mental schemas are:

- Choosing a schema is like betting on the situation;
- The schema may be incomplete or contain errors;
- The schema must be customized to the current situation; used in a generic way or incorrectly customized, it can also lead to errors;
- The schema allows one to understand, and thus control the situation; in the face of information that invalidates the schema, it is difficult to challenge it, because to abandon it means to find another one, which may not necessarily be easy at the moment; consequently, there is a risk of continuing to use the current schema, even if certain indications suggest its inadequacy.

h) Activity Control Levels



The activity control levels.

In an approach, not very far removed from Anderson, Rasmussen, a Danish scientist, proposed a model, S-R-K model (Skill-Rule-Knowledge), which describes three different levels of activity control (Figure below). The control levels correspond to the ways in which it is possible to process information to extract it from the environment and understand it.

- Knowledge-Based Operation
  Faced with a new situation that one does not know, an operator does not have to register an immediately available response. This means that a very analytical mode of operation must be implemented. On the basis of one's knowledge and know-how, it is necessary to go through each step, optimizing it in order to find a new and original solution.
  This mode of operation is very rich, because it allows one to be as thorough as possible. In return, it is long, costly in attentional resources, and thus generates a heavy workload.
- Rule-Based Operation
  Faced with a familiar, known situation, the human operator develops rules for selecting a solution more quickly when it has been identified that one is in this situation. The rules create shortcuts in the linear sequence for information processing by saying: "If I identified that …, then I can do …."
  By creating a shortcut, one gains time, saves attentional resources, and thereby reduces the repetitive workload. One frees up attentional resources, which allows one to do something else at the same time, i.e. manage other tasks.
  The rules are acquired with training, experience, and can also be transmitted between operators.
- Skill-Based Operation
  Faced with a frequently encountered situation, the operator tries to be even more effective in the operating register. The rule is transformed into a skill that allows one to go directly from observing a pattern of information in the environment to the execution of a solution. It is an automated behaviour that allows one to gain, while performing the same task, even more time and attentional resources than rule-based operation.
  All the time and attentional resources saved by the use of skills allow one to manage even more tasks simultaneously.
  Skills are acquired with a lot of practice and experience.

In expert activities, such as being a pilot, these three operating registers coexist. It is impossible to perform all piloting tasks simultaneously in a knowledge-based mode. This would exceed the available attentional and temporal resources. In practice, one realizes that the activity of the operators is composed of:

- 70% skill-based operation;
- 20% rule-based operation;
- 10% knowledge-based operation.

Without this automation of behaviour, it would be impossible to perform complex activities, such as piloting an aircraft.

By reducing the attentional resources to do the same thing but with various operating registers, it reduces the reliability of one's behaviour. This increases the likelihood of making mistakes.

- In skill-based operation, the risk of error lies in the choice and implementation of skills. Of course, one can commit a skill error, but one can also poorly perform the skill (i.e. run-time error) or, finally, the carrying out of an action can be interrupted by a skill that takes priority (capture error).
- In rule-based operation, the risk of error lies in choosing a bad rule or in the wrong application of a good rule.
- In knowledge-based operation, the risks of error are numerous. The lack of knowledge or use of inappropriate knowledge leads to representation and decision-making errors to achieve the intent.

1.4.2 - Motivation

a) Definition and Properties

Motivation is the mechanism by which an individual engages in an action or experience. It determines the initiation, direction and intensity of this commitment as well as its extension to completion or interruption.

Motivation is usually manifested by a display of energy that can take on different forms, such as enthusiasm, concentration, diligence, perseverance, etc.

The effects of motivation on performance are manifold. The effect most often cited involves its mobilizing power, i.e. its power to lead and to increase the use of individual cognitive and motor behaviours.
One can distinguish between non-specific effects and specific effects.

The main non-specific effects are increases in the level of vigilance, overall level of activity, perseverance, and mental load tolerated in a cognitive task as well as the fact that motivation is an excellent learning motor.

However, the more often the effect is specific, because the activity is channelled to behaviour deemed appropriate for the purpose.

The main specific effects are:
- Direction of the motor activity toward certain stimuli;
- The intervention of attentional processes that selectively guide perceptual and cognitive activity to aspects of the situation deemed relevant;
- The intervention of attentional processes that detect pertinent stimuli to the detriment of other aspects;
- Increased effectiveness of motor responses, such as decreased latency, increased speed of execution, and increased energy expended.

In the extreme, over-motivation may penalise priority management, creating a real focus on a single goal at the expense of other aspects of the task. Excessive motivation can thus lead to:
- Underestimation of risks;
- Unanticipated consequences;
- Predominance of the action on reflection.

Specific focusing leads to motor and cognitive activity guidelines that are carried out with low attentional control, where the risks of error are more significant.

b) Motivation and learning

In learning, motivation plays an essential role by being associated with the concept of competence: the feeling of perceived competence (the fact of knowing) has an effect on motivation.

If the efforts made by the trainee to control the situation succeed, the trainee feels competent. Then, the trainee finds pleasure and satisfaction and will maintain a high level of motivation.

If the efforts by the trainee lead to a failure, this causes anxiety, feelings of incompetence and loss of motivation. This negative impact can be minimized if the trainee is encouraged to try again and if someone shows that this one possesses the necessary competence to succeed, or that it is normal to not succeed the first time at this stage of progression.

In this approach, one can conclude that motivation is the result of two components: 1) satisfaction of needs and 2) feeling of competence.

c) Over-motivation

Significant motivation is required to perform complex tasks, but excessive motivation can lead to dangerous behaviour in terms of safety. Since excessive motivation may be linked to the importance of the task or the commitment of the individual to the extremely important task, excessive motivation can lead to inappropriate behaviour in terms of safety.

One characteristic encountered in aeronautics, is the fascination of the objective or "target fascination". Focusing on the achievement of the task results in the pilot or crew neglecting any of the items that ensure the task can be accomplished under normal safety conditions.

The desire to continue at any cost, regardless of the weather conditions, even below the minimum, is an example of "target fascination".

02 HUMAN ERROR AND RELIABILITY

2.1 - Reliability of Human Behaviour

2.1.1 - Definition and Principles of Human Reliability

Human reliability is the ability of a human operator or a group of operators to achieve a task successfully in any phase of system operations over a given time interval.

Since the 1970s, publications on safety and human reliability have made it possible to progress in understanding them.

- The error and the consequences of the error must not be confused.
- Error is the counterpart of human performance, which explains the saying "to err is human". When one seeks to be successful in complex tasks, there is more likelihood of making mistakes.
- The error is unintentional. It results from the pitfalls of human operating.
- Errors are not unusual. Everyone makes mistakes in their sphere of activity, but not all lead to disasters. Either they have no consequences, or they are detected and resolved, or the consequences are minimized once they have been detected.
- Errors can be useful, because they warn against the exceeding one's skills and know-how. In this sense, they have a significant role in regulating behaviour and use safe behaviour. Finally, errors facilitate memorization in any learning (learn from one's mistakes).
- The error is often treated as a cause of the air incident. In terms of prevention, it is much more productive to see the symptom in it, the materialization of a series of causes that contributed to creating the error.
- The human operator is an important factor in reliability, because one manages a number of dangerous situations on a daily basis that had not been imagined. By their adaption and creativity, these active actors contribute to the reliability of the socio-technical system.
- The reliability of the socio-technical system is the result of the complementarity between technical reliability and human reliability. Above all, what is important is the overall reliability of the system. Humans and techniques must be thought of as a single system, each one with strengths and weaknesses.
- Knowledge of errors is important for making progress in terms of safety, either on a crew or company level.

2.1.2 - Reliability Factors

The factors contributing to reliability are numerous, whether they are internal or external.

- Internal Factors. Qualification, knowledge, practice, training, stress management, fatigue level, motivation, confidence, personality, management of priorities, etc.
- External Factors. Flight constraints, non-flight professional constraints, time pressure, cockpit ergonomics and aircraft systems, economic constraints, social environment, private life, etc.

2.2 - Mental Models and Situational Awareness

2.2.1 - Situational Awareness

a) Definition

Endsley defines situational awareness as the perception of environmental elements within a volume of time and space, the comprehension of their meaning, and the projection of their status in the future.
In this definition, situational awareness is a transversal concept, which includes perception, memory, understanding and attention.
There are different levels of situational awareness, Level 3 being the most accomplished:

- Level 1 is perception;
- Level 2 is understanding;
- Level 3 is anticipation and planning.

Situational awareness is associated with the concept of controlling the situation, which is the case when understanding enables one to anticipate future states of the situation. It is then possible to prepare for better management of one's own mental resources according to situational constraints.

b) Proper and Improper Situational Awareness

The loss of situational awareness is reflected by a number of indicators: lost sense of situational control, feeling like one is a passenger and no longer the pilot of the aircraft, disorganized search for information, focusing on information, precipitation, alteration of communications, loss of confidence and hesitations, doubt in one's skills, primacy of action on reflection, misunderstandings with the other crew members, asking obvious things, impatience.

Decrease of situational awareness can also be unconscious. For example, a pilot thinks that he has proper situational awareness when in reality he does not.

The prerequisites to building proper situational awareness are:

- Being competent;
- Using all available resources to collect information (perceptive scanning, information sharing, announcing status changes, announcing system interventions, ATC, cabin, etc.);
- Taking the necessary time to understand based on the circumstances;
- Being wary of obvious solutions, which appear to be "too simple";
- Having the sensation of only doing one thing while neglecting other tasks (same for other crew members);
- Questioning one's understanding when situations do not go as planned;
- Being wary when one starts to reject information, casting doubt on the understanding one has of the situation, or when one begins to change their meaning to make them compatible with what one thinks;
- Ensuring through feedback that one's understanding is adapted to the situation and its outcome;
- Being ready to change one's understanding of the situation or when new information is perceived (particularly, the occurrence of events);
- Always comparing one's situational awareness to that of another crew member; it will strengthen and enrich oneself or, on the contrary, call one into question;

- Sharing one's situational awareness with another crew member to build a common understanding, and ensure safety and performance within the crew (discussing the time constraints, scheduling deadlines).

The factors that interfere positively or negatively with situational awareness are: qualification and experience, cockpit ergonomics and interfaces (presence and accessibility of information relevant to the current task, presence of feedback on performed actions, etc.), fatigue, boredom, stress level, communication and synergy of the crew, interruptions.

2.2.2 - Mental Models

a) Definition and Properties

The mental model is a representation to mentally simulate the course of a phenomenon and anticipate the results of an action. The mental model is built with experience. This means that the mental model is unique to each individual.

The mental model is important, because it is impossible for a human operator to manage all of the information from one's environment, just as it is also impossible to understand everything. One does not have sufficient capacity.
To understand the situation and anticipate its future at a given moment, one must be able to build a mental representation based on a limited amount of information to be able to understand the essentials. This is the objective of the mental model or mental schema.

The characteristics of the mental model are:

- To be a simplified image of the situation;
- To be an individual, thus inclined to subjectivity;
- To distort the situation, by accentuating the aspects that one thinks to be most important to the detriment of those considered to be less relevant (for example, if you ask a pilot to describe the operation of a jet engine, his description will be different from the one provided by a maintenance technician);
- To be easy to use;
- To interact with others, to the extent that one is assured that one has the same mental model.

Being a simplified, reduced and distorted view of the situation, the mental model can lead to errors of situational awareness to the extent that the mental model is incorrect, incomplete or not commonly shared among the crew members.

b) Cognitive Illusions

By anticipating the outcome of a situation, the mental model allows one to have expectations: expectations in terms of reasoning, but also perception.
If the mental model is inappropriate, it is at the root of perceptual expectations that do not correspond to sensations actually perceived by the sensory receptors. In this case, it creates a "cognitive" conflict between what one imagines and what one perceives. The brain cannot interpret this divergence, which causes a cognitive illusion.

2.3 - Theory and Model of Human Error

Crew errors, as defined by the ICAO in the TEM model, defines human error as crew actions or non-actions that result in a deviation from the original expectations or intentions of the crew or organization.

2.3.1 - Error Chain

The activity within the cockpit is a dynamic and changing activity. What has been done affects what is done, which determines what will be done.
Rare is the isolated error, which alone explains an air incident. It is much more common to observe a series of errors, which accumulate and create a real chain leading to the air incident. To qualify this phenomenon, we refer to it as an error chain.
The danger of the error chain is that it puts the crew into an error mindset, because one error leads more easily to another error. It is easy to say a posteriori that it would have been sufficient if only one error caused the accident. However, in the course of action, this is much more difficult.

Crew awareness must be raised to not tolerate error and, in case of doubt, we must step back to break the error chain. It is enough to open a link in the chain to avoid the accident.

2.3.2 - Error Forms and Types

The first error classifications were mainly descriptive. One of the best known classifications is that of Swain and Guttmann (1983):

- Error of omission: non-execution of an action during a task;
- Execution error: execution different from what should be done;
- Drift error: introduction of an unexpected action;
- Sequence error: execution of actions in another sequence;
- Time error: execution of actions outside of the time prescribed.

With the advent of the cognitive approaches to error, other classifications have emerged. These classifications are based on error generation mechanisms. Accordingly, Reason (1990) proposed a Generic Error-Modeling System (GEMS), derived from the SRK model (Skill, Rule, Knowledge) of cognitive control of human activities by Rasmussen.
Reason distinguishes three types of error:

- Slips, which refer to skills;
- Lapses, which refer to skills;
- Mistakes, which refer to decision errors and may therefore be rule-based or knowledge-based errors.

a) Slips and Lapses

Slips and lapses occur in automated, routine, skill-based behaviours. For example, these are actions that have nothing to do with the current task, omissions or repetitions.
Mistakes involve observable actions and are due to failures in perception or attention in the performance of familiar tasks performed using skills that lead to doing something different from what was intended. Mistakes only concern the "performance" part of a skill. Mistakes have nothing

to do with the validity of the purpose of the action. These are mistakes made during the performance of the action to achieve this goal. Performance mistakes include the following:

- Those that are linked to very similar actions and which, due to a lack of perception or attention, lead to an action which is not appropriate: for example, cutting the wrong "breaker" rather that the right "breaker". This is known as a performance mistake.
- Those related to environments with similar characteristics. An action is usually performed in a familiar environment. On the day when another action is performed in another environment that is very similar to the familiar environment, there may be, due to a lack of attention or perception, an environmental capture that leads to the action that in the most familiar environment being performed. For example, before landing, the controller asks the pilot to take a runway exit taxiway that is not the one normally used by the pilot. After landing and decelerating, the pilot takes the taxiway that they are used to using and not the one cleared by the controller because they are guided by the environment they are most familiar with. This is known as environmental capture.

Lapses relate to lapses in memory between forming an action plan and carrying it out. They will result, for example, in an action not being carried out, an action not being carried out in the right place or even the forgetting of an action plan.

The basic mechanism of slips and lapses is low attentional control exercised by the operator over what this one is doing. As a result, the automated sequences are vulnerable and subject to failures in their execution. As slips and lapses occur during routine behaviours, the opportunities that arise are very common.
Therefore, skill-based errors are rather characteristic of experts and, in general, quickly detected, but this very often requires receiving feedback. In contrast, they can also be totally unconscious and, in this case, much more difficult to detect.

b) Rule-Based Errors

Rule-based errors correspond to errors in understanding and decision making, whether in the definition of the objective or in the choice of solution to achieve this objective.
In rule-based errors, we observe choices of bad rule or misapplications of good rule. Rule-based errors may occur in non-routine problem solving situations. They are difficult to detect.

c) Knowledge-Based Errors

Knowledge-based errors are errors in understanding and decision making, whether in the definition of the objective or in the choice of solution to achieve this objective.

In knowledge-based errors, lack of knowledge is at the root of the errors. However, it is also common that one has the knowledge, but not available at the moment when it is needed. It has not been pre-activated in the working memory and one does not have the time and resources necessary to activate while performing the task.

Knowledge-based errors may occur in unfamiliar problem solving situations. Their detection is difficult and, in most cases, requires an external intervention. Knowledge-based errors are rather characteristic of newly qualified people and non-experts.

2.3.3 - Violations

Alongside errors, the concept of infringements must be considered.

Infringements are deliberate deviations from rules, procedures or training received to perform a task. The difference between error and infringement is based on the intention of the person making the deviation. If the deviation is unintentional, it is an error. If the deviation is intentional, it is an infringement.
Infringements may have several causes: inappropriate or non-existent procedures, restrictions (time, organizational) that do not allow tasks to be carried out as planned, or make it easier to do so.
For example, on an unstabilized approach, minima may be exceeded when it is considered that the aircraft will be stabilized "in time". This is less costly to manage than a go-around with all the consequences for passengers and the airline, not to mention the work involved in a new approach.

Infringements may be routine. These are often "tricks of the trade", shared by a large number of staff. They may also be situational or exceptional and allow a solution to be found in a delicate situation not described in procedures.

The violation is a practice not in accordance with the regulations, i.e. it does not necessarily include all the safety guarantees. It is for this reason that violations increase the risk of the occurrence of errors.

2.3.4 - Active Error and Latent Error

A distinction is made between errors that have consequences: active errors or latent errors. In this distinction, errors are separated according to the time period in which their consequences occur. Active errors have immediate consequences, whereas latent errors, or dormant, will have consequences in undetermined time frames. Such a time period can extend from a few minutes to several years, depending on the person who has committed the error.

In general, active errors are more commonly committed by frontline actors than by crew members. Erring in the rate of descent displayed while in automatic pilot is an active error.

Latent errors are typically characteristic of personnel located upstream from the frontline actors (management, training, procedure, design, etc.). Systematically, errors will not have consequences. For errors to reveal themselves, specific triggers that depend on operational circumstances are required. It is referred to as the incubation period, the time period between the moment when the error occurred and the moment when it is revealed, when it becomes active. Examples of latent errors are: a programming error embedded in software, a database error, a wrong procedure, the incorrect insertion of a navigation point, etc.

Active errors have meaning in relation to the sequence of crew actions. This increases the likelihood of their detection. Conversely, it is more difficult to detect and understand latent errors, because they are more the result of contextual elements than actually the result of actions by the crew.

2.4 - Error Generation

2.4.1 - Making Mistakes

There are a number of factors that contribute to the occurrence of errors. These factors are either internal, i.e. they are related to the characteristics of operators, or external, i.e. they depend on the situational conditions of the activity. The main factors involved are:

- Internal Factors. Experience, qualification, expertise, attention, vigilance, fatigue, stress level, health, personality, confidence, leadership, collective work.
- External Factors. Ergonomics, economic constraints, socio-professional environment, time pressure, procedures, nature of tasks (repetitive, etc.), complexity of tasks, workload, stress factors.

In terms of sensorimotor skills, for example, errors may be due to internal factors, such as qualification or expertise, but also to external factors, such as ergonomics.
Among the external factors, three are particularly significant: ergonomics, economic constraints and socio-professional environment.

- Cockpit ergonomic systems have a direct impact on how the crew works, understands the situation and makes decisions. It determines access to information (feedback on the automatic pilot mode, automatic transition of modes, etc.), but also how controls are operated by the cockpit crew (similarity of location and/or form between levers, logical data protection, format of inserting parameters, etc.).
- Economic constraints have a direct impact on the time pressure of crews (reduced layover time, adhering to hub schedules), workload (additional tasks, schedule rotations), flight management (fuel consumption), etc.
- Socio-professional environment including working conditions (rest time and conditions), professional status, remuneration conditions (profit-sharing, etc.), and socio-professional relationships are all external factors that can influence the decision-making of crews.

2.4.2 - Error management: Reducing their generation to minimize their consequences

Considering error as the counterpart of performance does not mean being fatalistic in terms of human reliability. Human operators are aware of their shortcomings and have learned to manage their errors. Managing one's errors is not synonymous with justifying the production of errors. Managing errors is integrated into human activity, which is evident by the fact that mechanisms are implemented to ensure that the errors have no consequences on safety.
By taking errors into account in human activity, one also creates more means of action to improve safety.

Better managing errors involves performing actions to:

- Definitely limit the production of errors;
- Promote detection of errors committed;
- Promote recovery from detected errors;
- Limit the severity of consequences for detected errors.

a) Error Detection and Error Recovery

Publications on the activity of pilots have shown that approximately 90% of the errors committed were detected and recovered. There are four mechanisms used to detect errors.

- Self-Checking. The subject makes systematic checks not scheduled by the checklists and regulatory documents.
- Sudden Detection. After a decision is made or an action has been performed, one begins to doubt its validity. An inspection is made and an error is discovered.
- Analysing the Results of the Action. The expected effects of an action or the implementation of a decision are not consistent with what is actually observed.
- Cross-Checks. This involves crew members checking each other. It is formalized by checklists and regulatory documentation. However, experience and knowledge of others leads, just as for self-checking, to developing additional, random cross-checks.

Error management by pilots contributes to safety improvements. Training must raise awareness of this ability to detect and recover from their own errors, and to teach the associated mechanisms.

b) Integrating Error into the Design of Systems

Error management is also envisaged through the design of human-machine interfaces. Since human operators make mistakes, one can design systems to prevent errors. If human operators detect and recover from their errors, one can design systems that support error detection and recovery.
We refer to this as human-centered design to characterize the human-machine interfaces integrating these properties. Such systems are called error-tolerant.

Error-tolerant systems can act on several levels of error management:

- Prevent an error for occurring. An example of this is protected formats which require the pilot to comply with a format to enter certain data into the flight management system.
- Avoiding the consequences of an error. The flight controls will not execute an action that would take the plane out of the flight envelope protection.
- Facilitating the detection of an error. Before deleting data or a flight plan, the system requires a confirmation indicating the pilot's volition of this deletion.
- Facilitating the detection and recovery from errors. Providing the pilot with feedback as quickly as possible for the actions ordered by this one. The Navigation Display (ND) and Primary Flight Display (PFD) screens present more and more integrated information in an analogue form for promoting situational awareness. The display of the vertical flight path on an A380 is an example. Alarms are also tools that raise crew awareness regarding the state of the aircraft, its systems and the flight. They detect errors committed by bad decisions or execution errors.

The development of error-tolerant systems in modern aircraft contributes to safety improvements, but it alone cannot guarantee that errors will not be committed or that it will systematically detect or recover from these errors.
It is for this reason that error management can only be planned based on the combination of actions that relate to crew behaviour, work procedures and interfaces (human-machine, human-centered, error-tolerant).

c) Planning and anticipation of future actions

The anticipation and planning of future actions conducive to the use of mental mechanisms that improve efficiency in information processing and therefore provide better error management are a central part of human reliability. As formalized by the Threat and Error Management (T.E.M.) model, anticipating and planning actions and errors also means defining and implementing countermeasures to prevent them and also detecting and recovering from them as early as possible to avoid their consequences on flight safety. In addition, anticipation and planning are conducive to the use of mental mechanisms that improve efficiency in information processing and therefore provide better error management.

03 DECISION-MAKING

Decision-making is a complex cognitive process that prompts an individual or a group to choose an option from many available solutions in order to reach a goal. Decisions are at the heart of cognitive mechanisms, located between understanding and action.

In high-risk professions, such as aeronautics, decision-making has always been an important concept due to the fact that serious consequences can result from bad decisions. That is why, on the one hand, training programs have the objective to help crews improve their decision-making skills and, on the other hand, designers seek to integrate decision support systems into the cockpits.

One can thus distinguish between two ways of making decisions:

- "Deciding", in which the decision-making process is arbitrary or guided by emotions;
- "Decision-making," which is a structured, formalized process leading to the solution.

Some authors prefer to speak of judgment (Jensen and Benel 1977) rather than decision-making. Judgment is a broader concept than decision-making, since it encompasses the aspects of implementing the decision by establishing a link between diagnosis, decision and execution of the solution. For these authors, judgment entails two aspects:

- Rational judgment, linked to the diagnosis and the choice of a solution;
- Motivational judgement, guided by the motivation of the individual to perform one solution over another, because it is appropriate for the requirements of the situation (e.g. deadlines) based on one's know-how and personality.

3.1 - Steps of Decision-Making

Decision-making breaks down into different steps. In the literature, there are various models that explain the steps: defining the goal, collecting information, risk assessment, developing options, evaluating the options, decision, execution, consequences, analysis and feedback.

These models aim to provide crews with a reference for making the right decisions. These models are prescriptive. One of the most widely used models in Europe is the "FORDEC" model.

F = Facts (what are the facts that characterise the situation?).
O = Options (what are the possible Options?).

R = Risks (What are the advantages and disadvantages of choosing larger aircraft?).
D = Decide (what option is chosen as the most suitable?).
E = Perform (What tasks should be performed to implement the decision and how are they distributed and carried out by crew members?).
C = Check (Are the results of the implemented decision consistent with the crew's expectations? Should what had been decided be changed?).

3.1.1 - Defining the Goal

It is based on the understanding of the situation (situational awareness) that it is possible to define the objective. Defining the goal requires listing the most significant or most urgent problems in order to prioritize them. Defining the objective also requires assessing the time available to ensure the validity of the goal.

3.1.2 - Collecting information

In flight, much information is available. The difficulty lies in knowing which information is useful and having the time to gather it before making decisions. In addition, some data is unclear and requires interpretations or inferences based on their progression (e.g. weather).

Collecting information is the operation by which we mobilize all the resources of the crew to gather, share and judge the relevance of information.

3.1.3 - Risk Assessment

Each decision is associated with a level of risk. In a cockpit, in the absence of a risk assessment system, it is the crew that performs this assessment on a subjective basis. Perception of the level of risk by the pilot is a compromise between the perceived risk and accepted risk.
Perceived risk or external risk is the assessment made by the pilot regarding the danger associated with the situation (technical problem, deteriorating weather, etc.) and the risk of failure or accident occurrence according to the solution chosen.
Accepted risk or internal risk reflects the know-how of the pilot to execute the chosen solution, either in relation to one's own competence or the time available to achieve the solution. It is the sort of feeling that the pilot has in knowing or not knowing how to execute the chosen solution.

Perceived risk and accepted risk combine to guide the decision of the pilot, while knowing that the reduction of internal risk is preferable, letting external risk increase.
Risk assessment explains that there are noticeable differences between pilots, related to their competence and experience levels, on the decisions made in similar situations. In addition, as a crew, each pilot has their own assessment of the level of risk.

3.1.4 - Developing Options

It depends on the time available and expertise of the pilot. The shorter the time, the less options or solutions there are available.
In these situations, intuition then becomes the predominant influence for immediately making one or more options available. Intuition is a double-edged sword: it allows one to immediately have

options, thus being efficient; the options available result more from habit and a simplified analysis of the situation than from an in-depth analysis.

The relevance of intuition is related to the experience and expertise of operators, but the risk of error is always greater with intuition.

3.1.5 - Evaluating the Options

Evaluation is made on two levels:

- Responding to the change observed in the environment;
- Meeting the defined objective.

It is only when these two levels are satisfied that each option must be evaluated in terms of performance criteria and level of risk.

3.1.6 - Decision

Decision involves choosing the most relevant option. The decision is made by the pilot in command. It ensures that responsibility is assumed.
Fundamentally, the most relevant option is the one that allows the best results to be achieved.
In practice, it is not as simple as it seems, because other factors should be taken into account:

- Risk taking. As was seen earlier in the evaluation of options, pilots prefer to stay in their area of expertise when choosing an option, even if this means increasing the external risk. However, the risk should also be considered in terms of the crew. The option chosen by the pilot in command must be in this one's fields of expertise, but also in those of the co-pilot, at the risk of the latter not knowing what to do. The danger is that the co-pilot, misjudging his own skills, accepts a decision made by the pilot in command and ends up with a high internal risk.
- Commitment. Commitment in an option that represents the moment when it is no longer possible to stop, change or reverse the option. It is a figurative point of no return in the application of the option. Some options heavily involve the crew (e.g. stop of an engine). In contrast, others are less involved. If in doubt on the relevance of a decision, it is beneficial to select the less significant options in the series that do not involve the crew over the long run. For example, if faced with a "de-icing" failure during winter and depending on the weather, one can delay making a decision to divert as long as the weather allows it in order to reach the destination airport.
  This option allows alternative solutions or even to return as the situation progresses and as new information becomes available. This strategy may increase the workload for the crew, because the options taken must be revised frequently.

- Time pressure. The less time the crew has to make the decision and apply the chosen option, the more it must appeal to expert know-how. Therefore, this increases the internal risk to the extent that crew members are not equipped with the skills to handle this level of time pressure. If the perceived internal risk is too great and in the measure that the situation permits it, two strategies are possible:
  - Anticipating the decision (flight preparation, flight briefing) or
  - Freeing up time to reduce the time pressure (go-around, holding pattern, etc.).

- The cost of the solution in terms of workload. It is preferable to choose an option compatible with the set of tasks to be performed in the cockpit rather than an option that requires attentional resources leading the crew to the limit of its capacity.

3.1.7 - Executing the Option

The execution of the option is made under the charge of the pilot in command. The pilot in command is responsible for delegating and assigning tasks to technical crew members, or even to other personnel if necessary. The pilot in command monitors and supervises the execution of tasks.

3.1.8 - Consequences

Before and during implementation of the chosen option, the crew assesses the consequences during inspection for the initial change and achievement of the objective. If the consequences of the chosen option do not allow for responding to the initial change and achieving the goal, either the situation has changed or the option chosen was incorrect.

3.1.9 - Analysis and Feedback

The crew must continually ensure the validity of the chosen option. Whether the situation changes, it is necessary to ensure that the option is always valid, otherwise it should be made in advance. If the option was not adapted, it must know how to change it. The pilot in command has the responsibility of monitoring the validity of the option executed.

3.2 - Elements Influencing Decision-Making

3.2.1 - Factors

The factors fall within five major categories:

- Task-Related Factors
  They include everything that makes up the complexity of the task, namely: all information, missing information, certain unclear information, conflict of objectives, interface, documents, time pressure, workload, etc.
- Cognitive Factors
  These are the limitations of information processing mechanisms (attention, perception, memory, understanding, action), but also the skills (knowledge, know-how, skills) resulting from qualification, experience and expertise.
- Factors Altering the Physical and Psychological State
  These are fatigue and high stress levels.
- Personality Factors
  Personality may be defined as a series of stable and sustainable characteristics and attributes (see Paragraph 5.3 “Dangerous Attitudes”). There are links between the personality traits of a subject and how one makes decisions. Reference is even made to the style of decision-making. Extroverts base their decisions more on raw external facts, whereas introverts are more sensitive to the very nature of the facts. Similarly, some subjects are "calculated", while others are more sensitive to "impressions". There are also subjects guided by "perceptions" and others by "intuition".

These personality factors explain that some people tend to have decision-making styles that are more logical, analytical, critical or empirical. Within the crew, it is also important that the personality is stable over time and in the face of emotions. All these characteristics are specific to each one and manifested through attitudes.
The attitude is a relatively stable mental disposition resulting from experience, which influences our reactions toward people and situations. Allport (1955) defined it as a predisposition to react in a certain way (see Paragraph 5.3 "Dangerous Attitudes").
Among pilots, it has been described as five hazardous attitudes for flight safety:
- Anti-authoritarian ("Don't tell me what to do"),
- Impulsivity ("We need to do something and quickly"),
- Invulnerability ("This cannot happen to me"),
- Macho ("I can do it"),
- Resignation ("Forget it. It's not worth it").

- Motivational and Emotional Factors
  Motivation is an important factor in seeking a solution and attaining a goal. It mobilizes the resources of the individual. Similarly, emotions play an important role in choosing a solution. The emotions associated with past decisions are stored in memories. When faced with situations similar to those already experienced, one may base a decision on the positive or negative emotions that were previously felt. These mechanisms are unconscious.

- Psychosocial Factors
  The behaviour of human operators may not be disconnected from relationships experienced with their environment, and particularly with other operators. In aeronautics, any decision made by a pilot can be judged and assessed by other crew members. The impression that one gives to another or the search for recognition are all elements that influence the choices that one makes. We can also mention the influential processes within the crew (compliance, group thinking, hierarchical relationships, etc.).

3.2.2 - Biases

Biases in decision-making are ''elementary'' errors, which are common to all human beings. They are due to several factors, but especially to the weaknesses of our information processing mechanisms. Many biases exist, but one can cite the most significant:
- Confirmation bias: the tendency to seek or interpret information in a way that confirms one's preconceptions;
- Belief bias: the tendency to favour one's own beliefs over more rational approaches;
- Valence effect of prediction bias: underestimates rare events and overestimates common events;
- Status-quo bias: choosing the most familiar and safe solution, even if this is not the most ideal.
- Overconfidence effect bias: the tendency to overestimate one's own abilities;
- Conformity bias: the tendency to prefer consensus and accept the decisions of the group.

3.3 - Decision-Making within the Crew

In the cockpit, decision-making is a collective mechanism orchestrated by the responsible party, the pilot in command. The goal is to use all the skill sets, abilities and resources of the crew.
The objective of a collective decision is:

- To make a better decision;
- To avoid errors in decision-making;
- To bring crew members together in the decision-making process;
- To ensure that the decision will be able to be carried out through a crew action.

Collective decision-making requires that the pilot in command organizes the crew and explains the standard operating rules (communication, sharing information, expressing doubts) and other crew members can express themselves when they consider it appropriate.

Then, there must be: gathering and sharing relevant information, sharing understanding of situational changes, seeking options along with the crew, describing possible alternatives, identifying associated risks, setting limits and stopping rules, confirming options, ensuring that they are understood by all crew members, doubt as soon as the situation does not proceed as planned and knowing how to challenge the decision made.
In certain circumstances, the timing and urgency of the situation does not allow for implementing an elaborate decision-making process (concept of Deadline).

For example, this is the case for a short-term failure, final or before V_1. It is so important that decisions are prepared and validated in advance. If this is not possible, the pilot in command can then make more decisions individually. Soon after, the pilot in command must share with the other crew members and especially explain to them, when it is convenient, the decision made, in order to regain the synergy and the cooperative spirit as soon as possible.

Within the crew, it is important to have in mind that:

- The decision should take into account the skills of other crew members;
- The performance of a crew maybe depends on its weakest link in the case of a decision made in the heat of the action;
- In the event of an emergency, return to simple familiar decisions (do not become isolated in a decision);
- The proper decision is not necessarily the "better", but it's the one that the crew knows how to implement through their actions;
- There may be several "good" decisions;
- Another crew member may help in the decision, but this one is also a "safeguard" (reminder of stopping rules);
- Changing an option may be a good decision that must not be ignored;
- Any challenging of a decision is difficult and costly in resources… and sometimes also for one's self-esteem or that of other crew members.

Collective decision making, as described above, is typically more effective than individual decision making because it is more resource-intensive and properly managed by the crew. However, it has been shown that a group can bring into play mechanisms that influence collective decision-making, in particular in risk assessment. This is known as group polarization or "risky shift". Group polarization is a mechanism for increasing risk within a group. It is the phenomenon whereby, after discussion, a group takes more extreme decisions in terms of risk than any one member of the

group would take. This means that a group will agree on accentuating the trend that was initially dominant in the group. If group members tend to take risks, the group's decision will be even more risky.

04 AVOIDING AND MANAGING ERRORS: COCKPIT MANAGEMENT

4.1 - Safety awareness

The cockpit is the control and command centre of the aircraft, where technological and human resources are concentrated to ensure successful flights with a high level of safety.

The presence of crew within the cockpit is the means to ensure sufficient human resources to complete the flight and manage the aeronautical situations using aircraft systems. Unfortunately, the main cause of many air accidents is the result of sub-optimal operating by the crew.

To this end, the accident of Tenerife (Canary Islands, 1977) raised the awareness of the aviation community to the importance, and primarily the impact, that improper operation by a crew could have on flight safety. Despite having a trained crew and an air-worthy plane, lack of communication, poor situational understanding and lack of clarification of doubts led to the worst disaster in the history of aviation.
Conversely, in the Sioux City (USA, 1989) accident, the operating crew was noted for its performance. When confronted with a total hydraulic failure on a DC10, following an explosion that occurred in the #2 engine located under the fin of the aircraft, the crew managed to land the aircraft, thus limiting the number of passengers killed.

All these events, but also and especially in daily air operations, show that the crew is the guarantor of safety. For this reason, safety and crew awareness is essential. Each crew member contributes to this safety awareness, to the extent that they are aware of their own performance, but also to that of their teammates. On the one hand, this allows the better complementarity between crew members and, on the other hand, to identify errors in order to protect themselves.

Each crew member exchanges, shares, confronts, monitors and assesses what is perceived, understood, decided and implemented, in order to develop a common awareness of the situation, which is founded on safety awareness.

The development and maintenance of safety awareness is based on the collective skills of cooperation, coordination, leadership/followership, and communication.

4.2 - Coordination

Coordination involves making skilled personnel work together to effectively achieve one or more common objectives.
Coordination:

- Goes beyond the simple juxtaposition of competent individuals, by organizing the efforts that each one must perform to achieve the objective;
- Avoids the deficiencies or repetitions between crew members in the execution of tasks.

The many benefits of coordination are:

- Safety, by creating redundancies that promote individual error detection and recovery;
- Crew efficiency, through an organized use of resources, which improve flight management;
- Effectiveness of communications in terms of quantity and quality;
- Distribution of tasks and mutual support based on flight constraints (flight phase, deteriorated situations, emergency situations);
- Cognitive synchronization of the crew, by building and maintaining a common representation of the situation;
- Collective decision-making within the cockpit;
- Time synchronization, to perform coordinated action sequences.

The elements determining the effectiveness of coordination are attitudes, motivation and training. Fatigue and high stress levels contribute to decreased coordination. However, on the contrary, compliance with rules and coordination tools are the ramparts to fight against the deleterious effects of fatigue and stress.

In aeronautics, coordination within the crew is based on three tools: standard operating procedures (SOPs), briefings, and checklists.

4.2.1 - Standard Operating Procedures

Standard operating procedures (SOPs) are a set of written instructions that must be followed in order to perform a task safely, i.e. without impact on people, the environment and equipment, and by optimizing the operational requirements and production. SOPs are written by the company and validated by the regulatory body.
SOPs:

- Ensure that crew practices are in accordance with the regulations;
- Ensure that flights are carried out, regardless of the crews, in a manner consistent with the quality criteria of the company;
- Ensure that deteriorating situations are managed by the crews in a manner consistent with the expectations of the company;
- Give to operating personnel the information relevant for achieving their tasks, while respecting safety and performance criteria;
- Minimize sources of poor coordination between crew members;
- Reduce the production of errors;
- Facilitating the detection and recovery from errors;
- Return to a known procedure in case of doubt on the proper behaviours;
- Define the bases for initial and continuous crew training.

Within the crew, SOPs are designed in such a way that:

- The pilot in command exercises management and decision-making functions independently, whether this one is the pilot at the controls or not;
- The tasks of the pilot at the controls (Pilot Flying, PF) and the pilot who is not at the controls (Pilot Monitoring, PM) are clearly and completely specified and distributed;
- Coordination between the crew members is carried out in an orderly manner, regardless of the situation;

- Supervision, the information and mutual support are continuously ensured.

SOPs are written on the basis of the operational expertise of the company and in accordance with the regulations. They must concisely describe the step-by-step procedure in an easily legible, non-ambiguous and simple format.
SOPs change with the operational practices and developments related to the operating conditions. SOP updates follow two mechanisms:

- Feedback, which highlights an inadequacy;
- A systematic review of all SOPs over a periodic basis to ensure that they are still current and adapted.

Procedures are designed to provide the crews with the behaviour to be applied to ensure flight safety in all situations encountered and the restrictions associated with these situations. To this effect, procedures are tools for identifying and managing threats as described in the T.E.M. model. By defining the steps to be followed to complete tasks, procedures are also a tool to avoid making errors. Finally, by including human fallibility, procedures are also established to promote the detection and recovery of errors made.

There are many pitfalls associated with the use of procedures which represent real safety threats. The following distinctions can thus be made:

- Automation of behaviours with the acquisition of motor or cognitive skills that reduce the attentional control needed to perform procedures;
- Familiarity with the situations and routine of the procedures used;
- Hazardous attitudes with regard to the use of procedures with in particular the attitude that tasks can be carried out perfectly well without rigorously applying or not complying with procedures (anti-authority attitude);
- The airline's culture regarding the rigour required to comply with procedures and supervise their application.

4.2.2 - Briefings

Briefings are formalized spaces allowing crews to communicate in order to:

- Share information;
- Confront the situational awareness issues of the various crew members and build a common situational awareness;
- Remove doubts;
- Make decisions;
- Define action plans;
- Distribute tasks;
- Activate relevant information in the working memory to be used during a future flight phase.

Briefings are regulatory requirements (e.g. before takeoff, before descent), but they can also be initiated upon request by one of the crew members, if the situation requires it (deteriorated situation) or in case of a misunderstanding.

Formalized briefings are intended to ensure that all crew members have relevant information and they share it. They follow a predetermined plan adapted to the situation in order to avoid errors.

With increasing cockpit automations that isolate crew members more and more, regulatory communications have increased.

Spontaneous briefings are less structured and require the rigor to be comprehensive and complete. The briefing is an operational tool to meet the cognitive requirements of operators, namely:

- Being practical;
- Being simple;
- Being short;
- Containing a limited number of ideas;
- Being adapted to the situation; there is no standard and generic briefing;
- Being understood by all crew members; this must be ensured.

4.2.3 - Checklists

Checklists are verification tools that allow the crew to ensure that the aircraft is properly configured for a flight segment. Checklists involve nearly all flight segments, particularly the most critical, including takeoff, approach and landing. There are also checklists for abnormal situations (e.g. alternator failure) and emergency situations (e.g. engine fire).

The checklists have multiple goals, including:

- Helping the crew to properly configure the aircraft, regardless of its physical and psychological state;
- Providing a sequential framework to meet internal and external operational requirements in the cockpit;
- Allowing mutual supervision between crew members (cross-checks);
- Prescribing tasks for each crew member to facilitate coordination according to an adapted workload distribution;
- Keeping crew members in the "flight" ("in the loop").

Using the checklist, within the crew, is based on the principle of double redundancy:

- Internal redundancy is where the crew configures the aircraft by memory and then, secondly, verifies that all items have been properly performed.
- Mutual redundancy is where each crew member monitors the one who performs the checklist items.

The checklist can also be used to guide the pilot step-by-step, just like a cookbook, in order to configure the aircraft. We refer to the checklist as a type of ''to-do list''. In this case, the internal redundancy disappears, making the method more susceptible to interruptions in the case of a forgotten item.

The design of the checklists is a challenge in itself, because it must respond to the following constraints:

- Does not impact other tasks (position of the checklist in the sequence of crew activities and adaptation of its length);
- Resists interruptions and distractions (ATC, maintenance crews, cabin crews);
- Resists monotony and repetition;

- Resists operating time pressures (checklist not too long);
- Highlights the most important items (at the beginning, redundancy of critical items in several checklists);
- Not ambiguous (always state with the expected value, the item concerned; announce the end of the checklist);
- Promotes organizational redundancy (logic with handling and locating systems; pointing the finger to be sure that the information is sampled) and mutual redundancy (pointing the finger to be seen by the other crew member).

Systematic in all flights, the use of checklists is subject to numerous deviances related to the routine of "questions-answers" or to workload:

- Performs the checklist from memory (the pilot may have the checklist in hand if desired);
- Checks are made only by the pilot responding to the request and not by the one who expresses it (no mutual redundancy);
- The answer is given by one of the pilots without verification (no organizational redundancy);
- Accumulation of requests or responses, instead of following a step-by-step process.

4.2.4 - Communication and Coordination

Communication in coordination is based on media that includes SOPs, briefings and checklists. It ensures the exchange of information to achieve coordinated actions between the crew members. Hence, communication allows:

- Sharing of information to perceive, understand, decide and act;
- Verification of actions and reasoning;
- Development of procedures.

4.3 - Cooperation

4.3.1 - Cooperation and Coaction

Cooperation is a more elaborate form of collective work than coordination. In cooperation, we search for a mutual benefit to work together to save time and resources. The actors build connections between themselves exceeding the framework of coordination, with a view to best performing the task.

Cooperation is based on:

- Confidence and mutual respect toward others;
- Consultation of others and sharing knowledge;
- Adaptation and distribution of tasks in the constraints of reality;
- Regulation of both collective and individual workloads;
- Mutual assistance in decision-making;
- Pooling of tools and resources;
- Support and monitoring of the activity of others.

Co-action is the juxtaposition of independent activities that aim for each one to achieve their own objectives, even if there is a very broad objective. Activities are carried out at the same time,

overlap, or follow one another, but can especially interfere with each other when there is no coordination.

An example of a co-action is what happens during layovers, when various actors (maintenance, catering, cleaning, refuelling, cabin preparation, flight preparation by the TFP, cargo, etc.) are involved on the aircraft. In a limited period of time, each actor has a different objective from other actors, and on which one will be judged, but the work space and the means available does not allow everyone to intervene at will. There are several sources of interference between different activities and this can impact the activity of one or lead to the occurrence of errors. Prudence and rigor are even more relevant in coaction situations.

4.3.2 – The structured group: the crew

A group can be defined as a set of people (two or more) united by a common goal, who interact to accomplish a task and achieve a goal. Beyond the common objective, group members also share skills, values, interests, motivation and a culture.
A crew is also a group in which there is a greater structuring of statuses and roles that are already stipulated and distributed by hierarchy. The crew is headed by a leader (captain). There is also greater interdependence in the work and closer coordination between the members to achieve the task.

The group can be distinguished from the notion of a band or a crowd, which bring people together on a much less elaborate organizational level (no well-established functioning and/or very limited common characteristics). While the group thrives on the individuality of its members, it also imposes a culture and a system of thought that has to be adopted by the individual for them to be recognized as legitimate. This may involve, for example, a way of dressing, of speaking, of understanding reality... Not observing these codes would be to go against the community and risk being excluded from it.

The relationships between the group members are governed by the interdependence of mechanisms based on several factors:

- Personality;
- Attitudes;
- Leadership styles and followership;
- Skills;
- Experience;
- Expertise;
- Status;
- Role;
- Notoriety;
- Familiarity;
- Confidence;
- Fatigue or stress levels.

Within the team, there are three levels for interdependence of mechanisms:

- From the leader to group members (e.g. an authoritarian leadership can influence how a crew member will express doubts on safety when faced with certain decisions);

- Between the group members (e.g. the reputation or status of one of the group members can influence how others may behave with this one; being more or less interventionist in relation to one's choice or behaviours);
- From the group to the members (e.g. it is difficult not to adhere to the group decision without risking marginalization).

4.3.3 - Teamwork

Teamwork defines the mechanisms that allow group members to work cooperatively. In aeronautics, the team or crew is an organized group working together to accomplish objectives that could not be effectively achieved by individuals alone. This means, among other things, that each crew member has a role in achieving the objective, otherwise one would not be in the aircraft.

Teamwork is sought for multiple reasons:
- Individual commitment and resource potentiation for achieving objectives;
- Sharing knowledge and exchanging ideas;
- Adapting to new and unforeseen situations;
- Innovation and originality;
- Learning;
- Efficiency of collective behaviours (ratio between the time available and the relevance of solutions chosen);
- Collective performance quality is more important than the quality of individual crew members;
- Mutual support, on the one hand, in sharing tasks according to situational requirements and individual skills, and, on the other hand, in preventing and managing errors;
- Individual motivation in favour of collective efficiency, belonging to the crew;
- Overcoming different viewpoints and avoiding conflicts.

Conversely, teamwork may have certain disadvantages:
- Limits individual autonomy;
- Consumes time;
- Requires a well-defined framework;
- Requires flawless adherence to the operating rules of the team;
- Requires consistent efforts on the part of team members, teamwork is not natural (criticism must be constructive; different viewpoints must be accepted; it is necessary for members to adapt to the personality of those who make up the team, their skills);
- One judges collective performance, and no longer individual performance;
- A source of conflict in case of disagreement, with significant deterioration of collective performance.

Successful teamwork is organized around various characteristics:
- Synergy;
- Cohesion;
- Group thinking.

a) Synergy

Synergy is the phenomenon by which several individuals acting together create an effect greater than the sum of the expected effects if they had operated independently, or create an effect that each of them would not have created individually.

Synergy is the phenomenon by which several individuals acting together create an effect greater than the sum of the expected effects if they had operated independently, or create an effect that each of them would not have created individually: 1 + 1 > 2.
Conversely, there is poor or no synergy when 1 + 1 < 2.

b) Cohesion

Cohesion is the set of forces that unite team members. Cohesion is an essential element of the relationship between crew members for the latter to be synergistic. These forces depend on:

- Sharing of common goals;
- Sharing of common goals;
- Individual commitment to the team.

Cohesion forces are characterized by five dimensions:

- Membership/isolation in relation to team values;
- Inclusion/exclusion in the team;
- Participation/passivity in team operation;
- Recognition/rejection by the team and team members (expression and acceptance of differences);
- Legitimacy/illegitimacy of team objectives and its operation.

In other words, team members must have the feeling that they are involved in a joint undertaking, have the same challenges, and are part of the same community. Beyond personal interests, common culture (aeronautics, company) serves as the basis for cohesion.

c) Group Thinking

Group thinking occurs in groups where there is an exacerbated cohesion, beyond any critical spirit, which leads the group to make bad or irrational decisions. In a group thinking situation, each member of the group tries to conform their opinion to what is believed to be the thinking of the group. The result is a situation in which the group eventually agrees on an action that each member of the group does not believe to be the most suitable.
The characteristics of group thinking are:

- Having the impression of invulnerability;
- Believing in the superiority of the group;
- Rationalizing group decisions;
- Rationalizing group decisions;
- Feeling pressure to conform to the group based on the opinions of its members, at the risk of excluding them in case of disagreement;
- Choosing self-censorship rather than to question group functioning;
- Giving the appearance of unanimity "who says nothing, consent";

- Protecting against any dissent by ensuring that some members are guardians of group thinking.

To avoid group thinking, two principles of operation are:
- Knowing who to place the responsibility and authority on in making the final decision; in the crew, it is the pilot in command;
- Knowing how to institutionalize criticism and suggestions as a normal and necessary element of group functioning to facilitate interactions and avoid the stigma of one of the members.

4.3.4 - Bases for Teamwork

Teamwork enables individuals to work together, beyond the formal rules of coordination, to achieve a result, which optimizes the skills of each one of the crew members. Specifically, synergy is the result of good teamwork. The conditions for good teamwork are:
- Well-identified roles and regulations, with their respective responsibilities;
- Skilled and trained personnel;
- Clear objectives that are shared by all members;
- Effective leadership;
- Constructive atmosphere;
- Commitment of all members to teamwork;
- Confidence, respect, consideration and mutual support;
- Effective work methods (SOPs, checklists, briefings, etc.);
- Constructive criticism, not aimed at persons and accepted by all;
- Open communication, without ulterior motives;
- Appreciation for the ideas of others;
- Acceptance of questions in case of doubt or lack of understanding;
- Avoidance and conflict resolution.

a) Team Building

Teamwork is not spontaneous. It is built from the first crew meeting and requires ongoing efforts throughout the flight or rotation. Proper functioning of teamwork must comply with the following steps:
- Building and maintenance of a healthy work and professional atmosphere;
- Development of goals and objectives;
- Clarification of roles;
- Preparation of the action plan;
- Definition of standards for crew behaviour;
- Continuous assessment of the work by the crew.

Team building begins with flight preparation, at the meeting with other crew members. The first contact is important, but too much attention should not be given to first impressions. They can be misleading. The first encounter is the beginning of a slice of life together, both professional and personal. It is important for the atmosphere; mutual respect should prevail and appreciation shown for each one's skills and role within the crew.
In terms of operating dynamics, the crew will constitute about five steps.

Forming (constitution, creation of the team)

In this phase, crew members meet, get to know each other, and position themselves in relation to one another. They may be cautious and reserved. To some extent, everyone expects that others reveal themselves and wish to be accepted by others. Thus, the role of the pilot in command is significant in providing the first directions to be carried out by the crew (objectives, methods, operating rules).

The captain has a decisive impact on the cohesion of the team from its inception. It falls upon the leader to unite the team, reassure its members, and create a climate of confidence as soon as possible.

Storming

This phase corresponds to confronting the opinions of each member. Differences emerge when individuals seek to be heard, often to the detriment of others. As decisions take shape, each one may feel frustrated due to differing viewpoints. Discrepancies appear and can be a source of tension, conflict and/or resistance. There is a risk of decreased adherence to crew objectives, accompanied by a decline in morale and personal satisfaction. Therefore, it is important to demonstrate the discrepancies to assess them, discuss what hinders the functioning of the team, and manage the emotions aroused by the conflict. This step is a normal phase in building the crew. It must be overcome to create the "glue" of synergy and, especially, avoid entering into a latent conflict. The role of the captain is to reduce tensions by allowing everyone to express themselves. The captain should be assertive, while respecting and listening to the different team members.

Norming

This step corresponds to the crew structure with the establishment of rules, ''operating standards'' accepted by all. Everyone begins to know one another and feel at ease in the crew. The task to be accomplished together takes precedence over individual approaches. The search for common solutions is the concerns of all. It is important to show the progress of the crew and not hesitate to confront the difficulties with the willingness to adjust. It is during norming that the following are defined and accepted: objectives, work rules specific to the crew, behaviours when handling certain situations, how to manage problems, intervening in case of doubts, conflicts, etc. The role of the captain is to allow the crew to reach a consensus around a common framework for working effectively together.

Performing

This phase corresponds to the actual work of the crew on the operating bases in place. This is the synergy and performance phase. Crew members focus on the achievement of objectives and management of interactions. Everyone cooperates to achieve the objectives, while being autonomous. Communication is informative. Actions are focused on results, and everyone is able to handle disagreements.

The role of the captain is to delegate.

Adjourning

This phase corresponds to separating the team. It is the end of the rotation; care should be taken to draw lessons from the crew and manage real-life situations. Adjourning come about through debriefing. If conflicts could not be resolved during the flight, it must be done before separating.

No resentment or frustrations should remain. It is important to recognize the work performed and thank everyone for their work. Adjourning is the pre-step for building a future crew if assigned to

fly together again. It avoids the halo phenomena between personnel, i.e. keeping a negative memory that will affect how they work together the next time.
Each crew member, depending on one's position, is actively building and maintaining the synergy of the crew. The position of a crew member is defined by one's status, role and standards.

b) Status

Status is the position occupied by a crew member within the crew and the company. This is the hierarchical position of the individual in the group. Within the aircrew, the positions are: Captain (Pilot in Command), First Officer (Co-Pilot), and Flight Engineer. If one considers the aircraft crew (cockpit and cabin), there are other positions, such as the Purser or Cabin Services Director. The status is recognized by the airline through a rating or licence.
Within the company, the Pilot in Command may have additional positions: Chief of Operations, Chief Pilot, Head of Division, instructor, etc.
Status confers authority and responsibilities, which are granted by the organization and recognized by the members of the group. Status is institutional. This means that assigning status is not enough to exercise it properly; it is necessary that the person has adequate abilities and skills.

c) Role

The role is a set of expected behaviours on the part of an individual, taking into account one's position. The role describes what the subject should do, while the position describes what the subject is. The roles of an aircrew in the cockpit are described in the operating manual of the company. This are the assigned, required or expected actions and activities for a crew member. Roles require acquired skills along with training.

Everything could be simple in the cockpit if each position corresponded to specific roles, not attainable by another position. In fact, there is a redundancy of some roles between the positions of crew members, but this is naturally for safety purposes. For example, many tasks in the cockpit can be performed both by the pilot in command and co-pilot. It is then important to specify who performs the tasks, in order to distribute the responsibilities related to roles. This is the case with the following roles: ''pilot at the controls'' renamed ''Pilot Flying'' (PF) and ''Pilot Not Flying'' (PNF) renamed ''Pilot Monitoring'' (PM), which are assumed either by the captain or co-pilot. If the responsibilities for certain roles can be assumed by different positions, it is not the same responsibilities related to the position, which are not transferable from one member to another.

In the flight phases where the decision-making loop is very short, status and role can be a source of ambiguity if they are shared by different crew members, because it is important that the crew member who occupies the role and position is the one to decide and act. Difficulties may also appear when there is an implicit role transfer, without real consultation or validation by the crew members. Similarly, the position does not confer all rights on role sharing.

The redundancy of roles within the crew is a guarantee of safety, but also regulation of activity according to situational constraints and respective workloads. It is an adjustment variable used by crew members to better adapt and distribute the work.

d) Standards

The roles are defined on the basis of professional standards. The standards are models, institutionalized rules governing the profession. The standards are explicit when they refer to a regulation, but they can be more implicit when they are based on values. They define the margins in which actions or their results are expected. According to the company culture or general culture, such as national culture, it is possible to have different standards for designing crew work. Therefore, multinational crews can be a source of difficulty for crew cohesion.

4.3.5 - Factors Affecting Behaviours within the Team

Behaviour within the team may be affected by the following factors: persuasion, compliance, acceptance and submission.

a) Persuasion

Persuasion is an influence mechanism by which one seeks to convince someone to adhere to an opinion, decision or get them to do something. Persuasion is common when opinions are different. Persuasion is natural in discussing and confronting ideas.

The methods of persuasion can be grouped into three categories:

- Rational Methods.
  They appeal to the argument, logic or evidence. They enrich debate, allowing the objective elements to be examined more closely and aiming towards the most appropriate choice. They contribute to a collective effective functioning.
- Emotional Methods.
  They appeal to the emotions, bypassing critical reflection. The arguments used to persuade are not professional. This type of persuasion is often associated with rational methods to better persuade. It is prohibited in the cockpit, because it is more in line with a logic of mental manipulation than optimization of resources.
- Methods by Coercion or Force.
  In this case, there was no longer discussion of persuasion, but of coercion. Coercion or force are especially envisaged in the cockpit under their psychological forms, and are then in line with authority and punishment. This type of persuasion is, of course, totally excluded from the cockpit. It reflects the pathological functioning of a crew.

b) Conformity

Conformity results from the feeling of belonging to the team. Conformity involves changing one's opinions and beliefs to be in agreement with those of the team. It is promoted by "group thinking", which seeks to create a pressure on its members to ensure that they are in agreement with the team.

Conformity to the group enables its members to avoid stress, which would result by taking a different position from the team. Conformity is much greater than the member is dependent on the group.

c) Acceptance

Acceptance (from the English "compliance") is to do something consecutively upon request or to comply with a social standard, even if, on the inside, one is not in agreement with the attitude or behaviour that is publicly manifested. Acceptance will be much easier than the beliefs and opinions of the subject, which are in accordance with the task that one wants to perform. There are acceptance techniques when the beliefs and opinions of the subject are removed from the task to be performed.

Used to manipulate people, there are techniques such as:

- "Foot in the door". The technique involves making an inexpensive request, which will likely be accepted, followed by a costlier request. This second request will have more chance of being accepted if it was preceded by the first, which creates a commitment. For example, it is more likely that one would give a euro to an individual, if one previously asked for information (e.g. what time it is) than if one made a direct request.
- "Door in the face". This technique is based on the principle of reciprocity. It involves first making a costly request to someone who can only refuse it. This makes them feel guilty. They are therefore ready to accept the second request, which is the one the person really wanted to make. Each of them feels like they are making an effort for the other person. Let's take an example: I ask something from someone that I know is far too costly (in terms of money, time, energy, willingness, etc.) to accept it, even though they agree in principle to help me. The person refuses, of course. At that point, I can ask for what I really want, in other words, something that would not have been accepted at first sight. But as I ask right after the first refusal, my request will get a better reception. This works on the principle of reciprocity: I have made a concession (lowered my demands) so the person in question feels obliged to make one too (in granting my second request). This technique is based on the feeling of guilt: we know that the person in question is willing to help us. As they turned down our first request, they are willing to accept the second one to make up for it.
- "Baiting and reality". The baiting technique shows only the acceptable side of the decision to be made or action to be taken (with the negative points omitted). It is about getting a person to make a decision without knowing the actual cost. After the decision is made, the real facts or truth is announced. The person here remains free to act, but it is common that retains their original decision. Let's take an example: you ask someone to come and help you carry 2 or 3 boxes for your move without saying that you live on the 5th floor without a lift and that there will only be two of you.

These techniques are dishonest manipulation techniques that have no place in the cockpit. When they are discovered, the trust built up in the relationship is ruined. Within the crew, acceptance only has meaning if there is a sharing of opinions between the crew members.

d) Submission

Submission is the mechanism by which a person does something, whether one likes it or not, because another person has given this one orders to do so. It involves executing an order, without question, because it is given by a legitimate authority. The act of submitting to authority has been demonstrated in a series of experiments conducted by Stanley Milgram (1963).

For one study on learning, in order to learn a series of words through association, he asked a naive subject (a volunteer participating in the experiment) acting under the authority of a professor to deliver electric shocks to a fake student (an accomplice of the experimenter professor) each time that the latter could not recall the words that he had to remember. The intensity of the electrical discharge increased as the performance of the student learning deteriorated. Under the influence of the authority of the professor, the person (naive subject) did not hesitate to deliver electric shocks that endangered the health of the learner. In reality, there was no electrical shock. This experiment highlighted the fact that a subject, without a particular predisposition, could act dangerously under the influence of a legitimate authority. The higher the status of the authority, the greater one's perceived legitimacy and thus the stronger submission will become. In the Milgram experiment, 65% of persons (all of the volunteers, 20 to 50 years) were inflicted with electric shocks up to 450 volts.

In the cockpit, submission may exist when there are major differences in status (e.g. a pilot in command who is also chief pilot) and experience (seniority, renown, etc.) between the crew members. Regardless of the composition of the crew, each crew member must be able to express their opinions, understand what is decided, express their doubts and adhere to the decisions made.

4.3.6 - Leadership and Followership

a) Leadership

The crew can only operate if it is directed by a leader, namely the pilot in command. Leadership means the ability of an individual to make others able to contribute effectively and successfully with the group to which they belong, by directing their desires and skills toward a goal to which they adhere.

Leadership requires two dimensions.

- An institutional and hierarchical dimension aimed at achieving the task and performance. The authority is given to a person for the group to attain an objective under the performance conditions defined in advance (safety, economy, commercial, etc.). The leader is responsible for this result. For this reason, leadership entitles the pilot in command to specific prerogatives. The institutional and hierarchical dimension is associated with a recognition of technical skills to be able to make decisions appropriate to the level of responsibility entrusted.
- A functional dimension aimed at managing the crew and its resources (building and maintaining crew operations).

This is why the leader is no longer the only person who exercises authority in a group, but it is the one who knows how to manage and use crew resources to achieve the objectives set out.

It is the crew who performs the task by means of the leader who has managed the resources of the crew.

Contrary to conventional wisdom, leadership is not an innate ability, even if some people have dispositions to be more natural leaders. Leadership is a skill that is learned, and requires development of the following characteristics: social maturity, motivation, accomplishment, self-confidence, and communication.

b) Followership

Followership, or being a team player, is equally important to the synergistic functioning of the crew. There can be no crew success without a leader/teammate relationship, respectful of the roles and skills of others. Beyond the authority relationship required, the relationship between the leader and crew members is a complementary relationship.

The qualities of a crew member are numerous. Among the most important, we can cite:

- Maintaining, skilfully, one's role in the cockpit;
- Not challenging the leadership of the pilot in command;
- Opening up avenues of discussion when necessary;
- Anticipating the expectations of others;
- Speaking up about one's point of view when necessary (self-assertion);
- Acknowledging different points of view;
- Not having implicit trust in the pilot in command;
- Believing in the effectiveness of the crew.

Self-assertion (or "assertiveness") in the crew is an important element in safety. Self-assertion involves making oneself be heard and defending one's point of view within the crew for it to be taken into account. Self-assertion is much more difficult than the factors of social influence are strong (e.g. conformity to the group, reputation, submission, etc.). The action of defending one's viewpoint depends on the person(s) to whom it is directed. In a synergistic operation, the crew members are open to the proposals of others.

4.3.7 - Authority Gradient and Leadership Style

The authority gradient reflects the way in which the captain exerts authority over their aircrew. It results from the authority conferred on them by their status as leader, but it also depends on the aircrew members' attitudes towards the leader.
The authority gradient defines the relational level of interactions between aircrew members.
A proper authority gradient in an aircraft's cockpit means that there is an imbalance in favour of the pilot in command. If this imbalance is excessive or if it disappears, it endangers the proper functioning of the crew. Therefore, good balance maintains an authority gradient by ensuring active participation and support of other crew members.
In aeronautics, we describe two styles of leadership that jeopardize the synergistic operation of the crew: the autocratic cockpit and the "laissez-faire" cockpit.

a) Autocratic Cockpit

The autocratic cockpit indicates a slight imbalance in authority in favour of the pilot in command.
It is characterized by a pilot in command who:

- Decides alone and imposes his decisions without informing the other crew members;
- Does not take into account the opinions of other crew members;
- Does not or rarely delegates;
- Makes disparaging remarks about the actions and/or skills of other crew members;
- Takes the remarks of others as criticism of his competence, or even questions his authority;

- Stirs up contention within the crew and an atmosphere of non-communication.

There are several reasons for an autocratic behaviour. Among the most common, we can cite:

- Strong personality of the pilot in command or, conversely, an unobtrusive personality of the co-pilot;
- Lack of confidence and/or competence by the pilot in command, which is masked by excessive authority;
- Significant gap in seniority (e.g. seniority in the company), skills (e.g. instructor) or hierarchy (e.g. Head of Division) between the pilot in command and co-pilot.

There are several safety risks for autocratic behaviour:

- Overload and isolation of the pilot in command, favouring the occurrence of errors;
- Lack of support for the pilot in command, limiting the possible solutions;
- Lack of cross-checks for detection of and recovery from errors;
- Submission by the co-pilot;
- Tension and aggression in the crew, shifting energies away from flight operations.

The crew must know how to recognize the signs of an autocratic operation, dangerous for safety, in order to return to a more synergistic mode. This comes about by a change of attitude on the part of the pilot in command. However, in any case and irrespective of the attitude of the pilot in command, the crew should remain professional and not aggravate the situation. To accomplish this, it:

- Will seek to establish, in spite of everything, contact;
- Will not yield on aspects of safety;
- Will maintain a calm and professional manner of speaking, by using the most appropriate tone of the voice.

b) "Laissez-Faire Cockpit"

The "laissez-faire" cockpit reflects low authority, or even a lack of authority, between the pilot in command and the crew members. It is characterized by a pilot in command who:

- Seeks to please other crew members;
- Adopts a passive attitude vis-a-vis the flight and situations that occur;
- Has little involvement in the decision-making process and allows crew members to have unrestrained freedom;
- Encourages a relaxed atmosphere in the cockpit, to the detriment of professional behaviour;
- Nurtures individual concerns at the expense of flight objectives.

There are several reasons for a "laissez-faire" behaviour. Among the most common reasons, we can cite crews with experienced and skilled members, where the captain shows excessive confidence and delegates all or a large part of his tasks to the crew.

Safety risks are great, because leadership no longer really exists. If another crew member has a strong personality or is a charismatic leader, there may be an inversion of authority.

In extreme cases, the cockpit can change toward an egocentric cockpit, where everyone works in one's corner without informing others, believing that others are aware of what one is doing. Communication is poor and, more often, ambiguous. This type of cockpit can occur in:

- Flight phases with a decreased workload (long flight legs over a long-haul flight);
- On the contrary, when there is an increased workload, each member is consumed by one's own task and loses any collective vision;
- During and after an unresolved conflict.

The crew must know how to recognize the signs of a "laissez-faire" operation, dangerous for safety, in order to return to a more synergistic mode.

This comes about by a change of attitude on the part of all crew members. It must:

- Break the isolation;
- Open up communication;
- Lead the other person to explain;
- Help one remain in one's role and in one's skills;
- Help one reclaim more leadership;
- Not seek to exploit the demagogic advantage.

c) Synergistic Cockpit

Synergistic leadership is the most appropriate mode of operation for teamwork. Synergy in the cockpit depends largely on the leader, who must:

- Set the example;
- Motivate the crew;
- Foster teamwork by maintaining a cordial and professional atmosphere;
- Clearly communicate his intentions;
- Share information;
- Monitor the performance of the crew and provide constructive advice for the crew members;
- Ensure that the actions are coordinated;
- Make decisions, with the help and active participation of other crew members;
- Define action plans with the accession of the crew;
- Delegate responsibilities and actions;
- Adapt the distribution of tasks for everyone on the basis of skills and workload;
- Commend for the work well done;
- Debrief and learn lessons collectively from what has been done.

Depending on the situational requirements and crew make-up, synergistic leadership must adapt. When the time pressure is high, such as during a V1 engine failure, decisions must be made quickly, without hesitation, according to the established patterns.
In such cases, it is not possible to implement a consultation process within the crew, which would be long, costly, and totally incompatible with proper treatment of the situation. In this case, leadership must be prescriptive, which does not exempt, a posteriori, from explaining the decision and making the crew adhere in order that it can renew support for the pilot in command.
When demands are low and situations are perfectly controlled, one should also know how to motivate the crew, by allowing areas of controlled freedom. Maintaining pressure in such situations would have no meaning, serve no useful purpose and drain the crew.

In practice, good leadership is not in a constant style, nor an extreme style (autocratic, "laissez-faire"). It must be dynamic to adapt to the situation and people.

d) Attributes of a Positive Style of Leadership

The main attributes of a positive style of leadership are, on the one hand, to ensure a synergistic operation of the crew and, on the other hand, to guide the crew to achieve the defined objectives. To ensure a synergistic operation of the crew, the leader must:

- Build and maintain the proper functioning of the crew, by establishing an atmosphere of communication and participation, by encouraging the input of others, and by not entering into competition with others;
- Consider and support the crew by listening to their opinions, valuing them, and offering assistance;
- Manage conflicts that can occur, by keeping one's calm, by suggesting possible solutions, and by identifying what is constructive and what is not.

To guide the crew to achieve the defined objectives, the leader must:

- Wisely use one's authority while arguing one's opinion, by involving the crews, by reacting to their suggestions, and by motivating the crew;
- Guarantee work with procedures, by ensuring the respect of their application, by intervening in case of deviance and when procedures have limitations;
- Plan and coordinate by determining and announcing the action plans, as well as executing the announced action plan.

The role of the leader, in building and maintaining the synergistic operation of the crew, falls within three phases of flight:

- Flight preparation;
- In flight;
- Debriefing.

The composition of the crew strongly influences how the synergy will be exercised. For example, some cockpits present more traps to proper functioning, particularly when the roles and status of the crew members are more confused and implicitly change the authority gradient.
This is the case for cockpit instruction or control, as well as for cockpits with strong hierarchical or experience differentials. In these situations, it is even more important to clarify the roles of each member before the flight, but also during briefings in flight, as well as to be even more alert to the occurrence of warning signs for collective dysfunctions.

4.4 - Communication

The accident of a B747-F from Flying Tigers Line in Kuala Lumpur (Malaysia) in 1989 well illustrates the difficulties of communication. While the cargo plane prepared for landing, the following communications were recorded:

- "ATC: Descend to two seven zero zero (2700).
- Pilot: Roger – Cleared to twenty seven hundred – we're out of forty-five.
- ATC: Descend two (to?) four zero zero – cleared for NDB approach 33.
- Pilot: OK – four zero zero".

The initial clearance was 2 400 ft, but what the pilot repeated was 400 ft. The controller did not identify the read back error, perhaps because English was not his mother tongue. The aircraft crashed into the mountain at 481 ft, killing the four crew members (NTSB, 1989).

4.4.1 – Definition of communication

Communication is the mechanism for the exchange of information between a transmitter and a receiver. In the professional field, the exchange of information aims to share this information to achieve an objective.

Communication enables the transmission of information, through a message, but it also has other functions: transmitting an emotion or expression; acting on the recipient by trying to influence or challenge; opening and maintaining contact to know that one could transmit a new message when it is necessary.

As a result, this communication actually presents two components in ongoing interaction:

- A relational component, which is based more on non-verbal forms;
- An informational component, which is instead based more on verbal forms of communication.

4.4.2 - Communication Model

a) Components of Communication

Transmitter. This is the person or system that transmits a message.

Message. All information transmitted in a physical form. This information must be coded to use media, a channel or medium of communication.

Code. This is the rule that transforms thoughts, knowledge and information into a different system of representation, transmissible and understandable by others. Language is a code. There are gestural codes, such as between the pilot and ground crew before startup of the engines.

Context. Information has meaning in relation to the context in which it is developed or manipulated. Knowledge of the context allows for understanding the true meaning of information. Each one involved in communication has its context.

Communication Channel. It is media used to transmit the message (voice, paper, radio, screens, etc.). The quality of transmission is important to ensure that the entire message can be understood by the receiver. Communication channels with parasites are a source of lost information.

Receiver. This is the person or system that receives a message.

Feedback or Retroaction. Feedback refers to the reaction of the receiver to the message issued and the return that is made to the transmitter. The concept of feedback makes it possible for one to move from a linear vision of communication to a circular mechanism at the origin of dialogue and exchanges. In feedback, the receiver becomes the transmitter and the initial transmitter becomes the receiver. Dialogue is characterized by the intentional commitment by two or more persons in a well-identified construction, which leads to a real contract obtained after negotiation and compromise. Only the succession of two unrelated messages does not constitute a dialogue. For

there to be dialogue, each statement builds on a previous statement and will induce another statement until there is consensus on an interpretation or a particular choice.

b) Unilateral or Bilateral Communication

The principle of feedback in communication is very important, because it allows one to distinguish unilateral communication without feedback ("one-way communication") from bilateral communication with feedback ("two-way communication").

- Unilateral communications are used to transmit information or orders, whereas the transmitter is not waiting for return on the part of the receiver. In aeronautics, the ATIS dissemination or TFP messages from the cabin by "public address" are habitual unilateral communications.
  Unilateral communication does not check whether the message has been well-received or well-interpreted. For this reason, the message must be interesting and relevant to the receiver, and expressed in clear and simple language. It should be short, concise and precise in order for the information to be easy to understand and interpret.
- Bilateral communications include all successive messages between a transmitter and a receiver. The transmitter transmits a message and expects a reaction from the receiver. This reaction can take many forms depending on the nature of the initial message. It can go from simple acknowledgement up to the most elaborate forms of negotiation.

The benefits of bilateral communication are:

- A quick clarification of misunderstandings;
- An "online" adaptation of the message, depending on the reactions of the receiver;
- The active search for an understanding and a decision by means of successive interactions;
- The sharing of information and opinions for co-constructing a representation and an action plan;
- The sharing of tasks and monitoring of actions.

4.4.3 - Basics for Effective Communication

Open and keep open the channel of communication between those involved (e.g. say "hello" with the runway or say ''I have something to say to you" or "you have seen'' to the crew making them more receptive; it creates an expectation).

Identification of the Transmitter.
It can be by name (e.g. "This is the captain…") or identifiable by physical characteristics of the transmitter (recognizable tone of voice, direction of the voice, movement, contact, etc.).

Recipient of the Message.
It is either specifically designated by the transmitter, and it is not ambiguous, or it can be more ambiguous when it is a look, a gesture, etc.

Using a common code between the transmitter and receiver.

The transmitter and receiver must have the same language. Most often in communications, the language is verbal, but it can also be non-verbal (gestures, tone, attitudes, etc.). The language must be adapted to the characteristics of the profession.
Thus, it is well that each profession creates specific languages that it refers to as professional languages. Doctors have a "jargon" that requires having explanations if one wants to understand what is said. Pilots also have their professional language.

Professional language is important because it aims to be as operational as possible. It is designed to be accurate, concise, unambiguous and suited to operational requirements. In contrast to natural language (social language), it facilitates effective communication in high workload flight phases. To be able to use it in all aviation circumstances, especially under stress, fatigue or a heavy workload, professional language must be used "naturally" in the work environment. In such situations, it is common to see a return to natural language to the detriment of professional language which is more effective. For this reason, its use must be systematic in daily life to make it familiar, automatic and able to withstand degrading factors.
In an aircraft, the aircrew works using professional language. But during a flight, as in any occupation, there may be non-occupational communications during low workload phases such as cruising. This is a pitfall as the same word can have different meanings in professional language and in natural language (for example the word train can refer to a railway train or a gear train). The danger is then professional and natural language being mixed up between the sender and receiver of a communicated message and thus unnecessary sources of ambiguity being created. For this reason, people should not hesitate to announce the communication environment in which they are operating: professional or non-professional. Likewise, when in doubt, the doubt must be removed.

Aeronautical language is characterized by:

- A glossary (words) adapted to aeronautical concepts. The objective of this glossary is to avoid paraphrases in order to have an economy of words (speed of understanding and decision-making in the cockpit, but also with ATC, e.g. when the frequency is saturated). It is also to avoid ambiguities, multiplying words with meanings close and error sources of understanding in deteriorated situations, when communications are deteriorating or communication channels are parasitized. For this reason, words can be created and the polysemy of words is banned. Each word has a very particular meaning in its professional context. The professional glossary is more specific than the language glossary, because its objective only concerns profession concepts.
- A syntax (grammar) adapted to professional constraints. There is no point in creating beautiful literary phrases, what matters is operational efficiency. To this end, the grammar is simplified or reduced to its simplest expression if necessary (simple juxtaposition of words without conjunction, etc.).

The content of the message must be built correctly and without ambiguity for the information to be transferred, with contextual elements that reduce the erroneous interpretations on the part of the receiver. Sharing the context is essential for good communication between the transmitter and the receiver. It is difficult to follow two conversations at the same time in two different contexts. The content of the message must also take into account the skills of the recipient. It is not expressed in the same way if the fellow crew member has a little seniority in the qualification or if one has several years of experience.

The content of the message must be consistent when multiple languages are used. For example, the attitudes or gestures of the transmitter must not contradict or cause ambiguity.

The message must be transmitted according to the rules that make it possible for one to cope with communication channels parasites (e.g. sufficient sound level, redundancies in the event of potential losses, etc.).

Read back of the message by the recipient ensures that the message received was well understood. If there is no read back, the transmitter must ensure proper understanding of the message.

All of these principles define the rules for aeronautical phraseology. Phraseology ensures effective communication, without which there can be no safety and performance in aeronautics.

4.4.4 - Communication Modes

a) Verbal Communication and Non-Verbal Communication

Non-verbal relational communication is complementary to the verbal communication and participates in the meaning of the message. It affects the way in which it will be available, or even received, vis-a-vis the message.

Non-verbal communication is reflected by behaviour, attitudes, gestures, tone of speech, etc. (e.g. tilting the head can be a sign of seduction, scratching the head a sign of perplexity). These behaviours directly contribute to the "form" of the message, which one knows can be more important for the receiver in the meaning that it gives the message than the background (i.e. meaning) of the message itself.

The functions of non-verbal communication are to give a self-image to others, more often positive (e.g. present oneself in a good light); to define desired relationships with others (e.g. first interaction strongly affects relations thereafter); to reveal our emotions while performing the task at hand (e.g. do we not say that stress or confidence are contagious?).

For good communication and fruitful exchanges between crew members, it is important that verbal and non-verbal communication are consistent, i.e. the information transmitted by non-verbal communication does not conflict or create ambiguity with verbal communication.

Relational communication is based on behaviours. Behaviour is defined as the part of the activity of an individual that is manifest to an observer. In this definition, it can be deduced that any action or non-action of an individual is a behaviour. Therefore, regardless of the behaviour of a person, it has a meaning for others. For example, the person who always remains in her office with the closed door has a behaviour reflecting a psychological state toward others. She does not want to talk to anyone and does not want to be spoken to. Reference is also made to gestural communication or "body language".

b) Explicit and Implicit Communication

The meaning of the message is linked to the context of the transmitter and the receiver. The more the contexts of those involved are similar and shared, the more it is possible to simplify communication, in form and in background. In this case, it is considered to be a part of implicit communication, i.e. it is not necessary to communicate all information.

Implicit communication is advantageous since it makes it possible to transmit the required information by using less temporal and attentional resources. However, it is only effective, under penalty of error, if the contexts of each one involved are similar. Knowledge of the context of the receiver is never totally complete. It is based on the representation that is made by the transmitter of skills and experience of the receiver. Any erroneous representation of the context by others is a source of error in the implicit transmission of a message.

For example, how a pilot in command handles communications with his co-pilot for diverting a flight will be different if he is with a young co-pilot who has just been qualified or with a co-pilot who has several years of experience on the aircraft and with the airline.

In contrast with implicit communications, there are explicit communications. Explicit communications have the advantage of minimizing ambiguities, but they are much more costly since they require "saying everything". Unlike implicit communications, the elements of context are detailed in the communication since sharing contexts is less between transmitter and receiver. When the crew members do not know themselves or when confidence does not exist, communication is built almost exclusively on the explicit. The explicit especially appeals to the verbal, whereas the implicit can appeal much more to the non-verbal.

When doubts arise in effective communication, the implicit may be too significant and requires knowing how to return to a more explicit mode of communication. It may even be the same when the workload increases and one no longer has sufficient resources to check the work of the other crew member and understand the context. In this case, it requires returning to closed, precise requests, leaving little room for interpretation.

4.4.5 – Aspects of effective speaking

Effective speaking (also referred to as communication, dialogue or briefing in an aircraft) is a skill based on oratory techniques developed as early as Ancient Greece by philosophers.
The aim of effective speaking is both to win over the listener and, in the context of an aircrew, to allow the listener to enhance the exchange of information. Effective speaking is based on four aspects:

- Speaker (great person): the speaker has to embody the message. This means that what is said by the speaker cannot be separated from what the speaker is as a person. It is what the speaker conveys in terms of conviction through their experience, motivation and even humour that will win support for what is said:
- The right time (noteworthy event): imparting a message properly calls for it to be done in a timely manner or the listener will not be receptive, thereby decreasing the message's effectiveness. You sometimes need to know how to wait for just the right time for the verbal message given the listener's availability or the operational relevance. The timing of the verbal message allows the available resources to be harnessed in the best possible way.
- Compelling message: the preparation of the message is essential to ensure that it is clear, precise, direct, and therefore convincing. It must be prepared so as to be both structured and contain sufficient information to remove ambiguities and doubts that could impair the listener's understanding, acceptance or participation. To facilitate the

work of crews, many communications such as briefings are structured around aspects described in work procedures. An effective message is a prepared message.

- Masterful delivery: the verbal message must be combined with intonations, facial expressions, eye contact, attention grabbers or gestures to reinforce the words. This involves making the message meaningful in order to convey it properly. Enunciation is an ability that is specific to each person but which can be developed to make it more masterful by becoming aware of and working on all non-verbal modes of communication.

4.4.6 - Obstacles to Communication

a) Personality and Attitudes of Listeners

Being too strict, when the situation does not require it, or a failure to listen to the remarks of another crew member are all factors that can create tensions, even conflicts if the subject of communication is vital for the flight and safety.

b) Workload

The relationship between workload and communications are two-fold. On the one hand, communicate increases the workload. On the other hand, the increased workload changes the communications in the cockpit. We observe:

- A rarefaction and a shortening of communications;
- The use of an increasingly simple syntax;
- An increase in code words;
- The expression of contexts is increasingly less explicit;
- A deterioration of phraseology (identification, recipient, read back, etc.);
- a loss of professional language and a return to natural language (social language);
- The relational aspects of communication are less well-managed and can be a source of more frequent misunderstandings.
- Receptiveness is impaired as we are less available;
- The ambiguities and sources of misunderstandings are more frequent;

c) Interruptions

Interruptions are common and natural in the cockpit: an ATC message, an alarm, a call from the purser, etc. An interruption is inconvenient for current activity, because it breaks up one's activity and can be detrimental to overall performance by forgetting, repeating, altering understanding and/or decision-making.

Handling interruptions during communications requires particular attention.

Before any communication, there is a need to ensure the availability of the receiver. If he is not available and there is no need to interrupt him immediately, communication must be delayed (but make sure not to forget it!).

If the receiver is not available, but it is considered to be important enough to interrupt him, he must be given the opportunity to refuse the message a first time by requesting permission to interrupt him. Before interrupting him, look at what he is doing to see if his task is one that he can return to after the interruption.

As a receiver, one must not hesitate to refuse a communication or to delay it if an essential task is in progress. When one is interrupted, it takes time to note what one has done in order to resume the task under proper conditions after an interruption.

The more routine and monotonous the task, the easier it is to be interrupted and the less chance there is of returning to and performing the initial task correctly. In contrast, the more delicate the task and need to be fully invested, the easier it is to be interrupted and the less chance there is of returning to and performing the initial task correctly.

d) Stress and Fatigue

High levels of stress and/or fatigue alter intellectual capacities and, thus, communications. We observe:

- A decline in communications with a tendency toward isolation;
- A loss of professional language and a return to natural language (social language);
- A loss of control in relational communications (attention to the contagion of stress);
- Difficulty of stopping non-professional communications, whereas one is engaged in delicate phases of flight (particularly with fatigue).

e) Aeronautical English

Speaking in a language that is not one's mother tongue is a source of difficulties. Yet, the professional language in aeronautics is English. As long as everything goes as planned, it is relatively easy to transmit and understand messages.

Difficulties arise as soon as one leaves the usual framework since, at the present time, the use of plain English language is more important. Vocabulary may exceed the framework of aeronautics. Sentences tend to lengthen and must then comply with the English syntax. In these phases, it is a requirement to be able to speak the English language naturally. During the aircrew training, efforts are made to improve the level of current English as part of this approach.

The accident of an Avianca B707 in New York during 1990 illustrates this fact. After several passes in a holding pattern, the crew informs ATC of their approach since they have no more fuel. The pilot in command, who speaks broken English, communicates with ATC through the co-pilot. The co-pilot does not use the word "emergency", but only says to ATC: "We request priority for landing." The co-pilot reiterates the request several times. When clearance is given, the crew starts but is not successful in its initial approach and makes another go-around. In the course of this go-around, the aircraft runs out of fuel and crashes. Seventy-three of the 158 persons aboard were killed.
The air traffic controller said he had not realized the peril of the situation following the requests of the crew.

f) Human-Machine Technology and Communications

The computerization and automation of cockpits alter the activity of crews. These points will be largely developed in the chapter on cockpit automation.
However, as regards human-machine communications, a few characteristics may already be cited:

- Tendency to isolate crew members, because automation enables each one to do everything within a limited work space;

- Accessibility to what others do is reduced (size of systems, interfaces, and alphanumeric characters);
- Greater difficulty in performing cross-checks;
- Decreased non-verbal communication, due to the limitation of workspace.

As a result, coordination and cooperation of the crew may be altered. This requires additional efforts to ensure that all crew members share the same action plan, same distribution of tasks and same monitoring criteria.

These efforts include briefings, checklists, or regulatory procedures. However, one must not hesitate to request clarification if there is any doubt.

4.4.7 - Intrapersonal and Interpersonal Conflict

a) Definitions

Conflicts arise from a total, partial, real or perceived state of opposition, disagreement or incompatibility between the roles, objectives, intentions and interests of one or several individuals or groups.

Intrapersonal conflict results from the opposition of an individual with conflicting motivations, objectives, feelings or requirements. Generally, this type of conflict implies that the subject confronts a certain incompatibility of goals or tensions generated by knowledge, decisions and actions contrary to the subject's beliefs or values.

Interpersonal conflict occurs when two individuals disagree about the goals to be achieved, measures to take, values, attitudes or behaviours to adopt. Interpersonal conflict may involve isolated individuals or those belonging to the same group (the crew).

b) Escalation of a Conflict

The escalation of a conflict reflects the destructive mechanism by which confrontation of viewpoints between crew members leads to no solution and destroys interpersonal relationships, resulting in disdain, aggression and rejection. The escalation occurs when attempts to gain the upper hand over another become increasingly important and trigger strong, or even violent, reactions.

The escalation of the conflict may occur on five levels. At each level, there is a point of no return that opens the door to the higher level. These are the following levels:

- Level 1: Problem to Resolve. The inflexibility of opinions of one of the crew members leads to the next level.
- Level 2: Observing a Difference. The silent treatment or apparent desire not to listen leads the next level.
- Level 3: Confrontation. An altercation and/or heated verbal exchanges leads to the next level.
- Level 4: Argument or Abandonment. An increasingly violent climate, total rejection of another, leads to the final stage.
- Level 5: Physical Brawl.

Depending on the level of conflict within the crew, multiple behaviours can be observed, ranging from collaboration to passive and active resistance. A conflict in the cockpit must not exceed Level 2. Crew members must be aware of their relationships to know how to implement resolution strategies.
In case of escalation, there will be immediate consequences for flight safety due to:

- Deterioration of synergy, decreased communications;
- Diversion of crew resources to the escalated conflict;
- Increased risk of misunderstanding;
- Suboptimal decision-making process;
- Deterioration of the distribution of tasks;
- Loss of cross-checks and monitoring of actions.

c) Communication in Conflict Resolution

In conflict resolution strategies, the following tools are useful.

- Identify the Source of the Conflict ("inquiry")
  This inquiry must be done with delicacy to avoid increasing the conflict. Do not seek to find who was right and who was wrong, seek what is appropriate and correct to do.
- Active Listening
  It ensures that one is listening attentively to the other and understands what the other is saying.
- Pleading ("advocacy")
  It is the act of arguing and pleading in favour of a cause or an opinion. The advocate requires time and active listening by the receiver.
- Feedback
  Feedback is fundamental in bilateral communications and dialogues. It makes it possible for the transmitter to ensure that the message has been well understood by the receiver.
- Metacommunication
  Literally communication on communication, metacommunication refers to the process of exchanges made on its own communication in content or in relationship. It is the attitude and behaviours that accompany the transmission of the message. When words and metacommunication are in the same line, they are mutually reinforcing. Conversely, if they are contradictory, they strongly disrupt the understanding of the message. For example, the captain tells his co-pilot to be sensitive to human relationships during the flight and yet ignores the remarks of the flight dispatcher during the layover. The flight dispatcher then asks the co-pilot about the captain’s ability to be sensitive to human relationships.
- Negotiation
  It is the search for an agreement, centred on quantifiable issues between two or more individuals, and within a limited time period. The search for agreement involves the confrontation of incompatible interests on miscellaneous points (for negotiation) that each party will attempt to make compatible through a set of mutual concessions. Negotiation leads to compromise, which is not the optimal method of conflict resolution in the cockpit. It is always the pilot in command, who has the responsibility to make the final decision.

05 HUMAN BEHAVIOUR

Human operators react to changes in their environment and are constantly adapting to meet their objectives. Adaptations and reactions are the result of a complex alchemy between cognitive, emotional and motivational components.

5.1 - Behaviour, Personality, and Attitude

5.1.1 - Behaviour

The behaviour of an operator is the part of the activity that is manifest to an observer. It involves all actions and reactions of an individual as a result of an interaction with the environment.

Behaviour results from factors grouped into five categories:

- Individual factors: personality, attitudes, values, expectations, motivation, knowledge, skills, intellectual mechanisms, etc.;
- Psychosocial factors: leadership, power, etc.;
- Organizational factors: training, regulations, working environment, etc.;
- Situational factors: task, environment, workspace, tools, etc.;
- Societal factors: culture, socio-economic level, occupation, family, etc.
- Behaviour can be innate or acquired, conscious or unconscious, and voluntary or involuntary.

5.1.2 - Personality

Personality is the structured and dynamic organization of a person, who they are, as well as their way thinking and acting. This is the "hard" and stable core of the individual, the result of integrating one's cognitive, emotional, and instinctual components. It includes heredity, the cultural background in which an individual develops, education and experiences acquired through professional and social skills.
Personality is characterized by two properties.

- Stability, which explains the permanence and continuity of action and reaction modes of the individual over time. The personality can change, but these changes take time to develop.
- Uniqueness, which explains that each individual is unique, original and specific. This makes one recognizable and distinct from another through one's behaviour in one's way of being. The uniqueness of the personality results from its method of construction.

5.1.3 - Attitudes

The attitude is a relatively stable mental disposition resulting from experience, which influences our reactions toward people and situations. Allport (1955) defined it as a predisposition to react in a certain way. In any attitude, there is a central evaluative aspect, an assessment of the subject, situation or person, either positively or negatively. For example, being supportive or not of additional skills testing in the simulator are two opposite attitudes.

Attitude is founded on three components:

- Cognitive component, namely all knowledge, thoughts and beliefs about the object or person;
- Emotional component reflecting the emotions and feelings vis-a-vis the object or person;
- Behavioural component, which reflects the actions carried out toward the object or person.

5.1.4 - Relationship between Attitudes, Behaviour and Personality

Even if the attitudes have a behavioural component, there is no systematic link between attitudes and behaviours. In fact, it is not because one is favourable to something that one will do it.
Thus, for example, as a result of human factors training, one may have a favourable attitude toward human factors, but this is not why, in the cockpit, one will have human factors behaviours.
However, it is clear that having a favourable attitude increases the chances of having behaviour accordingly, but it does not guarantee it.
The relationship between personality, attitudes and behaviours is complex. Behaviours are the result of personality and attitudes, but this is not all.
They are also the result of the integration of standards that govern them and the motivation to adhere to these standards. Attitudes are related to personality, but not exclusively. They also depend on assessing the consequences of attitude. Accordingly, all attitudes do not translate into behaviours.

The education and experience acquired during childhood, schooling and finally during training courses, allow each person to come to terms with their own personality and attitudes in various situations. It is an opportunity to learn about oneself in order to adapt one's behaviour and attitudes appropriately.

In flight, personality and attitudes are at the root of crew behaviours and have a direct impact on performance and safety. This impact may also be positive - what is desired (thoughtful, open, rarely anxious, crew-oriented, emotionally stable, etc.; attitudes toward cooperation and synergy, distrust of undue reliance on automation, etc.) - as well as negative, if attitudes and personalities are not consistent with the development of non-technical skills required for a crew.

In accidents, for example, it was noted that anxious extroverts tend to have more accidents when there is risk taking. Similarly, anxious introverts are less efficient when they are faced with emergency situations or under extreme time pressures due to more pronounced rigidity and discretion.

A selfish attitude is the opposite of what is desired from a crew member in achieving synergy resulting from cooperation. It is a factor in impaired aircrew performance.

Knowledge of one's personality, one's outstanding traits, but also one's attitudes is important for regulating one's behaviour in the cockpit depending on the situations and people with whom one flies.

5.2 - Personality and Motivation: Individual Differences

To illustrate the individual differences in personality traits, reference can be made to the personality model of Hans Eysenck (1953), which describes three dimensions.

- Introversion-Extraversion
  Extraversion measures the degree of commitment in one's interpersonal relationships and in one's external environment. Extroverts are active, energetic, enthusiastic, confident and have no fear of danger. They seek out and appreciate the company of others. Introverts are more oriented toward their inner world. They are quieter and more conscious of threats.
- Neuroticism - Emotional Stability
  Neuroticism characterizes persons who easily frightened and lose their faculties. They have a perception of the outside world as hostile or a source of problems. Subjects with high scores in this dimension commonly suffer from negative emotions and have a lower emotional reactivity threshold. It translates into low self-esteem and difficulty asserting themselves in a group. Individuals who do not show signs of neuroticism are qualified as stable.
- Psychoticism
  Psychoticism combines coldness, aggressiveness, lack of empathy, interpersonal hostility, egocentrism and impulsivity. Psychoticism is often mentioned as a factor characterizing antisocial behaviour. The opposite of psychoticism is empathy, socialization and altruism.
  For the three dimensions, each individual is divided over a continuum that goes from one extreme of the dimension to the other.

The question that arises then is whether there is an ideal personality profile for pilot. It is certain that the profession of the pilot requires adequate behaviours to handle the complexity and requirements related to the flight.
That is why certain personality traits appear to be essential for the profession of the pilot. We can cite the trend toward extraversion to the extent that it is not excessive, nor does it mask the qualities of introversion. Similarly, emotional stability, self-assertion, positive apprehension of the outside world, reflection, constructive social behaviours and self-discipline are all traits required in pilots.

However, we must be careful. As mentioned above, the individual is unique and personality is a whole. We cannot reduce an individual to a list of traits.

Personality must be assessed as a whole, as the harmonious integration of traits that allows one to develop behaviour adapted to situations. The situations vary and require different responses. One must not be rigid, even if it is important that one's behaviour may be anticipated by other crew members. It is particularly necessary to avoid behaviour that reflects extremes in some traits incompatible with teamwork, performance and safety.

5.2.1 - Concept of Oneself (Self-Concept)

The concept of oneself is the set of knowledge that an individual has about oneself. That is what one believes to be true of oneself. The concept of oneself enables one to have awareness of one's own identity, such as a separate and distinct entity from those of others and the environment.
The concept of oneself is built, organized and changes with experience. It includes three components:

- Personal component (elements or opinions that one has of oneself: e.g. "I am big" and "I am a good captain");
- Social component (ideas that others have of us: e.g. "within the company, the personnel think that I am someone pleasant to fly with");
- ''Ideal'' component (how I would like to be or how I would like others to consider me).

Knowledge of oneself directs the processing of information. One needs a stable concept of oneself from which it is possible to reinterpret the information so that it corresponds with the idea one has of themselves.

From the concept of oneself, motivations arise, aspirations that lead to adjustments and changes in personality, particularly if the image that one has of oneself is not satisfied or if the image that one reflects to others is not consistent with their values and ideals. For example, during the debriefing of an inspection or training, comments by the instructor can make one aware of the image that others have of them and move one to change if it is negative with regard to their ideals and values.
The concept of oneself is beneficial to safety, to the extent that it allows for adjustments in accordance with values and ideals in conformity with professional rules. It can be a source of danger when the ideals and values of the individual do not subscribe to this logic.

The image of what one is, what one would like to be, what one represents to others, may be at the root of a lack of confidence or, on the contrary, overconfidence.
The greater the consistency between the various components of the concept of oneself and professional rules and values, the more the behaviour will be appropriate, avoiding inappropriate behaviour, such as aggressiveness, withdrawal or lack of self-assertion.

5.2.2 - Self-Discipline

Self-discipline is the discipline that one imposes on oneself, an individual, or a crew, to achieve the objectives defined with regard to a successful flight, without letting themselves be influenced by their emotions.
In other words, this is what makes it possible to reach the goal without being disturbed by instant gratification, pleasure or satisfaction, which has no purpose in achieving the objective and could jeopardize its realization.

As regards flight safety, self-discipline corresponds to the systematic wilfulness to develop and adhere to the professional values of the profession of the pilot, and makes professional decisions despite the possibility of being tempted to do otherwise.
For the pilot or crew, it is the willingness to use the aircraft as directed under the operational guidelines, regulatory directives, organizational directives and rules of the profession.

Self-discipline enables one to minimize the "traps" of cognitive functioning, to avoid making mistakes and to not use the violation as a mode of operation.

5.3 - Dangerous Attitudes

In the 1980s, the Federal Aviation Administration (FAA) made the observation that more than 85% of air accidents were due to human error. Pushing the investigations further, the FAA identified five attitudes as being hazardous and dangerous to safety: 1) anti-authority, 2) impulsivity, 3) invulnerability, 4) macho, and 5) resignation.
Complacency is a sixth dangerous attitude that can now be added.
For crews, it is important to know these attitudes well, in order to recognize them in the cockpit, in oneself, or among other crew members, and to guard against the dangerous behaviours that could be at the root.

5.3.1 - Anti-Authority: "Don't tell me what to do"

This is a person who does not like to be told what to do. He/She loves her independence and finds that regulations are more annoying than they are useful. This attitude can lead the pilot to take excessive risks, just to show that he/she can do things differently from what he/she is told to do.
If a pilot realizes that he is always grumbling against the regulations, he must recognize that he has a tendency to be anti-authoritarian.
An example. Although one concedes that the aircraft must be stabilized at a certain height before landing, one has the feeling that this height is too restrictive and that in certain circumstances, it could be more lower.

To correct and prevent such an attitude, it is necessary to remember that rules must be followed. The rules have been developed from aeronautical experience and, particularly, lessons from air accidents. This is why they are an effective method in preventing inappropriate behaviour.

5.3.2 - Impulsivity: "Do something and quickly"

This is a person who needs to do something quickly and immediately. Faced with a problem, the pilot wants to solve the problem immediately and, to do this, does the first thing that comes to mind without taking the time for reflection. It is an attitude difficult to recognize, because the mistake in a decision may not be visible at the moment.
An example. While the pilot waits for clearance to land, he sees a gap in the landing queue. The pilot hastens to slide into the landing queue to initiate his final descent. At the time of touchdown, he notices that he is lined up on the taxiway.

To correct and prevent this attitude, it must take the time to reflect: thinking first before acting. There are few situations in the cockpit requiring immediate actions. For those who require it, they are briefed by the crew and are listed as "reflex" actions. Outside of ''reflex'' actions, always ask the question to justify a precipitation to want to act immediately.

5.3.3 - Invulnerability: "This cannot happen to me"

Accidents only happen to other people. A person is aware that there are accidents, that flying is an activity at risk, but this cannot happen to him. Pilots with this attitude tend to have risky behaviour, because they believe that nothing can happen to them.
They also tend to reinforce this attitude, by considering past successes as a guarantee of future successes. These pilots are very confident in their abilities, too confident.

An example. We have landed so many times by not being stabilized at the height required that there is no danger of not being stabilized at this height.

The antidote in the face of a trend of invulnerability is to take into account the fact that it could happen, even to oneself, and make decisions accordingly. There is no logical reason to feel immune to events that have happened to others.

5.3.4 - Macho: "I can do it"

The macho attitude is similar to invulnerability. In the macho attitude, pilots always want to try to show that they are good and better than others. They go to the limits of their abilities to demonstrate their value, impress others, but at the risk, conscious or not, of exceeding their limits and being dangerous. Even if macho is a masculine qualifier, a macho attitude can also develop in women. A pilot who says "I can do this, I will show you how to do it" or ''Eh, look at this'' probably has a tendency toward macho attitudes.
An example. A pilot in command who wants to show his co-pilot that he knows how to land in bad weather conditions can cross the limits to show that he knows how to do it.

Faced with such an attitude, we must say that taking risks is stupid and leads to nothing except an accident. It is more professional to show one's value through safe behaviour and observance of the regulations than through one's "bravery".

5.3.5 - Resignation: "Forget it. It's not worth it"

The pilot thinks that he has very little control over his destiny, and what one does has very little influence on what happens. When he succeeds in doing something, it is luck, and when it does not happen as expected, it is bad luck. It has a tendency to follow what others are doing, even if it is not in agreement. This contributes to letting bad decisions take place while one is aware of it.
An example. If I tell him that he is crossing the line, he will tell me that he knows how to do it, because he has already done it many times and he knows the terrain, and I will make myself look bad.

In the face of a resigned attitude, it is important to say that one has the skills to handle the situation, that one can get there and one will be able to justify one's choices. Any qualified person has the skills to cope with situations in one's professional life.

5.3.6 - Complacency: "We don't need to worry about anything"

Complacency is defined as a state of self-sufficiency that is accompanied by a lack of awareness of potential dangers. This condition is likely to occur during routine activities that are considered easy and safe. Complacency decreases stimulation and alertness thereby affecting the effectiveness of

situational awareness and decision-making mechanisms. It may also be caused by a relaxation after a high workload stage, after managing a high stress situation or during a high level of fatigue.
Complacency includes such concepts as overconfidence, contentment and low suspicion. The consequence of complacency is a sub-sampling of actions in supervising and controlling systems, situations or people. One can thus be complacent with an automatic control system, aeronautical risks or another crew member.
It may involve a novice pilot faced with a situation in which they are not aware of all the hazards or an expert pilot faced with a task they have already performed several times before without any problems.
Complacency is a pitfall into which any pilot and aircrew can easily fall. For this reason, each crew member must be aware of this to monitor themselves and other crew members. Fighting complacency involves maintaining a sufficient level of stimulation during routine tasks. For this purpose, following instructions and procedures with the proper level of attention increases the level of stimulation and alertness. It is also important not to overwork your memory or assume that something is going well without checking it. In any case, aircrew work and cross-checks are effective mechanisms which, if properly carried out, can prevent complacency, provided, of course, that there is no complacency with other crew members.

Handling dangerous attitudes in flight is essential for safety, but the best prevention is avoiding such attitudes. That is why it is important to be aware of one's own dangerous attitudes to minimize and remove them. It is beneficial to ask oneself questions: How do I behave in flight in my relations with others? In the way I make decisions? And in handling emergency situations? This awareness is the only way to change one's attitudes in the cockpit toward even safer attitudes, truly guaranteeing an efficient management of crew safety resources.

5.3.7 - Right Attitudes

Without the ambition to establish an exhaustive list of the ideal attitudes for being a good professional in the cockpit, it is possible to identify the following elements:

- Compliance with regulations;
- Self-confidence and confidence in others, but doubt is part of the profession;
- Respect for others;
- Accept that others may have better proposals than one's own;
- Think before acting;
- Know how to share one's point of view when it is necessary and not to give up on important points involving safety;
- Be humble;
- Prepare for all situations, knowing that anything can happen.

Each of these attitudes, individual behaviours that occur within the crew directly result from:

- Self-control;
- Understanding of situations (airplane, environment, flight);
- Decision-making;
- Sharing of tasks;
- Interpersonal relationships;
- Risk management;
- Error and safety management.

06 HUMAN WORK OVERLOAD AND WORK UNDERLOAD

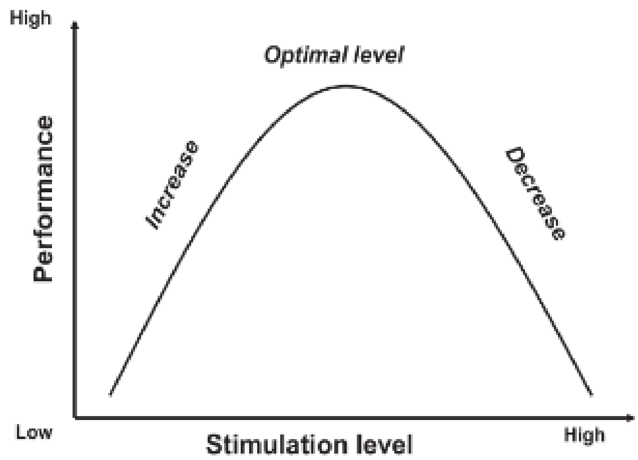
6.1 - Level of Stimulation/Awareness ("Arousal") and Performance: Work Underload and Work Overload

To be effective, it is necessary to have a certain level of awareness or stimulation, which will activate the nervous system.
There are two types of stimuli:

- Physiological, through the sensory receptors (stimuli from the outside world: visual signals, noise, heat, tactile perceptions, etc.);
- Psychological, related to motivations and task objectives to accomplish (challenges, success of the mission, deductions, inferences, problems, etc.).

The level of alertness or stimulation is a continuous natural state that is behind the mechanisms that govern alertness through the regulation of muscle tension, blood pressure or pulse rate and breathing rate.

On the basis of this finding, several authors (Yerkes and Dodson in 1908 or, later, Hebb in 1955) have suggested, from experimental data, that there was a non-linear relationship between the level of stimulation and performance of a task. This relationship is represented by a curve called an inverted "U", where performance reaches an optimum point for a moderate awareness level (stimulation), and diminishes for both a low awareness level and one that is too high (Figure on the side).



Inverted "U" relationship
between the level of stimulation and performance.

The workload is defined in relation to the level of stimulation. A low level of stimulation thus results in a state of work underload. Work underload can result from tasks that are not very stimulating (monotony and repetition of tasks resulting from low stimulus or a stimulus that is always the same) or from tasks that are considered to be of little interest to the operator.

In the long-haul cruising stage, the aircrew's task often involves little more than the repetition of housekeeping tasks (safety actions, monitoring an environment where nothing changes, etc.) which result in monotony thereby leading to the onset of drowsiness that can jeopardize safety.

6.2 - Stress

6.2 1 - Definition

Stress is a natural adaptation reaction when faced with a situation for which there is no immediate solution available. It enables the body to mobilize physiological and psychological resources in order to find a solution. Once the solution is found, the stress disappears.
It follows from this definition that stress is a normal reaction that occurs in every human being. There's nothing debasing about being stressed.
Knowing the mechanisms involved in stress means accepting that you can be stressed and also developing strategies to avoid and manage excessive levels of stress.

6.2.2 - General Adaptation Syndrome (GAS)

Stress reactions have historically been studied from a physiological perspective and were described by Hans Selye in 1955 as the General Adaptation Syndrome (GAS). The GAS refers to the set of mechanisms and physiological states that occur in response to a stress factor. The GAS is a model of an innate, stereotyped, non-specific response that is triggered in any individual, whether the stressor is physical or psychological, internal or external to the body, or objective or subjective. The reactions observed vary in strength from one individual to another, reflecting various adaptation capabilities.
It describes three stages of change that the body undergoes: 1) Alarm, 2) Resistance, and 3) Exhaustion.

a) Alarm Stage

Also called the "shock phase", the alarm reaction is the result of the initial confrontation with the stressor. The body will do everything to adapt to the new situation by massively and non-specifically mobilizing its resources through nerve responses (sympathetic nervous system) and endocrine responses (hormonal), which promote the ''flight or fight'' response when faced with the stressor. It is a general alert of the body, slightly controllable by the will (bold).

The sympathetic nervous system is part of the autonomic nervous system, which also includes the parasympathetic system. The autonomic nervous system, also called the ''vegetative system'', is responsible for the automatic functions of the body, such as digestion, sweating, mean arterial pressure, blood pressure, dilation of peripheral blood vessels, respiration, secretion of hormonal and non-hormonal glands, etc.

Sympathetic and parasympathetic systems are antagonistic. The sympathetic system prepares the body for action by producing energy, while the parasympathetic system has the opposite effect, i.e. restoring energy resources. The sympathetic system is involved in the initial acute phase of stress, while the parasympathetic system is involved after the alarm stage during the chronic stage.

Flight or fight reactions are archaic manifestations intended to preserve the body's integrity and to escape the stressor, either by destroying it or avoiding it. They occur during the alarm stage and depend on the sympathetic nervous system.

The alarm reaction causes secretion of adrenaline (bold) by the adrenal medulla, central part of the adrenal glands located on the kidneys. The adrenal medulla is stimulated by the sympathetic nervous system.

Adrenaline increases blood pressure, accelerates the heart rate and respiration, and then increases the rate of sugar in the blood. At this moment, pupils dilate to see better. The sympathetic nervous system inhibits the not directly operational functions (digestive system) and blocks the production of saliva (sensation of dry mouth).

All of these events promote the mobilizing and expending of energy in a short-term emergency response (a few minutes maximum) to foster fight or flight, by enabling the organs related to movement (muscles) to increase their function. This defense system, common to all animal species, is essentially oriented toward action and is not very effective for mental activities.

b) Resistance Stage

It is the result of the alarm reaction, to the extent that the stress factor persists. The resistance stage aims to gather the necessary resources for the body to, on the one hand, compensate for initial energy losses (that are important) and, on the other hand, to find a new balance, which will make it possible to cope with the stressor. This state is qualified as resistance, because it allows the body to rise above its normal level of functioning.

Organically, the resistance phase results in an activation of the parasympathetic nervous system in order to counter the effects of the sympathetic system in the alarm stage.
Parasympathetic activation is accompanied by a hormonal stimulation. It follows an activation of the adrenocortical glands, the external part of the adrenal glands located on the kidneys. The adrenal cortex secretes two types of hormones.

- Glucocorticoids (cortisol and cortisone) mobilize the energy reserves, because the first resources immediately available have been used by the alarm reaction. The glucocorticoids maintain a high rate of sugar in the blood by transforming fats into sugar. They also have anti-allergy and anti-inflammatory effects that inhibit the reactions of the body in the face of tissue injury that may be caused by the stressors.
- Mineralocorticoids (aldosterone and corticosterone) are involved in homeostasis, e.g. by promoting the storage of sodium in the blood.

Mineralocorticoids (aldosterone and corticosterone) are involved in homeostasis, e.g. by promoting the storage of sodium in the blood. It all depends on the intensity of the stressor and reserves of the individual. The resistance stage characterises the physiological manifestations of chronic stress.

c) Exhaustion Stage

Following the resistance stage, the exhaustion stage appears if exposure to the stressor continues, insofar as the body was unable to avoid it. It translates into intense fatigue of the body with appearance of significant psychological effects, such as discouragement, depression, or even abandonment.

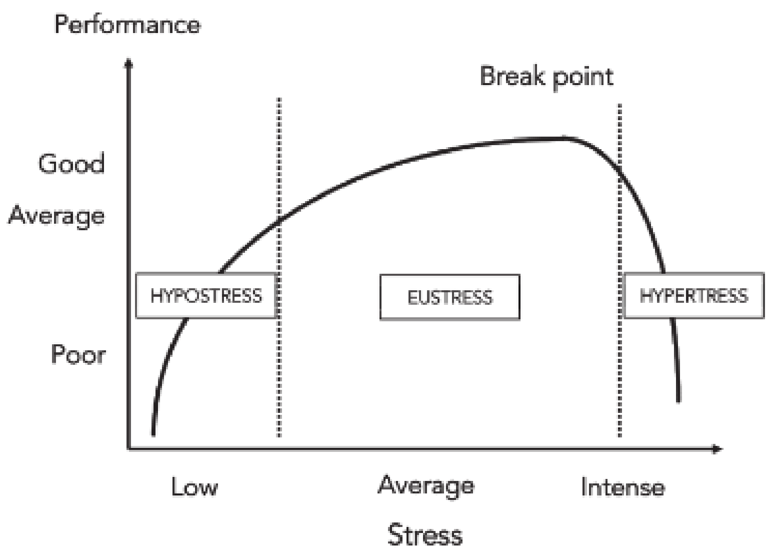
The body can no longer compensate for the expenditure of energy and immune defenses weaken, promoting external aggressions. Bodily dysfunction and diseases may occur in some organs, such as gastrointestinal ulcers, high blood pressure, bronchial asthma, eczema, cancers, etc. In extreme cases, the exhaustion stage can lead to death.
In the exhaustion stage, the body is no longer able to adapt even to the requirements of the stressor.

6.2.3 - Stress and Performance

Stress is conventionally referred to in relation to its negative effects on performance. In fact, the relationships between stress and performance are not as simple and on the same order as those described previously between the stimulation level and performance, i.e. in an inverted "U".

The relationship between stress and performance (figure below) can be broken down into three parts.

- "Hypostress" Area
  The low level of stress is accompanied by a low level of stimulation, which leads to a low level of vigilance. The operator is relaxed, his attention is wandering, and his ability to concentrate is diminished. In extreme cases, if the level of stimulation is very low, one may have periods of drowsiness. This area is paradoxically a bad stress area, because it is not synonymous with a high level of performance.
- "Eustress" Area or "Good Stress" Area
  This designation means that proper performance can only be achieved with a sufficient level of stress. There can be no high performance without stress. Stress is then positive and ensures performance. In the "eustress" area, performance improves as stress increases, until it reaches a point of rupture called a "breakpoint". Beyond this point, performance will decrease. This point is specific to each individual and may vary depending on the state of the individual (fatigue, motivation, etc.). It is important to know the behavioural signs that characterize it, because its appearance must be an alarm signal to implement strategies for managing stress, in order not to sink into the "hyperstress" area.



The relationship between stress and performance.

- "Hyperstress" Area
  In this area, stress is intense and is characterized by very rapid deterioration of performance, as stress level continues to increase. In this area, the feeling on workload is very high and characterized by a sense of overload.

6.2.4 - Cognitive Model of Stress

Stress has a physiological and psychological component. The psychological component is not only a result of the physiological component: it has its own full mechanisms. We refer to it as the cognitive approach to stress.

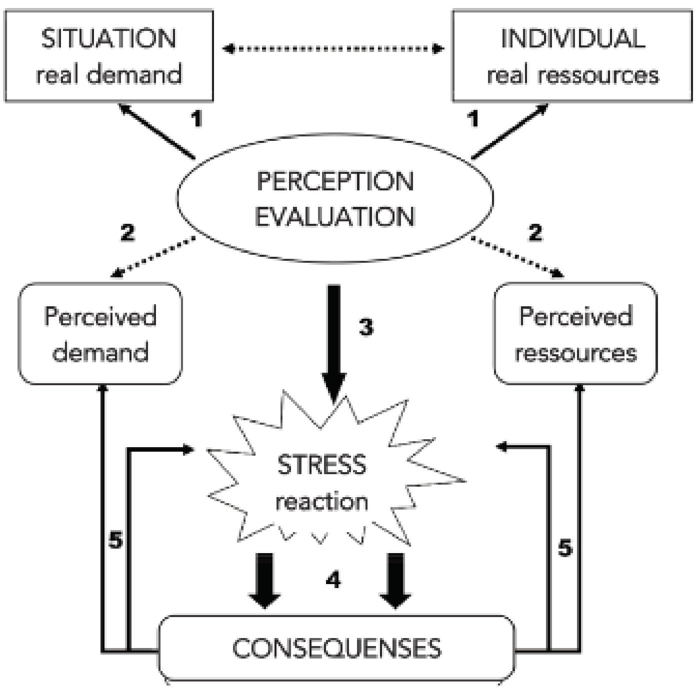
In the cognitive approach to stress, we consider that "what is important for an operator is not so much what happens to him, but the assessment of what is happening to him".

Two elements are then central to understanding stress in an individual:

- The perception of the individual regarding the situation that must be handled;
- The mechanisms of adaptation, or confronting ("coping"), which he possesses.

The level of stress will depend on the perceived imbalance (real or imagined) by the individual between the requirements of the situation and the resources available to cope with it.

The stress mechanism has five phases (figure below).



Cognitive model of stress.

Phase 1: Reality

A professional with actual resources (abilities, aptitudes, knowledge, etc.) is confronted with a situation involving the requirements (real demand).

Phase 2: Cognitive Assessment

The subject evaluates and assesses the situation according to personal characteristics (personality, beliefs, needs, motivation, previous experiences, skills, qualifications, physiological and psychological resources, etc.) and situational characteristics (requirements, constraints, available time, etc.).

Phase 3: Stress Reactions

To manage the new situation, the subject will present both physiological and psychological responses to appropriate stress (good stress) or inappropriate stress (bad stress), according to one's assessment.

Phase 4: Consequences

Based on the reactions to appropriate and inappropriate stress, the results obtained (success or failure) may or may not conform to those expected, and this could have emotional (interest, satisfaction, acquired resignation, etc.), cognitive (concentration, attention, etc.), and behavioural (adaptation strategies, perseverance, abandonment, etc.) consequences.

Phase 5: Feedback

The reactions of the subject and results obtained will, in turn, have an influence on the assessment that the subject will then have of himself (decreased or increased self-confidence) and the situation experienced (insurmountable obstacle or feasible action), as well as on stress reactions (that will remain or become appropriate or inappropriate).

6.2.5 - Stress Factors

The level of alertness or stimulation is one aspect that contributes to generating stress. The higher the number and level of stimulations, the higher the stress will potentially be.

There are several factors of stress. They mark the lives of people, both privately and professionally. They are chronic or acute. The levels of stress that they will induce vary according to the individuals, but in all cases, their effects are cumulative.
The main factors of stress with a direct link to the aviation community will only be considered in this chapter.

a) Physiological Factors

- Environmental Factors
  Among the most important, we can cite:
  - Heat;
  - Noise;
  - Vibration;
  - Low humidity rate in the cockpits;
  - Hypoxia; choice of cabin pressure affects the oxygen pressure;
  - Acutely, the crew may be exposed to environmental stress factors, such as hypoxia and the hypobaria in case of a pressurization failure or explosive decompression;
  - Takeoffs are not a specific problem in standard operating conditions; in case of deteriorated situations, they can be responsible for organic events to which one must adapt;
  - In contrast, sensory illusions are more frequent and may be at the root of major disturbances that could jeopardize safety.
- Internal Factors
  Intemal factors of a more conventional organic nature are hunger, thirst, fatigue, lack of sleep, pain, etc.

b) Professional Cognitive Stress Factors

They are the result of the interaction between the individual and the situation encountered. The main professional stress factors are: lack of knowledge, qualification or skills; complexity of situations (amount of information, uncertainty, etc.); no procedure or known solution in the face of unforeseen situations; shortage of time; work overload; lack of confidence; traps of automation; high stakes; high risk-taking; cognitive aspects of collective work; etc.

These factors are most often acute due to their link with the situations encountered in flight.

c) Professional Organizational Factors

They have a direct impact on the work of the air crew. Among the main factors, we can cite time pressure, training, working conditions and rest periods, work schedules (rotations), careerism, economic pressure (fuel, consequences of a diversion or working overtime, etc.), etc.

d) Non-Professional Stress Factors

In these causes of stress, we especially find chronic factors, such as housing conditions, transportation to move to the workplace, family life, health, economic conditions, etc.
These stress factors are also called domestic factors. Events considered to be positive (marriage, birth of a child, etc.) can also be stress generators.

e) Imagined Stress Factors

Humans have the ability to anticipate future situations, to imagine them, and therefore to define whether or not it will be possible to cope, without knowing whether they will be realized or not.
Imagined stress factors can be based on real facts or, on the contrary, be devoid of purpose. In the latter case, there is mention of anxiety. Anxiety creates a state of emotional tension in relation to a disagreeable feeling of concern, more often for no particular reason, or disproportionate to its subject.
The relationship between anxiety and stress is twofold. On the one hand, anxiety can be the trigger of stress, by creating a sort of fear without a cause, to which the individual reacts through an adaptation mechanism, stress. On the other hand, stress generates a feeling of fear as regards an unpleasant situation, which leads the individual to avoid it and, by the same token, to generate anxiety.

Organizationally, anxiety is reflected by an activation of the sympathetic nervous system, which produces signs identical to those of a stress alarm reaction, highlighting the close links between stress and anxiety.
Thus, anxiety manifests itself by tremors, muscle tension, accelerated heart rate and respiration, increased blood pressure, sweating, etc.
However, besides these physical manifestations, psychological and cognitive events are also observed, such as gloomy thoughts, negative thoughts, reduced attention (inattention), and lack of confidence.
All of these somatic, psychological and cognitive events show that anxiety has a direct impact on performance.

6.2.6 - Effects of Stress

There are several signs of stress. They are positive or negative, depending on the level of stress and situational analysis.

a) Stressful reactions

In the general adaptation syndrome, psychophysiological reactions follow on from each other in three different types of reactions.

Psychological reaction

This reflects the alerting of the brain following the assessment that there is no immediately known response to the situation encountered. It manifests itself as a feeling of fear, dread or struggle. The alarm is triggered and the brain will unconsciously begin to manage this crisis by triggering the next stage. It is an immediate reaction.

Psychosomatic reaction

This is associated with the triggering of the body's initial psychological and physiological reactions during the initial alert and solution-seeking stage. Physiological reactions are associated with the stimulation of the sympathetic nervous system and the adrenal medullary glands with the secretion of adrenaline, which is then relayed by the parasympathetic system and the adrenal cortex glands. This results in a set of characteristic somatic manifestations (see the chapter on the alarm response and the resistance stage in the GAS description).
At the same time, psychological manifestations develop which, depending on the stress level, may have positive effects (good stress) or negative effects (bad stress) on performance and solution-seeking. At this level, psychological manifestations are as important as physiological manifestations: motivation, attitudes, mood and information processing mechanisms. Psychosomatic reactions continue into the resistance stage of the GAS if no solution is found. It is a short- and medium-term reaction.

Somatic reaction

This reflects the prolonged effects of stress on the body, i.e. when the resistance stage persists or when the subject is in a state of exhaustion. The chronic stress stage is entered. The effects in this case are generally negative and mostly somatic (organs such as the digestive and cardiovascular systems, etc.).
This stage is also accompanied by psychological manifestations that cause behavioural disorders in the subject that may result in psychological pathologies.

b) Acute Stress

Acute stress is the result of initial exposure to the stressor. It is characterized by the early reactions described in the alarm stage and resistance stage of GAS. It includes psychological and psychosomatic reactions.

c) Chronic Stress

Chronic stress is the result of a prolonged exposure to stress factors and follows the acute phase. Chronic stress is characterized by the reactions described in the resistance and exhaustion stages of GAS. These events are essentially psychosomatic with appearance, in the long run, of organic pathologies (diseases).

In a chronic stress situation, the level of responsiveness is higher and promotes the triggering of other stress. It is by the increased level of responsiveness that we also explain the transfer of stress from one situation to another. There is an increase in sensitivity, to respond more easily to another stress factor.

In extreme cases, chronic stress can lead to **"burnout"**, real exhaustion, described in the professional world when an individual is subjected to intense and repeated chronic stress factors.

Situations contributing to "burnout" include those where there are:

- High intellectual and emotional demands;
- Important responsibilities, particularly those involving the lives of other persons;
- Imbalances between the tasks/objectives to be achieved and the means made available.

Some people are more at risk than others, in particular those who have performance and success ideals, or personalities that link self-esteem with their professional performance, or those who only have work as their focus and find refuge in it.

d) Cognitive Effects of Stress

Stress has positive effects on the mechanisms of information processing in the ''good stress'' area; senses are more alert, decision-making abilities are accelerated and their quality improved and memory capacities are increased.

When stress becomes negative, the main cognitive manifestations of stress are:

- Predominance of reflex action;
- Reduction of thought; assumptions and alternatives, both in situational analysis and decision-making, are reduced;
- Tunnel vision, the individual no longer sees beyond the problem;
- Regression toward the oldest acquired and/or most familiar knowledge; the most complex and most recent learning allowing place for the most structured and most available knowledge in the memory;
- Loss of the concept of passing time; it is often too late when one raises their head to look outside;
- Loss of priorities; the first hypothesis, first solution or first concern is considered good, without any real analysis of priorities with other alternatives;
- Rigidity and blocking of thought; it is the inability to re-analyse a situation once a hypothesis has been made;
- Doubting one's skills.

All these effects promote the occurrence of error and decrease the ability to detect produced errors.

e) Behavioural Effects of Stress

The behavioural manifestations of stress are many and varied. They differ from one individual to another and include both acute stress and chronic stress: nervousness, tremors, mood changes (irritability, aggressiveness or, on the contrary, passivity, mutism, submission, frustration), loss of interest, lack of motivation, bulimia, taking stimulants (coffee), recovery, increase, or even entry into addictive behaviours by taking psychoactive products (tobacco, alcohol or drugs), etc.

On the relational level, some effects are important, because they affect the collective behaviours within the crew: deterioration of communications and collective work, faltering voice (the voice may be a very good indicator of the stress level of an individual), silence or unproductive talkativeness (talking but saying nothing), tendency to do everything alone, etc.

f) Organic Manifestations of Stress

Conventionally, it describes tension and muscle pain or, conversely, weak legs; stomach disorders; sweating; heart palpitations; shortness of breath; etc.

In the longer term, there is fatigue and sleep disorders; headaches; signs of eating disorders (obesity); digestive pathologies (ulcers); cardiovascular disease (high blood pressure, angina pectoris, myocardial infarction); respiratory diseases (asthma); dermatological pathologies (eczema, allergies, psoriasis); cancers; lowered immunity and increased infections; anxiety disorders and neurosis, a depressive state; post-traumatic stress syndrome.

6.2.7 – Mental workload

An individual's workload in a work situation combines a physical dimension and a mental dimension. While some occupations are more physical than mental and vice versa, the two aspects are always combined. There is no such thing as a job without a mental workload, or the other way around.
The mental demands of flying are such that the mental workload is a fully-fledged issue for the pilot and aircrew. While there are physical workloads, they are generally well controlled. For this reason, only aspects related to mental workload will be discussed here and the concept of workload will be used instead of mental workload.
Workload reflects the level to which the individual has to mobilize their mental resources to meet the demands of the situation. The workload reflects the attentional demands made on the individual through the application of constraints.

The level of stimulation, through the activation of attentional capacities and information processing mechanisms, determines the individual's workload level. Workload can thus be defined as the amount of attentional resources required to complete the task. The more numerous and intense stimulations are, the more attentional resources are required to mobilize the information processing system, and the greater the mental workload will be.

a) Workload factors

- Factors relating to the work situation:
  - the type of task (amount of information to be processed, more or less well-defined problems, processing complexity, time constraints, risk level, etc.);
  - the circumstances under which the task is performed (required performance level, accuracy, parallelism with other tasks, etc.);
  - work organization (aircrew coordination and cooperation, organizational constraints, priorities, work pace, etc.);
  - the work station layout (accessibility to control systems and controls, assistance systems) and the cockpit environmental conditions (lighting, sound level, thermal environment, vibrations, etc.).

- Factors related to the individual: rating level, knowledge and competence; experience; fatigue level; stress level; personality traits and attitudes; motivation, interest and job satisfaction; age, healthiness and physical condition.

b) Work underload

Work underload denotes a low workload. It is characterised by a low level of stimulation due to monotonous, boring or limited tasks, making it difficult to maintain a continuous, sustained level of activity. The feeling of work underload is materialised as boredom. It is hard to focus on the task. The ability to detect relevant information is decreased. Memory is impaired. Understanding and decision making are slowed down and are less abundant. The possibility of making errors is greater and the ability to detect errors is less effective.

There is less communication at the level of collective work. It becomes an effort to create spaces for communication between crew members to share situational awareness and establish joint action plans. With so little to do, everyone tends to isolate themselves or occupy themselves with non-work activities.
Pilots are on passive standby and may experience episodes of drowsiness or even light sleep.

Work underload is characterised by a state of hypostress responsible for a low level of performance. To remain efficient, it is important to raise the level of stimulation by adding tasks. This maintains interest and motivation for ongoing activities.

c) Work overload

Work overload, on the other hand, denotes a flight situation in which the crew members are so busy that they cannot cope with the demands of the situation. The manifestations of overwork are equivalent to those of stress.

6.3 - Management of Fatigue and Stress

6.3.1 - Fatigue Management

a) Mental Fatigue and Physical Fatigue

When the stresses due to individual activities become higher than its capacity for physical and psychological recovery, the body reacts by feeling tired. This sensation is a subjective phenomenon, which is normal and common in any activity.

Fatigue is accentuated, or its appearance facilitated, by physiological (diseases, treatments,) or psychological (family problems, etc.) attacks.

Fatigue is actually an alarm signal of the body reflecting a decrease in the functional capacity of the organs due to overwork or working too long. This is a general defense phenomenon. Fatigue can be observed in different parts of the body, which is why there are typically two main types of fatigue that are combined: physical fatigue and mental fatigue.

According to the mode of recovery from fatigue, we distinguish between:

- acute fatigue, which lasts a day or so; it is recovered from during one or two consecutive nights of sleep. The causes of acute fatigue in aviation are, for example, long flight duty time, night flying, etc.;

- chronic fatigue, which lasts longer (a week, a month or sometimes even several months); it is recovered from more slowly and requires several days' rest. The causes of chronic fatigue in aviation are, for example, a sequence of morning flights over several days or schedules with no time off work for long periods, etc.

b) Effects of Fatigue

Two types of manifestations are generated by fatigue.

- Manifestations due to sleepiness. The recovery process associated with drowsiness is then triggered by sleep. Drowsiness, hypovigilance, or even sleepiness, which may be accompanied by stinging eyes, heavy eyelids, yawns, etc., are the main signs.
- Manifestations of mental and physical fatigue associated with service amplitude and workload. The recovery process then translates into stopping activity. The most common manifestations are:
  - Heaviness of members, neck stiffness, back pain, discomfort and desire to change position;
  - An elevation in sensitivity thresholds for sense organs, perception time being elongated;
  - Greater sensitivity to sensory illusions;
  - Reduced attention and greater sensitivity to distractions;
  - Motor skills slowdown, slower reaction time, less specific gestures;
  - Difficulty with memory (working memory), paradoxically with an excessive confidence in one's memorization abilities;
  - Generating fewer assumptions for understanding and decision-making;
  - Tendency to take more risks;
  - An increase in errors and a decreased ability to detect them;
  - Mood changes, irritability, nervousness;
  - Tendency to isolate oneself, withdrawal;
  - Doubts about one's skills or, conversely, over-confidence;
  - Decreased cooperation (complacency, over-confidence in another crew member, fewer cross-checks, etc.);
  - Communication changes (silence, increased non-professional communications at the expense of professional language, etc.);
  - Less motivation;
  - Greater sensitivity to stressors;
  - Hunger or, conversely, decreased food intake;
  - Taking stimulants (coffee, tea, etc.).

In the long term, a prolonged state of fatigue can lead to sleeping disorders, organic or psychological pathologies and mood disturbances.

c) Management of Fatigue and Hypovigilance

Principles of Fatigue Management

The principles of fatigue management are:

- Fatigue is a "taboo" subject in certain professional circles, but one must be able to speak about fatigue;
- Resistance to fatigue is not a criterion of professionalism, but it is behaviour involving safety;
- Fatigue is a subjective feeling; any person saying they are tired should be regarded as tired;
- Chronic fatigue or fatigue not explained by professional activities must be examined for an underlying pathology of an organic or psychological nature;
- Sleep is essential to life; we cannot live without sleep;
- Good sleep means quality sleep (which means respecting sleep cycles, ranging from light sleep to REM sleep) and quantity;
- One does not accumulate sleep in advance.
- Preventive Measures for Management of Fatigue

The first measures in fatigue management are preventative.

Organizational Measures

They begin on the organizational level with the definition of work schedules and rotations, as well as with the number and sequence of steps. Governed by national and/or international regulatory provisions, the working times and rest periods for the aircrew should endeavour to accommodate service times and sleep debts, which can accumulate one day after another.

Individual Measures

Individually, prevention involves doing everything possible to avoid having a sleep debt before beginning any service. Similarly, a good physical condition contributes to a higher level of vigilance. Being overweight promotes drowsiness.
One must also be cautious when taking products that can alter the level of vigilance. This is the case with many prescription drugs. In case of doubt, the advice of an aeronautical physician is required.

Management of Fatigue During Rotations

Logistical Aspects

During shift rotations, management of fatigue is the responsibility of the crew. However, the company contributes to fatigue management by its logistics: provision of balanced meals, accommodations during layovers permitting quality sleep (sound and light isolation, quality bedding, temperature and humidity, etc.), transfers between the operational areas and rest areas, conditions for establishing crews on the bases of attachment.

Preventing Decreased Vigilance

Within the crew, it is first necessary to avoid factors that contribute to decreased vigilance:

- Avoid meals that are too rich in carbohydrates and fats, eat a balanced diet, drink enough (1.5 liters of water per day is a minimum due to the low moisture rate in the cockpits);
- Within the crew, do not eat at the same time, to avoid having decreased vigilance postprandial (after the meal) at the same time;

- Be wary of routine and monotonous tasks, as they occur in flight segments where there is little stimulation (calm cruise stage); to avoid hypovigilance, it is recommended to desynchronize activities to alternate between crew members and over periods of 20 to 40 minutes, tasks of active vigilance (verbal exchanges, flight management, etc.) and passive vigilance (flight monitoring and supervision, cross-checks, etc.).

Sleep Recovery

A second priority for managing fatigue within the crew is to sleep when the operational setting permits it. The periods of sleep are short periods, planned according to the fatigue state of each crew member, one's status on board and operational requirements. Two types of sleep are possible.
A "nap" is a short sleep, 10 to 40 minutes maximum. It is important that it is not too long to avoid entering into a phase of deep sleep, which would have the effect to increase the period of consecutive sleep inertia. A twenty-minute nap enables one to gain two to three hours of additional alertness.
On long-haul flights, with an augmented flight crew, sleeping in the cabin (sleeper berth or passenger seat) is permitted. These rest periods should ideally last the time of a sleep cycle, or around 90 minutes, to avoid waking up in phases of deep sleep and reduce the period of consecutive sleep inertia.

Whether it is for a "nap" or resting in the cabin, it is always necessary to integrate time into the period of operational unavailability for falling asleep, actual sleep time and consecutive sleep inertia.

Adapting Activity in the Cockpit

A third priority for managing fatigue is to adapt activity in the cockpit depending on the level of fatigue in order not to exceed the available resources.
Once the crew or a crew member becomes aware of a state of fatigue, it is possible to implement mechanisms of adaption for collectively managing it: distribute activity differently (e.g. swapping the PF and PNF functions); increasing cross-checks; using automation; working even more under the SOPs and checklists; making spontaneous briefings in case of misunderstandings or doubts; working at the lowest risk level; not seeking solutions requiring high levels of performance; avoiding solutions that can result in deteriorated situations requiring high levels of performance.

Taking Stimulants

The last priority for managing fatigue is taking stimulants (coffee or tea). It must be moderate to avoid the side effects (diuresis, heart palpitations, tremors, etc.) of the active ingredient, caffeine.
It is recommended to take no more than three to four cups of coffee per day. Actually, it depends on the rate of caffeine in the coffee, which is difficult to know since there is a large variation between an "espresso" and a North American coffee.

d) Time Zone Differences

Time zone change syndrome (jet lag) results from a sudden desynchronization between our biological rhythm and social synchronizers of the country of arrival during a rapid movement through several time zones. During this period, the body is fragile and our performance can be mediocre.
(See: G - circadian rhythms, vigilance and sleep)

In the context of jet lag, it is recommended during short rotations (layovers at the destination of less than 48 hours) to remain in the circadian rhythm of the country of origin (this requires suitable hotel structures, particularly for meal time).
If one needs to change the rhythm, the signs observed are the result of the gap between the day-night rhythm of the country of arrival and the internal biological clock of the individual. The signs persist as long as the synchronization for the rhythm of the country of arrival is incomplete. The major signs of jet lag are fatigue, sleep disorders, hypovigilance, reduced performance, and mood changes.
As a general rule, jet lag is easier to cope with when travelling West than it is travelling East. On average, it takes about a day to a day and a half to recover from a time zone. The resynchronisation period is relatively consistent from one subject to another.

6.3.2 – Fatigue Risk Management System (FRMS)

A Fatigue Risk Management System (FRMS) is a variation of the Safety Management System (SMS) aiming to manage the risk of aircrew fatigue. All air operators are thus required to have a documented flight crew management system, either through the conventional SMS or through the coordination of a specific FRMS if the operator uses derogations for duty and rest periods.
The need for specific fatigue monitoring is associated with the multidimensional aspect of the causes of fatigue, which makes it very difficult to control the level of flight crew fatigue by regulation alone. Air operators are then asked to determine the fatigue levels and causes of fatigue of their operating personnel, assess the risks, and whether they are too high to make them acceptable.
For this purpose, an air operator's FCMS, like the SMS, is structured around the four pillars of fatigue risk management policy and documentation for flight safety, fatigue risk management, and ensuring, maintaining and promoting safety related to fatigue risks.
Fatigue risk management and continued safety assurance are based on an understanding of the fatigue levels and fatigue factors associated with operations. For this reason, these assessments require the tracking of information obtained directly from flight crews so as to be able to continuously monitor and manage the safety risks associated with fatigue.
In this approach, the use of the scientific knowledge and principles of fatigue management is essential. As such, airlines are required to use fatigue management models and tools approved by the scientific community:

- For example, it is recommended, in predictive fatigue management, to use biomathematical models to predict fatigue levels, performance levels, risks of error or air events in the design of crew schedules. These models can also be used retrospectively to analyze the potential impact of fatigue level in the event of an aviation incident.
- Another example is the proactive use of questionnaires or scales for subjective assessment of fatigue during operations. The data collected is intended to identify and quantify the risks associated with fatigue and their potential impact on safety to allow the required mitigating steps to be taken. Analogue fatigue scales, the Samn-Perelli fatigue scale or the Karolinska Sleepiness Scale (KSS) are thus widely used scientific tools.

The effectiveness of an FRMS depends on the trust and transparency between flight crews and those responsible for flight operations that must exist in order to objectively identify, quantify, mitigate and continuously monitor the risks associated with crew fatigue.

6.3.3 - Stress Management and Coping Strategies

By stress management, we mean managing very intense stress, which could lead to bad stress, to return to the area of good stress while one is in the hyperstress area, or to avoid going into the hyperstress area while the "breakpoint" symptoms are present.

Stress management strategies are typically referred to by the English word, "coping". Coping corresponds to all thoughts and actions developed by the individual to resolve the problems that one is confronted with, and thus reduce the stress they generate.
Coping strategies can be either conscious or unconscious. The defense mechanisms described by Freud, such as denial, repression or intellectualization, are unconscious mechanisms. Conscious mechanisms are subject to the laws of learning.

Conscious mechanisms may be split into individual mechanisms, collective mechanisms and organizational mechanisms.

a) Individual Mechanisms

- Situational Strategies
  Situational strategies involve changing the situation when possible, reorganizing it, even avoiding it, or still further changing the point of view one has of it (i.e. seeing things from a different angle, defusing). They aim to act directly on the source of stress. Changing the situation can be done on several levels.
  The Situation Itself. In terms of piloting, for example, it involves not engaging in a flight phase without having all the information related to weather changes.
  Skills or Knowledge. By enriching the knowledge and record of individual responses, one assesses the situation differently as well as one's ability to cope with it.
  Managing Priorities. This involves managing priorities differently to put them in line with the skills of the crew, and thus remain within the acceptable stress level margins.

- Individual-Oriented Strategies and Reactions to Stress
  When the situation cannot be changed, one must be accustomed to it. Strategies based on reactions to stress are then useful to avoid having significant physiological, cognitive and behavioural manifestations that are only detrimental to performance.
  The strategies centred on the subject focus on:
  - Cognitive self-assessment, assessment of one's emotions and the control that one has over them. The goal is to change the cognitive assessment of the demand and resources to transform negative responses into positive responses. These methods are based on controlled breathing, mental imagery, relaxation techniques, sophrology, to mention only a few.
  - Other strategies involve acting on the physiological responses to stress. Primarily, it will be to modulate the physiological responses to stress (e.g. muscle relaxation to relieve muscle tensions, autogenic training exercises to regulate cardio-respiratory reactions, cardiac consistency) so that the subject develops in the area of positive stress.
  - Finally, it is possible to change behavioural reactions. This involves changing inappropriate behaviours by teaching the subject new skills to help find suitable

strategies. We can cite as an example: slowing down in case of hyperactivity, thinking before acting, by simply returning to the basics, first "fly the plane", etc.

- Lifestyle-Oriented Strategies
  On top form, the individual is better able to cope with environmental demands. For the most part, the strategies are based on maintaining one's physical condition, managing sleep and rest depending on the professional requirements, and keeping a balanced and varied diet, despite the operating limitations.

b) Collective Management Mechanisms

They depend upon the cooperation and synergistic operation of the crew. Mutual support and allocation of tasks on the basis of the skills and abilities of each crew member in relation to the requirements of the situation are the foundations of collective management of stress factors related to flight.

c) Organizational Stress Management Mechanisms

Organizational management of stress is based on the generation or not of stress factors that will apply to crews (work schedules, sequence of rotations, working conditions, economic, employment or career pressures, etc.).

d) Flight Stress Management

Stress management strategies are many and varied. From an operational point of view, their implementation can be structured around three phases: pre-flight, inflight and post-flight.
In each of these phases, we describe long-term and short-term strategies.

- Pre-Flight
  The strategies to be implemented are primarily long-term strategies.
  They involve:
  - The skill level and qualification of the crew, the necessary training to have the expertise required for the successful operation of flights;
  - The reduction of chronic professional stress factors by the company, the airline or employment agency (schedules, working conditions, company safety policy, etc.);
  - The reduction of individual and private chronic stress factors;
  - The training of individual techniques for managing psychological, physiological and behavioural responses to stress, which will be used inflight;
  - Lifestyle (privacy and during layovers).

- Inflight
  At this level, the strategies are short-term strategies.
  They involve:
  - Flight preparation, on the one hand, aims to define the rules of cooperative crew work and, on the other hand, the action plans with their alternatives;
  - In flight, apply SOPs, briefings and checklists; remain professional;

- Anticipation, reduction and avoidance of stress factors linked to the particularities of flight; remove doubts;
- Managing priorities for the benefit of safety, with simple behaviours aimed at returning to the basics and related to safety;
- Self-monitoring of one's stress level and monitoring those of other crew members;
- Collective management of the stress level of the crew through cooperation;
- Lifestyle on board (power supply on board, limiting stimulants, rest time on long-haul flights, etc.);
- Use of individual techniques for managing responses to stress, to the extent that autonomy has been acquired through appropriate training.

- Post-Flight

  There are both short-term and long-term strategies.

  In the short term, flight debriefing is an important step in sharing flight experience and comparing viewpoints, particularly if a deteriorated situation or an emergency occurred. Debriefing is also an opportunity to learn lessons from the flight, in order to enrich one's store of knowledge and reactions in the face of stress.

  In the long term: enrichment of one's knowledge and skills from the flight experience; sharing of experience with the aircrew population, via feedback; feedback and impact on training, procedures, crew work and safety culture of the company; lessons to adjust one's techniques for managing responses to stress and one's own lifestyle; help in managing stress through appropriate psychological support, in case of feelings of marginalization and guilt.

07 ADVANCED AUTOMATION IN COCKPITS

Automation is the result of a twofold approach:

- Facilitates the work of crews to increase their performance;
- Improves safety by remedying human failures.

7.1 - Advantages and Disadvantages

The automation of cockpits includes various concepts:

- Glass cockpit: this refers to a cockpit in which the information display and control interfaces are mainly supported by screens (accounting for the term "glass cockpit").
- Programmable logic controller: refers to a device that behaves independently, without the need for action by a human operator. At best, pilots can connect or disconnect it. There are a number of PLCs in the aircraft which are used to control many functions, such as pressurization, temperature or engines. A particular type of PLC should be known: protective programmable logic controllers. They are intended to prevent the aircraft from ending up in a condition that is undesirable from a safety standpoint.
- Automation or automated system: refers to a device that carries out, at the pilot's request, a piloting function in the place of the pilot. The automated system is activated or deactivated by the flight crew. The autopilot, the Flight Management System (FMS) or auto joysticks are automated systems.

In the most recent aircraft, there are an increasing number of displays, PLCs and automated systems. For example, the integration of the autopilot, flight directors and automatic engine power management system provides the crew with a set of modes of varying levels of refinement (from all manual to all automatic) to manage the aircraft's flight as efficiently as possible in all flight situations. In the event of depressurization, automatic emergency descent modes are available, and in the event of pilot incapacitation, automatic landing systems are now available.
Current levels of automation represent a real change in the way an aircraft is managed compared to aircraft with dial type instrument panels, even though the aerodynamic laws of flight are still the same. Whatever the case and regardless the aircraft's automation, the flight crew remains ultimately responsible for their aircraft in assessing the use of onboard systems and their reliability.

7.1.1 – Automation philosophy

An aircraft's automation philosophy determines man/machine relations, i.e. the flight crew's role with regard to automated systems and the way in which they and onboard systems are complementary in performing a flight.

There is a different philosophy between the two major world manufacturers, Airbus and Boeing, in the automation of their aircraft.

The Airbus philosophy is primarily based on the autopilot as it is considered that a flight with a high level of automation is safer since it reduces human error. This is based on following characteristics:

- Automation must not reduce the overall reliability of aircraft but rather improve the safety of aircraft and systems, and the efficiency and cost-effectiveness of flight operations;
- Automation must not take the aircraft outside its safe flight envelope and maintain it within its normal flight envelope;
- Automation must allow the air operator to use the safe flight envelope throughout its range, due to extraordinary circumstances if necessary;
- In the normal flight envelope, automation must not operate against crew actions except when absolutely necessary for safety.

For Boeing, the crew must be able to override the autopilot controls if the need arises. This is based on following characteristics:

- The pilot always has final authority in the use of the aircraft;
- Two crew members are ultimately responsible for flight safety;
- The flight crew's tasks are, in priority order, safety, passenger comfort and efficiency;
- Systems are error-tolerant;
- The hierarchy in design alternatives is simplicity, redundancy and automation;
- Automation is a tool to help the flight crew and not replace it;
- Human/machine relations consider human strengths and limitations, as well as individual differences, for both normal and non-normal operations;
- Use new technologies and functional capabilities only if:
    - They provide clear, significant, operational and efficiency benefits;
    - They have no negative effect on man/machine relations.

In short, the main difference in the automation philosophies of Airbus and Boeing is in the area of flight envelope protection: it involves the positioning of the authority of the pilot or the automated system and, by extension, the limits (or expectations) imposed on flight crews:

- Airbus defines "hard" limits where the aircraft must not move outside the flight envelope regardless of the control actions of the flight crew;
- Boeing defines "soft" limits where the crew has to encounter increasing resistance to pilot control inputs that would take the aircraft beyond the normal flight envelope, but ultimately the crew can do so if they wish. Boeing leaves ultimate control of the aircraft in the pilot's hands.

In all cases, it is recognized that the flight crew is and remains ultimately responsible for the safety of the aircraft they operate.

Moving from one manufacturer's aircraft type to another manufacturer's aircraft type calls for the learning of the new philosophy, and therefore a different way of managing the aircraft. For this reason, it is advantageous for an airline, in terms of training and the use of its aircraft, to have aircraft with the same philosophy. This is known as the principle of "commonality" between aircraft from the same manufacturer.

7.1.2 - Ironies of Automation

The ironies of automation are a set of observations made by the ''Human Factors Community'', as a result of the mass introduction of automation into complex dynamic working conditions, such as aeronautics. The word irony has been used to mean that the consequences observed were contrary to their initial expectations, leading to real paradoxes. These ironies are as follows:

- Errors in the design of automated systems that penalise the activity of flight crews and do not achieve the expected levels of reliability as the actual workload of the pilot in airlines is not considered. The designers initially automated according to a perspective essentially engineer based rather than operator based: what we know how to automate is automated and what we don't know how to automate is left to the operator without considering the role of automated systems in the overall tasks and constraints of operators, or we determine the functions in which machines are most efficient and the functions in which flight crews are most efficient. Data and models that are not suited to the reality of operational piloting work cause design errors.
- Automation knows how to do what the pilot can do, but does not know how to do what the pilot does not know how to do well. Monitoring and managing automated systems is more delicate when the pilot has difficulty grasping the complexity of the situation.
- Automation reduces the workload during phases of flight where the workload is low or moderate. In contrast, workload is even higher in the flight phases where the workload is high, because automation must also be managed.
- Pilots lose their skills in the areas and functions handled by automation systems. This problem is now particularly significant in terms of the case of the cognitive skills of situational awareness and decision-making needed for manual piloting. As a result of a number of accidents, recommendations are made to airlines to encourage manual piloting as soon as possible in order to maintain the sensory-motor skills involved in manual piloting. Similarly, regular specific training has become mandatory to manage exiting from unusual flight situations in manual piloting mode.

- Finally, the pilot is even more necessary when automations are failing. The pilot must be able to resume the functions performed by the automated systems "on the fly". That is why one must stay in the loop and have a high level of awareness in regards to automation functioning. It is now impossible for pilots to know everything about the automated systems available to them. Pilots must be aware of their knowledge of automated systems and therefore also of their own limits in their use. For this reason, it is important for any flight crew to always remain within a known range of automated systems use.

7.1.3 - Autopilot and autoflight system

The autopilot (AP) and the autoflight system have now become essential piloting aids. The autopilot is a system that controls the flight control surfaces to perform a task assigned to it by the crew (maintain an altitude, maintain a rate of climb, maintain a heading, maintain a rate of turn, etc.). The autoflight system integrates the autopilot with the flight director (FD) and the auto-throttle (auto-thrust for Airbus and auto-throttle for Boeing) if the aircraft is provided with one (the auto-throttle is an aircraft automatic thrust control system).
In the autopilot flight system, the flight director is the autopilot's brain, since it computes the aircraft's attitude control signals that the autopilot will apply to reach a heading, a flight level or a navigation point, all considering the wind, for example. The pilot can use the flight director without the autopilot. In this case, the flight crew manually pilots the flight director's settings.
The use of these systems considerably reduces the flight crew's work load in flight path management, and even thrust management if the aircraft is provided with such systems. However, this essential aid should not obscure the fact that their use may also have an impact and change the behaviour of flight crews.

- If they are well designed, systems do very well what they are designed to do. To this effect, they are more precise than human operators as they are able to include a large amount of information due to computing capacities that human beings do not have. They are also more reliable to the extent that their level of performance cannot be impaired by fatigue, stress, monotony, moods, etc. whereas the flight crew's can. In conclusion, systems perform and monitor what they are asked to do well.
- From a tactical or strategic standpoint, however, systems do not know how to adapt to a situation, take a contingency into account or manage an unknown situation. This capability for adaptation, innovation and creativity, if necessary, is the hallmark of human intelligence. A flight crew will analyze a state present in an environment that is always unique, from a short-term tactical perspective and a longer-term strategic perspective. For this reason, in terms of decision-making and priorities in tasks or aims, analysis of situations not considered in the operation of systems, and human operators have a capability that automated systems do not have. Flight crews thus have an overall safety attitude that does not exist in automated systems. E.g. US Airways flight 1549 of 15 January 2009
- Weaknesses in human/machine relations occur if flight crews do not have sufficient knowledge of the operation, logic and limitations of systems. Systems now have such high levels of integration that it is very difficult to know everything. The range that corresponds to the most frequent situations is well known. The danger is that the flight crew will not understand what the automated system does and being aware of the limits of their own knowledge, the crew will think that they are the ones who do not know and that the system is doing the right thing, and therefore they will let the system do it without really understanding what it does.

- Another weakness is a sense of withdrawal from flying activities, as the crew becomes more of a client and a systems supervisor/manager than a true task performer. The role of the flight crew has changed with automated systems to that of a systems manager. This situation may lead to a loss of pilot motivation in flight management and monitoring, and thus in safety, since the machine does things well and provides high performance. This de-motivation will most likely appear during flight stages where crews are not stimulated much (low workload, routine, monotony, fatigue, etc.).

7.1.4 - Avoiding the disadvantages of autoflight systems

Whether the ironies of automation or changes in behaviour are involved, flight crews need to be aware of these issues and guard against them. For this purpose, it is recommended to:

- Maintain the highest possible level of practice in order to maintain manual piloting skills;
- When you are not the pilot flying, stay mentally involved in the flight path management as if you were flying the aircraft;
- Use flight simulators systematically to train pilots in the detection of and recovery from unusual situations;
- To avoid making mistakes (slips), comply with the distribution of tasks between crew members when programming the systems;
- To avoid slips, comply with crew task-sharing procedures to avoid simultaneously focusing on systems or outside the aircraft;
- To avoid slips in system programming, any programming or reprogramming must be checked by the other crew member (cross-checking). If it is known that monitoring checks cannot be performed, a system is not reprogrammed;
- Do not reprogram a system in flight stages with a high workload;
- In a high workload stage, you can try to understand the automated system once or twice, but no more. Beyond that, return to a known basic mode;
- In the event of misunderstanding, return to manual piloting mode;
- If there is any doubt as to the operation of the automated system in all matters relating to the aircraft's flight path or speed, do not attempt to reprogram the automated systems and return to a known basic mode of operation;
- Use the right level of automation based on the flight stage and the requirements of the situation;
- Do not use automated systems if the complexity of their use becomes a restriction given the requirements of the situation;
- Maintain a sufficient level of stimulation to ensure an effective level of alertness during cruising stages to avoid hypo-vigilance generated by monotony or work underload.
- During cruising stages, follow the procedures for programming and monitoring automated systems and mobilise all your attentive resources to carry them out efficiently.

7.2 - Excessive Confidence in Automation

Overconfidence or complacency is a factor often referred to in automated cockpits to explain the flight crew's failure to program systems or to detect their malfunctions.

Complacency qualifies the elaboration by the pilot of a high sense of safety vis-a-vis the highly reliable automated system, but that may be defective without it being reported to the crew by an alarm.
The difficulty to assess the confidence that can be given to an automated system results from the fact that the systems are powerful and have a great deal of autonomy. They can appear as highly skilled and intelligent "partners".

Factors that promote complacency are: autonomy of automation; low failure rate; positive experience in using automation, high levels of workload, fatigue or stress; distractions and interruptions; incomplete knowledge of automation, which led to doubting one's skills and to regard automation as more reliable than oneself.

In modern cockpits, the needs for direct control have decreased, or even disappeared. The crew is more in a role of passive monitoring than in active monitoring. Hypo-vigilance during flight and the loss of skills associated with the use of automated systems are two factors that decrease the effectiveness of their monitoring by flight crews. Monitoring the proper functioning of automation is just as important as monitoring flight activity.
Excessive confidence in automation may lead to:

- A lack of monitoring activity, which is responsible for boredom, drowsiness, lack of attention, and hypovigilance. We speak of passive monitoring to qualify a superficial supervision.
- A lack of control or a delayed control of the results for programmed actions that are not permitted, on the one hand, to detect automation failures or malfunctions and, on the other hand, to detect programming errors for automations or decision-making errors.
- Decision-making with a limited number of settings, because all of the settings are not stored due to passive monitoring. We speak of focusing attention or "blinkered concentration" to describe the act of focusing only on a limited amount of information.
- A decline in anticipation on the operation of the flight, with a tendency to be behind automation.
- A loss of active mode awareness for automation, during automatic transitions through lack of monitoring.
- A tendency to delay diagnosis of the occurrence of an undesired situation.
- One difficulty is attributing the cause of occurrence to automation for the undesired state, preferring to consider it as a misunderstanding by the pilot.
- In case of an emergency or uncontrolled situation, enable the automation and rely on it, even if one does not understand precisely what one is doing.
- A decrease in regulatory communications, with an increase in the implicit between crew members.
- Confusion over the information submitted or on the modes selected.

To combat against complacency and its negative effects, the actions to be undertaken are:

- Maintaining the "crew action-aircraft reaction" control loop systematically and regardless of the flight segments; not compromising on monitoring the achievement of any expected result after a crew action;
- keep both flight crew members in the control loop, announcing (call-outs) any action on automated systems and the checking of the expected results;
- Distributing tasks among the crew members to manage automation, control expected results and cross-check according to the duties on board, flight phases and respective workloads;
- Maintaining active monitoring on the operation of the flight and functioning of automation to stay in the "piloting loop"; this facilitates the controls, situational awareness and manual recovery in case of a misunderstanding or undesired occurrence. The role of regular call-outs of the status of the aircraft and system between crew members in accordance with work procedures is essential;
- Managing distractions and interruptions, so that they are not detrimental to the control activities.

7.3 - Principles of Work

The use of the automated systems is guided by an expectation of results which follows the following stages:

- What do I want the aircraft to do now?
- What do I want the aircraft to do next?
- What mode should be chosen, and what settings should be selected for the aircraft to fly now?
- What mode should be chosen, and what settings should be selected so that the aircraft behaves as I want it to next?
- Does the aircraft behave as I imagined it would?
- Is the planned aim achieved as planned?

7.3.1 - Cooperative Work and Communication

The introduction of automation into the cockpit has changed the relationships of coordination and cooperation between crew members. As a result of a concentration of information, the taking of information and the orders provided on much more limited spaces than in older-generation cockpits.
Visual scanning is carried out on screens and no longer on a set of dials scattered over the instrument panel, and on documents (paper and/or electronic). Likewise, slight movements of the hand allow the aircraft to be flown, at the level of flight controls, for example, using the mini side joystick fitted to some aircraft.

This results in a decrease in gestural communications and a potential to withdrawal, in as much as each crew member has equivalent interfaces allowing access to the same functions. Informational and relational communications are diminished.
The actions of another crew member are less visible, as well as what one does with the automation. Knowledge of one's activity is reduced, which can impact any assessments that may be made concerning the tasks realized, level of activity and workload. The ability to do informal cross-checks is also reduced, negatively affecting the detection of errors of another.

Verbal communication between crew members naturally tends to diminish, because one can have access to any information and can do everything alone. The need for others appears to be reduced.

The qualitative and quantitative reduction in verbal and non-verbal communications generated by automation is a source of a degradation in flight crew work to:

- detect input errors when programming and using automated systems;
- provide a proper awareness of the flight modes involved in the automated systems;
- detect failures as early as possible;
- understand failures and how to manage them;
- Share a proper awareness of the condition of the aircraft and its position.

In the face of these drawbacks, it is essential for the flight crew to implement effective, systematic and rigorous communication. For this reason, the automation of cockpits has called for a reinforcing of coordination, cooperation and communication actions. This is achieved through appropriate procedures, briefings and checklists, as well as systematic reinforcement of call-outs between crew members for any changes observed, any action taken and any detection of unforeseen events. These working methods, which are now a daily matter in the cockpits, are essential tools to provide the flight crew with have a shared awareness of the situation and automation modes, and beyond that to allow them to decide, define and implement the appropriate action projects.

7.3.2 - Automation level management

While pilots in early aircraft were given the straightforward choice of activating or deactivating the autopilot in basic modes (varying or maintaining aircraft attitudes), pilots in modern aircraft are provided with a number of combinations of automation levels. A continuum of automation levels can be described, in a caricatured way, from the simplest level, namely manual piloting (no autopilot, no flight director, no autothrottle, etc.), to the highest level where the autopilot is connected with the flight management modes of the FMS (LNAV horizontal navigation to follow a flight plan, radial, etc., or VNAV vertical navigation to follow a descent or climb profile). Between these two extremes, there are many possible combinations. Deciding which combinations to use can generate a workload, and configuring them can give rise to an even higher workload. Finally, once the mode has been programmed, the meaning of each mode and how the aircraft will behave have to be remembered. All these points are real challenges for pilots in the programming and monitoring of automated systems.

The choice of the level of automation is not without importance, as it will impose on the crew programming, engagement and monitoring actions that may or may not be compatible with the activity required for the flight stage. for this reason, the automation level must depend on:

- the task to be carried out: for this purpose, a distinction must be made between short-term and long-term tasks;
- the flight stage: each flight segment (departure, climb, cruise, approach, etc.) has its constraints in terms of workload, time pressure and risk factors;
- the time available for the occurrence or non-occurrence of unplanned events;
- the crew's knowledge and experience in the use of the various modes for different flight conditions.

To avoid too many difficulties for flight crews and to ensure safety, airlines define how to use automated systems (for example, some airlines do not allow the use of manual thrust, while others allow it, but only when the autopilot is disengaged).
In practice, pilots develop their own ways of doing things to suit their preferences, while remaining within the framework of the airline's policy on the use of automated systems. As a result, while there may, in theory, be hundreds of different ways of using automated systems, flight crews generally choose from a limited number of ways.

Whether it is the choice of flight crews or following airline recommendations, the use of the highest levels of automation is often used to reduce workload and promote safety. However, this may be a handicap if the crew is not aware of all the active functionalities of the high levels of automation, if the crew has to change system settings in dynamic, changing and high workload flight stages, or if there is a lack of understanding of aircraft behaviour. In all these situations, the flight crew may become unaware of the modes (which modes are active and what they are doing) and no longer understand what is happening.
For this reason, flight crews are asked to ensure that the management of any situation not understood or following the occurrence of a disruptive event should always begin by reading the autopilot engaged modes display panel (Flight Mode Annunciator - FMA - located at the top of the Primary Flight display - PFD) to determine which modes are actually active.
If the flight crew does not understand the aircraft's behaviour, they are asked to return to simpler automation modes to facilitate the understanding of what is happening. If it is still impossible to understand the aircraft's behaviour, returning to a manual piloting mode is the only way of really determining the state of automated systems (no mode is active) and returning to the basic principles of flight path management. It is a kind of a "reset".

One way of schematically illustrating this flight crew behaviour is to consider that there are 3 levels of automation:

- the highest and most complex level in terms of the interdependence of functions is that of flight management with the VNAV and LNAV modes. This is a level that could be described as strategic;
- intermediate tactical level based on basic autopilot modes such as reaching or maintaining a heading or altitude (HDG mode for Heading and ALT mode for Altitude);
- basic level of manual piloting where all automated systems are disconnected.

In the event of a misunderstanding in the aircraft's behaviour, the flight crew must not continue to fly in an automation level that they do not understand. They need to know how to return to a simpler level. For example, if the autopilot is connected to the flight management system, disengage the VNAV/LNAV modes to return to HDG/ALT modes and, if the flight crew still does not understand what is going on, disengage the HDG/ALT modes to return to a manual flight mode.

7.3.3 - Manual control versus autoflight system

Ensuring flight safety is based on adjusting the piloting mode (manual or with automated systems) to suit the aeronautical situations encountered.

Manual piloting is recommended for flight path management in situations that are difficult to anticipate due to potentially rapid changes in the situation or the high probability of occurrence of unknown restrictions or events. Too frequent flight path changes would be difficult to manage with automated systems to the extent that they are not anticipated or if there are too many uncertainties about future possibilities. During normal operations, there are thus only two short flight stages that involve the use of the lowest automation level (manual flight - with or without the flight director). These are take-off/initial climb and approach/final landing (when there is no automatic landing system). Some pilots like to perform certain phases manually, such as the climb or approach, when authorized by the airline's automation policy. These practices help to provide regular practice in manual piloting.
It is also recommended to use manual piloting in abnormal flight situations to stabilize the flight path from a safety standpoint if the flight path is a source of misunderstanding or changes in an unexpected way. Once the flight path is controlled, the pilot can use the systems again by gradually increasing the automation level if needed to free up the maximum amount of resources required to understand and take a decision at a tactical and strategic level. If, in an abnormal situation, the flight crew is proficient in automation level for flight path control, there is no justification for returning to a manual level. While this may be reassuring for the pilot, it also represents an additional workload factor given the other objectives to be addressed.

During frequent changes in flight profile, the high levels of the autoflight system may not be able to respond quickly enough to control inputs. The use of manual or basic autoflight system modes may be much more appropriate, especially if vertical control inputs are combined with lateral control inputs on approaches or during climbs. In cruising flight, changes to a flight profile are normally made through the autoflight system.

The use of the autoflight system is recommended for the more predictable stages in such changes. It is recommended by most airlines on from the climb stage to final approach. It is a considerable help for flight crews in terms of safety and precision in flight path control. Above all, it allows flight crews to devote themselves to other tasks, while continually monitoring the proper operation of the autoflight system and the smooth following of the flight path. Most flight crews wait until the aircraft is in a high automation level to undertake planning and other non-aircraft tasks such as eating or making commercial announcements to passengers. In very short-haul flights (and towards the end of long-haul flights), cruising may become an extremely busy process and automation relieves the workload of flight crews to allow them to concentrate on planning and preparation tasks. Likewise, the descent (which may start at the top of the climb in a short-haul flight) is usually prepared with a high level of automation.

Regardless of the flight stage and whatever the operational conditions, it is the crew's responsibility to define the safest possible flight level. If the flight crew does not understand the aircraft's behaviour or if they feel they are not proficient in automated systems, the rule, in all cases, is to return to a simpler automation level, which may go as far as manual piloting.

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