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# INFLUENCE OF METEOROLOGICAL CONDITIONS ON AIRCRAFT TAKE - OFF AND LANDING

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**Abstract**

*The division of meteorology is an integral part of aviation that informs about meteorological phenomena and defines their nature. This article focuses on the types of meteorological conditions with which the aircraft comes into contact during the flight, with a closer focus on the take-off and landing phases of the aircraft. The topic of meteorological conditions and their effects was chosen due to the enormous importance of this segment of aviation for the safety and operation of air traffic. The paper has a theoretical character and approaches the connection between individual meteorological conditions and their effect on the behavior of the aircraft. For air safety, a proper interpretation and subsequent adaptation to the corresponding weather events and deviations from standard conditions is essential. The aim of the publication is to define the basic meteorological conditions, weather phenomena and to underline their considerable importance for air traffic. The final part is devoted to the analysis of air accidents during takeoff and landing, which were caused by adverse weather conditions and their underestimation.*

**Keywords**

*Flight phases, Take - off, Landing, Meteorological conditions, Operational procedures*

## 1. INTRODUCTION

Meteorological conditions and related phenomena characterise the constantly changing state of the atmosphere. Based on the information provided about the current nature of the Earth's gaseous envelope and the more detailed knowledge associated with the occurrence of given weather phenomena, people can adapt their behaviour to the current conditions. It is of paramount importance for aviation to correctly record, evaluate and adapt its operations to the current meteorological conditions in order to maintain the continuity, safety and efficiency of flight operations.

The introductory part of the article deals with an introduction to the specific phases of flight: take-off and landing, which belong to the most demanding. The topic then moves smoothly to its meteorological part, with a definition of the Earth's atmosphere, specific meteorological conditions, their effects, and the ways in which information about the discussed meteorological conditions are provided.

The aim of the paper is to present the nature of the influence of basic meteorological conditions and to provide a comprehensive summary of information on the subject. Proof of the importance of the subject under discussion, highlight the accidents caused by the occurrence of adverse weather conditions during takeoff and landing.

## 2. FLIGHT MECHANICS

Flight mechanics is a scientific discipline dealing with the motion of aircraft, its laws and the causes of their motion. Aerodynamics together with flight mechanics define the fundamentals of flight - the theoretical principles and laws of flight. Classical flight mechanics deals with the basic summary of the problems of this discipline, flight characteristics and flight performance. According to performance, the flight of an aircraft is divided into 6 phases: take-off, climb, cruise, descent, approach and landing. Among the important observed performance values during takeoff and landing, the length of the takeoff and landing are particularly important [4] [6].

Take-off is a complex aircraft maneuver during which the aircraft is set in motion on the runway, accelerates and ends when it reaches a given altitude over a fictitious obstacle. It is divided into a ground part (ground roll) and an aerial part (rotation, transition, climb out) [4] [6].

Landing is the last phase of flight, which starts when the altitude at which the takeoff phase ends is reached, namely the minimum altitude above the fictitious obstacle. During landing, the aircraft gradually slows down in speed during both the airborne and ground parts. The aerial part consists of glideslope phase, flare out phase, touchdown and the ground part consists of after landing roll [4] [6].

## 3. EARTH'S ATMOSPHERE

The Earth's atmosphere forms a gaseous envelope around the entire surface of the Earth. It is characterized by its vertical stratification, as its medium, compressible air, is affected by the Earth's gravity. The individual layers of the atmosphere are thus compressed by the layers above them, concentrating about half of their mass to a height of 5.5 km. The height of the upper atmospheric boundary varies depending on the point of view under consideration. From an aeronautical point of view, the height at which the lift required for aircraft flight can still be generated is important. The composition of atmospheric air consists of three main components: clean dry air (99% oxygen-nitrogen mixture), water in all its states and atmospheric aerosol (gaseous and solid impurities). An important component of the atmosphere is ozone, which is most concentrated at an altitude of 25 to 30 km [1] [2] [5].

The basic division of the atmosphere is according to the vertical air temperature profile into the troposphere, stratosphere, mesosphere, thermosphere, and exosphere, which transitions smoothly into interplanetary space. In between the base layers there are transitional layers which are referred to as tropopause, stratopause, mesopause and thermopause [2] [5]. According to S. Krollová, other aspects of atmospheric partitioning include the division "according to chemical composition into homosphere and heterosphere, according to the concentration of atmospheric ions and free electrons into neutrosphere, ionosphere and magnetosphere, and according to the interaction with the Earth's surface into the boundary layer and free atmosphere," [2].

### *3.1. International Standard Atmosphere (ISA)*

The International Standard Atmosphere is an ideal model of the Earth's atmosphere, which is not affected by any dynamic factors, and therefore the actual value of the air parameters almost always differs from the model values. Specified in 1952 by ICAO, the ISA defines air as a homogeneous ideal gas whose parameters at sea level are: air pressure 1013.25 hPa, air density 1.225 kg.m-3 and air temperature 15 °C. The vertical temperature gradient is 6.5 °C per kilometre [1].

## 4. METEOROLOGICAL CONDITIONS

### *4.1. Temperature*

The temperature value indicates the thermal state of the atmosphere, and according to S. Kroll, temperature in physical terms expresses "the energy and thermal state of a body or environment, which is proportional to the mean kinetic energy of the molecules moving in it," [2]. The primary source of thermal energy acting on meteorological processes is the Sun. Air temperature varies due to several factors, these are divided into periodic (diurnal and annual course) and aperiodic (geographical distribution and horizontal movement of air masses) [2] [7].

The movement of air particles along the vertical line is accompanied by a change in temperature due to the conversion of internal energy into work or vice versa. The vertical temperature gradient expresses the change in air temperature with increasing height, with the ratio difference of the temperature to the height (mostly per 100 m) [2].

### *4.2. Density*

Air density is an important meteorological parameter, expressing the ratio of the mass of air to its corresponding volume. It influences aerodynamic and aerostatic forces, but also the performance of aircraft, their propulsion units, etc. The effect of air compressibility is reflected in the variation of the density value with increasing altitude. It has a decreasing character similar to the parameters of temperature and atmospheric pressure. However, the curve of the decrease in the value of air density is logarithmic, as is the nature of the decrease in atmospheric pressure. The decrease of temperature with increasing altitude in the ISA troposphere has a linear character [1] [2].

### *4.3. Pressure*

Air pressure is a scalar quantity that describes the amount of force applied per area unit. Depending on the motion of the air mass, pressure is divided into static and dynamic. The action of static pressure is uniform in all directions, under the condition of a resting air mass. If the air mass is moving, the pressure is applied to the area opposite to the direction of flow. In this case it is dynamic pressure. Atmospheric pressure, also referred to as barometric pressure, is a static pressure used in meteorology. The spatial distribution of atmospheric pressure is characterized by the pressure (bar) field. [1] [2].

The state of the atmosphere and the current values of air pressure, density and temperature affect the take-off speed, landing speed, take-off and run-up length. For aircraft with turbine powerplants, a 10 °C increase in temperature increases take-off length by up to 13%. A reverse decrease of 10% in temperature reduces the required take-off length by approximately 10%. With increasing altitude, the required take-off length also increases in connection with decreasing pressure and density value. When comparing the take-off length at an airport at sea level with an airport at an altitude of 1000 m above sea level, this value increases by up to 33% [3] [5].

### *4.4. Atmospheric flow*

In the atmosphere, there are constant movements of air particles, both horizontally and vertically. Both components of the flow are the result of different applied forces. The horizontal component of the flow in the atmosphere is referred to as wind and is a vector quantity whose main parameters are its direction and velocity. These have a significant impact on air traffic, especially in terms of the use of a particular runway [1] [2] [7].

Turbulent airflow is characterized by the disordered movement of air particles in space and time. In contrast to laminar flow, during which the streamlines are parallel and smooth, turbulent flow produces vortices with different sizes, lifetimes, streamline orientations and variable velocities. Thus, when flying in turbulent conditions, it is possible that the aerodynamic forces acting on the aircraft are violated, with the consequence of changes in the aircraft altitude and a decrease in its controllability [1] [3] [5] [7].

### *4.5. Humidity*

Humidity is a meteorological parameter that defines the proportion of water vapor in the air. The process of evaporation saturates the air, and once a certain level is reached, condensation, cloud formation and precipitation occur, returning some of the water back on the earth's surface. The cloudiness, otherwise known as clouds, are formed by clumps of water droplets, ice crystals, or both components at the same time. Atmospheric precipitation is the phenomenon of water in its various states falling to the Earth's surface. From an aviation point of view, precipitation has a significant impact, reducing visibility, polluting the runway, affecting the indication of aircraft instruments and under certain conditions, contributing significantly to the formation of icing. [1] [2] [7].

### 4.6. Visibility degrading phenomena

In the ground layer of the atmosphere, visibility is affected by dry particles and liquid particles, resulting in observable phenomena such as haze, mist and fog. In the free atmosphere, the visibility level is mainly influenced by the water content associated with cloud formation. The important parameters in this case are the height of the cloud base, its type, amount and density. Last but not least, it is necessary to mention the effects of volcanic activity [1] [5] [6].

### 4.7. Dangerous phenomena

The parameter values of all meteorological phenomena vary depending on location and time. The level of danger they represent, especially to air traffic, also varies. In particular, extreme values - temperature (both positive and negative), density, pressure, humidity and associated wind, cloud cover, precipitation, visibility - are a major problem. Special attention must be paid to phenomena such as thunderstorms, icing, gales, tornadoes and hurricanes.

Storm activity represents one of the most dangerous meteorological phenomena and is a significant threat to aviation, mainly due to the frequent occurrence of other accompanying meteorological phenomena: precipitation and high wind speeds, wind shear, icing and turbulence [1] [7].

Icing is a meteorological phenomenon in which water freezes on surfaces with a temperature of less than 0 °C. Icing forms when supercooled water droplets are in contact with each other, but also when surfaces come into contact with water vapor molecules. The atmospheric temperature that is most ideal for icing is between 0 and -12 °C. Small water droplets, unlike large droplets, freeze immediately upon contact with a supercooled surface. Large drops first spread on the surface and form a thinner film, which freezes afterwards [1] [7].

## 5. SOURCES OF METEOROLOGICAL INFORMATION

Meteorological observations provide information about the state of the atmosphere. These include measurements and qualitative assessments of meteorological elements. In order for the information to be comprehensive and comparable between different parts of the world, meteorological observations must be global in its character. The World Meteorological Organization (WMO) provides a complex form of observations within the meteorological service [2] [7].

### 5.1. METAR

The METAR (Meteorological Aerodrome Report) is one of the basic types of reports that provide information about the current weather conditions at the airport. It is issued at hourly or half-hourly intervals. In the event of an emergency, an emergency SPECI report is issued and is in the same format as a METAR report. The METAR is divided into several parts, describing the current state of meteorological elements and phenomena at the airport. Its form is not fixed, some parts may be omitted or modified if the phenomenon is not present in the airport area. [1] [5].

### 5.2. TAF

Terminal aerodrome forecast, TAF, is an airport forecast of selected meteorological elements. In Slovakia, it is being prepared for airports with controlled air traffic - Bratislava, Košice, Poprad, Piešťany, Žilina and Sliač. The frequency of the TAF forecast is either every 6 hours with a validity of 24 hours or every 3 hours with a validity of 9 hours [1] [12].

### 5.3. Take-off forecast

A special forecast issued at airports is the take-off forecast. The formulation of the forecast shall be determined by the air service provider and the user. They are issued hourly and contain data on wind direction, wind speed, air temperature and QNH pressure. The information from the take-off forecast is not only for the use of the flight crews, but it also derives the use of a specific runway and its direction [1].

## 6. ANALYSIS OF WEATHER AND ITS IMPACT ON THE SELECTED FLIGHT

| | | | |
|---|---|---|---|
| <u>Stockholm Arlanda Airport</u> | | → | <u>Faro Airport</u> |
| *Date:* | 7. 4. 2022 | *Duration of flight:* | 4 hours 30 minutes |
| *ETD:* | 15 UTC | *ETA:* | 19:30 UTC |

The ground pressure field map shows the distribution of pressure systems in Europe on the date of the planned flight. The airport from which the aircraft will take off towards Faro is Stockholm Arlanda Airport. The pressure formation influencing the nature of the meteorological phenomena at the take-off destination is the warm front of the low-pressure system Nasim centered over the North Sea with a minimum atmospheric pressure of 970 hPa. The low-pressure system Nasim is in a late stage of development due to the occurrence of an occluded front. The occluded front is the result of the merging of a warm front and a cold front as a result of the different speeds of the two fronts (the warm front is slower than the cold front).

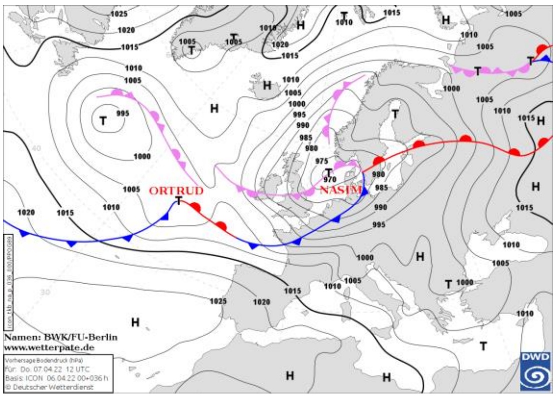


*Figure 1: Surface pressure field map, date: 7.4. 2022. [http://www.met.fu-berlin.de/de/wetter/maps/emtbkna.gif]*

<u>*Stockholm Arlanda Airport*</u>

METAR ESSA 071450Z 07014KT 5000 -SNRA BKN006 01/M00 Q0980 TEMPO 2000 -SN BKN012

Decoded report: 7th day of the month, 14:50 UTC, wind direction from 70°, wind speed 14 knots, visibility 5 km, light mixed precipitation, snow prevailing over rain, cloudiness BROKEN (5-7/8) at 600 ft above airport level, air temperature 1 °C, dew point temperature 0 °C, QNH at 980 hPa, temporary change in meteorological conditions within 2 hours, visibility 2 km, light snowfall, cloudiness BROKEN (5-7/8) at 1200 ft above airport level.

*Faro Airport*

METAR LPFR 071930Z VRB02KT CAVOK 16/13 Q1023

Decoded report: 7th day of the month, 19:30 UTC, variable wind direction, wind speed 2 knots, visibility more than 10 km, no significant clouds for air traffic, air temperature 16 °C, dew point temperature 13 °C, QNH at 1023 hPa.

The contrast in meteorological phenomena between destinations is significant and applies to all weather conditions. In addition to the differences in temperature and air density caused, among other things, by their different geographical locations, the two airports are affected by different pressure systems. In the Swedish capital, icing is possible as a result of low temperatures and precipitation. If not necessarily at the airport, then at least shortly after take-off, when the air temperature is below freezing point. There are three runways at Arlanda with designations 01L/19R, 01R/19L and 08/26. Due to the wind direction and runway orientations, runway 08 is the best choice for the flight. The wind would be head wind with a 10° deviation. In case of usage of other runway, it would be cross wind. At Faro airport, the use of runway 10/28 direction does not really matter in relation to the wind, as the wind direction is variable. In addition to temperature, density and air pressure, the length of take-off at Arlanda may be affected by runway pollution due to rainfall during the day.

## 7. TAKE-OFF AND LANDING ACCIDENTS CAUSED BY METEOROLOGICAL CONDITIONS

### *7.1. Delta Air Lines flight 191*

Delta Airlines Flight 191 took place on August 2nd, 1985, and was part of a scheduled flight from Fort Lauderdale, Florida, to Los Angeles with a stopover at Dallas/Fort Worth International Airport. The operating aircraft was a Lockheed L-1011-385-1 TriStar [13].

In the early stages of the flight, adverse weather conditions were not encountered, but this changed as the aircraft overflew the area over the city of New Orleans. Scattered showers and thunderstorms were predicted at the arrival destination. Similarly, isolated thunderstorms were reported occurring over north and northeast parts of Texas and over the Oklahoma. On approach to the Forth Worth airport, the captain requested a storm go-around, which the controller agreed to. Subsequently, the controller asked the crew to reduce speed repeatedly to maintain separation between aircraft during the approach to land. As the descent began, the first officer observed lightning in the clouds ahead of the aircraft and the predicted precipitation were also occurring. Approximately 2 km from Forth Worth Airport, the aircraft subsequently impacted the ground after passing through a microburst, a downdraft of cold air beneath the thunderstorm clouds [13].

The National Transportation Safety Board (NTSB), after investigating the accident, listed the cause of the accident as the failure of the crew, who decided to land despite the occurrence of thunderstorms in the area of the airport. This failure was also attributed to insufficient procedures, guidance and training in the similar weather conditions. The provision of information on the strong wind shear associated with the occurrence of a microburst was also identified as inadequate [13].

### *7.2. Anchorage Airport collision*

December 23rd, 1983, was marked by the crash of 2 planes at Anchorage International Airport. The first involved was a Korean Air Lines McDonnell Douglas DC-10-30 cargo plane. It was part of scheduled flight 084 from Anchorage to Los Angeles. At 14:06 YST, it struck a SouthCentral Air Piper PA-31-350 on runway 6L/24R while attempting takeoff.[14]

Adverse weather conditions significantly reduced visibility throughout the day, with fog occurring and overcast sky conditions. At the time of the accident, the weather was the same in all directions, visibility in fog was 250 m, wind was moderate at 3 knots from a 50° direction, and the RVR varied between 1000 and 1600 ft [14].

The cause of the accident was determined by the investigation to be a failure on the part of the Korean Air Lines crew who erred in the approach to the designated take-off runway. This was due to the reduced visibility caused by the presence of dense fog, which disoriented the DC-10 crew. After choosing an incorrect taxiway, the control tower was also unable to assist them due to the lack of visual contact [14].

### *7.3. USAir let 405*

USAir flight 405 took place on 22nd March 1992. The operating Fokker 28-4000 crashed on take-off from Runway 13, LaGuardia Airport, New York, USA. LaGuardia was a stopover airport between Jacksonville, Florida and the final destination of Cleveland, Ohio [15].

The weather at the New York airport did not change significantly during the day. The cloud base height was at 700 m and visibility was at 1200 m. There was fog and light snow precipitation, due to the low temperature of 0°C. The wind was blowing at 13 knots from a direction of 60-70°, the QNH pressure was 1004,4 hPa [15].

Flight 405 was delayed from its start, due to severe weather in the New York area. Upon arrival, the aircraft was de-iced twice due to snow and cold temperatures. The time between the last de-icing and the commencement of take-off was determined by the investigation to be approximately 35 minutes, during which precipitation were falling at low temperatures on the aircraft. During take-off, the aircraft did get its fuselage airborne, but lost lift shortly afterwards and crashed. The cause was a layer of ice on the wings, which disrupted the flow around the airfoil [15].

## 8. CONCLUSION

The article provides a comprehensive analysis of meteorological conditions and phenomena that can occur in the atmosphere. It informs about their specific effects on the behaviour of the aircraft during take-off and landing. The nature of the assembly of the theoretical knowledge has been compiled in the form of deduction, from general term to specific weather conditions.

The influence of meteorological conditions on air traffic is great, whose proof are the accidents caused precisely due to the influence of weather conditions. Weather may not be the primary cause of accidents, but in many cases it is a decisive factor without which the accident might not have occurred. Weather represents the current state of the atmosphere in a particular place at a particular time, which we cannot control. It is therefore up to people to adapt to it, not to underestimate it, and thus avoid unnecessarily endangering the air traffic.

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