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Sky Clear 2040

Reducing half of aviation's impact on the environment

Usaire Student Awards 2024

Introduction

The history of aviation has always been subject to complex **global challenges**. The most recent of them is a united effort to combat its impact on **climate change**, with an ambitious target of achieving **net zero carbon emissions by 2050** [1]. This goal, initially set by the industry, has also been endorsed by governments during the 41st Assembly of the International Civil Aviation Organization (ICAO) in 2022 [2]. Achieving this target will require the development of new energy sources, technological advancements, and improvements in fuel efficiency to **reduce carbon dioxide** (CO2) emissions from aircraft operations. While this is a great challenge, it is one that is well understood, with ongoing progress being made. With the right policies, commitment, and determination, the path to decarbonizing civil aviation will have us transition from fossil fuels to sustainable aviation fuels (SAF) and finally alternative energy sources like hydrogen [3][4].

However, in addition to CO2 emissions, the aviation industry is also addressing another climate impact that is less understood and has fewer developed solutions: the effects of other aviation-related emissions on the atmosphere. Among these non-CO2 emissions, **condensation trails**, or contrails (the visible white streaks in the sky that are essentially artificial clouds) are believed to have the most significant warming effect [5]. This potential of warming comes from the **persistence** of this condensation trails in the upper parts of the atmosphere: this is the *Cirrus Homogenitus* (literally the cirrus generated by human).

This paper will examine the current state of scientific knowledge regarding the climate impact of contrails before presenting what we believe is a **startup idea** that will disrupt de aerospace industry by 2040. This paper's purpose is informative but can also serve as an **investment recommendation** document that studies the value proposition of our idea and incites investment for the first stages of research and development.

Therefore, we will present in this document **Sky Clear 2040**, a deep-technology startup with the ambitious goal of cutting down half of aviation's impact by tackling contrails.

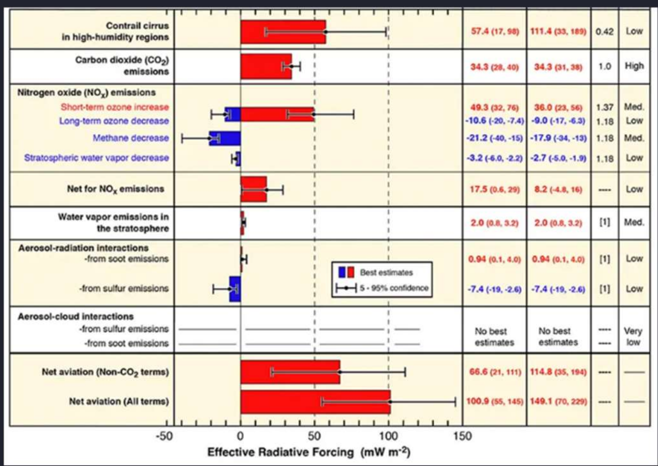
The contrail climate challenge

In addition to CO2 emissions, aviation, like many other sectors, contributes to various "non-CO2 effects" that impact the climate. These effects arise from complex interactions between aircraft emissions and the **atmosphere**, primarily involving soot particles, nitrogen oxides (NOx), and sulphur oxides (SOx). **Soot particles** result from the composition of carbon-based aviation fuel and the combustion technology used; **NOx** emissions are generated by high-temperature combustion; and **SOx** emissions stem from the sulphur content in the fuel. The aviation industry has long been committed to developing innovative combustion technologies to reduce soot particulates and NOx emissions, both of which are known to have significant climate impacts [5].

Water vapor, another byproduct of fuel combustion, can lead to the formation of condensation trails, or 'contrails,' which consist of ice crystals. Contrails form during flight when ambient conditions and atmospheric water vapor levels are conducive to the **condensation of water vapor** from the engine exhaust. As small carbon particles are released from the aircraft's exhaust, water vapor can condense on these particles, along with naturally occurring aerosols, leading to the formation of **high-altitude ice clouds**. While some of these clouds dissipate within seconds, others can persist for hours and spread across large areas if the air is sufficiently humid and cold [6]. Efforts today to prevent the formation of persistent contrails and their significant climate impacts include: the use of alternative fuels, advanced combustion technology, and especially trajectory modifications.

A dual phenomenon

The complexity in measuring accurately the impact on contrails arises from the fact that not all contrails contribute to warming. Some dissipate within minutes, while others may have a cooling effect or balance both cooling and warming impacts. However, a small percentage of contrails are responsible for a significant warming effect. The established scientific consensus indicates that, overall, **contrails tend to have a net warming impact** when considered collectively [8].



Global aviation effective radiative forcing [5]

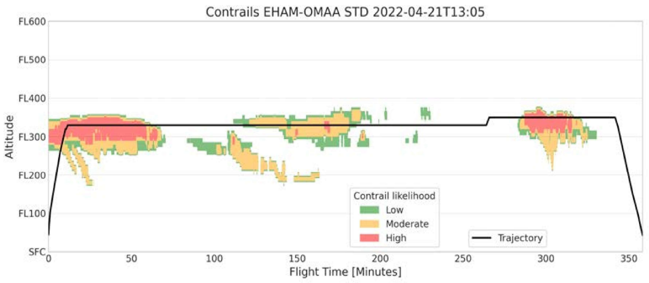
As it is proven by this study, contrail cirrus takes a great role in contributing to global warming. The effective **radiative forcing** due to contrails is up to 86% of the non-CO2 impact and up to 57% of the net aviation impact [5].

Today's contrail avoidance strategies

One rapidly developing method involves **adjusting flight paths** to avoid atmospheric conditions conducive to contrail formation [2]. Airlines and air traffic controllers use advanced weather forecasting and atmospheric data to identify and navigate around regions with high humidity and low temperatures where contrails are likely to form. This strategy involves dynamic route planning to detect and avoid **ice super-saturated regions (ISSR)** and altitude/trajectory adjustments [7]. This solution is today considered as the best short-term contrail mitigation technique thanks to two major improvements in the past years [7]:

Improved detection of ISSR

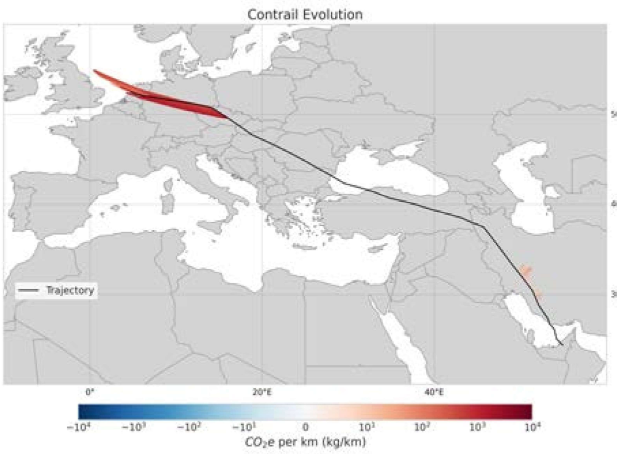
The hardest part of the contrail avoidance solution is the identification of ice super-saturated regions. Advanced computer models are being developed to forecast where and when ISSRs are likely to form [7]. Further progress will be made thanks to new sensors on board the aircraft for humidity and better atmospheric measurements.



Vertical profile of likelihood of contrail formation along a sample flight [8]

New CO2 equivalent for contrails

Airlines have started working with startups specialised in contrail avoidance software, including the conversion into **CO2 equivalent** that can be monetised and bring economical value to those airlines who monitor and reduce the climate impact of their contrails [4].

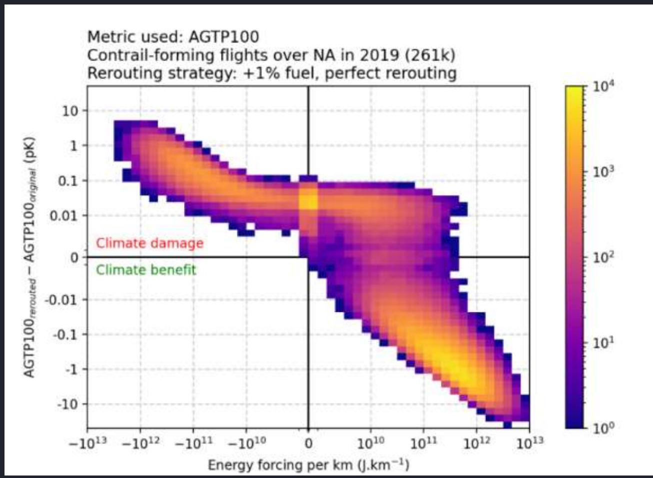


Climate impact of contrails displayed as C02 equivalent per km [8]

A solution with problematic side-effects

Additional Fuel Consumption

To avoid ISSRs, the aircraft must be re-routed above or below those regions. These changes in flight routing **increase fuel use** by 1-2% [9]. The overall climate benefit of deviating a flight will then be very variable, as shown in the figure below, with a significant amount of deviations that cause **more damage than good** to the climate.



Impact on the climate (benefit or damage) of trajectory modifications [17]

Operational Constraints

Another important constraint that limits the **scalability of this solution**, is that this would not be possible today in crowded airspace systems (for example over Central Europe, the North Atlantic or the US) in a safe viable way.

We could make the parallel with Continuous Climb (CCO) and descent operation (CDO). The practical application of these two procedures was, on paper, supposed to be easily implemented. However, after almost two decades since they were implemented, they still struggle to be followed by every airport and air traffic control operators. A good example is CDG airport where it was less than 3% in 2022 [10].

Furthermore, in the case of rerouting to avoid the formation of persistent contrails, this might be way more complex and induce new training for pilots and ATC. Today, this issue is of little importance because of the very small number of flights that apply contrail avoidance strategies. However, we decided to come up with a different approach that is not based around the detection and avoidance of ISSR but rather on the destruction of the ice-particles that could become condensation trails.

Our proposed solution for 2040

We propose a **ground-breaking product** inspired by research conducted by Cranfield University. This solution aims to mitigate the formation of contrails by leveraging advanced ultrasound technology [13].

Our project is to develop an advanced **ultrasound generator,** equipped with an ultrasonic actuator and a waveguide, designed to target, and disrupt contrail formation directly at the exhaust plume of an aircraft engine. This state-of-the-art technology employs ultrasound waves to **prevent the condensation of water vapor** and the formation of ice particles thanks to the fragmentation of ice into smaller particles within the exhaust [11]. This innovative approach not only provides a direct mechanism for combating contrail formation at the source but also represents a shift in how we address aviation-induced non-CO2 emissions: by integrating our ultrasound generator into the structure of the aircraft, we move beyond merely avoiding condensation zones to actively preventing the creation of contrails and induced cirrus clouds, offering a significant advancement in sustainable aviation technology.

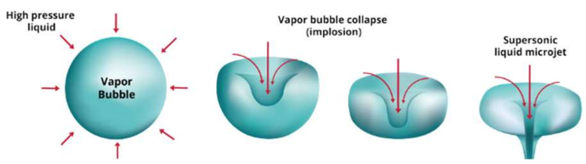
How Does it Work?

The ultrasound waves function in two primary ways to combat contrail formation:

Cavitation and Vaporization: Ultrasound-induced cavitation within the liquid water layer of nascent contrail particles facilitates their disintegration [7]. Depending on the atmospheric conditions and exhaust composition, the waves may also vaporize water condensate, thereby preventing the condensation of water and the coagulation of particles into larger ice crystals.

Particle Disintegration: The ultrasound waves directly break down small particles in the exhaust, such as soot and aerosols. This prevents these particles from serving as nuclei for ice formation [8].

With power outputs ranging from 100W to 10kW, the ultrasound generator induces vibrations that effectively **evaporate ice particles**. By ensuring that condensation does not occur—since the liquid phase of water is crucial for ice particle formation—our device represents a radical departure from existing solutions that merely attempt to avoid condensation zones [8].



Step-by-step ultra-sound induced cavitation within a liquid [12]

Power modulator: Transports the electrical input to the ultrasonic transducer/modulator that produces ultrasonic waves.

Control unit: Manage the activation and deactivation of the device given various atmospheric parameters.

Ultrasonic actuator: To generate ultrasonic waves

Humidity/Temperature sensor: Necessary to detect condensation trail formation zones.

Waveguide: Focuses the ultrasonic waves into a suitable ultrasonic wave beam for the plume and contrail characteristics.

On board camera (optional): Could facilitate and/or confirm the presence of contrails. Atmospheric analysis will still be necessary to know if these condensation trails will be persistent.

Theoretical main components of the contrail mitigation system

Addressing main concerns

Power consumption: Electrical power for the device is supplied by the engines or auxiliary power unit (APU) to the power amplifier/modulator in the form of alternating or direct current and is transformed to a high voltage. The ultrasonic generator will require power in the range of some hundred Watt to some kW (our estimation from the components energy requirements) which is an **insignificant** fraction of the aircraft's power supply, especially considering that the device will be used with engines running in cruise conditions [source].

Additional Weight: Weight characteristics of the device still must be detailed. Current weight of the above presented parts in addition to a protective structure allow us to estimate the device somewhere between 20 kg and 100 kg. This additional weight should be compensated by the major prospect of completely removing contrail formation (or at least significantly reducing it).

System integration: The control unit of this contrail avoidance device communicates with other avionics and sensors onboard.

Synergy with previous solution

On board sensors measure the ambient temperature, pressure, and humidity. Other sensors measure engine performance and are a common aspect of modern gas turbine engines and aircraft.

Depending on the contrail avoidance software calculations, it is decided whether contrail formation is possible, as shown in figure. In addition, a camera could observe the engine plume for contrail formation and serve as a concrete proof of the prediction (see section above).

However, the aircraft would still need humidity measurements to decide over whether the contrail is persistent or not. If the conditions for persistent contrail formation are satisfied, the contrail avoidance device is switched on until measurements indicate that the formation of persistent contrails is no longer possible.

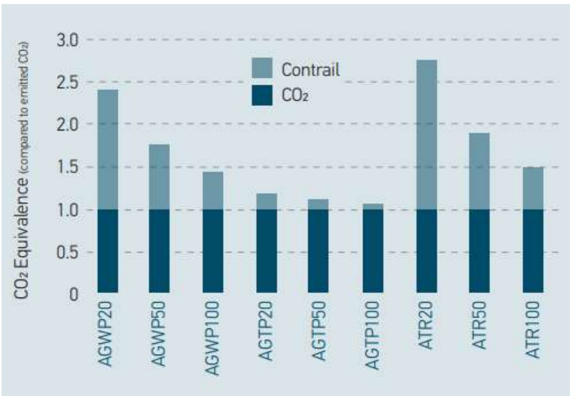
Why is there a worthwhile business case?

While the long-term climate impact of CO2 is well understood, contrails have a much **shorter-lived effect**, lasting only minutes to hours [6]. As a result, their total **impact on the climate varies** depending on the time frame considered. Commonly used metrics such as Global Warming Potential (GWP), Average Temperature Response (ATR), and Global Temperature Potential (GTP) can be calculated over different intervals (often 20, 50, or 100 years) each offering a different perspective on the impact of CO2 and non-CO2 emissions over that period. For instance, the climate impact of contrails can vary significantly, ranging from 2.3 times that of CO2 to less than half that of CO2 [14], depending on the selected metric and time frame, as shown in the figure below.

To evaluate an order of magnitude of the projected market some landmarks, hypothesis and background were necessary to took on: the evolution of the market, the emissions induced, the non-CO2 effect, and finally the price imposed by the policy makers.

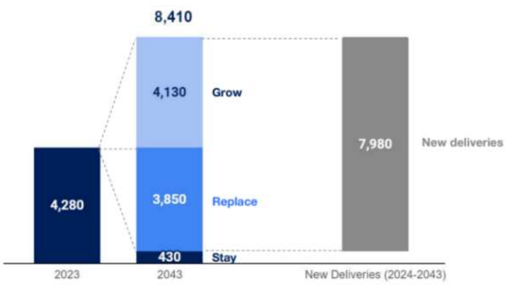
Measured Global Impact:

From a global view, contrails account for **652 million tons of carbon dioxide equivalent** each year. Conservative estimates calculate today that this is 35% of aviation's climate footprint [15].



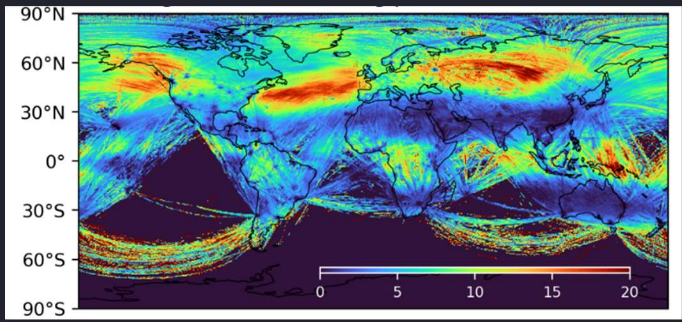
CO2 equivalence for contrails compared to C02 [17]

Evolution of the market: The market is about to double according to Airbus and Boeing forecast [10]. Going from about **24000 aircraft to 42000**. Moreover, this duplication is homogenous: the wide body aircraft will double overall as well.



Global Market Forecast for the 2024-2040 period

This fleet renewal and growth of **wide body aircrafts** is the most important in the case of contrails, because of their trajectory, tend to emit more contrails than singles aisle aircraft [6].



Different flight distances forming persistent contrails (as a percentage) [6]

However, these conclusions must be tempered, and that is where and why investment is needed: data.

The EFcontrail per contrail length also tends to be large over The Atlantic and Indian Ocean, Sahara, central Europe, and Greenland [6]. Consequently, a focus on single aisle going over these lands is also necessary.

Emissions

652 million tons of CO2e are effectively due to contrails [17]. This number is less or more what was the CO2 emissions for 2019.

Indeed, 3 scenarios will then be possible: from half to the double of the 652 million tons of CO2e due to contrails. Lacking data, we will fix our forecast to this number. Taking into consideration the growth of the market and the uncertainties about the renewal of the fleet and the according impact on contrails emissions.

For CO2, thus, **this remains an order of magnitude,** that can be divided or multiplied by two and so will for our forecast.

Policy makers

The effect of condensation trails is **just starting to be considered by regulators and institutions.** ICAO brought back the issue to debate on the 2019 Environmental Report. Raising the **uncertainties about the development of persistent Contrail** Cirrus and therefore the need to delve into it.

However, even if regulation is advancing in a way that favours research and development of ways to mitigate contrails, this incertitude about how this can be measured lead to two strategies:

IATA wants policy makers to wait for research, understanding and creating policies consequently. Overall, the Report on the Air Transport Industry at the 80th IATA AGM shows reluctance to already set deadlines [18].

While **European** policy makers see it in another way, announcing a legislation in coming so that research Poles put in the work to understand non Co2 effects and to tackle them with the **Non Co2 MRV** [19].

The contractor must collect, store, include on appropriate interfaces for **collecting large amounts of data**. Moreover, these data must be associated with models for MRV nonCO2 effects to allow the calculation of non-CO2 equivalents per flight.

This model of MRV is also already, more and more followed on a global scale with CORSIA. [14] We wonder if this model will be used as well for non Co2 MRV. This will be at stake during the 2024 ICAO Symposium on Non-CO_2 Aviation Emissions, taking place mid-September. Examining the formation and the **impact of contrails is already on the agenda** [20]. This will lead to discussions about ways of mitigating them and partnerships required to succeed.

Steps which airlines are about to undergo in the ETS system (that might be a similar with the Corsia system in the following years) [19]:

• *By 31 August 2024* – Implementing act including non-CO2 effects in MRV framework

enabling CO2e per flight to be produced.

• *From 1 January 2025* – MS shall ensure that each aircraft operator monitors and

reports the non-CO2 effects from each aircraft.

• *From 2026* – EC will publish the results from the MRV framework once a year.

• *By 31 December 2027* – based on the results of the MRV of non-CO2 aviation effects,

the EC will submit a report and, if appropriate, a legislative proposal after having

carried out an impact assessment to mitigate such effects by expanding the scope of

the EU ETS to include non-CO2 aviation effects.

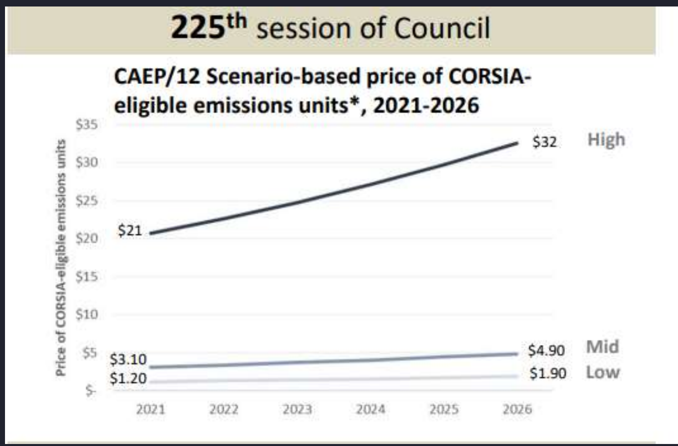
• *By 1 January 2028*, building on the results of that framework, **the Commission will propose, where appropriate, mitigation measures for non-CO2 aviation effects.**

Regardless of the strategy, this falls within the scope of the

The price of emitting contrails:

If the equivalence is effective, the non Co2 bill will also have to be paid. 3 scenarios are at stake: low, mid and high and so is our forecast. We followed two hypotheses:

-the prices will keep rising at the same pace for each scenario:



Corsia unit Price evolution forecast for the 2021-2026 period [21]

-the unit pricing for eCo2 will be the same as Co2 (the following chart is the product of 652 million tons of Eco2 by each price taking the evolution of it into account):

Global Corsia market for non-Co2 credits (contrails only) in dollars (US)

Which means, all hypotheses considered: the market will represent at the very least 4,2 billion in 2041 and up to more than 50 billion (about 88) in 2041. Consequently, there is also a great economic incentive to work hard on this matter, in addition to all the reasons above.

Airlines:

Airlines are the ones that are going to be hit very hard with the bill of contrails emissions. Consequently, rather than just see it coming, they should and are already investing in research for non Co2 effects of their aircrafts.

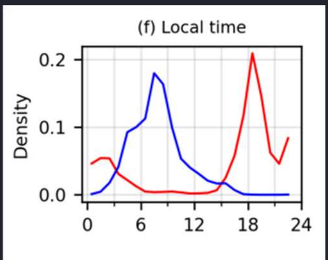
In Europe, they tend to unite their forces in research Infrastructure such as **IAGOS** [22] (In-service Aircraft for a Global Observing System), powered by the French National Centre for Scientific Research (CNRS). Some airlines have already showed their interest by equipping at least one aircraft of **sensors** focus on atmosphere humidity which helps to **determine the ISSR.** For information, these sensors were proven to be non-significant for the operational cost of these flights (impact on drag is negligible). Some European majors like Air France, Lufthansa, and Iberia are in the research group. **Air France** goes even further with the **COOP** (COntrail Observation Program) to collect data and observations on contrails and share them with Météo France and Google research. They designed tests where they integrated dispatcher and pilots in the process. In the **US**, Similar tests were conducted as well by **American airlines with Google** and Breakthrough Energy [7].

Tech Pole:

As it is revealed by the previous paragraph, research is a team effort. While airlines create the impulsion because they are to undergo costly policies. Tech companies boost it with investment, deep tech, and AI, and above all play the role of an orchestra conductor. The biggest tech actor investing in research about contrails mitigation is Google, as mentioned in the previous paragraph. The project is called **Project Contrails**: *A cost-effective and scalable way AI is helping to mitigate aviation's climate impact*. They invest massive time and money to detect ISSR, and train AI to identify persistent contrails and reroute consequently.

How can we use these breakthroughs it in our project?

As it is revealed by this paper [6], "around 14 % of all flights in 2019 formed a contrail with a net warming effect, yet only 2 % of all flights caused 80 % of the annual contrail energy forcing". The following graphic illustrates the link with precise parameters, such as the **strong dependency on the local time** of the effect induce by contrails (red: warming effect, blue: cooling effect). Focusing on such parameters will **avoid being counterproductive.**



Dependance on the effect of contrails with the local time [6]

If the device is **disposable** :

Even if technically, this is very unlikely to happen, if the device is disposable, **we put it when and where it is needed.** If, thanks to data, persistent contrails are to be emitted on a flight, the device is put on the aircraft.

If the device is **not disposable** :

It is not a real obstacle to its efficacity. Indeed, to optimise their operations, a particular **airplane of an airline is often dedicated to go to some places over and over** again. Even if this is optimised so that the plane fly as much as possible, we should use this operational segmentation to implement our device. Thanks to data, the airplanes taking most routes which are known to create persistent contrails should be the ones equipped with the device. Exactly like the A332 of Air France in the IAGOS which is mainly going to African countries and chosen on purpose for the research.

Therefore, even if the mass of the device is non-significant compared to the benefits permitted by it, it should not be forgotten. As well as the drag induced, wherever the device is put on. This needs to be taken into consideration in all the optimisation process (to maximise the profit).

Market overview synthesis: PESTEL Analysis

Political Factors

-The regulatory environment is always an important factor for any deep-tech venture. Aviation regulations worldwide (FAA, EASA, CAAC) provide the necessary certification to prove that our device respects strict safety standards.
-Government Support: They provide grants and credibility to the project.
-International Agreements: ETS and Corsia particularly will fundamentally encourage airlines to invest in solutions that reduce CO2 and non-CO2 emissions.

Potential positive impact
+Supportive regulatory and political environment enhances the possibility of access to grants.
+International regulation in aviation will encourage airlines to tackle condensation trails.

Potential negative impact
-Certification can be a long and tedious project for an innovative device.
-Non-CO2 emissions calculation in CO2 equivalent is still a big unknown for ETS and Corsia.

Economic Factors

-Fuel Costs: Rising fuel costs encourage airlines to adopt technologies that can reduce operational inefficiencies and environmental impacts.
-Macro-economic context: Economic downturns can lead to reduced air travel and budget cuts within airlines, potentially delaying investments in new technologies.
-Investment in climate: Growing interest in sustainable investments can provide access to capital and favorable funding conditions for deep-tech startups.

Potential positive impact:
High fuel costs and favorable investment climate can drive demand for cost-saving and eco-friendly technologies.

Potential negative impact:
Future economic recessions may reduce immediate investment capacity.

Social Factors

-Public Awareness: Increasing public awareness and concern about aviation impact on climate that can go as far as to avoid using air transportation (air bashing).
-Corporate Social Responsibility (CSR): Airlines and aircraft manufacturers are under pressure to demonstrate to the public their commitment to sustainability and corporate social responsibility.

Potential positive impact:
Visible solution to airlines impact on the climate that can be easily marketed and publicized

Potential positive impact:
Failure to meet public expectations could lead to reputational risks.

Technological Factors

-Innovating propulsion: Rapid technological advancements in the aviation industry, including hydrogen powered aircraft.

-Research and Development (R&D) in contrail formation: Important R&D efforts are currently being made to quantify more precisely what is the impact of condensation trail and induced cirrus.

-Integration with existing systems: Compatibility and integration with existing aircraft systems and operations are critical for adoption.

Potential positive impact:
+Condensation trail research is a leading force in innovation nowadays, especially those generated by the exhaust of hydrogen engines **[Blue Condor project source]**.

Potential negative impact:
-New competitors with new technologies could appear in the following years.

Environmental Factors

-Sustainability Goals: Airlines and manufacturers are setting ambitious sustainability goals, including reducing contrail formation and overall emissions.

Potential positive impact
+Strong alignment with global environmental priorities enhances the value proposition of Sky Clear 2040.

Potential negative impact:
-High environmental standards necessitate continuous improvement and innovation in contrail technology.

Legal Factors

-Intellectual Property: Protection of patents and intellectual property rights is crucial for maintaining competitive advantage.
-Compliance: Adherence to international aviation standards and regulations for new technologies is necessary for market acceptance.

Potential positive impact
Robust intellectual property protection and compliance with legal standards build trust and competitive advantage.

Potential negative impact
Legal challenges and liability risks may arise, especially concerning patent protection.

Timeline and value of this investment

2024-2030: R&D -> Investment: 200k/year [source finance]

This first phase will allow us to invest all our time and resources into research and development to justify that our product is technologically feasible but most importantly to determine if our startup has sufficient product-market fit. This first phase will therefore consist of multiple market analysis as well as continuous research in two main areas:

-**Contrail formation**: This area of research is more established today but will be necessary if we want to have an accurate and efficient usage of the device.

-**Ultrasonic mitigation**: This will be our differentiating factor from other mitigation techniques that exist today (route alteration) or will exist in the future (new engines that reduce the amount of water vapor).

2030-2035: Prototyping-> Investment: 500k/year

This is where our research work comes to fruition with the development of the first prototype of the SkyClear 2040 ultrasonics device. The several prototypes developed during these 5 years will have to undergo several test campaigns in special facilities and aboard aircraft.

This phase will be more expensive than the first one and will need to have strong support from commercial partners (airlines and constructors) that will invest in the idea with a prospect of implementing it in their aircraft when the product will be certified.

-**2030:** First Prototype

-**2035:** Final iteration of the prototype and first version of the final product

2035-2040: Certification/Scalation-> Investment:1M/year

The final phase is crucial. It will need to undergo the strict safety test imposed by regulation authorities and will end with the official certification of the product and the beginning of the mass adoption of it as either:

-**Retrofit** of existing aircraft (for airline customers)

-**Integrate** into new aircraft designs (for manufacturers customers)

This phase will be the first one where our startup will finally be profitable. More details about the financial projection below.

Our startup, Sky Clear 2040, is a deep-technology startup which necessarily includes a long initial development cycle with high financial capital requirements. To finance this high financial capital investment the startup will necessarily have to attract various types of investors that participate in the project via research grants and seed funds.

The first investors of our early-stage startup will need to project de value of our idea (and of their investment) over time. For that purpose, we propose here what our business strategy will be and how we can project our financials for the 2024-2040 period.

Monetization Strategy

-Device Pricing: Estimated price range (calculated from above cited components and a 30% margin): $500,000 - $1,000,000 per unit.

-Licensing Fees: Negotiated based on volume and exclusivity agreements.

Revenue Streams

-Direct Sales: One-time sales of the ultrasound generator systems to airlines and aircraft manufacturers.

-Service Contracts: Maintenance, updates, and calibration services to ensure optimal performance.

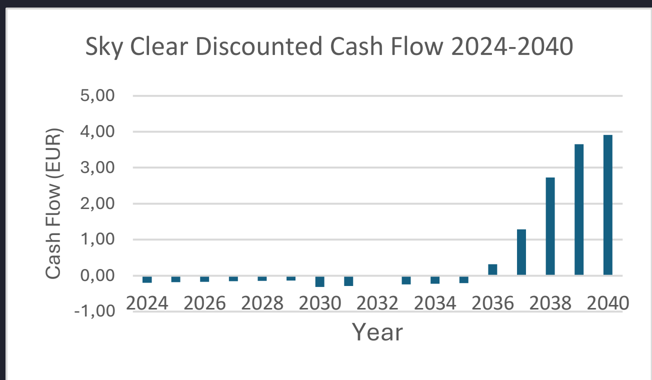
-Licensing: Licensing our technology to aircraft manufacturers for integration into new aircraft models.

-Data Analytics: Providing data services related to contrail formation and environmental impact assessments.

Net Present Value

These different assumptions and projections allow us to calculate the Net Present Value of the idea in 2024.

Even with the conservative hypothesis of no revenue until 2036, this Net Present Value stands at 10.18 million, which will give credibility and financial incentives to the early investors that help Sky Clear 2040 go through the first 2 phases where revenue will be minimal.



Cash Flow for the 2024-2040 period used to calculate de NPV

Conclusion

Overall, tackling contrails is seen as the best hanging fruit for disrupting aviation impact on global warming. Yet a lot of uncertainties are to be solved by 2040 on where, how, and why contrails have such an impact. A team effort is therefore required to collect data and push forward the research. This will be driven by how important the market of Non Co2 Carbon Credit will be in twenty years and the potential very lucrative return on investment for every stakeholder.

In our Particular project, the key part is believing into such a technical disruption. Yes, uncertainties remain on the technical feasibility of the project and to implement it on a global scale. However, as some areas are already known to be unavoidable operationally with rerouting: The need to explore other solutions such as ours will never be that high.

While doing the most important part, namely, search and development in our project, data collection and understanding will make a leap forward. Consequently, when the device is going to be integrable, it will be exclusively implemented on aircrafts that emit the most contrails of the airlines, according to their most taken routes.

Ultimately, disruption is a risk, and the higher is the risk, the higher is the reward: let us clear the skies of contrails.

Let us tackle a significant impact of aviation on the environment.

Let us make it together, now has never been a better time.

Bibilography

1. United Nations, For a livable climate: Net-zero commitments must be backed by credible action, 2024 https://www.un.org/en/climatechange/net-zero-coalition ,

2. ICAO, 41st Session of the ICAO Assembly – Environment, 2022, https://www.icao.int/environmental-protection/Pages/A41-ENV.aspx

3. Airbus, ZEROe, Towards the world's first hydrogen-powered commercial aircraft, 2024, https://www.airbus.com/en/innovation/energy-transition/hydrogen/zeroe

4. Sustainable aviation fuels : A new generation of reduced emissions fuel, Airbus, 2024, https://www.airbus.com/en/innovation/energy-transition/sustainable-aviation-fuels

5. The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018,Faculty of Science and Engineering, Manchester Metropolitan University and Several other stakeholders, 2020, https://www.sciencedirect.com/science/article/pii/S1352231020305689#sec3

6. Global aviation contrail climate effects from 2019 to 2021 Roger Teoh1 , Zebediah Engberg2 , Ulrich Schumann3 , Christiane Voigt3,4, Marc Shapiro2 , Susanne Rohs5 , and Marc E. J. Stettler1 https://acp.copernicus.org/articles/24/6071/2024/acp-24-6071-2024.pdf

7. Google, Project Contrails: A cost-effective and scalable way AI is helping to mitigate aviation's climate impact, 2024, https://sites.research.google/contrails/

8. Satavia, Contrail prevention through flight plan modification, 2024,

https://www.euspa.europa.eu/sites/default/files/4_2_satavia_decisionx_nz_2022_euspa.pdf

9. Reviate by breaktrough energy, website of the company, 2024, https://contrails.org/science

10. EUROCONTROL, Data Snapshot #32 focusing on continuous descent operations at the top 25 airports in Europe, 2022, https://www.eurocontrol.int/publication/eurocontrol-data-snapshot-32-focusing-continuous-descent-operations-top-25-airports

11. Cranfield University, F G NOPPEL, PHD : CONTRAIL AND CIRRUS CLOUD AVOIDANCE TECHNOLOGY, 2007, https://dspace.lib.cranfield.ac.uk/server/api/core/bitstreams/b4588ce3-f40b-42e6-bc0c-464403d2eabf/content

12. TSD surface drive, Cavitation Phenomenon and Surface Drive Systems,2024, https://www.surfacedrive.net/Cavitation-Phenomenon-And-Surface-Drive-Systems-id45629676.html

13. Rolls Royce PLC, METHOD, AND APPARATUS FOR SUPPRESSING AEROENGINE CONTRAILS,2008, https://patents.justia.com/patent/20100043443

14. German Environment Agency, Integration of Non-CO2 Effects of Aviation in

the EU ETS and under CORSIA,2020, https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2020-07-28_climatechange_20-2020_integrationofnonco2effects_finalreport_.pdf

15. IPCC, 2022 report : Transport, https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_Chapter10.pdf

16. Airbus, Global Market Forecast 2024, https://www.airbus.com/sites/g/files/jlcbta136/files/2024-07/GMF%202024-2043%20Presentation_4DTS.pdf

17. Satavia, Contrail management process and analysis,2023, https://satavia.com/wp-content/uploads/2023/11/Airline-Contrail-Management-briefer.pdf

18. IATA, Willie Walsh's Report on the Air Transport Industry at the 80th IATA AGM,2024, https://www.iata.org/en/pressroom/2024-speeches/2024-06-03-01/

19. European Comission, Non-CO2 MRV Consultation Meeting, 2024, https://climate.ec.europa.eu/document/download/b895f58d-0bdf-4ecb-b97a-d478c5b70b80_en?filename=event_20231201_presentation_en.pdf

20. ICAO, 2024 ICAO Symposium on Non-CO_2 Aviation Emissions, https://www.icao.int/Meetings/SymposiumNonCO2AviationEmissions2024/Pages/default.aspx

21. ICAO, Analyses in Support of the 2022 CORSIA Periodic Review, https://www.icao.int/environmental-protection/CORSIA/Documents/2_CAEP_CORSIA%20Periodic%20Review%20(C225)_Focus%20on%20Costs.pdf

22. IAGOS, website of the association, 2024, https://www.iagos.org/

23. Air France and Météo France, Prediction of contrails formation & Observation process, 2023, https://www.eurocontrol.int/sites/default/files/2023-11/2023-11-07-contrails-conference-session-004-curat-pechaut-prediction-contrail-formation-observation-process.pdf