Manhattan College
Soaring Into the 2050s
2022 Gateway to Blue Skies: Airports of Tomorrow Competition

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Table of Contents

Introduction

The goal of the aviation industry is to achieve net-zero carbon emissions by 2050. To attain this, various aviation technologies must be implemented into widespread commercial use to significantly reduce carbon emissions. Several green aircraft technologies are on track to maximize fuel efficiency and reduce fuel consumption. These revolutionary technologies include alternative fuels, primarily sustainable aviation fuels (SAF)s, new aircraft designs, electric-powered aircrafts, and new types of aircraft such as electric vertical take-off and landing aircraft (eVTOL). Changes in airframe and material design is also being considered, which include small and large blended wing body aircraft, cargo blended wing body, strut-braced wing, v-wing, double bubble fuselage, and box/joined wing. Additionally, new propulsion technology such as open rotor and boundary layer ingestion is another technology to consider. [1]

Fuel

For the aviation industry to meet net-zero carbon emissions by 2050, one of the key technologies that must be focused on are alternative fuels, as one of the most pressing matters of modern aviation are the increasing greenhouse gas levels. With an increase in research and technology, by 2050 airplanes will be able to use more environmentally friendly fuel such as SAF, hydrogen fuel, and ammonia hydrogen fuel. The most popular fuel is projected to be SAF, as this fuel can be easily integrated into current fuel systems with small to no retrofit, does not require different engines, lowers emissions significantly, and has already seen testing. [2][3] [4]

An important demonstration of good fuel is its sustainability. For fuel to be considered sustainable it must reduce carbon emissions, not compete with food production, and must not negatively affect the environment (ex: deforestation).[2] SAF works the same as jet fuel but is made up of waste products rather than fossil fuels. SAF is made up of biofuels from plant products, as well as household waste, cooking oil, etc. SAF is a “drop-in fuel”, meaning that it can be directly mixed into jet fuel without requiring any changes to the engine. By combining SAF with jet fuels, carbon emissions can be reduced by up to 80%. Additionally, given the sources of SAF, the production of this fuel recycles some waste products, further helping the environment. [4][5][6]

As of now, SAF costs more to produce than traditional jet fuel as its technology is still novel. However, as companies such as Shell continue to invest money and research into this alternative fuel source, demand for SAF will grow. Neste, a company that has shown great success with SAF, claims to be the fourth most sustainable company in the world. They also state that they will reduce climate emissions by twenty million tons annually by 2030 and have carbon-neutral production by 2035. [7] [8][9]

As SAF becomes more popular, more companies will invest in it, and will thus make it more accessible. Once 2% of all planes are powered by SAF, its use will increase exponentially. By 2050, SAF will be in a high enough demand that it will become widespread and more affordable. SAF will be used more than traditional jet fuel, and airports will need to accommodate those changes. Airports will need to switch some fueling stations to SAF, while few airlines will still likely be using jet fuel. It will not be necessary that every single airport is equipped with SAF because airplanes can run on both jet fuel and SAF. [5] However, at least the major airports worldwide will have SAF by 2050. Therefore, the changes airports will need to make will be minimal.

With the goals of many airlines to reduce carbon emissions, SAF will certainly be playing a role in powering airplanes by 2050. While SAF does reduce emissions, it is not at 0%. 2050 will likely see the emergence of new sources of fuel, including hydrogen fuel and ammonia fuel, which both work to eliminate carbon emissions. While the method is currently quite expensive, hydrogen can be produced from water during electrolysis and does not produce waste. Planes will need to modify their engines to use hydrogen as fuel unlike with SAF. Airports will need large, highly pressurized storage tanks to keep it as a liquid to account for its low energy density, and the airplanes will need to account for the added weight. Additionally, the storage tanks will need to be kept at temperatures as low as -253°C to keep it in a liquid state. Despite the drawbacks, hydrogen does provide a completely clean alternative to jet fuels and will play a role in 2050 airports. [10]

Similar to hydrogen fuel, using ammonia as fuel is also better for the environment, as the only waste is hydrogen and nitrogen. The density of liquid ammonia is close to that of jet fuel, making it easier to store and easier for the plane to carry. Additionally, similar to SAF, ammonia fuel can be used in current plane engines. Using ammonia fuel will require additional safety precautions since it is toxic, unlike SAF which is free of sulfur, oxygen, and aromatics for fewer harmful particulate matter emissions. However, as ammonia is less flammable than jet fuel, it does have some safety benefits. Ammonia fuel will increase costs due to its weight. Overall, ammonia fuel will certainly be seen in airplanes in 2050 as it is a clean energy source that does not require major modifications to airplanes. [11] [12]

As mentioned previously, Neste is a company that is working to resolve carbon emission issues. Neste's sustainable aviation fuel has been used on more than 300,000 commercial flights since 2016 and is made from 100% renewable waste and residue materials such as used cooking oils, animal waste, fish fat waste, and residues from vegetable oils. Neste has been working on waste and residue raw materials for over a decade, and their refineries have been capable of running on 100% waste and residues since 2015, but they also expect to be able to use other raw materials such as novel vegetable oils soon. Neste is not the only company working on reducing carbon emissions.[8][9] Boom, the airline company, is actively attempting to use SAF to be more environmentally friendly. A test trial was done with an XB-1s engine with a blend of fuel that contained 80% SAF. Prometheus technology can convert CO2 from the atmosphere into jet fuel. A deal between Boom and Prometheus fuel was signed to deliver low carbon fuel because of this testing.

Noise Reduction

In addition to researching CO2 emissions, Boom is investigating the impact of a sonic boom. Sonic boom shock waves are a major focus point for the redesign of supersonic planes. This is the most socially unacceptable aspect of supersonic aircraft as the noise and shock waves disturb the day to day life. Currently, it only flies over water to avoid negatively affecting people's home and work lives. Extensive research is being performed to fix this problem. Noise-reducing technology is being integrated into the engine and airframe. Some of these technologies include nozzles and advanced acoustic liners. Reportedly, "NASA has contracted Crystal Instruments of Santa Clara, California… to gather time, waveform, and spectral data related to sonic booms and sonic thumps." [13] With the novel instruments being designed, NASA will have the ability to analyze sonic thumps in real-time and in turn, potentially produce noise-reducing technology. [14]

In addition to Boom's noise-reducing technology, Joby Aviation, an aerospace company that develops eVTOLs which due to their electric power-driven by lithium-ion batteries, have quiet electric motors, and when cruising the noise is less than 45 decibels. However, the propellers cause most of the noise, and to decrease the noise the aircraft needs a lower disk loading which will allow the propellers to move slower, hence reducing noise. The more propellers added, the lower the disk loading because the disk area increases. Joby aviation's aircraft is estimated to have a disk loading of around 12 pounds per square foot. Propellers spinning at different speeds also help to reduce the noise.[15] Other factors that affect noise levels are rotor tip speed, blade geometry, and harmonic control. By ensuring a low tip speed, changing the blade geometry, and ensuring higher harmonic control, noise can be reduced.[16]

Aircraft Designs

On a more standard level, commercial aircrafts are also getting updates. For example, present standard aircraft cabins have circular cross-sections. The Boeing 737 can fit 6 people per row in the standard circular format.[17] The new double bubble (D-series) design fits 2 more people per row. The advantages of this new design include more passengers per flight and more space for luggage. Furthermore, it increases cabin width and comfort for passengers. According to a study done at MIT, this aircraft model would use about 70% less fuel while also reducing noise and emission of nitrogen oxides, in addition to using a shorter runway. The engine is located in the rear of the fuselage contrary to the current standard placement towards the front. Engines of present-day aircrafts take in high-speed airflow. On the contrary, the D-series takes in slow airflow in the rear but the engine uses the same amount of fuel with the same thrust. This process is known as Boundary layer ingestion. This propulsion technology is a major advancement in the efficiency of aircrafts. NASA's Glenn research center is working with this new technology to reduce costs and the environmental impact of aircraft operations. This specific propulsion technology reduces drag significantly because moving the engines toward the back of the fuselage causes the drag of the slower boundary layer to be "ingested" by the engines, hence the name. [18] [19]

Another commercial aircraft advancement is the incorporation of new wing designs, such as braced wings. Braced wings are external structures that carry the load. A strut-braced wing "carries the lift loads and stabilizes each of the spars so they do not bend significantly differently as a result of torsional aerodynamic loads."[20] Additionally, this design minimizes bending moments. The blend between the strut and wing is lighter than the current cantilever design. Also, this design allows for space between the tension elements, rather than current carry through the cabin layout. Another up-and-coming wing style is Blended wing bodies (BWB). They are designed to reduce drag and generate lift. A BWB aircraft is predicted to use 20% less fuel. The wingspan of a BWB aircraft would be larger than that of the Boeing 747, but it is lighter, more cost-efficient, and environmentally and socially safer. Small blended wing bodies are not as large as their counterparts. They "allow faster boarding and disembarking than similarly sized single-aisle aircraft."[20] This advantage results in high fuel efficiency and a shorter turnaround time. Another style is box wing which has the potential to reduce fuel consumption by reducing drag. This means they can take on heavier loads compared to current aircrafts, similar to the BWB advantages. A study at MIT is being conducted, experimenting with the H series, which incorporates another new wing style. This is very similar to the D series as it utilizes the double bubble fuselage design, but the H series is a triangular-shaped hybrid wing body. Although the design for this plane must be larger to fit more passengers than the D series, its wing shape improves aerodynamics. [21] [22]

Aircraft Modification Technologies

Aircraft modification technologies that are imminent are the ultrafan, counter-rotating fan, ultra-high bypass ratio engine, adaptive/active flow control, ubiquitous composites, natural laminar flow, hybrid laminar flow, variable camber with new control surfaces, and spiroid wingtip.[1] New materials for aircraft are also being developed. Biocomposites are made of renewable natural resources such as biomass, natural fibers and bio resins. These resources are then turned into biocomposites which are beneficial in terms of their cost-effectiveness, lightweightness, flexibility, and recyclability. [23] Silicon Carbide Fiber-Reinforced SiC Ceramic Matrix Composites is a flexible, lightweight material that is being developed by NASA. The material would be ideal for engines since it can take up to 2700 degrees Fahrenheit and can last years. [24]

In aerodynamics, laminar flow control reduces drag considerably, allowing for significant fuel-saving potential. There are different methods to achieve this. For example, Natural Laminar Flow (NLF) Control, which involves changing the design of wing surfaces, is in development via Airbus' project Breakthrough Laminar Aircraft Demonstrator in Europe (BLADE) which is working on a modified A340 with laminar profile wings. In addition to NLF control, Hybrid Laminar Flow Control (HLFC) is under development, which uses boundary layer ingestion to keep the laminar flow. [1]

Electric Aircraft

In addition to investigating sustainable fuel, improving aerodynamics, and modifying technologies, research on ways to make planes more sustainable is being performed. In addition to sustainable fuel, electric aircrafts are being considered for the future of environmentally friendly aeronautics. The weight of an electric aircraft is vastly more significant than that of a fuel-operated aircraft. For an electric aircraft, the batteries required to run the electric motors weigh anywhere from one thousand pounds to two thousand pounds depending on the aircraft's overall size. [25] The weight distribution of batteries on an electric aircraft is highly considered in the overall design of the aircraft. The aircraft needs powerful batteries with the ability to hold more power in a compact space size. Technology has not been able to make batteries like these yet, therefore lithium batteries are used. Lithium batteries, especially the vast majority that aircrafts use, are likely to overheat and explode. NASA, however, tested their X-57 battery setup, which overcomes thermal runaway safely by containing the heat. [25] NASA used wax disks that would melt due to extreme heat. [26] Even their X-57 battery, which combines two smaller batteries, weighs around eight hundred pounds in total.[27] This battery will not be big enough for a commercial aircraft. However, the same technology can be used and implemented into a bigger battery, perhaps into a battery with higher specific energy that is big enough for commercial aircraft. Implementing these types of batteries will need to consider the overall design of the electric aircraft.

From an economic point of view, the cost of maintaining an electric aircraft is significantly lower than that of a combustion aircraft. Even with an electric plane, the lithium battery will decay over time and thus will need to be replaced. Not only that, but electric motors on the aircraft also need to be maintained. Ganzarski, the CEO of MagniX, said at the 2019 Paris Air Show, “right now electric motors are all podded as a single unit to maintain or reduce complexity, but that means you need to replace the entire motor [after a fault], what we’ve done is make it completely maintainable… you can take one coil out and replace it, you can take one magnet out and replace it.” [28] This is an approach to making electric motors more maintainable. MagniX has made motors that are easy to maintain in an electric aircraft. Their approach is to replace singular units instead of replacing the entire motor. NASA even selected MagniX to continue the development of the electric propulsion system for aircraft. Overall, the maintenance cost is cheaper than that of a combustion engine.

The implementation of a c-wing design to an electric aircraft is being discussed. An investigation on the aerodynamics of the c-wing design states,“When a horizontal surface is added to the winglet, forming the ‘C-shape’, the circulation is further extended from the winglet, producing a download force on this surface for minimum induced drag at fixed total lift.” [29] The c-wing design decreases the drag force on the aircraft, decreasing electricity consumption. Due to a decrease in drag force, the aircraft can increase its airspeed.

The electric planes will have charging stations throughout the airport. These charging stations will be designed underground and placed throughout the airport to make them accessible everywhere.[30] Similar to how the current airports consist of underground gas lines, these electric cables will run underground for electric charging. The planes will be plugged in using cable extended from the plane to the ground. A problem encountered with refueling is the time it takes for an aircraft to reach full charge which is significantly longer than refueling a combustion aircraft. As time goes on, advancements in technology will make a solution to this problem and cut down the time required to charge. A potential solution is that batteries will have to be replaced when it reaches low charge with fully charged batteries, as it will cut time.

Airport Design

Although airplanes are a key part of the future of airports, design and efficiency of airports are also major to its success. For example, the entrance and check in points are popular topics in airport design to ensure travelers walk through the airport efficiently and safely. Vertical designs have proven to be more efficient than traditional horizontal designs. A vertical design will allow check-in to be faster by separating passengers into groups. New York's JFK airport is implementing a two-group system of high-tech and high-touch passengers. High-tech passengers use technology for assistance and high-touch passengers need extra guidance to their flight. The separation between these two groups will allow high-touch passengers to find assistance easier and high-tech passengers to move through the airport quicker because of reduced hold-ups from other passengers. [31]

In addition to reformatting entrance design, the airport terminal and gate design itself are being reinvented. The satellite design is one example of these reinventions. It makes it easier for planes to leave at any point. In this design, there are five terminal entrance buildings containing security and check-in points that correspond to different airlines. Underground tunnels connect each terminal to each satellite that contains the gates. In the case of a mistake, a tunnel connecting the two satellites of the same terminal will have an underground connecting tunnel. The air traffic control tower will be placed in between terminal 3 and its corresponding satellites.

Discussing the satellite design begs the question of where to put aircraft hangers. Current airplane hangers are permanent and require constant maintenance. Temporary hangers are the hangers of the future. They are less expensive, portable, require less maintenance, and do virtually anything a permanent hanger can. Temporary hangers allow for future airport design changes because they can be moved. Additionally, hangars can move to the aircraft, rather than aircrafts moving to hangars. Portable equipment is a bonus with aircraft temporary hangers because then equipment could be easily moved from one hangar to another. At the airport, the main parking lot is located in between the main entrance and exit roads. There are walking paths available but shuttles are provided to transport passengers to and from the terminal buildings. [32] [33]

The land around the airport can be used for solar panels. The airport will get electricity for the underground charging stations from the grid. Thus, solar panels will be used to help provide electricity for the aircraft along with autonomous vehicles.

Although electric aircrafts are predicted for the future, airports will still have some uniform methods of airplane refueling common to all types of fuel. For example, in this airport, the fuel will be stored off-site and delivered to the airport by a pipe system. This system will maximize available space at the airport and minimize traffic going to the airport. Additionally, the airplanes will be refueled by an underground hydrant system, which will be located at the gates. This location will be the most efficient as the airplanes can go directly to their gates as soon as they are open, rather than first going to another location at the airport. Here, a hose will connect to the hydrant and the fuel port beneath the wing of the airplane. The fuel will then be pumped to the two tanks located in each wing. As SAF has a similar chemical composition to the jet fuel used today, the methods of storage and refueling will remain the same. [5] Adjustments will be made for ammonia fuel and hydrogen fuel. Overall safety precautions, including fire precautions, will remain in place for the new fuel sources. Hydrogen fuel and ammonia fuel both need to be stored as liquid. Therefore, the tanks at the off-site location will be kept at low temperatures. For the transportation from the tanks to the airport, the hydrogen fuel will go through a throttling device underground to ensure that the temperature and pressure of the fuel are not too high. The ammonia fuel will go through a heat exchanger to keep the temperature low. The hydrogen fuel otherwise has no further restrictions on storage and transportation. The ammonia fuel, on the other hand, is toxic and will require additional safety measures. The storage tanks and transportation pipes will need to be reinforced to guarantee that there are no leaks. Anyone handling the fuel will need to wear personal protective equipment and ensure that those not authorized to handle the fuel are not in the area. [34] [35] [36]

Arriving at the airport is normally a dreadful experience. Air taxis propose a new time-saving, efficient transport. Archer aviation recently got its eVTOL aircraft, Maker, off the ground and plans on an air taxi service by 2024, which would reduce carbon emissions. It can travel up to 60 miles at 150 miles per hour for short-distance travel. [37] The CityAirbus NextGen developed by Airbus is a four-seat eVTOL, which has an 80 km range and a cruise speed of 120 km/hr. Its first flight is planned for 2023. To guarantee low noise levels its goal is to have under 65 decibels in-flight and below 70 decibels in landing. [38] Volocopter has developed their air taxi, VoloCity and Volocopter 2X, as well. [39] Due to the imminent integration of air taxis into commercial usage, air taxis can transport passengers to and from airports via an air taxi system that involves transport to the various smaller airports throughout the United States, of which there are over five thousand. [40] As air taxis are estimated to be in operation by the mid to late 2020s and airlines like United Airlines plan to buy 200 electric taxis to shuttle people to and from the airport, infrastructures must be added to airports to accommodate this new technology. [37] [41] As these aircraft do not require runways and take-off vertically, vertiports, similar to helipads, must be added to airport infrastructure as well as charging stations. The top of airport terminals and space near the airport structure can be used as vertiports for air taxis. [42][43][44][45][46][47]

These vertiports can be added to the roof of terminal buildings with an elevator leading down into the buildings, and include touchdown and lift-off areas (TLOF) and final approach and takeoff areas (FATO)[42][44]. Volocopter currently has a design that they plan to put on top of terminal buildings [46][47]. Additionally, space for approach and departure paths and electric propulsion charging stations or battery swapping stations must be readily available. However, ground-based vertiports have lower costs than above-ground vertiports [48]. If this design is used, it would have to connect to the airport structure with additional infrastructure. For a more streamlined check-in process, vertiports on top of the terminal buildings were chosen for this design. Passengers could land on top of the vertiports and go through security in a section above the terminal. Then they can easily be transferred to the docked planes.

Generally, air taxis are meant for short distances from around 25 miles except for Lilium which plans for 60-75 miles. These distances will drain the batteries and measures must be put in place to ensure the batteries have high energy densities. Since Lilium specifically plans for longer routes, they plan on "large-format lithium-ion pouch batteries with a cell chemistry based on a silicon-dominant anode combined with conventional nickel, manganese, and cobalt (NMC) cathodes and liquid electrolytes" [49], which they believe will provide high power and energy density while the battery is at a low state of charge. The company plans for an 80 percent charge in 15 minutes and a 100 percent charge in 30 minutes. Lilium also plans to put the battery packs low in the aircraft for crash safety. If Lilium's cell chemistry for batteries is effective, something similar could be implemented widely to reduce recharge time and maintain a high energy and power density.[50][51]

Safety

One goal of airports is to ensure that the airplanes receive fuel safely and efficiently. Airports will need to make adjustments to the fueling system to accommodate new types of fuel. Major factors contributing to fuel storage include density, toxicity, flammability, and temperature at which the fuel is a liquid. Commonly, fuel is stored at an off-site location and is sent to the airport either through underground pipes to smaller storage tanks, or is delivered by trucks. The airplanes then receive the gas via an underground hydrant system. By 2050, airports will have systems in place to fuel airplanes using standard aviation fuel, hydrogen fuel, and ammonium fuel plus to recharge the electrical batteries.

For battery safety, the batteries of these electric vertical take-off and landing aircraft (eVTOL), need to have a fast recharge rate to shuttle passengers at an efficient rate. However, lithium-ion batteries must also be kept in a safe region between the voltage of the cell and managing the temperature to prevent battery thermal runaway where "the heat generated within a battery exceeds the amount of heat that is dissipated to its surroundings".[52] The internal temperature will rise and affect other batteries nearby. [53]To prevent this, a battery management system must be implemented and "containment and propagation mechanisms in place to protect the battery from damaging itself and the vehicle structures"[51].

Conclusion

Overall, the airport design of the 2050s will encompass the most promising new technologies. The airport design will promote speed and efficiency, as well as a cleaner environment. The airport features five main terminals, each of which connects to two satellites for boarding. There are underground tunnels connecting the five terminals to one another, connecting each terminal to its two satellites, and connecting each pair of satellites. The airplanes of the 2050s will be running on electricity and sustainable aviation fuel. The airplanes receive the fuel and battery charge while docked at the satellite terminals as the energy runs through pipes underground. The electricity is taken from the airport's solar panels, as well as from the grid. All fuel is stored off-site and transported via pipes. Along with the source of energy, the shapes of planes will change as well. New wing shapes decrease the drag force planes experience, and thus lower energy consumption and increase speeds. To take into account the new shapes of planes, as well as the satellite terminals, the airport will have temporary hangars that can be moved around for convenience. Another feature of this new airport will be the addition of rooftop vertiports. Now, passengers will have the option of using air taxis for transportation to the airport, promoting speed and saving time. At this time, many of these changes, especially those in implementing new energy sources, are pricey. However, as companies continue to invest in alternative energy sources, the prices will go down to match the current prices of energy sources. The improvements in the environment will be a driving force in implementing these alternatives. By 2050, airports will see planes running on clean energy, as well as air taxis for transportation and satellite terminals.

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