Fuel Optimization in Commercial Supersonic Aircraft

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Challenges faced by past supersonic commercial aircraft manufacturers due to a lack of technological advancements have altered the perception and success of this type of aircraft. Recently, as new companies are aiming to pave the way for a resurgence, commercial supersonic planes are still suffering a significant issue concerning their suboptimal use of fuel. In the past, airplanes such as the Concorde used a large, expensive and environmentally damaging fuel source; for a proper resurgence of supersonic commercial transport, an optimal fuel source must be found. This paper examines multiple fuel types capable of supporting supersonic travel in commercial aircraft using decision matrices to determine the most optimal. We define optimal with the following parameters: payload capabilities, ease of storage, cost, sustainability and health effects. These parameters were examined in terms of the production and consumption of the fuels. The following fuel types have been examined: Kerosene based fuels (Jet-A JP-8), Hydrogen, and Sustainable Aviation Fuels (SAFs). The decision matrices determined that there is no singular most optimal fuel for commercial supersonic aircraft. While Jet-A and JP-8 are the most energy dense and cost-effective fuels they lack in the environmental fields. The opposite is true of Hydrogen and SAFs. Hydrogen, while potentially being the most environmentally friendly, is not currently suitable for the long flight routes of supersonic transport. Hydrogen and SAFs are also considerably more expensive compared to Jet-A and JP-8. While further research is needed, the authors believe it is likely that the use of multiple fuel types for a variety of distances and payload types will minimize carbon emissions and cost.

I. Nomenclature

SAF = sustainable aviation fuel
H2ICE = hydrogen internal combustion engine
GED = gravimetric energy density
VED = volumetric energy density
SST = supersonic transport
NO_x = Nitrogen Dioxides

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II. Introduction

A commercial supersonic jet is a plane that can travel long distances in a short period of time while carrying a passenger load. These planes achieve this by traveling at supersonic speeds (speeds that exceed the speed of sound) for a significant part of their journey. The history of supersonic passenger jets has been partially successful over the years, with their downfall mainly attributed to noise pollution. When breaching the sound barrier, the planes produced a sonic boom, an extremely loud and impulsive sound- near civilian airspace. The discomfort caused by vibrations and sound pollution, rather than the general ability of the planes to transport populations in a significantly shorter amount of time than regular aircraft, was the primary factor in their fall from popularity.

Fig. 1 Concorde in Flight [1]

Despite this primary challenge, an additional significant challenge to the success of supersonic planes is fuel. A regular plane requires fuel to have a high energy density, be economically affordable, and be stable in a plane and during production. These requirements become more noticeable/important for supersonic planes which need to travel at extremely high velocities for an extended period, requiring fuel with a large energy density and thermal stability to sustain the aircraft's high consumption and intense environment. In the past supersonic planes such as military aircraft and Concorde used Jet A-1 fuel [1]. This application, while adequate, was costly and needed in large supply. [2]

The standard for supersonic transport and valued parameters has changed over the years. As technology to reduce the threat of sonic booms is being developed, the next largest problem to overcome is the inadequate usage of fuel.

As the sizes and transport requirements of supersonic passenger jets are changing, historic and modern research into jet fuel developments and alternatives are applicable and should be considered in the generation of new supersonic transport jets. Commercial SSTs must accomplish a unique set of goals- they must be lightweight enough to travel long distances at a high speed and large enough to carry a passenger load, while balancing economics and sustainability parameters. This paper is designed to compare the most promising fuel sources for commercial SST amongst a variety of objectives.

In our comparison, we investigated all possible chemical propulsion fuel types. Although alternative propulsion systems driven by sources such as solar panels and nuclear reactions have been theorized, only chemical propulsion contains a large enough energy density as required for SST. The chemical propulsion fuel types we found worth mentioning are kerosene derivatives such as Jet-A and JP-8, sustainable aviation fuels, (SAF's), and hydrogen combustion.

The chosen fuel types were then examined through objectives in both the production and consumption stages of their use, deriving parameters to determine their performance in each objective. This paper will present Production performances of each fuel in a matrix design, then discuss the contributing reasons for each fuel type's performance, repeating the same for the consumption stage. Objectives observed during production include Ease of Storage, Cost, and Sustainability. The objectives observed during consumption include Sustainability, Health Effects, and Payload Capabilities.

III. History and Relevant Challenges

After Chuck Yeager's record-breaking flight proving that the sound barrier could be broken, the push for a supersonic form of transportation became too great to ignore. All over the world countries attempted to create a supersonic airliner. France, Great Britten and the USSR would all attempt to develop an SST program, and the US would follow developing a program of their own. However, this program would be very short lived as congress cut funding [3]. The USSR was the first to run an SST program, but it was soon halted due to the USSR not having much of an audience for supersonic travel. Air France and British airways would then begin running the Concorde service in 1976. Very quicky these flights would be banned over land due to the loud sonic booms. This change would not ground the Concorde however, the Concorde would continue to fly until 2003. The eventual demise of the Concorde was due to how expensive it was to operate, which was only multiplied by the restricted flight paths. The crash of a Concorde in France paired with the 9/11 terrorist attacks would eventually put the final nail in the coffin [4]. Following the end of the Concorde program supersonic transports would no longer be available.

Although the banning of supersonic flights over land was a massive blow to the success of SSTs this is not the only reason for the collapse of this form of transportation. A large portion of the allotted friction can also be accredited to the sub optimal fuel sources in production and use. In breaking down the downfalls of SSTs the volumetric issues caused by restricted flight paths did significantly impact the price and profitability of these aircraft. However, as the feat of silencing the sonic boom is incredibly daunting, it will not be the focus of this paper. Instead, in order to chip away at the issues of SSTs, we will examine how different fuels can be used to optimize within the restricted flight paths.

The issues SSTs faced fuel-wise were in price and sustainability. If the Concorde is taken as a case study, it can be concluded that the large fuel use contributed to the high price of tickets. This combined with the plane needing to be narrower to reach supersonic speeds meant very few people could fly in the plane, limiting the profitability of the service [5]. The Concorde had issues with fuel burning. In taxi, climb and descent the Concorde had very poor fuel economics. The massive fuel use in these stages of flight contributed greatly to the harmful emissions and the cost per flight; to account for the copious fuel burning, more fuel had to be stored in the aircraft. For these reasons if commercial supersonic aircraft are to be revived with flight path restrictions in place it is momentous that the fuel use is optimized.

Recently, there has been a push for revitalization of commercial supersonic flight as many different companies have made an effort to rebuild this industry. Boom Supersonic, based out of Colorado, has committed to developing an SST that runs completely on SAFs. Hermeus corporation is in the process of developing hypersonic transport aircraft and has paired with Pratt and Whittney to develop an engine. As legislation banning sonic booms over land is still in effect NASA has paired with Lockheed Martin’s Skunk Works in developing the QUESST project to develop a method to dampen sonic booms and to survey their effect over land [6]. This research shows that STT innovations are actively ongoing.

Although it is not in the scope of this paper, the current SST innovations are also powered by separate engine types (Turbojet, turbofan, Ramjet, etc.) and fuselage parameters- which will affect the fuel efficiency and fuel economy on a fuel-by-fuel basis. We choose not to factor this into our conclusions.

IV. Review of Fuels

The following fuels have been selected based on current research and development. Kerosene based fuels will act as a control group and serve as a basis of comparison for the other selected fuels. SAFs and Hydrogen have been selected because of their energy capabilities, current use in aviation, and as their focus in aviation research [Fig. 2].

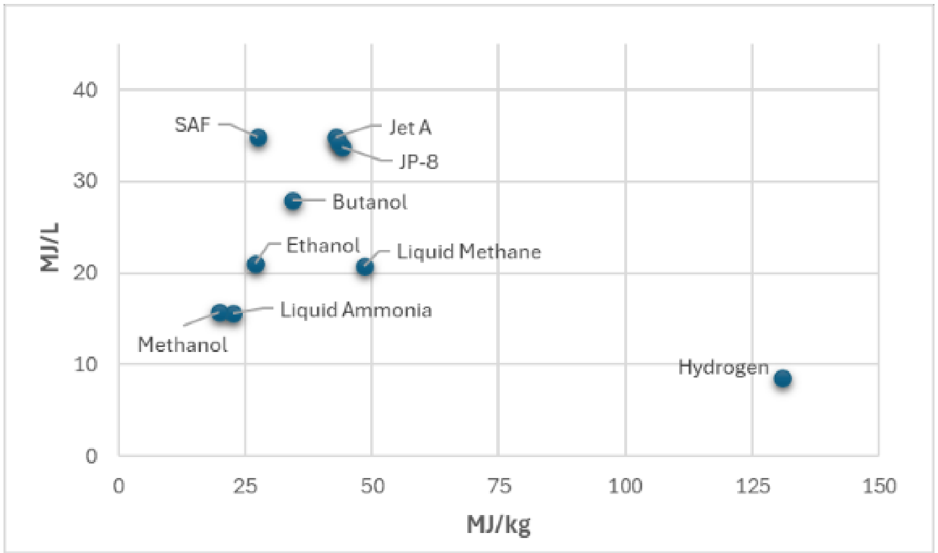

Fig. 2 Volumetric and gravimetric energy densities of proposed alternative aviation fuels. Adapted from [7].

In the case of expanding the scope of this paper the authors would include more fuel types, however due to limited knowledge on additional alternative fuel types this paper will only focus on kerosene-based fuels, SAFs, and hydrogen.

A. Kerosene-Based Fuels

Kerosene is the most common form of jet fuel created in the crude oil refining process. This process consists of drilling crude oil, sending it to a refinery, and distilling said fuel in atmospheric distilling units [8]. The distillation process is what sets different kerosene-based fuels apart. Once Kerosene is extracted it is treated with additives to create various jet fuels. The most common for usage in jet aircraft are Jet-A and JP-8, the focus of our research. In flight these fuels are sprayed into the combustion chamber of the engine of the aircraft, then the fuels are mixed with compressed air and ignited to produce thrust. JP-8 is the military equivalent of Jet-A and contains additives that enhance its performance, such as lowering its freezing point [9]. These fuels will act as a control variable in our examination.

Past SSTs used derivatives of these fuels- it can be determined that an alternate fuel must have similar or enhanced characteristics when compared against Jet-A and JP-8. For the sake of data collection these two fuels will be averaged to represent the characteristics of kerosene-based fuels. In circumstances where data is not available for Jet-A or JP-8 individually, but it is available for general kerosene, that data is used as representative.

B. Hydrogen

Hydrogen can be used as a direct fuel or a source of electrical power in aircraft. As a direct fuel it is combusted in hydrogen internal combustion engines, (H2ICE). These engines work very similarly to the standard gas-turbine engines used in commercial aircraft today, only slightly modified. While the standard engine injects kerosene-based fuels into the engine to be burned, H2ICE injects hydrogen [10]. This technology has been explored for a multitude of reasons. Primarily, these engines have significantly cleaner emissions when compared to the standard jet engine [11]. H2ICE engines only emit water vapor and a minor number of other particulates. However, the main adversary to the exploration of this technology arises in the payload capabilities and the conversion to this fuel type.

Additionally, the water vapor output increases contrail formation, which can accelerate the greenhouse effect. While hydrogens energy density is sufficient, these aircraft require larger fuel tanks. Hydrogen combustion is being researched by many companies including Pratt and Whitney, General Electric and Rolls Royce. Hydrogen can be produced in a variety of methods categorized by color. Each method has varying CO2 emissions and costs, with Hydrogen production through Natural Gas the most prominent.

Another way hydrogen can be used as a fuel source is in fuel cells. These fuel cells convert oxygen and hydrogen into electricity [12]. These fuel cells are advantageous because as the flight progresses the cells become lighter allowing for more efficient and longer durations of flights [13]. These fuel cells also have very clean emissions, only emitting water vapor. Adversely, a major issue with converting to fuel cells comes with redesigning aircraft in order to support the weight and dimensions of the cells. Redesigning the aircraft with these parameters in mind means that SST- which requires strict aerodynamic parameters- powered by 100% hydrogen fuel cells is not feasible at this time. However, there is evidence to support the use of fuel cells as a secondary or back up fuel source in aircraft in addition to current crude oil-based fuels, boosting efficiency and reducing emissions [14].

For this paper, due to the highly experimental nature of hydrogen fuel cells and lack of significant data, we will not factor fuel cells into the final matrices but felt it was important to mention as they often work in tandem with hydrogen combustion technologies.

C. Sustainable Aviation Fuel

Sustainable aviation fuel (SAF) is an alternative to conventional jet fuel derived from non-petroleum feedstocks. Interest in this fuel type has been driven primarily by its offer of significant reductions in greenhouse gas emissions. SAF can be blended with Jet A fuel in varying proportions and is fully compatible with existing aircraft and infrastructure. Its potential to lower emissions by up to 94% makes it a crucial component of the aviation industry's push for carbon neutrality [15].

SAF is produced from renewable resources such as municipal solid waste, woody biomass, and waste fats and oils. While production is still in its early stages, companies have begun commercial-scale production, supplying major airports [16]. Research continues to enhance feedstock processing and production efficiency to expand SAF availability and reduce costs.

Unlike fossil fuel-based kerosene, which releases carbon that has been stored for millions of years, SAF recycles carbon already present in the biosphere. Certified production pathways ensure SAFs meet operational, and performance standards equivalent to Jet-A fuel, making it a seamless drop-in solution for the aviation industry.

The adoption of SAFs faces economic challenges. Airlines are willing to pay a premium for SAFs, but the high costs will likely be passed on to consumers. Different production methods, blend proportions, and other factors such as governmental encouragement affect the demand for SAFs. Blending SAFs with conventional jet fuel occurs at existing refineries or fuel terminals before transportation to airports, ensuring minimal disruptions to current fuel supply chains.

There are multiple SAF production technologies, with Hydroprocessed Esters and Fatty Acids, (HEFA) and Alcohol-to-Jet, (AtJ) methods representing 70% to 10% of current total output, respectively. Due to the constraints of this paper, we will not break SAF capabilities apart through the different production methods despite the existing tangible differences between each. This paper will take the average of current production technologies and assume 100% SAF usage, despite most agencies and nations having set upcoming standards of minimum 50% SAF usage [17].

V. Objective Definitions

To optimize supersonic transport use of fuel, objectives must be put into place to quantify the effectiveness of the fuel sources. To quantify optimization the following objectives have been used. These objectives are based on what was believed to cause points of stress in past SSTs and potential issues in the future. In examining these objectives, the most optimal fuel source/ characteristics will be able to be determined.

A. Specific Cost

In determining the price of the fuels in the same units we used the **cost specific to energy** or **dollar per megajoule**. Fuels such as Jet A and SAFs are quantified per gallon, while fuel types such as hydrogen are quantified per kilogram, quantifying specific cost in terms of energy content allowed equal determination. We achieved this by taking the price per gallon of the kerosine based fuels and SAFs, converting them to dollar per liter, then divided by the density and the energy density of each corresponding fuels then multiplying by 1000 leaving units of dollars per gigajoule.

$$\frac{\left(\frac{USD}{Gallon}\right)\div\left(\frac{Gallon}{Liter}\right)}{\left(\frac{kg}{Liter}\right)\times\left(\frac{MJ}{kg}\right)}\times 1000 = \mathbf{(\$/GJ)}$$

Fig. 3 Equation to solve for specific cost in dollars per Gigajoule

Since Hydrogen is listed in price per kilogram, we simply divided this price by its GED to achieve our desired specific cost. Specific cost is only determined in the production of fuel- as it will have already been purchased during fuel consumption. This is due to the nature of the price of fuel. Many factors go into this price, primarily production and demand, (secondarily, tax incentives, time of year, etc. also exist and will be elaborated upon).

B. Sustainability

Sustainability is defined by net carbon emissions in both the production and consumption of fuel type. As carbon emissions play a significant role in climate change [18], we quantified emissions through grams CO2 emitted per Mega Joule of fuel. Through the separation of sustainability into production and consumption it is possible to consider the difference in carbon emissions in the production of these fuels as well as in the combustion of the fuels- which is significant as the method of producing a fuel type has a significant effect on the CO2 emissions produced.

C. Health Impacts

In measuring the health impacts, we consider each fuel separately during the fuel production and consumption processes as there are different health risks associated with the fuel in different stages, (that is, liquid and gas). In the production of fuel, we use the inhalation toxicity as a magnitude of harm.

In the consumption stage, we measured the health impacts as the magnitude of yearly premature mortalities due to particulates produced during combustion. It is important to note that all byproducts emitted from the burning of fuel, not including carbon dioxide, nitrogen dioxides, are the most harmful.

Nitrogen Dioxides, commonly referred to as ‘NOx”, constitutes 91% of premature deaths [19]. Other significant particulate emissions include fine particulate matter (PM2.5), and Ozone (O3).

For this reason, health effects were split into partial health effects, (attributes to strictly NOx emissions) and total health effects from complete particulate emissions.

D. Payload Capabilities

Payload Capabilities is how we will determine if the fuels can support supersonic flight. Payload is only in the consumption category, but it had been broken up into density (Kg/L), energy density (MJ/Kg) and volumetric density (MJ/L). These parameters can be used to determine if a fuel is capable to support supersonic flight because all three parameters must be proportional enough that sufficient thrust can be achieved without adding too much weight or size to the aircraft hindering its ability to fly supersonic through significant fuselage and aerodynamic modifications. While these parameters can be lenient in subsonic flight, the condition of supersonic flight narrows the scope. A fuel that is too heavy or too volumetric without providing enough energy or thrust becomes obsolete as higher speeds means higher drag as weight and area significantly impact drag especially around the sound barrier [20, 21].

E. Ease of Storage

To quantify “Ease of Storage” we decided the most accurate way to depict the effort that goes into storing each of our fuel types is by using the temperature range required for safe and effective storage. This range is given by the flash and freeze point of the fuels. For the sake of this paper, we will assume hydrogen is kept at a liquid state, cryogenically cooled. By using storage temperature as a metric for how easy a fuel is to store comparisons can be made and conclusions drawn since a fuel kept at room temperature is very objectively easier to store than one that is kept at 250 degrees Celsius. Storage is only considered in the consumption category since storage on an aircraft is considered payload.

VI. Objective Parameters in Fuel Production

Objective Parameter	Units of Measurement	JP-8	Jet A	Crude Oil Based	SAF (100% Blend)	Hydrogen
Specific Energy Cost	$/GJ	43.84	42.2	43.02	70.36	25 - 59
Sustainability	g CO_2/MJ	17	17	17	0	0 -20
Health Effects	mg/m^3	2	3	2.5	<2.5	0
Ease of Storage	degrees celcius	(-)40 - 38	(-)47 - 38	(-)40 - 38	(-)40 - 38	(-)253 to 120

Fig. 4 Matrix comparing fuel performances in different objective parameters during production

A. Ease of Storage

The ease of storage of the selected fuels says more about capabilities of SAFs than it does about hydrogen. It was expected that hydrogen would take much more effort in storage than the others. Hydrogen as a fuel is stored in its liquid state, requiring cryogenic temperatures [22, 23, 24]. The storage of SAFs is very telling because it gives an insight into the capabilities of these alternative fuels to be interchanged with the standard kerosene-based fuels. Since the majority of SAFs require the same temperatures as kerosene-based fuels and have the same flash point it can be concluded that they can replace kerosene-based fuels with much ease [25].

When looking at the freezing point of these fuels, the kerosene-based fuels with additives (JP-8) outperform SAFs. JP-8 has a freeze point of –47 degrees while SAFs typically have a freeze point of –43.5 degrees Celsius. JP-8 is engineered to have a lower freeze point since it is to be used in high performance military jets [26]. Freeze point is not something that can be glossed over, since higher altitudes are required for supersonic flight, the freeze point of the fuels used must be low enough to support this altitude without causing issues.

B. Specific Cost

The costs between JP-8 and Jet A differ very slightly, with the average cost per Gigajoule of kerosene-based fuel pricing around $43.02 [9, 27]. In comparison, a 100% SAF blend costs roughly $70.36, varying dependent on the feedstock and production type used [28]. However, as most implementing agencies have only approved up to 50%

SAF blend, it can be assumed that the most possible sustainable blend would range between the kerosene-based and 100% SAF fuel prices.

Hydrogen depends significantly on the method used to produce it. The values of 25-59 are the values to produce "clean hydrogen". The cheapest and most carbon emission intensive is Grey Hydrogen, which is produced from natural gas, valued at $0.67-1.31per kilogram compared to Green Hydrogen's $2.28 -7.39 evaluation.

As with all commodities, these fuel prices are subject to fluctuation over time. The average dollar per GH of jet fuel in 2023 measured $20.14 [29], indicating the effects that inflation and further SAF production has on kerosene-based fuel production.

To add, cost evaluation cannot be completed without factoring the existence of hydrogen and SAF production encouragement in the form of tax credits. Since 2022, the United States has implemented a tax credit program to incentivize both Hydrogen and SAF production, acting as a significant contributor to the alternative fuels' production [30].

C. Sustainability

SAFs and Hydrogen both show significant improvements in grams of carbon dioxide per megajoule produced. There are a range of values for carbon emissions for SAFs and hydrogen due to the different methods of production; to combat this, the minimum possible value was used. Some methods of producing hydrogen and SAFs emit carbon dioxide but since it is possible to create these fuels without a carbon footprint this was noted. Depending on production type both SAFs and hydrogen fuels emit zero grams of carbon dioxide per megajoule produced [31, 32]. In terms of sustainability in the production process, alternative fuels such as SAFs or hydrogen are the most optimal.

D. Health Effects

Kerosene based fuels have a minimal risk level of 2.5 between the average of Jet-A and JP-8. While there is concrete data for JP-8, there is no official minimal risk level for Jet-A- the authors took the liberty of assigning a value of 2, the same as JP-5 due to their chemical similarities. JP-8 presents lower toxicity than Jet-A. While there is minimal data for SAFs, there is evidence to suggest a lower inhalation and toxicity risk. Most adverse health effects are the same and are not slightly reduced when compared to JP-8 and Jet-A, and SAFs are absent of several carcinogens apparent in kerosene-based fuels, such as benzene. Also, when FT-SPK is mixed in a 50:50 JP-8 blend lower dermal irritation is induced on exposure [33].

Hydrogen has no minimal risk level and is considered nontoxic [34].

VII. Objective Performances in Fuel Consumption

Objective Parameter		Units of Measurement	JP-8	Jet A	Kerosene Based	SAF	Hydrogen
Sustainability		g CO_2/MJ	73	73	73	73	0
Partial Health Effects		Nox attributed	1100	1100	1100	1100	100-120
Total Health Effects		Total particulate attributed	1200	1200	1200	1100-1200	-
Payload	Density	kg/liter	0.788-0.845	0.775-0.840	0.7815 - 0.8425	0.757 - 0.805	0.09
	Gravimetric Energy Density	MJ/Kg	44	42.8	43.5	25-30	120-142
	Volumetric Energy Density	MJ/L	33.7	34.9	34.3	34.8	8.5

Fig. 5 Matrix comparing fuel performances in different objective parameters during consumption

A. Sustainability

Kerosene-based fuels and SAFs have significant carbon emissions when combusted, especially in comparison to hydrogen fuels. Kerosene-based fuels emit 73 grams of carbon dioxide in combustion while hydrogen emits virtually zero in combustion [31, 35]. SAFs emit virtually the same amount of carbon dioxide as kerosene-based fuels in consumption. Although kerosene-based fuels are very efficient and are fairly cheap it is not necessarily absurd to say that maybe environmental impact should play a role in aircraft fuel selection.

B. Health Effects

NOx attributed premature mortalities, which contribute to a majority of premature mortalities, were found to not differ noticeably between Kerosene based fuels and SAF. There is evidence to suggest that Hydrogen powered aircraft could contribute to an 86% reduction in NOx levels, (in addition to the obvious in increased water vapor emission).[36] This reduction was quantified as an artificially calculated range in possible NOx emissions.

However, in total aerosol attributed premature mortalities, there was a minor reduction in SAFs compared to Kerosene based fuels, notably due to the difference in compositions. [37] The source utilized both a 5% and a 50% blend of SAFs-JP8 to compare, and in the 50% blend there was a significant decline in PM2.5 premature mortalities. There is not significant data to state whether Hydrogen fuel would directly reduce or erase non-NO_2 emissions, although it can be assumed that as kerosene powered planes emit chemicals such as CO_2, Co, NO_x, SO_x and more, and hydrogen produces only H_2O and NO_x as waste products, in theory, hydrogen combustion should not emit particulate matter. Additionally, new research is revealing innovations in minimizing NO_x emissions to the point of near zero. [38]

While health effects quantify the magnitude of potential harm a fuel can cause to human health, it is important to note that due to the nature of supersonic transport in their elevation, the NO_x emissions could potentially affect stratospheric ozone and climate [39]. "With a potential range of cruise altitudes from 13 to 23 km, the majority of emissions from supersonic aircraft would occur in the stratosphere and would have longer atmospheric lifetimes than the emissions occurring from subsonic aircraft that primarily fly in the troposphere." Additionally, potential climate concerns from SST emissions arise both from the direct effects of H_2O emission, as well as the distribution of additional ozone. [39] H_2O emissions in the form of ice crystals are accelerators of global warming due to their ability to form contrails and trap heat in the atmosphere. [40] Despite their minimal to zero output of CO_2, hydrogen powered flight is still likely to produce quantifiable acceleration to global warming- albeit at a rate lower than kerosene-based fuels.

C. Payload

Some key distinctions can be made from the payload capabilities of the selected fuels. Most notably the similarities between the kerosine-based and SAFs and the high GED of hydrogen. SAFs are designed to perform like kerosene-based fuels and thus they have similar specifications in terms of density and VED [26, 41, 42, 43, 44]. It is noted that SAFs typically have a lower GED of about 10 Mega Joules per kilogram [45, 46, 47]. This means more kilograms of SAFs are required to match the energy density of kerosene-based fuels. While this might not make a significant difference in subsonic flight, weight significantly impacts the performance of the aircraft in high drag situations like accelerating through the sound barrier.

The high GED of hydrogen is also very apparent. While kerosene-based fuels and SAFs have a GED range of about 30-50 megajoules per kilogram hydrogen has a towering GED of 120 megajoules per kilogram [48]. However, volumetrically it takes up significant space. Hydrogens VED is only about 8.5 megajoules per liter [12]. In comparison with kerosene's and SAF's VED of about 35 megajoules per kilogram. Past SST such as Concorde, in their usage of kerosene derivates, faced significant fuel storage issues limiting cabin space and increasing drag- this raises questions on the feasibility of extremely low volumetric density Hydrogen efficiently powered SST.

VIII. Limitations

Many limitations arise in the collection and analysis of fuel data, particularly due to the newly experimental and freshly theorized ideas. One such limitation is in collecting the cost of the fuels, specifically hydrogen. Since hydrogen fuel for aviation is considerably new and experimental the price for this fuel type is not completely understood. On top of the unit conversion discrepancies, data on the price of hydrogen by the kilogram poses a very broad range. Once hydrogen is used more commonly used for aviation the price should be more easily accessible and a better comparison will be able to be made between the price of hydrogen, SAFs and kerosene-based fuels.

The broadness of SAFs also causes some issues in data collection. There is no singular SAF fuel, so wide ranges of data can be found based on the specific type of SAF used in data collection. The choice to generalize and take SAFs instead of breaking them into different types poses issues in data collection- but we feel that our data represents the potential of this fuel source. Although the generalization of an entire fuel source does not provide the most accurate data it does give a solid estimate of what can be done.

IX. Conclusion

Despite some complications in data collection, this paper still provides an important metric for synthesizing the optimization of aircraft fuels. This topic raised by the discontinuation of SSTs does not only apply to supersonic flight. The implementation of alternative fuels requires more research but poses a very bright future for the aviation industry. It is determined there is no one best fuel for supersonic flight but rather it depends on what fuel qualities are most important to manufacturers. If cost is the highest priority, it is safe to stay with kerosene-based fuels. If sustainability is more of the focus, then alternative fuels should be investigated. While hydrogen and SAFs may not be as efficient and cost effective as kerosene-based fuels- due to their potential it is crucial that these alternatives are researched more.

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