Report Draft

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Title

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Abstract

The purpose of this report is to develop short-term and long-term projections on the outlook of air transportation and to produce recommendations for the direction of NASA aviation research.

Introduction

The COVID-19 pandemic has had an unprecedented impact on the globe and on the aviation industry, sending the country into a recession in addition to a public health crisis. We analyze how the pandemic has affected various aspects of the industry, including: passenger travel, cargo operations, Urban Air Mobility (UAM), aircraft manufacturing, management of the National Airspace System (NAS), and more, and detail the projected changes each sector of the industry will undergo in future years. We then provide relevant recommendations to how NASA should focus its course of aeronautics research to the now-disrupted industry, as the aviation industry cannot simply return to 2019 operations, but must reinvent itself to ensure survival in the changing globe.

Effects of COVID-19 on the Aviation Industry

Industry Overview

The United States air transportation system is large and complex, carrying a billion passengers in 2019 (BTS data), more than any other country (ICAO World Bank data). Aviation is a multi faceted industry, with multiple sectors including: passenger travel, cargo/air freight travel, manufacturing, and management of the National Airspace System. The aviation industry's economic impact is huge: combined with its connected sectors (related goods and services), civil air transportation represents approximately 5.2% of the US's GDP, contributes about 1.8 trillion dollars in total economic activity and supports 10.9 million jobs each year. (FAA Civil Aviation Economic Impact Report). Civil aircraft manufacturing was also the US's largest net export in 2016 (FAA Civil Aviation Economic Impact Report). Each year, the industry expands, and airlines generate more revenue than the year before.

Over the last few decades, air transportation has become a necessity in American daily life. However, though airline revenue remains high and operations increase each year, the average passenger experience on commercial flights is decreasing. More and more passengers are being fit into each aircraft, and the number of seats per aircraft is increasing with production of large widebody aircrafts like the Airbus A380 and Boeing 747. The aviation industry is cyclical, heavily dependent on the economy, and US airlines have adapted to new methods to ensure profit, including ancillary revenue (charging passengers for services that used to be included in the traditional ticket fare), and mergers and acquisitions. These strategies have allowed the airlines to gain revenue each year, but leaves passengers with growing dissatisfaction.

Months into the COVID-19 pandemic, it is clear this health crisis has greatly impacted every community and every sector across the globe. The pandemic has had a massive effect on air transportation and the travel industry, with the US Travel Association calling this time the "Great Travel Depression". Together, passenger fears of contracting the virus and the industry's susceptibility to economic recessions have caused a massive decline in airline operations. Aircrafts have been grounded across the country, flights have been canceled, and many airlines have either temporarily or permanently laid off staff, responding to the drastic decrease in demand.

We will discuss some of the effects of COVID-19 on a few sectors of aviation below (Passenger Travel, Air Freight, Manufacturing, Urban Air Mobility, Management of the NAS, and aviation's environmental impact).

Passenger Travel

With an increasingly interconnected world, commercial aviation has become a vital mechanism for the global economy and specifically, US airlines, for which passenger travel has been a flourishing source of revenue in the past decade. From 2018 to 2019, revenue passenger miles (RPMs) increased by an impressive 4.3%, escalating to 1.04 trillion (FAA Fact Sheet). Domestic travelers, which encompasses about 89% of US passenger travel, rose to 813.3 million passengers in 2019, a 4.2% increase from the previous year (FAA Fact Sheet). International travelers, making up the remaining 11% of US passenger travel, grew to 103.4 million passengers in 2019, a 3.8% increase from the previous year (FAA Fact Sheet). This growth can be attributed to the rise in both leisure and business travel. The growing necessity for air travel prompted by leisure and business travelers has allowed airlines to expand on profitability through the diversification of in-flight services, capitalizing on business travelers. Leisure travelers spent $762 billion in 2019, 4.1% higher than in 2018 (U.S. Travel Association 2019 Overview). Business travelers spent $334 billion, 2.2% higher than in 2018 (U.S. Travel Association 2019 Overview). Consequently, the aviation industry has been thriving for the past few years, reliant on strong passenger travel demand. But with this growth came repercussions. US airports became more crowded, planes cramped, and flight schedules subject to delays, demonstrating the prioritization of US airlines in favoring profit and functionality over the development of an enjoyable passenger experience for all. Jeffrey Wong, a professor at the University of Nevada, conducted a study comparing consumer satisfaction with airline profits, finding that in the past, demand has continued regardless of poor service due to the necessity for air travel(Airline Profitability and Consumers). Wong noted, “Airlines don’t seem to place a priority on customer service despite the fact that they advertise to the contrary," explaining how airlines have raised profits through cramming more passengers onto planes, helping load factors. In fact, the load factor for US carriers grew almost 12% from 2002 to 2019, showing how airline profitability and flight congestion has increased and in turn caused the passenger experience to continuously decline over the years (BTS Load Factor Stats). However, this flawed prioritization threatens US airlines as it has caused them to sacrifice a fundamental consideration for air travel; passenger welfare, leaving them incapable of ensuring a safe flying experience that can function in a variety of circumstances. Thus once the unprecedented pandemic struck, the crowded nature of air travel transformed from a typical hassle for passengers to a dangerous facilitator for the spread of the coronavirus, condemning air travel as a catastrophic threat to lives across the globe.

Passenger travel has metamorphosed as a result of the proliferating spread of COVID-19. Once occurring as a popular leisure pastime and vital business operation, passenger travel is now deemed a menace towards global safety. This has caused passenger numbers to plummet, reaching levels lower than ever before. As of early July 2020, passenger volume levels have dropped 74% from 2019 levels. Domestic travel has decreased by 73% and international travel dropping 93% from 2019, demonstrating that while air travel has plunged from its previous trends of growth, it has also restructured to favor domestic travel as a result of new international travel policies. Travel bans restricting travel to and from various countries have been put in place as regions have been forced to disrupt traditional systems and implement lockdowns, in hopes to contain the virus. In the US, travel advisories are being administered at state levels, based on COVID-19 spikes across the region. Overall bookings for US airlines have lowered by 80%, expressing the lasting impact the pandemic has had on air travel. The little demand for US airlines has generated a revenue loss of 91%, forcing regional airlines such as Miami Air International to bankruptcy, hence, expanding the role of mainline carriers in air transportation. A survey from market research company, Destination Analysts, found that 37.3% of travelers are wary of traveling to places they would under normal circumstances with 47% concerned on the COVID-19 spikes, and 39% concerned on inadequate safety measures being taken. Longwoods International found that 76% of subjects have changed travel plans, with 59% of travelers hesitant to travel outside of their area. With the norm of crowded airports, cramped flights and lack of hygienic services, people no longer envision safety and comfort when traveling through systems of public air transport, losing trust in air travel. This has had an immense impact on the industry as a whole as hospitality and public safety are fundamental to generating demand, a core factor that upholds the entire aviation industry. With demand hitting rock bottom, the future survival of aviation as we know it remains uncertain.

Cargo Operations

Air freight, a key component of commercial aviation, is transported using designated freight aircraft and passenger aircraft. Though air freight makes up less than 1% of global trade in regards to tonnage, it moves $6 trillion worth of commodities, accounting for 35% of global trade in regards to value (Boeing World Air Cargo Forecast). This disparity in weight and worth expresses the unique functionality of air freight in being an efficient method of transport for goods. In 2019, US passenger aircraft transported 42.9 billion revenue tonne miles (RTMs), a slight increase of .2% from the previous year (FAA Aerospace Forecast). Of this total, 16.2 billion RTMs were transported domestically while the remaining 26.2 billion RTMs were transported internationally, demonstrating the prominence of international trade in supporting US air freight (FAA Aerospace Forecast). Seeing that international transport is traditionally superior to domestic transport for air freight, a similar pattern appears with freight and passenger aircraft. In 2019, freight aircraft experienced a 2.3% increase in its RTMs while passenger aircraft experienced a 7.2% decrease in its RTMs (FAA Aerospace Forecast). Therefore, freight aircraft became more significant as it accounted for 80.3% of freight RTMs leaving passenger aircraft to hold the remaining 19.7% of freight RTMs (FAA Aerospace Forecast). Because passenger carriers are restricted in freight capacity, safety accommodations, flight routes, and load factor, freight carriers remain superior as the method of transport for air freight (Boeing World Air Cargo Forecast).

Commercial aviation has traditionally relied on passenger travel for the majority of its profits. However, with declining passenger demand and unfavorable traveler sentiment, airlines are shifting their sights towards air freight as a new major source of profit, disrupting the traditional structure of commercial aviation. After having relied heavily on passenger travel to generate revenues through various sales such as frequent flyer miles and credit card deals, US airlines have been forced to concentrate efforts towards air freight in order to adapt to the impacts of the pandemic. Southwest Airlines’ load factors have declined to the point of unsustainability while Delta loses $60 million each day. Because of these losses, the significance of air freight has tremendously increased, as it is needed to sustain airlines so that future recovery is a possibility. Therefore, airlines have transitioned their focus. Delta has begun to operate cargo flights every week carrying personal protective equipment such as masks and gowns. American Airlines has limited its airline in

Dallas and Frankfurt to cargo-only services and United has been flying Boeing 777s and 787s, operating 40 cargo-only charter flights. Additionally, Southwest is using 737 narrowbodies, carrying medical goods through cargo-only charter flights. With the decline in passenger travel, airlines have also disturbed their traditional focus on designated freight aircraft for freight purposes and resorted to removing the seats from passenger aircraft, using the space to carry cargo. While the process is long and tedious, requiring additional approval from the manufacturer and a certifying authority, the health crisis has rendered it useful in order to maximize loading capacity and increase air travel revenues. However, only a fraction of airlines' typical revenue has been gained from these efforts as after transporting goods, carriers must fly back empty due to the single directional nature of air freight. Although freight is not able to offset the economic devastation that has resulted from diminished passenger demand, it has restructured due to the major growth in e-commerce. A report from Adobe reveals that e-commerce has risen 77% from what it was last year, resulting in $82.5 billion of sales. With businesses closing down and increased free time from enforced lockdowns, people who have traditionally relied on in person shopping have been forced to switch to online shopping, an even vaster market with increased products and advertising. The practice of buying goods online and picking up in-store has increased 195% from its levels in 2018. With the immense growth in e-commerce, US air freight has been able to sustain itself throughout COVID-19.

Urban Air Mobility

Prior to 2020, the Urban Air Mobility(UAM) was a growing industry, with little progress but significant predicted growth. In 2017, the industry was expected to grow from $8.2 billion to $11.6 billion in 2027. Growth in the market was driven by continuous investment and a demand for taxi services resembling Uber and Lyft.

Despite its growth, the rules and regulations needed for UAM to function are still under review. The FAA and state regulation process began in 2017 and has not been finalized yet. NASA is working on UAM in an effort to make AAM safe, sustainable, accessible, and affordable. NASA, the FAA, and other federal agencies have partnered together to establish and explore a framework that allows for drone operations at low altitudes where FAA air traffic services are not available.

The main markets NASA will pursue are air taxi, air ambulance, and airport shuttle. However, many aspects of UAM have not been met with enthusiasm from the public, which is why NASA has been planning a national campaign set to launch in 2022 to promote its public acceptance. The campaign will also help manufacturers, operation and service providers insight into future regulations and airspace environments. Additionally, many private companies and universities have been working with NASA to achieve their vision of AAM. Over 250 companies have worked on all aspects of UAM, from designing aircraft to propulsion, battery, and control systems.

Many innovations in both small and large UAM vehicles had been carried out in the industry prior to 2020. EHang, a Chinese delivery drone and AAV manufacturer, launched its first AAV in 2016. The vehicle had a one-person cabin, 8 propellers on 4 axes, and could carry a passenger that weighed up to 200kg for 20 min at a speed of 100km/hour. By 2019, they upgraded their model to a two-seater. The model has gone through 2, 000 unmanned and manned flight tests, signalling that it is ready for commercial operation. Alakai Technologies Corporation also released a UAM drone that runs fully on hydrogen fuel cells, an amazing breakthrough

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Some barriers that the UAM industry faces is cost, fuel efficiency, and public acceptance. A five-seat eVTOL costs around $6.25 per passenger miles, significantly more expensive than current ride hailing services. Better electricity efficiency can improve prices by 60%, however, work is needed on current technology to get to this point.

Although UAM is not expected to have a viable market until 2028, delivery drones have seen massive success during the pandemic, suggesting that market may become profitable and more common before then. However, companies with a focus on AAVs are likely to struggle during the pandemic. With so many competitors in the field, many companies were destined to fail organically, but the current pandemic and financial crisis may accelerate that process. Companies who are working on AAVs on the side are likely to divert funding away from those programs to save their core business. So far, many companies have announced that they plan to continue their AAV development, among the most prominent is Uber Elevate, who is sticking to its 2023 target for launching air taxi services. The pandemic has allowed for the continuation of many UAM operations, but many are unable to perform research and development activities.

Companies that were in business prior to 2020 have seen lots of growth during the pandemic. Wing by Alphabet has been used to deliver household essentials during the pandemic, completing more than 1000 deliveries in two weeks. The increase in demand was largely driven by customers' desire to have their packages be delivered without human contact as fears of contracting COVID-19 sweep the globe. During the pandemic, EHang has used passenger and non-passenger AAVs to transport valuable medical supplies and personnel, as well as for in-air inspections and to broadcast instructions over populated areas of China. EHang's actions created a market for AAVs in emergency situations, leading the Chinese government to grant EHang permission to carry out commercial pilot operations at the end of May. Additionally, EHang has seen massive financial growth during the pandemic. In the first quarter of 2020 sales of EHang 216 grew 200% compared to the first quarter of 2019. Their revenues also increased by 80.3% this first quarter.

Manufacturing

Boeing and Airbus, the world's biggest commercial aircraft manufacturers, dominate 99% of the large jet market. Together, they support airlines, the United States government and allied governments from over 150 countries (Boeing-General Information).

In 2019, Boeing was suffering financially from the grounding of the 737 MAX Jet, which had previously been involved in two fatal crashes in 2019. Investigations following the crashes blamed

Boeing for introducing the MCAS, a flight control law used to improve aircraft handling at elevated angles of attack, without properly instructing pilots about how to override the software if it malfunctioned (NY Times). Boeing was looking forward to the return of the 737 MAX in 2020 to restore their customers' trust and bring in revenue after facing scrutiny for the past year (Boeing-Investors).

Airbus announced in February of 2019 that it would cease the production of its wide-body A380 - the manufacturer's largest aircraft, with the capacity to seat more than 850 passengers, because Airbus had been struggling to receive orders for the A380 (The Guardian).

Boeing and Airbus rely on the support of many industry partners. Spirit Aerosystems supplies Boeing fuselages, Hexcel provides carbon fiber composite airframes, and GE provides jet engines. These partners are also heavily reliant on Boeing and Airbus for their profit - fuselages purchased by Boeing account for about half of Spirit's yearly revenue. Hexcel and GE lost significant revenue after the grounding of the 737 MAX.

Deloitte released a 2020 outlook on the Global Aerospace and Defense Industry, in which they observe that 2019 saw a smaller backlog of orders as a result of order cancellations and a decrease in new orders from customers (Deloitte 2020 Outlook). Deliveries and aircraft production were expected to bounce back during 2020 in anticipation of the return of the 737 MAX.

The problems the aviation manufacturing industry faced prior to 2020 have intensified during the COVID-19 pandemic. Spirit Aerosystems was directed by Boeing to pause all production of current and future 737 MAX shipsets this June (Leeham News&Analysis). Employees working on the 737 MAX were placed on leave, and saw significant loss in revenue during the first quarter of 2020. Spirit expects to see further losses during the second quarter of approximately $70-90 million from Boeing 737 MAX programs and $15-20 million from Airbus programs. Hexcel Corp, which supplies the material for the 787's carbon fiber frame, said they were aware that once the production of the 787 Dreamliner resumed, the demand from Boeing would be lower (Bloomberg).

In March, Boeing shut down production in multiple facilities for nearly 1.5 months (CNBC). Once production resumed, Boeing lost revenue on approximately thirteen to fifteen 787 Dreamliners, equivalent to $2.36 billion. It is estimated that Boeing will need to reduce production for the third remaining quarters of 2020 to satisfy demand (Boeing- Investors). Boeing's first quarter report for 2020 shows that revenues dropped a total of 26% compared to the first quarter of 2019 (Boeing-Investors). Commercial airplane deliveries dropped 66% in 2020, causing revenue to fall 48%. Boeing predicts that during and after the pandemic, production will resume at low rates and then gradually increase.

Many airlines are actively retiring or considering the retirement of many of their aircraft earlier than predicted to conserve money; order cancellations have also occurred (Forbes). Airlines struggle to make the once coveted A380 profitable due to high operational and maintenance costs, signifying the end of wide-body aircrafts. In total, there have been 313 order cancellations for the Boeing 737 MAX; Airbus has seen 29 cancellations of its A320 family (Flight Global).

In order to adapt to the financial crisis caused by the pandemic, aircraft manufacturers and the supply chain have made major decisions. Spirit Aerosystems announced a temporary production partnership with Vyaire Medical to produce ventilators for hospitals (Vyaire). SpaceX, Virgin Orbit, Blue Origin, and Lockheed Martin have also shifted their manufacturing operations to provide resources during the pandemic.

NAS

The US National Airspace System (NAS) is the largest and most complex air transportation system on the globe. It manages about 29,000,000 mi.^{2} of aerospace, handling about 44,000 flights and 2.6 million passengers each day. (NextGen: Where are we now?) Due to the scope of the system, efficiency and growth management were large challenges before the pandemic hit.

In 2019, operations at FAA and contract tower airports reached their fifth consecutive year of positive growth, growing the largest amount in more than 20 years. (2020-2040 FAA Forecast) Air traffic management had been modernized and redefined in recent years, with increasing use of semi-automated technology to carry out the system's main goals: to increase the safety, efficiency, and predictability of air travel. (Modernization of US Airspace). NextGen, the FAA's widespread project to modernize the US Air Transportation System, was part way through a multi-year plan to innovate all aspects of the NAS.

While the updates may not have been noticeable to passengers, many air traffic control facilities had been modernized and some even replaced by semi-automated systems, redefining the role of an air traffic controller.Between infrastructure upgrades at airports, air traffic control towers, Tracon terminals, and en route sites, various modernization projects had greatly changed the air traffic management system of the NAS. However, congestion and delays were still common at many US and global airports prior to 2020, though various programs had taken pressure off of air traffic controllers, emphasizing another challenge in the current passenger experience.

Like every other sector of aviation, COVID-19 had a massive impact on NAS systems management, drastically decreasing overall operations and creating new logistical challenges.

The FAA announced at the end of April that they would adjust the operating hours of 100 control towers across the country, after seeing a massive reduction in operations due to the COVID-19 pandemic. (FAA press release, List of towers) Other facilities have been forced to close after air traffic controllers tested positive for the virus, with high risk of spread in the small, closed centers (LA Times). While the towers are closed, the FAA will be monitoring the facilities from various radar facilities. (FAA press release) These reduced aviation operations make us consider whether just how many people should be employed, and what the role of automation should play in air traffic management once the pandemic ends.

Some airports are taking advantage of the reduction in operations to accelerate infrastructure upgrades/expansion, including LAX, while others, like SFO and Heathrow, have postponed renovations and even scaled back proposed projects since the pandemic began (LA Airports, WSJ - Reduced Renovations).

Environment

The aviation industry has an enormous impact on the environment. About 2% of all CO_2 emissions in 2019 were produced by the global aviation industry, producing 915 million tonnes (or more than a billion US tons) of CO_2. (ATAG) The US is a global leader in aviation emissions, with about 1/4 of CO_2 emissions from global passenger air transport coming from flights departing from the US and its territories (ICCT). Prior to COVID-19, aviation emissions were increasing each year, a contrast to the slow increase in overall greenhouse gases (FAA), and actions to decrease emissions and decarbonize other industries (Transport and Environment). Today's aircrafts are more than 70% more fuel efficient than the first aircrafts in the 1960s (FAA). However, the increasing operations of the industry and long time use of aircrafts have made for slow overall improvement in aviation emissions.

The aviation industry has identified a few core environmental concerns, including aircraft noise, air quality, energy use, and water quality. (FAA) Regulatory bodies across the industry have also set a variety of environmental goals that aim to reduce the massive and detrimental impacts of the aviation industry on the globe as the realities of climate change increase.

Airline manufacturers, NASA aeronautics and private-public partnerships aim to create technologies that will decrease these environmental concerns and help achieve these goals, hoping to innovate on various parts of the aviation system, including fuel combustion, aircraft aerodynamics, aircraft operation efficiency, fuel consumption, airport infrastructure, and more. NASA's aeronautics research mission directorate includes the "transition to low-carbon propulsion" as one of its main areas of research, and is an industry leader paving the way for sustainable aviation.

COVID-19 has greatly reduced airline operations, therefore reducing the industry's environmental emissions for the year, but has also shifted the focus of the industry away from becoming more sustainable. Tracking environmental progress currently seems irrelevant as the massive reduction in flights and decreased manufacturing makes for incomparable levels of emissions. In fact, this year's emissions are being disregarded for the CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation) program (ICAO), potentially allowing airlines to pay reduced carbon offset prices in future years (Reuters). Historically, when the economy declines, policies/actions are less likely to be prioritized (Report), which is being witnessed as environmental standards are temporarily loosened and across the globe under the rationale of the COVID-19 pandemic (EPA). In the current state of chaos due to COVID-19, the aviation industry is focusing on its recovery, regaining passengers and increasing operations to generate revenue, instead of prioritizing sustainability.

As airlines across the globe negotiate billions of dollars in bailouts to cover the extreme losses in revenue due to COVID-19, airline bailouts present an interesting potential environmental impact on aviation, as global leaders and environmental lobbyists are pushing for climate agreements in bailout deals. Various European governments, such as the French and Dutch governments, have discussed environmental conditions and restrictions that will come with the bailouts of airlines Air France and KLM. (Fortune, Reuters) Environmental activists claim that government bailouts must force a green transition of the aviation industry, and that the industry cannot return to its state pre-2020 where it had massive emissions, tax exemptions, and very few pollution laws. (Transport and Environment) However, very few bailout agreements currently include these "green strings", with US airlines expected to get $25 billion in bailouts without any environmental conditions (NYT).

The outlook of US air transportation

Model

Introduction

Throughout our research, when hypothesizing what the outlook of aviation may look like, two questions frequently came to mind: *to what extent has covid-19 impacted domestic air travel,* and *what are some possible short term outlooks of domestic air travel demand.* To answer these questions, we developed 4 models. Each model uses Revenue Passenger Miles(RPMs) to measure domestic air travel demand. The first 3 models are predictive models that implement an artificial neural network to give us an idea of what the next few months may look like for domestic aviation. The three models each account for a different scenario: the pessimistic model predicts what RPMs may look like in the case of a large surge of new coronavirus cases in the late summer/fall, the baseline model predicts what RPMs may look like in the case of a surge of new coronavirus cases in the late summer/fall that is less severe than the pessimistic scenario, and the optimistic model predicts what RPMs may look like in the case that coronavirus cases briefly surge in July and then return to decreasing through the fall[1]. The fourth model implements a counterfactual multiplicative time series decomposition to predict what demand would have looked like had the covid-19 pandemic not occurred[2]. Note that the counterfactual model's only purpose is to serve as a reference to determine the extent that covid-19 has impacted domestic air travel. The data used to train the three predictive models is similar to the data used to train Ito and Lee's model that analyzes the impact of 9/11 on domestic air travel demand.

Results

The results after training the model are shown in Table 1 and displayed in Figure 1. For more information on the performance of the models and some potential limitations, read the Validation section of Appendix C for the predictive models and of Appendix D for the counterfactual model. For the purposes of this section however, we will only discuss the results of the model. Figure 2 displays the percent change of the actual[3] post covid-19 RPMs as well as the projected RPMs in comparison to the counterfactual reference model. The exact percentages are shown in Table 2.

Figure 1 Model Predictions

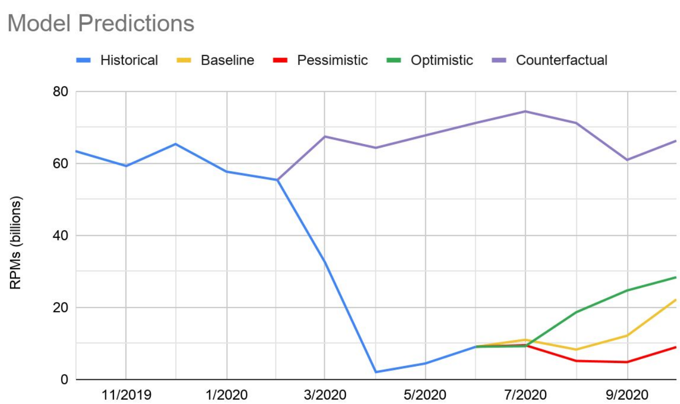

Table 1 Model Predictions (RPMs)

Date	Baseline	Pessimistic	Optimistic	Counterfactual
7/20	11025619360	9519224875	9258157794	74411367247
8/20	8315106271	5160126269	18668740756	71189248837
9/20	12168713658	4835580366	24711683401	60959193777
10/20	22218041780	9003937883	28379643947	66262443952

Figure 2 Percent decrease in post-covid data and projections in comparison to counterfactual reference

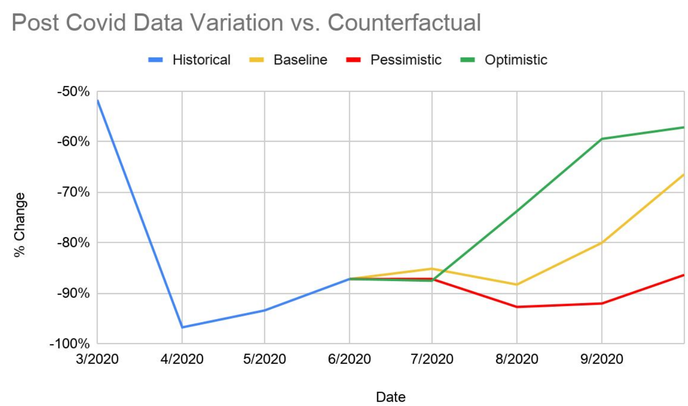

Table 2 Percent decrease in post-covid data and projections in comparison to counterfactual reference

Date	Historical	Baseline	Pessimistic	Optimistic
3/2020	-51.74%			
4/2020	-96.79%			
5/2020	-93.44%			
6/2020	-87.22%			
7/2020		-85.18%	-87.21%	-87.56%
8/2020		-88.32%	-92.75%	-73.78%
9/2020		-80.04%	-92.07%	-59.46%
10/2020		-66.47%	-86.41%	-57.17%

Discussion

In this section we will analyze the three different projections being made. To further understand how the model came about those projections, read Appendix A. As seen in Figure 1, all three projections more or less agree with what will happen in July, and then diverge after.

The optimistic scenario shows a similar nike-swoosh shaped recovery that has already been seen not only in the US domestic air travel demand from April to June but also in other regions of the world (IATA, Eurocontrol). Interestingly, the optimistic scenario is predicting that after two months of sustained growth in August and September, growth begins to slow down during October. This can be explained by the fact that although as the covid-19 pandemic is brought under control more people will feel comfortable flying again, there will most likely still be a significant portion of the population that will not be willing to fly as long as covid-19 is circulating.

The pessimistic scenario shows a dip in RPMs from its June levels for the remainder of the summer that starts recovering

[1] This section of the report only briefly summarizes the methodology for the predictive models, to view the full methodologies read the methodology section of Appendix C
[2] To view the full methodology of the counterfactual model view the methodology section of Appendix D
[3] RPMs data for April, May, and June are estimated from traffic percent decreases given by A4A in their covid-19 updates

again in September. In this scenario, we would be looking at only a 1.01% increase in RPMs from June to October. This second wave and the resulting four month stalling of the recovery process could prove disastrous for many airlines, which are already facing enormous financial strain because of the lack of demand.

In the baseline scenario, recovery would stall through August but demand would only experience a dip 1.03% dip in comparison to the June levels, much better than the pessimistic scenario's 5.58% decrease. Additionally the baseline scenario shows a promising path to recovery during the fall, with a 21.87% increase from August to October.

The covid-19 pandemic has already resulted in unprecedented blows to the air travel industry. At its worst, demand was down 96.79% than what it would have been had the pandemic not occurred. The pandemic has additionally brought a lot of uncertainty to the industry, and with this model we hope to provide some guidance as to what the following months may look like. Throughout the rest of this report we will refer back to the model when making predictions on the outlook of the air industry, and contrast the predictions being made with what other industry experts are saying.

Research

Industry Overview

There are many unknowns when thinking about the future of US air transportation. The COVID-19 pandemic has completely shaken up the global economy and the lives of people across the globe, and has disrupted every aspect of the aviation industry. As indicated in the discussion about our model, a variety of factors will affect the recovery of air transportation, including economic stability, the state of the virus, but also a potential vaccine, forced quarantines and travel bans, and more. While these social factors are almost impossible to predict, we supply an analysis of the various factors that will play into sector recovery.

9/11 and the Great Recession both greatly impacted the state of aviation operations, adding airport security and altering airline business models, respectively. *Read more about the effects of previous crises on aviation in Appendix B* COVID-19 has had a much larger effect on aviation than either of those crises, so we can anticipate equivalently large (or even larger) changes to the industry in coming months/years.

Passenger Travel

With aviation struggling more than ever before, the future of passenger travel remains a crucial question when considering the path to recovery. In order to determine the impact of COVID-19, the National Center for Biotechnology Information interviewed various aviation industry executives about the evolving nature of air travel in these uncertain times. As a result, they concluded that business travel would return to some degree in the short term in order to maintain and strengthen international relationships with clients. On the other hand, other sources including Delta Airlines CEO Ed Bastien predict that business travel will never return to 2019 levels (Source). Long term business travel demand may be reduced as many conferences and meetings have been cancelled, and millions of companies and employees have adapted to working from home, an experience that will only improve as advanced collaborative online platforms are developed. However, due to the formation of strict travel bans across the globe, long haul flights are no longer occurring and thus, conferences and exhibitions will take much longer to return. Travel budget cuts and cancelled bookings have also contributed to this lag in recovery, causing businesses to restructure their interactions through regular use of virtual platforms, already having invested in various online workplace mechanisms. As these platforms innovate to better suit business needs, business travel demand will see less demand in the long term therefore threatening airlines as they rely on business travelers for profitability. This will push airlines to emphasize efforts towards leisure travelers, and better the passenger experience in order to generate satisfactory yields. Leisure travel will recover faster than business travel, though will remain low due to a general decline in disposable income of Americans paired with weak traveler sentiment. In order to improve these factors, airlines will have to rely on local authorities for increased tourist marketing and will need to sell tickets to cheaper destinations, completely shifting the marketing focus and traditional vacationing from expensive beach trips to more affordable locations such as in Southern Europe or North Africa. For demand to return, consumers must regain a sense of trust in US airlines through a shift from traditional procedures to new necessary safety precautions. To do this, airlines must sacrifice their traditional priority of profitability and direct their efforts towards the passenger experience through developing extensive safety measures. Recently, the US government devised a new standard, Runway to Recovery, to help airlines adapt to the current circumstances by mitigating health risks and with strict compliance from airlines, recovery will become a clearer path. The IATA predicts that for the rest of 2020, international air travel demand will experience gradual growth while still resulting in a 55% loss in passenger revenues. As it will take a year for a functional vaccine to develop, recovery will continue to lag until passenger health is better assured.

Cargo Operations

The nature of air freight has massively shifted from its traditional structures such as with the transition to an increased reliance on passenger aircraft as a mechanism of freight transport. This shift will not be long term as passenger travel demand will pick back up once a functional vaccine is created, reverting aircraft back for passenger travel and allowing freight designated aircraft to retake a more dominant role once again. However, the circumstances of the pandemic have forced airlines to adapt and make necessary changes to traditional structures, demonstrating how passenger aircraft have been able to be made compatible with increased freight loads. So while the conversion of passenger aircraft for freight purposes remains temporary, as it is a lengthy process, advanced passenger carriers designed with greater freight capacity and compatibility along with systemic changes in airports to include more freight accommodations can be seen with innovation in the long term.

The past trend in growing e-commerce has been emphasized under the conditions of the pandemic and will continue to see short-term growth for the next couple years as shops remain restricted by social distancing practices and travel policies. Yet, as people who have traditionally relied on in-person shopping have been forced to navigate the online market for shopping purposes, e-commerce will see a long-term increase. The online market is vast, containing a much larger variety of goods than stores in person, and exposing shoppers to advertisements that are more capable of reaching target markets. Additionally, the pandemic has forced consumers to become more comfortable with the practice of buying online and picking up in store, adding on to the versatility associated with online shopping. Thus, online shopping will take a stronger role from what it was in the past, and stores will meet these new changes by expanding their online presence, offering customizable services that will tailor the shopping experience to consumer needs, and make shopping more efficient. The aviation industry will adapt to and support this growth by expanding express routes, eliminating time and geographical constraints by making paths more efficient.

Furthermore, the transition towards increased automation within air freight transport will be emphasized to maximize efficiency. While a significant portion of air freight growth during COVID-19 has been attributed to increased need in emergency medical supplies, this trend will be short-term as society adapts to the pandemic circumstances. However, there will be a long term impact on the emphasis for innovation towards drones and better collaborative efforts for emergency supply delivery as the need for freight grows.

Finally, travel restrictions that have hurt efforts in efficient air freight travel will become more flexible in the long-term through altered regulations and increased charter flights as this pandemic has revealed the harms in poor communication and strict general international policies regarding the transport of air freight. Policy changes to support airlines regarding the provision of financial relief as well as an emphasis on freight operations should be implemented to better aid the recovery of aviation in the US. Because air freight is so dependent on and connected with the economy, the road to recovery will be long, as the economy has declined significantly due to COVID-19. But with various systemic changes as well as continued adaptation to the changing circumstances, the industry can better itself and foster a better outlook to come.

Urban Air Mobility

UAM has experienced massive progress in recent years, and though UAM technology is not currently available, it is expected to emerge in the next decade. NASA's predictions from November 2018 stated that small UAM use as last-mile delivery drones are expected to become profitable by 2030.

The original technology is expected to be somewhat costly, with air metros will be charging approximately $50 per trip in 2028, but costs will decrease over time, with an estimated and then transition to about $30 per trip by 2030. A potential market for air taxis is not likely and very limited. NASA expects air taxis to be viable after 2030, with the original market limited to wealthy commuters hoping to avoid traffic. High investment costs would also hinder success by 2030. In a comparison between UAM and existing ridesharing services, air metro technologies like that of EHang appear to be preferable to ridesharing. Riding in a car allows for human error, safety concerns, traffic, pollution, and for companies like Uber and Lyft, it has low profit margins. Automated aerial vehicles, however, are fully autonomous, safe, zero emission, have low maintenance costs, and don't have to deal with congestion. EHang recognizes that ridesharing services are successful because they are accessible through mobile apps and offer instant services. They think it is possible to replicate that system, however, they believe it's best to ditch the driver and use autonomous vehicles. As we've seen with EHang and Wing, a market already exists for delivery drones and air taxis. Their operations have soared during this pandemic - unlike other sectors of aviation, UAM development was positively impacted by the pandemic, as certain regulations were lifted to allow the delivery of essential goods by UAM. UAM has also emerged as a potentially preferable means of transportation during pandemics due to the reduced human contact the system offers - as current efforts in UAM development strive to create autonomous navigation and personalized mobility. McKinsey Analytics explains that the virus causes people to adjust their means of transport to reduce the risk of infection, shifting away from shared forms of transportation and instead increasing personal vehicle use. There will be an emergence of both large and small UAM in coming years, but continued efforts are necessary to ensure that UAM technology is ready, and that it is appropriately integrated into society.

In order for UAM to become viable, UAM developers will need government support. For example, EHang sees regulations, government approval, and technology as key factors for the viability of UAM. Approval from local governments such as the FAA are needed. The FAA has an Unmanned Traffic System Management in place that will manage multiple drone operations conducted beyond the visual line-of-sight. UAM also requires cutting edge technology from every STEM field, as well as a strong supply chain and a centralized platform for commercial operations. Massive infrastructure optimization would also be required for UAM to become a viable alternative to ground vehicles. In the future, it will be important to continue research on UAM. Independent of COVID-19, UAM is generally unproven for its capabilities (aircraft, battery technology, noise pollution). There is little experience of safe UAM operations in high density areas , and progress is needed before the public can accept it as a safe, comfortable, and affordable method of transportation. Research is key for the rapid development of UAM.

Given the nature of the success of delivery drones during the pandemic, UAM research is absolutely necessary. It is still not clear how long the effects of COVID-19 are expected to last, but we can assume that people will continue to order online. Deliveries will need to become safer, and delivery drones can replace delivery people to make the process as contact-free as possible.Significant efforts are needed to alter public acceptance of UAM as well, as people currently prefer pilots to autonomous flight, even if the autonomous ride is cheaper than manned flight. There is also significant progress needed to be made in the infrastructure that is required for UAM, mainly landing pads, charging stations, and repair centers.

Manufacturing

In a shareholder meeting in April, Boeing's CEO Dave Calhoun stated, "It will take two to three years for travel to return to 2019 levels and an additional few years beyond that for the industry's long-term growth trend to return." Despite setbacks, the demand for increasingly more efficient aircraft is growing. Once the turmoil in the airline industry does stabilize, Calhoun says "the commercial market will be smaller, and our customers' needs will be different."

When airlines begin to order aircraft again, it is expected that they will turn to narrow-bodied planes which will be used for shorter routes. High-maintenance and operational costs are driving down demand for wide-body aircraft. Considering that airlines are retiring their wide-body fleets, we can assume that they will be using smaller aircraft in the future. Those aircraft will also need to be reconfigurable, as well as COVID-friendly. Manufacturers will need to look into different materials that are germ-resistant, like copper, to use inside cabins. The space between passengers will require adjustment, to allow for social distancing even after the pandemic has subsided.

With the decline in passenger travel, airlines have also disturbed their traditional focus on designated freight aircraft for freight purposes and resorted to removing the seats from passenger aircraft, using the space to carry cargo. While the process is long and tedious, requiring additional approval from the manufacturer and a certifying authority, the health crisis has rendered it useful in order to maximize loading capacity and increase air travel revenues. It will be important in the future for aircraft manufacturers to make their planes reconfigurable. Airlines will want removing seats from airplanes to make room for cargo a fast and inexpensive process, and it will certainly drive demand for these new aircraft.

Manufacturers should also be expected to put their technology through multiple rounds of testing in labs and in the field. Following the Boeing 737 MAX jet crashes, there has been more pressure and scrutiny on the industry to ensure flights are safe and there are no more deaths. In the coming years, aircraft manufacturing can be expected to occur beyond the traditional industry leaders, such as Boeing and Airbus. Non-traditional aviation groups are already leading innovation in UAM, and we can anticipate other companies will begin expanding their scope. They will also be expected to perform similar, if not more rigorous testing than traditional manufacturers to prevent crises that may slow down innovation.

NAS

Before the COVID-19 pandemic began, the FAA estimated that airline operations would consistently increase in the next 2 decades. Though current aviation operations are far reduced from that of 2019, and significantly decreased operations are projected through 2020, the demand for aviation will return with time, and it is likely that operations will continue to grow once the pandemic ends.

We can expect to see the continuation of prior infrastructure modernization projects in the post COVID-19 world. After receiving government funding from the CARES act and almost $700 million in Airport Improvement Program (AIP) funding, the FAA declared that they will increase funds for airport safety and infrastructure improvements as airports face challenging financial circumstances (FAA: CARES for airports). However, besides funding, programs to modernize infrastructure experienced more challenges before the pandemic including the length of construction projects and concerns about various environmental factors, so it is still unclear whether the efforts will be prioritized in the post-covid environment.

The NAS will face great challenges in coming years as the industry aims to integrate commercial space flight, UAS, and other NextGen additions to the national airspace system without compromising traditional operations in the current system. Significant research and development in software and automation capabilities will be needed to ensure this safe integration. (FAA: NextGen: Future of the NAS) Automation will have a huge role in all future projects and programs, as automated systems will also prioritize the core goals of the NAS: efficiency, consistency/dependability, safety, and the environment.

We can also expect a change in employment in the air traffic management / NAS system management sector. For decades, experts have warned of the changes to the job of an air traffic control specialist as automated systems are implemented (FAA: Selection of Air Traffic Controllers for Automated Systems). There has been evident change in the role of an air traffic controller over the years, with new technologies being said to "reduce the traffic complexity and cognitive workload" of air traffic controllers (FAA: NextGen: Future of the NAS). As the number of automated systems increases, the role of air traffic controllers (and even pilots) will be heavily focused towards understanding the automated platform, and there may be less demand for ATM employees. The current mass unemployment of air traffic controllers during the covid-19 pandemic may continue/re-emerge as modernized systems are put in place, greatly impacting yet another aspect of the industry.

Environment

It is unclear how much of an impact COVID-19 will have on the future environmental progress of the aviation industry. Green strings attached to airline bailouts will increase the attention and emphasis on electrifying aviation, while the loosening of environmental restrictions, focus on regaining revenue, and cancellation of electric aircraft projects will be setbacks for the industry's environmental progress. In the next few years, airlines will prioritize revenue to ensure that they survive the long-term economic challenges of COVID-19. However, though environmental restrictions may be loosened and environmental concerns may be pushed to the back burner, it is of the utmost importance that airlines and the industry take large strides towards decarbonizing aviation.

The future of aviation is sustainable aviation. Climate change has been slowly occurring for decades, causing rising sea levels, global temperature increases, dangerous extreme weather patterns, and more. The UN has declared that the globe has 10 years left before the effects of climate change are irreversible. (UN: 11 years to prevent irreversible climate damage) In contrast, the aviation industry continues to increase its emissions, and is on track to triple its emissions by 2050, where aviation may account for 25% of global carbon emissions. (The International Council on Clean Transportation - CO2 Emissions from Commercial Aviation, 2018) Overall aviation operations are also expected to increase in coming years as UAM usage becomes widespread.

Despite progress in fuel efficiency, aircraft system design, aerodynamic changes, optimization strategies, and other retrofits and innovations to current aircraft technologies, advancing conventional technologies will have limited potential for a future sustainable improvement. (IATA: Aircraft Technology Roadmap to 2050) Instead, the industry must direct its focus towards the development of revolutionary aircraft, aiming to produce aircraft much more environmentally friendly than any conventional technology. NASA aviation research and aviation industry leaders must invest in the production of these future aircraft, and put significant time and funds into various airframe configurations (blended wing body, “flying V”, etc), aircraft structure and materials (alloys, morphing wings), and future propulsion technology (open rotors, hybrid electric, full electric propulsion). The industry must use this pandemic to reflect on its massive contributions to climate change, and take bold actions to achieve sustainable aviation, as it will be a necessity in the near future. The industry cannot just offset their emissions through programs like CORSIA, but must develop revolutionary aircraft that will re-define aviation.

Conclusion

From the model and the research analysis of different sectors of aviation, it is clear that COVID-19 has created significant changes across the board that will continue beyond 2020 and will affect the state of the industry after the threat of the virus is eliminated. COVID-19 has produced an unprecedented effect on the aviation industry - problems that were occurring before the pandemic have been magnified, and new challenges have emerged. Though the industry wants to promptly recover from the pandemic and return to the state of the industry in 2019, this will not happen overnight - our model shows that even in the best case scenario, regular passenger miles will be 50% of what they would have been without the pandemic in the next four months, and external sources state that the industry recovery will take about three years. The industry cannot simply revert to its previous operating strategies, or it will become highly susceptible to future crises similar to COVID-19. In addition, the pandemic has highlighted the negative passenger experience when flying, and airlines must rapidly improve their services to increase demand. The pandemic presents an opportunity for the industry to focus on reinvention instead of recovery, allowing it to restructure its operations and alter each sector to adapt to the changes in the industry that have emerged due to COVID-19, and prepare for future changes of the industry in the next decade.

Every company and sector within the aviation industry must consider how they will alter their operations to fit the newly disrupted globe. Widespread changes are needed across the board to ensure a successful revitalization of the industry. We have focused on how NASA should cater its research to assist the reinvention of the aviation industry and better fit the changing climate, and will detail our recommendations below.

NASA’s Aviation Research

The state of NASA’s Aviation Research pre-2020

NASA has a long history of developing revolutionary aviation technology since its formation in 1958. NASA has always looked towards the future and has taken on monumental challenges that seemed impossible at the time, from war planes, helicopters, to the passenger jet. Now, in the 21st-century, NASA's aeronautic flight teams focus on tackling the monumental challenges of the next generation of aviation, with the Aeronautics Research Mission Directorate detailing efforts in “Safe, Efficient Growth in Global Operations”, “Innovation in Commercial Supersonic Aircraft”, “Ultra-Efficient Commercial Vehicles”, “Transition to Low-Carbon Propulsion”, “In-Time System-Wide Safety Assurance”, and “Assured Autonomy for Aviation Transformation”. (Source)

Recommendations for NASA’s Aviation Research

The COVID-19 pandemic has revealed the significant structural flaws in US aviation, as an industry based on the notion of safety has instead caused the entire opposite, posing a threat to lives around the world. Though US airlines experienced growth and appeared strong just last year, it is evident that they were wholly unprepared for the circumstances that came along with the pandemic, therefore causing irreversible damage and revealing how weak the industry actually was - as it was essentially set up to fail in the situation of a deadly virus. While the persistent need for air travel has been able to conceal such flaws, this pandemic has exposed the underlying insufficiency of the US air travel system, providing NASA a unique opportunity to refocus the industry’s direction as it looks towards the future. The passenger experience today is widely negative, with cramped and often outdated aircraft, frequent delays, large crowds, tedious security processes at airports, and more. Many Americans have avoided air transport due to fears of contracting COVID-19 in the airport crowds and packed planes with circulating air. There has also been a recent growing awareness of the detrimental effects of aviation on the environment as the globe prepares for the massive effects of climate change. Thus, we urge the perception of recovery to extend past a mere restoration of demand and instead envision true recovery as worthwhile reinvention within the entire aviation system. With this in mind, **we encourage NASA to concentrate its efforts on rapidly accelerating the industry’s innovation through increased focus on passenger satisfaction, substantial action towards**

sustainability, and significant collaboration with a diverse range of industry partners.

Accelerated innovation is key to ensuring the survival of the aviation industry. Massive strides must be taken immediately in order to motivate demand and stabilize airlines, preventing irreparable repercussions from harming the industry. As the next few decades head towards advanced transportation technologies, passenger travel demand for airlines will become at risk, reinforcing the need to begin to improve aviation as a whole right now. Similarly, each day that passes increases the need for sustainable modes of transport, with climate change quickly becoming a horrifying reality. COVID-19 has produced mass disruptions within air travel systems which not only threaten the survival of aviation but also provide an opportunity for the industry to introspect on traditional frameworks and restructure to create notable change. We are currently at an inflection point, and it is of paramount importance that NASA seizes this moment to accelerate innovation and spark a period of reinvention.

Passenger Satisfaction

Passenger satisfaction is crucial in fostering demand for air travel. Passengers have been dissatisfied about a variety of factors for years, with the COVID-19 pandemic putting specific emphasis on the lack of health safety when flying. To ensure future profits, NASA must research the technologies that will improve passenger satisfaction, build fast and convenient air travel systems, and leverage its partnership with the FAA to make airports safer environments.

NASA must invest in passenger health and welfare technologies to ensure that air travel is safe and profitable. COVID-19 has created new safety standards, as passengers are concerned with human contact, airflow, and other health demands. ~~COVID-19 is likely to continue for at least one more year, and air travel demand will not increase significant amounts until the industry proves that traveling by air is not dangerous (in the context of the virus).~~ Similar to how the industry implemented widespread security measures after 9/11 to reduce the risk of future attacks, NASA must work to implement technologies that will mitigate the effects of future pandemics, and allow the aviation industry to regain its credibility as a safe method of transportation. Biological sensors are emerging as a necessity on all aircraft and in all airports, with Airbus working to detect COVID-19 and other biological hazards on aircraft through air monitors. Airports and aircraft are also working to develop cleaning technologies that will reduce risk of infection, researching and implementing UV light cleaning robots, and providing a potential market for ecoDemonstrator's self cleaning aircraft lavatories. Using testing platforms such as the ecoDemonstrator can help speed up the FAA regulation process for implementing cleaning technologies systemwide. This is significant as physical changes within traditional systems of airports and aircraft are vital to reconstructing a sense of trust in aviation. Even beyond COVID-19, the virus has highlighted the negative and unhealthy passenger experience when flying, and NASA must shift its efforts towards improving this experience to restore confidence in air travel and ensure long term demand and revenue.

Developing a fast and convenient aviation system is crucial towards fulfilling passenger satisfaction and contributing to the system's overall reinvention. The current aviation systems have become significantly more efficient in past years, with NASA optimization software aiding in this improvement. However, the typical passenger experience still includes long times spent in airport security, multi-hour flights, and frequent flight delays. With steps towards emerging technologies such as air taxis and UAM along with the unique opportunity for airlines to alter traditional systems, efficiency in aviation is made even more important in order to escalate traveler demand. Amidst the COVID-19 pandemic, it is clear that the industry's revenue is heavily reliant on passenger satisfaction and demand. Passengers have always wanted efficient travel journeys, from streamlined airport experiences to shorter flights, but COVID-19 has put an even greater emphasis on efficiency, as passengers want to reduce the amount of time they are potentially exposed to the virus. This notes a potential market for supersonic aircraft in the future, as the powerful supersonic aircraft technology currently being developed will greatly reduce flight times. Creating a safe, efficient aviation system will also produce monetary results - the Department of Transportation estimates that flight delays and congestion cost the economy more than $20 billion each year (DoT: Beyond Traffic 2045) - which is more crucial than ever as the industry experiences massive losses.

In addition, passenger satisfaction is greatly increased by the convenience of air travel. To increase ridership and allow for advanced mobility across different forms of transportation, NASA must ensure that the air transportation is seamlessly connected to both traditional and emerging transportation systems (UAM, supersonic flight, automated vehicles, hyperloop, etc), including the integration of various transportation data. Considerable effort is necessary to safely integrate UAM and other future aviation systems into the NAS, and NASA must continue to develop software to help modernize the NAS and make UAM a reality.

Sustainability

Despite NASA's progress in improving aviation's massive environmental impact, significantly more research and development is needed in the next few years to ensure that zero-carbon aircraft are quickly developed as the global climate crisis rapidly approaches. Airlines have been able to justify their enormous environmental impact of aviation prior to 2020 as operations grew and revenue increased. However, the industry's stability has already been disrupted by COVID-19, and this is a perfect opportunity for the industry to restructure and refocus on what's important: improving aviation to become more sustainable and help save humanity from the growing threat of climate change. Evolutionary aircraft technologies, including retrofits of current aircrafts, production upgrades, and new aircraft designs, are critical in improving fuel efficiency in the near future. However, there are limitations to the extent of which evolutionary technologies may improve efficiency, and it is estimated that beyond 2030, these improvements will have little impact (Roadmap to 2050). To achieve large scale, long term reductions in CO_2 emissions, NASA must increase their emphasis on the development of revolutionary aircraft technologies. Unlike evolutionary technologies, these nontraditional concepts allow for long term improvement in aviation's environmental impact, and can act as a long term mission within NASA aeronautics. The aviation industry is currently on track to triple its emissions by 2050, when it will account for 25% of global carbon emissions (The International Council on Clean Transportation - CO2 Emissions from Commercial Aviation, 2018). Simultaneously, the industry is expected to experience a mass increase in aviation operations as UAM use expands. NASA must work to guarantee the responsible integration of UAM, both in sustainable technology development and conscious operations, as to avoid a further increase in industry emissions. In addition, NASA must accelerate innovation of sustainable passenger jets, investing large amounts in revolutionary aircraft technologies (nonconventional airframe configurations, revolutionary structure and materials, various propulsion systems, and more) to ensure that decarbonized aviation becomes a reality in the next few decades. NASA should alter its mission directorate to shift the aeronautics mission from “transition to low carbon propulsion” to “transition to zero carbon propulsion”, providing a bold goal and comparable metric to strive towards.

NASA must consider how its other programs support this mission to develop zero carbon aviation. Current research of supersonic aircraft has indicated large potential fuel emissions and noise pollution, and development has reached large challenges, from technical capabilities to social integration. NASA should focus on producing fast, sustainable aircrafts - if sustainable supersonic aircrafts are viable, then NASA should expand its research in that field, but aircraft that compromise the environment and do not align with NASA's sustainability mission should not be developed. This will ensure clarified and meaningful use of NASA's resources, allowing for stronger steps to be taken in regards to the environment as well as reallocation of funds towards relevant projects that better support aviation in this pressing pandemic.

The decarbonization of the aviation industry does not have to compromise any aspects of enjoyable flight. Research must be done in creating fast electric aircrafts that are able to carry passengers long lengths- as the industry continues to thrive because of the current lack of alternatives to fast long-haul travel. Though the price of future sustainable aircrafts is unknown, the reduced use of fuel poses a potential benefit for airlines, who spend a considerable amount on fuel each year. In addition, the price of sustainable technology currently on the market, including solar panels and electric cars, has been shown to drastically decrease over time as iterations of the technology improve. For sustainable aviation to succeed, it must not be a sacrifice for the industry, but must improve upon current systems and become the prefered choice of travel for passengers across the globe.

Industry Collaboration

As a national system, NASA must expand beyond the traditional manufacturers like Boeing, Airbus and Lockheed Martin, but also support and propel the growth of the disruptive contributors to aviation. In order to successfully restructure after the COVID-19 pandemic and achieve its goals in passenger satisfaction and sustainability, the industry must have an “all hands on deck” mindset, and making contributions beyond traditional aviation leaders (Boeing, NASA, etc), is crucial to accelerating innovation. Tech companies and startups are innovating on UAM at a fast pace, while attempts by Boeing and the traditional aviation manufacturers to innovate quickly have been destructive: the Boeing 737 Max crashes emphasized the quality errors associated with attempts to speed up the rate of innovation without proper collaboration. NASA must provide a platform for nontraditional aerospace groups (startups, tech companies, etc) to support the outside development of aviation, creating strong public/private partnerships, and propelling the innovation cycle. As seen with past technologies such as ~~TestBed and~~ the ecoDemonstrator, NASA can leverage its resources to create some platform focused long term industry stability, pushing members to innovate in regards to COVID-19 to broaden the scope of ideas in reshaping aviation. The ecoDemonstrator tests a variety of sensors in parallel in realistic conditions (on a real Boeing plane), which quickly proves their technology's capabilities and allows for a potentially increased regulation process. Collaborating with other groups also allows NASA to innovate more than they could on their own, accelerating the overall innovation process. relieves some of the pressure off NASA to pour its own resources in helping reinvent the industry and instead encouraging other companies to collaborate and create necessary technologies. Additionally, having some sort of testing format for COVID-19 related technologies can help make the FAA regulation process more efficient, allowing for innovation to more easily become a reality within airlines. The innovation cycle of the aviation industry is notoriously slow, and NASA has the capability to support small startups and tech companies and help propel them through the FAA approval process, allowing for increased innovation to reach the market.

In recent years, aircraft technology and air traffic management systems, along with other aspects of the aviation industry, have become increasingly modernized, with the development and implementation of semi-automated features. Over the next few decades, many aspects of the world as we know it will become automated, including the aviation industry. COVID-19 has propelled the innovation and implementation of automated technologies due to the desire for interactions without any human contact. In fact, the government recently developed a set of guidelines for airlines to direct airlines in mitigating the public health risks associated with COVID-19. Included are recommendations to minimize wait times, develop a system of contactless document exchange, and implement sanitization technologies, highlighting on this vital shift to automation within air travel systems. However, there are few fully automated technologies currently on the market, and demand for modernized aviation systems and autonomous technologies in every sector will greatly increase in coming years. With NASA's significant role in being a government agency and a noted provider of research and technology, it is essential for NASA to support this government framework and assist in the major operational changes within airports. Additionally, NASA's Aeronautics Research Mission Directorate specifically mentions, "In-Time System-Wide Safety Assurance" and "Assured Autonomy for Aviation Transformation", demonstrating the undeniable obligation of NASA to shift from its current background approach and take direct action in providing necessary support for US aviation. NASA must collaborate with other industry partners including tech companies and startups to produce automated technologies that will help aviation adapt to the changing globe. When developing these innovations, NASA must work with the FAA to create an efficient approval process and form regulations that require implementation of these COVID-19 based technologies within airlines. These efforts will ensure passenger satisfaction through redesigning a vision of safety in systems of air travel. NASA must also collaborate with the FAA to support the development of infrastructure that will support the next generation of revolutionary aircraft. As supersonic aircraft, UAM, commercial spacecraft, and other non-traditional aviation operations emerge, advanced air traffic management systems will be needed to safely integrate other revolutionary technologies to the traditional airspace currently in place. The continuation and expansion of current ATM and system management platforms like TestBed will be crucial as the air transportation becomes more complex, and NASA's development of automated technologies will help modernize the NAS.

Appendix A: Glossary of Acronyms

Appendix B: Previous Industry-wide Disruptions

9/11

Until covid-19, no event had caused such a resounding impact on the aviation industry as 9/11. The hijacking of 4 commercial jetliners during the terrorist attacks of September 11th led to some revolutionary changes that permanently transformed the aviation industry.

Immediately following the attacks there was a transitory shock to the aviation industry, driven by an initial panic and fear of flying. This temporary shock resulted in a 31.3% decrease in air travel demand, however this decrease dissipated 4-5 months after the attack (IATA). However, 9/11 additionally resulted in a permanent decrease in air travel demand of 7.4%(IATA). This permanent impact can be attributed to the increased hassle passengers had to go through because of stricter security measures put in place by the TSA.

The decrease in air travel demand paved the way for 4 major airline bankruptcies and 2 major mergers (Berry and Jia). The airlines that did survive had to shrink their capacity to remain afloat. Almost 48 thousand air travel workers were laid off (BLS). This decrease in capacity resulted in customers having less options when buying tickets. However, this positively impacted airlines because it drove up their load factor (BTS).

In response to the decrease in domestic demand following 9/11, major carriers shifted their capacity to the international market (BTS). LCCs responded to this by aggressively filling in the gaps that were being left by the major carriers, thus increasing LCCs domestic market share (BTS).

Great Recession

The global financial crisis of 2007-2009, also known as the Great Recession had economic repercussions that impacted virtually every industry. However, the aviation industry, which is known to be more susceptible to economic conditions than other industries, was especially devastated during this period of economic downturn. With air travel demand plummeting, airlines were forced to completely rethink how they were operating in order to stay afloat.

To survive the recession, airlines modified their business models in various ways. One adjustment was adding auxiliary forms of income by removing services previously included in a standard ticket and charging additional fees for them (DOT). These services include things such as the amount of baggage passengers can take on flights, in-flight meals, in-flight drinks, in-flight entertainment, etc. These additional fees gave airlines a more stable source of income to aid them through unfavorable economic conditions. Another adjustment made by airlines was transitioning from buying aircrafts to leasing them on an as-needed basis (BLS). This allowed airlines to be more nimble in responding to reductions of demand, thus helping them minimize cash burn.

In response to the surplus availability of seats due to the lack of demand, airlines reduced their capacity, with ASMs decreasing an average of 5.1% in 2009 (BLS). Additionally, as demand started picking up at the end of the recession, airlines continued decreasing their ASMs, driving up their load factor and thus increasing profitability (DOT).

The lack of demand during the recession led to three major airline mergers. The mergers meant that airlines could remove redundant and unnecessary flights from the market, further driving up the load factor and giving consumers less options when flying (DOT). Furthermore, major airlines removed small inefficient regional flights, increasing regional carriers' market share (DOT). These changes contributed to flights being longer, larger, and fuller in the years following the great recession. Today, 4 American airlines - Delta, American, United, and Southwest dominate US air travel, represent X% of ...

Appendix C: Defense Aviation Manufacturing

Effects of Covid-19

The defence sector of aircraft manufacturing was doing well prior to 2020. Lockheed Martin's biggest client is the United States Department of Defense, who is responsible for almost 70% of the company's revenue in 2018. A large number of Lockkheed's international customers are US allies, whom they cannot accept orders from without permission from the US. In the same 2020 Global Aerospace and Defense Industry Outlook report, Deloitte states that the defense sector maintained its growth during 2019. Bigger security threats have pushed governments from around the world to increase their defense budgets. They expected government defense expenditures to rise between 3-4% in 2020, with the US in the lead. The sector was expected to grow given that global defense spending was also expected to grow by 3% by 2023.

On the other hand, the defense sector of aviation has been doing extremely well during the pandemic. Lockheed Martin has two plants located outside the US that manufacture the F-35 Joint Strike Fighters, both of which were closed for a week or less in March. The plant in Italy closed for two days to clean and sanitize its facilities. The Mitsubishi Heavy Industries F-35 plant in Japan was closed for just one week and reopened the following. LMT's Texas plant, which builds F-35s for the US military and most overseas customers, remained open during March. LMT reported first quarter net sales of $15.7 billion, compared to $14.3 billion from the first quarter of 2019. Cash operation and net earnings were also higher in the first quarter of 2020 compared to the first quarter earnings in 2019. According to the report, "the outbreak did not have a material impact on the corporation's operation results or business in the first quarter of 2020." Higher net sales are attributed to $695 million in sales of the F-35 aircraft, which saw high production volumes, sustainment and development contracts. LMT has also begun working with the US Department of Defense to provide critical financial aid to vulnerable elements of the US defense industrial base; $600 million in accelerated payments are estimated to flow into LMT's supply chain partners.

Sector Projections

The funding provided to the US Department of Defense will affect whether they will continue to order aircraft from LMT. The contract LMT has with the US government could be terminated for convenience and based on negotiable contract terms. Trade policies and sanctions imposed by the US to countries like Turkey and Saudi Arabia will affect LMT's business, as they can only work with countries approved by the US government. Overall, the industry is expected to continue growing as security threats continue to grow.

Appendix D: Predictive Models

This appendix will rigorously discuss how the predictive models work, and go over the model's performance and some potential limitations.

Methodology

As previously stated in the report, the predictive models implement an Artificial Neural Network. The network is trained on various economic, seasonal, and covid-19 historical data[4], and it also takes into account several major events that have disrupted the air industry. The model then makes predictions by feeding economic and covid-19 projections, as well as the appropriate seasonal variables into the network. It is important to note that there are many similarities between these predictive models and the analytical model developed by Ito and Lee.

Data

In this section we will go over the data that is used to train and make predictions with the neural network. All the data that is used to train the model is monthly and spans from January 1990 to June 2020. Prediction data used to make projections with the model is also monthly and spans from July 2020 to October 2020.

Economic Features

The air travel industry has been known to be heavily dependent on economic cycles. The model takes into account the state of the economy by considering monthly total nonfarm payrolls[5] and the monthly unemployment rate[6]. Historical total nonfarm payrolls and unemployment data is sourced from the BLS and both are seasonally adjusted. The total nonfarm payrolls data is shown in figure 3 and the unemployment rate data is shown in figure 4.

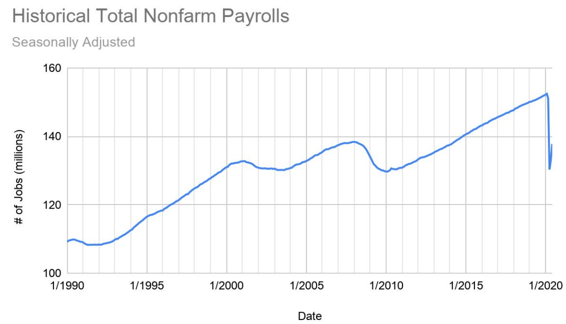

Figure 3.

Figure 4.

The total nonfarm payrolls and unemployment rate predictions used to make projections are sourced from The Financial Forecast Center and are seasonally adjusted. The predictions for total nonfarm payrolls are shown in Figure 5, and the predictions for unemployment rate are shown in Figure 6.

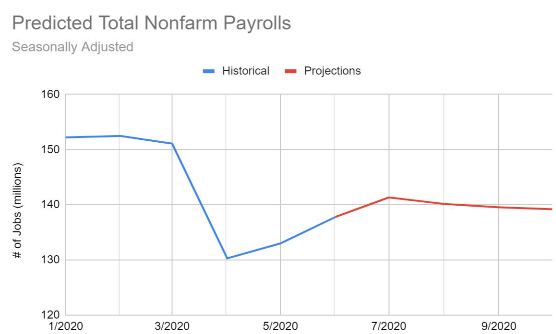

Figure 5.

[4] Initially we were also using the same supply side variables used by Ito and Lee, but decided to drop them because when we removed those variables from the model because we did not find any predictions for the supply side variables, which complicated making projections because we would have to come up with our own predictions for these variables to feed into the model. Additionally, when we removed these variables model accuracy did not decrease.

[5] Initially we were using total labor force instead of total nonfarm payrolls, however we switched over because we found that there were available predictions for total nonfarm payrolls and none for total labor force, and when switching over we did not find any noticeable changes in model accuracy.

[6] Although GDP is the standard for metric for determining the state of the economy, GDP data is only available on a quarterly basis and for our model we need monthly data.

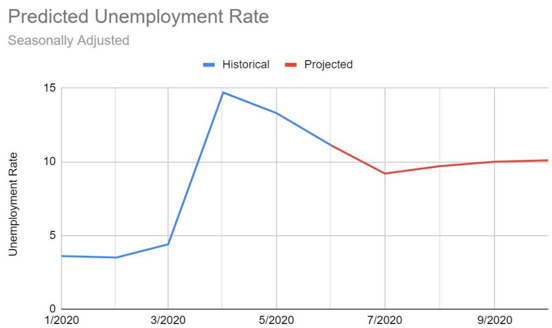

Figure 6.

Seasonal Features

Demand for air travel is heavily dependent on multiple seasonal factors. To capture these seasonal factors, the model uses 15 variables:

To account for monthly fluctuations in demand, the model uses 12 one hot encoded variables, each representing a separate month.

The Sunday after Thanksgiving generally results in a surge of air travel demand as people are flying back home from visiting their relatives. However, some years the Sunday after Thanksgiving falls in November and some years it falls in December. To account for this increase in demand, the model has two one hot encoded variables: one variable takes a value of 1 when it is November and the Sunday after Thanksgiving is in November, and the other takes a value of 1 when it is December and the Sunday after Thanksgiving is in December.

Since in leap years February has an extra day, this results in February during leap years having more relative demand than February when it is not a leap year. Because of this, we added a one hot encoded variable that takes the value of one when it is a February during leap year.

Industry Disruption Features

Although seasonal and economic variables are good indicators of the air travel industry, there are certain events that have caused a large decrease of demand that can not be solely explained by economic and seasonal factors. For this reason, the model has 6 variables to account for anomalies in demand. These variables are:

- A one hot encoded variable that takes a value of 1 during the Gulf War
- A one hot encoded variable that takes a value of 1 in September 2001
- A variable that represents the squared inverse[7] of the number of months elapsed since October 2001[8]
- A one hot encoded variable that takes a value of 1 during the Iraq War
- A one hot encoded variable that takes a value of 1 during the SARS outbreak
- A one hot encoded variable that takes a value of 1 during the Great Recession

Covid-19 Features

The covid-19 pandemic has brought unprecedented challenges to the air travel industry. Because it is unprecedented, it is hard to understand the relationship between the state of the pandemic and an increase or decrease in air travel demand. However, some patterns have been seen during the first few months of the pandemic, and thus the model attempts to capitalize on these patterns.

The first pattern that has been observed not only in the United States(A4A) but also in other regions of the world ((IATA, Eurocontrol), is that generally, as countries experience decreases in cases and deaths, air travel demand slowly recovers in a shape resembling that of a nike swoosh. For the model to determine the relationship between cases and deaths and a change in demand, the model is fed 3 variables: average daily deaths, estimated average new daily cases, and estimated average active cases[9]. The data for these three variables is sourced[10] from COVID-19 Projections, one of the models used by the CDC. Their model provides a lower, baseline, and upper range for their projections, which is where we get the pessimistic, baseline, and optimistic scenarios for our RPMs predictions from. The three scenarios for deaths, new cases, and active cases can be seen in Figure 1, Figure 2, and Figure 3 respectively.

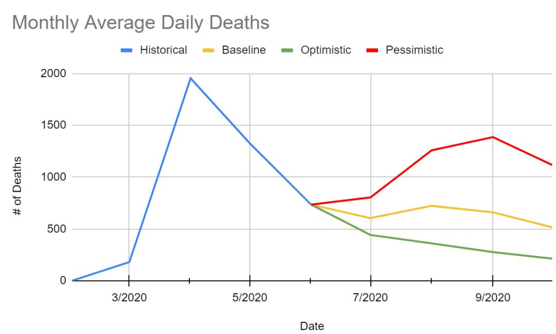

Figure 7.

[7] The variable uses an inverse square relationship because Ito and Lee found that this equation was a good estimation of the decay of the impact of 9/11 on air travel demand over time

[8] The variable starts counting from October and not September because there is already a variable accounting for the transitory shock that 9/11 had on air travel demand, and this variable accounts for the permanent downwards shift that 9/11 had on air travel demand.

[9] It is important to emphasize that these variables are the *estimated* average new daily cases and the *estimated* average active cases, not the actual cases that are being detected

[10] Data sourced on July 8th 2020

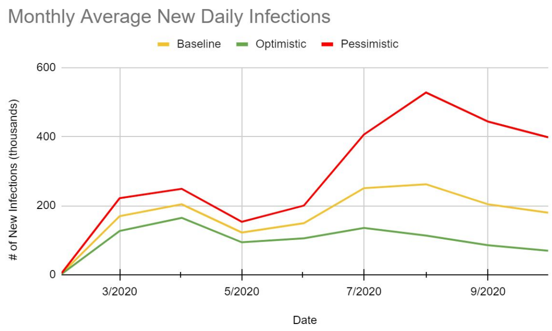

Figure 8.

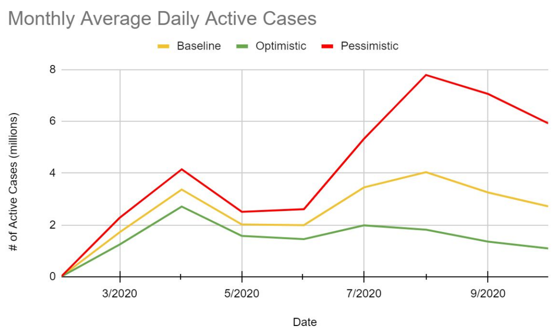

Figure 9.

The second pattern that has been observed is that as the pandemic drags on, people are becoming more willing to fly again (Destination Analysis, Longwoods International)[11]. To capture the duration of the pandemic factor for the model, we are using a variable that represents the inverse[12] of the number of months since April 2020[13].

Demand Label

The standard measure of passenger air travel is RPMs, which is the variable that the model is trying to predict. The RPMs data the model is trained on is sourced from the BTS T-100 Domestic Market Database. However this database, at the time the model was developed,had only released data up until March. To gather RPMs data for April, May, and June, we took the average year over year change in RPMs for each month from the A4A Covid Updates, and multiplied them by the corresponding month from 2019. As A4A don't publish the raw data, the values we came up with were only estimates. The RPMs data from January 1990 to June 2020 is displayed in Figure 10.

[11] Although results from both sources show that people are becoming less willing to travel again, it is not as bad as it was in April, even though in July we are experiencing more than 1.5 times the number of cases that were reported in April. The fact that we have more cases now yet more people are willing to travel now than were in April indicates that as the pandemic drags on people do become more willing to travel.

[12] We experimented with different rates of decay and found that modeling the time effect as an inverse relationship resulted in the best accuracy for the model

[13] We start counting from April 2020 because this was the month were people were the least willing to fly

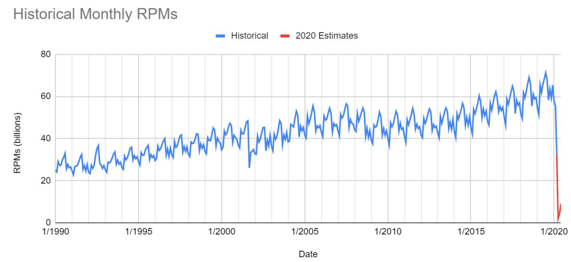

Figure 10.

Neural Network

The Artificial Neural Network used by the predictive model consists of 6 layers. In order, the number of nodes on each layer are 512, 512, 256, 128, 128, and 64. The neural network is a regression model, with 27 training features and RPMs as the label. The 27 training features consist of 20 one hot encoded variables and 7 other variables, as shown in Table 3. Like previously stated, the historical data ranges from January 1990 to June 2020, and the prediction data ranges from July 2020 to October 2020. Thus, there are a total of 373 historical and 4 prediction data points for each variable. Similarly, there are a total of 3737 historical data points for RPMs, and the model aims to make projections for the next 4 data points. The model is open source and the source code can be accessed here.

Variable Name	**Description**
Unemployment Rate$_t$	National unemployment rate at month t
Total Nonfarm Payrolls$_t$	Total nonfarm payrolls at month t
Covid-19 Deaths$_t$	Average daily covid-19 deaths at month t
Covid-19 New Cases$_t$	Estimated average new daily cases at month t
Covid-19 Active Cases$_t$	Estimated average active cases at month t
Covid-19 Elapsed$_t$	The inverse of the number of months elapsed since the April 2020 covid-19 peak (Covid-19 Elapsed$_{4/2020}$ = 1)
9/11 Elapsed$_t$	The squared inverse of the number of months elapsed since 9/11 (9/11 Elapsed$_{10/2001}$ = 1)
9/11$_t$	One hot encoded variable that takes

	a value of 1 if t is September 2001
Months$_t$	Vector of 12 one hot encoded variables that each represent a month and take a value of 1if t is that month and 0 otherwise
Thanksgiving 11$_t$	One hot encoded variable that takes a value of 1 if t is November and the Sunday after Thanksgiving is in November, and 0 otherwise
Thanksgiving 12$_t$	One hot encoded variable that takes a value of 1 if t is December and the Sunday after Thanksgiving is in December, and 0 otherwise
Leap February$_t$	One hot encoded variable that takes a value of 1 if t is February during a leap year, and 0 otherwise
Gulf War$_t$	One hot encoded variable taking a value of 1 from August 1990 to March 1991, and 0 otherwise
Iraq War$_t$	One hot encoded variable taking a value of 1 from February to April 2003, and 0 otherwise
SARS Outbreak$_t$	One hot encoded variable taking a value of 1 from March to July 2003, and 0 otherwise
Great Recession$_t$	One hot encoded variable taking a value of 1 from December 2007 to June 2009, and 0 otherwise
RPMs$_r$	Domestic RPMs at month t

Table 3.

Validation

In this section we will discuss the validity of the model and some possible pitfalls that affect the models' accuracy.

Model Performance

To validate the models' predictions, we will look at some metrics that measure how well the models perform when predicting historical data. Figure 11 displays the 3 different models' predictions and how they compare to historical data.

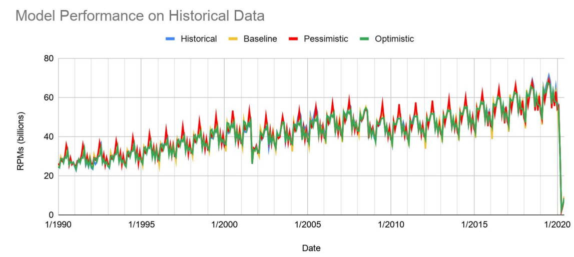

Figure 11.

As you can see, the models serve as pretty good predictors for historical data, including post-covid data. However, it is not enough to just visualize the performance. Table 4 shows different statistical metrics that measure how much the models vary from the historical data.

Model	MAE (billions)	RMSE (billions)	MAPE
Pessimistic	1.59	2.11	3.82%
Baseline	1.20	1.72	2.96%
Optimistic	1.37	1.85	3.31%
Average	1.39	2.89%	3.36%

Table 4.

As shown in table 4, the 3 models have a combined average absolute percentage error of 3.36% when compared to the historical data, which statistically speaking is pretty good. However, in the next section we will discuss some possible limitations of this model.

Limitations

Although the report statistically performs well on historical data, there are some possible limitations that should be taken into consideration when analyzing future projections.

Firstly, to make projections, the model requires predictions for both covid related metrics and economic metrics. Making predictions for those statistics falls out of the scope of this report, thus we rely on outside sources for predictions. Although we tried to choose the most credible predictions available, we can not fully guarantee that these predictions are accurate. Additionally, since we rely on outside sources for covid and economic predictions, we were only able to obtain 3 scenarios for covid data, thus we only use one scenario for economic predictions. This is obviously not the best way to make projections, because if covid cases rise then for example unemployment will drop, and vice versa, which is not taken into account when we are making projections. However, the economic predictions used are still good enough to provide some predictions that can give us an idea of what the few months may look like in terms of demand for air travel.

Additionally, since the covid-19 pandemic has only been around for 7 months at the time of writing this report, and has only really impacted US aviation for 4 months, that gives the model only four data points to train the covid related parameters. Furthermore, the model only takes into consideration 4 covid-related factors, meaning that there may be other underlying factors such as number of hospitalizations, average age of infection, number of states that are in quarantine, etc. that could potentially be affecting air travel demand. This combination of lack of available data and variables that are being used to train the model could mean that the model isn't able to accurately determine the relationship between the state of the pandemic and an increase or decrease in air travel demand.

The covid-19 pandemic has truly brought unprecedented circumstances to not only aviation but the world in general. These times are very unpredictable and conditions can change very rapidly without much warning. For this reason it is challenging to make predictions on what the future may look like. However, even though there are various limitations, the predictive models outlined in the report offer some valuable insight on what the outlook of air travel demand may look like in the coming months.

Appendix E: Counterfactual Reference Model

This appendix will rigorously discuss how the counterfactual model works, and go over the model's performance and some potential limitations. The purpose of the counterfactual model is to provide a reference for what air travel demand would have most likely looked liked had the covid-19 pandemic not occured

Methodology

The counterfactual model applies multiplicative decomposition to RPMs time series data. The multiplicative model decomposes the time series data into Trend, Seasonal, and Irregular components:

$RPMs_t = Trend_t \times Seasonal_t \times Irregular_t$ where $t = 0$ at 1/2014.

The model uses data from 1/2014 to 2/2020 because during this time period the trend of the data was nearly linear, making it ideal for modeling. The original times series data as well as the Trend, Seasonal, and Irregular components are shown in Figure 5, Figure 6, Figure 7, and Figure 8 respectively.

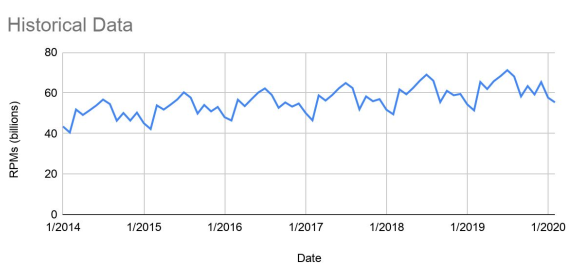

Figure 12.

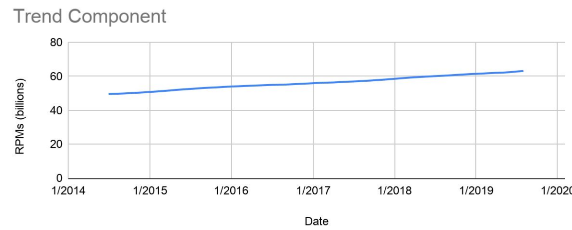

Figure 13.

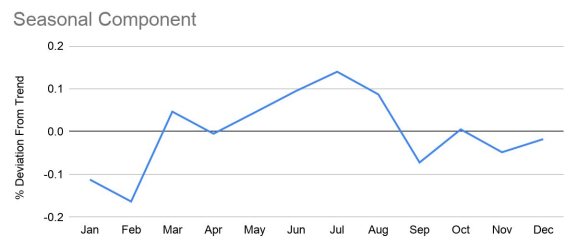

Figure 14.

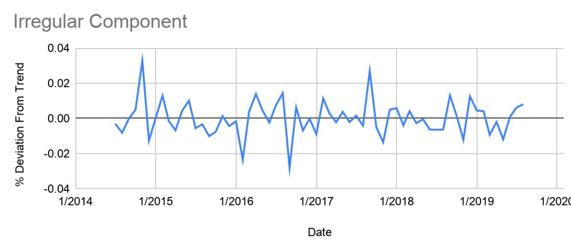

Figure 15.

The seasonal component is estimated by dividing the original time series data by its 12 month moving average, and then normalizing the results by averaging out the irregularities. The estimated times series components are shown in Table 11.

Month	**Seasonal**
January	0.8876499899
February	0.8363806616
March	1.046599498
April	0.9949147069
May	1.044533784
June	1.094736184
July	1.139857178
August	1.086907681
September	0.9276609336
October	1.00506463
November	0.9516411236
December	0.9822295287

Table 5.

Once the seasonal components are estimated, the times series data is deseasonalized by dividing it by the seasonal components. The trend is then estimated by fitting the results with a linear regression model. The resulting estimated trend equation is:

$Trend = 215744169.8t + 48237518346$, where $t = 0$ at 1/2014

Once the Trend and Seasonal components are estimated, the model makes predictions by multiplying the estimated Trend and Seasonal components together.

Validation

In this section we will discuss the validity of the model and some possible pitfalls that affect the models' accuracy.

Model Performance

To validate the models' predictions, we will look at some metrics that measure how well the models perform when predicting historical data. Figure 11 displays counterfactual model's predictions against the actual historical data.

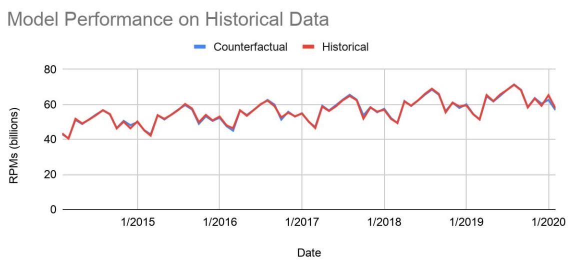

Figure 16.

As you can see, the counterfactual model serves as an excellent predictors for historical data, outperforming the predictive models. However, it is not enough to just visualize the performance. Table 4 shows different statistical metrics that measure how well the counterfactual model performs against historical data.

MAE (billions)	**RMSE (billions)**	**MAPE**
0.51	0.70	0.94%

Table 6.

References