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The Reinvention of Aviation: The Effects of Covid-19 on the Aviation Industry, and Actions Needed to Ensure its Future Success

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Abstract

This research project sought to develop short-term and long-term projections on the outlook of air transportation and to produce relevant recommendations for the direction of NASA aviation research as it adapts to the disrupted industry. We developed a model to estimate airline recovery trajectories, and researched the unique effects of the pandemic on various sectors of aviation. We found that the pandemic highlighted past flaws in the aviation system, creating widespread effects across the industry. As the industry looks towards recovery, we believe that it cannot simply return to 2019 operations, but instead perform a full reinvention to support long-term demand and prepare for future catastrophes. We recommend that NASA seize this opportunity to accelerate innovation through an increased focus on passenger satisfaction, meaningful steps towards sustainability, and significant collaboration with a diverse range of groups.

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. Our report consists of a “Setting the Stage” section, where 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), Later, we detail the projected changes each sector of the industry will undergo in future years along with a machine learning model to predict the outlook in “The Outlook of US Air Transportation”. 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.

Setting The Stage

Industry Overview

The United States air transportation system is large and complex, carrying a billion passengers in 2019 (BTS), more than any other country (ICAO). The aviation industry's economic impact is huge—combined with its connected sectors , civil air transportation represents approximately 5.2% of the US’s GDP, contributes around 1.8 trillion dollars in total economic activity, and supports 10.9 million jobs each year. (FAA). 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. Furthermore, 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.

The Covid-19 pandemic has already had massive consequences across the globe, greatly impacting the air transportation industry. Together, passenger fears of contracting the virus and the industry’s susceptibility to economic recessions have caused a massive decline in airline operations, with the US Travel Association calling this time the "Great Travel Depression”. Aircrafts have been grounded across the country, flights have been canceled, and many airlines have either temporarily or permanently laid off staff. We will discuss some of the effects of Covid-19 on a few main sectors of aviation below.

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). 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. Consequently, the aviation industry has been thriving for the past few years, reliant on strong passenger travel demand. However, this growth has been accompanied with some repercussions. US airports have become more crowded, planes increasingly 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 (Forbes). 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 continuously increased and in turn caused the passenger experience to decline over the years (BTS). 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 such as that of a deadly virus. Thus once the unprecedented pandemic struck, the crowded nature of air travel transformed from a typical hassle 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. The low demand levels for US airlines has generated a revenue loss of 91%, forcing regional airlines such as Miami Air International to file bankruptcy, hence, expanding the role of mainline carriers in air transportation. A survey from market research company, Destination Analysts, found that in early July, 37.3% of travelers reported they would not visit places that they typically would under normal circumstances, a significant 29.6% increase from just the previous week. Additionally, 47% remain concerned on the Covid-19 spikes, and 39% concerned on inadequate safety measures being taken (Destination Analysts). Longwoods International found that 76% of subjects have changed travel plans, with 59% of travelers hesitant to travel outside of their area (Longwoods International). 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 for considerable safety measures. With demand hitting new lows, the future survival of aviation as we know it remains uncertain.

Air Freight

Air freight, a key component of commercial aviation, is transported using designated freight aircraft and passenger aircraft. In 2019, US passenger aircraft transported 42.9 billion revenue tonne miles (RTMs), a slight increase of .2% from the previous year (FAA). Of this total, 16.2 billion RTMs were transported domestically while the remaining 26.2 billion RTMs were transported internationally, demonstrating the superiority of international trade in freight operations (FAA). E-commerce was a significant factor in this growth with consumers spending $601.75 billion online in 2019, a 14.95% increase from the previous year (US Department of Commerce). Additionally, a traditional pattern is seen through how freight operations rely much more on freight aircraft than 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, expressing the rising necessity for freight aircraft as the preferred method of transportation for goods (FAA). As a result, freight aircraft had expanded its role, accounting for 80.3% of freight RTMs and leaving passenger aircraft responsible for the remaining 19.7% of freight RTMs (FAA). This is due to the fact that passenger carriers are restricted considerably in freight capacity, safety accommodations, flight routes, and load factors, therefore allowing freight carriers to remain superior (Boeing).

Commercial aviation has traditionally relied on passenger travel for the majority of its profits. But while the aviation industry suffers from declining passenger demand as a result of the Covid-19 pandemic, a simultaneous rise in air freight operations has opened up new windows for profitability, reshaping traditional patterns. An Adobe report reveals that e-commerce has risen 77% from what it was last year, resulting in $82.5 billion of sales (Adobe). 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, encompassing an even vaster market with much more products and advertising that encourage further shopping. Additionally, the practice of buying goods online and picking up in-store has increased 195% from its levels in 2018, showing how Covid-19 has expanded the importance of e-commerce (Adobe). This major change has caused airlines to direct their sights on air freight in becoming a more significant source of profit. Delta has begun to operate freight flights every week that help deliver personal protective equipment while American Airlines has limited some of its airlines to offering freight-only services (Centre for Aviation). This has disrupted the traditional structure of commercial aviation, which relied much more heavily on passenger travel. With this unusual emphasis on air freight operations and 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. Growth in the market was driven by continuous investment and a demand for ride-hailing services. In 2017, UAM was expected to grow to a $8.2-$11.6 billion industry by 2027 (NASA). NASA has been working with over 250 private companies and universities to achieve their vision of UAM (NASA). From designing aircraft to propulsion, battery, and control systems, NASA has been crucial in the development of UAM. The Federal Aviation Administration (FAA) has also been a key partner, working on establishing a framework that allows for drone operation at low altitudes where FAA air traffic services are not available (FAA). The process is tedious, and functions are still under review.

Many innovations in both small and large UAM vehicles have been carried out in the private sector. International research and development of delivery drones and autonomous aerial vehicles (AAVs) has been in the works since 2014 (EHang). Since then, UAM vehicle capability has improved its capabilities to handle more weight and travel at increased speeds. Thousands of successful unmanned and manned flight tests have readied vehicles for commercial operation. Innovation in the industry ranges from reduced noise pollution to new fuel alternatives (Alakai).

Some barriers that the UAM industry faces are "significant legal, regulatory, infrastructure and weather constraints, along with concerns about public perception related to noise, pollution and safety"(NASA). A five-seat eVTOL could cost around $6.25 per passenger miles, significantly more expensive than current ride hailing services (NASA). Better electricity efficiency can lower prices by 60%, however, work is needed on current technology to get to this point.

Although UAM is not expected to have a market until 2028, delivery drones have seen massive success during the pandemic, suggesting that market could become viable before then (NASA). In the US and abroad, delivery drone companies have seen an increase in demand driven by customers' desire to have their packages be delivered without human contact as fears of contracting Covid-19 sweep the globe. Substantial financial growth has followed the demand (EHang). 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 (WIRED). Companies who are working on UAM on the side are likely to divert funding away from those programs to save their core business. So far, NASA and the private sector continued their UAM development. The pandemic has allowed for the continuation of many UAM operations, but many are unable to perform research and development activities.

Manufacturing

Commercial aircraft manufacturing is key to US aviation success, and was even the US's largest net export in 2016 (FAA). 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).

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 widely introducing a flight control software without proper instruction (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).

Similarly, Airbus was struggling to receive demand, and announced in February of 2019 that they would cease the production of its wide-body A380 - the manufacturer's largest aircraft, with the capacity to seat more than 850 passengers - after minimal A380 orders.(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 (CNN). Hexcel and GE lost significant revenue after the grounding of the 737 MAX.

The problems the aviation manufacturing industry faced prior to 2020 have intensified during the Covid-19 pandemic. In March, after the Covid-19 spread to the US, Boeing shut down production in multiple facilities for nearly 1.5 months (CNBC). During this period, Boeing lost revenue on approximately thirteen to fifteen 787 Dreamliners, equivalent to $2.36 billion in revenue. It is estimated that Boeing will need to reduce production for the remaining quarters of 2020 to satisfy demand (Boeing). Boeing's first quarter report for 2020 shows that revenues dropped a total of 26% compared to the first quarter of 2019 (Boeing). 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.

Spirit Aerosystems was directed by Boeing to pause all production of current and future 737 MAX shipsets this June (Leeham). 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).

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).

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.

(FAA) 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, with its yearly growth in 2019 surpassing that of any other year in the past 2 decades. (FAA) 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. (FAA). 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, 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, FAA Tower List) 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) This shift to remote air traffic management makes us consider the need for air traffic controllers beyond the pandemic, as air traffic management has become increasingly automated and will continue to do so in upcoming years.

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).

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, working to regain 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 (NY Times).

The outlook of US air transportation

Model

Introduction

Throughout our research, two questions frequently came to mind: *to what extent has Covid-19 impacted domestic air travel demand,* and *what is the expected outlook for air travel demand in the coming months* To answer these questions, we developed two models. The first model is a predictive model that implements an artificial neural network to project domestic air travel demand, represented by Revenue Passenger Miles (RPMs)[1]. The second 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 predictive model 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[3] after training the models are displayed in Figure 1. To see the exact predictions, and view more information on the performance of the models and some potential limitations, read the Results and Validation sections of Appendix B for the predictive model and of Appendix C for the counterfactual model. For the purposes of this section however, we will only discuss the results of the models. Figure 2 displays the percent change of the actual[4] post Covid-19 RPMs as well as the projected RPMs in comparison to the counterfactual reference model. The exact percentages can also be found in the corresponding appendices mentioned previously.

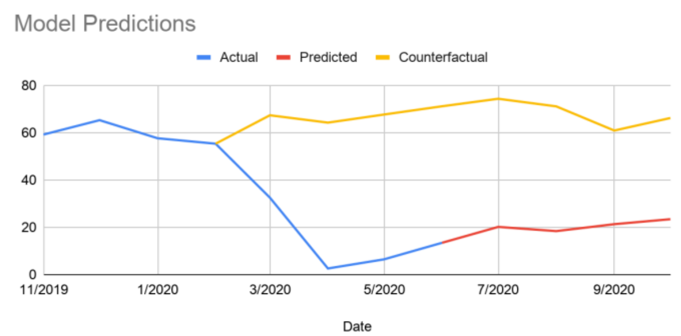

Figure 1 Model Predictions.

[1] To view the full methodologies read the methodology section of Appendix B

[2] To view the full methodology of the counterfactual model view the methodology section of Appendix C

[3] The projections shown were made using data from August 1st, for the latest projections visit our website.

[4] RPMs data for May and June are estimated from year over year percent change in onboard passengers given by A4A in their Covid-19 updates

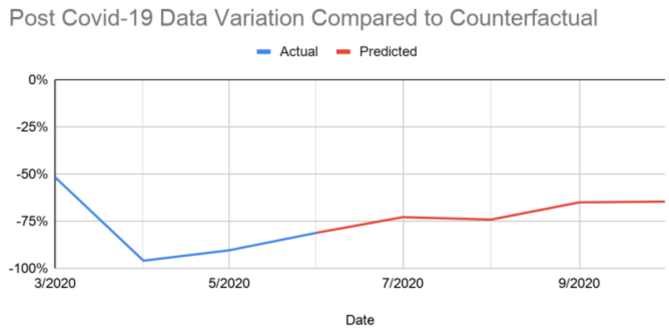

Figure 2 Percent decrease in post-Covid data and projections in comparison to counterfactual reference.

Discussion

In this section we will analyze the projections made by our model. As seen in Figure 1, the model is predicting recovery in demand through July, but as the consequences from the summer peak in cases and deaths become more evident, demand is predicted to dip again in August. However, once we surpass the summer wave, demand recovery is expected to pick back up, although at a slower pace than before.

The Covid-19 pandemic has already resulted in unprecedented blows to the air travel industry. At its worst, demand was down 96.79% compared to what it would have been had the pandemic not occurred. The pandemic has brought a lot of uncertainty to the industry, and we hope that this model provides some guidance regarding 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 our model projections with that of other industry experts.

Industry Overview

As indicated in the discussion of our model, 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. A variety of factors will affect the recovery of air transportation, including economic stability, the state of the virus, 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.

Past crises have greatly impacted the state of aviation operations, with 9/11 leading to the addition of airport security and the Great Recession altering airline business models[5]. The Covid-19 pandemic 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. 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. In order to determine the specific impacts 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 (National Center for Biotechnology Information). However business travel demand will be reduced to a large extent as many conferences and meetings have been cancelled. Due to the formation of strict travel bans across the globe, long haul flights are no longer occurring and with the new norm of social distancing, conferences and exhibitions will take much longer to return. This has caused millions of companies and employees to adapt to working from home, an experience that will only improve as advanced collaborative online platforms are developed. Travel budget cuts and cancelled bookings have further contributed to the lag in air travel recovery, causing businesses to restructure their interactions through preparing for regular use of virtual platforms, already having invested in various online workplace mechanisms. As these platforms innovate to better suit business needs, business travel will see reduced demand in the long term therefore threatening airlines as they rely extensively 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 (Reuters). Leisure travel will recover faster than business travel, as more people will choose to travel once airlines make the necessary additions to rebuild the people's trust in air travel. However, leisure travel will continue to 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 from

[5] To better understand the effects of 9/11 and the Great Recession on the aviation industry, see Appendix A

expensive beach trips to more affordable locations such as in Southern Europe or North Africa (National Center for Biotechnology Information). 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 and technologies. Recently, the US government devised a new standard, Runway to Recovery, to help airlines adapt to the current circumstances by mitigating public health risks and with strict compliance from airlines, recovery will become a much clearer path (Department of Transportation). 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 that have distinguished this use of air travel. This is seen in the increasing reliance on passenger aircraft as a mechanism of freight transport instead of the typical freight aircraft. However, this shift will not be long term as passenger travel demand will return once a functional vaccine is created, causing aircraft to revert 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 flexibility within 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 prepare itself for a successful future.

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 (NASA). 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 appear to be preferable to ridesharing. Riding in a car allows for human error, safety concerns, traffic, pollution, and 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. Because current ride sharing services are readily accessible through mobile apps and offer instant services, it is of best interest to replicate that system with autonomous vehicles(EHang). As we've seen with many private sector developers, 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 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 (McKinsey Analytics). Significant efforts are needed to alter public acceptance of UAM, however, as people currently prefer pilots to autonomous flight, even if the autonomous ride is cheaper than manned flight (NASA- UAM Market Study).

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 (EHang). Approval from local governments such as the FAA are needed. The FAA already 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. Large aviation manufacturers have these systems in place, and it would make sense for UAM developers to mirror them. 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.

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" (NPR). Once the turmoil in the airline industry does stabilize, Calhoun says "the commercial market will be smaller, and our customers' needs will be different."

Despite setbacks, the demand for increasingly more efficient aircraft is growing. 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 (CNBC). 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 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 (Forbes). 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. Working with NASA should be a priority, as they have produced safe and efficient technology used in every control tower and airplane in the US. 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. Working with NASA could reduce the risk of producing faulty innovation, and ultimately accelerate its process. Innovation is crucial now more than ever. In order to recover from the financial crisis the Covid-19 pandemic has caused, manufacturers will need to expand their market to produce cost efficient, reconfigurable aircraft that are appealing to airlines. 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. Partnering with NASA will also be crucial to ensure the industry is on the same page regarding safety and 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). 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) 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). 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). 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) 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. (CO2 Emissions) 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) 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.

Recommendations for NASA’s Aviation Research

From the model and the research analyses of different sectors of aviation, it is clear that Covid-19 has created significant changes across the board that will continue beyond 2020, affecting the state of the industry even 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 air travel demand will likely stall through the fall, and external sources state that the industry recovery will take from 2 to 4 years. This is significant as prior to the crippling pandemic, the aviation industry appeared to be unquestionably strong. Demand continuously grew, fueling airlines' revenues and establishing consumer confidence in air travel. However, this stability was merely a facade for the industry as it has been able to conceal deep-rooted flaws within its convoluted system, resulting in a grossly unsatisfactory passenger experience and blatant disregard for sustainable technologies. This is facilitated by the dreadfully slow growth in innovation among manufacturers, necessitating the use of outdated carriers and hindering efficient and sustainable aircraft from becoming a reality in aviation systems. When considering these factors, it is evident that the industry had, essentially, been set up to fail in the situation of a deadly virus. As a result, its flawed nature combined with the pandemic has entirely reversed the notion of air travel, remolding it from a reliable source of transportation to a deadly threat on countless lives around the world. This failure to guarantee passenger well-being has fostered severe distrust and suspicion in air travel, deterring levels of demand. All in all, the irreversible devastation that has resulted from the weaknesses in the industry could have been greatly reduced had there been a better system in the first place. However, this pandemic has helped to unveil these major faults in aviation, therefore acting as not only a menace but a lesson; an opportunity for the aviation industry to introspect and make fundamental changes, sparking a period of reinvention that drives the industry to go beyond its previous state and truly flourish. While airlines wish to swiftly recover, this is simply not the solution as sticking temporary band-aid fixes over gaping wounds would only be more detrimental to the long-term survival of the industry. Hence, recovery for aviation is not merely a restoration of demand from before the pandemic- it is worthwhile reinvention of the current systems to support long-term demand and prevent the destructive effects of future catastrophes. Accelerated innovation is key to addressing the industry's flaws and the pandemic's irreversible changes, thus ensuring this transformation. Without changes in the industry's traditional structures and prioritization, we cannot reshape aviation and thus, cannot guarantee true, lasting recovery. So as we stand at this inflection point, it becomes of paramount importance that NASA seizes this opportunity to expedite innovation through an increased focus on passenger satisfaction, meaningful steps towards sustainability, and significant collaboration with a diverse range of groups.

Passenger Satisfaction

Passenger satisfaction is absolutely crucial in fostering demand for air travel and therefore, must be prioritized in order to support the recovery of the industry. Passengers have been dissatisfied about a variety of factors for years, with the Covid-19 pandemic only worsening the issue by revealing the lack of health assurances when flying. To ensure future profits and a stable recovery, NASA must focus its efforts on accelerating technologies needed for building fast and convenient air travel systems in order to improve passenger satisfaction.

NASA must invest in passenger health and welfare technologies to ensure that air travel is safe and profitable. The industry's traditional prioritization of profitability has forced aviation systems to encourage congestion on flights, exacerbating the passenger experience. The overwhelming system has led to flight cancellations, overbookings, insanitation, and excessive crowding which have transformed from occasional and even embarrassing failures to typical issues associated with air travel. Additionally, Covid-19 has created new safety standards, as passengers are now concerned with human contact, airflow, and other health demands. 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, and cleaning technologies are being researched and implemented that will reduce the risk of future infection, providing a potential market for ecoDemonstrator's self cleaning aircraft lavatories. 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 stability.

Developing an efficient 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 - irritations that have snowballed into threats on human health since the Covid-19 pandemic began. Passengers have always desired efficient travel journeys, from streamlined airport experiences to shorter flights, but Covid-19 has put an even greater emphasis on efficiency, as passengers wish 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) - 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 develop and 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 efficient air travel 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. The industry had been able to justify the enormous environmental impact of aviation prior to 2020 as operations grew and revenue increased. However, as the industry restructures after the mass disruption of Covid-19, this is an opportunity for aviation to finally prioritize the reduction of its massive environmental impact.

Aviation demand will return from the deficit of Covid-19 with time, and without any drastic measures, the industry will continue to increase its emissions. To make matters worse, the industry is expected to experience a mass increase in aviation operations as the market for nontraditional aircraft like UAM expands. NASA must work to guarantee the responsible integration of UAM, both in sustainable technology development and conscious operations, in order to avoid a further increase in industry emissions. Overall, NASA must take bold strides to develop technology - both mechanical and operational improvements - that will reduce the environmental impact of current aviation systems before the imminent climate crisis disrupts the aviation industry as Covid-19 has done.

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 (IATA). To achieve large scale, long term reductions in CO_2 emissions, NASA must accelerate the development of revolutionary aircraft technologies, investing large amounts in nonconventional airframe configurations, revolutionary aircraft structure and materials, various propulsion systems and more to ensure that decarbonized aviation becomes a reality before it is simply too late.

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. The agency must also 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, detrimental to sustainability missions and the health of the environment. However innovative efforts have helped address this as seen with the NASA X-59 aircraft which aims to "reduce sonic booms to a quiet thump" (NASA), and Aerion Supersonic which has committed to carbon neutrality (Aerion). NASA must narrow its focus on this path of producing fast, sustainable aircraft that create a positive passenger experience, and aircraft that compromise the environment and contradict NASA's sustainability mission should not be developed. This will ensure clarity in sustainability goals and meaningful use of NASA's resources, allowing for stronger steps to be taken in fuel efficiency as well as reallocation of funds towards relevant projects that better support the massive industry reinvention.

Collaboration

In order to successfully restructure after the Covid-19 pandemic and achieve the aforementioned goals relating to passenger satisfaction and sustainability, the aviation industry must have an "all hands on deck" mindset, as collaboration is crucial to accelerating innovation. NASA must provide a platform for both traditional and nontraditional aerospace groups (startups, tech companies, etc) to clearly establish the collective mission to reinvent aviation. Strong partnerships between the private, public, and academic sectors will allow NASA to innovate more than they could on their own, accelerating the overall innovation process, which is crucial as the industry strives to restructure and adapt to its new disrupted state. As seen with past programs such as the ecoDemonstrator, these collaborative projects foster innovation, pushing contributors to innovate and work towards a common goal. In addition, the ecoDemonstrator tests a variety of technologies 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. The innovation cycle of the aviation industry is notoriously slow, and due to the pressing nature of climate change and possibility of future pandemics, NASA cannot afford to continue with this slow pace in developing crucial technology. However, the industry must also continue to prioritize safety, as past attempts by Boeing and the traditional aviation manufacturers to innovate quickly have been destructive - the Boeing 737 Max crashes were largely attributed to the rushed development and implementation of new features. Unlike the historically slow innovation rate of traditional aviation groups, tech companies and startups are developing new technologies much quicker, from Google Wing and Amazon.com's drone delivery services to Uber Elevate, Lilium and EHang's air taxi programs, with more nontraditional contributors entering the aviation field each year. As a global influence, NASA must step up during this pressing pandemic and combine disjointed efforts to create a strong holistic approach. Broadening collaboration will empower other aviation partners to work together and strengthen the industry's reinvention.

Conclusion

The Covid-19 pandemic completely disrupted the aviation industry, creating a period of great fear and uncertainty, but also offering an unusual opportunity for the industry to restructure and adapt to the ever-changing future. We have outlined the widespread changes the various sectors of aviation may undergo in coming years, and have proposed bold efforts for NASA to tackle as the agency leads the industry towards a large-scale reinvention. Despite it being a massive challenge requiring intensive efforts in innovation, this drastic directional shift towards passenger satisfaction and sustainability will prepare aviation in the case of future pandemics and ensure the industry's long term stability as the state of the globe greatly changes in coming years. By empowering other groups through collaborative efforts, NASA will be able to amplify current missions and create lasting solutions. We recognize that our recommendations will have restrictions as NASA has limited funding and thus, the emphasis on passenger satisfaction and sustainability will shift efforts from other important projects or provide little impact. We also acknowledge the restraints of our claims to accelerate innovation due to the necessary and tedious approval process for new technologies to enter the market. Disagreement among authorities in developing and implementing such technologies is bound to occur. However by narrowing the focus on passengers and the environment, we hope to better direct NASA to investing in projects that address the pressing, widespread impacts of the pandemic and of the industry itself. Reinvention has been long overdue for aviation and with the unique opportunity Covid-19 has offered, these recommendations remain essential. Looking forward, the future of aviation appears hopeful. With the emergence of nontraditional aviation systems like UAM, sustainable aircrafts, and more, we can expect greater inspirational developments like the ones NASA aeronautics has delivered for decades. Through reinventing the aviation industry, we aspire to echo the core ambitions of NASA reflected in their missions, and ensure a bright, everlasting future for aviation.

Appendix A: 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 B: Predictive Model

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

Methodology

As previously stated in the report, the predictive model implements an artificial neural network. The network is trained on various economic, seasonal, and Covid-19 historical data[6], and it also takes into account several major events that have disrupted the air industry. The model then makes predictions by feeding it 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 our predictive model and the analytical model developed by Ito and Lee.

[6] 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.

Data

In this section we will go over the data that is used to train and make predictions with the neural network. The data that is used to train the model is monthly and spans from January 1990 to June 2020, with our validation dataset spanning from January 1986 to December 1989. 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[7] and the monthly unemployment rate[8]. Historical total nonfarm payrolls and unemployment data are sourced from the BLS, with both being seasonally adjusted ([BLS], [BLS]). The total nonfarm payrolls data is shown in Figure 3 and the unemployment rate data is shown in Figure 4.

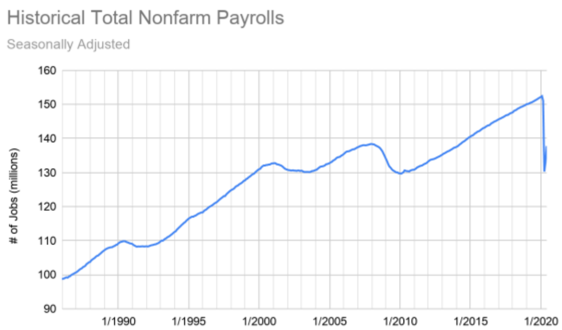

Figure 3.

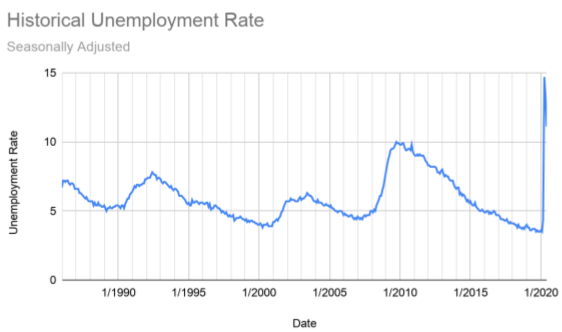

Figure 4.

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

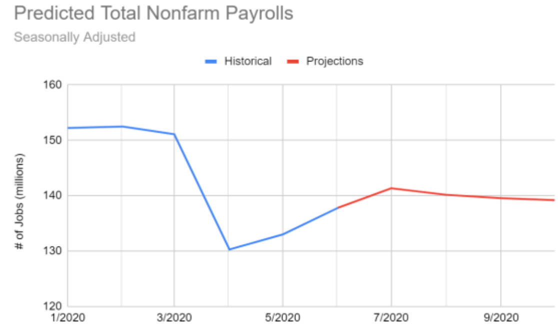

Figure 5.

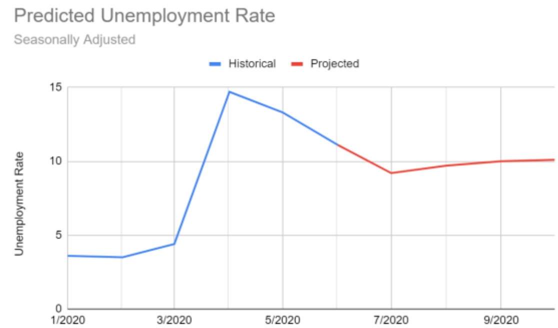

Figure 6.

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 surge 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

[7] 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.

[8] 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.

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[9] of the number of months elapsed since October 2001[10]
- 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”. After experimenting with a combination of new cases, active cases, and deaths, we found that the best covid-19 predictor for demand turned out to be solely deaths. Historical deaths and projected deaths are sourced[11] from Covid-19 Projections, one of the models used by the CDC. The historical and projected deaths can be seen in Figure 7.

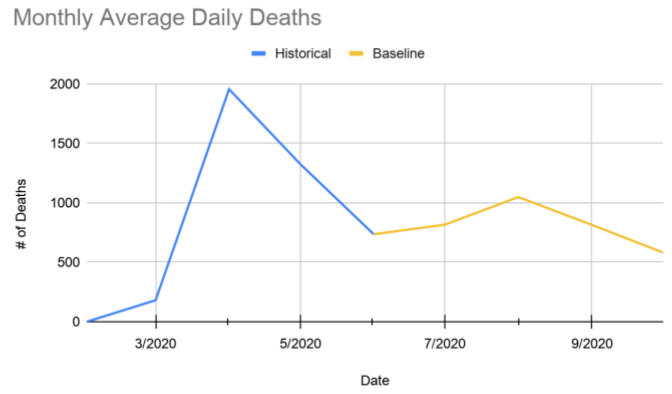

Figure 7.

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)[12]. To capture the duration of the pandemic factor for the model, we are using a variable that represents the inverse[13] of the number of months since April 2020[14].

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. The validation data is sourced from the BTS T-1 U.S. Air Carrier Traffic And Capacity Summary by Service Class database. However the BTS, at the time the data was sourced[15], had only released data up until April. To gather RPMs data for May and June, we took the average year over year change in domestic onboard passengers for each month from the A4A Covid Updates, and multiplied them by the corresponding month from 2019. As A4A doesn't publish the raw data, the values we came up with were only estimates. The RPMs data from January 1986 to June 2020 is displayed in Figure 8.

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[9] 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

[10] 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.

[11] Data sourced on August 1st 2020

[12] 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.

[13] 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

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

[15] Data sourced on August 1st

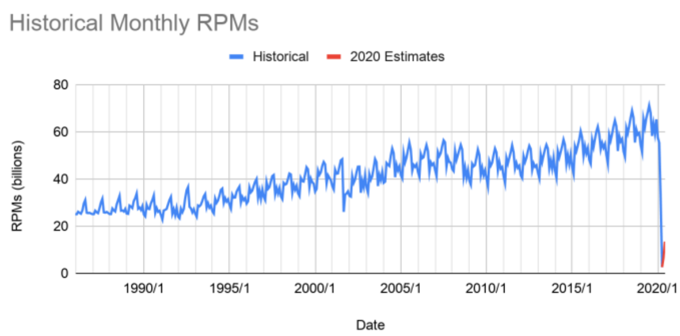

Figure 8.

Neural Network

The Artificial Neural Network used by the predictive model consists of a 6 layer Tensorflow sequential model. 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 25 training features and RPMs as the label. The 25 training features consist of 20 one hot encoded variables and 5 other variables, as shown in Table 1. Like previously stated, the training data ranges from January 1990 to June 2020, the validation data from January 1986 to December 1989, and the prediction data ranges from July 2020 to October 2020. Thus, there are a total of 373 training, 48 validation, and 4 prediction data points for each variable. Similarly, there are a total of 373 training data points for RPMs, 48 validation data points, 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 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 Nov$_t$	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 Dec$_t$	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 Recession$_t$	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 1.

Results

The results displayed in Table 1 and Table 2 were predicted on August 1st. To see our latest predictions check out our website at andres-carranza.github.io

Date	**Projections**	**Counterfactual**
3/2020		67420192977

4/2020		64305392035
5/2020		67737827247
6/2020		71229626797
7/2020	20156528684	74411367247
8/2020	18373392181	71189248837
9/2020	21307727926	60959193777
10/2020	23422241581	66262443952

Table 2 Model Predictions (RPMs).

Date	Actual	Projections
3/2020	-51.74069365%	
4/2020	-96.0201891%	
5/2020	-90.5104555%	
6/2020	-81.14238869%	
7/2020		-72.9120302%
8/2020		-74.19077672%
9/2020		-65.04591579%
10/2020		-64.65231256%

Table 3 Percent decrease in post-Covid data and projections in comparison to counterfactual reference.

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 against the training and validation data. Figure 9 displays the model's predictions and how they compare to the training data, and Figure 10 displays the model's predictions and how they compare to the validation data.

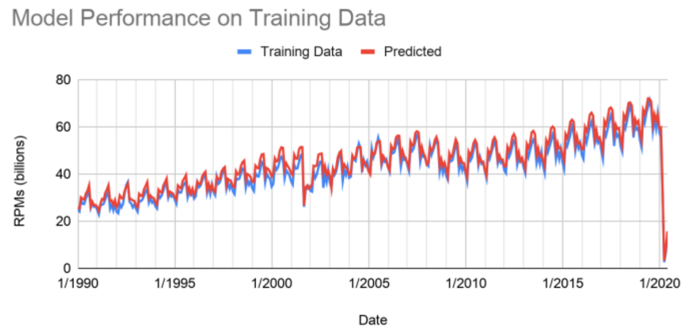

Figure 9.

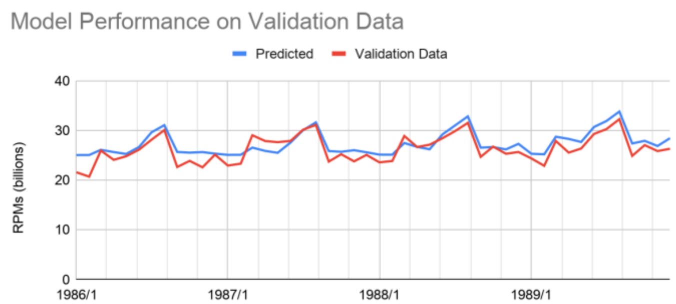

Figure 10

Table 4 shows different statistical metrics that measure how much the model's predictions vary from the training and validation data.

Metric	Training Data	Validation Data
MAE (billions)	2.279788391	1.457299342
RMSE (billions)	2.607675508	1.735815553
MAPE	5.579404943%	5.81419392%

Table 4.

Limitations

Although the model 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 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 two covid-related features, 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 that are not being accounted for. 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 model outlined in the report offers some valuable insight on what the outlook of air travel demand may look like in the coming months.

Appendix C: 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 13, Figure 14, Figure 15, and Figure 16 respectively.

Figure 12.

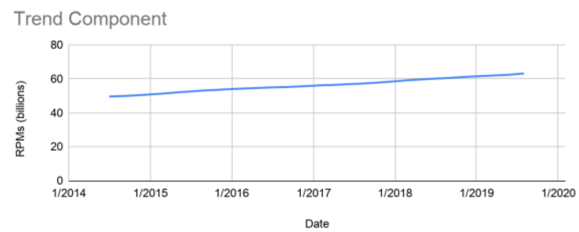

Figure 13.

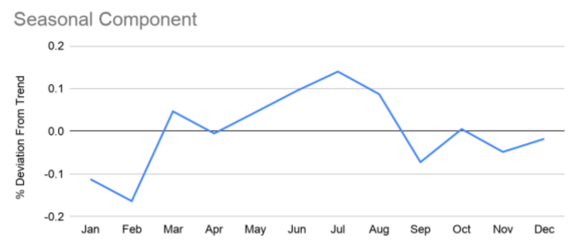

Figure 14.

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 5.

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 16 displays counterfactual model's predictions against the actual historical data.

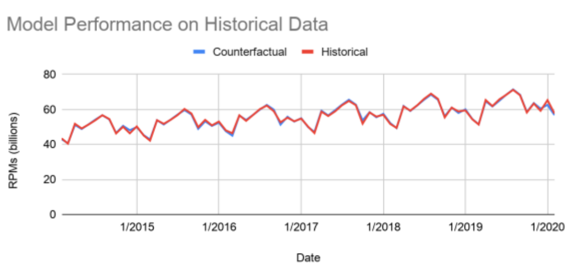

Figure 16.

As you can see, the counterfactual model serves as an excellent predictors for historical data, outperforming the predictive model. However, it is not enough to just visualize the performance. Table 6 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.

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