AIAA HIGH-SPEED FLIGHT TASK FORCE

ENVIRONMENT AND SUSTAINABILITY SUBGROUP

AIAA

MEMBERS

NICOLE VIOLA (LEAD), Politecnico di Torino
AKSHAY ASHOK, Boeing
MAX KACHORIA, SPIKE Aerospace
DAVID LAZZARA, Boom Supersonic
JOHN MORGENSTERN, Mach Industries
LORI OZOROSKI, NASA
JULIET PAGE, Blue Ridge Research and Consulting
ROBERTO SABATINI, Khalifa University

High Speed Flight Task Force Chair: Todd Magee, High Speed Flight Task Force Vice Chair: Rodney Bowersox

Q4 2024 Report
Draft, 6 December 2024
Inputs and Updates: 6 December 2024
Methodology: Monthly calls and ad-hoc group members interactions.
Calls as main tool for brainstorming and group inputs entered in PPT as notes and transferred to report and PPT deliverables.

Environment and Sustainability's Record of Revisions

Group	Revision	Date	Changes	Notes
Environment and Sustainability	1.0	May 2024	N/A	First Draft
Environment and Sustainability	2.0	September 2024	N/A	Second Draft
Environment and Sustainability	3.0	December 2024	N/A	Third Draft

Table of Contents

Preface

The environment and sustainability subgroup recommendations are submitted as a partial deliverable for the AIAA High-Speed Flight (HSF) Task Force Chairs. In turn, the HSF Task Force's full portfolio of deliverables are meant to inform the AIAA strategic planners, including the CEO, the Executive Committee, the Council of Directors and the Board of Trustees. The Environment and Sustainability members have been guided by the AIAA's most recent Annual Report (2020) and its current strategic goals, as shown in Figure 1 below. annual-report-2020_web.pdf (aiaa.org)

Background

Title Statement:

Guidance and insights for expanding scientific knowledge in environment and sustainability and gaining consensus in support of the introduction of new and innovative high-speed air and space flight vehicles capable of flight speeds above Mach 1.

Scope Statement:

The Environment and Sustainability group was one of five subgroups (See Figure 2) in the High Speed Flight Task Force (HSFTF). It focuses on areas including sonic boom, community noise, emissions, fuels and enabling technologies within which Mach 1+ (high-speed flight) capable vehicles will need to be compliant to operate safely, sustainably, reliably, economically and seamlessly within the existing National and International Subsonic-flight Air Transportation Systems (NISATS).

Figure 1. AIAA Strategic Goals guided the development of findings for the Environment and Sustainability subgroup.

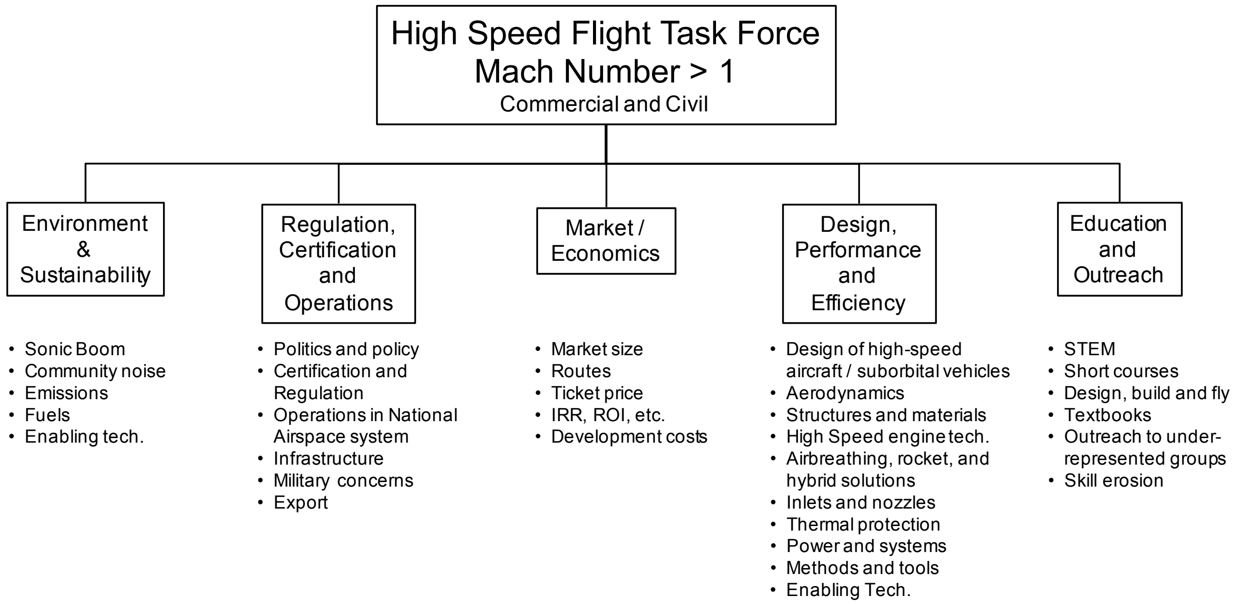

Figure 2. High Speed Flight Task Force Organization Structure

The group conducted a landscape assessment to identify opportunities and visions for these vehicles, their related programs and applicable environment and sustainability technical areas. This assessment supports the entire life cycle of Research and Development (R&D), Test and Evaluation (T&E), Entry into Service (EIS), routine service, environmental impacts, and end-of-life considerations.

Rationale Statement

Scientific advances and enabling technologies are needed which are compatibile with environmental requirements and sustainable aviation practices that can facilitate the introduction of high-speed air (endo-atmospheric and suborbital) vehicles into the forthcoming ecosystem of High-Speed vehicles. This group will inform AIAA on possible measures to close existing environment and sustainability gaps and recommended actions to successfully and seamlessly align technical disciplines with new technologies, advanced systems, and innovations required across a vehicle life cycle, from R&D through entry into service and maturity.

Objectives

The Environment and Sustainability subgroup will deliver Findings and Recommendations (FRs) to AIAA that are relevant to the emerging ecosystem of High-Speed Flight vehicles. These FRs will consist of suggestions for AIAA to consider and implement, aimed at empowering environment and sustainability practitioners with tools and knowledge for innovation, agile performance-based design, R&D, T&E, demonstrations, and support throughout vehicle life cycles.

Methodology and Deliverables

The Environment and Sustainability subgroup will provide AIAA with a Need-Gap-Recommendation-Action (NGRA) for every task envisioned. The NGRA format allows for revisions to be made from time to time as the HSF Task Force develops and evolves.

AIAA Tasks assigned

Based on AIAA guidance, three tasks were assigned to each subgroup in the HSFTF to determine the landscape, opportunities and vision for achieving civil high-speed flight.

1. **Subgroups have conducted a Landscape Assessment for their subject area**
   - 1.1 What are AIAA, Industry, Government and Academia currently doing in this area?
   - 1.2 What are the issues, barriers and concerns?
   - 1.3 What are the gaps in this area?
2. **Subgroups have conducted an Opportunities Assessment for their subject area**
   - 2.1 Are there obvious actions that would remove barriers to high-speed flight?
   - 2.2 What can AIAA and industry do to advance high-speed flight in this subject area?
3. **Subgroups have developed AIAA Vision Capabilities for their subject area**
   - 3.1 What is the end state for this subject area in 3, 10, and 15 years?
   - 3.2 What is the AIAA end state over this same interval?
   - 3.3 What are the key actions over this same interval?

Landscape assessment and opportunities assessment

A collection of current projects targeting environmental and sustainability issues in the field of high-speed flight is summarized in Table 1. Indications of the specific areas covered by each project are also given. The present list of projects is by no means exhaustive. Contributions to high-speed flight are expected to be forthcoming from additional countries and institutions.

Projects	Sonic Boom	LTO noise	Community Noise	Emissions	Fuels	Enabling Technologies
NASA Quesst, X-59 (NASA – US)	☑	☒	☒	☒	☒	☑
Adaptive Aerostructures for Revolutionary Civil Supersonic Transportation (NASA – Boeing – Universities)	☑	☒	☒	☒	☒	☑
Geometry Optimization and Sensing with Integration and Flight Test (GoSwift) (NASA – Boeing – Universities)	☑	☒	☒	☒	☒	☑
LEAN-CST: Lowering Emissions and Environmental Impact from Civil Supersonic Transport (NASA – Georgia Tech + supporting companies & universities)	☒	☒	☒	☑	☒	☑
H2020 STRATOFLY, Stratospheric Flying Opportunities for High-Speed Propulsion Concepts, (European Commission – Europe)	☒	☑	☒	☑	☑	☑
H2020 MORE&LESS, MDO and REgulations for Low-boom and Environmentally Sustainable Supersonic aviation (European Commission-Europe/UK/US)	☑	☑	☒	☑	☑	☑
H2020 SENECA, (LTO) noiSe and EmissioNs of supErsoniC Aircraft (European Commission-Europe)	☒	☑	☑	☑	☒	☑
Development of new High-Speed Commercial Vehicle Conceptual Designs and Technology Roadmap (NASA – US)	☑	☑	☑	☑	☑	☑
Commercial Supersonic Technology Project Research Portfolio (NASA – US)	☑	☑	☑	☑	☑	☑
STORMIE, Supersonic Transport Open Research Models and Impact on Environment (DLR-Germany)	☑	☑	☑	☑	☒	☒
H2020 RUMBLE, RegUlation and norM for low sonic Boom LEvels (European Commission-Europe/UK/Russia)	☑	?	☑	☒	☒	☒
S4/Re-BooT Project (JAXA – Japan)	☑	☑	☑	☒	☒	☑

Table 1. List of current projects dealing with environmental and sustainability issues for high-speed flight. The green ticked box indicates that the project covers that specific area. The red cross indicates that the project does not cover that specific area. The question mark indicates that it is uncertain whether the project covers or does not cover that specific areas. The specific areas to describe environment and sustainability are: sonic boom, LTO noise, community noise, emissions, fuels and enabling technologies.

Sonic boom

Current activities and findings are divided into three categories: experimental tests, numerical simulations and analytical formulations as listed below. Countries of reference are also included.

EXPERIMENTAL TESTS:

- Outdoor tests for small scale projectiles for waverider and fuselage-wing configurations at Mach 5 (MORE&LESS Project, European Commission – Europe).
- Near-field pressure measurement using static pressure rails (S4/Re-BooT Project, JAXA - Japan).
- Extensive wind tunnel testing of NASA-X59 – Mach 1.4 (NASA – US).
- NASA X-59 built to support in-flight shaped sonic boom technology validation (NASA – US).

NUMERICAL SIMULATIONS:

- Validation of CFD simulation models against tests for waverider and fuselage-wing configuration at Mach 5 considering small scale projectiles (MORE&LESS Project, European Commission-Europe).
- Development of numerical models to capture the variability of sonic boom propagation due to meteorology (MORE&LESS Project-EU-Europe).
- Extensive CFD and propagation code development and simulations supporting X-59 (NASA – US).
- **Sonic Boom Prediction Workshop:** current focus on focus boom prediction; past focus on nearfield and primary boom carpet propagation (AIAA).
- Numerical estimation of loudness distribution in a primary boom carpet for a robustly low-boom designed aircraft (S4/Re-BooT Project, JAXA-Japan).
- Near-field and full-field sonic boom simulation based on space marching method considering stratified atmosphere (S4/Re-BooT Project, JAXA-Japan).
- Numerical simulation of sonic boom propagation through atmospheric turbulence (S4/Re-BooT Project, JAXA-Japan).

ANALYTICAL FORMULATIONS:

- Upgrade of existing analytical formulations to extend its applicability to waverider and low-boom configuration (MORE&LESS Project-EU-Europe).

Gaps in this area are divided into experimental tests, numerical simulations and analytical formulations and are reported below. Countries of reference are also included because gaps may differ significantly from one country to another. When countries are not explicitly mentioned, gaps are considered global.

EXPERIMENTAL TESTS:

- Small scale flight test projectiles' controllability (FCS/CoG) (Europe).
- Low boom configurations flight tests (Europe).
- Low boom inflight validation data (planned to be collected from X-59).

NUMERICAL SIMULATIONS:

- Prediction of secondary sonic boom, Mach cut-off, Lateral cut-off, focus boom, etc.
- Sonic boom turbulence modelling.

ANALYTICAL FORMULATIONS:

- Validation of upgraded analytical formulations (e.g. Carlson method) to extend their applicability to waverider and other configurations.

Issues, barriers and concerns in this area and potential actions to remove barriers are summarized in Table 2.

Issues/barriers/concerns	Actions to remove barriers
Regulatory barriers	› International partnerships and collaborations to review current regulations and suggest recommendations for future regulations (ICAO/CAEP WG1 "Noise Technical"). › Low boom aircraft configuration to reduce pressure signature of future supersonic aircraft. › Primary carpet, as well as off-design Mach and focus boom shall be considered for future new regulations to address all flight phases. Off-track sonic boom signature shall be considered too.
Lack of common metrics to define international standards, in addition to Δp and Δt, including psychoacoustic measurements/ effects	› International partnerships and collaborations to define international standards.
Public acceptance	› Conduct community exposure testing to identify acceptable levels of supersonic aircraft noise. › To increase and improve communications and disseminations.
Environmental impact	› Performance, sonic boom prediction and environmental impact assessment using low boom conceptual supersonic aircraft (low-boom STCA) to reduce pressure signature of future aircraft. Primary carpet, as well as off-design Mach and focus boom shall be considered. Off-track sonic boom signature shall be modelled too. › International partnerships and collaborations to overcome technical barriers to reduce environmental impact. › To increase ground and flight tests opportunities.

Table 2. Issues/barriers/concerns in sonic boom and actions to possibly remove the aforementioned barriers.

LTO noise

Current activities and findings for Landing and Take Off (LTO) noise are categorized into experimental tests, numerical simulations and analytical formulations, which are listed below. Relevant countries are also included.

EXPERIMENTAL TESTS:

- Small scale test rig for jet noise (SENECA Project, European Commission – Europe).
- Experimental tests on two nozzle configurations (single stream and dual stream) under different test conditions, with the aim of measuring the jet-noise associated with both mixing and shock contributions (MORE&LESS Project, European Commission – Europe)
- Human perception studies with auralized LTO noise of supersonic aircraft (STORMIE Project, DLR - Europe).
- Small-scale jet noise test to investigate jet noise reduction devices and jet noise shielding (S4/Re-BooT Project, JAXA-Japan).
- Standardize rig and flight jet databases and provide diagnostics for Large Eddy Simulation (LES) validation of internally mixed exhaust systems (NASA - US).

NUMERICAL SIMULATIONS:

- Simulation of airframe shielding and noise attenuation through lined inlets (SENECA Project, European Commission – Europe).
- Numerical simulations for the single stream and dual stream test cases using RANS-based CFD in Ansys Fluent, along with an proprietary code for acoustic predictions. The code uses a RANS-based acoustic analogy to predict jet-noise, which also enables the evaluation of jet-noise at airport-level (MORE&LESS Project, European Commission – Europe).
- High-fidelity RANS simulations to calculate aerodynamic properties at low speeds, determine impact on possible LTO procedures, and comparison with methods with lower fidelity (STORMIE Project, DLR - Europe).
- Multi-fidelity aeroacoustic simulations for fan noise, jet noise, and shielding effects (STORMIE Project, DLR - Europe).
- Simulation to investigate the effects of airframe integration and jet noise shielding(S4/Re-BooT Project, JAXA-Japan).
- Advance and validate LES methods for complex exhaust systems; simulate noise of two-stage fan behind supersonic inlet at LTO (NASA - US).

ANALYTICAL FORMULATIONS:

- Analytical prediction of one and two stage fans considering interaction noise with inlet guide vanes (SENECA Project, European Commission – Europe).
- Analytical models from the literature, such as the Stone jet-noise model, integrated in the overall aircraft noise prediction to compute NPD curves and noise at ICAO LTO certification measurements points (MORE&LESS Project, European Commission – Europe).
- Formulate and validate empirical noise source models for supersonic propulsion (fan and jet) at LTO (NASA - US).

Gaps in this area are divided into experimental tests, numerical simulations, analytical formulations and operational procedures, which are listed below. Countries of reference are also included because gaps may differ significantly from one country to another. When countries are not explicitly mentioned, gaps are global.

EXPERIMENTAL TESTS:

- Noise experiments of two-stage fans to validate analytical prediction (Europe).
- Noise experiments to estimate uncertainties for the use of VNRS and jet noise reduction devices (Japan).
- Importance of installation and internal boundary layers on exhaust noise. Verification of propulsion noise models and optimum designs for low-BPR, variable area exhaust (US).

NUMERICAL SIMULATIONS:

- Impact of data uncertainties (aerodynamics, etc.) and methods on LTO noise and proposed procedures.
- Large Eddy Simulation (LES) of internally mixed exhaust systems overlooks a significant noise source: aft fan noise.

ANALYTICAL FORMULATIONS:

- Considering transmission effects especially for multi-stage fans (Europe).
- Greens functions for RANS prediction methods.
- **Operational procedures:**

ADVANCED TAKE-OFF PROCEDURES REQUIRED TO MEET NOISE LIMITS.

Issues, barriers and concerns in this area and potential actions to remove barriers are summarized in Table 3.

Issues/barriers/concerns	Actions to remove barriers
Public acceptance	To increase and improve communications and disseminations.
Regulatory barriers	Inclusion of Variable Noise Reduction Systems (VNRS) in ICAO/CAEP noise regulations, to reduce community noise from supersonic aeroplanes during takeoff and landing and support the certification process. International partnerships and collaborations to review current regulations and suggest recommendations for future regulations (ICAO/CAEP WG1 "Noise Technical").
LTO noise and environmental impact for low boom aircraft	Performance, LTO noise prediction and environmental assessment using low boom conceptual supersonic aircraft (low-boom STCA).
Conventional noise models used in systems studies of civil supersonic aircraft may not apply and need to establish uncertainty levels.	Prediction Uncertainty Reduction Tech Challenge to update noise models and compare with limited supersonic-relevant configurations.
Long-term need for innovative variable cycle propulsion, high lift technology to meet noise regulations	Start planning for future effort.

Table 3. Issues/barriers/concerns in LTO noise and actions to possibly remove the aforementioned barriers.

Emissions

Current activities and findings for emissions are categorized into experimental tests, numerical simulations and analytical formulations, which are listed below. Countries of reference are also included.

EXPERIMENTAL TESTS:

- Real engine test to measure emissions in ICAO LTO modes of operations for bio-fuels (MORE&LESS Project, European Commission – Europe).
- Combustion and emissions tests with a cavity injector using hydrogen in ramjet and scramjet conditions (MORE&LESS Project, European Commission – Europe).

NUMERICAL SIMULATIONS:

- Validation against tests of LES hydrogen combustion and emissions models in ramjet and scramjet conditions (MORE&LESS Project, European Commission – Europe).
- Validation (against LES validated models) of 0D/1D chemical kinetic simulation models for hydrogen combustion and emissions in ramjet/scramjet conditions for cavity injector and then entire combustor (MORE&LESS Project, European Commission – Europe).
- Finite Rate Chemistry LES with small comprehensive reaction mechanisms are performed. These need to be supplemented with corresponding NOX and soot models (MORE&LESS Project, European Commission – Europe).

ANALYTICAL FORMULATION:

- Upgrade of analytical formulations (original BFFM2 and P3T3) to extend their applicability to high-speed and bio-fuels/hydrogen (MORE&LESS Project, European Commission – Europe).

Gaps in this area are categorized into experimental tests, numerical simulations and analytical formulations, which are listed hereafter.

EXPERIMENTAL TESTS:

- Development of low-emission combustion technologies (e.g., plasma-assisted combustion, staged combustors). Both Microwave and Dielectric barrier discharge technologies have successfully been tested.
- Validation of high altitude emissions climate impact models.
- Validation of high altitude water vapor/contrail climate impact models.

NUMERICAL SIMULATIONS:

- Thourough understanding of bio-fuels combustion chemistry and emissions characterization.
- Combustor stability and relight capability over large flight operating envelope.
- Understand changes in lean and rich blowout, and associated physical phenomena.
- Agreed upon fleet forecast model for use in climate impact modelling.

ANALYTICAL FORMULATIONS:

- Physics-based, publically available emissions prediction methodologies not validated/reliable for large volume, high temperature, low pressure combustor designs. This gap requires consideration of higher uncertainties in emissions impacts modelling (e.g. range of scenarios).

Issues, barriers and concerns in this area and potential actions to remove barriers are summarized in Table 4.

Issues/barriers/concerns	Actions to remove barriers
Environmental impact	› Reduce emissions of future aircraft › International partnerships and collaborations to overcome technical barriers › Increase ground and flight test possibilities
Regulatory barriers	› International partnerships and collaborations to review current regulations and suggest recommendations for future regulations (ICAO/CAEP WG3, “Emissions technical”): › Engine emissions requirements for supersonic (i.e. LTO NOx); › New potential CO2 Metric Value formulation for supersonic aircraft; › Cruise NOx reduction
Very high computational resources required to perform LES simulations of full-scale combustors/engines	› Only cost-effective (albeit expensive) way to develop knowledge about incipient thermoacoustic instabilities due to different fuels
Public acceptance	› Increase and improve public communication and information dissemination
Technological Feasibility	› Numerical modeling, rig testing and engine tests to demonstrate achievable emission limits for supersonic propulsion systems
Uncertainties of climate models to assess climate impact of emissions	› Encourage the scientific community to come together to share and compare results for validating climate models › Leverage flights in the commercial space or aviation industries to gather opportunistic data on climate impacts

Table 4. Issues/barriers/concerns in emissions and actions to possibly remove the aforementioned barriers.

Fuels

Current activities and findings on fuels are divided into experimental tests and numerical simulations , which are listed below.

EXPERIMENTAL TESTS:

- Testing of alternative fuels (SAF, e-kerosene, etc.) requires testing many parameters including (i) fuel properties, such as the carbon distribution and the amount of n-, iso- and cycloparaffins and aromatics, (ii) thermophysical properties, such as viscosity, density, lower heating value, surface tension, H/C ratio, Cetane number etc., (iii) combustion properties, such as ignition delay time, laminar flame speed, flame temperature and extinction strain rates at different temperatures and pressures, and (iv) emissions. Besides these parameters we need to test the fuels with respect to (i) compatibilities with typical seal materials, such as nitrile rubber and other materials participating in a typical fuel manifold, (ii) aging, and (iii) corrosion and deposits. This involves many complex and expensive tests, and the most challenging aspects are to develop testing methods that require less amounts of fuel than present day methods to facilitate new fuels development.

NUMERICAL SIMULATIONS:

- The thermophysical properties as well as the combustion properties need to be modeled in order to examine the performance of the alternative fuels. The thermophysical models can be developed based on measuring the aforementioned quantities followed by curve fitting in the JANAF framework. Chemical reaction mechanisms can also be developed based on chemical kinetics theory and experimental data. Different classes of chemical reaction mechanism are available, ranging from 1- and 2-step global reaction mechanisms, via skeletal or small comprehensive reaction mechanisms with 100 to 300 steps, to comprehensive reaction mechanisms with 20,000 to 30,000 reaction mechanisms. For practical CFD simulations we now have the capability of running LES simulations using reaction mechanisms between a few hundred to 1000 steps.

Gaps in this area are categorized into experimental tests and numerical simulations, which are listed hereafter.

EXPERIMENTAL TESTS:

- Laminar flame speed, ignition delay time and extinction strain rate data (combustion characteristics) must be made available for a wide range of advanced bio-jet fuels (i.e. neat SAF).
- nvPM emissions and water vapor measurements testing using SAF (especially non drop-in).
- Improvements to advanced SAF production pathways (e.g. power-to-liquid fuels).
- Thermal stability and heat-sink capabilities of bio-fuels, additives, et al.

NUMERICAL SIMULATIONS:

- The development of chemical reaction mechanism is required for all neat SAF and their blends with Jet A, JP5, etc. It is anticipated that we will need small comprehensive or large reduced reaction mechanisms with 500 to 1000 reactions.
- Thermophysical data need to be accurately measured and models need to be developed.
- Finite rate chemistry Large Eddy Simulations must be further developed to be able to handle small comprehensive or large reduced reaction mechanisms with 500 to 1000 reactions.

Issues, barriers and concerns in this area and potential actions to remove barriers are summarized in Table 5.

Issues/barriers/concerns	Actions to remove barriers
Environmental impact	› Utilize sustainable aviation fuels" or "Utilize sustainable aviation fuels and hydrogen, with significant impact on vehicle's configuration and integration › International partnerships and collaborations to overcome technical barriers related to the production, distrubtion, storage and utilization of sustainable aviation fuels and hydrogen › Increase ground and flight test possibilities
Advanced bio-jet fuels (i.e. neat SAF) challenging to obtain in sufficient quantities for engine testing. Also challenging to obtain in smaller quantities for testing and mechanism development due to IP rights etc.	› International partnerships and collaboration
Economic sustainability of green hydrogen	› Analysis of LCA (Life Cycle Assessment) of green hydrogen › Improvement of green hydrogen production processes
Infrastructure needs for non drop-in SAFs (SAF that have theoretically near zero lifecycle carbon footprint and non-CO2 benefits, but which would require some changes to existing fuel infrastructure and aircraft systems, e.g., zero aromatics fuels produced from power-to-liquids processes)	› Supply chain evaluations for fuel delivery to airports › Development of book-and-claim systems to decouple geographical barriers of supply vs. demand
Limited production capabilities of neat SAF	› Analysis and improvement of the chemical unit operations required for neat SAF production

Table 5. Issues/barriers/concerns in fuels and actions to possibly remove the aforementioned barriers.

Enabling technologies

Current activities and findings for enabling technologies are categorized into experimental tests and numerical simulations and are listed below.

Gaps in this area are categorized into experimental tests and numerical simulations, which are detailed below. Both propulsive and fuel systems are included.

EXPERIMENTAL TESTS:

- Propulsive Technology
  - Analysis of the transition from turbine-based propulsion to dual-mode ramjet propulsion.
  - Analysis of the the transition between the ramjet operation and scramjet operation in the ramjet-based propulsion system.
  - Development of low-emission combustion technologies (e.g., plasma-assisted combustion, staged combustors).
- Fuel system
  - Fuel system component compatibility with non drop-in SAFs.
  - Fuel system component compatibility with hydrogen.
- Structures and Materials
  - Development of improved materials and structural solutions to mitigate thin-wing aeroelastic challenges.

NUMERICAL SIMULATIONS:

- Propulsive Technology
  - Analysis of the transition from turbine-based propulsion to dual-mode ramjet propulsion.
  - Analysis of the the transition between the ramjet operation and scramjet operation in the ramjet-based propulsion system.
  - Fuel and isolator/combustor geometries need to be designed through a multidisciplinary integrated approach, as fuels with longer ignition delay times usually require additional flame-holders such as cavities, steps and/or struts, which typically also increase the pressure losses.

Issues, barriers and concerns in this area and potential actions to remove barriers are summarized in Table 6.

Issues/barriers/concerns	Actions to remove barriers
Propulsive Technology: lack of communications between scientists, i.e. experimentalists and computational physicists: only in some cases are the results validated against each other.	› Close collaboration between experimentalists and computational physicists should begin early in the design process, as jointly analyzing both experimental and computational results can provide complementary insights.

Table 6. Issues/barriers/concerns in enabling technologies and actions to possibly remove the aforementioned barriers.

Vision capabilities

Near Term (1, 3, 5 years): Need-Gap-Recommendations-Actions (NGRA)

AIAA has asked what they can immediately do to support high-speed commercial flight.

Summary NGRAs

A summary of the Need, Gap, Reccomendations and Actions (NGRAs) is as follows:

- **Promote and facilitate international scientific workshops or dedicated sessions to investigate further:**
  - **Sonic-boom:** compare results and generate solid scientific and technical knowledge on low boom aircraft, sonic boom propagation methods, sonic boom monitoring and onboard avionics capable of projecting sonic boom footprints.
  - **Chemical emissions metrics:** conduct data comparisons to support current and emergent metrics and interact with regulatory bodies.
  - **Chemical emissions and impact on climate:** exchange and compare data and results (including emissions inventories[1]) to cross-validate climate models.
  - **Fuels and combustion: SAF:** exchange and compare data and results to improve the understanding of the chemical and physical characterization and combustion phenomena of neat SAF, as well as of blended SAF.
  - **Fuels and combustion: green hydrogen:** exchange and compare data and results to improve the assessment of the life cycle of the cryogenic green hydrogen, the understating of its production, storage and distribution, and its impact on aircraft systems and operations.

1. Emissions inventories are databases that quantify pollutants and greenhouse gases emitted by aircraft throughout their flight paths. They include the concentration of chemical species at various altitudes and latitudes along the trajectory.

- **Establish a link between AIAA and regulatory bodies (i.e. FAA, ICAO-CAEP, EASA, etc.)** to share the main outcomes of scientific workshops on environmental issues (sonic boom, noise and chemical emissions, emissions metrics, etc.) with relevant Working Groups, i.e. ICAO/CAEP Working Group 1 "Noise Technical" and Working Group 3 "Emissions Technical", through presentations, written materials and official information and working papers.
- **Establish a dedicated AIAA Committee to manage interactions with regulatory bodies** (to interact regularly with the ICAO/CAEP 3-year cycle), if no already existing AIAA Committees can take up this action.
- **Facilitate collaboration between the scientific community and companies producing alternative fuels to address challenges in procuring Sustainable Aviation Fuel (SAF) for engine and combustion tests**. This task can be accomplished by an already existing AIAA Committee or by a newly established AIAA Committee to facilitate collaboration between scientific and industrial communities, as well as between scientific communities and regulatory entities.

Detailed NGRAs

The details of the NGRAs are reported in Table 7, Table 8, Table 9, Table 10, Table 11, and Table 12.

Sonic boom
Need
NASA X-59 (US) and S4/Re-BooT Project-JAXA (Japan) are examples of current programs that are investigating low boom aircraft configurations. The measurement and estimation of sonic boom, as well as the assessment of its impact on citizens and infrastructures, for low boom aircraft configurations need to be thoroughly and extensively carried out to inform the Regulatory Entities and ICAO/CAEP and to suggest modifications to current regulations. This requires a common international effort to compare results and generate solid scientific and technical knowledge.
Gap
Primary carpet, as well as off-design Mach, secondary booms, and focus boom shall be considered to investigate all flight phases. Off-track sonic boom signature shall be measured and modeled too.
Recommendation
› AIAA shall continue to facilitate a dedicated workshop to push the common international effort to compare results and generate scientific and technical knowledge on low boom aircraft. AIAA should then provide a forum for its dissemination (e.g. via conference or publication). AIAA shall outline technical focus areas related to sonic boom needing R&D attention and organize dedicated workshops or sessions to promote visibility, greater collaboration and integration, and discussion of work done in those areas.
Need date
Present and near-term future.

Table 7. NGRA: Sonic boom

Chemical emissions metrics
Need
Emissions (CO_2 and non-CO_2) during Landing and Take-Off(LTO) and Climb, Cruise, and Descend (CCD) phases should be measured and estimated to compare high-speed aircraft with subsonic aircraft. Regulatory entities like ICAO/CAEP generally use subsonic aircraft as a reference for supersonic counterparts, applying subsonic metrics to supersonic aircraft. However, these metrics may not always be suitable for supersonic aircraft. Therefore, it is essential to determine whether subsonic metrics are appropriate for supersonic aircraft and, if not, to develop new metrics specifically for them.
Gap
The existing metrics for estimating LTO and cruise emissions, accepted by regulatory entities, were developed for kerosene subsonic aircraft and may not accurately represent supersonic aircraft. There is a clear need for new, widely agreed-upon metrics to better represent future supersonic aircraft, whether using fossil fuels or sustainable alternatives, including hydrogen.
Recommendation
› AIAA shall promote international scientific community collaboration with dedicated workshops or sessions to allow for comparisons of current and newly developed metrics for supersonic aircraft to support regulatory entity actions. AIAA shall outline technical focus areas related to emissions needing R&D attention and organize dedicated workshops or sessions to promote visibility, greater collaboration and integration, and discussion of work done in those areas. › AIAA will facilitate connections between the scientific community and regulatory bodies (e.g., FAA, ICAO-CAEP, EASA) to share key outcomes from scientific workshops with relevant Working Groups, such as ICAO/CAEP Working Group 3 “Emissions Technical,” through presentations and official documents. To ensure ongoing communication, AIAA will establish a dedicated committee to manage interactions with regulatory bodies, including regular engagement with the ICAO/CAEP three-year cycle, if no existing committees can fulfill this role.
Need date
Present and near-term future

Table 8. NGRA: Chemical emissions metrics

Chemical emissions and climate impact
Need
Emissions inventories for novel aircraft configurations and operations, various propulsive technologies and alternative fuels (including sustainable aviation fuels and hydrogen, in addition to fossil fuels) are valuable sources for estimating the impact on air quality and climate due to the introduction of supersonic aircraft into the current or future fleet of subsonic aircraft. Emissions inventories are propagated in climate models to understand the evolution of atmospheric chemistry and consequently the impact on air quality and climate. Comparing results of different climate models, considering the same initial hypotheses, is crucial to improve the accuracy of estimation and to define strategies to improve the environmental sustainability of future supersonic aircraft.
Gap
The scarse availability of reliable emissions inventories for novel aircraft configurations, various propulsive technologies and alternative fuels for supersonic aircraft, and the limited comparison of results of different climate models have not allowed a clear and robust understanding of the environmental impact of supersonic aircraft. Operational procedures and trajectories may also play an important role in mitigating their environmental impact.
Recommendation
AIAA shall promote international scientific community collaboration with dedicated workshops or sessions to allow for exchange and comparison of results to “cross-validate” climate models, to favour a clear and robust understanding of the evolution of atmospheric chemistry and environmental impact, and to highlight technical and operative solutions that mitigate the impact on climate. AIAA shall outline technical focus areas related to climate models needing R&D attention and organize dedicated workshops or sessions to promote visibility, greater collaboration and integration, and discussion of work done in those areas.
Need date
Present and near-term future

Table 9. NGRA: Chemical emissions and climate impact

Chemical and noise emissions
Need
Results of tests and multi-fidelity simulations on chemical and noise emissions of high-speed aircraft, across different flight phases, alternative fuels and various technologies, are precious data to share among the scientific community. This information should then be conveyed to Regulatory Entities to lay the groundwork for solid understanding of the scientific and technical issues to eventually support establishment of new regulations to enable the entry into service of future civil high-speed aircraft.
Gap
The link between the scientific community and regulatory bodies (i.e. FAA, ICAO-CAEP, EASA, etc.) is not always straightforward. This hinders the continuous development of a robust scientific understanding of chemical and noise emissions by regulatory entities, leading to delays in defining new regulations for the entry of future civil high-speed aircraft into service.
Recommendation
› AIAA should facilitate connections between the scientific community and regulatory bodies (e.g., FAA, ICAO-CAEP, EASA) to share key outcomes from scientific workshops on environmental issues (such as sonic boom and emissions) with relevant Working Groups, including ICAO/CAEP Working Group 1 "Noise Technical" and Working Group 3 "Emissions Technical," through presentations and official documents. To ensure ongoing communication, AIAA should establish a dedicated committee to manage interactions with regulatory bodies, including regular engagement with the ICAO/CAEP three-year cycle, if no existing committees can fulfill this role. › AIAA should outline technical focus areas related to chemical and noise emissions needing R&D attention and organize dedicated workshops or sessions to promote visibility, greater collaboration and integration, and discussion of work done in those areas.
Need date
Present and near-term future.

Table 10. NGRA: Chemical and noise emissions

Fuels and combustion: SAF
Need
Sustainable Aviation Fuels (SAF) and particularly neat SAF may be used as alternative fuels in future civil aircraft (subsonic and supersonic) to reduce aviation's climate impact. To reach this objective, there is the need to further improve the chemical and physical understanding of the combustion and emissions, including water vapor, of SAF. The development of chemical reaction mechanisms is still required for neat SAF as well as for most of the blends with Jet A, JP5, etc. Thermophysical data need to be accurately measured, and models need to be developed.
Gap
Sufficient quantities of advanced bio-jet fuels (i.e. neat SAF) for engine tests are challenging to obtain. Smaller quantities for combustion tests and mechanism development are challenging to obtain as well due to IP rights. Moreover there are limited production capabilities of neat SAF. Analysis and improvement of chemical unit operations are required for neat SAF's production.
Recommendation
› AIAA shall promote international scientific community collaboration through dedicated workshops or sessions to allow for exchange and comparison of results to improve the understanding of the chemical and physical characterization and combustion phenomena of neat SAF, as well as of blended SAF. AIAA shall outline technical focus areas related to fuels and combustion, particularly for SAF, needing R&D attention and organize dedicated workshops or sessions to promote visibility, greater collaboration and integration, and discussion of work done in those areas. › AIAA shall promote international scientific community collaboration through dedicated workshops or sessions to allow for exchange and comparison of results to improve SAFs production. › AIAA shall support the scientific community to overcome the challenges related to the procurement of SAF for engine and combustion tests by facilitating the connection between scientific/technological research teams and fuels production facilities.
Need date
Present and near-term future

Table 11. NGRA: Fuels and combustion: SAF

Fuels and combustion: green hydrogen
Need
Cryogenic hydrogen may be used as alternative fuel in future civil aircraft (subsonic and supersonic) to reduce aviation's climate impact in the long term future. To achieve this objective, there is the need to further improve the production of green hydrogen to ensure economic sustainability. Moreover the ground infrastructures for the storage, distribution and resupply of cryogenic hydrogen shall be designed and developed. Finally, the impact of cryogenic hydrogen on aircraft operations and systems shall be fully understood.
Gap
The production of green hydrogen should be developed and improved further to target economic sustainability. The adaptations of ground infrastructures for storage, distrubution and resupply of cryogenic hydrogen should be designed and developed. On-ground procedures and operations should be re-defined and the impact of cryogenic hydrogen on aircraft systems should be fully understood, including climate impact due to high altitude water vapor insertion and contrails.
Recommendation
AIAA should promote international scientific community collaboration of aircraft designers, manufacturers and operators through dedicated workshops or sessions to allow for exchange and comparison of results to further progress the assessment of the life cycle of the cryogenic green hydrogen, the understating of its production, storage and distribution, and its impact on aircraft systems and operations. AIAA should outline technical focus areas related to green hydrogen needing R&D attention and organize dedicated workshops or sessions to promote visibility, greater collaboration and integration, and discussion of work done in those areas.
Need date
Present and near-term future

Table 12. NGRA: Fuels and combustion: green hydrogen

Long Term (5, 15, 25 years): End State Vision

Table 13 includes long-term vision targets for 5, 15, and 25 years.

	Within 5 years	Within 15 years	Within 25 years
Sonic boom	Community exposure tests to identify acceptable levels of (low boom) supersonic aircraft noise have been completed. Data and modelling of primary carpet, as well as off-design Mach, focus boom, and off-track sonic boom signature for (low boom) supersonic aircraft have been completed.	Entry into service of civil supersonic aircraft in compliance to current (2024) regulations. Civil supersonic aircraft fully operational in compliance to current (2024) regulations. New regulations for civil supersonic aircraft to fly overland have been approved.	Entry into service of low boom civil supersonic aircraft Low boom civil supersonic aircraft fully operational in compliance with new regulations that allow overland flight.
LTO noise	Industry has identified and advanced technologies for reducing noise during LTO operations and has engaged with regulators regarding procedures for testing certification.	Regulatory agencies have adopted procedures to facilitate implementation of advanced technologies during LTO operations to reduce noise Regulatory agencies have adopted certification and operational requirements for LTO noise.	
Emissions (LTO and cruise -> air quality and climate impact)	Active research regarding climate effects from supersonic aviation are attracting a scientific consensus. CO2 regulations for subsonic aircraft have been adopted and extensions for supersonic vehicles are under consideration for LTO emissions and air quality. Climate impacts from supersonic vehicles are being studied and possible regulatory constructs are under consideration internationally	Regulatory agencies have adopted climate impact regulations.	
Fuels	Improvement of the understanding of the chemical and physical phenomena of SAF's combustion and emissions, including water vapor/contrails, through engine and combustion tests. Improvement of the strategies for green hydrogen's production. Significant progress in the design and development of ground infrastructures for storage, distribution and resupply of cryogenic hydrogen.	All main issues for production and provision of neat and blended SAFs have been solved. Most medium-long range civil aircraft use neat SAFs as alternative fuels. Green hydrogen's production is fully operative. The development of ground infrastructures for storage, distribution and resupply of cryogenic hydrogen has taken place in most hubs. First civil aircraft exploiting liquid cryogenic hydrogen as fuel are entering into service.	Most medium-long range civil aircraft use either neat SAFs or cryogenic liquid hydrogen as fuels.

Table 13. Environment and Sustainability Long-term Vision Targets

Main recommendations

During the panel session at AIAA Aviation Forum in July 2024, in Las Vegas USA, several key recommendations were proposed by the experts to address the challenges and opportunities in high-speed flight. These recommendations focused on regulatory, economic, technological, and environmental aspects to drive progress in the industry. Main recommendations on technological and environmental aspects are listed below.

Technological Recommendations

4. Frequent Testing: Increasing the cadence of hypersonic testing to accelerate technological development and attract investment.
5. Advanced Propulsion Research: Continuing research into advanced propulsion technologies, including nuclear propulsion, to enhance performance and feasibility.
6. Interdisciplinary Integration: Encouraging collaboration between aerospace and climate scientists to address environmental impacts and leverage technological advancements.
7. Environmental and Public Relations Recommendations
8. Environmental Impact Assessments: Conducting early and comprehensive environmental impact studies to understand and mitigate the effects of high-speed flight.
9. Public Perception and Education: Enhancing public relations efforts to communicate the societal benefits of high-speed flight and address environmental concerns.
10. Collaborative Approach with Climate Scientists: Advocating for open communication and collaboration with climate scientists to address environmental challenges rather than viewing them as roadblocks.

The recommendations underscore the need for a multifaceted approach, combining regulatory reform, economic strategies, technological advancements, environmental considerations and science, and public relations efforts to drive the successful development and implementation of civil high-speed flight.

AIAA

aiaa.org/aeronautics