CZECH TECHNICAL UNIVERSITY IN PRAGUE

Faculty of Transportation Sciences
Department of Air Transport

Correlation of Airline Diversions and Adverse Meteorological Phenomena

Korelace adverzních meteorologických jevů a odklonů letů

Bachelor's Thesis

Study Programme: Technology in Transportation and Telecommunications

Study Field: Air Transport

Thesis Supervisor: Ing. Peter Olexa

Marek Loukota

Prague 2022

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BACHELOR'S THESIS ASSIGNMENT

(PROJECT, WORK OF ART)

Student's name and surname (including degrees):

Marek Loukota

Study programme (field/specialization) of the student:

bachelor's degree – LED – Air Transport

Theme title (in Czech): **Korelace adverzních meteorologických jevů a odklonů letů**

Theme title (in English): **Correlation of Airline Diversions and Adverse Meteorological Phenomena**

Guidelines for elaboration

During the elaboration of the bachelor's thesis follow the outline below:

- This work aims to determine the effect of adverse meteorological phenomena on flight diversions.
- Carry out an analysis of flight diversions due to meteorological conditions.
- Define economic and operational impacts, current approaches to alternate airport operational selection, and their limitations.
- Compare a set of weather reports and forecasts (METAR, TAF) with the number of diverted flights for selected airports and identify meteorological phenomena causing diversions.
- Assess the risks of the most adverse meteorological conditions from data pairing.
- Discuss the results and draw conclusions.

Graphical work range: according to the instructions of thesis supervisor

Accompanying report length: minimum of 35 pages of text (including pictures, graphs, tables)

Bibliography:

YU Gang, QI Xiangtong. Disruption Management. Singapore. World Scientific Publishing Co Pte Ltd, 2004

WALD Andreas, GLEICH Ronald , et. al. Introduction to Aviation Management . Berlin: LIT Verlag, 2010

KURZ Manfred, Synoptic Meteology. German Meteorological Service, 1998

Bachelor's thesis supervisor: **Ing. Peter Olexa**

Ing. Slobodan Stojić, Ph.D.

Date of bachelor's thesis assignment: **October 08, 2021**

(date of the first assignment of this work, that has be minimum of 10 months before the deadline of the theses submission based on the standard duration of the study)

Date of bachelor's thesis submission: **August 8, 2022**

a) date of first anticipated submission of the thesis based on the standard study duration and the recommended study time schedule
b) in case of postponing the submission of the thesis, next submission date results from the recommended time schedule

L.S.

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I confirm assumption of bachelor's thesis assignment.

Marek Loukota
Student's name and signature

Prague .... May 5, 2022

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Jméno a příjmení studenta (včetně titulů):

Marek Loukota

Studijní program (obor/specializace) studenta:

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Název tématu (česky): **Korelace adverzních meteorologických jevů a odklonů letů**

Název tématu (anglicky): Correlation of Airline Diversions and Adverse Meteorological Phenomena

Zásady pro vypracování

Při zpracování bakalářské práce se řiďte následujícími pokyny:

- Tato práce si klade za cíl zjistit vliv nepříznivých meteorologických jevů na odklon letů.
- Proveďte analýzu odklonů letů v důsledku meteorologických podmínek.
- Definujte ekonomické a provozní dopady divertů, současné přístupy k výběru náhradních letišť a jejich omezení.
- Porovnejte sadu zpráv a předpovědí počasí (METAR, TAF) s počtem odkloněných letů pro vybraná letiště a identifikujte meteorologické jevy způsobující odklony.
- Vyhodnoťte rizika nejnepříznivějších meteorologických podmínek z párování dat.
- Diskutujte o výsledcích a vyvoďte závěry.

Rozsah grafických prací: dle požadavků vedoucího práce

Rozsah průvodní zprávy: minimálně 35 stran textu (včetně obrázků, grafů a tabulek, které jsou součástí průvodní zprávy)

Seznam odborné literatury:

YU Gang, QI Xiangtong. Disruption Management. Singapore. World Scientific Publishing Co Pte Ltd, 2004

WALD Andreas, GLEICH Ronald , et. al. Introduction to Aviation Management . Berlin: LIT Verlag, 2010

KURZ Manfred, Synoptic Meteology. German Meteorological Service, 1998

Vedoucí bakalářské práce: **Ing. Peter Olexa**

Ing. Slobodan Stojić, Ph.D

Datum zadání bakalářské práce: **8. října 2021**

(datum prvního zadání této práce, které musí být nejpozději 10 měsíců před datem prvního předpokládaného odevzdání této práce vyplývajícího ze standardní doby studia)

Datum odevzdání bakalářské práce: **8. srpna 2022**

a) datum prvního předpokládaného odevzdání práce vyplývající ze standardní doby studia a z doporučeného časového plánu studia

b) v případě odkladu odevzdání práce následující datum odevzdání práce vyplývající z doporučeného časového plánu studia

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Potvrzuji převzetí zadání bakalářské práce.

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V Praze dne .... 5. května 2022

Abstract

The safety and efficiency of air traffic can be adversely affected by meteorological phenomena such as fog, convective clouds, wind shear, and strong winds. The results may be flight delays, cancellations, reduced runway throughput, and flight diversions to other airports. Especially, flight diversions due to adverse weather at the destination, cause airlines and airport stakeholders considerable financial penalties. Although weather is considered one of the most common reasons for flight diversion, detailed data on the reason for flight diversion are not available centrally for European air traffic. This bachelor's thesis aims to determine the influence of adverse meteorological phenomena on fight diversions, analyze diverted flights due to weather, and identify phenomena that most often cause these diversions. The theoretical part of the thesis deals with the overview of meteorological phenomena with a high impact on aviation and the application of meteorological reports and forecasts. At the same time, the approach to the selection of an alternate airport is described and a recommended selection procedure for flight operators is proposed. The practical part of the thesis works with data provided by the European Aviation Safety Organization and historical meteorological data from 2019 for ten selected European airports.

Keywords: alternate airport, flight diversion, flight planning, weather

Abstrakt

Bezpečnost a efektivitu letového provozu mohou negativně ovlivnit meteorologické jevy, jako je například mlha, bouřková oblačnost, střih větru a silný vítr. Výsledkem mohou být zpoždění a rušení letů, snížená kapacita letišť a odklony na jiná letiště. Odklon letu z důvodu nepříznivého počasí v destinaci stojí letecké společnosti a ostatní zainteresované strany nemalé finanční prostředky. Přestože je počasí považováno za jeden z nejčastějších důvodů pro odklon letu, podrobná data o důvodu odklonu nejsou na evropském trhu centralizovaně dostupná. Cílem této bakalářské práce je určit vliv nepříznivých meteorologických jevů na odklon letů, zanalyzovat odkloněné lety z důvodu počasí a identifikovat jevy, které tyto odklony nejčastěji způsobují. Teoretická část práce se zabývá popisem meteorologických jevů s dopadem na letectví a použitím meteorologických zpráv a předpovědí. Současně je popsán přístup k výběru záložního letiště a navržen doporučený postup výběru pro letecké dopravce. Praktická část práce pracuje s daty poskytnutými Evropskou organizací pro bezpečnost leteckého provozu a historickými meteorologickými daty z roku 2019 pro deset vybraných evropských letišť.

Klíčová slova: odklon letu, plánování letu, počasí, záložní letiště

Acknowledgements

This thesis would not have been possible without the scientific and private support of many people, my family, colleagues, pilots, meteorologists, and flight dispatchers. My first thanks go to my supervisor, Ing. Peter Olexa, who had the idea for this work. I must not forget Eurocontrol for providing valuable flight diversion data and access to the Network Manager Interactive Reporting Dashboard. In addition, I express my gratitude to the TimeAir and Smartwings navigation departments for consultations and recommendations. They always answered my questions to my satisfaction and helped me gain more insight into the topic from real operations.

Declaration

I hereby declare that the presented thesis is my own work and that I have cited all sources of information in accordance with the Guideline for adhering to ethical principles when elaborating a final academic thesis.

I acknowledge that my thesis is subject to the rights and obligations stipulated by the Act No. 121/2000 Coll., the Copyright Act, as amended, in particular, that the Czech Technical University in Prague has the right to conclude a license agreement on the utilization of this thesis as schoolwork under the provisions of Article 60 (1) of the Act.

In Prague, 8th of July 2022

Signature

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List of Acronyms

ACN	Aircraft Classification Number
AD	Aerodrome
ADEP	Aerodrome of Departure
ADES	Aerodrome of Destination
AIP	Aeronautical Information Publication
ANS	Air Navigation Services
ATA	Actual Time of Arrival
ATOT	Actual Take-off Time
ATS	Air Traffic Service
BR	Mist
CAT	Commercial Air Transport
CB	Cumulonimbus
DZ	Drizzle
EBBR	Brussels Airport
EDDC	Dresden Airport
EDDF	Frankfurt Airport
EDDK	Cologne Bonn Airport
EDDP	Leipzig Halle Airport
EFKK	Gatwick Airport
EGGD	Bristol Airport
EGGP	Liverpool John Lennon Airport
EHAA	Amsterdam Flight Information Region
EHAM	Amsterdam Airport Schiphol
EKCH	Copenhagen Airport
ESSA	Stockholm Arlanda Airport
ETA	Estimated Time of Arrival
ETOT	Estimated Take-Off Time
FAA	Federal Aviation Administration
FG	Fog
GNSS	Global Navigation Satellite Systems
GR	Hail
GS	Small hail
ICAO	International Civil Aviation Organisation
ILS CAT I, II, II	Instrument Landing System Category I, II, II
LEBL	Barcelona El-Prat Airport
LEMH	Menorca Airport
LEPA	Palma de Mallorca Airport
LFBD	Bordeaux–Mérignac Airport
LIMC	Milan Malpensa Airport
LIMF	Turin Airport

LKKV	Karlovy Vary Airport
LKPR	Václav Havel Prague Airport
LOBT	Last Off-Block Time
LROP	Henri Coanda Airport
LVP	Low Visibility Procedures
MEL	Minimum Equipment List
METAR	Meteorological Aerodrome Report
NMIR	Network Manager Interactive Reporting Dashboard
NOTAM	Notice To Airmen
OFP	Operational Flight Plan
OH	Operating Hours
PCN	Pavement Classification Number
RA	Rain
RFFS	Rescue and Fire Fighting Services
RVR	Runway Visual Range
RWY	Runway
SN	Snow
TAF	Terminal Area Forecast
TCU	Towering cumulus
TS	Thunderstorm
TSRA	Thunderstorm with rain
TSRAGR	Thunderstorm with hail
TSRAGS	Thunderstorm with small hail
UKKK	Kyiv International Airport
UTC	Coordinated Universal Time
WS	Windshear

Introduction

The flight diversion is a deviation from the intended route for various reasons. Weather in the destination, medical problems, closed airport, or aircraft technical problems. Although flight diversions have operational and economic impacts, the safety of operations must be observed at all costs. Due to the improved airport infrastructure and aircraft systems, airlines can operate even under adverse weather conditions. However, thunderstorms, fog, hail, severe wind, and other risky phenomena over a destination airport can lead to a possible flight rerouting to a more convenient airport. This rerouting can be partially avoided by proper flight planning, analyzing possible weather deterioration, and preparing for a diversion prior to the flight. It results in reduced financial impacts, increased flight safety, comfort, and overall efficiency. Weather-related flight planning evaluates mainly meteorological reports and forecasts for the expected time and validity. It compares them to a planning minima of intended airports, checks the wind and significant weather charts. Comparing flight diversion data provided by Eurocontrol with time-matched weather reports and locating the most significant phenomena that cause diversions could positively impact the safety and continuity of air traffic, in addition to reducing operational and economic impacts by applying the results of this thesis in the enhancement of the diversion airport selection methodology by airlines and airport stakeholders.

1. Theory

The flight diversion is a deviation from the intended route that ends at a different airport than the original destination. The safety of passengers, crew, and aircraft cannot be jeopardized despite the negative economic and operational impact on the operator.

1.1 Impact of Flight Diversion on the Aircraft Operator

Each flight diversion is perceived as a negative occasion, primarily for the aircraft operator, secondarily for the airport stakeholders, and for other business stakeholders associated with air traffic. Many services are arranged for the flight, and cancellation fees are often as high as the price of the service, regardless of charges for using an alternate airport. Flight operations are dependent on an accurate timetable, and delays have a highly negative impact on the entire process, irrespective of the cause. This basically means that delayed flights cause a loss of money, and diverted flights generate significant extra costs, reducing the rentability of flight operations. Delays and diversions cause a downgraded quality of the service, together with an impact on the crew and passengers, even when they are performed for safety reasons. As the delay in the diverted destination increases, these costs and subsequent consequences of the impacts gradually worsen. [3,4] For example, according to Alexander Grous of the London School of Economics and Political Science, just a 10% decrease in flight diversions due to medical emergencies alone could save airlines over $ 55 million in the United States. An international diversion can cost an airline $ 200 000 for a wide-body aircraft, with the average estimated to be 50% to 66% of this cost. Diversions for a narrow-body aircraft can range from $ 15 000 to $ 25 000. [5] Therefore, making diversions as efficient as possible is completely reasonable.

Diversion Recovery

When the flight is diverted to the alternate airport because the original destination airport cannot accept the flight or the safe continuation of the flight cannot be attained, flight operators have to decide whether the flight can be continued to the final destination or if the flight will terminate at the alternate airport and passengers will be transported to the destination by different means of transport. The decision to terminate the flight at the alternate airport may be affected by several factors depending on the reason for the flight diversion. It may be faster and more comfortable for passengers to reach their destination using another form of transportation if the original destination is simply not expected to become available in a specific amount of time. [3]

1.2 Reasons for Flight Diversion

The following chapter contains a breakdown of scenarios and reasons for flight diversions, as several factors can affect the flight and cause unplanned flight rerouting.

1.2.1 Technical, Health, Safety, and Security Flight Diversions

Technical

Modern aircraft are incredibly sophisticated machines with millions of different parts. Systems do experience failures, just like any machine. Most of them are not jeopardizing the safety of the flight, and the flight can be continued to the destination. When a serious failure occurs, the flight has to be diverted to a suitable airport.

Health Related

There are two types of medical emergencies onboard. Those that involve injuries and those that involve diseases. A turbulence encounter, luggage falling from an overhead bin, an argument within the aircraft, or burns or scalds brought on by contact with hot liquids are just a few of the accidents that can result in injuries. Sometimes passengers may experience several health problems, including dizziness, allergic reaction, forgotten medication, gastrointestinal problems, stroke, heart attack, or even death. Occasionally, several passengers may become sick simultaneously from food poisoning. [2] Most emergencies (94%) involve passengers, with the crew making up a relatively small portion (6%). There were approximately 61000 emergencies worldwide in 2017, or one in every 604 flights, according to estimates of medical emergencies. [5]

Safety and Security Incidents in the Air

Disturbing or dangerous passenger behaviour that affects the safety of passengers and crew onboard. There are many causes and triggers that can influence a typical traveller to act out. These include, but are not limited to, intoxication, drug use, mental health problems, anxiety, and frustration. [3] Terrorism also contributes to this category.

Safety and Security Incidents on the Ground

Airports are a critical infrastructure point and become partially or completely unable to accept any fight if one or more of its systems, as well as backups of these systems, fail. There are many potential causes for this, including a power outage, a damaged or flooded runway, an occupied runway, or a serious violent act against airport personnel or property. [3]

1.2.2 Flight Diversions Caused by Weather

Weather is one of the most common reasons for a flight diversion. [1] Although a very complex and precise flight preparation from the flight planning department, pilots, meteorologists, and other ground operations personnel, weather can change rapidly in a short period of time, causing possible weather deterioration and subsequent flight diversion. Short-haul flights are usually dispatched a few hours before departure, which gives a relatively accurate forecast. Long-haul flights last significantly longer, making them more susceptible to different weather at the destination than those briefed prior to the flight. Significant weather, low visibility, low clouds, wind, and a combination of phenomena can jeopardize the safety of the flight. Convective weather over French Riviera can be seen in Figure 1.1 and weather radar detection in Figure 1.2.

Figure 1.1: Convective weather over Nice, France [13]

Figure 1.2: Convective weather over Nice, France on the weather radar [13]

1.2.2.1 Cumulonimbus Cloud

Cumulonimbus clouds are clouds born through convection with a great vertical extent, often growing from small cumulus clouds over a hot surface. They can also form along cold fronts as a result of forced convection, where the air is forced to rise above incoming cold air. The base is often dark and located in the lower troposphere; on the contrary, the upper cloud consists of supercooled water droplets and ice crystals. Peaks typically reach as high as 40000 ft. The product of cumulonimbus is severe precipitation in the form of rain, snow, and hail accompanied by turbulence and icing. [8,27]

There are two main species of cumulonimbus based on the appearance of the cloud:

Cumulonimbus calvus - the tops are rounded but do not have a fibrous appearance, and there is no anvil on the top as can be seen in Figure 1.3 [27,28]

Cumulonimbus capillatus – characterised by the presence of cirriform parts of the clearly fibrous or striated structure in the upper portion. They have a typical anvil on the top, shown in Figure 1.4 [8,27]

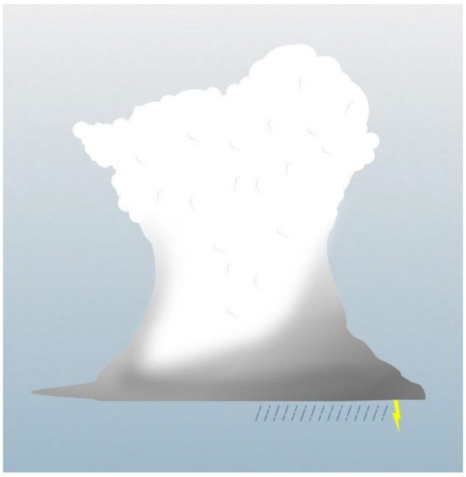

Figure 1.3: Cumulonimbus calvus [28]

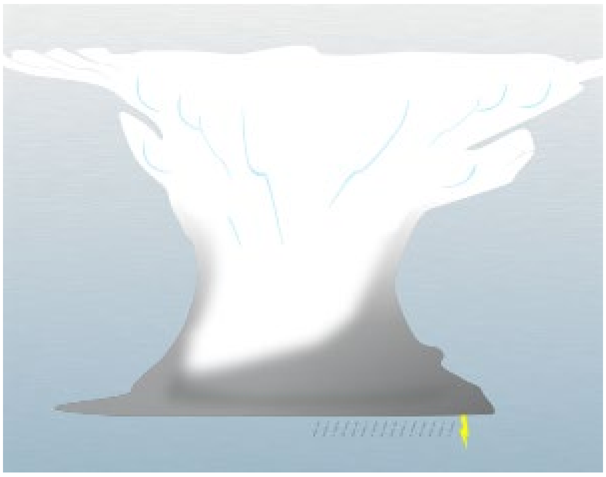

Figure 1.4: Cumulonimbus capillatus [28]

1.2.2.2 Thunderstorm

Because of their severity, thunderstorms are exemplarily chosen in the scope of this work as being the representative adverse weather event. Thunderstorms occur in well-developed cumulonimbus clouds, though not all produce thunderstorms.

Thunderstorms are classified as:

Air Mass Types

In general, air-mass thunderstorms are scattered and can be avoided by a detour. They are frequently referred to as heat thunderstorms, as they are caused by intense solar heating over the land. The heating from below steepens the environment lapse rate and provides the trigger action for the initial cloud formation. A stagnant mass of warm moist air is required for subsequent growth. Typically, air mass thunderstorms develop over land in the afternoon. [33]

Frontal Type

Frontal thunderstorms may extend in an unbroken line for hundreds of kilometres. Most frequently occur when a cold air mass forces warm, moist, unstable air to rise. They may be characterized by the formation of a continuous line of a thunderstorm parallel to cold front thunderstorms. This is known as the squall line. [33]

Thunderstorm Development

Warm air has a lower density than cool air, so warmer air rises upward, and cooler air subsides. Clouds are formed when moist, relatively warm air rises within cooler air. When moist air rises, it cools, which causes some of the water vapor to condense. When the moisture condenses, it releases energy known as latent heat; this permits the ascending parcel of air to cool more slowly than the cooler surrounding air, causing the cloud to continue to rise. If enough instability is present in the atmosphere, this process will continue long enough for cumulonimbus clouds to form and produce lightning and thunder. [47] All thunderstorms, regardless of the type, go through three stages divided by the predominant vertical motion.

Initial Stage

In its initial stage shown in Figure 1.5 is the cumulus cloud characterized by updraughts that increase to the centre of the cloud and with altitude. Condensation of water vapour leads to a strong elevation of the cloud and the formation of a towering cumulus. [27]

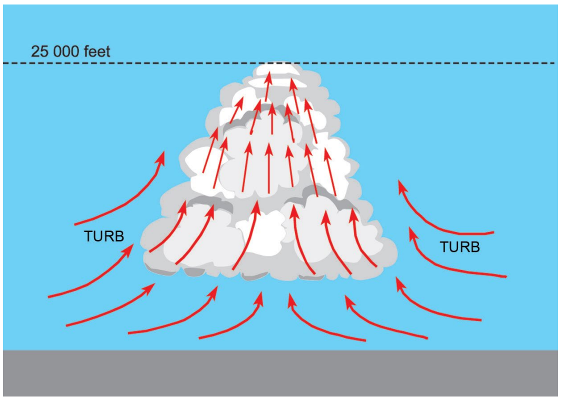

Figure 1.5: Initial cumulus stage of thunderstorm development [8]

Mature Stage

From a large number of cumulus clouds in the initial phase that formed on a warm summer day because of instability of the atmosphere, only a few continue to grow. [29] When precipitation occurs, the storm has reached the mature stage. The updraught reaches maximum speed, and the downdraught accelerates with precipitation. [28]

Mature stage of a thunderstorm shown in Figure 1.6 reaches the highest intensities, accompanied by electrical discharges in the form of lightning. [30]

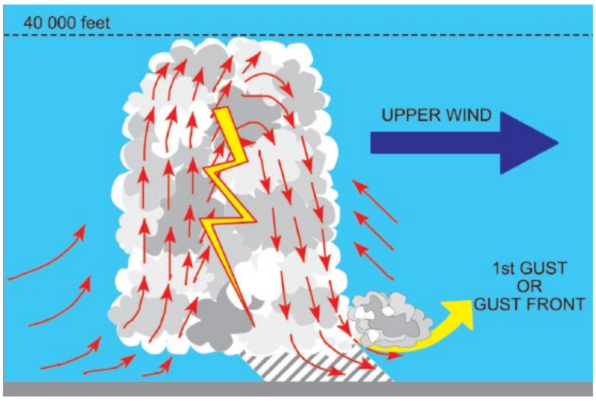

Figure 1.6: Mature stage of thunderstorm development [8]

Dissipating Stage

The cooling effect of the downdrafts on the air beneath the cloud reduces the strength of the updrafts until the updrafts eventually stop, and the lower cloud begins to dissipate. [28] At this stage, there is precipitation and heavy turbulence. [30] The dissipating stage is shown in Figure 1.7.

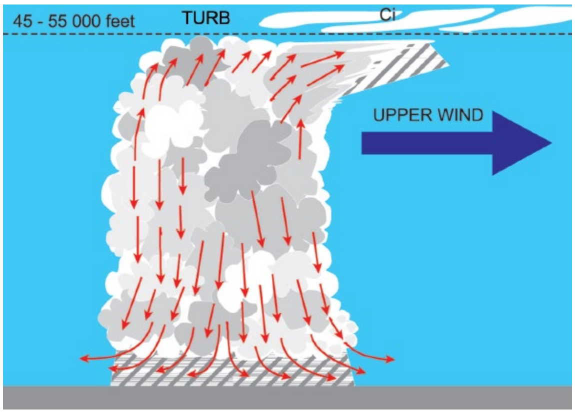

Figure 1.7: Dissipating stage of thunderstorm development [8]

Hazards for Aviation

Thunderstorms are one of the most threatening events in the atmosphere of the Earth. [8] They are associated with many dangers, which adversely affect safe flight execution.

The main aviation hazards associated with thunderstorms are the following:

- Turbulence
- Downburst
- Windshear
- Hail and heavy precipitation
- Icing
- Lightning
- Tornados

1.2.2.3 Fog

The worst visibility conditions occur in fog, clouds, and strong precipitation and have a significant impact on the conduct of flight operations, particularly landing and take-off. Fog is the term used when visibility is less than 1 km, and the obscuring agent is water droplets with a relative humidity close to 100%. [7] Forecasting these rapidly changing conditions has proven difficult.

There are different types of fog:

Radiation Fog

The radiation fog is caused by the radiation of the Earth's heat at night and the conductive cooling below the dew point of the air in contact with the ground, in conditions of calm or very light wind and clear skies. [8,31,33] The formation of radiation fog is shown in Figure 1.8.

Formation of Radiation Fog

- Clear sky – increases the rate of terrestrial radiation and cooling of the ground
- High relative humidity – little cooling will be enough to cause saturation and condensation
- Calm or very light wind – result in rapid cooling
- Surface – the ground surface is a better heat conductor than the sea surface
- Pressure system – high-pressure systems are favourable to radiation fog [8,33]

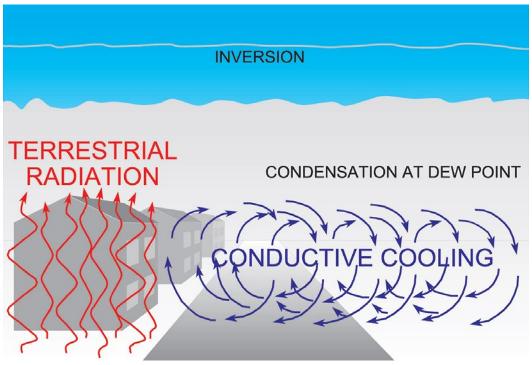

Figure 1.8: Formation of radiation fog [8]

Dispersal of Radiation Fog

The air in contact with the surface will warm as the sun rises and the surface temperature rises, which will cause the fog to gradually dissipate. A thin layer of stratus may arise from the rising fog. [8,31,33]

Advection Fog

Advection fog is formed by the movement of warm, moist air over a cold surface shown in Figure 1.9. The air mass is cooled from below, giving rise to an inversion. The surface can be land or sea. [8,31,33]

Formation of Advection Fog

- Wind speed around 15kts – best conditions for vertical development of advection fog
- Cold surface – colder than the dewpoint of the air moving over to ensure condensation
- Humid air – little cooling is required to produce saturation and condensation
- Temperature difference – the greater difference between warm air and colder ground, the greater likelihood of fog formation [8,33]

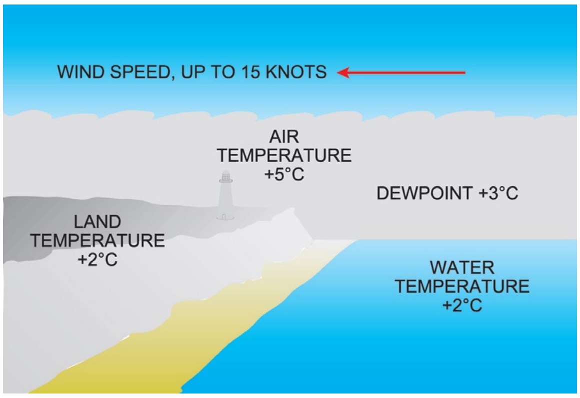

Figure 1.9: Formation of advection fog [8]

Frontal Fog and Hill Fog

Occurs at a warm front or occlusion. The main cause is precipitation that lowers the cloud base to the ground. It is formed as a result of evaporation and following condensation of warm falling precipitation down in a cold, moist layer ahead of a warm front as shown in Figure 1.10. It is formed by day and night. [8,31]

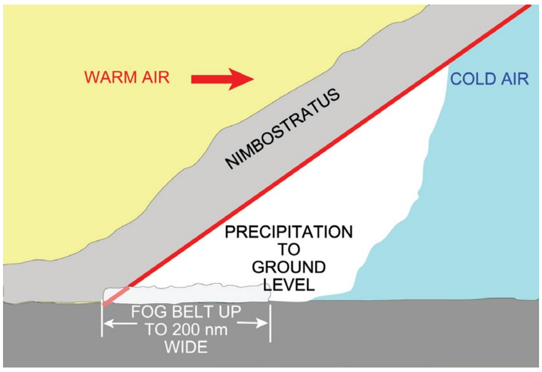

Figure 1.10: Formation of frontal fog [8]

Steam Fog

Also known as artic smoke. Occurs over the sea when cold air from a land mass moves over a warmer sea. [8]. The formation of steam fog is shown in Figure 1.11.

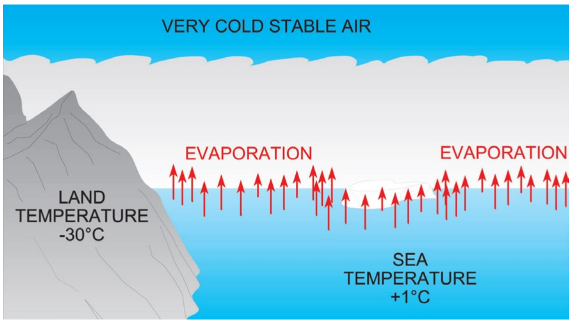

Figure 1.11: Formation of steam fog [8]

Flight Operations in Low Visibility Conditions

Airport ANS (Air Navigation Services) performance, runway throughput, and delays vary depending on the level of visibility. The instrument approach systems available determine how well an airport performs in low visibility. [26] The decrease in performance during poor visibility has an impact on arrival flights, but may also have an impact on departure flights, runway occupancy times, and taxi durations. [32] Establishing low visibility operations may be necessary. Low Visibility Procedures (LVP) are usually defined as a set of procedures established at an aerodrome in support of ILS CAT II/III landings and of take-offs with RVR below 550 m. LVP enable to operate flights even in adverse weather conditions and with lower minima as with CAT I operations. An example of LVP conditions can be seen in Figure 1.12. The implementation of LVP is often a challenge to aerodrome operators as it requires the fulfilment of numerous additional criteria related to the aerodrome infrastructure and equipment as well as specific documented procedures. [46] Aircraft operators also have to prepare for LVP. Aircraft equipment, certification, crew training, and experience have to meet legislative requirements.

Figure 1.12: Low visibility operations [45]

1.3 Interpretation of Meteorological Reports and Forecasts

Aviation meteorology is the study of weather from the unique perspective of the aviation industry, attaining and increasing the safety of flight and ground operations. Observations of meteorological conditions are made through instruments and visual estimation by meteorological offices and aeronautical meteorological stations. For example, an automated surface observing system, which can be seen in Figure 1.13. The data obtained are used for flight operations, navigation, flight performance, operational planning, protection of aeronautical equipment on the ground, and various other aeronautical uses. To ensure safe flight execution, especially in critical phases, pilots need precise meteorological reports. It is essential that aviation professionals can understand and read them, as aviation is heavily dependent on knowing the weather conditions to be encountered when flying in advance. A unified weather reports and forecast system was necessary to ensure high safety standards, terminology, and unified procedures worldwide. Subsequently, the creation of an international decoding system with unique identifiers for each phenomenon was carried out. [6]

Figure 1.13: Automated surface observing system [12]

1.3.1 Meteorological Report

The Meteorological Aerodrome Report (METAR) is an observation of current weather reported in a standard international format, issued on a regularly scheduled basis. It is usually issued twice an hour, and once an hour on a less frequent airports during the airport operating hours. [6] Outside of operating hours, METAR is identified as METAR AUTO. Special METAR (SPECI) can be issued anytime if significant changes occur.

METAR LKPR 051400Z 25016KT 9999 FEW033 05/01 Q1019 NOSIG=

Both METAR and SPECI contain the following information in the order shown:

Identification Groups

- The report code name is the identification type of report (METAR or SPECI)
- Four-letter ICAO designator of the issuing airport (e.g., LKPR, LKTB)
- The day of the month and the time of observation in hours and minutes, time is always given as Coordinated Universal Time (UTC), indicated by the code Z [7,8]

Surface Wind

- The observed wind five-figure group indicates the 10 min mean wind followed by an abbreviation to indicate the wind speed units used, in Europe mainly knots, but meters per second can also be used [6,8]
- The first three figures show the direction from which the wind blows, and the last two show the wind speed [7]

If, within the preceding 10 minutes of the observation, the maximum gust speed has been 10 kt or greater than the mean speed, this gust will be recorded by putting the letter G after the mean speed. [9]

Prevailing Visibility

Reported in a four-figure group (e.g., 0600 = 600 metres; 7000 = 7 km) up to but excluding 10 km; 9999 = 10km or more; 0000 = less than 50 metres visibility. [7,8]

RVR – Runway Visual Range

RVR is the maximum distance that a pilot 15 ft above the runway in the touchdown area can see marker boards by day or runway lights by night when looking in the direction of take-off or landing. [8] When visibility or RVR is less than 1500 meters, it

should be reported, especially at airports with precision approach runways or take-off runways with high-intensity edge lighting and/or centre line lights.
RVR is reported in metres with an indication of the unit and the runway to which the values refer. [6]

e.g., *RVR RWY 20: 500M RVR RWY 26: 800M.*

This form of record may vary, but the meaning remains unchanged.

e.g., RVR R20/0500

If RVR is observed for more than one position along a runway, the value representative of the touchdown zone is given first, followed by the location's representative of the mid-point and stop-end. [7,8] On shorter runways, the mid-point may not be specified.

e.g., *RVR RWY 16 TDZ 600M MID 500M END 400M.*

If RVR trends can be measured, then U, D, or N will follow the RVR value to indicate an increase, a decrease, or no change, respectively. [7]

Measurement of Runway Visual Range

Special optical devices for measurement must be placed in the airport infrastructure.

Transmissometer

An electronic device, which includes an emitter and receiver. [34] The intensity of light penetrates to a distance from a photoelectric cell and gives an indication of the equivalent daytime visibility. This has the advantage of a constant measurement of visibility, but the disadvantage is that only a small portion of the atmosphere is being sampled. [35] Two or three transmissometers are placed along the instrument runway. [8]

Scatterometer

Transmissometers are being replaced with forward scatter visibility meters. [8] They emit an infrared light beam at an offset angle from the receiver to the transmitter. [35] The receiver measures the amount of scattered light received from the transmitter. This amount depend on the number and type of particles (water droplets, ice crystals, or solid particles) that are present in the atmosphere. [8]

Present Weather

The present weather information should be representative of the conditions at the airport, within a radius of approximately 8 km from the airport reference point. [7]

For an easy description of the weather, significant present and forecast weather codes shown in Tables 1.1 and 1.2 have been developed.

Table 1.1: Significant present and forecast weather codes [7]

Significant Present and Forecast Weather Codes	
Qualifier	
Intensity or Proximity	Descriptor
- Light	MI – Shallow
+ Heavy/Well developed	BC – Patches
P – More than	BL – Blowing
M – Less than	SH – Showers
B – Began	TS – Thunderstorm
E – Ended	FZ – Freezing
U – RVR increasing	PR – Partial
D – RVR decreasing	DR – Low drifting
N – RVR no change	
VC – In the vicinity	

Table 1.2: Significant present and forecast weather codes [7]

Significant Present and Forecast Weather Codes		
Weather Phenomena		
Precipitation	Obscuration	Other
DZ – Drizzle	BR – Mist	PO – Dust/Sand Whirls
RA – Rain	FG – Fog	SQ – Squall
SN – Snow	FU – Smoke	FC – Funnel Cloud(s)
IC – Ice Crystals	VA – Volcanic Ash	SS - Sandstorm/ Duststorm
PL – Ice Pellets	DU – Widespread Dust	WS – Windshear
GR – Hail	DS – Dust Storm	CB – Cumulonimbus
GS – Small hail	SA – Sand	TCU – Towering Cumulus
UP – Unknown Precipitation	HZ – Haze	NSC – No significant cloud
PY – Spray		

Cloud

The cloud amount is reported as:

- FEW = few (1-2 oktas)
- SCT = scattered (3-4 oktas)
- BKN = broken (5-7 oktas)
- OVC = overcast (8 oktas) [6]

Followed by the height of the cloud base or ceiling in hundreds of feet above airport elevation.

The selection of reported cloud layers is made as follows:

- The lowest layer
- The next lowest layer of SCT
- The next higher layer of BKN
- Significant convective cloud (CB or TCU) if not already reported [6]

A laser cloud base recorder is used to estimate the partial cloud amount. For each layer of cloud identified by the instrument, a time-weighted average is used to derive the average amount. The height of the cloud base is recorded by light detection and ranging technology. [36]

e.g., *SCT019* = scattered clouds at 1900 ft above the aerodrome level.

Sky obscured[1] is given as VV followed by the vertical visibility in hundreds of feet. When the vertical visibility has not been measured, the group will be VV///. When there are no clouds of operational significance to report, no CB or TCU and CAVOK is not appropriate, the abbreviation NSC (No Significant Cloud) is used. [6,38]

CAVOK

Clouds, visibility, and weather groups are replaced by the term CAVOK (cloud and visibility OK) when the following conditions exist simultaneously:

- Visibility is 10 km or more
- No CB or TCU and no cloud below 5000 feet or Minimum Sector Altitude (whichever is the greater)
- No significant weather at or in the vicinity of the airport [37]

Air and Dewpoint Temperature

Air temperature and dewpoint are reported in whole degrees Celsius. [7,8]

e.g., *05/01* = Temperature 5°C/ Dew point 1°C, freezing is indicated with M

Pressure – QNH

The atmospheric pressure is given in hectopascals followed by Q, rounded down to the nearest lower whole hectopascal and reported in four figures. [7,8]

TREND, BECMG, TEMPO, NOSIG

A TREND forecast is appended to METAR or SPECI and is valid for 2 hours after the time of the observation of the METAR and constitutes the final section of the METAR. [7] The change in weather conditions indicated by the code, TREND, can be further qualified by the codes, BECMG, which means becoming, TEMPO, which means temporarily, or NOSIG, which means that there is no significant change [9,10].

Supplementary Information / RMK

Includes information on recent weather observed at the airport during the period since the last issued routine report or the last hour, whichever is the shorter. [8,9]

e.g., WS RWY 12

[1] Obscured – Something is blocking view of the sky and the clouds. This could be dust, haze, smoke, volcanic ash, and even heavy rain or snow. [38]

1.3.2 Terminal Aerodrome Forecast

In contrast to a METAR report on current conditions, Terminal Aerodrome Forecasts (TAFs) are forecasts of the weather at an airport, including any modifications that may have a significant impact on aircraft operations. However, the format of the TAF is comparable to that of a METAR, with many of the coding groups being the same in both formats. [8] TAFs are prepared by professional staff who, using the latest available regulations, ensure that international agreed practices are followed. TAFs describe the expected conditions at an airport and cover a period of not less than 6 h and not longer than 30 h. The validity period produced by meteorological offices should be determined by a regional air navigation agreement. Routine TAFs that are valid for less than 12 h should be issued every 3 h, and those valid for 12 h up to 30 h every 6 h. Amendments are issued as and when necessary. It is assumed that a later TAF automatically amends and updates those issued previously, and that not more than one TAF is valid at an airport at any given time. TAFs are issued separately from the METAR or SPECI and do not refer to any specific report. [6]

TAF LKPR 250200Z 2506/2612 20006KT 8000 BKN008=

TAF contains the following information in the order shown:

Identification Groups

- The report code name is the identification of the report (TAF)
- FC: TAF short valid for 6 to 9 hours
- FT: TAF long valid for 18 to 30 hours
- Four-letter ICAO designator of the issuing airport (e.g., LKPR, LKTB) [7]

The date-time information provided in TAFs differs slightly from that of a METAR. In the TAF, there are two items of date-time information. The first date-time group indicates the date and time at which the TAF was issued. [7,8]

- *250200Z*

The first two digits identify the day of the month, this information is followed by the time in hours and minutes UTC. [7,8]

The next code group identifies the period of validity of the TAF.

- *2506/2612*

The first two digits show the start date and the second two hours in UTC. The next four digits are the end date and the time of the validity period. [7,8]

Surface Wind

- The wind format in the TAF is the same as in METAR

Prevailing Visibility

- The visibility format in the TAF is the same as in METAR

Weather

- The weather format in the TAF uses the same weather codes as METAR

Cloud

The cloud coding in the TAF and METAR differ slightly. The code NSC, which stands for no significant cloud, is used if there are no clouds below the greater of 5000 feet or the minimum sector altitude, if there are no CB or TCU, and if CAVOK is not appropriate. [7,8,9]

The main TAF information ends with the cloud group. TAFs do not have any data on current weather, windshear, QNH, temperature and dew point, or runway state. However, some regions do predict the highest and lowest temperatures for the anticipated period. Only significant weather changes occur after the cloud group. These significant changes are introduced by codes classified as forecast change indicators. [7,8,9]

Temperature

Some meteorological authorities predict the highest and lowest temperatures that are likely to be experienced for the expected period of the TAF. [8,9]

- TX25, meaning the maximum temperature is expected to be 25°C
- TN09, meaning the minimum temperature is expected to be 9°C

Forecasts Change Indicators

The forecast change indicator codes indicate that a change is expected in some or all of the forecast meteorological conditions. The duration of the change may vary. It may be, for example, a rapid, gradual, or temporary change. These codes are FM, BECMG, TEMPO, and PROB. [8,9]

FROM Indicator

The FROM group in a TAF is introduced by the code FM and marks the fact that a rapid change in the forecast conditions is expected, which will lead to the appearance of a new set of prevailing conditions becoming established at the airport. This weather forecast following the FM code supersedes the TAF forecast prior to the indicator. The forecast following the FM indicator continues either to the end of the current TAF or until another change indicator occurs in the TAF. [8,9]

e.g., *FM 251220 21032KT 3000 BKN010=*

BECMG Indicator

The code BECMG, which means becoming, is followed by the date and time, which indicates the period during which there will be a permanent change in the forecast conditions. The forecast change, introduced by BECMG, will occur at an unspecified time within the stated period. [8,9]

e.g., *BECMG 2509/2511 2000 TSRA=*

TEMPO Indicator

The code TEMPO, which means temporarily, indicates that a change in meteorological conditions will occur at any time within the specified period but is expected to last less than one hour each time. The TEMPO indicator is followed by a date and time indicating the hours between which the temporary conditions are expected to begin and end. [8,9]

e.g., *TEMPO 2509/2511 3000 TSRA BKN010CB=*

PROB Indicator

The code PROB, which means probability, in a TAF indicates the probability of the occurrence of specified weather phenomena. Probability indication is a percentage probability of the occurrence of significant weather events such as thunderstorms and associated precipitation. A 30% probability is considered low, while a 40% probability indicates that it is highly likely that the weather that is forecast will occur.

The code PROB can be followed by a time group of its own, or by an indicator, such as BECMG or TEMPO. [8,9]

e.g., *PROB40 TEMPO 2509/2514 +TSRAGR SCT006TCU=*

Application of Forecast Change Indicators in the TAF and TREND

Tables 1.3 and 1.4 shall be applied to TAF one hour before and one hour after the ETA.

Table 1.3: Application of forecast change indicators in the TAF and TREND [7,10]

TAF or TREND for aerodrome planned as:	**Destination Take-Off Alternate Destination Alternate Enroute Alternate**
FM (alone) and **BECMG:**	
Deterioration and improvement	Applicable from the start of the change Mean wind should be within required limits Gusts may be disregarded
BECMG (alone), **BECMG FM, BECMG TL:**	
Improvement	Applicable from time of end of the change Mean wind should be within required limits Gusts may be disregarded
Deterioration	Applicable from time of start of the change Mean wind should be within required limits Gusts may be disregarded

Table 1.4: Application of forecast change indicators in the TAF and TREND [7,10]

TAF or TREND for aerodrome planned as:	**Destination Take-Off Alternate Destination Alternate En-route Alternate**
TEMPO (alone)**, TEMPO FM, TEMPO FM...TL, PROB 30/40** (alone):	
Improvement	Should be disregarded
Deterioration (transient / showery / short-lived conditions e.g., thunderstorms, showers	Should be disregarded Mean wind may be disregarded Gusts may be disregarded
Deterioration (Persistent conditions e.g., haze, mist, fog, dust/sandstorms, continuous precipitation	Applicable Mean wind should be within limits Gusts may be disregarded
PROB TEMPO:	
Improvement	Should be disregarded Mean wind should be disregarded Gusts should be disregarded
Deterioration	May be disregarded

Each aircraft operator can tighten up these tables for their own operations, but never ease them.

1.4 Selection of Alternate Airports

ICAO defines an alternate airport as an airport to which an aircraft may proceed when it becomes either impossible or inadvisable to land at the airport of intended landing. In addition, the necessary services and facilities are available, the aircraft performance requirements can be met, and the airport is operational at the expected time of use. [11]

Alternate airports for the flight can be:

- **Take-off alternate** - an alternate airport where an aircraft can land if meteorological or operational reasons do not permit to return to the airport of departure
- **En-route alternate** - an airport where an aircraft would be able to land after experiencing an abnormal or emergency condition while en-route. This alternate airport must also be selected when flying with 3% contingency fuel[2].
- **Destination alternate** - an alternate airport where an aircraft may proceed when it becomes impossible or inadvisable to land at the airport of intended landing [10]

However, it is completely legal to fly without an alternate airport if all conditions are met. [11]

1.4.1 Take-off Alternate Airport

When it is not possible to return to the departure airport, a take-off alternate has to be chosen and specified in the OFP (operational flight plan).

Planning Minima for Take-off Alternate Airport

The following requirements must be met for the take-off alternate:

- *"The appropriate weather reports or forecasts or any combination thereof indicate that, during the period commencing one hour before and one hour after the ETA to the take-off alternate airport, the weather condition will be at or above the applicable airport landing minima."*
- *"Ceiling must be considered when only approaches available are non-precision and/or circling approaches."* [11]

[2]According to ICAO Annex 6, the recommended minimum contingency fuel is the greater of 5% of the trip fuel or 5 minutes holding consumption at 1500 ft above destination airfield elevation computed based on calculated arrival weight. Some authorities allow contingency fuel reduction to 3% of trip fuel with use of enroute alternates. [11]

1.4.2 Destination Alternate Airport

An alternate destination airport is not required when:

- *"The duration of the planned flight from take-off to landing, or, in the event of in-flight replanning, the remaining flying time to destination does not exceed six hours."*
- *"Two separate runways are available and usable at the destination airport and the appropriate weather reports and/or forecasts for the destination airport indicate that, for the period from one hour before until one hour after the expected time of arrival at the destination airport, the ceiling will be at least 2 000 ft or circling height + 500 ft, whichever is greater, and the ground visibility will be at least 5 km."* [11]

At least one alternate destination airport must be selected and specified in OFP for conditions different from the previous paragraphs.

Two destination alternate airports must be selected when:

- *"The appropriate weather reports and/or forecasts for the destination airport indicate that during a period commencing one hour before and ending one hour after the estimated time of arrival, the weather conditions will be below the applicable planning minima."*
- *"No meteorological information is available."* [11]

Planning Minima for Alternate Destination Airport

The airport shall be selected when the appropriate weather reports or forecasts indicate that during a period beginning one hour before and ending one hour after the estimated time of arrival at the airport, the weather conditions will be at or above the planning minima in Table 1.5.

Table 1.5: Destination alternate airport planning minima [10]

TYPE OF APPROACH	PLANNING MINIMA
CAT II and III	CAT I RVR
CAT I	NPA RVR/VIS Ceiling shall be at or above MDH
NPA	NPA RVR/VIS + 1000 m Ceiling shall be at or above MDH + 200 ft
CIRCLING	CIRCLING

1.4.3 Alternate Airport Selection Checklist for Aircraft Operators

As there is no unified system in the selection process of alternate airports, flight planning departments may follow slightly different procedures, depending on the kind of activities they carry out. [3] For airports that are regularly operated, companies usually create a list of alternate airports stored in flight planning software. The list should be reviewed at the selected intervals.

The aircraft operator has to check:

Take-off Alternate Airport

- Distance to the take-off alternate airport (TALT)
- Aeronautical Information Publication – operational hours (OH), rescue and firefighting services (RFFS)
- Notices to Airmen (NOTAMs)
- Minimum Equipment List (MEL)
- Performance
- Available approaches
- Weather, planning minima
- Is alternate (ALT) relatable for the company?

Destination Alternate Airport

- Aeronautical Information Publication – operational hours (OH), rescue and firefighting services (RFFS)
- Notices to Airmen (NOTAMs)
- Minimum Equipment List (MEL)
- Performance
- Available approaches
- Weather
- Planning minima
- Is alternate (ALT) relatable to the company?
- Is 1x ALT appropriate?

Check the Distance to the Alternate Airport

The take-off alternate airport for two-engine airplanes shall not be further from the departure airport than one hour flight time at a one-engine cruising speed or the ETOPS diversion time approved in accordance with Annex V up to a maximum of two hours in still air standard conditions based on the actual take-off mass. For three and four-engine airplanes, two hours flight time in still air standard conditions based on the actual take-off mass. [39]

The specific distance must be stated in the Type B operational manual for each type of aircraft. The distance is determined by the operator by risk assessment and validated by the authority.

e.g., The maximum distance between the departure airport and the take-off alternate airport of selected Czech operators:

- Cessna C510 – 200 NM [16]
- Nextant 400XT - 237 NM [14]
- Challenger 300 - 323 NM [15]
- Boeing B737-800 - 400 NM [17]

Check the Aeronautical Information Publication[3]

An Aeronautical Information Publication (AIP) is a publication issued by or with the authority of a state and containing aeronautical information of lasting character essential to air navigation. [19]

The operator has to comply with all requirements for operations at the selected airport:

- Physical characteristics (RWY and TWY dimensions, compare PCN and ACN, equipment)
- Operational hours (ATS, customs, fuelling, handling)
- Rescue and firefighting services category – LKKV RFFS is shown in Table 1.6

Table 1.6: Rescue and firefighting services, LKKV AIP [20]

LKKV AD 2.6 Rescue and firefighting services	
AD category for fire fighting	CAT 4 during aerodrome OH. CAT 7 is provided for regular an irregular flights listed in the aerodrome flight schedule. For other flights CAT 5-7 is provided on request only, send minimally 24H in advance during AD OH.

Check NOTAMs

Checking NOTAMs for the pre-selected alternate airport is important. Even if we have used the airport as an alternate in the past, changes in capacity, or unserviceability of navigation systems may occur. Therefore, the airport will not be suitable for the selection as an alternate.
As an example, Amsterdam Schiphol airport has published the notam A1453/22 prohibiting the airport as an alternate.

A1453/22
Q) EHAA/QFALT/IV/NBO/A/000/999/5218N00446E005
A) EHAM
B) 2206151058
C) 2207191500
E) AD NOT AVBL AS COMMERCIAL ALTERNATE. [18]

[3] Information may also be obtained from external providers, e.g., Jeppesen, Lido. Information in AIP is always the official.

Check MEL

A Minimum Equipment List allows for the functioning of an airplane while some equipment is inoperative under certain circumstances. Check the Minimum Equipment List (MEL) if the malfunction does not affect landing at the alternate. [11]

Check Performance

All relevant factors that affect the aircraft during the performance calculation must be considered.

- Aircraft weight, aircraft configuration
- Pressure altitude, temperature, wind
- Runway dimensions, runway state

Check the Available Approaches

The airport should only be selected as a destination alternate airport if an instrument approach procedure that does not rely on the global navigation satellite system (GNSS) is available at that airport or at the destination airport. [10]

Check Weather

Refer to the application of the forecast change indicators and TAF interpretation in Section 1.3.2.

Check Planning Minima

Refer to the planning minima for alternate airport in Section 1.4.2.

Is Alternate Relatable to the Company?

Consider the economic and operational impacts of airport selection.

- The relative proximity of the flight diversion location – affects alternatives for transporting passengers to their destination
- Agreements with handlers, refuellers, contracts with other operators and businesses at the alternate
- Commercial and customer factors – hotels, transportation, facilities [4]
- Airline infrastructure – company personnel at the location
- Company policies [3]

2. Methodology

2.1 Airport Selection

For the identification of meteorological phenomena that cause diversions, a group of airports had to be selected. The main requirement was to select European airports with a precision approach from both runway directions. The Category I Instrument Landing System (ILS CAT I) from both directions is available at all airports in data pairing. Figure 2.1 shows the selected airports. Selecting airports not equipped with the precision approach would lead to higher minimums compared to airports equipped with the precision approach and would be more susceptible to flight diversions in adverse weather. A total of ten airports were selected and consulted with the Smartwings and TimeAir navigation departments.

Figure 2.1: Map of selected airports [21]

1. **EBBR** - Brussels Airport
2. **EDDF** - Frankfurt Airport
3. **EDDK** - Cologne Bonn Airport
4. **EGKK** - Gatwick Airport
5. **ESSA** - Stockholm Arlanda Airport
6. **LEPA** - Palma de Mallorca Airport
7. **LIMC** - Milan Malpensa Airport
8. **LKPR** - Václav Havel Prague Airport
9. **LROP** - Henri Coanda Airport
10. **UKKK**[4] - Kyiv International Airport

[4] UKKK was selected before Russian invasion of Ukraine

2.2 Data Acquisition

2.2.1 Flight Diversion Data

Official flight diversion data archives cannot be publicly accessed and published. Special permission and access to the Eurocontrol network manager interactive reporting dashboard (NMIR) had to be issued. With access to NMIR, it was able to obtain flight diversion data from selected airports for the selected period. The thesis worked with data from 1 January 2019 to 31 December 2019, when air traffic was not affected by the COVID-19 crisis. Tables 2.1 and 2.2 show examples of the data accessed.

The next step was to redesign the provided data to a more accessible form and separate small single-engine piston aircraft from the rest of commercial and airline traffic because the data contained all traffic with a filled flight plan and flying under instrument flight rules. This would narrow the data set only to performance class A aircraft and performance class B aircraft with turbine propulsion. Another difficulty that had to be overcome is that Eurocontrol does not have data specifically on weather-caused flight diversions. The data comprised all types of diversions. Weather-caused flight diversions had to be separated from other types of flight diversions by comparing meteorological conditions at the time of landing at the destination with METARs and TAFs. A total of 1187 flights have been processed and examined.

Table 2.1: NMIR flight diversion data example [23]

AIRCRAFT ID	AIRCRAFT TYPE	AIRCRAFT OPERATOR	ADEP	ADES	DIVERTED ADES
EZY6043	A319	EZY	EGGD	LEPA	LEBL

Table 2.2: NMIR flight diversion data example [23]

AIRCRAFT ID	LOBT[5]	ETOT[6]	ATOT[7]	ETA[8]	ATA[9]
EZY6043	13.09.2019 19:30:00	13.09.2019 19:41:00	13.09.2019 19:46:00	13.09.2019 21:45:58	13.09.2019 22:27:00

5 Last Off-Block Time
6 Estimated Take-Off Time
7 Actual Take-Off Time
8 Estimated Time of Arrival
9 Actual Time of Arrival

2.2.2 Weather Data

Weather data for 2019 for all selected airports were obtained from a company Aaltronav, which provides access to recent and historical METAR, SPECI, and TAF reports since 2008 and Ogimet, which provides access to recent and historical METAR, SPECI, and TAF reports since 2005. Although the data were the same, Aaltronav data were used for easier export. Tables 2.3 and 2.4 show examples of the weather data accessed.

Table 2.3: Aaltronav METAR example [22]

METAR
ESSA 030650Z 35010KT 9999 FEW007 SCT010 OVC033 05/04 Q1010 TEMPO BKN010
ESSA 030720Z 35010KT 9999 SCT007 BKN028 05/04 Q1010 TEMPO BKN010
ESSA 030750Z 35009KT 9999 FEW009 BKN027 05/04 Q1010 TEMPO BKN010
ESSA 030820Z 36010KT 9999 SCT010 BKN020 BKN027 05/04 Q1010 TEMPO BKN010
ESSA 030850Z 36012KT 9999 -SHRA SCT009 BKN024 06/04 Q1011 REDZ TEMPO BKN010
ESSA 030920Z 36011KT 9999 SCT011 BKN018 06/04 Q1011 RERA TEMPO BKN010
ESSA 030950Z 01013KT 9999 SCT012 BKN017 BKN023 07/05 Q1011 TEMPO BKN010
ESSA 031020Z 36013KT 9999 SCT013 SCT028 07/04 Q1011 NOSIG

Table 2.4: Aaltronav TAF example [22]

TAF
ESSA 032330Z 0400/0424 35010KT 9999 FEW006 BKN025 PROB40 0400/0403 SHRA BKN012 BKN025CB PROB40 0403/0424 SCT025TCU
ESSA 030530Z 0306/0406 01010KT 9000 -RA BKN020 PROB40 0306/0308 BKN009 TEMPO 0308/0312 RA BKN012 TEMPO 0312/0320 SHRA VV010 BKN030CB PROB40 0320/0406 3000 BR
ESSA 031130Z 0312/0412 01012KT 9999 BKN016 TEMPO 0312/0320 SHRA VV010 BKN030CB PROB40 0320/0406 3000 BR PROB40 0408/0412 SHRA VV012 BKN020CB
ESSA 031730Z 0318/0418 01012KT 9999 SCT015 BKN025 PROB40 0318/0402 SHRA BKN014 BKN025CB PROB40 0409/0418 SCT020TCU BECMG 0416/0418 31005KT

2.3 Data Pairing

In order to identify meteorological phenomena that cause diversions, two data sets had to be paired. Data set of flight diversions provided by Eurocontrol, and data set of weather reports and forecasts provided by Aaltronav. As mentioned in the previous sections, the flight diversion data included all types of flight diversion. Medical, technical, safety, and weather. Weather-caused flight diversions had to be selected and then examined on the contributing weather phenomena.

Data pairing was done manually as the process would be very difficult to automate due to a large number of inputs and the need to individually assess each individual flight. As no database exists only for flight diversions caused by weather in Eurocontrol archives, all are the result of selected classification procedures, phenomena assessment, and my conception of the given meteorological situation in the area.

Parameters for Evaluating Weather-Related Flight Diversions

To assess whether flight diversion was caused by weather, it was necessary to create boundaries for weather that does not affect flight and weather that creates a risk to flight. Four different weather classes were created, as can be seen in Tables 2.5, 2.6, 2.7, 2.8, and the flight undergoing pairing had to be affected by at least one of the classes. Destination airport METAR was compared with the arrival time window of the flight taken from NMIR and Flight Radar 24. Flights that met the conditions were further examined.

Weather Class: Ceiling and Visibility

Table 2.5: Ceiling and visibility limits

VISIBILITY	RVR	CLOUD CEILING
<800 m	<550 m	<300 ft

The ceiling and visibility correspond to the precision approach runways, Category I. The ceiling is lifted to 300 ft, because not all category I has minimums at 200 ft.

Weather Class: Dangerous Phenomena

Table 2.6: Type of dangerous phenomena

TYPE OF DANGEROUS PHENOMENA
CB, TCU, TS, PL, GS, GR, FC, SQ, VA, DS, SS, SA, PO

This weather class includes weather phenomena that are dangerous for the safety of aircraft operations.

Weather Class: Precipitation

Table 2.7: Type of precipitation

TYPE OF PRECIPITATION
-RA, RA, +RA, -SN, SN, +SN, SG, DZ, IC, UP, FZxx

Precipitations have an impact on the level of runway friction, negatively affect aircraft performance, and reduce visibility.

Weather Class: Wind and Windshear

Table 2.8: Wind speed and gusts

WIND SPEED / GUSTS
> 20 kt / >25 kt
WS
WS stated in METAR

Wind speed affects aircraft performance, airport operations, and adds additional risk in marginal weather. Later in the data processing, the crosswind was distinguished from the wind connected to convective clouds, which adds additional risk to operations even when lined up with the runway in use. The weather class is based on commercial aircraft, where the crosswind limit for possible diversion usually starts at 20 kt. [26,40]

For weather examination at arrival, METAR and SIGMET were used because the thesis wanted to find real-time weather phenomena that affect the destination. TAF was only used to interpret the development of the weather from the last TAF before departure.

Each flight was processed in the following order.

1.	Open flight diversion data set [attachment A]
2.	Open weather data for the destination airport
3.	Find the flight on Flightradar24.com
4.	Find the time before making the decision to divert
5.	Eliminate the flight if squawked 7500[10], 7600[11], 7700[12]
6.	Compare the time to METAR and SIGMET to get the prevailing weather at that time
7.	Compare the METAR and SIGMET to the weather class parameters
8.	Eliminate the flight if it does not meet at least one of the weather class parameters
9.	Proceed with a further examination and decide whether the phenomena posed a risk to the flight and caused the flight to divert
10.	Eliminate the flight if the phenomenon or combination of phenomena is not serious enough to cause a flight diversion
11.	Select weather phenomena causing flight diversion
12.	Record the results [attachment B]

[10] 7500 - unlawful interference
[11] 7600 - communication failure
[12] 7700 - emergency

Five sample cases have been prepared for a better understanding of the process.

2.3.1 Example 1

In this case, the EasyJet Airbus A319-100 scheduled to Palma de Mallorca (LEPA) diverted to Barcelona Airport (LEBL), as stated in the NMIR data in Tables 2.9 and 2.10.

Table 2.9: EZY6043 NMIR flight data [23]

AIRCRAFT ID	AIRCRAFT TYPE	AIRCRAFT OPERATOR	ADEP	ADES	DIVERTED ADES
EZY6043	A319	EZY	EGGD	LEPA	LEBL

Table 2.10: EZY6043 NMIR flight data [23]

AIRCRAFT ID	LOBT	ETOT	ATOT	ETA	ATA
EZY6043	13.09.2019 19:30:00	13.09.2019 19:41:00	13.09.2019 19:46:00	13.09.2019 21:45:58	13.09.2019 22:27:00

From the historic METAR data in Table 2.11, it is obvious that at the time of arrival to LEPA, a thunderstorm with scattered cumulonimbus was in place. Tempo indicated that conditions were expected to worsen within the next 2 hours.

Table 2.11: Aaltronav METAR data for LEPA [22]

METAR/SPECI LEPA
LEPA 132115Z 33006KT 9999 TS FEW015 SCT025CB 26/15 Q1026 TEMPO 27025G35KT 3000 TSRA
LEPA 132130Z 35007KT 270V060 9999 TS FEW015 SCT025CB 26/14 Q1024 TEMPO 27025G35KT 3000 TSRA
LEPA 132153Z 06011KT 010V100 9999 FEW015 SCT025CB 25/14 Q1024 RETS TEMPO 27025G35KT 3000 TSRA

Table 2.12: Aaltronav METAR data for LEBL [22]

METAR LEBL
LEBL 132100Z 36005KT 9999 FEW020 FEW025CB 22/18 Q1027 NOSIG
LEBL 132200Z 22005KT 9999 FEW020 FEW025CB 22/19 Q1028 NOSIG

The aircraft was held north of Palma de Mallorca as a thunderstorm occurred south of the island. The situation is shown in Figures 2.2 and 2.3. After a few holding patterns, the flight was diverted to Barcelona Airport, where the weather was acceptable, as can be seen in Table 2.12.

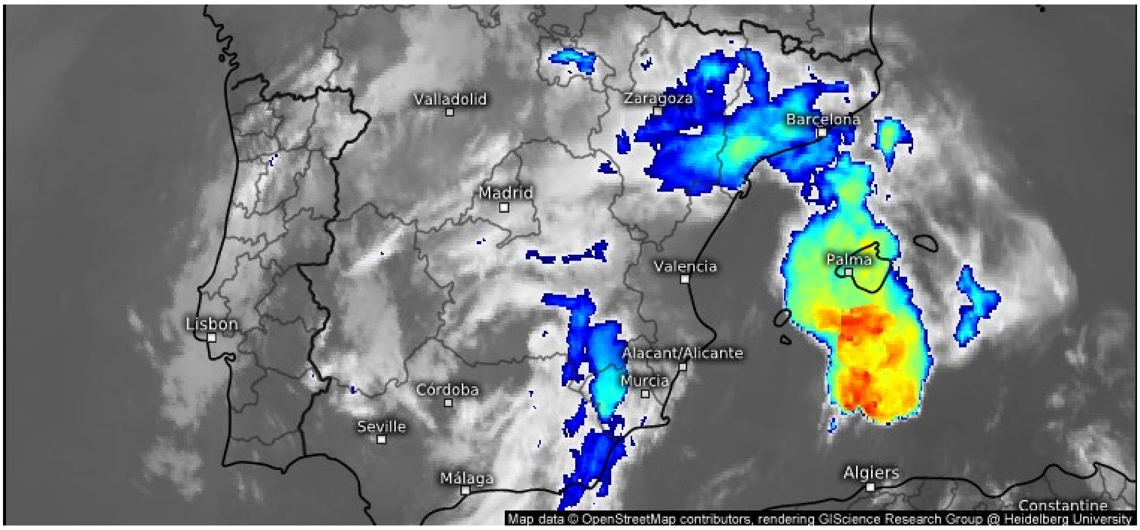

Figure 2.2: Satellite image of Spain, 13.09.2019 21:30z [41]

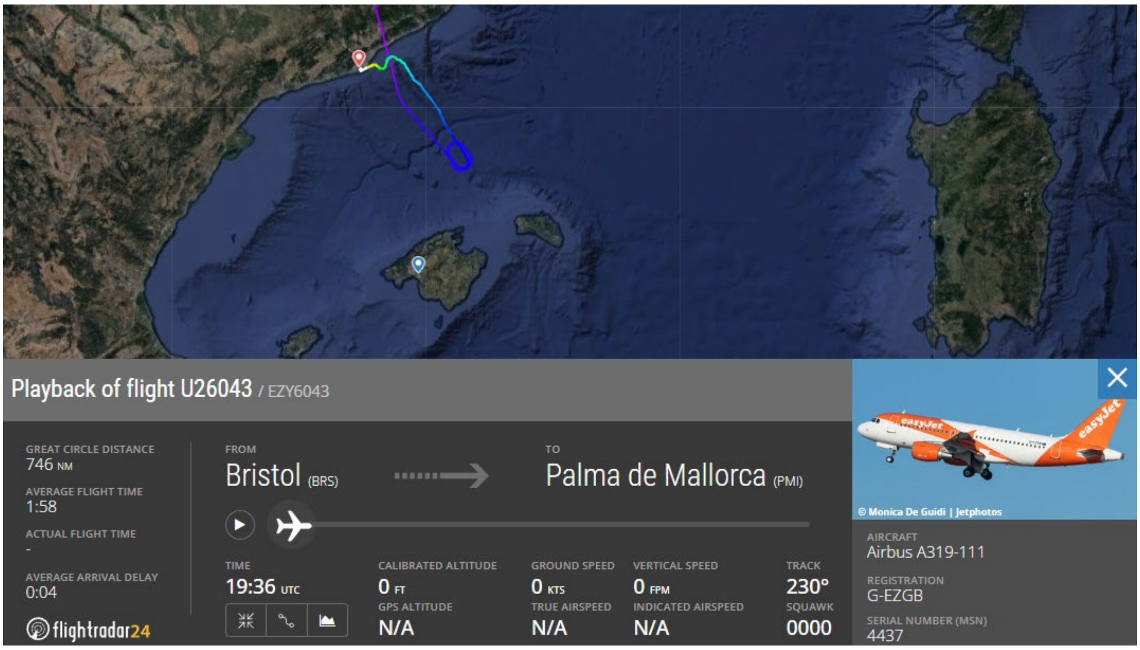

Figure 2.3: EZY6043 flight path [24]

Weather phenomena causing diversion: TS, CB

2.3.2 Example 2

The EasyJet Airbus A319-100 diverted to Menorca Airport (LEMH), as stated in the NMIR data in Tables 2.13 and 2.14. The reason for the diversion was a strong wind at Mallorca Airport (LEPA), as can be seen in Figure 2.15.

Table 2.13: EZY58GM NMIR flight data [23]

AIRCRAFT ID	**AIRCRAFT TYPE**	**AIRCRAFT OPERATOR**	**ADEP**	**ADES**	**DIVERTED ADES**
EZY58GM	A319	EZY	EGGP	LEPA	LEMH

Table 2.14: EZY58GM NMIR flight data [23]

AIRCRAFT ID	**LOBT**	**ETOT**	**ATOT**	**ETA**	**ATA**
EZY58GM	09.12.2019 10:10:00	09.12.2019 10:20:00	09.12.2019 10:14:38	09.12.2019 12:22:25	09.12.2019 12:44:00

The wind on the final approach for runway 24L was an almost direct crosswind of 30 kt with gusts of 43 kt, as shown in Figure 2.4. The maximum crosswind limitation demonstrated for Airbus A319 is 38 knots with gusts included. [43]

Table 2.15: Aaltronav METAR data for LEPA [22]

METAR LEPA
LEPA 091200Z 33034G46KT 9999 FEW018 18/06 Q1020 NOSIG
LEPA 091230Z 32030G43KT 9999 FEW018 18/05 Q1020 NOSIG

Table 2.16: Aaltronav METAR data for LEMH [22]

METAR LEMH
LEMH 091230Z 30010G20KT 250V340 9999 BKN038 15/08 Q1019
LEMH 091300Z 30010G20KT 250V340 9999 BKN040 14/07 Q1019

The aircraft continued to Menorca Airport, where the wind did not pose a risk to the flight as shown in Table 2.16 and Figure 2.5.

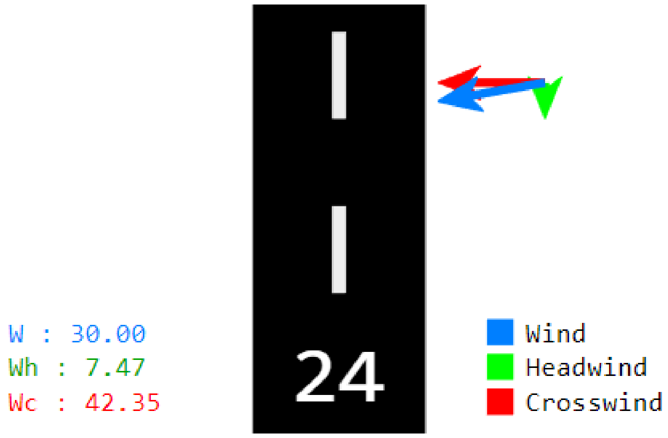

Figure 2.4: Crosswind component of EZY58GM at LEPA [42]

Figure 2.5: EZY58GM flight path [24]

Weather phenomena causing diversion: Strong crosswind

2.3.3 Example 3

The EasyJet Airbus A320-200 diverted to Turin Airport (LIMF) due to reduced visibility and low ceiling at the destination, as stated in the NMIR data in Tables 2.17 and 2.18.

Table 2.17: EJU12GP NMIR flight data [23]

AIRCRAFT ID	AIRCRAFT TYPE	AIRCRAFT OPERATOR	ADEP	ADES	DIVERTED ADES
EJU12GP	A320	EJU	LFBD	LIMC	LIMF

Table 2.18: EJU12GP NMIR flight data [23]

AIRCRAFT ID	LOBT	ETOT	ATOT	ETA	ATA
EJU12GP	29.12.2019 16:55:00	29.12.2019 17:08:00	29.12.2019 17:14:00	29.12.2019 18:40:32	29.12.2019 18:51:52

The light wind and high-pressure system created ideal conditions for the creation of a fog and the weather was below limits with the category I precision approach, as shown in Metar in Table 2.19. No information on aircraft MEL, crew experience, and training has been available. It has to be assumed that the crew could not land under ILS CAT II/III.

Table 2.19: Aaltronav METAR data for LIMC [22]

METAR LIMC
LIMC 291820Z VRB02KT 0200 R35R/0900VP1500U R17L/1300D R35L/0200N FG BKN001 01/01 Q1032 NOSIG
LIMC 291850Z 02002KT 0100 R35R/0200N R17L/0400U R35L/0275N FG BKN001 00/00 Q1033 NOSIG

Table 2.20: Aaltronav METAR data for LIMF [22]

METAR LIMF
LIMF 291820Z 28004KT 3500 BR NSC 03/01 Q1032
LIMF 291850Z 31004KT 3500 BR NSC 02/00 Q1032

The area of fog ranged to the southeast of Milan, leaving Turin with good conditions for landing, as shown in Table 2.20 and Figure 2.7. Figure 2.6 shows the flight path of diversion to Turin.

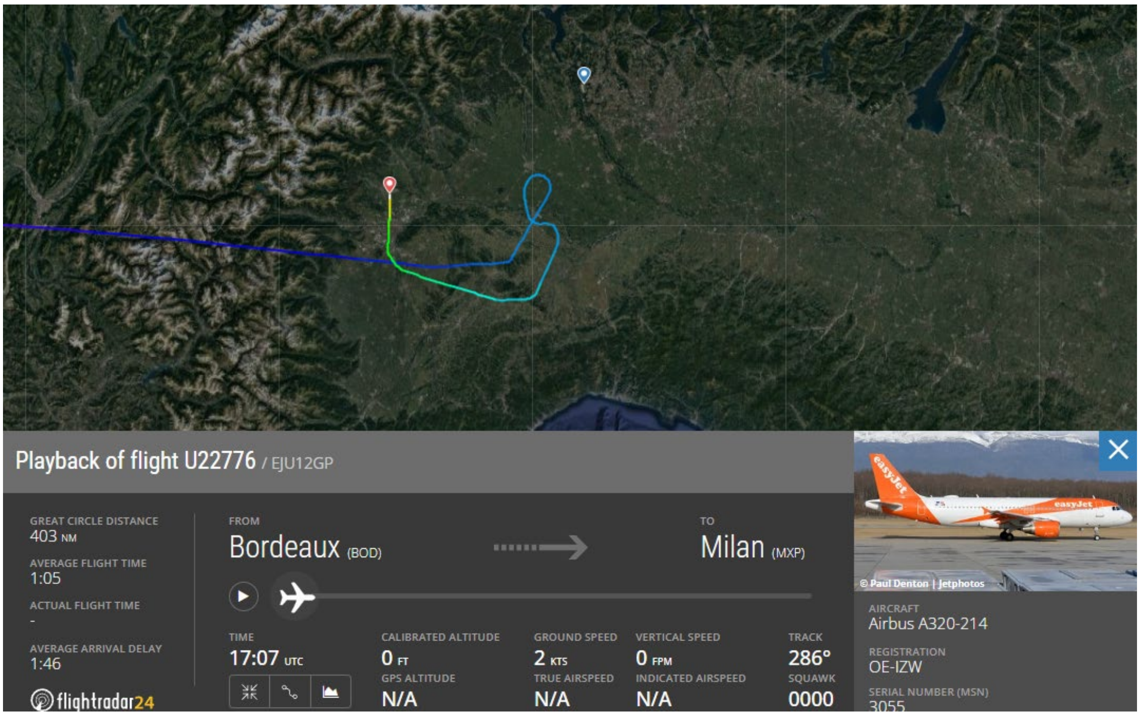

Figure 2.6: EJU12GP flight path [24]

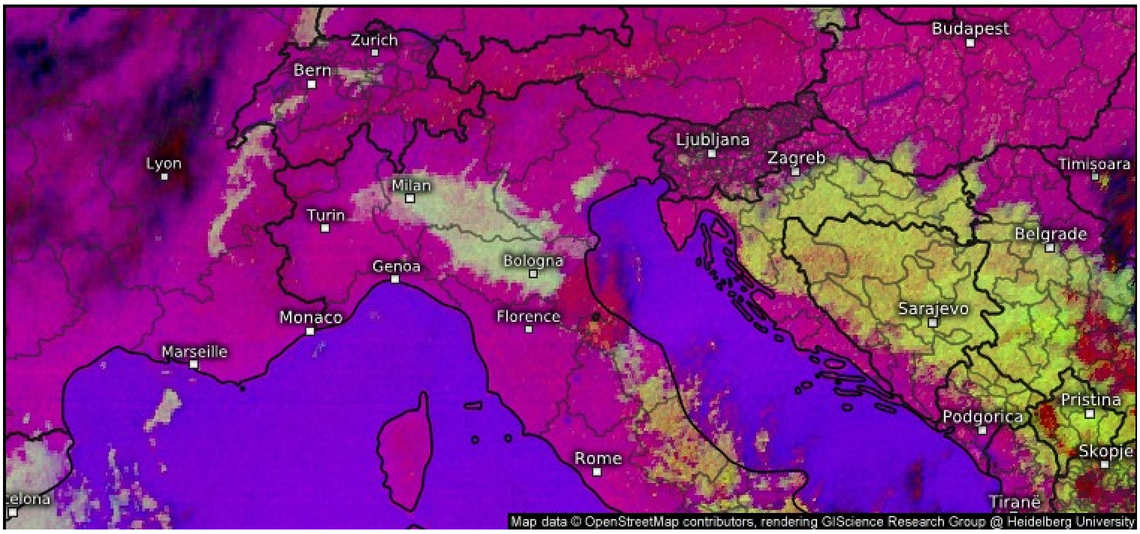

Figure 2.7: Satellite image of Italy, fog 29.12.2019 18:20z [41]

Weather phenomena causing diversion: RVR, VIS, FG, LOW CLOUD CEILING

2.3.4 Example 4

DHL Boeing B757-200 performed a night cargo flight to Brussels. The rapid development of a thunderstorm with rain shown in Table 2.23 forced the fight to divert to Cologne Airport, as stated in the NMIR data in Tables 2.21 and 2.22.

Table 2.21: BCS120 NMIR flight data [23]

AIRCRAFT ID	AIRCRAFT TYPE	AIRCRAFT OPERATOR	ADEP	ADES	DIVERTED ADES
BCS120	B752	BCS	EDDP	EBBR	EDDK

Table 2.22: BCS120 NMIR flight data [23]

AIRCRAFT ID	LOBT	ETOT	ATOT	ETA	ATA
BCS120	28.08.2019 23:35:00	28.08.2019 23:50:00	28.08.2019 23:53:00	29.08.2019 0:45:16	29.08.2019 1:44:12

The crew was held in a holding pattern for 15 minutes and then tried to circumnavigate through convective weather, but without success. They landed at Cologne Airport 50 minutes later, where the weather was clear, as stated in the Metar in Table 2.24.

Table 2.23: Aaltronav METAR data for EBBR [22]

METAR EBBR
EBBR 290020Z 24004KT 9000 TSRA FEW012 BKN045CB 18/16 Q1017 TEMPO 2500 TSRA BKN014CB
EBBR 290050Z 29009KT 9000 TSRA FEW012 BKN045CB 18/15 Q1017 TEMPO 2500 TSRA BKN014CB
EBBR 290120Z 29005KT 9999 VCTS RA FEW012 BKN045CB 17/15 Q1017 NOSIG

Table 2.24: Aaltronav METAR data for EDDK [22]

METAR EDDK
EDDK 290120Z 05004KT CAVOK 18/17 Q1015 NOSIG
EDDK 290150Z VRB02KT CAVOK 18/17 Q1015 NOSIG

The flight path is shown in Figure 2.8.

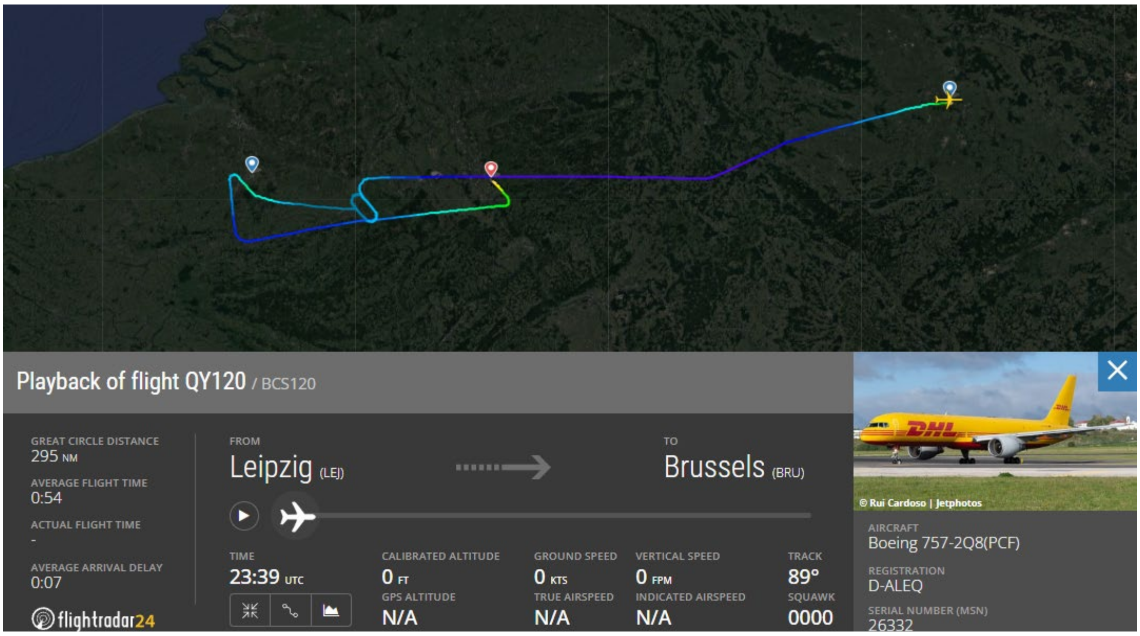

Figure 2.8: BCS120 flight path [24]

The satellite images in Figures 2.9 and 2.10 show the Thunderstorm over Brussels.

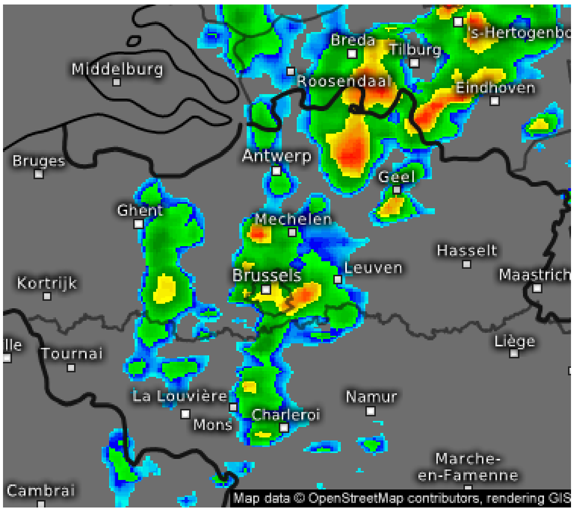

Figure 2.9: Satellite image of Belgium, 29.08.2019 00:30z [41]

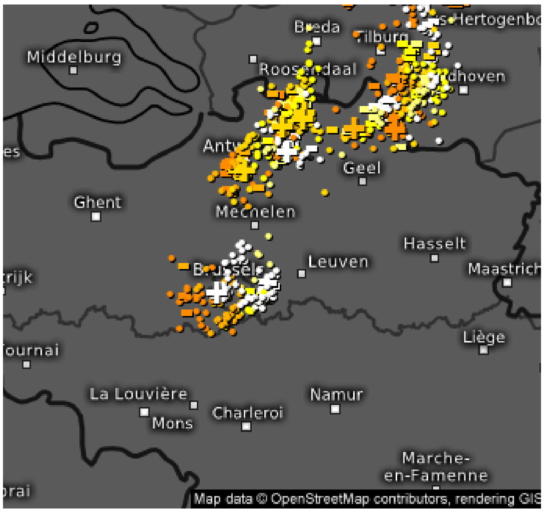

Figure 2.10: Lightning image of Belgium, 29.08.2019 00:30z [41]

Weather phenomena causing diversion: TSRA, CB

2.3.5 Example 5

The last example is a flight diversion of Norwegian Airlines operated by the Danish airline Jettime. A Boeing 737-800 diverted to Dresden, as stated in the NMIR data in Tables 2.25 and 2.26. The weather in Dresden did not pose a risk to the flight, as shown in Table 2.28.

Table 2.25: IBK3580 NMIR flight data [23]

AIRCRAFT ID	AIRCRAFT TYPE	AIRCRAFT OPERATOR	ADEP	ADES	DIVERTED ADES
IBK3580	B738	IBK	EKCH	LKPR	EDDC

Table 2.26: IBK3580 NMIR flight data [23]

AIRCRAFT ID	LOBT	ETOT	ATOT	ETA	ATA
IBK3580	19.12.2019 9:30:00	19.12.2019 9:40:00	19.12.2019 9:45:00	19.12.2019 10:46:17	19.12.2019 11:15:31

Low visibility and fog was present in Prague at the time of arrival. And the weather was on limits with the category I precision approach as shown in Table 2.27. Further limitations on low visibility procedures and ILS CAT II, III are discussed in the limitations of the thesis.

Table 2.27: Aaltronav METAR data for LKPR [22]

METAR LKPR
LKPR 191000Z 34004KT 0500 R24/0700D R30/0700N FG VV002 01/01 Q1019 BECMG 1200 BR BKN003
LKPR 191030Z 35004KT 0400 R24/0450D R30/0500N FG VV002 02/01 Q1019 RMK REG QNH 1015
LKPR 191100Z VRB02KT 0400 R24/0800U R30/0550N -DZ FG VV002 02/02 Q1018 BECMG 0700 FG

Table 2.28: Aaltronav METAR data for EDDC [22]

METAR EDDC
EDDC 191050Z 15014KT CAVOK 09/06 Q1017 BECMG 15015G25KT
EDDC 191120Z 14013KT 110V170 9999 FEW012 09/06 Q1016 TEMPO 15015G25KT

The flight path is shown in Figure 2.11

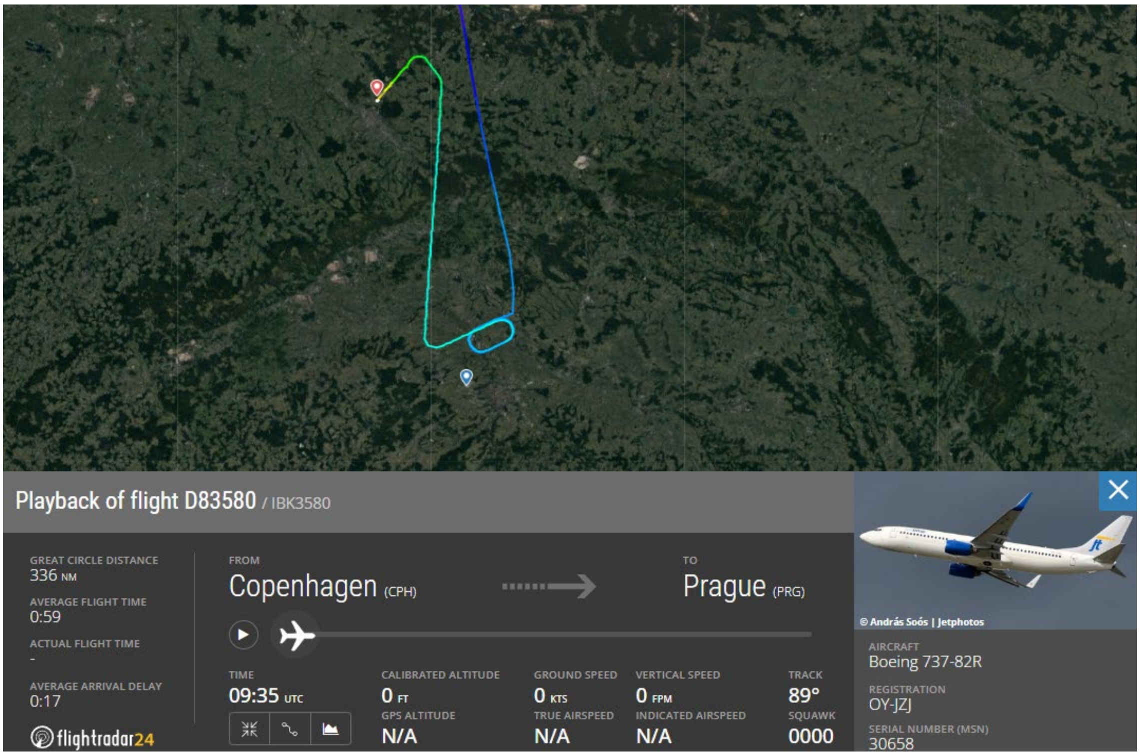

Figure 2.11: IBK3580 flight path [24]

In the satellite image shown in Figure 2.12 an extensive area of fog covers the centre and southeast of the Czech Republic, leaving Dresden with a clear sky.

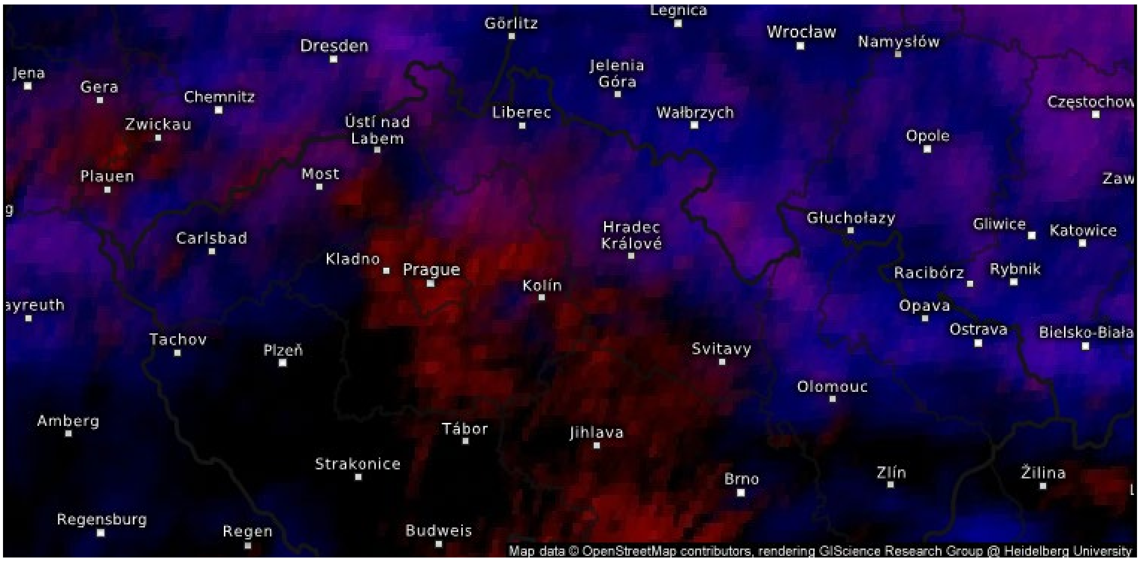

Figure 2.12: Satellite image of the Czech Republic, fog 19.12.2019 10:30z [41]

Weather phenomena causing diversion: RVR, VIS, FG, LOW CLOUD CEILING

3. Results

A total of 1187 flights have been subjected to examination. The data pairing process revealed that 59% of diverted flights are presumably diverted without being related to adverse weather. They include diversions due to technical problems, health-related, safety and security incidents in the air and on the ground. The remaining 41% are due to weather based on the data pairing. The breakdown of data pairing can be seen in Table 3.1. Along with the basic meteorological elements, such as pressure, density, wind, temperature, and humidity, more factors are relevant for flying, such as visibility, low clouds, precipitation, thunderstorms and, connected dangers.

Table 3.1: Breakdown of flight diversions

ALL FLIGHT DIVERSIONS FROM DATA SET	
1187	
WEATHER RELATED	494
OTHER CAUSES	693

Most of the flight diversions were caused by dangerous phenomena. Deep convection in the form of cumulonimbus clouds poses a great risk to flight, as these clouds can lead to the development of thunderstorms, squalls and, in extreme cases, funnel clouds. Very often, they are accompanied by heavy precipitation, severe turbulence, and are very hard to forecast due to their rapid development.

The second largest part belongs to reduced visibility and low cloud. The worst visibility conditions occur in fog, clouds, and in precipitation. Low clouds and reduced visibility are often associated with a stable atmosphere and stratus-type cloud. The vertical extent of the stratus cloud may range from a few hundred feet up to several thousand feet.

The rest is covered by crosswind and windshear. Detailed classification is shown in Table 3.2 and Figure 3.1.

Table 3.2: Weather classes causing flight diversions at selected airports in 2019

WEATHER	DIVERTED FLIGHTS
DANGEROUS PHENOMENA	288
CEILING AND VISIBILITY	191
CROSSWIND, WS[13]	15

[13] WS without presence of dangerous phenomena

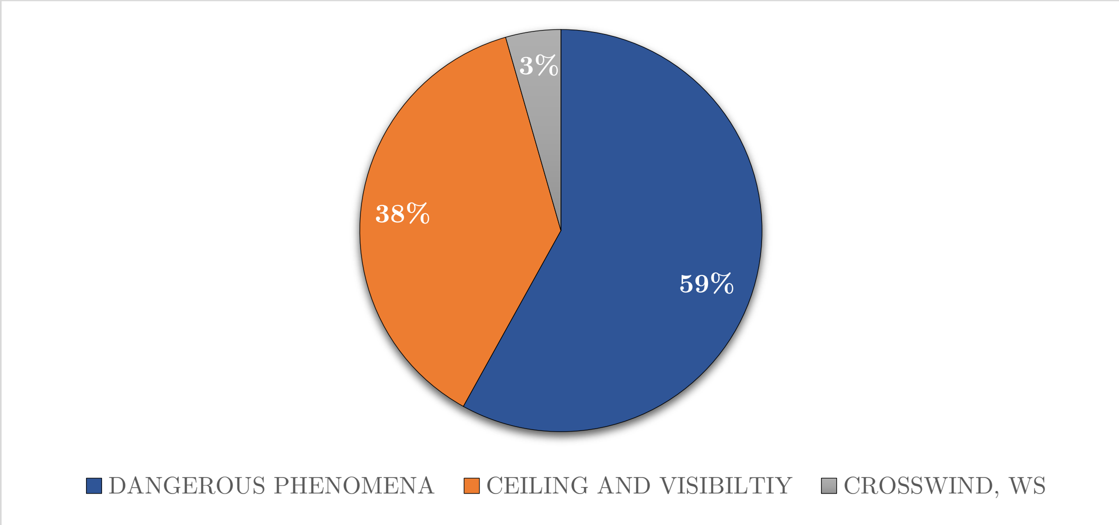

Figure 3.1: Percentage expression of weather classes causing flight diversions

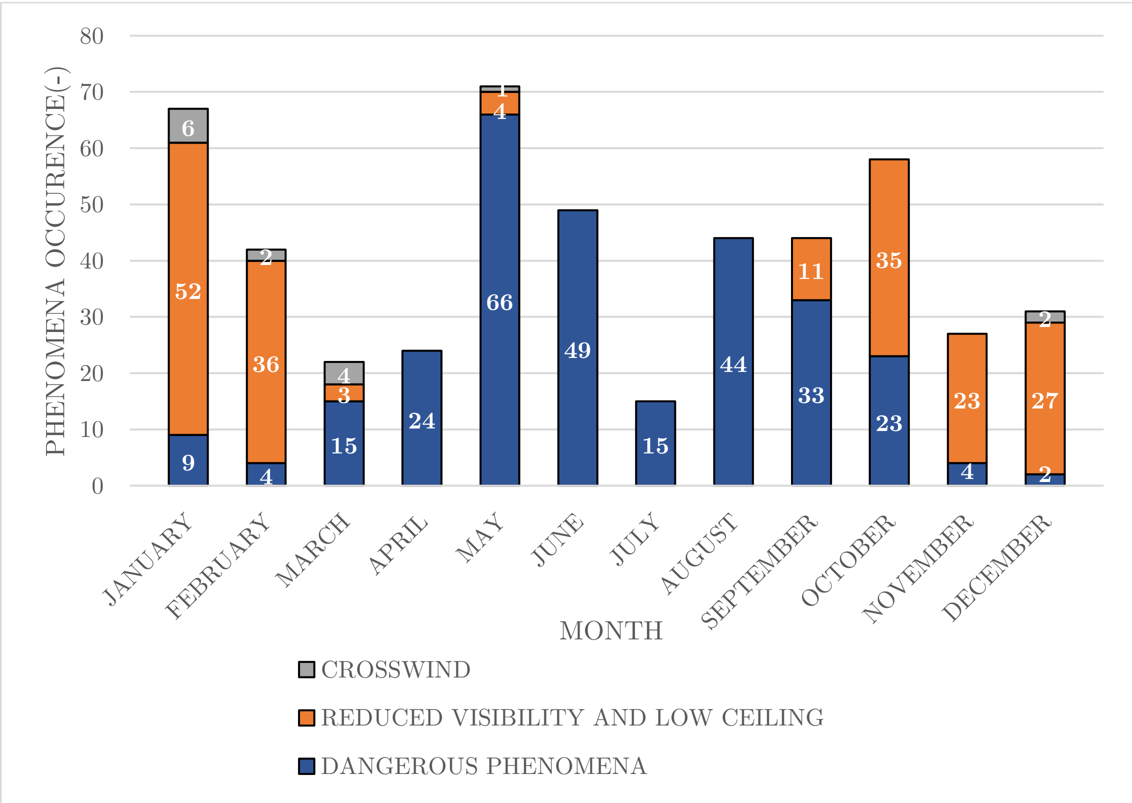

Figure 3.2: Monthly analysis of weather classes causing flight diversions

Based on the results, some months are more susceptible to flight diversion than others, and the composition of the causes of flight diversion depends on the time of year, as can be seen in Figure 3.2.

March, April, and July have the lowest flight diversion rate. March and April are months when spring begins, and convection increases its intensity, but it does not reach its maximum. By the beginning of spring, temperatures start to increase, and fogs gradually stop creating. The reduced number of flight diversions in July might be caused by a high number of cloudless days and days with overcast medium and high cloud coverage. With a stable atmosphere most of the time, convective clouds did not overdevelop into cumulonimbus clouds and thunderstorms. Satellite images have been looked up for each day in July, and they showed less convection overdevelopment than in the adjacent months.

Figure 3.3: Summary of weather classes causing flight diversions

Figure 3.3 shows that each airport shows a different number of flight diversions; this is caused by the fact that each airport has different yearly traffic. For example, EDDF has the highest number of flight diversions, but also the highest yearly traffic from the selected airports. The geographic location of the airport is also important for the number of flight diversions. All airports in the data pairing had the same requirements for airport navigation equipment, but the number of flight diversions due to dangerous phenomena was higher in LIMC due to the proximity of the Alps, which supports convective overdevelopment with its rugged contours of the landscape, and in LEPA due to Mediterranean climate.

3.1 Dangerous Phenomena

During the spring and summer months, most flight diversions were caused by dangerous phenomena, especially convective weather. Cumulonimbus and towering cumulus are clouds which should be avoided and represent a danger to a flight. Strong updraughts and downdraughts are constantly present, producing severe precipitation in the form of rain showers, hail, and strong wind. Convective clouds also developed in thunderstorms and squall lines. [8] Table 3.3 shows a detailed analysis of flights diverted due to dangerous phenomena.

Table 3.3: Analysis of dangerous phenomena

<table>
<tr><th colspan="4">DANGEROUS PHENOMENA</th></tr>
<tr><td colspan="4">288 FLIGHTS</td></tr>
<tr><td colspan="4">CONVECTIVE CLOUDS</td></tr>
<tr><td>CB</td><td colspan="3">242</td></tr>
<tr><td>TCU</td><td colspan="3">71</td></tr>
<tr><td colspan="4">PRECIPITATION</td></tr>
<tr><td>RA</td><td colspan="3">241</td></tr>
<tr><td>SN</td><td colspan="3">12</td></tr>
<tr><td>GR</td><td colspan="3">27</td></tr>
<tr><td>GS</td><td colspan="3">5</td></tr>
<tr><td colspan="4">CONVECTIVE OVERDEVELOPMENT</td></tr>
<tr><td>TS</td><td>9</td><td colspan="2">-</td></tr>
<tr><td>TSRA</td><td>153</td><td>SQ</td><td>4</td></tr>
<tr><td>TSRAGR</td><td>27</td><td colspan="2">-</td></tr>
<tr><td>TSRAGS</td><td>2</td><td colspan="2">-</td></tr>
<tr><td colspan="4">WIND EMERGING FROM CONVECTIVE OVERDEVELOPMENT</td></tr>
<tr><td>WIND >20KT / GUSTS >20KT</td><td colspan="3">40</td></tr>
<tr><td>WS</td><td colspan="3">13</td></tr>
</table>

Table 3.4: Weather phenomena example

WEATHER PHENOMENA
TSRA, CB, SQ

This specific example in Table 3.4 was classified as weather class dangerous phenomena as it successfully fulfilled conditions stated in the data pairing parameters for evaluating weather-related flight diversions section. Each weather phenomenon was sorted and added to the table category. 288 flights were diverted due to dangerous phenomena, but more than one phenomenon could be present at the time of flight diversion.

As we can see in Figure 3.4, convective weather is highest during the summer months when high humidity, in conjunction with warm temperatures, creates areas of warm, moist air rising into the atmosphere. [25]

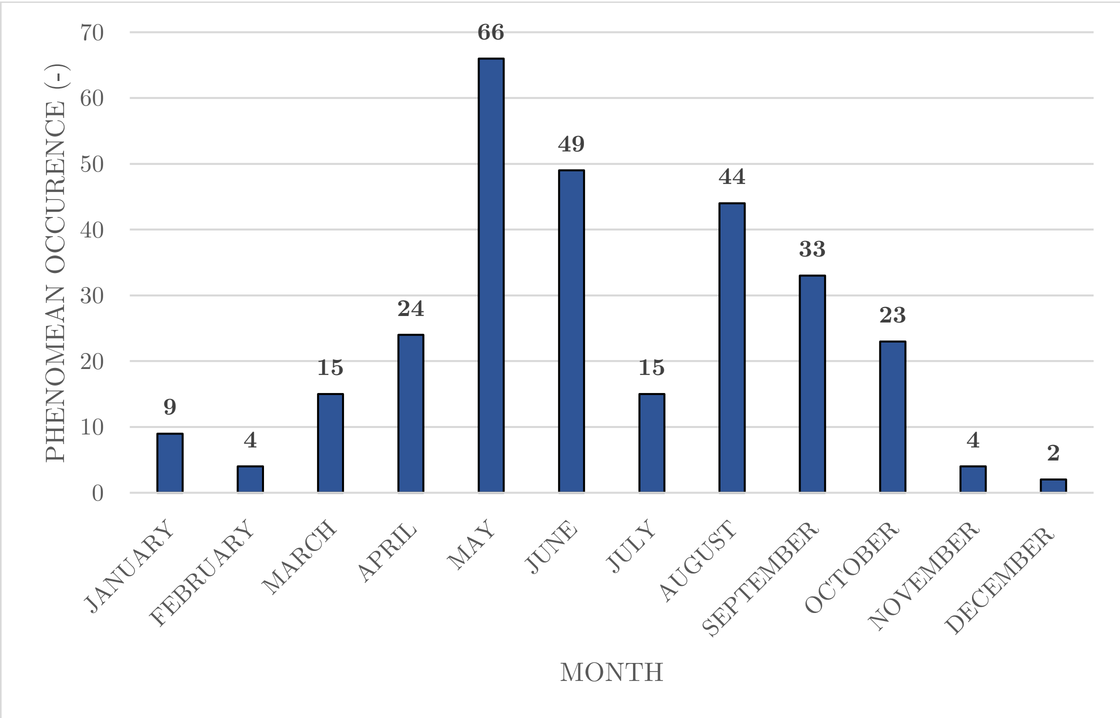

Figure 3.4: Occurrence of dangerous phenomena during the year

3.2 Low Cloud Ceiling and Reduced Visibility

During the autumn and winter months, flight crews and flight planning departments have to deal with reduced visibility in the form of fog and mist associated with low cloud. Snow has a significant impact on operations, especially in the initial phase of snowing, when airport operations have to adapt to the situation. Table 3.5 shows a detailed analysis of flights diverted due to a low ceiling and reduced visibility.

Table 3.5: Analysis of ceiling and visibility

CEILING AND VISIBILITY	
191 FLIGHTS	
CLOUD CEILING <300 ft	155
RVR <550 m	100
VISIBILITY <800 m	134
OBSCURATION	
FG	115
BR	29
PRECIPITATION	
SN	55
RA	15
DZ	9

A total of 191 flights have been classified as flight diversions due to a low ceiling and reduced visibility. Each flight has been paired with METAR, and the phenomena that contribute to the diversion were assigned.

Table 3.6: Weather phenomena example

WEATHER PHENOMENA
RVR, VIS, FG, LOW CLOUD CEILING

This specific example in Table 3.6 was classified as weather class ceiling and visibility as it successfully fulfilled conditions stated in the data pairing parameters for evaluating weather-related flight diversions section. Each weather phenomenon was sorted and added to the table. The RVR was <550 m, the visibility of <800 m was caused by fog, and the cloud ceiling was also <300 ft.

At 191 flights, the cloud ceiling <300 ft occurred 155 times, the RVR <550 m 100 times, and visibility 134 times. Reduced visibility was caused 115 times by fog and 29 times by mist. Simultaneously, precipitation occurred in the form of snow, rain, and drizzle.

The low ceiling and reduced visibility cause flight diversions mainly in autumn and winter, as shown in Figure 3.5.

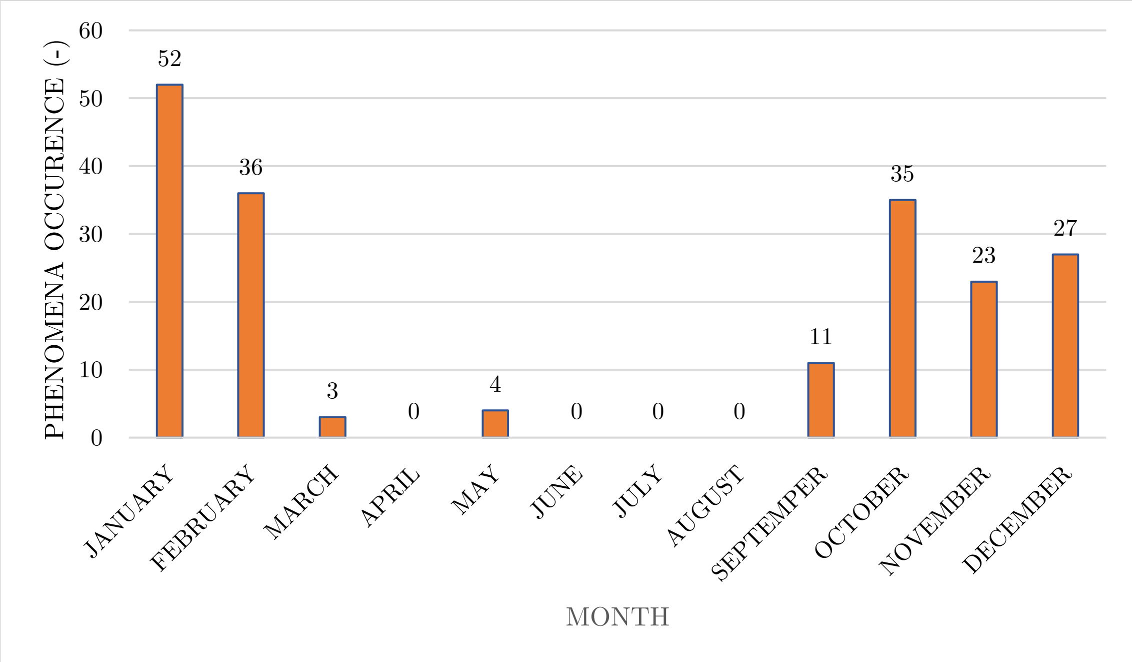

Figure 3.5: Occurrence of reduced visibility and low ceiling during the year

3.3 Crosswind and Windshear

Airport efficiency and flight operations are affected by the wind in various ways. Strong headwind and crosswind could reduce runway throughput and increase delays. Tailwind does not usually add excessive complexity to operations until the runway direction in use can be changed. [26] For commercial aircraft, the crosswind component is the most critical wind factor in determining whether the diversion was caused by the wind. A strong direct headwind is not a factor for most airliners. All data with winds above 20 kt were further processed and divided into categories. Due to the access to flightradar24.com historical data and METARs, it was able to determine the runway in use and calculate the crosswind component, the results are shown in Table 3.7.

Table 3.7: Wind as the main cause of the flight diversion

CROSSWIND	
CROSSWIND > 20 KT / GUSTS > 25 KT	11
PRECIPITATION	
RA	5
SN	5
WINDSHEAR	
4	
PRECIPITATION	
RA	1

Discussion

During research, it was unable to find a study that directly analyzed the meteorological phenomena that cause flight diversions. All papers mainly analyzed flight delays and the influence on airport operations, where bad weather is also one of the factors. Flight delays and flight diversions certainly have a lot in common, but only part of flights affected by weather have to be diverted to another airport. The rest are just delayed. An example of thunderstorms temporarily preventing landings at airports happened on 2 July 2014 in the New York area. The aircraft were forced to hold until the weather cleared. In total, 177 flights were held, representing more than 5000 minutes of delay, but only 97 aircraft diverted to alternate airports. [44]. Although not all flights diverted to alternate airports, it is a very good indicator, highlighting phenomena that have a high impact on air traffic. Weather is considered one of the most common reasons for flight diversion; however, detailed data on weather diversions are not centrally available for the European market, and the European Organization for the Safety of Air Navigation does not archive the data and does not have them available. However, access to databases of the European Organisation for the Safety of Air Navigation of all diverted flights that occurred in the integrated initial flight plan processing system zone was given. Using the diversion data and a set of meteorological reports obtained from Aaltronav and Ogimet, it was possible to determine weather-caused flight diversions and locate the individual phenomena that caused the flight to divert. The data pairing revealed that at ten selected airports, a total of 494 flight diversions due to weather occurred in 2019. In the summer months, flight diversions were mostly caused by dangerous phenomena related to convective clouds and their overdevelopment. In the winter months, reduced visibility, low ceiling, and fog appeared. A strong wind was not a problem in most cases, as the main component was a headwind, which at most creates a delay due to a reduction in the capacity of the airport or sector. However, a strong crosswind is a reason for a flight diversion.

The validation of the methodology and results used can be confirmed by a study published by FAA, which analyzes weather delays at New York airports. [44] The meteorological phenomena that cause flight diversions depend on the geographic location of the airport. Based on the data-pairing, in temperate climate zone were, most flight diversions caused by three main phenomena. Convective weather, reduced visibility and low ceiling and crosswind. According to Figure 4.1, in the winter months, operations were affected by reduced visibility and low ceiling. The increased value of wind would be attributed to the fact that wind has multiple effects on air navigation services and airport performance. Strong wind could reduce runway throughput and increase delays, but it will not automatically cause a diversion to a different airport. In the summer months, most of the delays were caused by convective weather. The delay results presented here correspond to the results found from the data pairing, with the exception that for a diversion, it is necessary that the phenomena not only reduce the capacity of the throughput of the sector and the airport, but also create a significant risk for the safe completion of the flight.

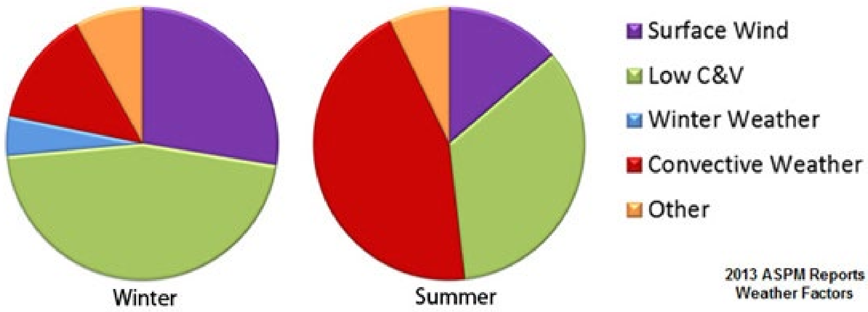

Figure 4.1: FAA weather delays, New York airports, 2013 [44]

Limitations

From the METAR we do not know the exact situation at the airport, which the crew will request from the air traffic controller by frequency, so we have to rely on the information from the last METAR, SIGMET and satellite pictures. At most airports, meteorological reports are issued once every 30 minutes, which is a considerably long time in the case of weather development. For example, rapidly changing RVR or the development of convective clouds.

In data pairing, some flights have been diverted due to reduced visibility and a low ceiling that did not meet the conditions of the CAT ILS I precision approach, although they are equipped with modern navigational equipment for low visibility procedures allowing operations under CAT ILS II, III. As no information on the MEL of the aircraft, the experience of the crew, and training has been available, all these flights had to be classified as flight diversions due to weather. It can be seen here that even though the airport and the aircraft are equipped with modern systems, this does not mean that the flight can always land safely in low visibility.

Ten selected airports were consulted and proposed by the navigation departments of Czech aircraft operators. Based on the data pairing, geographic location affects the composition of the phenomena that influence airports. Although the data pairing produced the desired results. For further research, selection of more European airports or processing a narrowed geographic area would be recommended and would provide more detailed results.

Conclusion

Weather has a significant effect on the efficient and safe operations of air transport and must be closely considered at all stages of flight preparation and flight itself. Precise forecasts and reports help minimize unexpected reroutings and allow airlines to take mitigating actions, however, weather sometimes deteriorates, and flight have to be diverted to alternate airport. The approach to the selection of an alternate airport was described and a recommended selection procedure for flight operators was proposed. The methodology of this work analyzed flight diversions due to weather and identified adverse weather phenomena at ten selected airports in Europe for 2019. Data pairing was done manually, as the process would be very difficult to automate due to a large number of inputs and the need to individually assess each individual flight. Automatization might be possible with the use of artificial intelligence or machine learning, although the commissioning of the algorithm and the application would be very complex. As there is no detailed database of flight diversions, a flight diversions reporting system should be created. Airlines and airports would report the reason and details about flight diversions to the system. Accessible data would help better optimize diverted flights and reduce financial penalties. Unlike diversions for technical and medical reasons, where the incriminated aircraft is diverted as the only aircraft in the area. Flight diversions of multiple aircraft at the same time are more of a concern than flight diversions of individual aircraft. Weather can cause events in which several flights are forced to divert. As traffic in adjacent airports increases, congestion will arise. Airports have predetermined performance and capacity, and diverted flights must be evenly spread to multiple airports. Most flight diversions were caused by convective weather. Cumulonimbus clouds affected air traffic mainly in the months with intense solar heating over the surface and were often overdeveloped into thunderstorms associated with precipitation and strong winds. The second most common phenomena that predominantly affected operations in the winter months were a low cloud ceiling and reduced visibility. The main obscuration was a fog, which reduces the runway visual range and visibility. Wind also contributed to flight diversions, especially the crosswind, which is the most limiting for the landing. The results of this thesis can be used in the further enhancement of the diversion airport selection methodology and used by European airports and aircraft operators, as there are almost no statistics available for weather flight diversions. An international diversion can cost an airline up to $ 200 000. [5] When multiplied by the global number of diverted flights, even a small contribution to reducing aircraft delays and flight diversions can represent significant cost savings. The wrong selection of an alternate airport that does not have enough capacity, personnel, or material resources to handle a flight diversion in a timely manner can negatively influence airline operations and increase the loss of revenue.

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Attachments

Attachment A – All flight diversions

Attachment B – Flight diversions caused by weather