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An Overview and Analysis of the Impacts of Extreme Heat on the Aviation Industry

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1. Introduction

There are many issues that can lead to a delayed or cancelled flight: maintenance problem, scheduling issue, late aircraft arrival, security threat, heavy air traffic, etc. However, one of the most common causes is weather. From heavy fog, to convective weather, to snowstorms, there are many ways Mother Nature can cause headaches within the travel industry. While there has been a gradual downwards trend in the percentage impact of weather on total delay minutes, it remains a significant cause of the overall delay minutes – above 30% in 2016.[1]

Within the first couple of days of 2018, the bomb cyclone resulting from Winter Storm Grayson wreaked havoc on transportation along the Eastern United States, resulting in thousands of cancelled flights. This incident is just one of countless examples of how weather has impacted airlines. Likewise, this incident is just one of many examples of the type of weather people associate with airline delays and cancellations. Interestingly, the exact opposite of winter weather can cause similar issues. Heat alone – no fog, haze, or thunderstorms required – can be enough to significantly affect airline operations.

As global temperatures rise and extreme weather conditions become more common, how will incidents of extreme heat affect the future of both the airline and aerospace industries? Furthermore, what are some ways to help mitigate the effects of extreme heat on aviation? The purpose of this research is to examine how heat affects both small and large aircraft and to explore potential solutions that can mitigate the negative effects of heat on aviation.

2. The Effect of Heat on Airline Operations: The Phoenix Case Study

On Tuesday, June 20, 2017, temperatures sweltered at the Phoenix Sky Harbor International Airport (PHX) in Arizona, close to the record high of 122 degrees Fahrenheit. Table 1 outlines the temperature timeline of this day.

Canadair Regional Jets (CRJs), manufactured by Bombardier, have a maximum operating temperature of 118 degrees Fahrenheit. However, for four hours, temperatures at PHX remained at or above 118 degrees, reaching their peak at 118.9°F at 15:51. The actual temperature on the tarmac was likely even higher than the reported temperatures because of the sun reflecting off the land mass of concrete. In response to these extreme temperatures, a significant number of flights were cancelled – the vast majority of which were scheduled to fly with the CRJ.

masFlight is a data analytics platform and has completed extensive research outlining airline cancellation costs and the subsequent passenger disruption. By their numbers, the cost of all the cancelled flights on June 20 was approximately $26,250. But the events on that day go beyond costs. Time and effort had to be spent to rebook a large number of passengers (by masFlight's numbers, 1,000 passengers needed to be rebooked).[4] Rebooking can significantly inconvenience passengers through longer travel times and additional flight legs. Furthermore, the airline must figure out how they can position their current, available fleet to best deal with the cancellations and avoid any subsequent cancellations or delays. This problem is exacerbated by regional aircraft because they operate more daily flights on average than other types of aircraft.

PHX on June 20, 2017		
Time	**Temperature**	**Cancellations**
09:51	104.0 °F	
10:51	108.0 °F	
11:51	108.0 °F	
12:51	111.9 °F	2
13:51	116.1 °F	1
14:51	118.0 °F	5
15:51	118.9 °F	6
16:51	118.0 °F	2
17:51	118.0 °F	3
18:51	117.0 °F	5
** No Temperature Data for 19:51 **		
20:51	109.0 °F	1
21:51	105.1 °F	

Table 1.
(Sources: Weather Underground[2] & Bureau of Transportation[3])

Although the incident in Phoenix might be considered more of an isolated incident, it is important to study and understand it to be better prepared for future incidents. According to Coffel, Thompson, and Horton, "global mean surface temperatures have increased approximately one degree Celsius above pre-industrial levels, with most of that change occurring after 1980."[5] As urban heat islands increase and global temperatures rise, extreme weather becomes more frequent, and the likelihood of an event similar to that day at PHX occurring is probable. For example, McCarran International Airport (LAS) in Las Vegas, Nevada has experienced similar conditions and disruptions to PHX.

Because of their ability to service smaller markets with a higher frequency, the use of regional jets has significantly increased. Brueckner and Pai found that the number of regional jet routes grew from 6 in 1990 to 1,091 in 2005,[6] and this growth is expected only to increase. The Federal Aviation Administration forecasts the number of jets in regional carrier fleets to increase from 1,637 in 2016 to 1,828 in 2037.[7] As this number continues to grow, more flights are susceptible to heat cancellations.

3. Not Just Regional – How Heat Significantly Affects Large Aircraft: Part I

While the discussion so far has focused on regional aircraft, it is important to understand that heat also significantly impacts non-regional aircraft. Understanding why and how is vital, especially since non-regional jets make up the majority percentage of the US carrier fleet and are expected to increase in number in the future.[7] Larger narrow-body and wide-body aircraft have higher operating temperatures, so they are probably not going to be cancelled due to temperatures exceeding their overall temperature limitation. However, thousands, if not tens of thousands, of flights each year are subjected to weight restrictions resulting from high temperatures. Every plane has a maximum takeoff weight, but very frequently, they are subject to additional weight restrictions for a variety of reasons such as the length of runways, the altitude of the airport, and the temperature.

As temperatures heat up, air becomes less dense and the airport's effective density altitude increases, which decreases aircraft performance and the ability to generate lift because air molecules are spread further apart in hot weather. Even though PHX is 1,134.6 feet above sea level, on June 20, 2017 at 15:51, planes departing Phoenix took off as though they were already at an elevation of approximately 5,707.96 feet (an increase of 4,233.36 feet). This increase means the effective maximum takeoff weight of the aircraft is decreased.

Airline operations and strategy must account for these weight restrictions and frequently have to deal with them same-day by denying boarding to a certain number of passengers. Weight restrictions can lead to less cargo and passenger revenue for the airline, passenger disruptions, and departure delays.

4. Phoenix Case Study Continued

Now that we've established that heat affects larger aircraft in the form of weight restrictions, let us take another look at Phoenix Sky Harbor International Airport the day of June 20, 2017. According to information from Boeing, Boeing 737s at PHX are subject to a 1,000 lb. (454kg) weight reduction at 38°C (100.4°F) and a 10,000 lb. (4536kg) weight reduction at 47°C (116.6°F).[8] Cross-referencing temperature data from Weather Underground and flight data from the Bureau of Transportation, we can see in Table 2 that a total of 122 Boeing 737 flights departed PHX subject to weight restrictions that day. Some of the planes might not have been realistically affected for a variety of reasons. The plane might not have had a high load factor, or the flight route could have been relatively short. However, it is safe to assume that some of the aircraft were forced to deal with the weight restriction.

Of the 122 weight restricted flights, 52 flights departed 15 minutes or more past their scheduled time (flights with a late aircraft delay equal to their departure delay were factored out of this calculation). One possible cause of delay is dealing with a larger number of passengers than the plane can effectively depart with. This should not suggest the assumption that all 52 delays were caused because of heat, but it is highly likely that a number of the aircraft were delayed because the weight restrictions resulted in the airline having to deal with the subsequent obstacle of handling an over-capacity of passengers.

Number of Affected PHX Boeing 737 Flights on 6/20/2017			
Time	Temperature	1,000 lb reductions	10,000 lb reductions
09:51	104.0 °F	15	
10:51	108.0 °F	10	
11:51	108.0 °F	9	
12:51	111.9 °F	12	
13:51	116.1 °F	4	
14:51	118.0 °F		11
15:51	118.9 °F		7
16:51	118.0 °F		4
17:51	118.0 °F		8
18:51	117.0 °F		19
** No Temperature Data for 19:51 **			
20:51	109.0 °F	17	
21:51	105.1 °F	4	
22:51	102.9 °F	2	

Table 2.

(Sources: Weather Underground[2] & Bureau of Transportation[3])

5. How Heat Significantly Affects Large Aircraft: Part II

Some studies have begun to analyze the current effects and to predict the future of how climate change will affect airline operations. As mean temperatures continue to rise, so will the number of weight restricted flights. Coffel and Horton describe:

"For a given runway length, airport elevation, and aircraft type, there is a temperature threshold above which the airplane cannot take off at its maximum weight and thus must be weight restricted. The number of summer days necessitating weight restriction has increased since 1980 along with the observed increase in surface temperature… These changes will negatively affect aircraft performance, leading to increased weight restrictions, especially at airports with short runways and little room to expand. For a Boeing 737-800 aircraft, it was found that the number of weight-restriction days between May and September will increase by 50%-200% at four major airports in the United States by 2050-70 under the RCP8.5 emissions scenario." (p. 94)[8]

Each airport will be affected differently, but some airports might see greater affects since their geography and layout already present a restriction. In Table 3, Coffel and Horton analyze the B737-800's temperature thresholds at a variety of airports – PHX (high summer temperatures), DEN (high elevation), and both LGA and DCA (shorter runways, little-to-no room for expansion, and a large amount of traffic). For a cross-country route on this aircraft, "a 15,000 lb. weight restriction represents approximately 30% of the payload capacity of the aircraft," which translates into 79 less passengers (52 less at 10,000 lbs. and 5 less at 1,000 lbs.).[8]

B737-800 Temperature Thresholds				
Airport	**2013 Flight #s**	**1,000-lb reduction**	**10,000-lb reduction**	**15,000-lb reduction**
PHX	180,044	100.4	116.6	127.4
DEN	267,649	Always	86	98.6
LGA	163,883	Always	87.8	91.4
DCA	137,262	Always	87.8	91.4
*Temperatures in Fahrenheit				

Table 3.
(Source: Coffel and Horton)[8]

Based on the daily max temperatures for the summer of 2017, Table 4 shows how many days these four airports saw a restriction. However, as shown by Coffel and Horton's research, the number of B737 weight restricted days at these four airports will significantly increase (as much as 100-300%), and in turn, significantly affect aircraft operations, airline revenues, and passenger disruptions.

Number of Days of B737 Weight Restriction				
Airport	**2017**	**1,000 lb**	**10,000 lb**	**15,000 lb**
PHX	June	27	3	0
PHX	July	28	1	0
PHX	August	29	0	0
DEN	June	Always	13	1
DEN	July	Always	26	3
DEN	August	Always	20	0
LGA	June	Always	5	3
LGA	July	Always	12	4
LGA	August	Always	5	0
DCA	June	Always	15	5
DCA	July	Always	22	13
DCA	August	Always	11	1

Table 4.

Because of its medium size and efficiency, the B737 is a favorite among airlines, and it now holds a Guinness World Record for being the "most produced commercial jet aircraft model."[10] Thus, it is reasonable to assume that the 737 will be relevant well into the future, so it is important to understand how heat affects the 737. However, heat affects more than just this aircraft type, and Coffel and Horton, along with Thompson, expanded upon their research to analyze the effects of heat on other aircraft types and at more airports. They predict the Boeing 777-300 and Boeing 787-8 will feel the effects of weight restrictions the most, seeing 30-40% of flights experiencing a restriction with a fuel and payload reduction of 3-5%).[5]

6. Additional Effects of Heat on Aviation

In addition to weight restrictions, heat also affects aviation through increased turbulence, lengthened flight times, and heightened threats for airports located near the sea.

Williams completed research that suggests climate change increases the prevalence of transatlantic wintertime clear-air turbulence. Estimates show that there are over 63,000 encounters with moderate turbulence and 5,000 encounters with severe turbulence. The effects (passenger/crew injuries, aircraft damage, inspections, investigations, delays, etc.) from this turbulence can tally up to $200 million per year. Furthermore, "flight paths could become more convoluted, lengthening journey times and increasing fuel consumption and emissions" because pilots often try to avoid turbulence.[11]

Williams completed another study examining transatlantic flight times between LHR and JFK and their relationship with climate change. The results of his study indicate that jet-stream winds will increase, meaning eastbound flight-times will shorten while westbound flight times will increase; however, the shortening of eastbound flights does not mitigate the longer westbound flights, so the round-trip time will actually increase. This extra time means that aircraft could "be airborne for an extra 2000 h each year, burning an extra 7.2 million gallons of jet fuel at a cost of US$ 22 million, and emitting an extra 70 million kg of carbon dioxide." (p. 7)[12]

The International Civil Aviation Organization (ICAO) has discussed how heat and the subsequent rise of the average global sea level will affect airports. They also provide a case study examining how the Brisbane Airport (BNE) in Australia accounted for and did their best to mitigate climate change affects in its airport planning and construction. The airport location is near the coast, is subject to flooding, and experiences a subtropical climate, but airport planners took these factors into account when designing and constructing a new runway.[13]

7. *Potential Solutions*

Whether it be the Canadair Regional Jet or the Boeing 737, the Phoenix International Airport or LaGuardia Airport, or one of the other effects we have discussed, it is clear that heat has a number of wide-ranging effects on aircraft, airports, and airlines. As temperatures, as well as air traffic, are expected to increase in the future, it is important to understand how heat affects aviation and how to best mitigate the negative effects. There are a number of potential solutions that will help alleviate the issues of heat, but these solutions also include challenges that might make their implementation very difficult, or even near-impossible.

Solutions such as increasing runway lengths, adjusting airport routing, swapping aircraft on routes, adjusting departure times, improving aircraft design, and decreasing on-board weight have been suggested to address the issue of heat. Each of these are discussed in the following sections.

7.1. Increasing Runway Lengths

As previously noted, each airport has their own weight restriction threshold due to their specific elevation and runway lengths. In places such as LGA and DCA, where runway lengths are shorter, some weight restrictions are always in place because the plane does not have sufficient time to reach takeoff speed. In other locations, such as DEN, weight restrictions are in place because of the higher altitude. Trani concludes that the Boeing 737-800 needs 18% more runway at sea-level airports when the temperature increases 25 °C.[14] We focus on takeoff length requirements as opposed to landing length requirements because less length is needed for a plane to land. According to Boeing charts for takeoff runway length requirements,[15] a Boeing 737-400 with a weight of 130,000 lbs. and departing an airport at 4,000 feet would require approximately 350 more feet of runway on a day that is 27°F warmer than an airport at 59°F at sea level. The FAA also mentions temperature as a factor to consider in runway length design.[16]

Using data from the Air Cyber Alliance,[17] Figure 1 shows the distribution of airports' maximum runway length (note: unsure of date of data; potentially outdated). The longest runway is DEN at 16,000 feet, and the shortest is Compton/Woodley Airport (CPM) at 3,322 feet.

In some locations, current runways may be able to be extended or longer runways constructed. For example, the ICAO completed a case study of the Brisbane Airport, which noted that "temperature increases in future decades [were] automatically accounted for in the ultimate length planning for both the existing runway and for the new runway, each of which has significant additional lengths available to be added in the future."[13]

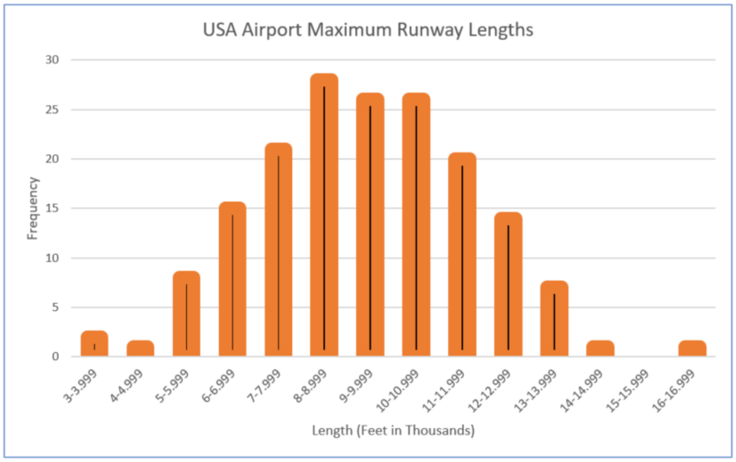


Figure 1.
(Source: Air Cyber Alliance)[17]

McGhee Tyson Airport in Knoxville, Tennessee is currently undergoing a $108 million project to extend its 9,005 foot runway another 1,000 feet, among other projects such as updating and modernizing the airport and its taxiways/runways. The goal of the runway expansion is to attract more long-distance flights,[18] but the expansion will simultaneously alleviate the issue of some possible weight restrictions since the runway will be longer.

It is not necessarily easy to simply expand a runway because there are many potential challenges and obstacles. First, expansions and construction cost money. Grants can be available; TYS received a $27.9 million grant from the FAA for its projects.[18] Second, regulations exist and government approvals may be needed. There might exist noise regulations, no-fly zone regulations, and safety regulations. Furthermore, if the airport doesn't already own the land where it could potentially expand, it must first purchase and acquire the land. The Brisbane Airport expansion project was "subject to numerous legislated planning conditions and approvals; involve[d] detailed stakeholder engagement; and, pose[d] a range of construction and operational challenges." It was finally approved in 2007 after submitting and receiving approval on a "comprehensive" Environmental Impact Statement and Major Development Plan.[13] Another example of a regulation challenge is the case where plans to expand the Wellington International Airport (WLG) in 2017 were blocked by the New Zealand Supreme Court over safety concerns.[19]

In addition to these challenges, airports need to actually have room to expand. Airports very close to big cities and/or near water can be very limited when it comes to space. For example, LaGuardia Airport (LGA) has utilized all of its available runway space. Ronald Reagan Washington National Airport (DCA) also appears to have no more room for runway expansion. They actually did maneuver through costs and challenges to expand one of their runways in 2013, although the length ultimately remained the same because they had to remove some of the runway on the opposite end. Because Runway 15-33 failed FAA safety standards, the project had to be completed, and 24 alternatives were considered before deciding on this project. Some 4.51 acres of the Potomac River were filled to pave over in order to make up for removing part of the opposite end of the runway, which was part of the $7.16 million project. Part of that land was transferred from the National Park Service to the FAA for the project, which was going to "adversely impact approximately 1.94 acres of NPS-managed riverine tidal wetlands." In response, the airport had to pay another $2.5 million to fund a restoration project.[20]

Phoenix Sky Harbor International Airport (PHX), which has been a focus airport throughout this paper, is land-locked by the city and river and thus is unable to expand. Even if there were room for runway expansion does not necessarily mean it would mitigate weight restrictions. According to Coffel and Horton, the Denver International Airport runways are "sufficiently long [16,000 feet], but the required takeoff speed would exceed the maximum tire speed of 225 mph (Boeing 2013)."[8]

7.2. Adjusting Airport Routing

In many cities, especially larger ones, there are multiple airports in relatively close proximity to one another. Ronald Reagan Washington National Airport (DCA) and Dulles International Airport (IAD) are only a driving distance of 29.1 miles from each other, according to Google Maps. IAD has a runway that is much longer than DCA (11,500 feet vs. 7,169 feet). LaGuardia Airport (LGA) and John F. Kennedy International Airport (JFK) are only a driving distance of 9.6 miles, according to Google, and both of these airports are only a little over 30 miles away from Newark Liberty International Airport (EWR) in New Jersey. JFK has a runway length of 14,511 feet and EWR has a runway length of 11,000 feet, compared to LGA's 7,003 feet. Therefore, one option could be for airlines to alter their departures during hotter months to favor airports with the longer runways.

However, airlines have a very well developed structure at their current airports, with facilities, contracts, fees, personnel, etc., and passengers also might only want to leave from a specific airport. Other cities don't have another airport option, and even with cities that do, the other option might not be any better: runways might not be as long, capacity might already be full, infrastructure might not allow for mass influx of capacity, etc. For example, Phoenix-Mesa Gateway Airport (AZA) is a little over 30 miles from PHX, but its runways are not as long as PHX, and the only airlines currently serving AZA are Allegiant alongside a seasonal service from WestJet.

Most airports, especially in big cities, are already operating near or at capacity and would not be able to handle an influx of more flights. JFK is a perfect example of an airport already at capacity. It serves as a focus city for JetBlue and is a hub for both American Airlines and Delta Air Lines, in addition to multiple cargo airlines. It sees hundreds of flights per day, and according to a capacity analysis completed by the FAA in 2014,[21] it is right at its max capacity. JFK felt the effects of operating near max capacity during the bomb cyclone, the winter storm that hit the Northeast in January of 2018. Many planes had to sit on the tarmac full of passengers for hours because all the gates were full. For example, an Air China flight was "stranded" on the tarmac for seven hours.[22]

While the option of altering flight routes exists, it would be extremely difficult. Not only are several airports near capacity, trying to simultaneously alter airport contracts, personnel, operations, ticketing, etc. would be extremely difficult, if not impossible, therefore making this potential solution not viable.

7.3. Swapping Aircraft

A different option that is much simpler and easier than changing airport destinations/departures is altering the type of aircraft that is flown on a particular route. However, to do this well requires some advanced planning. Last minute swaps are possible, but forecasting methods should be used to determine plane swaps in advance.

Different planes have different characteristics – for example, some planes and their particular engines can generate more thrust and lift than other types of aircraft. Coffel and Horton note that "airlines may need to allocate summertime cross-country flights to aircraft with better takeoff performance, such as the 757 today or perhaps a new aircraft in the future."[8] According to Patrick Smith, a Boeing 757 pilot, "the 737 falls way short of the 757 in terms of runway performance. The 737 requires a much higher takeoff speed and much more runway to get off the ground."[23] After interviewing Vasu Raja, American Airlines Vice President of Planning, for an article about American Airlines and long-haul routes, Brian Sumers discusses:

"American may also use the 'wrong' airplane if it needs better performance characteristics. The Airbus A319 and Boeing 757 have more power than the rest of the fleet, and they can take off at hot and high airports with full payloads. You might see American fly an A319 to some Rocky Mountain destinations, even if the smaller Embraer 175 is a better fit by seat count."[24]

When deciding on aircraft route swaps in anticipation of higher heat, airlines must consider the specific limitations and restrictions of the aircraft (range, capacity, performance, etc.), the number of that type of plane in the fleet and its availability, how the swap affects other route structures, difference in class types and number of seats, etc. There's a common saying: the only way planes make money is if they are in the air. Flight routing is very similar to a "puzzle"[24], and all the pieces need to fit together as efficiently and effectively as possible. The further in advance airlines can plan for an alteration, the easier it will be to implement.

United Airlines states on their website that flight schedules are published "up to 11 months in advance," but "may make some adjustments to accommodate changes to aircraft and routes." One of the adjustment reasons is "changes to type of aircraft."[25]

One reason it is easier to alter aircraft routes earlier rather than later is to not have to rebook or downgrade first class passengers. The further out from the flight date, the less likely the flight is to be nearing capacity. Even if one route is upgraded to a larger plane, the smaller plane that was originally on this route will likely be used on a different route.

An additional obstacle to consider with aircraft route restructuring is fleet availability. According to PlaneSpotters.net, American only has 34 B757s compared to 309 B737s. Delta has 127 B757s compared to 178 B737s. United has 77 B757s compared to 329 B737s.[26] Southwest is unable to switch from a 737 to a 757 because their fleet is comprised exclusively of B737s.

7.4. Adjusting Departure Times

In addition to adjusting aircraft route structures, airlines can alter departure times. At busier airports such as JFK, which we examined earlier, adjusting flight times is more difficult because the airport is near or at capacity, and the maximum number of planes are already taking off and landing most of the day. Also, at a hub airport, an airline is going to have several flights departing most hours of the day, and they need that frequency. Another issue to be aware of is the issue with flight frequency. Flights are offered at different times of the day for customer convenience and to allow for consumer choice. Moving flight times from certain parts of the day due to heat restricts some of this consumer choice and can cause more of an inconvenience for the passenger. Furthermore, restricting flight times can make it harder for the "puzzle" pieces to come together to maximize flying (and subsequently, revenue-earning) time of an airline's aircraft.

One airline that flies in and out of McCarran International Airport in Las Vegas chose this flight departure time solution, and another cancelled their flights altogether this past summer. Chinese airline, Hainan Airlines, moved their departure for Beijing from 2:10pm to 1:10am. They were forced to leave cargo in Las Vegas (they chose this option as opposed to removing passengers) in order to take off in the afternoon, "resulting in hefty financial penalties." Hainan resumed the afternoon departure time in October, when daily temperatures did not reach as high as the hotter summer months. In the summer, airport officials worked to keep some employees, especially those fluent in Chinese, there later and concessions open longer to accommodate this late-night/early-morning departure. Because of frequent "hours-long delays" due to heat, Norwegian Air Shuttle suspended their service between Europe and Las Vegas at the end of March and resumed "seasonal service" in November.[27]

7.5.1. Changes and Improvements in Plane Structure and Technology

Over the years, many technological innovations have vastly improved the performance of aircraft. As we look towards the future, further innovation and improvements can help mitigate the effects of higher temperatures. While newer planes might include advancements that increase their performance in hotter weather, commercial planes remain in service for multiple decades. For example, the MD-80, whose production ended in 1999, is still in service by American and Delta. Therefore, older planes will take a long time to phase out and will still be an issue in times of high heat. However, some modifications can be made during retrofitting of aircraft to improve their performance immediately, such as installing winglets on older B737s.

7.5.2. Improving Aircraft Design

Engines can be designed to generate more thrust. However, as Coffel and Horton note, engines and planes are designed for one another, so "a new generation of engines cannot be installed on existing aircraft without significant effort."[8] Business Insider notes that Boeing "has all but maxed out on the size of the engines it can mount on the 737 without completely redesigning the plane's under carriage."[23]

Engineers could create new wing designs to generate better lift. For example, maybe improvements exist in flaps and ailerons. Another example of an actual new wing design in practice is the Boeing 777X. This aircraft has not been delivered for commercial service yet but is expected to be within the next couple of years. As Boeing describes, "the 777X will be the largest and most efficient twin-engine jet in the world, unmatched in every aspect of performance."[28] This new aircraft has long composite wings, which are lighter, more efficient, better aerodynamically, and require less fuel.[29] The wings are actually so long, that the 777X would not be able to operate at some of the same airports that the 777 can because of gate limitations. Boeing wanted to maintain its airport compatibility, so their engineers developed a safe way for the wingtips to be folded up while on the ground at the gate and to be fully down during flight.

Lighter planes could potentially mitigate the effects of heat in the future. The Boeing 787 is mainly composed of composite materials, making it much lighter than other aircraft. However, as we saw from the Coffel and Horton study earlier, the B787 is projected to have some of the most weight restrictions in the future. Unfortunately, the heat-lift problem may still exist even with wing, engine, and structural improvements because Coffel and Horton describe:

"The wings of commercial aircraft are designed to be most efficient at high speeds, since the vast majority of flight time is spent in cruise. There is a trade-off between high speed efficiency and low speed lift generation, and both cannot generally be increased together."

"Changes in technology will no doubt revolutionize the aviation industry in the next 50 years. Carbon fiber structures will make aircraft lighter and new engines will produce more thrust with less fuel. However, these changes do not inherently result in better takeoff performance – aircraft manufacturers may need to prioritize this in the future." (p. 99)[8]

7.5.3. Decreasing On-Board Weight

What can airlines do right now to help prevent weight restrictions from causing them and their passengers headaches? American, Delta, United, and other airlines are all changing their strategy in regard to how they offer in-flight entertainment options. Many planes nowadays are wired with screens/monitors on the back of each seat to keep passengers entertained during flight. However, so many passengers bring their own devices such as phones and tablets on board, that these on-board devices seem unnecessary. The system of screens and wiring costs money, requires maintenance, and takes up a fairly significant amount of weight. Now that in-flight internet connectivity has significantly improved, airlines are strategically offering this better internet service instead of focusing on on-board screens. Passengers can access a library of movies, TV shows, music, games, etc. offered by the airline via their own smart device, in addition to browsing the internet.

American Airlines estimates 90% of its passengers bring their own devices on board. These seatback screens will begin disappearing with their 100 new Boeing 737 Max planes. The company contends, "It makes sense for American to focus on giving customers the best entertainment and fast connection options rather than installing seatback monitors that will be obsolete within a few years."[30] United is also going to phase-out seatback screens in their single-aisle jets. It is likely the airlines will keep seatback screens on their long-haul jets, however.[30] WestJet Airlines is also eliminating seatback screens, in an effort to eliminate an estimated 1,200 pounds from their aircraft's weight.[31] The seatback screens not only take up weight and become "technologically obsolete" relatively quickly, but they also can cost approximately $10,000 per seat, according to one transportation consulting firm.[32] With regards to the weight aspect, the less weight taken up by IFE (in-flight entertainment) devices, the more 'wiggle-room' an airline has to keep more passengers on board during a weight restriction. The Points Guy, a popular airline travel blog, describes one instance of how weight and fuel is saved by eliminating IFE devices:

"Airlines benefit from getting rid of built-in screens, too: Passing the device obligation from the carrier to the passenger decreases airline overhead and aircraft downtime. When Lufthansa began offering its wireless IFE solution, BoardConnect, the airline discovered it could reduce weight by decreasing the amount of equipment carried aboard. For the four-engine Airbus A340-600 carrying up to 380 passengers, the reduction in weight allowed the aircraft to save 47 metric tons (that is, roughly 103,617 pounds) of fuel per year. The technical wing of the German carrier noted the reduced weight came from removing screens from aircraft, which also reduced maintenance… With so much money saved in fuel and maintenance, it's no wonder airlines are pushing toward streaming IFE."[33]

Delta is not quite yet ready to eliminate onboard IFE devices altogether, but they are still responding to the changing landscape, just in a different way. They are rolling out their new idea on 75 new Bombardier aircraft. "Rather than a wired, custom-designed screen, Delta would install standardized Android tablets at each seat that would wirelessly stream content from an on-board server." This new idea would still reduce the weight from what a traditional IFE seatback system would look like.[34]

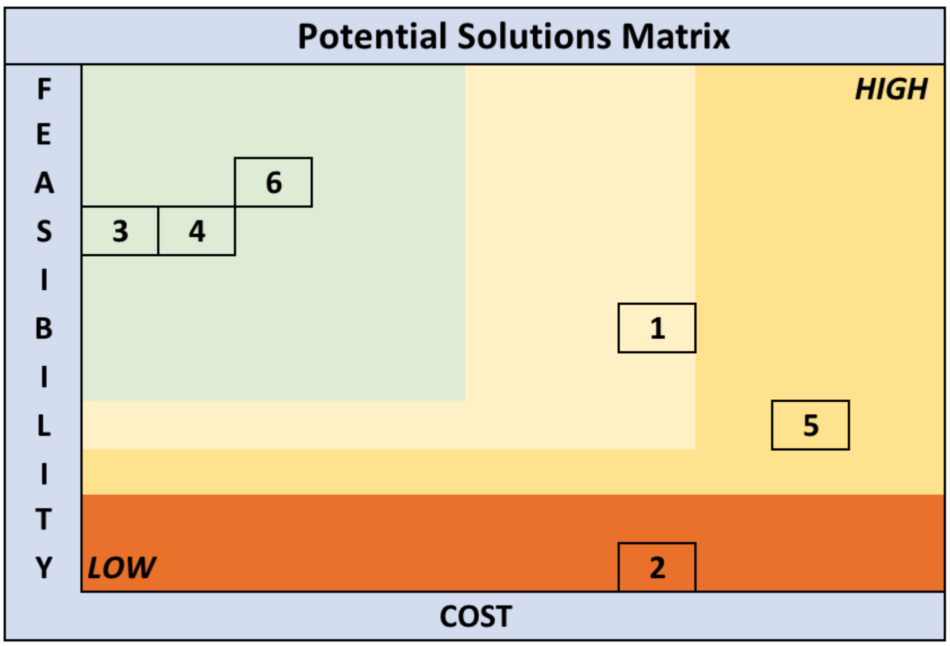
While structural design changes of airplanes would take a very long time to fully integrate and mitigate the effects of extreme heat, a solution such as removing IFE seatback screens is a very viable and relatively simple option that airlines can do to save weight and reduce the effect of weight restrictions. Airlines can choose this no-screen idea on their new planes, as well as retrofit older planes by briefly taking the plane out of service to remove them.

8. Conclusion

"This fact is true of all climate impacts: even if they can be adapted to, they still have a cost. A variety of climate impacts on the aviation industry are likely to occur in the coming decades, and the sooner climate change is incorporated into mid- and long-range plans, the more effective adaption efforts can be."[5]

As we have seen, heat can significantly affect the aviation industry. From cancellations of regional jets to weight restrictions of larger jets, the effect of heat is far-reaching and costs airlines millions per year, in addition to creating many headaches for passengers. As both temperatures and enplanements are expected to increase in the future (from 741 million in 2017 to 1,037 million in 2037),[7] it is vital that all parties in the aerospace and airline industry realize and understand the negative effects of heat and attempt to mitigate these effects. The more aware we are of the impacts of heat on aviation, the more well-suited we are in terms of seeking feasible, cost effective solutions.

There are a number of potential solutions available – some more viable than others, but none of the solutions are lacking challenges. Figure 2 provides a matrix of cost vs. feasibility for the proposed solutions. The sooner airplane manufacturers and airline operators begin implementing solutions, the better. The faster we begin coming up with ideas and solutions, the more prepared we will be to deal with and minimize the negative effects of heat on the aviation industry.



KEY	
1. Increasing Runway Lengths	4. Adjusting Departure Times
2. Adjusting Airport Routing	5. Improving Aircraft Design
3. Swapping Aircraft	6. Decreasing On-Board Weight

Figure 2.

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