CZECH TECHNICAL UNIVERSITY IN PRAGUE

FACULTY OF TRANSPORTATION SCIENCES

Bc. Martin Pospíšil

Airlines Decision on Aircraft Parking in Covid-19 Crisis

Master thesis

2022

ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE
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ZADÁNÍ DIPLOMOVÉ PRÁCE

(PROJEKTU, UMĚLECKÉHO DÍLA, UMĚLECKÉHO VÝKONU)

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Bc. Martin Pospíšil

Studijní program (obor/specializace) studenta:

navazující magisterské –PL– Provoz a řízení letecké dopravy

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Zásady pro vypracování

Při zpracování diplomové práce se řiďte následujícími pokyny:

- Cílem práce je nalézt model, který bude popisovat rozhodování leteckých společností o parkování svých flotil v průběhu Covid-19. Základem pro analýzu jsou atributy letadel, letišť a vnějších vlivů.
- Technické souvislosti při údržbě v rámci parkování letadel
- Letadlové flotily, zdroje dat, jejich struktura, zpracování a vyhodnocení
- Popis atributů parkování letadel a jejich analýza
- Analýza parkování flotil leteckých společností
- Vytvoření modelu rozhodování a validace

Rozsah grafických prací:	dle pokynů vedoucího diplomové práce
Rozsah průvodní zprávy:	minimálně 55 stran textu (včetně obrázků, grafů a tabulek, které jsou součástí průvodní zprávy)
Seznam odborné literatury:	Budd, L; Ison, S; Adrienne, N; - European airline response to the COVID-19 pandemic, 2020 Adrienne, N; Budd, L; Ison, S; - An airfield operations perspective of the challenges of resuming flights post COVID, 2020 Serrano, F; Kazda, A; - The future of airport post COVID-19, 2020

Vedoucí diplomové práce: **doc. Ing. Peter Vittek, Ph.D.**

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Datum zadání diplomové práce: **16. července 2021**
(datum prvního zadání této práce, které musí být nejpozději 10 měsíců před datem prvního předpokládaného odevzdání této práce vyplývajícího ze standardní doby studia)

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

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MASTER'S THESIS ASSIGNMENT

(PROJECT, WORK OF ART)

Student's name and surname (including degrees):

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Study programme (field/specialization) of the student:

master's degree – PL – Air Traffic Control and Management

Theme title (in Czech): **Rozhodování leteckých společností při parkování letadel v krizi Covid-19**

Theme title (in English): Airlines Decision on Aircraft Parking in Covid-19 Crisis

Guidelines for elaboration

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

- Goal of the thesis is to find a model, that will describe airlines decision on parking of their fleets during Covid-19. Basis for analysis are attributes of aircraft, airports and external factors.
- Technical context in maintenance in the frame of aircraft parking.
- Aircraft fleets, data sources, their structure, processing and evaluation.
- Description of aircraft parking attributes and their analysis.
- Analysis of parking of airlines fleets.
- Creation of decision-making model and validation.

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Graphical work range: according to the instructions of thesis supervisor

Accompanying report length: minimum of 55 text pages (including figures, graphs and sheets which are part of the main text)

Bibliography:

Budd, L; Ison, S; Adrienne, N; - European airline response to the COVID-19 pandemic, 2020

Adrienne, N; Budd, L; Ison, S; - An airfield operations perspective of the challenges of resuming flights post COVID, 2020

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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

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I confirm assumption of master's thesis assignment.

Bc. Martin Pospíšil
Student's name and signature

Prague .... July 16, 2021

Preface

With this paper I mark the end of my journey here at Czech Technical University. I would like to thank Mr. Peter Vittek for his supervising activities and enthusiasm during our meetings. His guidance skills left a contribution to this enterprise.

Declaration

I hereby declare that I have developed this thesis independently and that I have listed all used sources of information in accordance with Methodical Guidelines on the Ethical Preparation of University Thesis.

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podpis

CZECH TECHNICAL UNIVERSITY IN PRAGUE
Faculty of Transportation Sciences

AIRLINES DECISION ON AIRCRAFT PARKING IN COVID-19 CRISIS

Master thesis
May 2022

Martin Pospíšil

ABSTRACT

The purpose of this thesis is to present a research on decision-making process of aircraft operators on aircraft parking in response to Covid-19 pandemic. The idea is to address individual factors that had a significant influence on such decision-making and fuse them into a simple functional model. This heuristic approach is based on a sample of aircraft parking records. Various statistics and findings will be presented.

KEYWORDS

Aircraft parking, Covid-19, aircraft storage, decision-making, data analysis, data, aircraft maintenance, airport, aircraft grounding

ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE
Fakulta dopravní

Rozhodování leteckých společností při parkování letadel v krizi Covid-19

Diplomová práce
Květen 2022
Martin Pospíšil

ABSTRAKT

Cílem této diplomové práce je představit výzkum k rozhodování leteckých společností při parkování letadel v reakci na pandemii Covid-19. Myšlenkou je adresovat jednotlivé faktory, které měly významný vliv na tento rozhodovací proces a spojit je do jednoduchého funkčního modelu. Tento heuristický přístup je založen na vzorku záznamů parkování letadel. Budou představeny různé statistiky a nálezy.

KLÍČOVÉ SLOVA

Parkování letadel, Covid-19, uzemnění letadel, rozhodovací proces, analýza dat, data, údržba letadel, letiště

Table of Contents

Acronyms and abbreviations

ACI	Airports Council International
ACN	Aircraft Classification Number
AD	Airworthiness Directive
ADS-B	Automatic Dependent Surveillance - Broadcast
AMM	Aircraft Maintenance Manual
AMO	Approved Maintenance Organization
AOC	Air Operator Certificate
APU	Auxiliary Power Unit
ARC	Airworthiness Review Certificate
ASK	Available seat-kilometer
BAW	British Airways
CAMO	Continuing Airworthiness Management Organization
CMM	Component Maintenance Manual
CPU	Central Processing Unit
EASA	European Union Safety Agency
EU	European Union
FAA	Federal Aviation Administration
FAQ	Frequently Asked Questions
FTK	Freight tonne-kilometer
GA	General Aviation
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
INS	Inertial Navigation System
MPD	Maintenance Planning Document
MTO	Maintenance Training Organization
MTOW	Maximum Take-off Weight
NAA	National Aviation Academy
OAMP	Operators Aircraft Maintenance Program
PAX	Passengers
PCN	Pavement Classification Number
RAM	Random Access Memory
RPK	Revenue passenger-kilometer
SB	Service Bulletin
SL	Service Letter
UK	United Kingdom
U.S	United States
USD	United States dollar

1 Introduction

Commercial air transport plays an important role in our society. This unique means of transportation is a key to the never stopping clockwork our society represents. This ability to pass long distances in a fast manner is the backbone of global network and keeping these connections is vital to the global economic system. It is also the reason aviation is the dominant means of transportation over long and medium distances. No other transport medium is capable of transporting passengers, goods, and other payload in such a short time, with such precision and availability. Of course, other shipment methods offer as a solution, however the pace does not satisfy requirements of high-end logistics. High level of safety is also a remarkable property of aviation. Commercial air transport is, however, a challenging business. Free market allows airlines to compete among themselves and to create a harsh business environment. On top of that, other means of transport – railways, maritime – also present an alternate solution. Aircraft operators tend to maximize utilization of their fleets to gain the maximum revenue. A grounded aircraft is hardly making any money.

Aviation market is, however, prone to slight changes in external factors. The Covid-19 pandemic has brought significant downfall to this sector. Safety measures adopted by world countries, as well as fear of travelling resulted in many cancelled flights, loss of revenue for aviation stakeholders, and job losses. Aircraft operators shared the same target – to return aircraft back in service, as soon as possible. However, with such hostile conditions, potential border openings and return to service remained uncertain. In order to cope with such situation, aircraft operators had to ground portions of their fleets for an indefinite time. One can imagine that grounding of this size would arise as a problem with respect to economics, logistics and maintenance. Aircraft operators had to decide where to park their fleets, for how long, how to provide maintenance etc.

This thesis aims to catch this decision-making process and examine behavior of aircraft operators with respect to parking of their fleets. For purposes of this thesis, a sample of data has been collected. This data show parking records of several major airlines. Various aircraft attributes, as well as external factors, which had an influence on this decision making will be further analyzed. Statistics derived from obtained data will be presented.

2 Background

The aviation sector has experienced period of growth for nearly two decades. Globalization and industrialization brought demand for eye-to-eye communication and therefore more demand for air transport. New airline economic models have made flying available to all social classes. Tourism has become a standard practice of our lives. Therefore, there was an increase in both domestic and international traffic demand. Passenger traffic in 2010 experienced just about 4 800 billion RPKs (revenue passenger-kilometers) performed, followed by 5 150 billion RPKs at 6.5 percent increase in 2011, 6 145 billion RPKs at 5.8 percent increase in 2014. Year 2016 then observed approximately 7 124 billion RPKs after a 7.4 percent increase compared to 2015. Finally, 2019 has been blessed with a 4.9 percent increase of approximately 8 686 billion RPKs. After years of steady growth, following outbreak of Covid-19 pandemic, 2020 has shown a significant reduction in traffic volume compared to 2019 with the annual decrease of 65.5 percent, equating to 2 990 billion RPKs. Cargo flights have also experienced a period of growth, with maximum in 2018 of approx. 230 billion FTKs (freight tonne-kilometers), followed by a slight decrease in 2019 of 3.5 percent and finally year 2020 with yet another decrease due to Covid-19 pandemic of 20.3 percent [1].

Slight changes can be spotted in traffic behavior among different bodies. For instance, European passenger air traffic in 2019 had a growth of 6.6 percent, whereas Latin America with a lesser value of 3.6 percent. Different behavior can also be spotted between international and domestic traffic. International air traffic grew by 4.7 percent in RPKs in 2019, whereas domestic air traffic accounted for 5.2 percent RPKs [2]. Significant differences can be seen between international and domestic air traffic in 2020. Decline in international passenger traffic was 75.4 percent RPKs, whereas only 48.7 percent RPKs in domestic [1]. This statement only confirms that closed borders made international travelling very difficult.

Although the numbers above suggest otherwise, there have been cases when external factors noticeably stimulated passenger demand. Recall September 11, 2001, when terrorist attacks struck fear among frequent travelers. Along with national security measures, reduced capacity of airspace and long queues at airports causing discomfort introduced reduced demand. Truthfully, yes, these events have happened in the past with a decent impact on aviation, however the sector itself proved to be resilient against this kind of deviation and managed to find path to its harmony in a relatively short time.

That being said, despite several setbacks, the sector has flourished in recent years, and there definitely was room for improvement. The sector was expected to grow not only in traffic volume, but in all aspects, hence acquisition of new aircraft, lower unemployment, etc. Non-traditional economic models of lesser airlines seemed to be a powerful tool how to offer a reasonably priced flight ticket to gain a competitive advantage especially on medium routes. Looking at EUROCONTROL regular forecasting reports released back in 2019, their numbers confirm statements above. 2019 has experienced 4.1 percent boost in IFR flight movements compared to previous year. Forecasting then projected another annual 4.1 percent boost in IFR for 2020, 3.3 percent boost in 2021, 2.8 percent boost in 2022 to 2.2 percent boost in 2025 [3]. Although EUROCONTROL only projects their services to a regional area, positive forecast values in other parts of the world can be suspected. With all these numbers above being of positive value, aviation stakeholders had also planned their own growth with respect to traffic volume. To keep up with potential demand, airlines had planned to increase their capacity to maintain their position on market and cover new potential free space in the network. That would include acquisition of new aircraft, expanding their network to increase scope, hiring new workforce, operating on new bases, etc. Airports would open projects for their expansion to offer more capacity. Ground handlers and maintenance organizations would also increase their scope and capacity to deal with more demand. For instance, Ryanair agreed to purchase 135 units of Boeing 737 MAX 200 aircraft to grow their traffic to two hundred mil. customers by 2024 [4]. This tremendous acquisition was supposed to add 3 000 new jobs for pilots, cabin crew and engineers and expand their fleet to 520 aircraft, which is a solid amount for a low-cost carrier [5]. British Airways announced acquisition of 42 units of Boeing 777X airplanes to eventually replace an existing pool of Boeing 747s, but with more cost efficiencies, environmental benefits, and better passenger experience. Similarly, an acquisition of Boeing 787s has been announced to replace an existing fleet medium-sized widebody jets in British Airways [6]. British government also announced plans for expansion of Heathrow airport. Building a new runway would create tens of thousands of local jobs and add an extra 16 million long-haul seats by 2040. Additionally, this new north-west runway would provide a better connection to Scotland, Northern Ireland, and Northern England [7].

These forecasting data can only suffice without occurrence of non-expected events. Master planning is critical to continue operations in a long-term scale, however it is extremely difficult to withdraw financing to any projects that have come to a halt. Without access to these critical assets, dealing with any kind of crisis is difficult.

The outbreak of Covid-19 pandemic shattered any forecasts for upcoming years. Any remarks of potential growth had become irrelevant and the whole sector was battling for survival. In fact, aviation sector had one of the worst impacts among other industries. Aviation being a key factor in transmission of this contiguous disease, national lockdowns as well as fear of travelling among customers resulted in reduced demand and many flight cancellations. This pandemic being of global scope and lasting for several years now have made historic downfall to aviation sector and a potential recovery pathway lasting a couple of years. Never in history has such a global downfall been observed. The coronavirus, which is believed to have been spreading since January 2020 has discontinued air traffic ever since. In 2020 alone, airlines have lost approx. USD 372 billion gross passenger operating revenues. There was also a 60% reduction in number of passengers compared to 2019 [8].

The first recovery pathways announced by IATA were projecting hope into 2021. The forecast was only 4.2% reduction in profits compared to 2019 [9]. This forecast was however based without presence of another wave of Covid cases. The second and eventually third wave crushed the industry again with an approx. loss of USD 324 billion of gross passenger operating revenues of airlines with a 49% reduction in passengers. The forecast for 2022 is not however that good either. Airlines are still projected to lose up to USD 200 billion compared to 2019 levels [8]. Now these numbers sorely represent losses just for airlines.

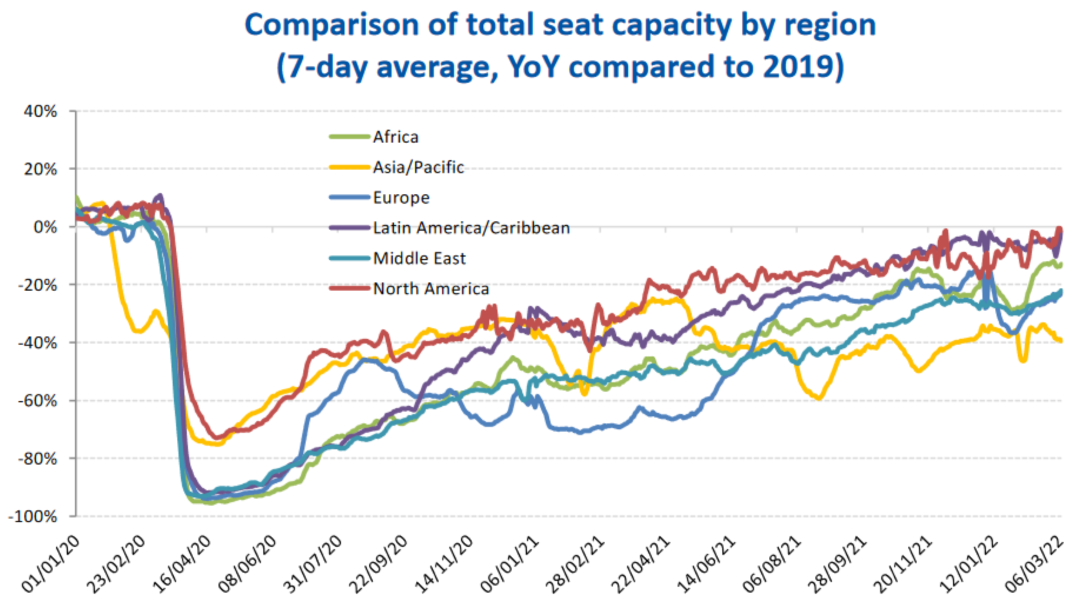


Figure 1 – progress of ASK during Covid-19 [8]

Although aviation industry has been hit globally, individual regions of the world had been hit differently. It needs to be understood that all aviation stakeholders shared the same target – to resume operations as soon as possible. However, the performance of air traffic was heavily dependent on current coronavirus situation. Considering each region had different progress of Covid-19 cases, it makes sense that regions suffered different impact. Figure 1 above represents regional differences in resilience.

The initial drop in traffic in Asia/Pacific region in the early 2020 can be accounted for the origin of the coronavirus. While the rest of the world was operating on a normal basis, China and neighboring countries experienced first spike in new Covid cases and therefore ceased any international travel. Later, in March 2020, the virus has spread uniformly all around the world and therefore a significant drop with all lines can be seen. The reasoning behind this is that air transport can be seen as a powerful transmission medium. It had also been a key factor in spread of other terminating diseases, such as SARS/MERS, Ebola, Malaria [10].

To better understand the nature of this crisis in Europe, one has to look at behavior of European countries, which dictate the tempo of regional air traffic. European region is comprised of a significant number of individual countries. This makes air transport vulnerable to any regulations imposed by individual countries. That is totally different compared to other major aviation regions, such as USA or China. According to EUROCONTROL, by April 1st all European countries have experienced some form of border closure or lockdown. Looking at major players – France: lockdown until 15th April, Germany: border closure for non-Schengen flights, UK: national lockdown until 13th April. Most countries however left their airports open for domestic travel, for returning flights of their citizens, and some even left Schengen travel still available. Now these restrictions had had impact on operations of airlines. Looking at major airlines, again, Air France had cut their capacity by 90% until end of May, Lufthansa experienced reduction in flights by 95%, British Airways down by 94% in mid-April [11].

Looking at Figure 1, again, an approx. 20% difference can be seen between Asia/Pacific and North America region versus rest of the world. Now this can be easily accounted for the difference in international vs domestic flights ratio in individual regions. Judging that international travel suffered while domestic travel still remained somewhat available, U.S and some Asian airlines still managed to operate under limited conditions. For instance, sorely domestic flights accounted for 93.4 percent of U.S Airlines flights in 2019 [12]. That makes a better business environment in terms of any regulations and lockdowns.

Air traffic in Europe was responsible for 74% of carried international passengers in 2019. For a given situation described above, when closed borders occurred all around Europe, keeping international travel at some decent level was impossible. This effect was multiplied by fear among regular passengers and uncertainty of a seamless entrance to the destination country. The lack of travel possibilities was also unfavored for business operations, leisure travel and working possibilities since many European citizens are working abroad.

Going forward in Figure 1, a sudden recovery can be seen beginning June 2020. This can be accounted for a suppress in new Covid cases as the summer had been approaching. New cases had been as low as units per day in some countries. Calls for reopening borders and resumed life back to normal were emerging. Looking at report from July 1st, it is clear that all European nations eased their restrictions in some way. Most countries of the European Union had gotten completely accessible for flights from EU/Schengen area to cling the fundamental principles of the European Union – free movement. Other countries allowed international travel from outside EU or required a certificate or quarantine upon arrival [13]. The air traffic during summer 2020 was however still down at least 40% compared to 2019 baseline. Many airlines decided to keep part of their fleet grounded because there simply was not enough demand for their capacity – e.g., double deck aircraft.

As the time has progressed, air traffic was stuck in a never-ending loop of downfalls and recoveries that met actual Covid situation and restrictions imposed by states. Figure 1 clearly shows that air traffic is slowly returning to 2019 levels since vaccines are vaccines are worldwide available and governments are pressured to lift restrictions to establish economic flourishment. Some forecasts for the future are less optimistic, with IATA, EUROCONTROL not expecting 2019 baseline target until 2024 [14], [15].

Now since demand for air transport had been suppressed over past two years, airlines were pushed to cancel portion of their flights. With so many aircraft without a destination, a new problem had arisen. Working out a parking solution for many aircraft all around the world comes as a problem in terms of economics (parking fees), maintenance, logistics (closed borders etc.). This thesis further evaluates airlines approach in dealing with these challenges. It is necessary to navigate through all attributes this parking possesses and to find a pattern in airlines decision-making process. Every airline had to make a series of decisions – where to store their fleet, for how long, how to keep it under maintenance. There is a nice amount of data, which was helpful in deep diving into this problematic.

With so many airlines in pursuit for a parking space, a race to get the best parking possibilities has begun. During grounding of Boeing 737 MAX, approximately 800 aircraft had had to be grounded worldwide [16]. That might had come as an economic loss for airlines, since they could not operate their new acquisitions, but parking-wise any set of airports can consume this amount. After 9/11 attacks and during Gulf War, only 13% of commercial jets have been grounded [17]. With respect to Covid-19, however, more than 16 000 passenger jets had to be grounded [18], which happened to be '*The largest grounding of commercial aircraft ever*' [17].

Some airlines have looked to park their fleet at their major hubs, with easy access for maintenance purposes. This also benefits for their resume to service. Other airlines, however, decided to park portion of their fleet at distant, smaller airports with limited maintenance options. This parking, usually for a lower price, is suited for long-term storage. With the global airport network being so interconnected, most airports hosted a parking space for a combination of aircraft operators. Figure 2 below shows an overview of worldwide airports with most aircraft parked by May 2021.

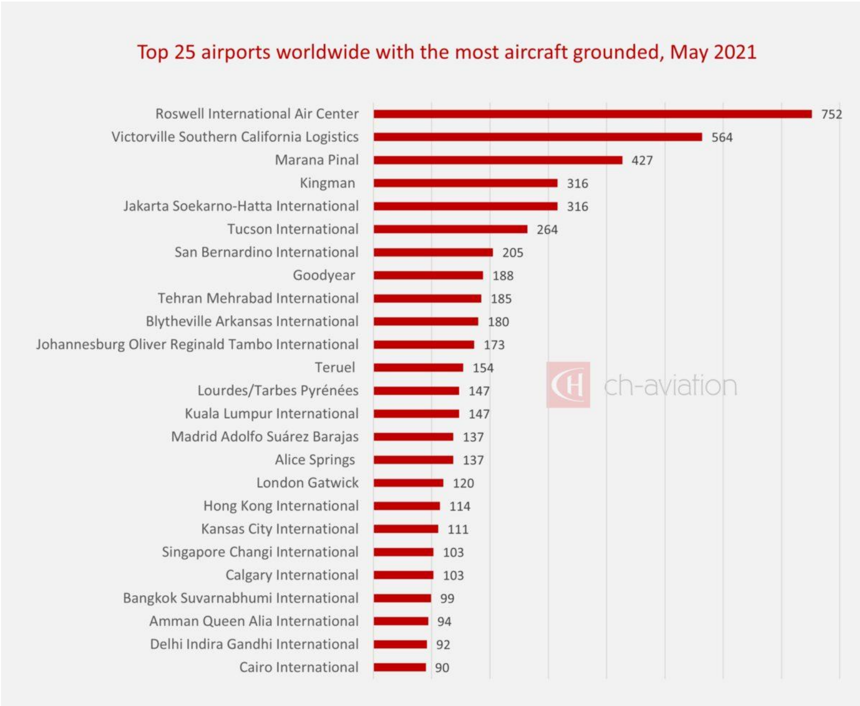


Figure 2 – overview of airports by most aircraft grounded [19]

One might understand that parking only serves as an auxiliary income to airports. Therefore, their parking space is also limited, and the majority of their capacity is focused on regular operations. With such high demand for aircraft parking and air traffic being ever so low, parking aprons had reached their maximum capacity very fast. To accommodate a surplus in demand, some less favorable options of parking must have been selected. Now with parking aircraft on an area that is designed for different purposes under regular operations, some risks need to be assessed.

[16] suggests prioritizing parking aprons, contact, and remote gates, de-icing pads before parking on active taxiways and closed runways. The traffic flow is quite busy on runway and taxiway system, and they are key to maintain efficient flow at the airport. Another suggestion is to temporarily use part of active taxiway system that of being closed does not disrupt efficient flow. Standard size of aircraft stands on an apron require a minimum clearance between an adjacent stand, aircraft, or an object per EASA requirements. The purpose of this clearance is to provide safe separation between aircraft and objects, and to provide enough space for maintenance purposes, maneuverability constraints with a desired level of safety. [16] then suggests denser parking on ramps and aprons before considering taxiways. Parking on runways must be considered as the last option due to the potential of inadvertent landings on a closed runway [20].

During this rare phase of overflow parking, there are some fundamental principles that need to be followed. This way, a sufficient level of safety and circumstances for continuation of normal operations are provided. For instance, parked aircraft must allow smooth and efficient flow. Aircraft must be parked in a way that provides maintenance staff easy access and allows aircraft maintenance, fueling, cleaning, engine runs, etc. There are also limitations with respect to pavement conditions. ACI suggests preferring concrete pavements for long term parking to using asphalt pavements [21], because of their higher sensitivity to static loads and high temperatures [16]. ACI also suggests checking Aircraft Classification Number (ACN) and Pavement Classification Number (PCN) compatibility.

Roswell International Air Center for instance, took a different approach. Instead of infringing safety requirements by over occupying existing aprons, they decided to add 300 more acres to accommodate up to 800 more aircraft, hence Figure 3 below [22]. That allowed Roswell to be 1st airport with most aircraft grounded, hence Figure 2.

Figure 3 – Roswell Air Center adding more space [22]

News of airlines grounding their fleets have pierced through the entire world. Photos of mass aircraft parked on closed taxiways and runways have never been seen before. For instance, KLM has grounded the majority of their fleet in their main hub, Schiphol airport. That would include all A330s, B777s as well as narrow body aircraft, B737s [23].

Figure 4 – KLM aircraft parked on Schiphol [23]

Qantas grounded majority of their fleet on major Australian hub airports, including Sydney, Melbourne, Brisbane. Part of their fleet had resided on smaller airports, such as Avalon Airport which will take 50 Qantas and Jetstar planes [24].

Figure 5 – Qantas parking at Avalon Airport [24]

British Airways also accommodated majority of their fleet on major hubs in London. However, BA aircraft could have been seen parked around the world. Their Airbus A380s found place in a small airport in Chateauroux, France [25].

Figure 6 – British Airways parking their A380s [25]

3 Maintenance – an essential care

Although grounded aircraft are not directly in service, they require a certain level of maintenance work to retain their airworthiness, mitigate impact of environmental conditions such as rain and ensure smooth transition back to service. With aircraft nowhere to fly, not only do they generate no revenue, but they also bring costs that need to be paid for. Such costs would include parking fees, lease, regular maintenance – workforce costs, material costs, etc. With an uncertain length of parking interval, maintenance work would represent a challenge to all airlines while trying to purge negative economic impact of this crisis and push aircraft back into service as soon as possible. This maintenance in question is thus a key factor in the decision-making process in pursuit in this thesis.

When grounding their fleet, aircraft operators needed to schedule their maintenance. Since aviation industry and thus major airports are not designed to handle a large number of aircraft being grounded simultaneously, aircraft operators had to ground portions of their fleets beyond their hubs, and thus beyond their maintenance facilities. This arrives as another problem in form of limited maintenance workforce, limited aircraft accessibility, limited access to spare parts and consumables, and different meteorological conditions. Some airlines even had to transfer maintenance services to 3rd party operators outside their own subsidiary system. The depth of provided maintenance while parking varies between different aircraft and length of the parking period. Maintenance tasks can rarely be found in a MPD (Maintenance Planning Document) issued by a manufacturer, since long-term parking is not presumed to occur during lifetime operations of an aircraft. It is up to the aircraft operator to designate their maintenance schedule [26]. One could recognize variety of types of aircraft parking/storage that differ in length of parking/storage interval and extent of maintenance provided. This terminology is however not uniform across the aviation industry and therefore a place for misunderstanding arises. For purposes of this thesis, 4 types of aircraft parking recognized by IATA can be defined:

- Normal Parking – typically lasts dozens of minutes, to several hours and up to several days. Technically one can reckon flight turnarounds as normal parking. This type of parking also occurs when aircraft is overnight parked at the airport. The aircraft remains ready to return to service or requires a small amount of maintenance work to return to service, usually same maintenance work as is provided during flight turnarounds. Since this type of parking happens on regular basis, it is not in the scope of this thesis.

- Active (Short-Term) Parking – here the duration of parking exceeds several days up to several weeks. The aircraft is therefore not in an immediate return-to-service state and undergoes some procedures for initial preservation, which includes safety-pins, installation of covers and plugs. Due to this preservation, aircraft is on ground, undergoing periodical maintenance checks, such as APU and engine runs, but not undergoing any planned heavy maintenance. Return to service is also possible shortly.
- Prolonged (Long-Term) Parking – grounded aircraft is out of service for a longer period, typically several weeks up to several months with no scheduled heavy maintenance under MPD. Installation of safety pins, covers and plugs is needed. Initial preservation includes basic maintenance work to mitigate long term effects of consumable materials inside the aircraft – fuel circuit, hydraulic circuit, etc. Maintenance is provided on regular basis, however return to service requires more procedures and may take up to several days.
- Storage – in this case the aircraft is grounded typically for several months, often outside airport hubs. The aircraft is deeply conserved with most fluids and consumables disposed, some body parts are detached from the body, engine covers installed, etc. Periodical maintenance is very limited since aircraft is not expected to return to service and the aircraft may also be in areas with limited maintenance providers.

Detailed maintenance instructions for parking, periodic checks and return to service can be found within AMM (Aircraft Maintenance Manual) under ATA Chapter 10 of given aircraft. Some additional procedures may be introduced in an unfavorable environment – such as heat, humidity, ice, snow, rain, hail, wind. Additional instructions may be provided by the aircraft operator itself. A different partition of long-term aircraft parking can be encountered in AMMs and other materials. This way Active Storage is interpreted as longer parking period with regular maintenance checks where the aircraft is expected to return to service in a short time. This way the aircraft is maintained in a somewhat operational state and therefore return to service is done on a short notice. This was a frequent feature observed during Covid-19 crisis since airlines were eager to resume operations and aircraft were put into storage for an indefinite period. The downside to this is that frequent maintenance checks with broad spectrum of provided work brings higher costs that are quite unpleasant especially during a crisis. On the other hand, long-term parking is interpreted as a longer period of parking, where the aircraft is not expected to return to service anytime soon, and thus has lesser requirements for periodical maintenance. This type of parking was regularly seen among some wide-body aircraft, such as Airbus A380s, where reduced PAX demand could have been covered by smaller, more cost-effective aircraft. Although lesser maintenance requirements allow for lower costs, returning such aircraft from storage would require work lasting from several days, up to weeks.

As mentioned above, maintenance tasks designated for aircraft parking/storage are in the AMM of respective aircraft. This document is an essential “cookbook” for aircraft operators, CAMO (Continuing Airworthiness Management Organization) and maintenance providers themselves. Depth of the maintenance tasks for aircraft parking/storage can therefore be used for maintenance planning and scheduling purposes determined when grounding an aircraft. Another sources of information regarding maintenance during Covid-19 pandemic were issued by aircraft manufacturers and equipment manufacturers. These brochures are available online and have been sent to all parties involved [27]. Additional supplementary information on maintenance has been released by various organizations aiming to assist aircraft operators during these challenging times, such as IATA. Such documents would be IATAs “Guidance for Managing Aircraft Airworthiness for Operations During and Post Pandemic” of 2020 and “Return to service of aircraft after storage: Guidelines in relation to the COVID-19 pandemic” released by EASA in 2021.

Using these documents, a series of maintenance tasks essential to aircraft parking/storage can be defined. Please note that procedures related to “Normal Parking” (short-term parking) are not within scope of this thesis and thus have been rendered irrelevant. The key difference between “Normal Parking” and “Prolonged Parking” as in AMM to Boeing 737 is the scale of work needed for preservation, maintenance and return to service. These maintenance tasks are essential to get close to the decision-making process of airlines. This list of aircraft systems corresponding to ATA chapters are aimed to highlight the complexity of just essential maintenance tasks that must be considered during aircraft parking/storage. By no means does it represent the entirety of all maintenance tasks that might occur during storage. It is quite unnecessary to merge all maintenance tasks into a united block of text since maintenance differ between aircraft and organizations.

With respect to electrical systems and Avionics, Boeing’s AMM states that initial procedures include aircraft grounding, pulling all switches and circuit breakers to OFF position, capping of all disconnected electrical connectors. Main batteries, auxiliary batteries and emergency batteries should be initially disconnected and removed from the aircraft and put into storage, with regular checks performed (voltage check, charging, discharging). An optional approach for aircraft batteries is to be kept on-wing if environmental conditions and battery type allow it. This way regular battery checks are performed directly on the aircraft and any subsequent tests of aircraft systems do not require plugging and unplugging the battery every time. AMM also suggests applying power to all electronic systems, lights, directional gyros, weather radar, INS (Inertial Navigation System) and FMS for 2 hours every 30 days. Operating gyros, INS and weather radar for a while is also suggested [28].

Another important step per Boeing's AMM is taking care of air data probes and sensors. First and foremost, all pitot tubes, pitot static probes, static ports, temperature probes, angle of attack sensors and ice detectors must be protected with covers and plugs. This is an essential procedure for grounded aircraft that prevents any damage to these probes caused by corrosion or contamination by insects, dust, pollen, birds, or other nesting animals. Return to service is a vice-versa procedure, so all probe covers, and plugs must be removed. It is also suggested to do a complete inspection of all probes for contamination, functionality, and system check [28].

Fuel system must be preserved during storage. Fuel tanks must be filled at a minimum 10 % of their capacity. Sometimes more fuel is required to artificially increase weight of the aircraft to sustain heavy winds that might occur at the airport. Fuel also happens to be drained away in case maintenance procedures require to do so. All water collected in fuel tanks must be periodically drained away. Another issue comes with microbial contamination of the fuel. This can cause blocking of scavenge systems, fuel filters, fuel quantity indication problems and corrosion of metallic materials. Fuel is therefore periodically monitored for microbiological contamination and treated with biocide if necessary. Common practice is to apply biocide at initial preservation. To circulate fuel in distribution system, periodical engine runs are useful [28].

Surfaces of flight controls should be kept clean, with protective coating applied. All drain holes must remain unhampered. Control cables in the wing leading edge, trailing edge and wheel well need lubrication. All service points, reservoirs and the gearbox gears must also be lubricated. Unpainted parts of flaps, steel fittings should have corrosion prevention applied. For the duration of parking, flight controls are positioned in neutral. Depending on duration of parking, flight control might require operation of a full range of travel. Flaps and slats require one full cycle movement every 180 days, stabilizer, rudder trim, aileron trim require one full cycle movement every 90 days, as per B737 AMM. Primary flight controls (ailerons, elevators, etc.) also require periodical movement [28].

Hydraulic systems remain in operational state to allow performance of maintenance tasks that arise during aircraft parking – typically movement of flight controls. An alternative approach is to use a ground hydraulic cart to pressurize the system [26]. Hydraulic system must therefore be filled with corresponding hydraulic fluid to correct levels. This also involves periodic checks for system leaks by monitoring hydraulic fluid level every 30 days. Exposed unpainted tubes, actuators, bearings, rods, valves need initial lubrication and corrosive prevention treatment. Every 30 days, a corrosion check is recommended [28].

Boeing's AMM says that storing engines might be of a confusing nature since they are also subject to preservation maintenance program defined by the engine manufacturer. This way instructions defined by engine manufacturer and aircraft manufacturer might bring conflict of interest. Most common practice is storing engines while mounted on the aircraft. This allows for periodical maintenance to be done altogether with the aircraft and allows smooth engine runs. Another approach is to store engines removed from the aircraft. This can however be limited with respect to storage facilities. Generally, inlet and exhaust covers on engines an APU should be installed to prevent corrosion damage and contamination. Periodic starts of engines are essential and should be performed in accordance with engine run profile [26]. Same procedures apply for APU preservation.

To retain aircraft in a fixed position, landing gear down locks (safety pins) and wheel chocks must be installed on all wheels of the main landing gear. Initial visual inspection for any leaks, cracks and other damage is recommended. Tires must be pressurized to specified level; this tire pressure must be periodically checked. To prevent flat patches, wheels must be rotated periodically (a 14-day interval is quite common) with a one-third revolution by towing the aircraft or while doing engine runs. Unpainted parts of the landing gear need to be lubricated and have corrosion prevention applied. Operational checks of gear steering system and braking system need to be performed.

After many people have been on-board, interior of the aircraft deserves some maintenance and cleaning. A grounding is a perfect occasion to do so. This guarantees that all passengers will get their comfort once this aircraft is returned to service. Water system and toilet waste system must be serviced – drained/cleaned. All tray carriers, waste containers, dispenser compartments in lavatories and galleys should be cleaned. It is also recommended to clean cabin seats and carpets, surfaces of cabin enclosures (overhead bins, etc.), flight deck compartment, and cargo compartments [26]. Windows shades should be closed, and door windows should be covered to prevent fading of cabin seats due to exposure to sun's ultraviolet rays. Sometimes, in case of D-check maintenance, cabin seats and carpets are removed from the aircraft. A contributing factor with respect to interior is humidity. Cabin average humidity is periodically checked for maximum of 70%. Seats and carpets are checked for moisture. To guarantee humidity within safe levels, de-humidifiers are often deployed.

Grounded aircraft are subject to many costs – maintenance costs, parking fees, lease, etc. Some airlines having limited assets to work with, as a result of this pandemic, decided to surrender some of their aircraft to reduce these costs. Making a decision to get rid of an aircraft is a complicated task. Generally, an aircraft and each of its equipment has a designated service life. Depending on the product, it could be flight hours, flight cycles, run cycles, etc. Sometimes the aircraft is operated for a longer time than its service life, has it been maintained well and is it still airworthy. Some airlines might find difficulties in replacing this particular type of aircraft with a different type, or they find maintaining an older aircraft more financially beneficial rather than acquiring a new one.

Has an aircraft been designated for end-of-life, there is still value on it. A common practice, especially for premium airlines who like to offer their customers the best comfort, is to sell the salvaged aircraft as a whole to another operator. This is known as a "second-hand" purchase. It is a win-win condition for both parties, since seller gets a significant value from selling the aircraft, and buyer gets hold of the aircraft they otherwise might not be able to purchase. In times of Covid-19, however, most airlines were grounding their fleet, so there was an overall surplus in aircraft. Everyone had too many aircraft for this period, and they were also trying to save money. Therefore, prices for second-hand aircraft rapidly decreased and there were very few buyers.

Most aircraft were placed into their final destination, commonly known as aircraft boneyards. This way the aircraft is being disassembled into spare parts that still might have value and the rest is being rendered into recyclable materials and waste. Functional parts and systems are extracted from the aircraft and returned to the airline or sold to a different party to continue operations. This salvage process generates on average 800 to 1,000 spare parts, which can be repaired, tested, and certified to serve in aviation again. Most valuable are engines (contributing to 70% of second-hand market), landing gears, avionics, power units, generators, navigation systems flight controls and other electronics. [29]. Interior is also quite commonly reusable. These components are then sold for an affordable price compared to new ones. Again, with so many airlines grounding and scraping their aircraft, this scrap aftermarket was being destabilized with surplus in supply and lower demand.

The rest is then transferred into either recyclable materials and rendered into raw materials, or simply disposed as a waste. Metal materials – steel, titanium, aluminum are being more valuable each day. The aircraft also contains hazardous components like batteries, fire extinguishers, various fluid and chemicals that must be addressed properly.

Maintenance on a smaller aircraft is a straightforward process. The owner is often capable of doing basic maintenance themselves and maintenance organizations of concern require little facility. Documentation is also subpar compared to commercial aircraft. This involves a “Hard Time” approach, where aircraft frames and equipment have fixed maintenance intervals and fixed life-time intervals. Since it is necessary to comply with these maximum intervals, this allows for a simpler maintenance programme, but at the cost of higher costs. GA (General Aviation) aircraft are less utilized, and their spare parts are quite cheaper and affordable.

Providing maintenance for a commercial aircraft is however a complicated process and is subject to deep regulation by both European and American legislation. It also requires deeper planning since maximum aircraft utilization is a target for every airline. This comes with an “On-Condition” or “Condition Monitoring” approach, where periodic inspections and tests of aircraft frames and systems are performed to determine functionality of the item and whether it can continue in service. This approach requires deeper planning, but rewards lower costs compared to the “Hard Time” approach, and that is essential to all airlines considering how expensive spare parts for commercial aircraft can be. There are multiple parties interested in this process.

CAMO

The purpose of CAMO (Continuing Airworthiness Management Organization) is to manage continuing airworthiness of an aircraft and its parts. CAMO is providing these services usually for an AOC (Air Operator Certificate) holder under a contract. The organization is therefore responsible for developing and updating an MP (Maintenance Programme) and reliability programme for the aircraft, having this MP approved by competent authority, scheduling maintenance, ensuring that all ICAs (Instructions for Continued Airworthiness) are applied, ensuring that all maintenance is carried out in unity with maintenance programme, ensuring that all defects are reported and corrected, archiving all records of performed maintenance, managing the approval of modification and repairs, and more. CAMO can operate under approval in form of a valid certificate issued by a competent authority. In case of aircraft operators licensed under AOC, this approval is part of this certificate. This allows CAMO to manage airworthiness on aircraft used by AOC holder, if that type of aircraft is listed in the certificate. It also allows CAMO to designate part of continuing airworthiness tasks to a subcontracted organization, extend an airworthiness review certificate and approve MPs for aircraft used in General Aviation.

To ensure an aircraft meets all airworthiness requirements and its airworthiness certificate is of valid nature, periodic reviews of the aircraft and its airworthiness records must be performed. CAMO is then able to issue a new airworthiness certificate or extend validity of the previous certificate. This airworthiness review has goals to check the aircraft that:

- all maintenance in compliance to approved maintenance programme has been performed,
- its flight manual is applicable and updated,
- all airworthiness directives of concern have been applied,
- flying hours and flight cycles of airframe, engine and propeller have been recorded,
- all known defects have been removed and recorded,
- all components installed on the aircraft have not had their service life exceeded,
- weight and balance certificate of the aircraft is valid,
- noise certificate of the aircraft is valid in compliance with Regulation (EU) No 748/2012.,

and more. CAMO has thus played an important part in ensuring aircraft will maintain their airworthiness throughout their parking. Major airlines tend to provide CAMO services for themselves, by a branch of their company (e.g., Air France, Czech Airlines) or by their subsidiary (e.g., Lufthansa).

AMO

The main task of AMO (Approved Maintenance Organization) is providing physical maintenance on airframes, engines, propellers, or parts it has approval for, designated in their certificate and exposition. Organizations providing maintenance on large aircraft and aircraft in commercial air transport must be approved under Part 145 of Regulation (EU) No 1321/2014 Approval certificate is issued by European national authorities. This maintenance in question can only be done in locations identified in the approval certificate and exposition. The AMO can also subcontract maintenance work on aircraft it has approval for with other organizations under Quality System. This work should not be a base maintenance of an aircraft, or overhaul of an engine. Lastly, AMO shall issue release to service certificate after finishing maintenance.

Again, major airlines have an AMO as part of their business or a subsidiary, capable of doing both line maintenance and heavy, base maintenance. Major German airline, Lufthansa uses services of Lufthansa Technik Aktiengesellschaft. British Airways has a subsidiary British Airways Engineering, and a major French and Dutch airline uses services of a join company Air France-KLM. Other airlines, like Czech Airlines, are only capable of doing line maintenance themselves and have base maintenance subcontracted. AMOs thus played an important part in terms of aircraft parking as they directly provided maintenance in order to keep airworthiness. As stated above, an AMO can only provide maintenance in identified and approved locations. This must have been taken into considering once airlines started grounding their fleets. For instance, Lufthansa cannot expect their subsidiary, Lufthansa Technik AG to migrate across Europe to perform regular maintenance as they might not have a permission to do so on certain airports, and it is extremely financially ineffective. Thus, choosing an airport with subcontracted AMO was critical. The best practice was to choose an airport with an AMO, where a contract was already in place, since a new contract would often include long negotiations.

As Part 145 of Regulation (EU) No 1321/2014 states, AMO should have available all necessary equipment to perform approved scope of work. This tooling and equipment should also be regularly controlled and calibrated by recognized standards. This could have raised as another barrier in the decision-making process as some aircraft require very specific equipment specified by the manufacturer, which might not be available on all airports. Czech Airlines Technics for instance, was performing maintenance on variety of airports across Czech Republic and Slovakia. Their common practice was to either dispatch a mobile unit with necessary equipment or rent unavailable equipment from 3rd parties. Same principles apply to personnel. As Regulation (EU) No 1321/2014 states, all staff working in maintenance must have an understanding of the relevant aircraft, license held under Part-66, completed relevant training and certification authorizations. This staff was also part of the mobile unit, as the AMO have no facilities on some airports, and thus staff had to migrate.

MTO

Although MTOs (Maintenance Training Organization) are not directly providing maintenance on grounded aircraft, and they have very little interaction with airlines, they are worth mentioning for summary. The purpose of an MTO is to provide theoretical and practical training for aircraft maintenance personnel under Part 147 of Regulation (EU) No 1321/2014. Their work is based upon approval by a national authority. This approval specifies types of aircraft they can provide training for. Major airlines have MTO approval under their organization, for instance, Air France.

MTOs might have found themselves in a challenging position during Covid as there was a surplus in aircraft technicians and therefore fresh technicians stumbled upon a hard pathway to join the business.

To keep an aircraft safe and airworthy, the aircraft operator must perform regular maintenance checks under a defined maintenance programme. Generally, there are various types of maintenance checks that can be performed on an aircraft. These differ based on scale of maintenance work provided, how often this maintenance is provided and where this maintenance is provided. This terminology is sadly not unified in its entirety across the industry and thus a small room for differences is allowed. Another reason is that different types of aircraft require different maintenance checks at different times and therefore it is hard to ballpark renewal interval for each maintenance check in general. This one presented below is one of many kinds that can be found in resources.

Line Maintenance

This maintenance is performed most regularly. Line Maintenance usually refers to any "light" maintenance carried out before the flight to make sure this aircraft is safe and ready to fly. It is carried out directly on aircraft stand and thus there is no need for a hangar. It also only requires basic equipment. This involves visual inspection to detect any defects but is not a subject to deeper inspection. Also, minor repairs are carried out that do not involve disassembly of aircraft components and require basic equipment. The visual inspection should be performed on wheels, brakes, and fluid levels. It also involves checking aircraft logbook for entries and failures. Line Maintenance on average takes 2 Man hours to complete and should be performed every 24 to 60 hours of flight time [30].

Base Maintenance

Base (Heavy) Maintenance is usually carried out in a hangar as it requires more time to complete. This way the aircraft is protected from the outside environment and unpleasant wind conditions, gives better access to artificial lighting, easier access to tools and equipment and is also easier to store disassembled aircraft components. Base maintenance then contains more tasks to complete and requires more people working on the aircraft, but they are not so frequent. Since it often requires specific equipment and more certified staff, many aircraft operators tend to outsource this service. A common practice is to group the required tasks into maintenance packages that share the same renewal interval. In the aviation industry, these maintenance packages are labeled with a letter A-D where A marks the simplest of packages and D marks the most difficult and time-consuming.

A Check

A Check is provided most frequently which could be several hundred flight hours depending on the aircraft type. Some aircraft may require it as soon as 100 flight hours. It is usually performed at specific routes per airlines network and is complex enough to be performed in a hangar. This check involves basic inspection of interior and exterior and basic functionality checks. Exterior is checked for any damage, corrosion, and missing parts [30]. Some service access panels are also opened to inspect emergency equipment and oxygen system pressure. Some filters may also be changed, and some parts may be lubricated.

B Check

B Check in its definition would include more detailed work than A Check but not detailed enough to require disassembly of aircraft components. This would be done every several months and require approx. 150-man hours. With several staff working on the aircraft, this would be easily finished in 2 days. More detailed work can include alignment of the nose landing gear or inspecting the wheel well [30]. A common practice is to merge A and B checks and distribute the required work into A and C checks. This way many maintenance programs do not include B checks which results in reduced downtime, higher aircraft utilization, lesser load on maintenance technicians and overall, more cost-effective approach.

C Check

C and D checks are often identified as “Heavy” maintenance checks and they include very detailed work which takes aircraft out of service for a longer time an requires specific equipment and facilities to be performed. It is usually performed up to every 2 years and takes up to 6 000-man hours to complete. This includes detailed inspection of aircraft structures, in-depth lubrication, checking asymmetry on flight controls, pressure check in fuel system, operation check on electrical system and much more.

D Check

D Check is the most complex check that is performed up to every 10 years depending on the aircraft and takes it out of service for several weeks, up to 2 months. This can only be performed on maintenance bases on the given airlines as it requires more man work to perform. D Check includes very detailed inspection of structures for corrosion and damage and that includes disassembly of most aircraft parts and subsequent repairs. Interior carpets and seats are dismantled and either repaired or replaced. Engines, landing gears are also removed and inspected off the aircraft. Needlessly to say, this very complex maintenance can rise up hundreds of thousands, or millions of dollars. At some point, it is no longer desired to perform D checks on an older aircraft, as their costs supersede the remaining economic value of the aircraft and are further sold or scraped.

There is a certain documentation linked to aircraft storage. Below is a brief overview the main documents that aircraft operator and maintenance technicians might encounter during the period of aircraft storage.

Maintenance Planning Document (MPD)

Is an essential document coming from the aircraft manufacturer containing list of scheduled maintenance tasks and their repetition intervals. Aircraft operators use this information to assembly their own Operators Aircraft Maintenance Program (OAMP) that is subject to approval by national authority. An MPD can contain thousands of task items and they serve as a reference to detailed instructions in Aircraft Maintenance Manual (AMM). Additional information, such as man-hours, access panels, required skills and more can be involved [31].

Aircraft Maintenance Manual (AMM)

Serves as a cookbook for maintenance engineers and maintenance technicians. It contains detailed, specific instructions for a required maintenance task for a given aircraft. These instructions refer to maintenance tasks and inspections and unimportant repairs of components mounted on the aircraft. More unusual and specific tasks and repairs can be found within AMM as a reference to other documents, such as Overhaul Manual, Structural Repair Manual, and more.

Component Maintenance Manual (CMM)

Released by manufacturers of aircraft components and systems removable from the aircraft. This document involves tasks performed on off-aircraft components and how to achieve these tasks. This might include regular maintenance, repair, or refurbishing. It is thus the same as AMM but related to off-aircraft components.

Airworthiness Review Certificate (ARC)

This is essentially a proof of airworthiness of the aircraft and thus a necessity to allow to fly. Its issuance is subject to review of aircraft records and inspection of the aircraft and can only be issued by authorized staff under either CAMO, national authority, an appropriate AMO.

Airworthiness Directive (AD)

Is one of three Instructions for Continued Airworthiness and is sometimes the reason for grounded aircraft which then leads to aircraft storage. This document orders aircraft operators to eliminate hazardous or undesirable characteristics of aircraft, engines or propellers and defines conditions under which safe operations can continue. This "elimination" can also be expressed in a form of mandatory grounding of the aircraft. Executing an AD is binding for the aircraft operator under given deadline and under conditions specified in the AD. Shall the AD not be executed before deadline; the product loses its airworthiness. In Europe, ADs are issued by EASA or national authority.

Such an AD related to aircraft parking can be dated back to 2019 when EASA issued Airworthiness Directive No. 2019-0051R1. This AD suspended all flight operations of Boeing 737-8 and 737-9 'MAX' aircraft due to ongoing investigation of two former fatal accidents. As stated in first chapter, the result was 800 grounded aircraft. This AD also allowed a single non-commercial ferry flight to be executed to get the aircraft to a location where the expected corrective actions can be performed. Obviously, in comparison to Covid-19 crisis that is a much smaller number, but the decision-making process for aircraft parking was present there as well. Given that major maintenance facilities of airlines are located at major hubs where expected parking fees can be much higher.

Service Bulletin (SB)

Is a document issued by aircraft, engine or component manufacturer and serves as a means of communication to inform about product improvement, such as: changes in the technical documentation, ordered or recommended inspections and adjustments, implementation of approved modifications. Service Bulletins are usually non-binding, however when the modification is a matter of safety rather than product improvement [32], then the SB is referenced to an appropriate AD, and thus binding – also known as Alert SB.

Service Letter (SL)

This document also issued by manufacturer of aircraft technology to inform about less important modifications, advisory actions, or other useful information. It is also used to inform aircraft operators and AMOs about a newly issued SB.

4 Legislative frame of the European Union

Consolidated Regulation (EU) No 1321/2014 on Continuing Airworthiness defines responsibilities of aircraft owner with respect to airworthiness and maintenance. Section A, Subpart B M.A.201 (Responsibilities) states the following:

- "*The owner is responsible for the continuing airworthiness of an aircraft and shall ensure that no flight takes place unless:*
  - *the aircraft is maintained in an airworthy condition,*
  - *the airworthiness certificate remains valid,*
  - *the maintenance of the aircraft is performed in accordance with the approved maintenance programme.*
- *The owner of an aircraft may contract the tasks associated with continuing airworthiness to a continuing airworthiness management organization.*
- *Maintenance of large aircraft, aircraft used for commercial air transport and components thereof shall be carried out by a Part-145 approved maintenance organization.*" [33]

Subpart C, M.A.301 (Continuing airworthiness tasks) states:

- "*The aircraft continuing airworthiness and the serviceability of both operational and emergency equipment shall be ensured by:*
  - *the accomplishment of all maintenance in accordance with the AMP,*
  - *the release of all maintenance,*
  - *the accomplishment of any applicable:*
    - *airworthiness directive,*
    - *operational directive with a continuing airworthiness impact,*
    - *continued airworthiness requirement established by the Agency.*
  - *the accomplishment of modifications and repairs.*" [33]

Subpart C, M.A.302 (Aircraft maintenance programme) states:

- "*Maintenance of each aircraft shall be organized in accordance with an aircraft maintenance programme.*
- *The aircraft maintenance programme shall contain details, including frequency, of all maintenance to be conducted.*
- *The aircraft maintenance programme must establish compliance with instructions for continuing airworthiness (AD, SB, SL)*" [33]

EASA then provided additional information for aircraft operators with respect to difficulties in continuing airworthiness caused by grounded aircraft and organization issues during Covid-19. Document FAQ n.116314 states that during storage of an aircraft, its maintenance tasks expressed in flight hours or flight cycles are not impacted as its not in service. On the other hand, maintenance tasks expressed in calendar times can become due during parking / storage period and thus can create imbalance in maintenance planning. Sometimes this maintenance cannot be provided as often aircraft are grounded at remote locations with truly little maintenance facilities. Document states that if this scheduled maintenance task cannot be carried out, owner or CAMO can request postponement at a competent authority. EASA states that it is acceptable to postpone these tasks to be performed at the next suitable opportunity or at the end of the storage/parking period. EASA also states that if postponement is extended beyond point of return to service, it is recommended to receive advice from Type Certificate Holder on such postponement.

Document FAQ n.116316 states that due to Covid-19 crisis, movement restrictions and lack of access to certain facilities and services had arisen. Under normal circumstances the aircraft owner or CAMO shall establish a system to ensure all maintenance tasks are performed within limit intervals defined in approved Aircraft Maintenance Programme. A widespread practice for aircraft under Annex I to 1321/2014 is to combine individual maintenance tasks into packages of same intervals or letter-checks (hence A-check above). With restricted access to facilities, services and authorized staff, packages might had been rendered infeasible. To split a package or letter-check back into individual tasks would require an amendment to an existing AMP and is subject to approval by competent authority.

Document FAQ n.116317 states that due to some aircraft grounded on remote airports with no authorized maintenance organization to perform required maintenance tasks, this would result in insufficient maintenance work provided. The maintenance organization shall have a list of approved locations for line maintenance in their Exposition. EASA states that in order to perform line maintenance on a remote airport, a competent authority shall temporarily permit performance of line maintenance on a non-approved location for a period up to 3 months. This shall shorten the approval process in question and easy approval requirements. The request for such approval shall be reviewed based on previous performance of the organization, and confidence of the competent authority in the ability of the organization to ensure safe operations. After the initial concession is expired, the competent authority may approve an extension to the existing concession for another period up to 3 months.

5 Methodology

The purpose of following chapters is to introduce a “deep-diving” method into decision-making process of aircraft operators in aircraft parking. This shall introduce a brand-new research as aviation has undergone a period of time like never before. Therefore, the following research shall be very unique. The purpose here is to describe progress of aircraft parking in Europe and to determine a model of such decision-making process. Unfortunately, when it comes to aircraft parking, the amount of available information resources is extremely limited. Not only is it connected to the fact that coronavirus was a unique experience to the industry, but aircraft operators also had never had to ground their fleet to this extent and thus such research had not been concluded. Aircraft parking in general is also lacking a proper information library.

In order to pursue goals of this thesis mentioned above, this research combines several research methods to achieve the best result. Descriptive method refers to description of aircraft parking market in Europe during coronavirus years. The aim is to determine and describe statistics that arise from aircraft parking in Europe. It is expected to figure certain characteristics and trends in those statistics. Another important feature is to observe differences in various subjects and categories, such as different statistics between airlines or different statistics between various aircraft types.

There were dozens of variables that contributed to aircraft parking during Covid-19 times. In order to analyze statistics and to determine a decision-making model, these variables need to be analyzed to see how they correlate to each other and to explore relationships in-between them. This is part of a correlational method. Understanding of these variables allows to merge them into a functional decision-making model that shall investigate behaviors of European airlines when it came to aircraft parking and to find similar and opposite behavior patterns.

Due to the lack of information resources mentioned above, the focus turned on using data as a potential information carrier. The information presented in chapters above shall serve as a background for further analysis. Data serves as a perfect means for analysis and processing. Although Covid-19 is a quite recent experience, more than a million flights and thousands of grounded aircraft have been registered in European area since the pandemic started. This amount of data serves more than just a sample and shall provide valuable results in the end.

Again, looking for an available set of data related to aircraft parking is a quite challenging process since it is not commonly processed into great detail and archived. As mentioned above, Covid-19 is a unique experience and grounding of aircraft of this size has not been seen. Therefore, there are no public libraries containing this type of data. Data however remains the only approachable path to get behind goals of this thesis.

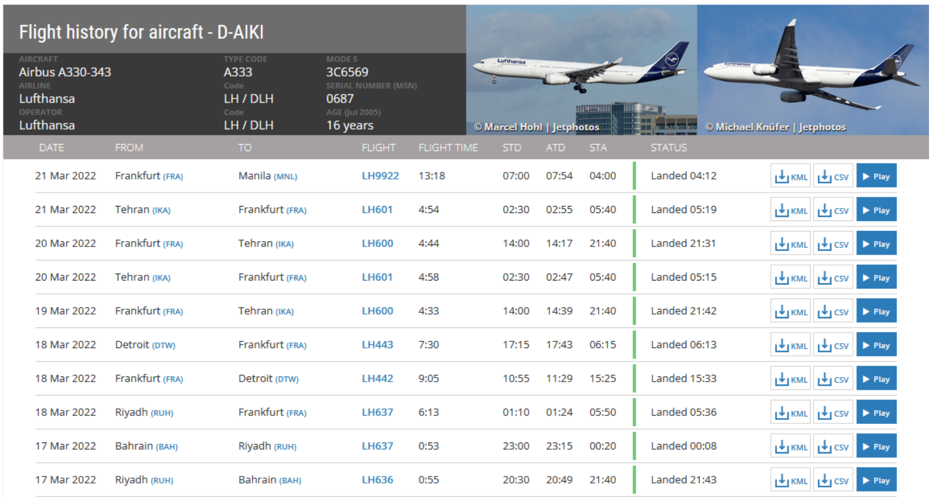
As part of this research, a simple ADS-B receiver was built in order to get access and fetch data related to aircraft parking (Figure 7). The processing unit was represented by a Raspberry Pi 3 Model B computer with 1.2GHz CPU and 1GB RAM. This device is quite common in simple and affordable solutions. The Raspberry hosted a R820T2 ADS-B USB-Dongle receiver made by jetvision® company. This build features a small indoor antenna receiving at 1090 MHz. Figure 7 below represents the build used for fetching ADS-B data.

Figure 7 – ADS-B receiver without connected antenna

Range of this device moves in tens of kilometers. This device has then been connected to Flightradar24 network of ADS-B receivers. This company provides flight tracking services and real-time surveillance information of aircraft around the world. By joining their ADS-B network and constantly sharing data fetched by this receiver, a business account has been granted and is subject to continuous data sharing. This business account grants access to a large amount of past and present data fetched by Flightradar24 facilities and users.

There is, however, no direct option to dive into aircraft parking data and thus need to be rendered using alternative solution. An effective way is to look at flight history of a given aircraft and compare two adjacent flights. Using time difference between those two flights, the duration of how long the aircraft has been parking at first flights destination can be derived. Is there a longer interval, it can be considered relevant for this thesis.

The figure below represents a brief flight history of a Lufthansa A330 aircraft. A “Load earlier flights” button on the bottom of the webpage (out of focus in Figure 8) allows user to fetch in data about next 100 previous flights.



DATE	FROM	TO	FLIGHT	FLIGHT TIME	STD	ATD	STA	STATUS
21 Mar 2022	Frankfurt (FRA)	Manila (MNL)	LH9922	13:18	07:00	07:54	04:00	Landed 04:12
21 Mar 2022	Tehran (IKA)	Frankfurt (FRA)	LH601	4:54	02:30	02:55	05:40	Landed 05:19
20 Mar 2022	Frankfurt (FRA)	Tehran (IKA)	LH600	4:44	14:00	14:17	21:40	Landed 21:31
20 Mar 2022	Tehran (IKA)	Frankfurt (FRA)	LH601	4:58	02:30	02:47	05:40	Landed 05:15
19 Mar 2022	Frankfurt (FRA)	Tehran (IKA)	LH600	4:33	14:00	14:39	21:40	Landed 21:42
18 Mar 2022	Detroit (DTW)	Frankfurt (FRA)	LH443	7:30	17:15	17:43	06:15	Landed 06:13
18 Mar 2022	Frankfurt (FRA)	Detroit (DTW)	LH442	9:05	10:55	11:29	15:25	Landed 15:33
18 Mar 2022	Riyadh (RUH)	Frankfurt (FRA)	LH637	6:13	01:10	01:24	05:50	Landed 05:36
17 Mar 2022	Bahrain (BAH)	Riyadh (RUH)	LH637	0:53	23:00	23:15	00:20	Landed 00:08
17 Mar 2022	Riyadh (RUH)	Bahrain (BAH)	LH636	0:55	20:30	20:49	21:40	Landed 21:43

Figure 8 – Flightradar24 online interface

Header of this page contains important information about the given aircraft – aircraft type code, age, aircraft operator. These aircraft attributes will be further used as variables entering the desired model. Moving forward, each row represents one concluded flight in the past. To distinguish aircraft parking, the process is to subtract values of two adjacent rows in column “Date”. In theory, all results shall be considered as aircraft parking, no matter how much of a time difference there is. In most cases, during regular traffic with proper aircraft utilization, these results correspond to basic aircraft turnaround or overnight parking. In accordance with terminology presented in chapter “Maintenance”, this shall count as a “Normal Parking” and is considered irrelevant for purpose of this thesis. The goal is to move row by row and record any significant aircraft parking intervals until 1st Jan 2020 is reached. If a significant parking interval occurs, airport, dates from both rows, their difference (delta) along with information in header is recorded. By significant parking interval (delta), 30 days has been chosen as a reasonable value. Some may argue that it is too high, and therefore some records would have been left out although they were part of the decision-making process in question. Others may allege that it is too low as this would include any heavy maintenance provided on the aircraft. To riposte any disputes, lowering or raising this delta would mean that more error data and less correct data would be added, respectively. Some airlines were quite flexible in aircraft parking, meaning that 30-60 days delta would be a common occurrence. On the other hand, considering the periodicity of heavy maintenance and limited finances of airlines, the probability of error data is very low.

The data contained in a text file then may be further processed. The original data range parsed from Flgihtradar24 contains the following attributes: Airline, Aircraft registration, Aircraft type, Aircraft age, Airport where parking occurred, Date of start and Date of end of parking, and Days meaning length of parking in days. This text shall then be imported into MS Excel environment for further processing. After importing, text is converted into columns as they are delimited by a space character. Each row now represents one parking record and can be seen as a vector where each column are attributes of this parking. Considering that some aircraft have been parked multiple times during Covid-19, a single aircraft might therefore be expressed in multiple rows. Preliminary study of the data shows that some aircraft even had four parking intervals longer than 30 days over the period of 2 years. Some data have also been collected from EUROCONTROL's STATFOR dashboard. Next, more attributes need to be added to each vector. The attributes can be divided into two categories: attributes of the aircraft and attributes of the airport, where parking occurred. Adding attributes row by row is quite time ineffective. Another sheet is thus created to hold values for these attributes. A list of airports and a list of aircraft types is created using the `UNIQUE` function. To each aircraft is a binary value (0 or 1) assigned that represents whether the aircraft is of narrow-body (1) or wide-body (0). This attribute will be used to see differences in aircraft parking between narrow-body and wide-body aircraft.

Airline	Registratic	Aircraft	Age	Airport	Date_Entry	Date_Exit	Days	Months	Narrow Body	Base	MRO Subsidiary	L. Temperature	H. Temperature	Rainfall
AirFrance	F-GMZA	A321	27	LFPO	20210423	20210624	62	16	1	1	1	2	25	45,7
AirFrance	F-GMZA	A321	27	LFBO	20201025	20210423	180	10	1	0	1	2	28	56,9
AirFrance	F-GMZA	A321	27	LFPO	20200321	20200601	72	3	1	1	1	2	25	45,7
AirFrance	F-GMZB	A321	27	LFPO	20210317	20210516	60	15	1	1	1	2	25	45,7
AirFrance	F-GMZB	A321	27	LFBO	20201012	20210212	123	10	1	0	1	2	28	56,9
AirFrance	F-GMZB	A321	27	LFPO	20200317	20200703	108	3	1	1	1	2	25	45,7
AirFrance	F-GMZC	A321	26	LFPO	20210325	20210514	50	15	1	1	1	2	25	45,7
AirFrance	F-GMZC	A321	26	LFBO	20201012	20210315	154	10	1	0	1	2	28	56,9
AirFrance	F-GMZC	A321	26	LFPO	20200330	20200626	88	3	1	1	1	2	25	45,7
AirFrance	F-GMZD	A321	26	LFBO	20210221	20210601	100	14	1	0	1	2	28	56,9
AirFrance	F-GMZD	A321	26	LFPO	20201102	20201219	47	11	1	1	1	2	25	45,7
AirFrance	F-GMZE	A321	26	LFPO	20201025	20210701	249	10	1	1	1	2	25	45,7
AirFrance	F-GMZE	A321	26	LFPO	20200316	20200718	124	3	1	1	1	2	25	45,7
AirFrance	F-GTAD	A321	23	LFPG	20210912	20211208	87	21	1	1	1	2	25	45,7
AirFrance	F-GTAE	A321	23	GMMN	20210830	20211001	32	20	1	0	0	9	26	63,8
AirFrance	F-GTAE	A321	23	LFPG	20200830	20210812	347	8	1	1	1	2	25	45,7
AirFrance	F-GTAH	A321	22	LFPG	20200321	20200714	115	3	1	1	1	2	25	45,7
AirFrance	F-GTAH	A321	22	LFPG	20201004	20210420	198	10	1	1	1	2	25	45,7
AirFrance	F-GTAJ	A321	20	LFPG	20200317	20200430	44	3	1	1	1	2	25	45,7
AirFrance	F-GTAJ	A321	20	LFPG	20200901	20211118	443	9	1	1	1	2	25	45,7
AirFrance	F-GTAK	A321	20	LFBO	20200520	20210421	336	5	1	0	1	2	28	56,9
AirFrance	F-GTAM	A321	19	LFPG	20200322	20200422	31	3	1	1	1	2	25	45,7
AirFrance	F-GTAM	A321	19	LFPG	20200906	20201215	100	9	1	1	1	2	25	45,7
AirFrance	F-GTAM	A321	19	LFPG	20210412	20210623	72	16	1	1	1	2	25	45,7
AirFrance	F-GTAP	A321	13	LFPO	20210401	20210703	93	16	1	1	1	2	25	45,7

Figure 9 – Data processing in Excel

Processing data in Excel was at this point complete. Further statistical analysis would be performed in MATLAB as it provides a better computing environment. It also provides better means for further data filtration and an unlimited range of statistic possibilities. `Airline` attribute has been automatically fetched with parking data. It represents airline to whom the aircraft belongs. For the purpose of this thesis, only European airlines have been selected. Comparing individual airlines returned promising results in the previous chapter.

`Aircraft registration` attribute served as a unique identifier for individual aircraft. This argument was crucial, because some aircraft have parked multiple times during the 2 year period. To determine certain statistics, such as „Average Days of Parking vs Aircraft Type“, it was necessary to target each registration individually.

`Aircraft type` was another attribute fetched automatically and represents type code of the observed aircraft. It was used to determine different behavior in various aircraft types. It cannot be used in the regression model as it is not a numerical value.

`Age of the aircraft` was also automatically fetched from the source, and it is expected that it has significant impact on the decision-making process. The null hypothesis states that older aircraft have been parking for a significantly longer period of time as they are usually less cost-effective and provide less comfort. Older aircraft have also been subject to scraping or re-selling, so for that purpose, they should have been parking longer.

A binary value `Narrow-body / wide-body` has been estabilished to differentiate between aircraft often categorized as narrow-body aircraft or wide-body aircraft. The main idea behind this attribute is that narrow-bodies are mostly used for regional travel, while wide-bodies are mostly used on medium and long-haul flights, due to their nature to carry more passengers and fuel. Regional and long-haul markets have behaved differently during Covid-19, therefore it is expected that they emit different regression results.

`Capacity of the aircraft` attribute has been manually added after all necessary data was collected to substitute the Aircraft type attribute with a numerical value. The idea null hypothesis states that as demand rapidly reduced during Covid-19, it would be irrational to use larger aircraft for a reduced demand. Therefore, it is expected that larger aircraft would be parking for a longer time.

`Date of start of parking` was automatically fetched and represents the date when aircraft landed on the airport where parking occured. Mean and standard deviation cannot be calculated as it is a datetime variable. The same procedure applies for next variable, `Date of end of parking`.

`Total days of parking` represents time length of parking and is calculated as time difference (delta) between previous two datetime attributes. Only parking records with delta more than 30 days have been selected for this thesis. This attribute serves as an important carrier of information related to the parking itself and can be used to determine a series of statistics.

`Months` attribute represents number of months that have passed since beginning of 2020 (which is start of focus of this thesis) until given aircraft started parking.

A binary value `Base` represents whether the given airline has a base on airport, where parking occurred. The idea for this is that bases might have played one of the most important factors in the decision-making process. It is believed that airlines preferred to store aircraft on their bases due to existing facilities rather than on third party airports.

Next binary attribute `MRO Subsidiary` represents whether maintenance provided on that airport is done by a subsidiary company with respect to given airline. For instance, Lufthansa aircraft parked on LMML (Malta) airport would have 1 assigned to this attribute since Lufthansa Technics Malta is an existing facility. This attribute is also expected to have played a big role since maintenance is a necessity during aircraft parking and access to such maintenance facilities is a must. Chapter *Maintenance – an essential care* provides more information on this topic.

`Parking fee` attribute represents standard parking fees enforced by this airport per month expressed in Euros. This data has been collected using price lists of each airport. These charges are usually related to duration of parking, MTOW of the aircraft and position on the airport. It has been therefore calculated for a 30-day interval for Airbus A320-neo. This attribute has limited informative value for following reasons. Some airports provide a different price for long-term parking. Such airports then have the calculated price lower than airports who do not provide this option in their price lists. Next, some airports state different price for different parking aprons, runways, etc. If so, the most remote parking position, usually used for long-term parking, has been chosen. Finally, long-term parking in mass is usually subject to a contract between the airline and airport. That being said, contracted prices are expected to be much lower than price lists to make parking affordable. This effect is even amplified if the airline has a base on that airport. Therefore, the purpose of Parking fee attribute is not to express real parking prices, but to only state “this airport is more expensive compared to this one” and to see if costliness of that airport played a role in the decision-making process.

`Maintenance costs` As mentioned in previous chapters, maintenance plays an important role during aircraft parking. This maintenance comes with a cost of labor and material. Prices for material, repairs and spare parts are expected to be uniform around the world, however there is a significant difference in costs related to workforce done during maintenance. Data for this attribute has been expressed in annual income of an aircraft maintenance technician at the given location. This data has been derived using Glassdoor – an online service providing intel on companies and their employees. Notably, this attribute is not meant to express the actual price airlines have to pay for maintenance. Instead, it focuses on differences that might arise in maintenance on different airports. Again, the meaning of “this MRO is more expensive compared to this one” is established.

`Temperature` can be seen as a decisive factor since it has great impact on aircraft structure and corrosion. It is also closely connected to humidity – an eternal enemy to the aircraft. An optimal temperature range varies between studies. There are different materials used on the aircraft that each react differently. For instance, Civil Aviation Department of India recommends for rubber parts to be stored in between 50 to 70 degrees Fahrenheit [34]. Another important view on temperature is presented by [35]. For purposes of this thesis, temperature has been divided into two attributes – `Lowest temperature` and `Highest temperature`, representing lowest and highest temperature, respectively, during the months of parking at that airport.

`Rainfall` is also an important meteorological factor as it contributes to humidity and thus to corrosion and structures damage. It is believed that less rainfall provides better storage condition for aircraft. A common practice was to store aircraft at “desert yards” – places with lack of rainfall, humidity, insects, and wildlife. Popular desert yards for aircraft parking would include Alice Springs in Australia, Roswell, NM in United States or Victorville, CA in United States.

6 European Parking Market

Europe is home to a fleet of over six thousand aircraft and a majority of them has spent some time grounded. This region plays an important part of global aviation as it hosts millions of passengers each year. It also serves with major hubs connecting the world. No wonder aviation subjects in Europe are big players in the global aviation industry. Major European airlines are recognized globally and are often the first choice when it comes to foreign tourists. European airports are also battlegrounds as new airlines are trying to get in and secure themselves an airport slot. European airlines would include Ryanair, a low-cost carrier with headquarters in Ireland, another low-cost carrier Wizz Air, headquartered in Hungary. Next, Lufthansa Group – Lufthansa, Swiss Airlines, Eurowings, Austrian Airlines. Others would include Air France, KLM, Turkish Airlines, Scandinavian Airlines, easyJet, Finnair, LOT Polish Airlines, British Airways, Iberia and more.

Passengers would frequently travel to the busiest airports - Istanbul Airport, Charles de Gaulle Airport in Paris, Schiphol Airport in Amsterdam, Frankfurt Airport, Madrid, Heathrow Airport in London, Paris-Orly Airport, Munich Airport, Barcelona, Vienna, Prague, Zurich, Rome, Berlin, Lisbon, Copenhagen, Brussels, Oslo, Warsaw, and Stockholm.

Lufthansa

Deutsche Lufthansa AG is one of the major European airlines (currently stated as second largest in terms of PAX). This German carrier is a key player in the global aviation as it provides flights to all continents. The classic legacy business model that Lufthansa represented in the past is now supplemented by their sister companies and subsidiaries Austrian Airlines, Swiss Air Lines, Lufthansa CityLine, Eurowings with a different, even a low-cost model. Then other subsidiaries strike in - Lufthansa Technik, Lufthansa Cargo, Lufthansa Aviation Training, etc. and together they form Lufthansa Group. The Group is projected to have over 700 aircraft in their fleet solely for commercial flights, with Lufthansa fluctuating around 300 aircraft itself. The actual number size of their fleet changes as aircraft are being sold or scraped and new ones are acquired. At the time this text is being written, Flightradar24 states total of 306 aircraft in their fleet, which is in detail: 30 units of Airbus A320-N (all newer than 6 years), 14 units of Airbus A321-NX (all newer than 3 years), 34 units of Airbus A319, 52 units of Airbus A320, 50 units of Airbus A321, 13 units of Airbus A330, 17 units of Airbus A340-300, 10 units of Airbus A340-600, 21 units of Airbus A350, 8 units of Boeing 747-400, 19 units of Boeing 747-800, 1 Brand new Boeing 787-9 Dreamliner, 28 units of Mitsubishi CRJ-900LR and finally 9 units of Embraer E190LR. As noticed, Lufthansa has a multi-purpose aircraft fleet and covers wide range of services and connects destinations on both long-haul and regional trips. Formerly their fleet would include more "unique" planes, such as Airbus A380-800s. Since it is a European carrier, the negative impact caused by Covid-19 was significant. EUROCONTROL on Apr 14th, 2020, reported that Lufthansa was 94% down on flights compared to the same day previous year. Same results did occur on their subsidiaries, Austrian and Eurowings, with 99% and 95% reduction, respectively [36]. The resurrection was also much slower compared to other European carriers. EUROCONTROL report from Sep 8th, 2020, shows a 72% reduction in flights compared to same day in 2019, whereas Air France showed a 53% reduction and British Airways an increase of 24%. This poor traffic performance was often the subject to a discussion in German government. Eventual struggles have passed, and Lufthansa now remains as German flag carrier. The headquarters are located in Cologne, Germany and their portfolio includes several bases in Germany and neighboring countries: bases in Frankfurt, Munich, Berlin, Dusseldorf, Vienna, and Zurich. There are some bases in other countries too, for instance, Lufthansa Technik has a dominant facility at Malta airport.

This variety of services and variety of aircraft allows for a variety in statistics. Progress in Lufthansa (without subsidiaries) parking during Jan 1st, 2020, to Dec 31st, 2021 can be presented. Each data point in this chart represents the precise number of Lufthansa aircraft that have been parking on that specific day.

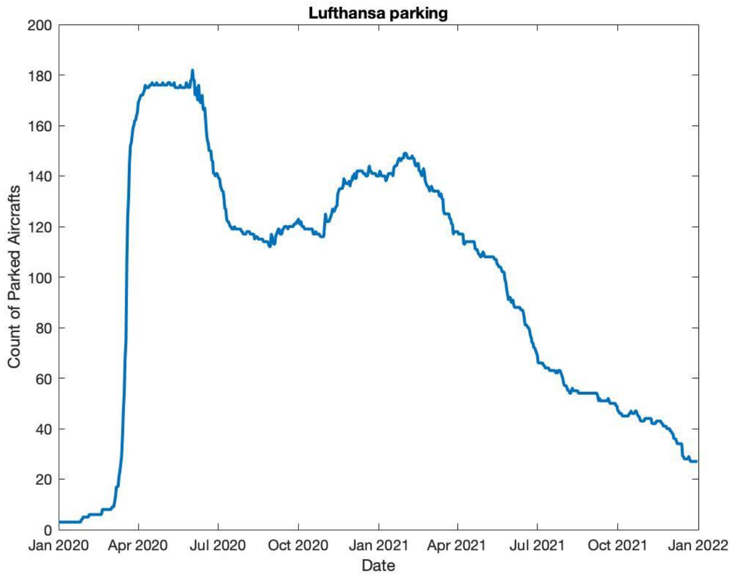


Figure 10 – Progress of Lufthansa parking

Only parking intervals longer than 30 days are taken into account in Figure 10. It is clear that parking began in the late March 2020 in correlation with start of the pandemic in Europe. The first parking loop sticked for 3 months until coronavirus got suppressed in summer 2020. As it is with many respiratory diseases, the arrival of fall allows for easier transmission of the disease. Therefore, a second wave of parking has occurred with a smaller peak. According to gathered data, on June 1st, 2020, 182 Lufthansa aircraft have been parking on an interval longer than 30 days. The second wave registered 149 parked aircraft on Jan 31st, 2020, again on 30-day interval. It can be seen that the progress of parking during 2020 is correlating to progress of new Covid-19 cases in Europe. It is clear that the first wave of pandemic in March 2020 had the most significant impact, as border restrictions and fear among passengers were staggering. Later waves had lower influence, hence smaller peak in winter 2020/21.

Figure 11 shows airports Lufthansa has chosen for parking. The Y axis represents total number of days of parking of all Lufthansa aircraft (sum of all parking records on given airport among Lufthansa fleet). Several other airports did not fit in the graph as their values are too small (probably a product of parking of only one or two aircraft). It can be seen that all Lufthansa bases in Germany were popular for parking (airports starting with EDxx). Other, more affordable airports in Hungary were also popular (LHBP – Budapest, LFDC – Debrecen). Eventually, Teruel Airport (LETL) was also a significant player.

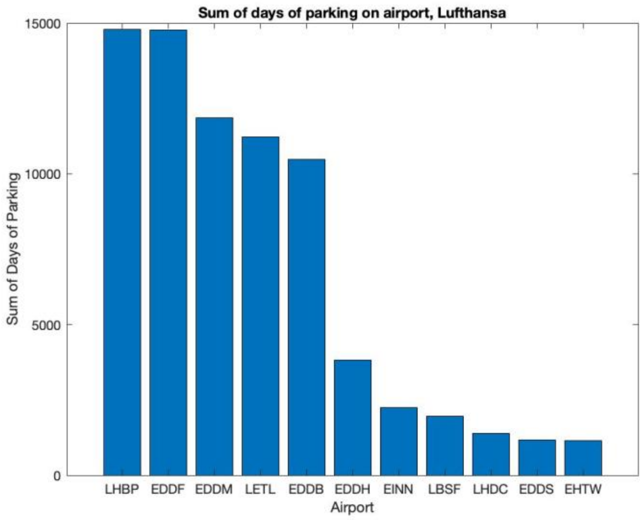


Figure 11 – Airports of Lufthansa parking

Frankfurt Airport (EDDF) was home to most wide-body Lufthansa aircraft, such as Airbus A340-300, A340-600, A320-N, A380-800, and Boeing 747-400, 747-800. Munich Airport (EDDM) also hosted some wide-body aircraft like Airbus A350, couple A340-600s, A380-800s. However, the majority of parking in Munich was represented by Lufthansa narrow-body aircraft: Airbus A320, A319, A320-N and A321-NX. Teruel Airport (LETL) hosted aircraft chosen for long-term parking, either expecting their late return-to-service or scraping. Such aircraft would include old Airbus A340-600s, old Boeing 747-400 and Airbus A380-800s. Lastly, Budapest Airport (LHBP) hosted dozens of narrow-body aircraft: Airbus A320s and A321s suited for long-term parking, usually parking for more than one and a half a year.

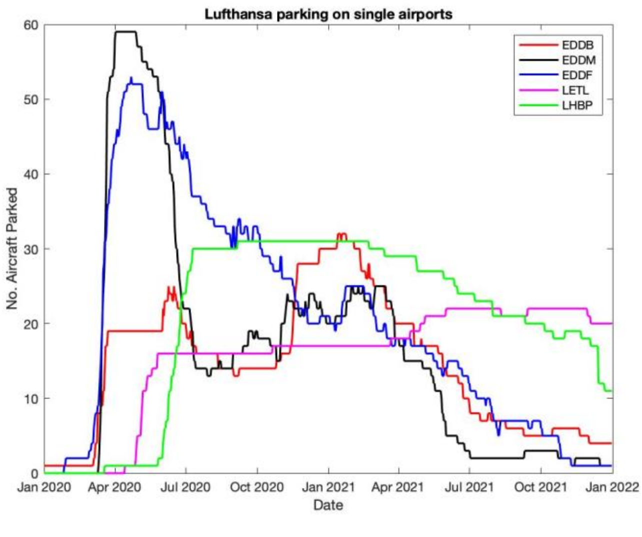


Figure 12 – Progress on major airports of Lufthansa parking

Some differences have been found between parking of narrow-body aircraft and wide-body aircraft. The reasoning behind this is that both narrow-body and wide-body are exclusive to a specific market. Preferably, narrow-bodies are used for regional and domestic flights, whereas wide-bodies are used for medium and long-range flights. Both these segments project different properties and therefore parking is also different. This chart uses a reference number of days for 2 years. Values then mark the percentage of days they spent parked vs number of days in 2 years.

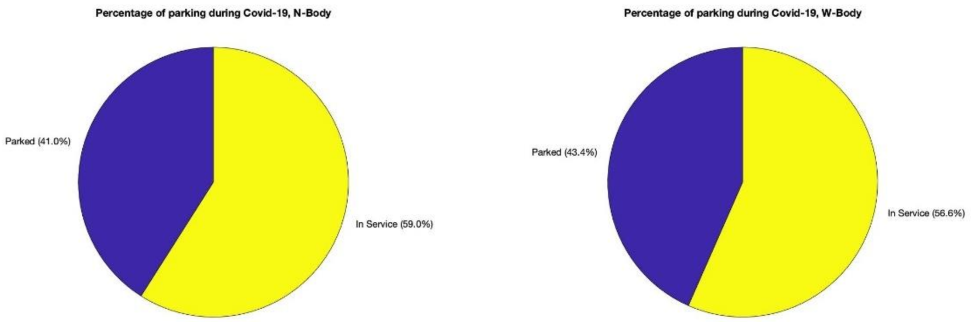


Figure 13 and 14 – Percentage of service state in 2020 - 2021, Lufthansa

Figure 15 represents the average days of parking for each aircraft type of Lufthansa fleet. Height of the bars represents the average days; green marks represents maximum days in the sample and red marks represent the minimum days. In general, some wide-body aircraft have been parking for a super-long time as part of their scraping process (A388, A346). Other wide-bodies also show long parking (B744, B748) although they remain active in the fleet. The rest of wide-bodies show insignificant duration of parking (A333, A343, A359) as they remained in service during the pandemic.

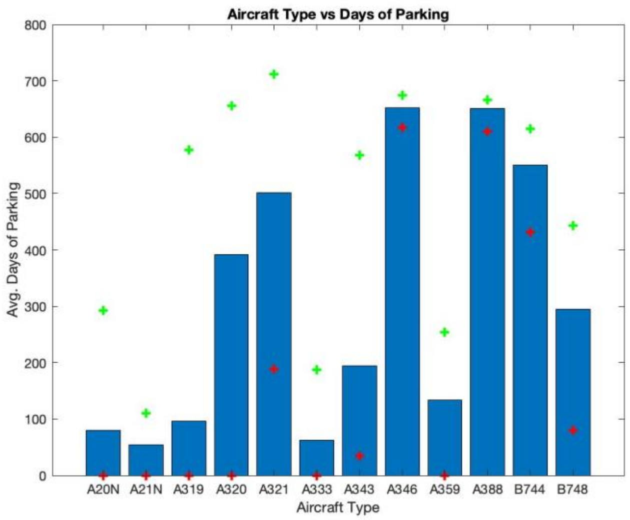


Figure 15 – Average days of parking for each A/C type, Lufthansa

Interesting statistics arise from narrow-body aircraft. Lufthansa parked their younger narrow-bodies (A20N, A21N) only during the first wave in March 2020 or no parking at all. Older narrow-bodies (A320, A321) have been parked for a significant time.

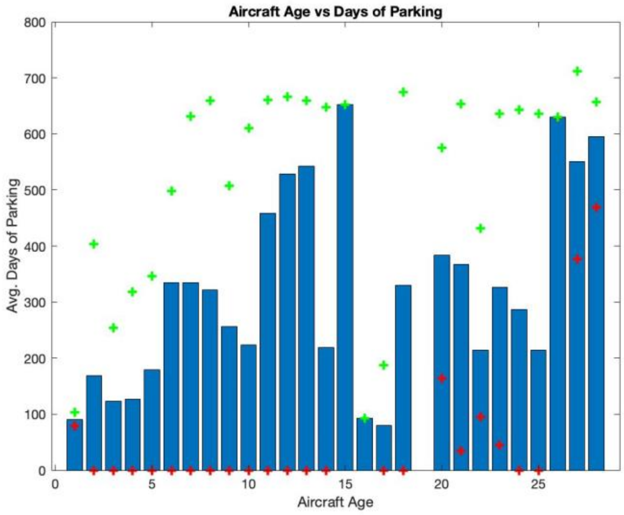


Figure 16 – Average days of parking for each A/C age, Lufthansa

Some weird statistics can be seen in Figure 16. As predicted, younger aircraft have been parking the least. Older aircraft (25+ years) have been parking for the majority of the pandemic. The middle part shows insignificant statistics. This is mainly because acquisition of aircraft is done in bulks and only in certain times. Often, aircraft are switched for a newer model if available. Therefore, some aircraft types only have 15+ years models, others have only <6 years models, etc. It is possible that if each aircraft type in the fleet had uniform distribution of age, some statistics could be observed.

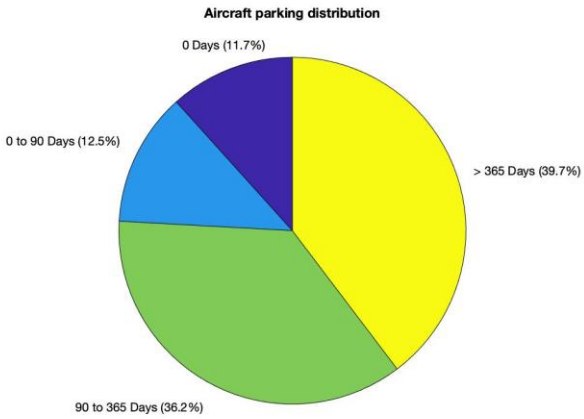


Figure 17 – Overall parking distribution, Lufthansa

Overall, almost 40% of Lufthansa fleet has parked for more than a year during the 2 years of pandemic. Again, this includes aircraft that have been sold or scraped. Vast majority of their fleet has parked more than 3 months but less than a year. This interval usually represents aircraft that have been parking during first and second wave in spring 2020 and winter 2020, respectively. 12.5% aircraft have parked less than 3 months, meaning they were the first ones to exit the first wave of parking. 11.7% did not park at all.

British Airways

This United Kingdom flag carrier has been around for decades and has been known for their premium service and reputation. Despite being a flag carrier, they often switch positions with easyJet in terms of PAX carried and fleet size. British Airways however offer a wide-range of services and covers worldwide destinations. Their headquarters are located in London, and they operate bases on major British airports – Heathrow, Gatwick, Luton, and some extra in Europe. They are also expected to open a new base in Madrid in summer 2022 [37]. Accordingly to their network, they operate a wide range of aircraft: 17 units of Airbus A320-251N, 10 units of Airbus A321-251NX, 30 units of Airbus A319-131, 67 units of Airbus A320-232, 18 units of Airbus A321-231, 12 units of Airbus A350, 12 units of Airbus A380, 11 units of Boeing 737, 59 units of Boeing 777, 37 units of Boeing 787 Dreamliner, 23 units of Embraer E190LR and 3 units of Dornier 328-310. The airline also had a maintenance subsidiary called British Airways Engineering, responsible for maintaining their fleet and providing support for other airlines. Their major maintenance stations are located in Gatwick Airport, Glasgow Airport and Cardiff Airport. They also have facilities for line maintenance around the world. British Airways, along with Ryanair, was one of the least hit airlines during the pandemic. Although EUROCONTROL reports show a 96% reduction in flights in mid-April, there was 24% increase in early September 2020 compared to same days in 2019.

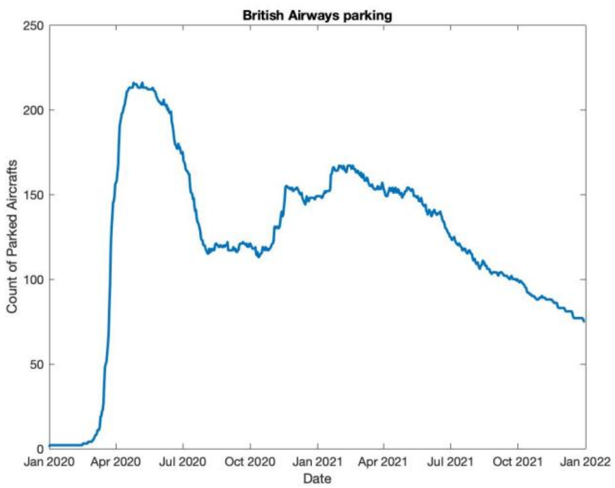


Figure 18 – Progress of British Airways parking

Figure 18 displays a similar progress of parking as Figure 10 (Lufthansa). This airline, although not part of the European Union, is quite dependent on flights to many European destinations. The first wave introduced 216 parked aircraft on interval longer than 30 days, prohibit some aircraft that have been discarded shortly after. Second wave was also quite significant, registering 167 parked aircraft on interval longer than 30 days. Numbers have been dropping ever since.

Figure 19 shows airports used for most parking of British Airways fleet. The Y axis is the sum of days of parking of all Lufthansa aircraft on the given airport. Lesser airports (sum of days < 2000) are not shown in this figure. It is clear that airports located in the United Kingdom (airports starting with EGxx) were popular. Madrid Airport (LEMD) and Teruel Airport (LETL) were also used due to their proximity to British islands.

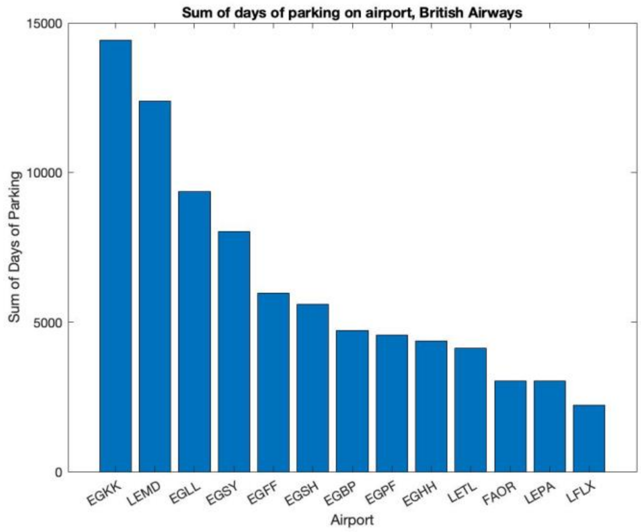


Figure 19 – Airports of British Airways parking

Madrid Airport hosted aircraft suited for longer parking – Airbus A380s, some older A320s and A321s. An average parking interval in Madrid for a single aircraft would be approx. 400 days. Teruel Airport hosted a couple Jumbo Jets designated for scraping, some A380s and B777s. Gatwick airport (EGKK) hosted some of B777s, dozens of A320s and some A319s. Due to Gatwick's location, this airport was used mainly for shorter parking intervals, averaging at somewhat 70 days, however it was quite common for a single aircraft to park there multiple times during the pandemic. Heathrow airport (EGLL) hosted the majority of Jumbo Jets, a dozen of B777s and some narrow-bodies. Sheffield City Airport (EGSY) hosted eleven units of Jumbo Jets who are no longer under BA's registration. Figure 20 shows progress of parking on these airports:

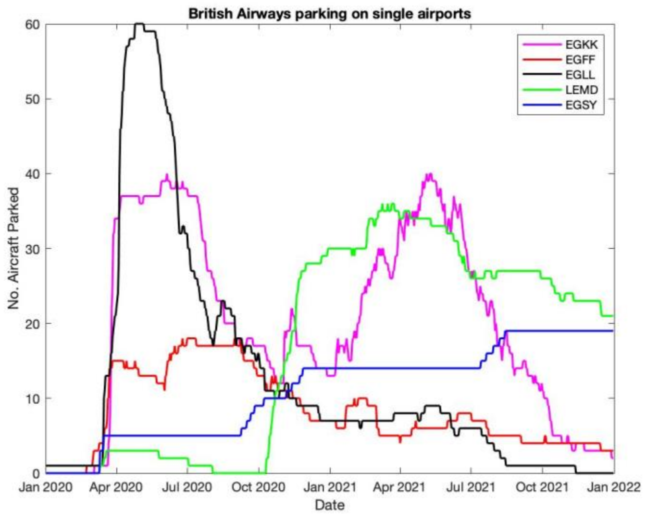


Figure 20 – Progress on major airports of British Airways parking

Narrow-body aircraft have been parking for almost 43% of days of the 2-year interval. Again, this is the product of BA's dependency on flight to Europe. European nations introduced a series of Covid-19 countermeasures to reduce travelling possibilities. Wide-bodies have been suffering less, with a 36.2% parking share of the 2-year interval. Please note, both of these charts are deflected by aircraft that have been sold or scraped.

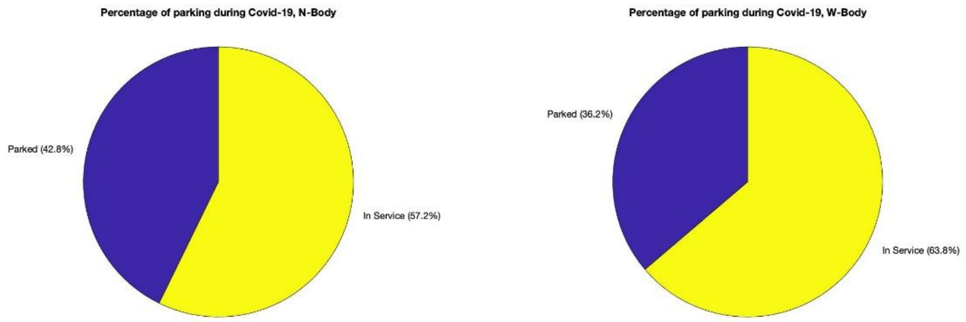


Figure 21 and 22 – Percentage of service state in 2020 - 2021, British Airways

Figure 23 represents the average days of parking for each aircraft type of British Airways fleet. Height of the bars represents the average days; green marks represents maximum days in the sample and red marks represent the minimum days. Jumbo Jets and A380s were subject to longest parking, although A380s remain in service to this day. Interestingly, newer, fuel-efficient models (A35K, Dreamliner) experienced almost no parking. Figure 23 also shows that E190 and J328 used for travelling between British islands, were also suspended.

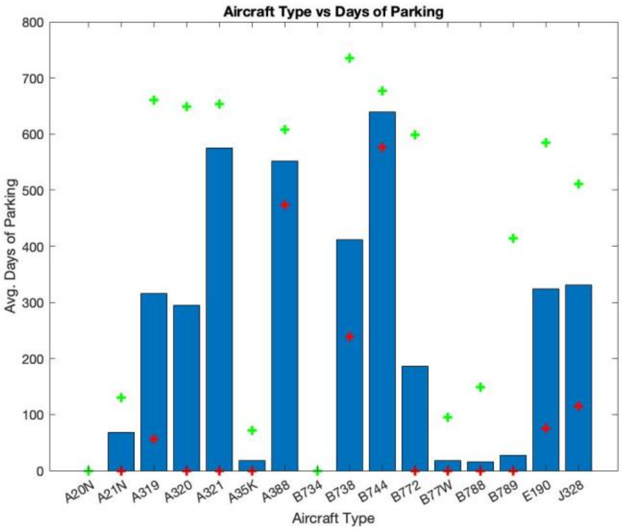


Figure 23 – Average days of parking for each A/C type, British Airways

Figure 24 displays average days of parking with respect to age of the aircraft. Bars represent average days; green marks represent maximum days of that age and red marks minimum days of that age. Interestingly, British Airways project a much more dependent statistics on age. Newer aircraft, which tend to be modern and fuel-efficient were absent from parking. As we approach higher age, the interval for parking gets higher (prohibit some exceptions). There is a mark at the age of 33, which represents a Boeing 737 daily used in South Africa.

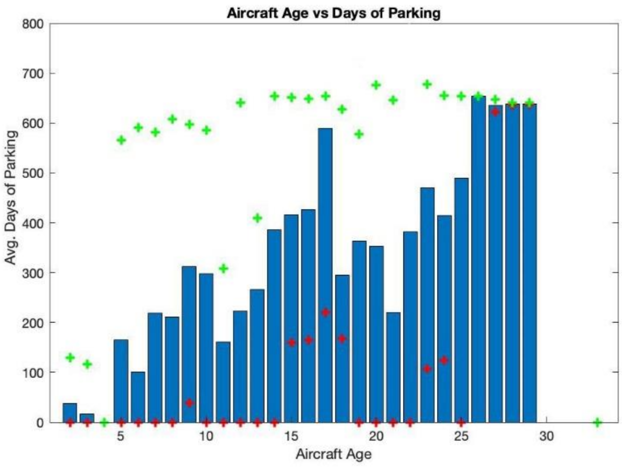


Figure 24 – Average days of parking for each A/C age, British Airways

Overall, over 34% of BA's fleet has parked for more than a year, including scraped units. Surprisingly, British Airways are still using their range of Airbus A380s. The majority of their fleet (37.6%) has parked more than 3 months but less than a year. Finally, 22.5% did not park a single day, mostly Airbus A320s, Dreamliners, some B777s and A350s.

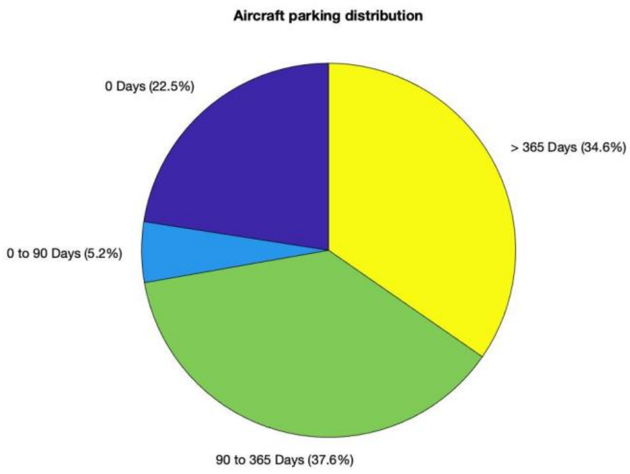


Figure 25 – Overall parking distribution, British Airways

Air France

This French flag airline is a global aviation player as it serves over 200 destinations. Its headquarters are located close to Paris and main hub is Charles de Gaulle Airport. Today, this airline is a subsidiary of the Air France–KLM Group, founded in 2004 by merging Air France and KLM. This joint holding company shall provide better competitiveness of the French and Dutch flag airlines. This part of the text shall examine the Air France subsidiary only. Within Air France part, there are subsidiaries of Air France Cargo, regional carrier Air France HOP and a low-cost carrier Transavia. Similarly to other legacy carriers, they offer a wide range of services and offer flights to many long-haul destinations. Air France facilitate bases on major French airports: Charles de Gaulle Airport, Orly Airport, Marseille Airport, Lyon–Saint Exupéry Airport, Toulouse–Blagnac Airport, Nantes Airport and Nice Airport. They also possess many line maintenance facilities in their network. To offer a wide-range services and to operate both regional and long-haul flights, their fleet shall also be diverse: 12 units of Airbus A318, 30 units of Airbus A319, 42 units of Airbus A320, 19 units of Airbus A321, 15 units of Airbus A330, 17 units of Airbus A350, then 11 units of Boeing 737 (low-cost subsidiary not included), 59 units of Boeing 777, 37 units of Boeing 787, 23 units of Embraer E190LR and finally 3 units of Dornier 328-310. Together with low-cost subsidiary Transavia, it would add another over 100 units of Boeing 737. Early stages of the pandemic showed 98% reduction of flights in April 2020, making it one of the worst legacy performances [36]. September reports showed a 53% downfall compared to same day in 2019.

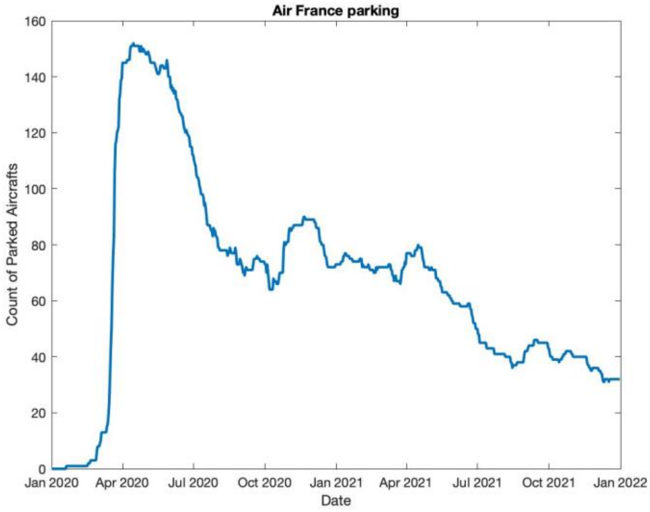


Figure 26 – Progress of Air France parking

Progress of Air France parking was very similar to Lufthansa and British Airways mentioned earlier. The first wave introduced 152 Air France aircraft parking on interval longer than 30 days, second and third wave in winter 2020 and spring 2021 introduced 90 and 80 parked aircraft, respectively. Notably, progress of this airline has been more flexible compared to previous two legacy carriers. At the end of the year 2021, 30 aircraft have been registered to be parking longer than 30 days.

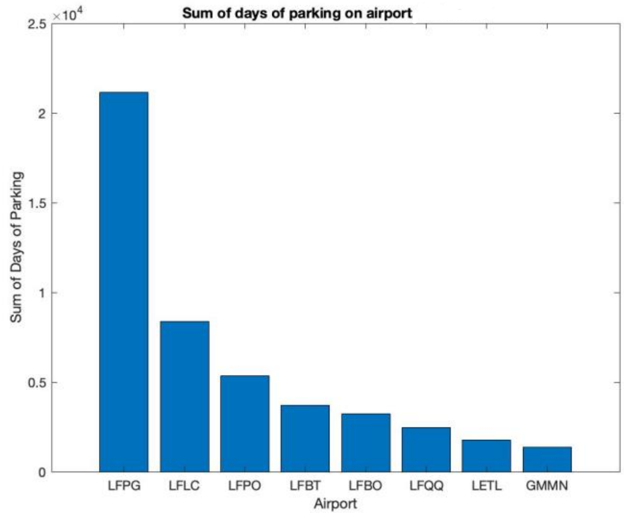


Figure 27 – Airports of Air France parking

Figure 27 represent the major airports where Air France was parking their fleet. It is clear that Charles de Gaulle Airport (LFPG) dominates all others by a huge margin. It was subject to over 21 thousand days of joint parking of all Air France aircraft. LFPG hosted a wide range of aircraft: A320s, A350s, A330s, A319s, A380s, A340s, B777s and B787s. Paris-Orly

Airport hosted a limited range of B777s and A320s. Clermont-Ferrand Airport (LFLC) was used for parking of regional Embraer aircraft. Finally, Tarbes Airport (LFBT) was used for long-term parking of Airbus A380 that are no longer under Air France registration.

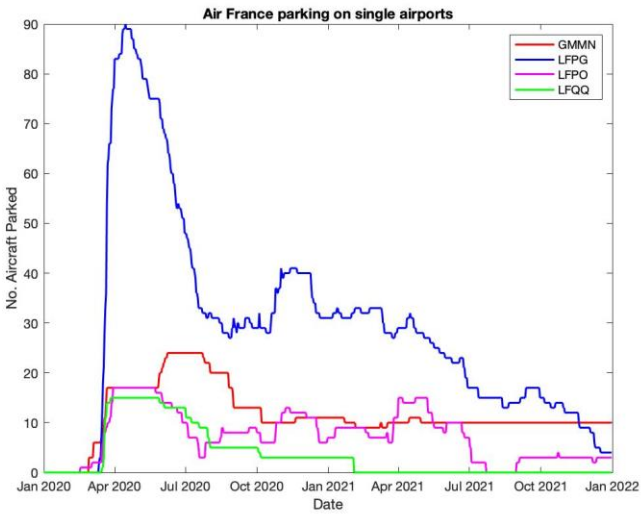


Figure 28 – Progress on major airports of Air France parking

Utilization of their aircraft was much better compared to previous two legacy carriers. Data shows 73.5% of the pandemic narrow-bodies were in service. Wide-bodies were 72.4% in service, which is surprisingly lower than narrow-bodies (previous legacy carriers had utilization of wide-bodies higher compared to narrow-bodies).

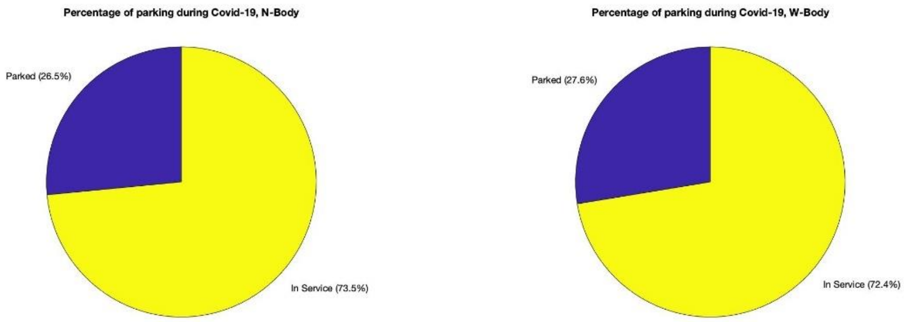


Figure 29 and 30 – Percentage of service state in 2020 - 2021, Air France

Figure 31 represents the average days of parking for each aircraft type of Air France fleet. Height of the bars represents the average days; green marks represents maximum days in the sample and red marks represent the minimum days. Airbus A340s, A380s and Embraer ERJ 145s show parking up to 700 days, meaning they were designated for scraping.

Today, these aircraft are no longer under Air France registration. Notably, Airbus A318s were used during the pandemic for French domestic travel. Modern, fuel-efficient aircraft such as Airbus A350s and Boeing 787 Dreamliners were parked only during the first wave of the pandemic and remained in service to maintain long-haul flights.

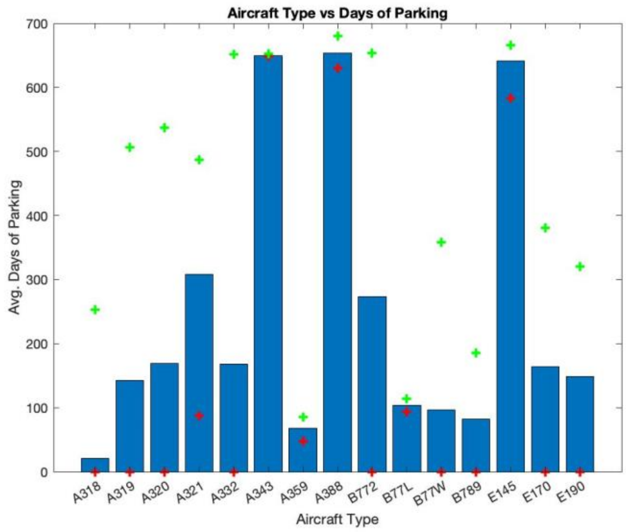


Figure 31 – Average days of parking for each A/C type, Air France

Figure 32 represents average days of parking dependency on aircraft age. This statistic is less straightforward and has no meaningful value. There is a slight difference between older and younger aircraft, however the difference is insignificant compared to British Airways. It can be declared that age had no dependency on Air France's decision-making process.

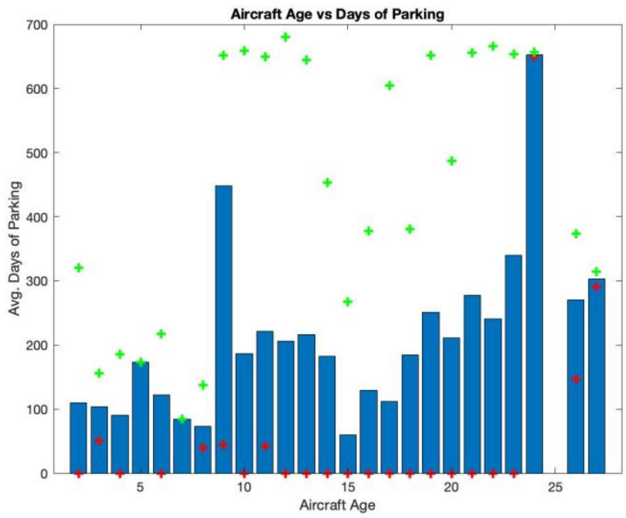


Figure 32 – Average days of parking for each A/C age, Air France

Overall, only 17.3% of Air France's fleet did indeed park for more than a year during the 2-year interval of the pandemic. The composition is rather diverse – several B777s, A340s, Embraers, A320s and of course scraped A380s. The same percentage did not park at all. That would include several Boeing 777s which remained to serve long-haul destinations even during the first wave, and Airbus A318s that served domestic travel. Almost half of their fleet (47.1%) were subject to parking in-between 90 to 365 days.

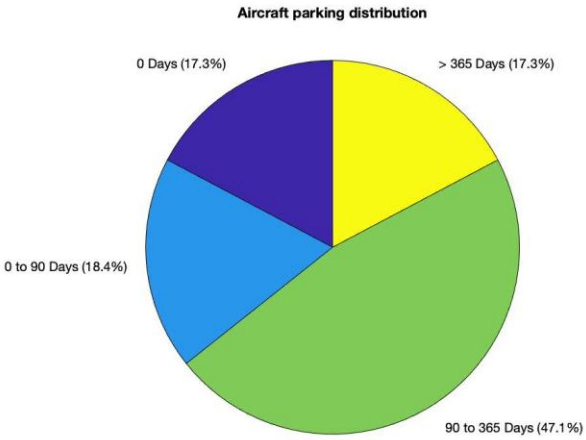


Figure 33 – Overall parking distribution, Air France

Ryanair

Ryanair is a major low-cost European airline with headquarters in Ireland. Compared to other, legacy carriers, Ryanair is more recent innovation, and their low-cost model has also gotten popular in the latest 20 years. Latest statistics show this airline is responsible for the most passengers carried within the European airspace. The airline has been subject to criticism with regards to safety and quality of their services, however their performance shows popularity among European travelers, who rather give up some comfort for an affordable price. Their services have slightly expanded by acquisition of Malta Air (a Maltese low-cost carrier) and Lauda Europe, providing charter flights for Ryanair.

Their fleet is of uniform character, consisting of exclusively narrow-body aircraft designed for regional travel. At the moment, Flightradar24 registers 468 aircraft in their fleet – 55 units of Boeing 737 MAX 8, 409 units of Boeing 737-8AS , 1 unit of Boeing 737-73S and 3 units of Learjet 45. All units above exclude fleets of subsidiaries.

To match their lesser services, Ryanair's destinations are often cheaper, secondary airports. This is an important factor in their decision-making process. They indeed facilitate many bases throughout Europe, most commonly known are Dublin (EIDW), London-Stansted (EGSS), Brussels-Charleroi (EBCI), or Milan-Bergamo (LIME). It is therefore expected that Ryanair would have preferred to park on "secondary" airports.

Figure 34 below displays progress of parking of Ryanair aircraft. Compared to previous legacy airlines, Ryanair was more flexible in their aircraft parking. Progress in spring 2020 was quite similar to previous airlines. As restrictions in Europe started to get lifted, Ryanair was the first carrier to resume operations. Another big wave of parking took pace in early 2021 as coronavirus spiked without present vaccination in Europe. A small drop in parking can be observed in late December 2020, as demand for travel spiked during Christmas. Overall, utilization of their fleet was much higher during "steady" times, when no border restrictions took place. However, as this airline is heavily dependent on regional travel within Europe, any form of border restrictions caused disruption in their services.

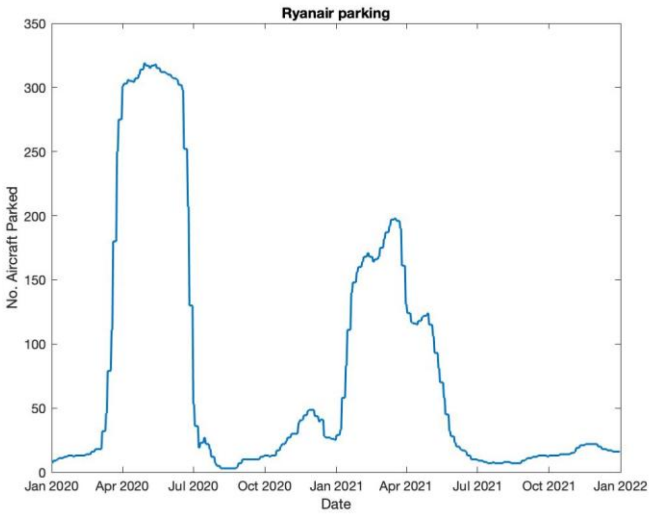


Figure 34 – Progress of Ryanair parking

Wizz air

This Hungarian low-cost airline is a major player in European airspace as it serves over 150 destinations primarily in Europe, and some in North Africa and Middle East. Again, this low-cost airline has greeted the increase demand for low-cost air travel. Their headquarters can be found in Budapest, Hungary and simultaneously their largest base is at Budapest Ferenc Liszt International Airport. Other bases shall include major airports in Eastern Europe – Belgrade Airport, Bucharest Airport, Katowice Airport and more. Their fleet is also uniform but focuses rather on European models. Flightradar24 at the moment registers 64 units of Airbus A320 and 91 units of Airbus A321. As a European low-cost carrier, Wizz air's traffic is heavily dependent on European region. Similarly to Ryanair presented above, any border restrictions within Europe would have cause disruptions to their traffic performance.

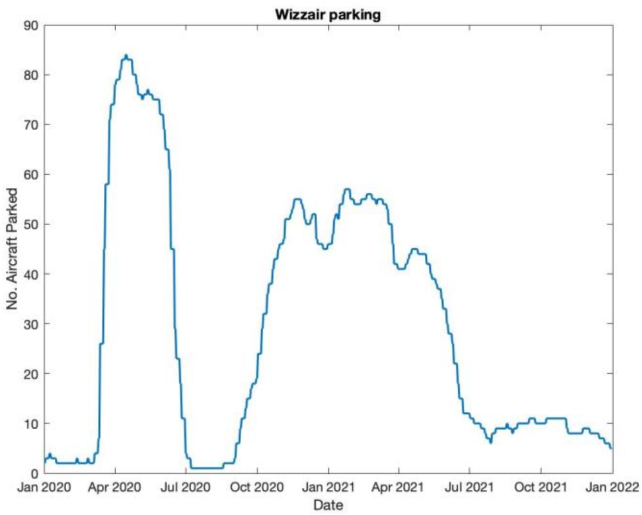


Figure 35 – Progress of Wizz air parking

Figure 35 above displays progress of their parking during 2020/21. Please note, this chart displays a maximum of 85 parked units. That is contradictory to their actual fleet of over 150 aircraft. There was an acquisition of dozens of Airbus A321-271NX units in the last 2 years, therefore their current fleet has more volume compared to 2020.

easyJet

Another popular low-cost airline in Europe is easyJet. It has headquarters in London Luton Airport and operates on dozens of bases in Europe, most notably London Gatwick Airport. The company has been through series of acquisitions and subsidiaries and today it is listed on London Stock Exchange. In 2021, they flew over 20.4 million passengers [38], which is only a fraction compared to pre-pandemic levels. Structure of their fleet matches the low-cost economic model. At the moment Flightradar24 registers 87 units of Airbus A319, 214 units of Airbus A320 variants and 15 units of Airbus A321-251NX. All of these numbers include aircraft of subsidiaries easyJet Europe, easyJet UK.

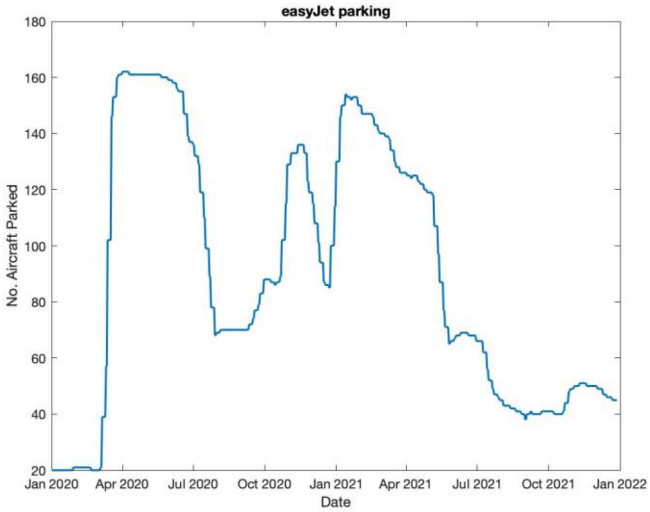


Figure 36 – Progress of easyJet parking

Figure 36 displays most turbulent progress of parking of all figures presented so far. This carrier is also dependent on regional travel within Europe and thus any nationwide measures had negative impact on their traffic. First wave in spring 2020 show a peak of 162 aircrafts solely of parent company easyJet (with no subsidiaries). Their return to service after first wave was a bit slower compared to other low-cost carriers. Another two peaks appeared on fall 2020 and spring 2021 as coronavirus spiked again.

Finnair

Finnair is a Finnish flag carrier and is partially state-owned. Finnair's primary hub is the Helsinki Airport. It is a key European player as it serves destinations mostly in Europe, North America, and Asia. Their various routes match their diverse fleet – Flightradar24 currently registers six units of Airbus A319, 10 units of Airbus A320, 19 units of Airbus A321, 8 units of Airbus A330, 17 units of Airbus A350, 12 units of ATR 72-500 and 12 units of Embraer E190LR. Figure 37 displays progress of parking of Finnair's fleet. This Figure looks quite unfavorable as Finnair's return to service was not as prominent compared to other airlines.

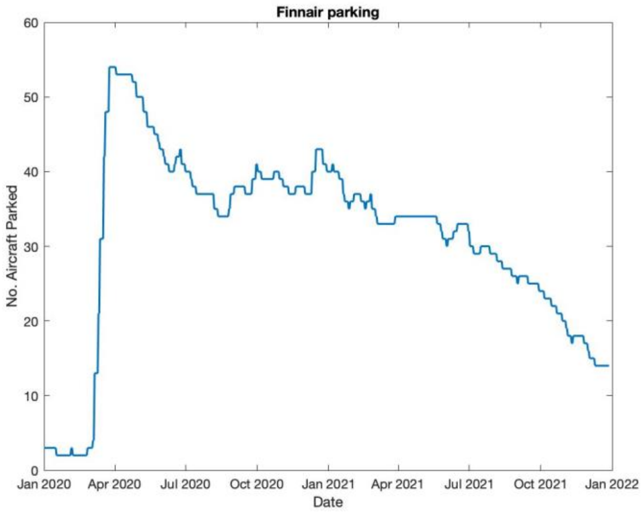


Figure 37 – Progress of Finnair parking

Smartwings

This Czech airline offers scheduled and charter flights and is headquartered at Vaclav Havel Airport in Prague. They operate flights to many European destinations and many holiday destinations during summer.

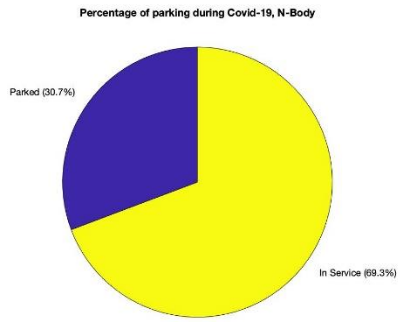


Figure 38 – Percentage of service state in 2020 - 2021, Smartwings

Figure 38 above displays utilization of Smartwings aircraft during 2020 and 2021. Data shows 30.7 % of time was spent in parking and 69.3 % in service state. There is a room for potential error within this Figure as the sample of data did not include entire fleet of Smartwings and excludes Boeing 737 MAX aircraft.

SAS

Scandinavian Airlines is a flag carrier of the three Scandinavian countries and facilitates hubs in all of them - Stockholm Arlanda Airport in Sweden, Copenhagen Airport in Denmark, and Gardermoen Airport in Norway. There are some other SAS bases within these Scandinavian countries. They offer flights within Europe, then North America, South America, Africa, and Asia. The airline holding company, SAS Group also includes subsidiary supportive companies - SAS Technical Services, SAS Ground Handling, SAS Cargo Group. Structure of their fleet is of rather diverse character. Flightradar24 currently registers four units of Airbus A319, 59 units of Airbus A320, 11 units of Airbus A321, 8 units of Airbus A330, 6 units of Airbus A350, 6 units of ATR 72-600, 13 units of Boeing 737, 24 units of Mitsubishi CRJ-900LR and 6 units of Embraer E195LR.

Figure 39 displays progress of Scandinavian Airlines parking. Quite a lot of aircraft remained grounded during summer 2020 and summer 2021 compared to previous airlines. On the other hand, spring 2021 did not introduce another mass grounding of aircraft as only approx. 15 aircraft have been parked in the span of one month.

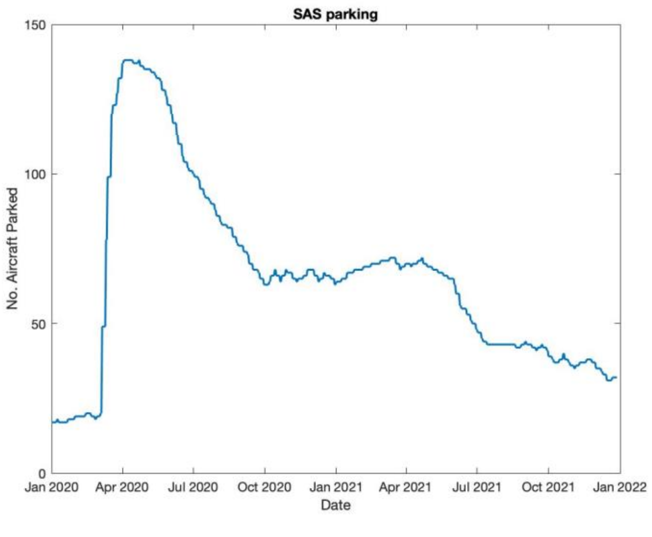


Figure 39 – Progress of SAS parking

Conclusion of this chapter

Judging from airline examples presented above, some differences can be noticed. The scope of this thesis only includes several airlines to point out their different performance during Covid-19. The first wave of pandemic introduced very similar progress of parking in all presented airlines. This was present due to the fact that demand for travel was basically nonexistent among all airlines. Aviation was also seen as a means of transmission of the virus, so grounding was also of safety concern. Progress in later stages of the pandemic however show significant differences between low-cost and legacy airlines. As previously mentioned, low-cost airlines are solely dependent on European region, which was very defensive when it came to Covid-19 countermeasures. This allowed them to maximize utilization of their fleet during “steady” periods of the pandemic, with only several units grounded during summer 2020 and summer 2021. As nations started introducing restrictions, mass grounding of their fleet began. Flexibility basically means that progress in low-cost carriers happened at much higher gradient ∇. Differences can be observed within legacy carriers as well.

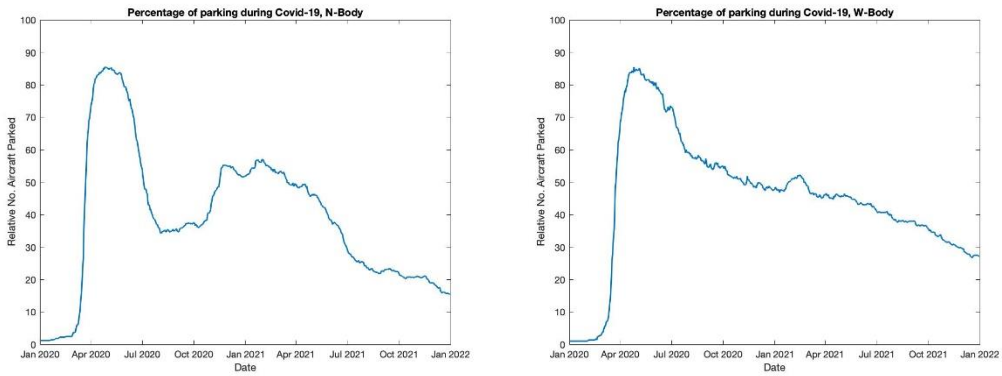


Figure 40 and 41 – Overall progress of parking of narrow-body and wide-body aircraft

Figures 40 and 41 display how parking of narrow-bodies and wide-bodies respectively has developed. Wide-bodies have been slowly reintroduced into service. The curve would have been even steeper if scraped aircraft were excluded. Progress of narrow-bodies show much more flexibility.

7 Decision-making model

The purpose of this chapter is to present a model that would describe decision-making process of airlines with respect to aircraft parking during Covid-19. Each airline has to undergo a series of questions when parking an aircraft: “Where is it going to park?”, “How long is it going to park?”, “Do we prefer parking on our bases?”, “What kind of maintenance is going to be provided?”, etc. The previous chapter indeed proved that airlines emitted different behavior when it came to aircraft parking. For instance, airports were the area of major concern as each airline preferred to park at their own pool of airports. Sure, some airports have hosted multiple airlines at once, for instance Madrid Airport or Teruel Airport, but the extent of this effect was much lower compared to, for instance, United States, where it was a quite common occurrence. Other traits, such as dependency on age, have also proven significant in British Airways and less significant at Lufthansa.

This chapter introduces a series of models which takes attributes as inputs and outputs and by applying simple statistic methods provides numerical data that would describe the decision-making process. This same dataset which was used in previous chapter will serve as a source of information in this chapter. Using this data, it should be able to describe relations between these attributes and how each one of them contributes to the decision-making process. In the end, a correlation matrix of these attributes shall numerically express relations between them, and a regression method shall numerically express how each of the attributes have contributed to the output. For the purpose of this thesis, several regression methods will be used. Each method has its limitations and thus a combination of them will provide a comprehensive overview on the topic. A multivariate regression, a logistic regression and a linear regression will be used.

A regression analysis is a powerful tool to model relationship between an output, response variable Y and one / a set of input, explanatory variables X_i. Response variable and input variable are often addressed as dependent variable and independent variable, respectively. There are multiple types of a regression analysis, depending on distribution of the response variable, with linear regression being the most common. In general, regression analysis is based on the principle that output is a function of input, coefficients, and error vector. The purpose of regression analysis is to calculate such function. The precise form of the function will differ with each dataset and used regression variant.

A linear regression is a regression method modelling a linear predictor function and estimating parameters of a linear equation. By using linear approach, output is expected to be continuous with a normal distribution. It is then possible to forecast output based on an existing dataset or to describe changes of response variable due to changes of explanatory variables. A general linear equation would look like:

$$y_i = \beta_0 + \beta_1 x_{i1} + \cdots + \beta_n x_{in} + \varepsilon_i \tag{1}$$

where y represents the predicted response, xi are the independent variables, β are the regression coefficients (specially β_0 called the intercept and mostly has small informative value), and lastly ε, an error term. This method allows to find a regression line or curve Y = a + bX, where $\hat{Y}_i = a + bX_i$ is a predicted value on the line, and difference between predicted response $\hat{Y}_i$ and an actual response Yi is called the residual. The regression line is fitted in a least squares method, so standard deviation of squared residuals is minimized. The purpose here is to determine the regression coefficients β_0, β_1 ... β_n. For instance, value of β1 represents increase in Y per unit increase in Xi, while other Xi's do not change [39]. For each independent variable a β coefficient will be introduced with respected p-value and standard errors for these coefficients will be introduced.

In this chapter, the response value based on multiple variables are predicted. Thus, an extended form of linear regression is needed, a multiple linear regression analysis. This type of regression also allows to determine overall fit of the model and determine how each independent variable contributes to the response variable [40]. Before using multiple linear regression, several assumptions must be met to make sure dataset is worthy. First, dependent variable needs to be on continuous scale. Secondly, independent variables need to be continuous or categorical. Third, there should be a linear relationship between each predictor variable and the response variable. It is often visually observed using scatterplot for each response-predictor value pair. Fourth assumption is, predictor variables should not be highly correlated. This way it cannot be determined which independent variable contributes to the dependent and regression model is overall unreliable. One can prove this by inspecting correlation coefficients. Fifth, observations must be independent. Sixth assumption is homoscedasticity, where residuals must have constant variance along the fitted regression line. There are several methods to compute this regression. For this thesis, MATLAB environment has been used with a respective *fitlm* function, which returns a linear regression model using a matrix input data set. Most importantly, normality of data was assumed.

A dichotomous variable can be targeted as a dependent variable. Due to its dichotomous nature, first assumption of a multiple linear regression is violated and thus an alternative must be used. Here, a common approach is to use a Logistic regression. The purpose remains the same – prediction of the dependent variable based on a set of independent variables. Second assumption can also be violated, as logistic regression allows independent variables to be of nominal, ordinal or interval nature. Here, a MATLAB's *mnrfit* function has been used to perform a multinomial logistic regression, which returns coefficient estimates of the nominal response Y based on the predictors X_i. Deviance of the fit and advanced matrix of statistics are also returned.

Table 1 below describes attributes used in the statistical approach:

Table 1: Attributes of parking with respect to aircraft, airport and the parking itself

Attribute	Mean	Std. deviation	Min value	Max value
Airline	Non-numeric value			
Aircraft registration	Non-numeric value			
Aircraft type	Non-numeric value			
Age of the aircraft	13.749	7.1995	1	33
Narrow-body / wide-body	0.6299	0.4830	0	1
Capacity of the aircraft	268.739	167.377	30	853
Date of start of parking	Non-numeric value		1/1/2020	21/12/2021
Date of end of parking	Non-numeric value		18/02/2020	31/12/2021
Total days of parking	159.9432	153.444	20	680
Months (start)	7.3642	5.4087	1	25
Base	0.5466	0.4980	0	1
Maintenance organization	0.7486	0.4339	0	1
Rainfall on the airport	63.624	30.090	10.300	344.800
Parking fee	24 568	19 785	869	74 880
Maintenance costs	42 033	13 187	1 225	86 303
Lowest temperature	1.2337	3.6743	-8	23
Highest temperature	24.482	3.3064	17	41

These attributes are either related to the observed aircraft, or airport where parking occured, or the parking period itself. It is expected that these attributes had impact on the decision-making process of airlines. As presented, it is a combination of numerical, datetime and text values. Only numerical values have been used in statistical methods in this chapter.

Table 2: Correlation matrix to given, non-text attributes

	Age	N-body	Capacity	Total days	Date of start	Date of end	Months	Base
Age	1.000							
Narrow-body	-0.101	1.000						
Capacity	-0.138	-0.675	1.000					
Total day	0.186	-0.113	0.144	1.000				
Date of start	0.122	0.075	-0.080	-0.249	1.000			
Date of end	0.176	0.048	-0.012	0.436	0.581	1.000		
Months	0.123	0.083	-0.068	-0.183	0.866	0.716	1.000	
Base	-0.051	-0.102	-0.032	-0.314	0.101	-0.173	0.012	1.000
Maintenance	0.079	-0.026	-0.074	-0.133	0.115	0.019	0.102	0.589
Rainfall	-0.086	-0.002	0.018	-0.138	-0.043	-0.115	-0.043	-0.072
Parking fee	0.221	-0.024	-0.046	-0.227	0.239	0.017	0.192	0.449
Maintenance costs	-0.057	-0.110	-0.047	-0.230	-0.055	-0.241	-0.110	0.297
Lowest temp.	0.178	-0.036	-0.023	-0.152	0.161	0.028	0.176	-0.056
Highest temp.	-0.159	0.007	0.199	0.089	0.005	0.146	0.066	-0.156

A significant negative relationship can be seen between capacity and narrow/wide-body designation. This obviously make sense since narrow/wide-body designation comes from width of the fuselage, which directly impacts number of seats per row and epso facto impacts capacity. The negative value comes from referencing wide-body aircraft as 0, and narrow-body aircraft as 1, while capacity increases with width of the fuselage. Shall wide-body be referenced as 1, the correlation coefficient would be of positive value. Another high correlation can be observed between months and Date of Start attribute, since they basically reference to each other. Months attribute is directly derived from the day aircraft started parking and they first day in range of focus (Jan 1st, 2020), which is a constant.

Table 3: Correlation matrix continuation

	Maintenance	Rainfall	Parking fee	Maintenance costs	Lowest temperature	Highest temperature
Age						
Narrow-body						
Capacity						
Total days						
Date of start						
Date of end						
Months						
Base						
Maintenance	1.000					
Rainfall	-0.080	1.000				
Parking fee	0.302	-0.188	1.000			
Maintenance costs	0.222	-0.154	0.139	1.000		
Lowest temp.	-0.204	0.162	0.334	-0.116	1.000	
Highest temp.	-0.179	-0.007	-0.064	-0.447	0.231	1.000

Certainly, a high correlation can be seen between Parking fees and Base attribute. This is aligned with the fact that the correlation matrix was derived using data for three major legacy airlines in Europe, which tend to have bases on major hubs in their country, where parking fees are more expensive.

For the purpose of this research, only two regression methods have been chosen. Also, only numerical attributes have been included (Date of start and Date of end have been excluded, although converting them into Unix Epoch format would be a solution). First, a multivariate linear regression targets number of days of parking as an output, while chooses non-categorical inputs. Secondly, a multinomial logistic regression has been chosen, that takes Base attribute as an output. This way it would describe whether the airline would choose to park the aircraft on a base, or on third party airport, using statistics.

The basic idea of using regression revolves around expressing decision-making process in an equation formula:

$$Days = \beta_0 + \beta_1 x_{i1} + \cdots + \beta_n x_{in} \tag{2}$$

$$log(p/1 - p) = \beta_0 + \beta_1 x_{i1} + \cdots + \beta_n x_{in} \tag{3}$$

, for multivariate regression (2) and logistic regression (3), respectively. Table 4 shows estimated β coefficients for whole dataset using two regression methods:

Table 4: Coefficient estimates

	Multivariate linear regression		Multinomial logistic regression	
	Coef. estimate	Std. error	Coef. estimate	Std. error
Output attribute:	Total days of parking		Probability of parking on a base	
Intercept	304.85	19.628	1.1513	0.5698
Aircraft attributes:				
Age of the aircraft	5.6999	0.5131	0.0722	0.0123
Narrow-body / wide-body			1.2506	0.2391
Capacity of the aircraft	0.1299	0.0200	0.0033	0.0007
Parking attributes:				
Total days of parking	–	–	0.0048	0.0006
Months	-5.1850	0.6662	0.0916	0.0156
Airport attributes:				
Base			–	–
Maintenance organization			-4.0190	0.3060
Rainfall on the airport	-0.9679	0.1220	0.0030**	0.0039**
Parking fee	-0.0016	0.0002	-0.00007	0.0000
Maintenance costs	-0.00027	0.00003	-0.00002	0.0000
Lowest temperature	-3.6592	1.0565	0.1084	0.0274
Highest temperature	0.8556**	1.278**	-0.0181**	0.0273**

**Insignificant at 5% level.

At first glance, multivariate linear regression and its output variable Total days of parking promise the most informative results. Coefficient estimates presented in Table 4 return the following equation:

$$Days = 304.85 + 5.6999\,AGE + 0.1299\,ACP - 5.1850\,MTH - 0.9679\,RAIN - 0.0016\,FEE - 0.0027\,CST - 3.6592\,LMP \quad (4)$$

Validation and discussion

Equation 4 can be translated into verbal language. All presented values have been proven statistically significant judging from their respective p-value of less than 0.05 and their t-value/p-value relationship. Coefficient at each independent variable represents increase in dependent variable, if given independent variable is increased by 1 unit, and all others are kept constant. For instance, looking at equation 4, a unit increase in Age (which happens to be 1 year), would result in 5.6999 Days average increase in parking, if all other inputs are kept constant. The value 5.6999 is partly aligned with the original hypothesis, which states that duration of parking would increase with age of the aircraft. The increase was originally expected to be much higher, but Figures 24 and 32 show that some relationship is present. It would come logical that airlines would rather preserve older aircrafts which tend to be less cost-effective, and bring more comfort to their passengers. Based on the equation, a 20 year margin would result in a over 100 day increase in parking period. Aircraft capacity (ACP) indicates that with growing aircraft capacity, the length of parking slightly extends. This is aligned with Figures 40 and 41. If curves introduced in Figures 40 and 41 get integrated, surface under narrow-body line would be a bit smaller than surface under wide-body line. As narrow-body / wide-body designation is highly correlated to aircraft capacity, it can be stated that aircraft with lower capacity did indeed park less, and thus the coefficient estimate is correct. Significant contribution has the Months (MTH) attribute with value of -5.1850. This means that with increasing time, aircraft would be parking for a shorter time. This is in conclusion a true statement, because, judging from previous chapter, aircraft which would start parking in 2021 would be soon returned to service once coronavirus situation became more stable. Another significant input can be seen on Rainfall on the airport (RAIN). This is, by definition, a true statement as rainfall negatively impacts structure of the aircraft and thus the goal is to park on airports with less rain. Some influence can be seen on Parking fees (FEE) and Maintenance costs (CST) attributes. The coefficients are however quite small and originally more influence was expected. This is consistent with [41] and with figures in previous chapter. Figures 11 and 19 show that fleet of Lufthansa and British Airways was equally distributed between base and non-base airports, which sustains this small coefficient. Lowest temperature (LMP) is of surprising value, since this way with decreasing lowest temperature, length of parking would increase. This contradicts [42], which states there is a negative correlation between temperature and humidity, and thus -3.6592 would indicate longer parking at humid airports. Lastly, Highest temperature (HMP) would indicate an increase of days with increasing temperature. This phenomena could have been observed in United States, where parking on desert airports was a common occurence. However, using European data, a high p-value indicates this attribute is not statistically significant and thus should not be taken into considering. Table 4 displays coefficient estimates derived from the entire dataset. The coefficients can be estimated for an individual airline. Table 5 represents coefficient estimates for multivariate linear regression for 3 major European legacy airlines.

Table 5: Comparison of coefficients for European legacy airlines

	Multivariate linear regression					
	Air France		British Airways		Lufthansa	
	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error
Output attribute:	Total days of parking					
Intercept	293.91	44.381	359.08	34.326	588.51	34.146
Aircraft attributes:						
Age of the aircraft	5.4485	1.435	6.5863	0.8189	1.7827	0.8794
Narrow-body / wide-body						
Capacity of the aircraft	0.2636	0.0467	0.0607	0.0275	0.1178	0.0392
Parking attributes:						
Total days of parking	–	–	–	–	–	–
Months	-4.8517	1.4903	-5.6633	0.8884	-7.0693	1.3799
Airport attributes:						
Base						
Maintenance organization						
Rainfall on the airport	0.7735**	0.5415**	-1.1847	0.2004	-1.3562	0.1581
Parking fee	-0.0010	0.0002	-0.0017	0.0002	-0.0024	0.0006
Maintenance costs	0.0007**	0.0001*	-0.0010	0.0001	-0.0016	0.0003
Lowest temperature	-7.3932	3.0167	-3.9815**	2.6155**	-2.2248**	2.3181**
Highest temperature	-0.5848**	6.1942**	2.0991**	2.2267**	3.4663**	5.1346**

**Insignificant at 5% level.

Validation and discussion

Different statistics can be observed between legacy airlines, while length of parking was observed as output. The purpose here was to point out that some airlines might emit different coefficients. Given that input attributes have same range of values for each airline, a different coefficient then represents different impact on decision-making. Apparently, British Airways show the most influence of Age, as presented on Figure 24. A high impact of Age can be also seen within Air France. Both of these coefficients multiplied by an age of 20 add approx. 110 days to parking interval. A much lesser influence of Age among Lufthansa aircraft is confirmed by Figure 16. Capacity of aircraft had the most positive impact in Air France, meaning with increasing capacity, length of parking would also increase, which is consistent with Figure 31, because of many Airbus A340’s that have been parking for over a year. Capacity also contributed to Lufthansa’s decisions with coefficient 0.1178. This contribution is consistent with Figure 15. There was a neglectable influence of capacity at British Airways, because as Figure 23 displays, many of their narrow-bodies had been parking for almost a year. Months attribute had negative value among all three airlines, meaning the later parking started, the shorter it lasted. The most significant impact was at Lufthansa airline, which is aligned with Figure 10, where progress line is quite steep. That indicates this airline was flexible in parking in 2021. Rainfall seemed to have a positive value in Air France's decisions, which would indicate that with more rain, parking would be longer. This coefficient is however burdened by a huge error, and thus has been rendered insignificant. British Airways and Lufthansa show negative influence of rain and is in both cases statistically significant. Parking fee seemed to have most impact in Lufthansa's decisions, which is consistent with Figure 11, showing large parking ratio on Budapest (LHBP) and Teruel (LETL) Airport, where parking fees are relatively small. The same can be accounted to British Airways, parking on cheaper airports (LEMD, LETL, EGSY). Air France shows the highest coefficient (-0.0010), which is aligned with Figure 27, showing a high ratio of parking on LFPG – a quite expensive airport. Lowest temperature attribute is of surprising value, because this indicates that with dropping temperature, length of parking would rise, which contradicts relationship between temperature and humidity. The result has however proven statistically insignificant and thus not taken into considering. Highest temperature had a positive value in Lufthansa and British Airways sample. Again this means aircraft would be stored in a less humid environment, but the result is statistically insignificant on a 5% level.

Few things about the model need to be pointed out. Because of the high variability in all attributes, and because each airline might have had different preferences in decision-making, the final statistical model is subject to a great error. The R-squared value, which represents how much variance of output variable is explained by input variables, is ranging between 0.3 to 0.5 for each model. The Root Mean Square Error, which represents squared number of residuals of all observations, are ranging between 116 to 137 days. That is indeed a huge error for the dataset, where actual number of days were ranging from 30 to 650 days. Although the presented model sustains observations and figures from previous chapter, as well as articles from other authors, the error arising from linear regression is simply too high. This model must be therefore rendered **inconclusive**. Any ideas for improvement of overall fit of this model call for speculation. Some attributes have been burdened by a significant error from the beginning (recall Parking fee has been derived from a price list, the actual prices for long-term parking might be subject to contract). There was however no better method to get hold of these attributes, simply because it is not a public information.

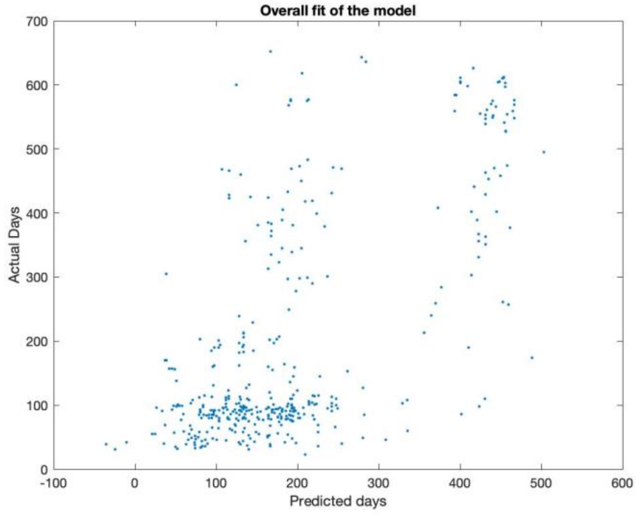


Figure 42 – Overall fit of linear model, Lufthansa

Figure 42 displays the error between predicted and actual length of parking in Lufthansa's dataset. Very similar errors can be seen in whole dataset. Clarity of the figure was the reason why only Lufthansa was plotted. The X axis represents predicted amount of days for each parking record coming from linear regression. Y axis represents actual number of days of parking coming from dataset. The optimal result should be a diagonal line. There might be other outside, inexplicable factors to this decision-making process. For instance, take a sample of three Air France Boeing 777's. Each of the same age, parking around the same time on the same airport (LFPG), one for 410 days, second for 608 days and third one for 231 days. The input attributes for these aircraft would be the same, however the output is drastically changing. This was one of many examples that can be found within available dataset, and it is a great contribution to the overall error of the linear regression model. For instance, the Root Mean Square Error for Ryanair's data was approx. 19 days. That is a much lower error, indeed, but the maximum length of parking of Ryanair was up to 4 months. Lower parking periods result in lower error, therefore it is still inconclusive. There might be other, internal factors contributing to the desicison-making process that were unable to comprehend. It is believed that available data of approx. 2 thousand parking records had enough observations to perform regression analysis. Whether a linear regression was not the best fit is a speculation. An alternative approach would be to perform a polynomial regression of higher degree and observe the results. Performing such complicated analysis was however outside range of skills of the author and could only bring more uncertainty to this thesis.

8 Conclusion

Aircraft parking during Covid-19 was a unique event aviation has never seen before and thus was subject to a unique research. The aftermath of this pandemic is still strong in 2022 and will be recognizable in couple future years. This pandemic definitely set a background to numerous research works, including this one and there still is room for more research. With this conclusion, few things need to be pointed out. The purpose of this thesis was to give a brief overview in the topic of aircraft parking and introduce actual results from interpreting collected data. The first and second chapter introduced a brief summary of air traffic that occured prior to and during Covid-19 years, which served as an image of what aviation looked like and how it suffered due to the pandemic. Third and fourth chapter introduced a detailed overview of an important part of aircraft parking – maintenance. It is clear that maintenance also had an influence on decision-making process of airlines, since it is crucial for aircraft airworthiness and thus must be accounted for, once airline is deciding where to park their fleet. The third chapter also introduced detailed steps that must be followed during preservation / storage of an aircraft, which do not necessarily serve further chapters, but it has origiinally been yet another goal of this thesis. Sixth chapter, „European Parking Market" introduced detailed examination of how major European airlines have been parking during 2020 and 2021. It is believed this chapter fulfilled yet another goal of this thesis as numerous figures had arisen from this research and interesting observations had been brought. The range of airlines, which had been examined, was limited, as more detailed research would be outside of size range of this thesis. Differences in parking between major European legacy airlines can be observed. There are also clear differences in parking progress between legacy and low-cost airlines.

Lastly, seventh chapter presented a statistical process of available data. The statistical results indicate that estimated regression coefficients make some sense and selected attributes played a role in the decision-making process. Coefficients themselves do not describe range of their influence, but they must be multiplied by their respective input value. Intercept, on the other hand, describes mean value of output attribute, if all input attributes are set to zero. The linear model is however burdened by a significant error of unknown source and must be rendered inconclusive. Elimination of such error is outside scope of this thesis and probably is not possible using public information. Perhaps if more information had been available, a better fit would have been introduced. Results from logistic regression had not been further described, as they seem to be self-explanatory.

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Figures

Tables