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How Airport Construction will Evolve with the Increased Effects of Climate Change

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Abstract

This report addressed the effects rising global temperatures resulting from climate change have had on flight operations in their entirety. The research objective was to discover what methods could enhance climate adaptation in airport construction, as higher mean-surface temperatures have an increasingly negative effect on aircraft performance. The findings would primarily be of interest to the Federal Aviation Administration (FAA) Primary Office presiding over the planning and development of airports. Overall, the report provided a comprehensive analysis of global warming's effects on aviation, including the implications of degraded aircraft performance and sea-level rise for coastal airports. Additionally, it examined comparative solutions relating to the improved development of aircraft engine efficiency and takeoff weight (TOW) restrictions, as well as explored established airport construction practices. The study revealed that the most effective way to acclimatize to rising global temperature is to develop innovative airport architecture, while also modernizing present structures. Furthermore, solutions worth considering include the construction of airports at locations with higher latitudes and medium-elevations, and equipping airport terminal areas with advanced heating/cooling systems.

Introduction

From the Industrial Revolution onward, there has been an increased presence of carbon dioxide and other greenhouse gasses in the atmosphere, which in turn has caused distinctive warming of regional climates throughout the world (Coffel & Horton, 2015). As for the United States, it has continued to experience an increase in surface temperatures since the 1900s of around .8 °C (Coffel & Horton, 2015). This increase is exponential in nature, therefore most of the growth has taken place since 1980. The change has impacted the environment in various ways, which have significantly influenced aviation operations (Coffel & Horton, 2015). High temperatures and lower air density (the number of air molecules in a given volume of air), have thus led to the degradation of aircraft performance to the point where an aircraft is at times unable to takeoff in a given runway distance (Coffel et al., 2017).

Furthermore, as global temperatures continue to rise due to man-made climate change, important aspects of the aviation industry will increasingly be affected. Although general flight operations and aircraft performance are among these aspects, the structural characteristics of airports and their runways will also require consideration. Airports located at high altitudes and/or places that have high surface temperatures are not always constructed to permit aircraft to takeoff as desired, due to the density of the air around the airport being too low to allow for a successful takeoff roll. Such events have unfortunately resulted in flight delays and/or cancellations in parts of the United States that have the highest surface temperatures. Also, global sea-level rise (SLR), which is also a product of climate change, has the potential to interfere with airport operations, specifically in coastal areas. The complete ramifications of these circumstances remain largely unknown due to the study of a changing climate's effect on aviation being relatively recent and limited in quantity (Coffel et al., 2017). In order to further the research of this topic, this report addresses the concerns of global temperature's impact on an aircraft's ability to achieve safe and uninhibited flight. Specifically, this report outlines the effects climate has on aircraft performance, and its ability to make operative use of an airport. Then the report considers solutions, relating to airport construction and operations, that are feasibly effective against the projected impact climate change will have in the coming decades. This will be primarily accomplished in the proceeding sections through reviewing the relevant literature.

Methods

The implications of a changing climate can be reasonably defined as wide and varied, even upon conducting a confined analysis of its impact on aviation and aerospace. As a result, this study primarily conducted a literature review on research concerning the consequences of escalations in average global temperature. This study utilized the Embry-Riddle Aeronautical University's eagle search database and the ProQuest database in order to locate scholarly, peer-reviewed sources. A total of nine sources were reviewed and analyzed in detail, and their information was compiled into the literature review to convey climate change's impact on the natural environment and aviation.

Literature Review

A review of the literature discovered the following themes: contemporary climatology, aircraft performance, sea-level rise, comparative alternatives, and airport construction. These themes will be delved into further in the proceeding sections.

Contemporary Climatology

Since the end of the nineteenth century, global surface temperatures have increased by approximately 1 °C, and this change is expected to progress (Coffel & Horton, 2015). In the United States, there are instances when the temperature remains above average, at about 1–1.5 °C; these events have been observed to be most prevalent in the central and eastern regions of the continental U.S. (Coffel & Horton, 2015). At the present rate, Coffel and Horton (2015) show that temperatures can be expected to increase 4–5 °C on average by the end of the century. Additionally, annual maximum airport temperatures are projected to increase by 4–8 °C, which would mean that substantial parts of the year will be spent above the historical annual maximum temperature (Coffel et al., 2017). In heavily populated and congested areas, this could be between "10 and 50 days per year by 2060–2080" (Coffel et al., 2017, p. 384).

Although additional days exceeding historical annual maximums would be detrimental in any portion of the country, due to the nature of the earth's atmosphere, the burden of increased temperatures is greatest at high elevations. For aircraft that depart airports that are located at high altitudes, such as those in Colorado that has an average elevation of 6,800 feet, experience the most restrictions due to a disadvantageous density altitude (DA). As emphasized by Goodman and Griswold (2018), studying how seasonal averaged DA is affected by fluctuations in climate will afford the aviation community the opportunity to more conscientiously anticipate the projected changes in environmental conditions, that have an effect on density altitude. The warming of the planet's atmosphere by 1 °C thus far has

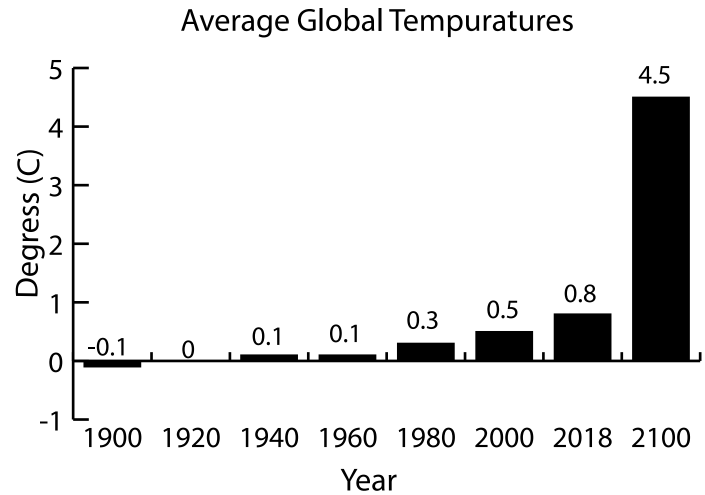

Figure 1. Graph on changes in global temperatures and their projected increase. Adapted from "Climate change and the impact of extreme temperatures on aviation," by E. D. Coffel and R. M. Horton, 2015, Weather, Climate, and Society, 7(1), p. 94. https://doi.org/10.1175/WCAS-D-14-00026.1

resulted in a mean-density altitude that is approximately 100 feet higher, therefore density altitude, as with temperature, can be expected to increase exponentially over the next century (Coffel et al., 2017). Global warming and DA will remain paramount in determining when and at what elevation aircraft departures and arrivals can safely take place. Aircraft Performance

Aircraft Performance

Aircraft performance depends directly on conditions present within the atmosphere, and these conditions are recorded and used to calculate takeoff, climb, cruise, and landing performance. Global warming has resulted in higher surface temperatures and atmospheric physics dictate that these higher temperatures cause air to become less dense at a constant pressure. An airplane wing produces less lift when it goes through this less dense air, and as a result on warm days during the summer, these aircraft have relatively higher takeoff speeds (Coffel & Horton, 2015). In extreme cases when the temperature and density altitude is too high, an aircraft's departure must be delayed because takeoff performance calculations reveal that the aircraft would not be able to build up enough speed during the ground role to takeoff in the allowable runway distance. The current and common response to this problem is for airlines to lower the aircraft's weight by decreasing the number of passengers or amount of cargo onboard, which lowers the takeoff speed (Coffel & Horton, 2015). According to Coffel et al. (2017) studies have determined that "the frequency of days on which a

Boeing 737-800 requires weight restriction is likely to increase by 100–300 [percent] at several airports in the USA in the coming decades" (p. 382). What can be concluded from this assessment is that more aircraft will be unable to depart without limitations due to climate change as time advances.

Sea-Level Rise

From what is known about the effect temperature and density altitude has on the environment, airports at low elevations such as those that reside near the coastline are the least susceptible to performance limitations, and it would, therefore, seem most advantageous for airports to be constructed there in the coming decades. Although this is true, such an endeavor would present complications because of the effect climate change has on the Earth's oceans and coastal areas. According to the Intergovernmental Panel on Climate Change (IPCC), "the global sea level will rise by more than 59 cm by the year 2100" (as cited in Djouer & Boutiba, 2017, p. 2). However, more recent studies have concluded that a sea-level rise (SLR) of 1.5 meters to above 2 meters could occur within the same time frame. This can be attributed primarily to the thermal expansion of the ocean and water flowing into the ocean from land ice and land water reservoirs (Nicholls & Cazenave, 2010). Additionally, higher sea-levels also contribute to the increased devastation caused by tropical cyclones. As established by Woodruff et al. (2013), storm damage will be highest where modifications to the natural landscape have taken place, such as shorelines where large populations reside. Additionally, coastal populations are largely not prepared for more frequent extreme flooding events, due in part because both coastal planners and policy makers find themselves unable to effectively respond to the threat. The hesitance and ineffectiveness stems from possible inaccuracies in data relating to fluctuations in tropical cyclone climatology, sea-level rise, and shoreline reduction. Sea-level rise and accompanying weather phenomena, therefore, pose a serious threat to these areas that often contain major airports used to accommodate the coastal population.

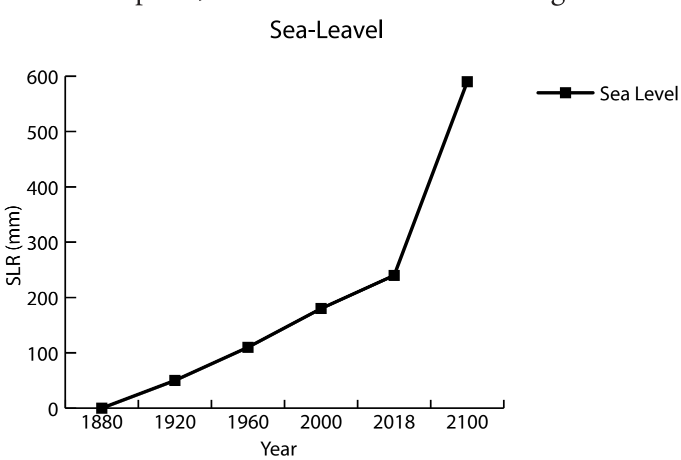

Figure 2. Graph on sea-level rise and its projected increase. Adapted from "Vulnerability assessment of coastal areas to sea-level rise from the physical and socioeconomic parameters: Case of the gulf coast of Bejaia, Algeria" by F. Djouder and M. Boutiba, 2017, Arabian Journal of Geosciences, 10(14), p. 2. doi:10.1007/s12517-017-3062-5

Coastal areas contain two-thirds of the largest cities and 60 percent of the world's population (Thompson, 2016). As for airports, "more than 25 percent of the largest airports have at least one runway with an elevation within the reach of moderate to high storm surge", which leaves these airports vulnerable (Thompson, 2016, p. 2). An example of such an airport is the San Francisco International Airport, which has an elevation of approximately 4 meters and is located only a few miles from the Pacific Ocean. According to Thompson (2016), local, state, and federal directives are in place for the purpose of climate adaptation and are being used to lead planning efforts and respond to public concern. A Shoreline Protection Project designed to further develop tide gates and seawalls is also being acted upon and is estimated to cost 58 million US dollars. This level of response is common in most other countries that conduct vulnerability assessments, and it is these assessments that allow national and local governments to determine what areas of coastline are most susceptible (Djouder & Boutiba, 2017). This type of investigative activity may be necessary to protect coastline infrastructure from the events to come.

Comparative Alternatives

Since the Earth has already experienced a mean-surface temperature increase of approximately 1 °C, solutions have already been developed that are designed to mitigate the risk of degraded aircraft performance, however, these solutions do not necessarily relate to airport construction. The most prominent of these solutions are the use of takeoff weight (TOW) restrictions, flight rescheduling, and the utilization of more efficient aircraft. For example, the already developed Airbus A320 and Boeing 737-800 can operate effectively near their maximum takeoff weight. Specifically, Coffel et al. (2017) convey that when these aircraft are flown, about 5–10 percent of the flights may experience restrictions of about 0.5 percent on average in fuel and payload capacity. These restrictions can be attributed to aspects of aircraft design.

Additionally, Coffel et al. (2017) noted the validity of scheduling aircraft with relatively high takeoff weights and/or low performance to depart during the early morning, evening, or night while the temperature is lower, and thus more favorable for flight. Despite the existence of this solution, it should still be noted that the Boeing 737-800, as stated previously, is expected to have more weight restrictions placed upon it by the amount of 100–300 percent, in the coming decades (Coffel et al., 2017). Airlines may find as time progresses, older aircraft will be increasingly less able to balance the demands of weight and the limitations of a changing climate.

Regarding the effectiveness of new and innovative aircraft designs, it is the assessment of Coffel and Horton (2015) that any design is not likely to do away with weight restrictions. This is primarily because the wings of commercial aircraft are constructed to be very aerodynamically efficient at high speeds, which occur during cruise flight and not during takeoff and landing when speeds are low. Coffel et al. (2017) noted that there is a trade-off between high-speed efficiency and low-speed lift generation, and both are not generally able to be increased simultaneously. This solution is therefore not an immediate one but one that might be realized in the relatively distant future.

Airport Construction

Aspects of climate change such as global warming and sea-level rise have raised questions about how airports will evolve in their entirety to adapt. Due to temperature, airport terminal areas might have to accommodate for an increasingly humid environment, while runways may be subjected to lengthening to meet the performance demands of large aircraft. Airport terminal areas are characteristically constructed to include large open spaces that make use of glass curtain walls or glazing areas, which let in natural light. They also are very energy-intensive environments that can easily match the energy demands of small cities. Much of this energy consumption stems from the need for lighting, heating, ventilation, air conditioning, and conveyance systems. The heating, ventilation, and air conditioning (HVAC) systems alone can exceed 40 percent of the total electrical energy consumed (Kotopouleas & Nikolopoulou, 2016). However, due to climate change these needs can be expected, for the most part, to increase. For example, Thompson (2016) estimates that cooling needs could increase by approximately 40 percent, while heating needs could decrease by approximately 20 percent. Such changes would certainly result in an increase in operational costs for airports.

Since the degradation of aircraft performance results in longer takeoff rolls, lengthening runways has been an expected response to this undesirable condition. However, the general concerns associated with this solution is the cost of construction, a lack of space, and a possible increase in noise pollution in the surrounding area (Thompson, 2016, p. 2). As for airports located at higher elevations, an additional element that requires consideration is being able to accurately determine the degree that a runway needs adjustments, especially with surface temperatures increasing in an exponential manner (Smith, 2006, p. 3). Coffel and Horton (2015) best articulate factors worth considering for airports located in urban areas on the east coast of the U.S.

> They state that: "urban airports like LGA [LaGuardia Airport] and DCA [Ronald Reagan Washington National Airport], runway extension is likely to be difficult, leading to more constrained summertime operations and potentially the loss of longer flights to nearby airports with longer runways, such as the John F. Kennedy International Airport in New York, Newark Liberty International Airport in New Jersey, and Washington Dulles International Airport in Virginia. However, such decisions would require advanced planning, especially since these airports operate at near 100 percent capacity today (p. 99)."

Overall, runway extension is considered a viable solution but may only be applicable to select airports.

Discussion

The following considerations have been crafted from the research and various findings mentioned and are designed to sensibly mitigate the impact of climate change on aviation. Additionally, they largely require immediate and long-term planning, as well as the purposeful allocation of resources.

Consider Investing, Promoting, and Reinforcing Major Medium-elevation Airports

Because airports located in mountainous regions such as the western United States have higher density altitudes, aircraft departing there have the longest takeoff rolls and the most weight restrictions (Coffel & Horton, 2015). Coastal airports allow for the lowest density altitude but are faced with a rise in sea level that could eventually leave them inoperable. A viable option then is to support airports located in between these two extremes. The most favorable region may be the mid-western United States due to its medium elevation, relatively higher latitude, and currently moderate population density. An airport located in that region that would be open to modification and reinforcement would be O'Hare International Airport in Chicago.

Consider Investing in Heating, Ventilation, and Air Conditioning (HVAC) Technologies to Increase Their Effectiveness and Efficiency

A general increase in global temperatures and constantly exceeding maximum recorded temperatures will likely put stress on cooling systems in large infrastructures such as airports (Thompson, 2016). To ensure the comfort of customers and airport staff alike, new technology and methods relating to the heating, ventilation, and air conditioning of airport terminal buildings should be considered for use. For example, a study by Mary Reena et al. (2018) of India's Cochin International Airport considers new methods and technology that would allow HVAC technology to become more efficient in its operation. Much of India lies within a tropical region of the Earth, which characteristically has a climate that can be varying in nature and hot due to humidity. These conditions are similar to what an increase in mean-global temperatures due to climate change would result in, in the U.S. For large airport terminal areas with varying occupancy throughout, there are three elements that would contribute to the increased energy and cost efficiency of an HVAC system. They include variable speed electric drives, which would regulate air volume and flow rate in a building, humidification/dehumidification modules in conjunction with air-handling units (AHU), and CO2 sensors to automatically safeguard air quality (Mary Reena et al., 2018).

Consider Investing in the Construction of Seawalls and Tide Gates, as well as SLR Cost and Risk assessments for U.S. Coastal Airports

Many urban centers and accompanying major airports in the United States are in close proximity to the coast. As a result, it is just as vital to protect these well-established areas as it is to consider new long-term locations. As stated previously, measures such as the Shoreline Protection Project, which is estimated to cost 58 million US dollars and designed to further develop tide gates and seawalls, are being realized at airports like San Francisco International (Thompson, 2016). The projects and others similar to them will continue to be an effective plan to address the rise in sea level and possible storm surge. Additionally, climate change risk assessments along with tracking past weather-related costs would ensure future construction projects are resilient and flood avoidant. They would also ensure that past costs are analyzed to more accurately quantify future costs associated with shifts in weather resulting from climate change. Newark airport in New Jersey has already developed a sustainability plan that includes initiatives encompassing these assessments (Thompson, 2016).

Conclusion

Since the twentieth century, climate change has slowly developed into an occurrence of great significance to the natural environment. Its effects are impressive and far-reaching, impacting many aspects of the modern world, including aviation. Because weather is the most pertinent factor to consider for aviation operations, it is especially necessary to analyze the various aspects of climate change, such as increased global temperatures and sea-level rise, which will have the greatest effect on future operations. Modern climate science has concluded that global warming has resulted in a 1 °C increase in global temperatures thus far, and this trend is expected to continue. This will have an increasingly detrimental effect on aircraft performance, as higher temperatures result in less dense air. Additionally, sea-level rise, as a product of a changing climate, will affect aviation by causing the coastline that major U.S. airports and potential future airports reside on, to recede. In response solutions have been developed, such as weight restriction, however it remains challenging to ascertain how effective they will be as time progress. The following research all leads to solutions through means of airport construction, including accommodating aircraft with longer takeoff rolls and the geographic location of airports. It is of great importance that the aviation community invests in effective and feasible solutions to address the implications of a changing climate as expediently as possible.

References

Coffel E. D., & Horton R. M. (2015). Climate change and the impact of extreme temperatures on aviation. *Weather, Climate, and Society*, *7*(1), 94–102. https://doi.org/10.1175/WCAS-D-14-00026.1

Coffel, E. D., Thompson, T. R., & Horton, R. M. (2017). The impacts of rising temperatures on aircraft takeoff performance. *Climatic Change*, *144*(2), 381-388. doi:10.1007/s10584-017-2018-9

Djouder, F., & Boutiba, M. (2017). Vulnerability assessment of coastal areas to sea level rise from the physical and socioeconomic parameters: Case of the gulf coast of Bejaia, Algeria. *Arabian Journal of Geosciences*, *10*(14), 1-20. doi:10.1007/s12517-017-3062-5

Goodman, C. J., & Griswold, J. D. S. (2018,). Climate impacts on density altitude and aviation operations. *Bulletin of the American Meteorological Society*, *99*(5), 884+. Retrieved from http://link.galegroup.com.ezproxy.libproxy.db.erau.edu/apps/doc/A544403758/AONE?u=embry&sid=AONE&xid=064592a0

Kotopouleas, A., & Nikolopoulou, M. (2016). Thermal comfort conditions in airport terminals: Indoor or transition spaces? *Building and Environment*, *99*, 184-199. doi:10.1016/j.buildenv.2016.01.021

Mary Reena, K. E., Mathew, A. T., & Jacob, L. (2018). A flexible control strategy for energy and comfort aware HVAC in large buildings. *Building and Environment, 145*, 330-342. doi:10.1016/j.buildenv.2018.09.016

Nicholls, R. J., & Cazenave, A. (2010). Sea-level rise and its impact on coastal zones. *Science*, *328*(5985), 1517-1520. doi:10.1126/science.1185782

Smith, J. R. (2006). *Aircraft performance explanation and concerns for takeoff from a high altitude airport* (Order No. 1433095). Retrieved from ProQuest Dissertations & Theses Global. (304920839).

Thompson, T. R. (2016). Climate change impacts upon the commercial air transport industry: An overview. *Carbon & Climate Law Review: CCLR*, *10*(2), 105-112. Retrieved from http://search.proquest.com.ezproxy.libproxy.db.erau.edu/docview/1822636420?accountid=27203

Woodruff, J. D., Irish, J. L., & Camargo, S. J. (2013). Coastal flooding by tropical cyclones and sea-level rise. *Nature*, *504*(7478), 44-52. doi:10.1038/nature12855