The Relationship of Aviation to Global Climate Change: The Development of the Aviation Industry's Mitigation Measures and their Practicality

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Background

The effect of emissions from the aviation industry on global climate change has led the aviation industry to come under increasing pressure to reduce their overall environmental impact. This is indicated by governmental and business groups related to the aviation industry setting emissions reduction targets, such as the inter-governmental International Civil Aviation Organization (ICAO) setting a target of carbon neutral growth from 2020 onwards (ICAO, 2022, p. 83), with groups representing businesses such as General Aviation Manufacturers Association (GAMA) and National Business Aviation Administration (NBAA) committing to decarbonization by 2050 (ICAO, 2022, p. 106). As the White House's recent investment of 4.5 billion dollars into sustainable aviation fuels (The White House, 2021) shows, all this governmental and industry pressure from the increasing importance of emissions and climate impact reduction, has led to increased resources being invested into innovations that could potentially mitigate emissions and climate impact. This has resulted in new programs and plans pursuing the development of emissions reduction innovations such as the European Clean Sky 2 development program, with the goal of reducing CO2 and NOx emissions by 20 to 30 percent (Clean Aviation Joint Undertaking, 2021, p. 17), and NASA's new Strategic Implementation Plan including goals of CO2 and NOx emissions reductions of 10 to 15 percent by the 2035 period (NASA ARMD, 2019, p. 40). While this general overview of the current government and business stakeholders and their effects on the aviation industry and its engineers due to climate change pressure may paint a positive picture regarding of the development of emissions and climate impact mitigation technologies and operations, very similar pressures and developments have occurred in past crises that have failed to materialize technological solutions, the Advanced Turboprop (ATP) being a good example of this.

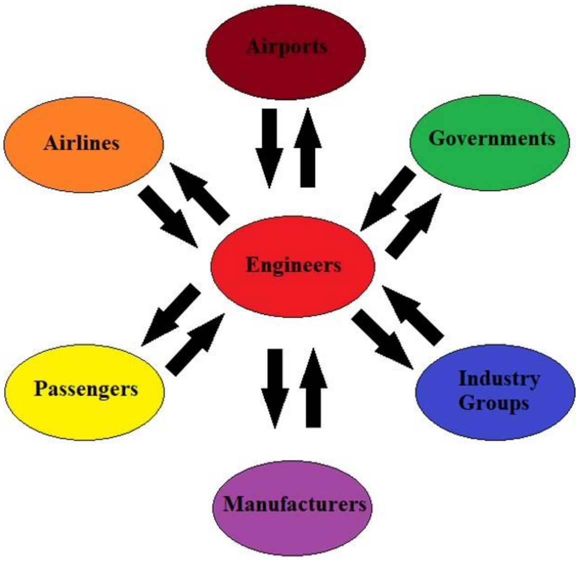
Introduction

The ATP, also known as the Unducted Fan (UDF) is considered to be promising for emissions reduction, due to its higher efficiency and lower fuel consumption compared to traditional aircraft turbofans. The technology was pursued in the past from the mid-to-late 70s to the early 80s and had a large amount of governmental and business supporters, due to the coinciding oil shocks of 1973 and 1979 making such a technology extremely attractive in the aviation landscape at the time, and the technology was made a top research priority (Kajikawa et al, 2012, p. 94). However, despite this support and being developed under NASA, the technology ultimately failed to develop into a commercial product and was unable to be diffused across the aviation industry (Kajikawa et al, 2012, p. 92). This was because the technology was hampered by a variety of issues. There were safety concerns regarding the excessive vibration caused by the ATP, concerns about the high engine noise causing passenger discomfort and regulatory issues, and possible fatigue problems (Kajikawa et al, 2012, p. 94). Additionally, airlines were reluctant to adopt the technology due to possible risks regarding the brand-new engine (Kajikawa et al, 2012, p. 98). This all had the effect of considerably delaying the development of the technology until the period of high oil costs caused by the oil shocks had ended. With no high oil costs to push the development of the technology, the potentially riskier and maintenance intensive ATP's impetus of development disappeared, which caused the development of the technology to stagnate and ultimately become dormant. It is only recently that the technology has attracted new development due to the new pressures from emissions reductions goals. It is unlikely that engineers currently working on similar technologies will have to be concerned about the developmental opportunity window for the technology that they are working on closing, as climate change unlike high oil costs is not a temporary issue. However, the ATP example shows that engineers will need to factor in the potential risks of new technologies and communicate and receive feedback from stakeholders who are backing the development of the technology they are working on, such as airlines, passengers, and regulatory bodies on the risks and tradeoffs of new mitigation technologies to allow timely development of said technologies, and to prevent another situation where the development of said technologies becomes dormant. A good example of this approach is the study done by Capurro et al. (2015) regarding sustainable biofuels, a technology very similar to sustainable aviation fuel, where the public's views regarding the potential benefits and risks of the technology were polled to better understand what drives public values about the technology of sustainable biofuels (p. 1). This type of proper communication between stakeholders (in this case being the public) and industry engineers, will ultimately allow engineers to develop mitigation measures that are practical and usable for the stakeholders, allowing them to succeed where past efforts failed.

This interaction between passengers, airlines, regulators, governments, etc. with industry and engineers, with both positive and negative relationships can be illustrated through the Social 8 Construction of Technology (SCOT) model as seen in Figure 1. This framework (Bjiker et al, 1984, p. 43) shows the mutual relationship between various social groups and the engineers at the center of the relationship influence the development of technology. The engineers, when developing the mitigation measures must carefully balance the feedback and requirements from airlines, airports, governments, industry groups, manufacturers, and passengers, and negotiate between said groups to enable the development of a practical mitigation measure in a timely manner.

Figure 1:

SCOT Model for Mitigation Measures



Note. Engineers developing mitigation technologies must balance and negotiate demands from at least six different groups. (Adapted by Hunter (2023) from Carlson, 2009)

So, to determine the possible practicality of a mitigation measure, one can analyze how well the mitigation measure can meet the requirements given by the various groups, how flexible said groups are to possibly changing their requirements according to feedback from the engineers working on the measure, and how well the engineers can negotiate between the requirements and needs of the different groups influencing the development of the measure. By seeing how each analyzed measure compares to others in these qualities of the SCOT model, one can determine how practical and implementable each measure may be, allowing for possible prioritization of measures that have a high chance of success. Additionally, thanks to the visualization of the relationships between technology and society by the SCOT model, one can easily identify where in the network there is an issue that may be holding back the development of a measure. This can all be used as useful information and feedback by the aviation industry when developing their mitigation measures. Engineers working on a mitigation measure must negotiate between the conflicting requirements (such as comfort versus superior emissions performance) to make sure the mitigation measure is ultimately practical and likely to be adopted.

Research Methods

The information created for the SCOT model analysis was gathered through a literature review of existing aviation-related databases/journals such as AIAA ARC and NASA NTRS databases, with some additional contributions from databases/journals with a focus on Sustainability and climate impact such as the Sustainability Science journal. The aviation technology related journals provided detailed breakdowns of certain mitigation measures from both a development and potential impact standpoint, acting as a good way to help gather data regarding the justification of development of certain mitigation measures (including which groups are looking to primarily benefit from them), and providing data about certain problem points of a mitigation measure. Identifying problem points was crucial, as they were likely the leading causes of conflict between groups in a SCOT model.

Results and Discussion

The first mitigation measure to be analyzed using this method was the blended- wing-body (BWB) configuration for an aircraft. The BWB is a novel configuration for aircraft, that departs from the common “tube-and-wing” approach of a cylindrical fuselage with a wing attached to the fuselage midsection. Instead, the fuselage and wing are entirely blended together into a single lifting shape. This results in an overall much more efficient design due to a reduced wetted area and greater spanwise efficiency with lower from and interference drag (Chen et al, 2019, p.

1799). This approach has numerous potential benefits from a climate impact standpoint. For one, the greater efficiency allows for much less fuel burn, with a significant fuel burn reduction from 27% (Liebeck et al, 1998, p. 1) to as much 45% (Yang et al, 2018, p. 5) versus standard configuration aircraft being identified by various researchers. Lower fuel burn results in less overall climate impact from fuel, both in emissions and in extraction/transportation of fuel, as less fuel is needed by the aircraft. This also benefits airlines as well as they can spend less fuel costs for a lower fuel burn aircraft. From a purely emissions standpoint, the benefits are reduced NOx emissions (Yang et al, 2018, p. 5) and up to 50% reduced CO2 emissions (Reim, 2020), both very important for climate impact. Additionally, noise reduction benefits were also seen in studied configurations (Okonkwo, 2016, p. 3), which may be attractive to both operators (airlines and airports) and passengers.

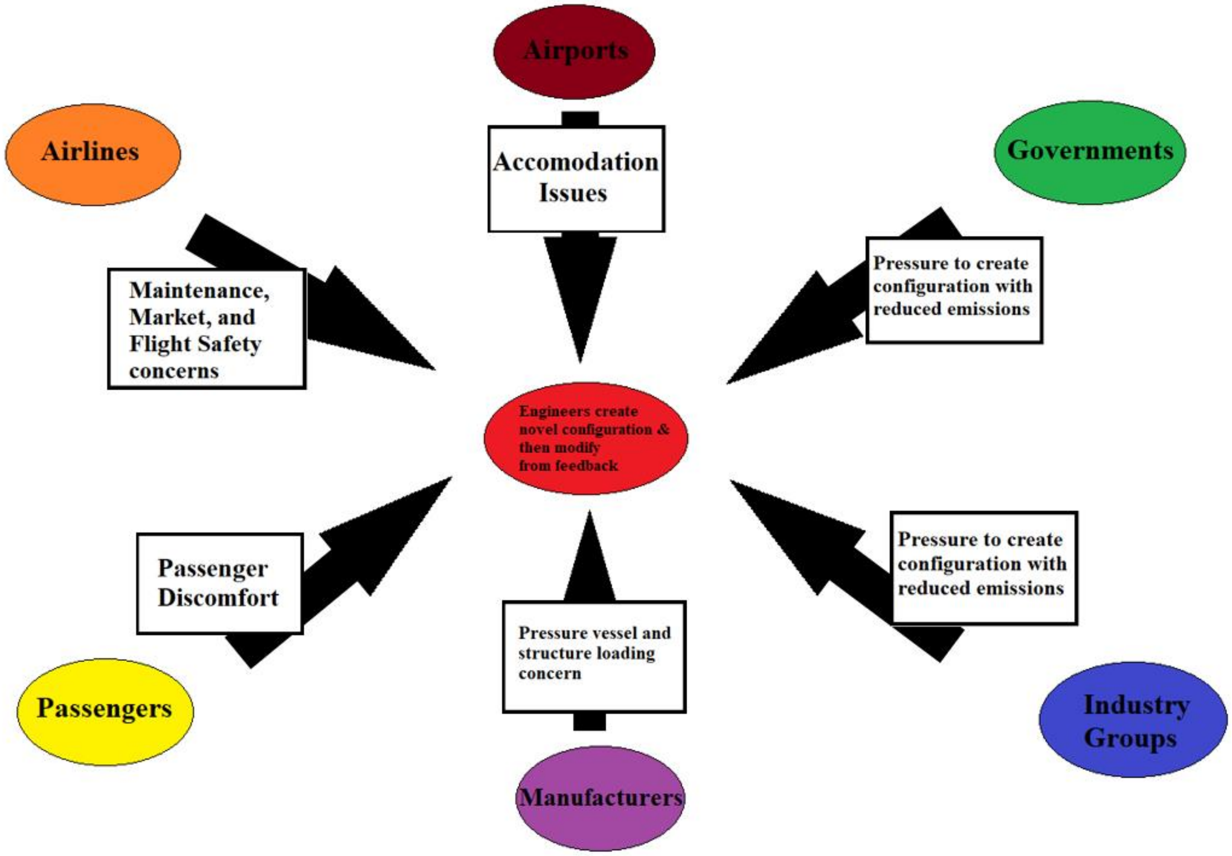
While this mitigation measure has clear climate impact benefits, with some additional benefits that may be beneficial to social groups in the SCOT model, there are several shortfalls with the concept that have kept it from being implemented historically. Being a completely novel configuration, the BWB configuration has seen to be regarded as challenging to accommodate using existing airport infrastructure, which primarily revolve around accommodating standard configuration aircraft (Chen et al, 2019, p. 1800). Further, airlines have concerns about the maintenance needs of the BWB configuration compared to a standard tube-and-wing configuration aircraft (Chen et al, 2019, p. 1800), likely requiring massive changes to technician training and operation (Okonkwo, 2016, p. 49). A further problem for airlines and their pilots is that due to the BWB configuration being statically unstable (Liebeck et al, 1998, p. 5), the configuration presents challenging handling qualities to pilots (Chen et al, 2019, p. 1800) and is prone to Pilot Induced Oscillations and has poor Dutch roll characteristics (Okonkwo, 2016, p.

46). Additionally, the majority of the BWB designs in the past focused on 200+ passenger class aircraft, making them less attractive to airlines which prefer smaller, less risky aircraft for insertion of new technologies to the aircraft market (Yang et al, 2018, p. 5, 6). Passengers are also uncomfortable with the largely windowless seating arrangement caused by most of the passengers being seated in the inner fuselage (Chen et al, 2019, p. 1800). Finally, the non-cylindrical pressure vessel required by the BWB configuration may present challenges to manufacturers in terms of designing a fuselage that can handle repeated pressurization loads, as non-cylindrical pressure vessels are less ideal than cylindrical vessels in this factor (Hansen et al, 2007, p. 2), and BWB configurations require high load tolerance composite structures (Yovanof, 2012, p. 1).

To paint a clearer picture of the collected information, one can apply the SCOT model to the BWB configuration to map the requirements from the social groups that shape this mitigation measure, as seen in Figure 2. The primary requirements and impetus of the design to the engineers would be from the emissions reduction goals mentioned by both government and industry groups (NASA and Clean Sky 2 targets for example). However, they would also receive feedback from passengers about the discomfort of the largely windowless seating arrangement and feedback from airports about the difficulty of accommodating an aircraft using a novel configuration in existing airport infrastructure. Additionally, feedback from airlines about the difficulty of maintaining said configuration, its flight safety issues, and it being oversized for the market, with feedback from manufacturers about the potential risks of a non-cylindrical pressure vessel.

Figure 2

SCOT Example for BWB



Note. Engineers, during the development of mitigation measures, often must balance conflicting feedback from social groups as shown here. This is often done by giving their own feedback back to the social groups to negotiate (Adapted by Hunter (2023) from Carlson, 2009)

This may paint a somewhat negative picture of the mitigation measure, but engineers have shown themselves to be able to respond to this feedback to produce a refined approach to the configuration. Firstly, the flight control issue can be addressed with active flight controls, which in simulations have shown to significantly improve the handling qualities of BWB aircraft (Okonkwo, 2016, p. 46). Additionally, newer BWB configurations have begun targeting a market segment more attractive to airliners by being smaller, as seen in the 112 passenger DZYNE Ascent 1000 (Yang et al, 2018, p. 6). Manufacture pressure vessel and composite structure concerns are being addressed through new advanced composite structures such as the Pultruded Rod Stitched Efficient Unitized Structure (PRSEUS) composite structure concept where composites are stitched together to form a structure (Yovanof, 2012, p. 2). Passenger discomfort from lack of windows can be addressed by adding skylights to the central cabin as in the DZYNE Ascent 1000 to allow for more natural light in the large, central portion of the cabin. However, maintenance and airport accommodation will likely remain challenges, as the novel design will fundamentally require changes in maintenance procedure and airport accommodation no matter what modifications are made to the basic BWB configuration.

Therefore, from the SCOT model framework, it appears that the BWB configuration as a mitigation measure, while being a novel configuration, is likely practicable. This is because there appears to be a “healthy” socio-technical relationship between the social groups and the engineers where the engineers are able to respond to and accommodate the majority requirements of the social groups, without having to negotiate large conflicts between the requirements of several different social groups , and are able to modify the mitigation measure to suit the majority of the requirements. For the issues regarding airport accommodation and maintenance, engineers should negotiate with airports on finding ways to reduce the cost or difficulty of creating accommodations for the configuration, and should negotiate with airlines how to have maximum “carry-over” of maintenance experience from a tube-and-wing configuration to that of a BWB configuration. Addressing these issues would lead a further increase in chance of implementation of the mitigation measure in the real world.

Another significant mitigation measure currently being studied is electric propulsion. There exist several different types of propulsion systems being explored under current efforts, these being either turboelectric, hybrid electric, or purely electric. In a turboelectric propulsion system, there exists a gas turbine which mechanically drives an electric generator. In a hybrid electric propulsion system, unlike in a turboelectric propulsion system, there exists an electrical battery that contributes to driving the propulsor through a power converter with the aid of a gas turbine also present in the system. In a fully electric system, the propulsor is simply driven purely by an electric motor.

These electrical propulsion systems have been shown to have very large potential benefits in terms of climate impact. Very large fuel burn improvements have been indicated, with as much as 33% to 55% improvement in fuel burn for a hybrid electric vehicle compared to that of a standard gas turbine vehicle (Brelje & Martins, 2019, p. 7). Turboelectric propulsion has a lower improvement, being around 7% to 12% improvement in fuel burn (Jansen & Duffy, 2018, p. 3), due to being wholly dependent on a gas turbine for power generation. This, as stated before, is beneficial both in climate impact reduction and airliner operation cost reduction. Purely electric propulsion does not have any fuel burn and emissions from it, lacking gas turbines at all.

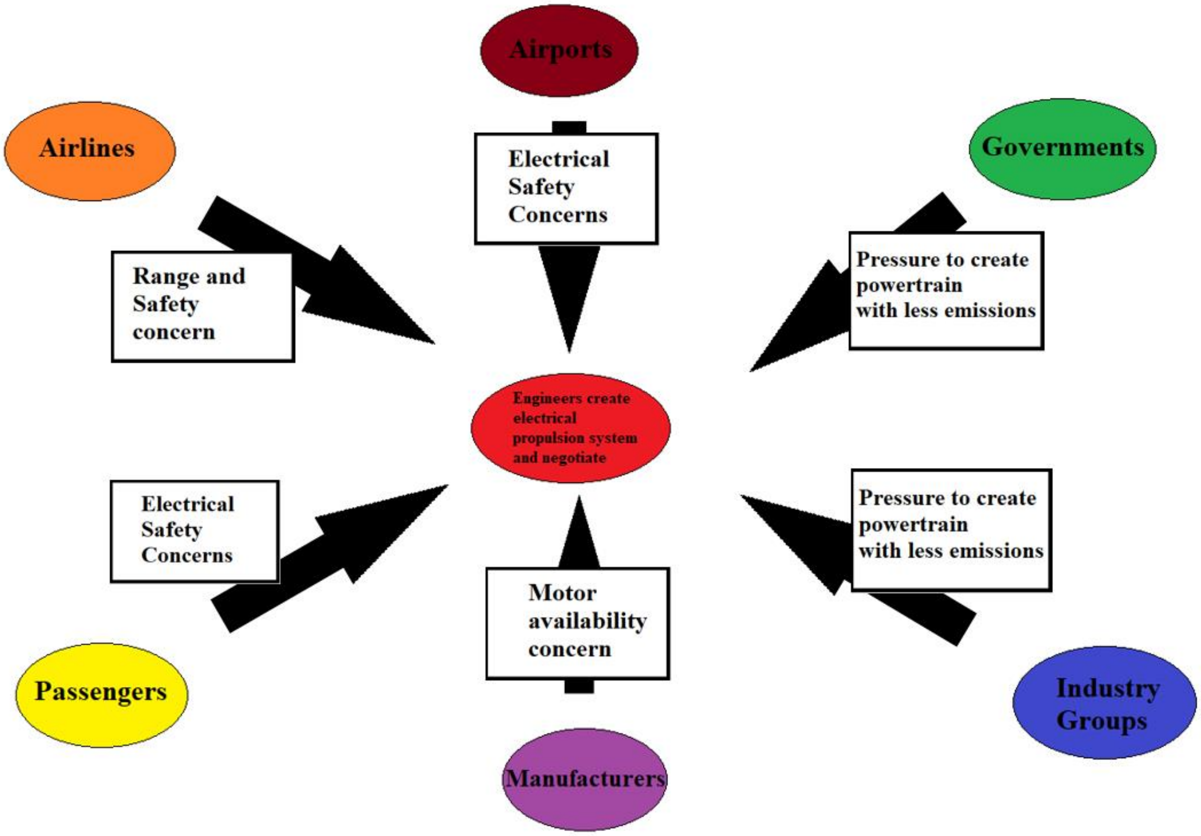
However, while potentially very effective in reducing emissions and climate impact through reduced fuel burn, electric propulsion as a mitigation measure faces several issues. For one, for electric propulsion that relies on batteries, are more vulnerable to safety issues regarding them such as thermal runaway (Brelje & Martins, 2019, p. 11), and for all electric propulsion, their electrical systems may be vulnerable to short circuit fires or act has hazards to maintainers due to their high voltage (Brelje & Martins, 2019, p. 11). Additionally, batteries due to their lower energy density compared to fuel, take up much more of the weight of an aircraft using them than fuel, resulting in overall heavier aircraft as seen in a study done by Cai et al. (2023) which showed an 22.08% increase in empty weight for a hybrid electric vehicle dependent on batteries compared to standard aircraft of the same configuration (p. 20). This is an issue as the greater weight and worse power density cut into the range performance of the aircraft, with an all-electric aircraft with the same range as a conventional aircraft of the same configuration not being possible with current battery technology (Strathoff et al, 2020, p. 1). Another issue is the fact that as of now, high power density electric motors required for large aircraft wishing to use these electric powertrains do not yet exist (Wroblewsk & Ansell, 2019, p. 1201), presenting a problem for any manufacturers wishing to create a large aircraft using an electric powertrain.

Applying the SCOT framework to the given data, as seen in Figure 3, the pressure to create an electric powertrain primarily stems from Industry Group and Government pressure as in the case of the BWB. The primary passenger concern would be the safety of the electrical systems, which would be a concern for airlines and airports as well. For airlines, an additional concern is the poor range performance of more electrified systems. For manufactures, their primary concern would be the lack of capable electric motors for large aircraft.

This indicates that the engineers working on the mitigation measure must conduct more compromises and negotiations compared to the BWB mitigation measure. If they wish to fulfill the requirements of industry and government groups, it would be best to pursue an electric or hybrid electric configuration at the cost of airline requirements, and if they wish to pursue the airline requirements, it would be best to pursue the turboelectric configuration. In either case, it is important that the engineers mediate between the two groups so that a suitable compromise can be reached between the parties. Additionally, engineers should work with relevant groups to mature the electrical system tech technology required for electric propulsion if they wish to see it implemented. Overall, electric propulsion is likely possible, but would require more development and compromises and negotiations to be made between social groups affecting the mitigation measure.

Figure 3

SCOT Example for Electric Propulsion



Note. Engineers, in this case must balance more between conflicting requirements by acting as a bridge to negotiate compromises in requirements between groups (Adapted by Hunter (2023) from Carlson, 2009)

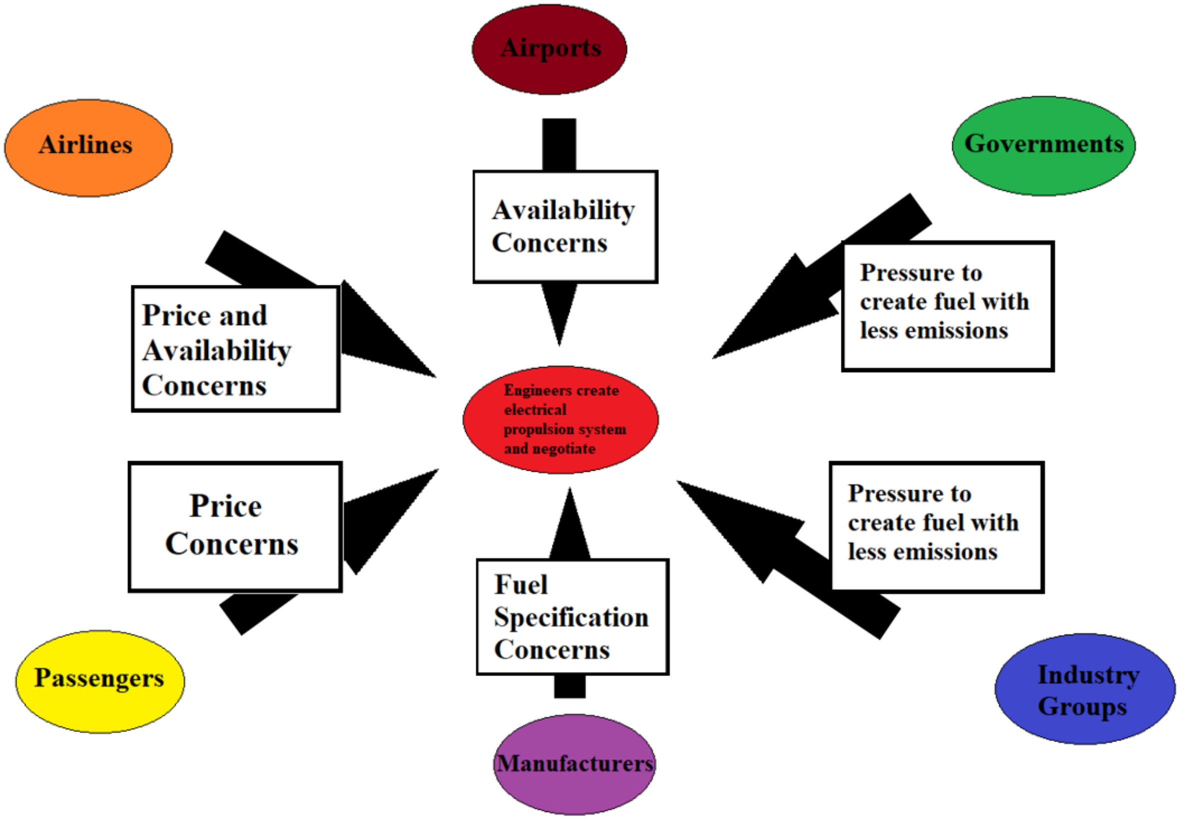
The final mitigation measure to be analyzed is Sustainable Aviation Fuel, also known as SAF. SAF is derived from non-traditional fuel sources that are seen as sustainable, such as biomassderived fuel. Derivation from non-traditional sources allows SAF to have a smaller emissions footprint than regular jet fuel, despite emitting almost the same emissions when burned, due to having overall lower life cycle emissions, and it is estimated that it could reduce international flight emissions by as much as 63% by 2050 (ICAO, 2018, p. 9). Of particular interest is “Drop-in” SAF, where the fuel is derived from non-traditional sources but still uses the existing infrastructure used by regular fuel (ICAO, 2018, p. 8). Critically, drop-in fuel must be compatible with existing jet fuel, and existing engine technology (ICAO, 2018, p. 9). Drop-in SAF is advantageous mainly because no new additional infrastructure or technology developments are needed for its use. SAF could have additional benefits outside of emissions reduction, such as boosting the agricultural job market, or the provision of energy services to local communities (ICAO, 2018, p. 10).

However, like the other mitigation measures, SAF is not without its issues. As of now the availability of SAF in world is very low, as the global production of SAF sits at less than 1%. This production will only be able to match total consumption by 2050 (Kramer et al, p. 2). Additionally, current “drop-in” fuels that can be blended with traditional fuel due not match exactly the specifications of traditional fuel, particularly in aromatics which are important to engine seals, and may cause issues in the engines of current models of aircraft (Kramer et al, p. 3). Additionally, the price of SAF is much higher than conventional fuels (ICAO, 2013, p.3).

Applying the SCOT framework, to this mitigation measure, as seen in Figure 4, the pressure to develop and adopt SAF for the engineers comes from government and industry groups who want to reduce environmental emissions. However, engineers involved with SAF also receive concerns from airports about the low availability of SAF, and airlines will pressure engineers about the higher costs of SAF. Additionally, manufactures and airlines will be concerned about the potential specification and resulting performance issues in engines that may be caused by current SAF blends. Passengers would be concerned by the potential for higher fares caused by the higher costs of SAF.

Figure 4

SCOT Example for Electric Propulsion



Note. Engineers, in respond to both the demands and concerns of groups for SAF (Adapted by Hunter (2023) from Carlson, 2009)

While there are clear concerns for SAF as a mitigation measure, there does not seem to be any outstanding issue that may put a stop or significantly delay its development. The availability issues, while they will exist for some time, are actively being addressed with the United States planning to increase production to about 3 billion barrels a year by 2030 (Kramer et al, p. 2). Additional availability will help to ease the price, as more supply will be available to meet demand. For the specification issues, some solutions are already being investigated, such as lowering the required sealant specification, or the research and production of improved blends of SAF (Kramer et al, p. 4).

Conclusion

Therefore, based on the SCOT model analysis of the mitigation measures, there appear to be mitigation measures more practical for implementation than others and that there are clear problematic areas in current mitigation measures that should be addressed. The BWB configuration mitigation measure, which requires less compromise between requirements and therefore a more balanced framework and therefore development of the technology, should be prioritized for development in the near term if possible. Electric propulsion, while having clear upsides, has a more unbalanced framework and therefore it is less practical in the near-term and its implementation is more troublesome. The technology needs more time to mature for true commercial use, and social groups (primarily airlines and government/industry groups) must work a compromise between climate impact targets and performance for a practical implementation to be successful. SAF seems the most implementable in the short term and such should be prioritized most, as it has very little potential conflict in its framework, and areas of conflict are already being addressed. However, it will not be able to address the climate issue in a large manner in the near term due to its lack of availability. Therefore, it will have to be paired with an additional measure to make up for this shortfall. Overall, while the discusses mitigation measures appear to have viable frameworks supporting them, engineers and the social groups involved must take care to make sure these frameworks remain viable through communication, discussion, and proper compromise, so that these mitigation measures can be successfully implemented in the future to help combat climate change.

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