SEVENTH FRAMEWORK PROGRAMME

Topic AAT.2012.6.1-5.

Enhancing cooperation with Japan in the field of high speed aircraft

Project acronym: HIKARI

Project full title: "**HI**gh speed **K**ey technologies for future **A**ir transport - **R**esearch & **I**nnovation cooperation scheme"

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HIKARI

Publishable Summary

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GLOSSARY

ATLLAS	Aero-Thermodynamic Loads on Lightweight Advanced Structures
ATR	Air Turbo Rocket
DGAC	Direction Générale de l'Aviation Civile
DMR	Dual Mode Ramjet
DOC	Direct Operating Costs
EASA	European Aviation Safety Agency
ECS	Environmental Control System
ERF	Extended Range Factor
ESPSS	European Space Propulsion System Simulator
FAST20XX	Future Advanced Suborbital Transport 20XX
GHG	Green House Gas
HIKARI	HIgh speed Key technologies for future Air transport - Research & Innovation cooperation scheme
HST	High Speed Transport
JADC	Japan Aircraft Development Corporation
LAPCAT	Long-term Advanced Propulsion Concepts And Technologies
LNG	Liquid Natural Gas
MECO	Maximum binding Energy Circular Orbit
MTOW	Maximum Take Off Weight
OEW	Operating Empty Weight
PAX	Passenger
PCTJ	Pre-Cooled Turbo Jet
RF	Radiative Forcing
SBLE	Swept Back Leading Edge
ZEHST	Zero Emission High Speed Transport

REFERENCES

[1] Whitlow, J. B. and Heisenberg, J. D. Potential of liquid–methane fuel for Mach 3 commercial supersonic transports. NASA TN D–3471. *NASA Technical Note*, 1966.

[2] Walton, C. and Cain, T. Thermal management layout. D2.2.1. *ATLLAS II Deliverable*, 2013.

[3] Laux, T. Requirements for sharp leading edge applications. D3.3.1. *ATLLAS Deliverable*, 2007.

[4] Mahulikar, S. P. Theoretical aerothermal concepts for configuration design of hypersonic vehicles. *Aerospace Science and Technology* 9 (2005) 681–685.

[5] Langener, T and Steelant, J. High level requirements for market analysis for high–speed concepts. D2.1.1. *HIKARI Deliverable*, 2013.

[6] Pérez-Grande, I. and Leo, T. J. Optimization of a commercial aircraft environmental control system. *Applied Thermal Engineering* 22 (2002) 1885-1904.

[7] Ardema, Mark D., Minimum Weight Passive Insulation Requirements for Hypersonic Cruise Vehicles, *AIAA Journal*, (July 1972) 968-970.

EXECUTIVE SUMMARY

The HIKARI project has brought together all the hypersonic initiatives in Europe and Japan to drive the convergence of their concepts and roadmaps.
Thanks to the expertise of its 16 partners from industry, research centers and academia, it has derived a common path towards a joint design for high speed air transport and ultimately towards joint flight testing.

The market analysis and high level technical trades have shown that the most promising vehicle to address high speed passenger transport would be a ~14000km range ~ Mach 5 aircraft, with high performance levels to ensure affordable ticket prices. The market capture could then exceed 20% and allow sustainable operations of a worldwide fleet of more than 200 aircraft by 2040+.
To accompany the market growth and master the risk associated with such a development, an incremental approach is recommended, starting first with a smaller size vehicle (<100 passengers) and progressively moving towards larger aircraft.

Technology wise, the hydrogen fuel, though providing excellent range and cooling capacity, might not be the only alternative to consider, for other fuels (bio liquid hydrocarbons) might provide better overall climate/performance characteristics.

Regarding the energy and thermal optimization, and the propulsion, the technology progresses accomplished within HIKARI, both on the modelling side and on the demonstration side provide credible building blocks to the future aircraft joint concept. Furthermore, these technologies offer real synergies with other industries, and promising short term applications.

HIKARI has shown how the Europe-Japan partnership could allow achieving such high ambitions as defining the guidelines and roadmaps towards future high speed air transport.
This fruitful outcome allows considering a natural next step for this cooperation, in order to achieve a joint design following the HIKARI guidelines, and to prepare joint flight demonstrations following the HIKARI roadmap.

The results have been made possible thanks to the strong support from the European Commission and METI.

1. INTRODUCTION

1.1 Reminder of HIKARI project objectives

The initial observation who laid the foundation of HIKARI is that, even with aviation craving for growth and disruptive progress and so many research initiatives in high speed transport, passengers traveling routinely onboard a high speed airplane is still a long way ahead.
There are two major hindrances to the emergence of this product: the first one are development costs and risks associated to such a program, the second is the technology readiness level of its building bricks.

To reduce risks and share costs, HIKARI federates all the hypersonic initiatives in Europe and Japan (Figure 1.1) to converge on common design goals, and benefit from the huge know-how built over the years by its industrial, research centers and academic partners. A strong market analysis should comfort the ability for this target design to meet the market expectations.

To address the technology readiness issue, HIKARI should pursue research in three key critical areas for high speed transport: thermal and energy, propulsion and environment, and should derive a joint technology maturation path towards flight experimentations.

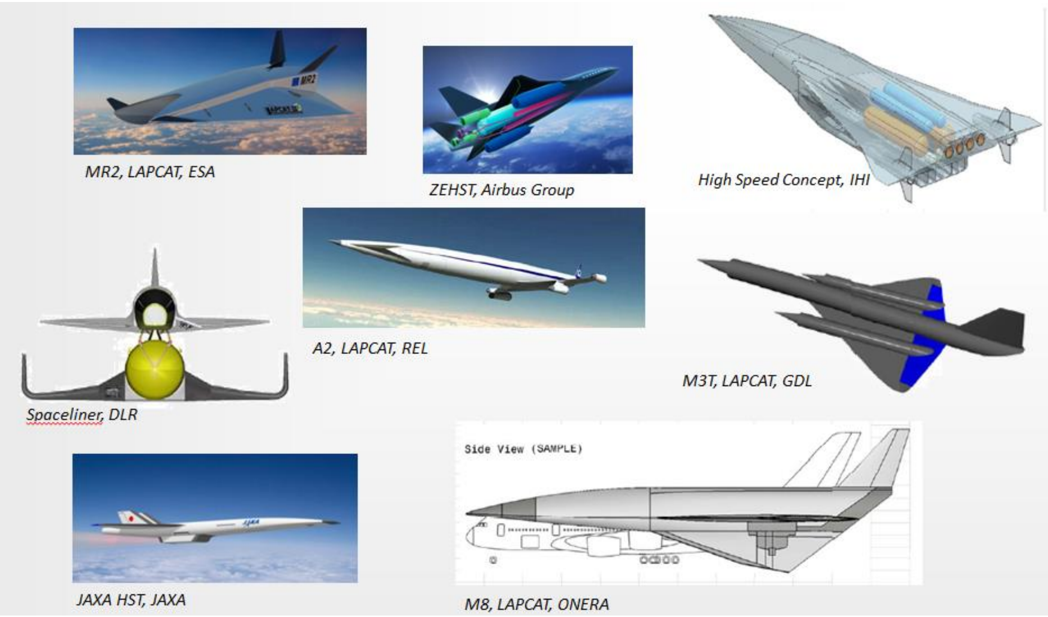

Figure 1.1: Several vehicle designs from HIKARI "parent-initiatives"

1.2 Objective and Structure of the document

This final report summarizes the outcome of the research performed within the HIKARI project.

First, the main guidelines towards a joint high speed vehicle are presented, highlighting the conclusions from the convergence process and the main rationale behind the decision made. The roadmaps leading to this ultimate joint design are described, detailing each step of the technology development and of the validation, including ground and flight tests.

Second, the key findings in the three technology areas investigated (environment, thermal and energy, and propulsion) are summarized.

Third, the lessons learned during the entire project are presented, especially in the light of the Europe-Japan cooperation.

The proposed structure of the core document allows to highlight the logical exchanges and interactions between the Work Packages and between their contributing partners of Europe and Japan.

2. GUIDELINES TOWARDS A JOINT HIGH-SPEED TRANSPORT VEHICLE

The process to progress towards converged design requirements involves several steps.

- First the technical data collection from the “parent” concepts illustrated in Figure 1.1, and their associated statistical analysis, to understand the relevant trends.
- Then, an analysis of all the external influence factors driving the design decisions, and ultimately the vehicle performance. These influences are mapped in Figure 1.2, highlighting for instance the importance of the commercial & operational requirements on the design, as well as the strong influence from the environment constraints.

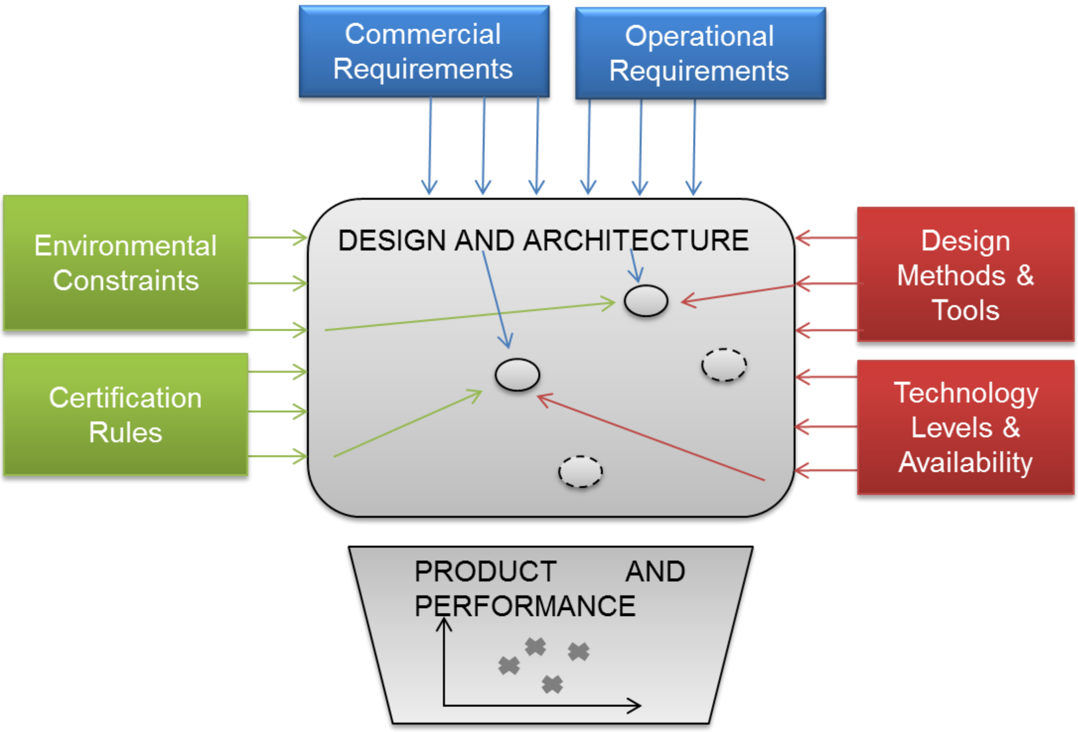

Figure 1.2: Design Process

Once the mapping of the influence factors is understood, the following step is to quantify these interdependencies, to support the decision making.

All this process is supported by direct exchanges between the consortium experts, to reach this final joint vision.

In the following paragraphs, one will first map the interdependencies of the key design parameters of a high speed air vehicle. Second, some elements of justification to support decision making will be presented, in the specific case of the market and economic analysis. Finally, the outcome of the convergence process will be presented in the form of guidelines for the key design requirements of the high speed transport aircraft.

2.1: Flowchart of Key Design parameters

To understand at a finer level the interdependencies of the technical requirements, how they are influenced by external constraints, and the sequence in which they inter-relate, a flow chart of the main parameters is presented in Figure 1.3.
It is to be noticed that because certification and ground constraints influence the design at a broader level, they are not depicted here.

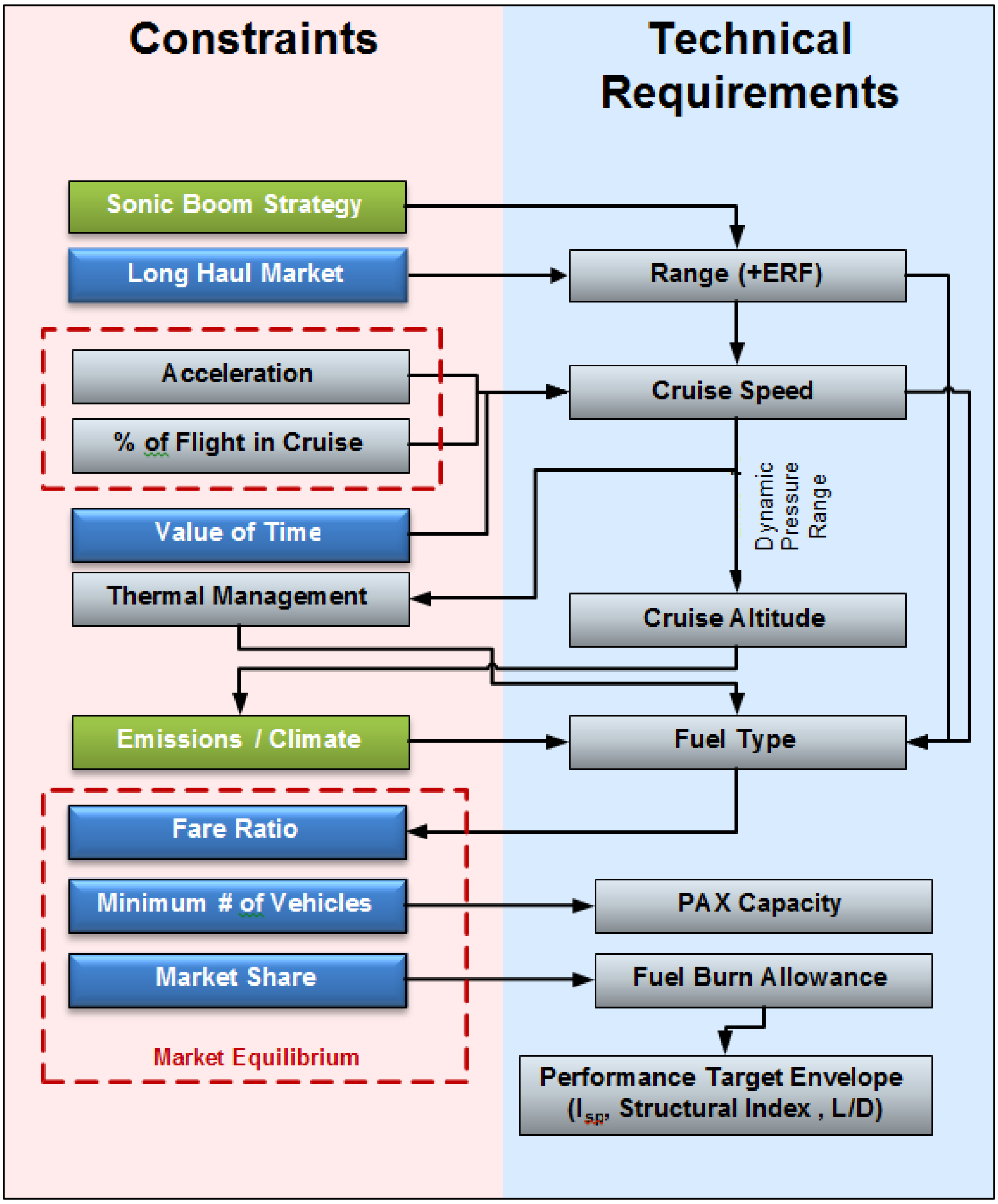

Figure 1.3: Flow Chart of main parameters

The very first global observation on the high level requirements of an high speed aircraft is that they are more complex and more coupled than for a subsonic aircraft.

For instance, one has to consider an additional factor to compute the range on top of the city-pairs that compose the long haul market. The “sonic boom strategy” selected (ie to fly overland or only overwater in supersonic mode) might generate in the later case an “Extended Range Factor” , ie a multiplying factor to apply on direct distance between the city pairs to capture the detours.

Likewise, the cruise speed, which is driven by the value of time saved for the passenger, also depends on the range targeted and the acceleration level, for acceleration phases are proportionally longer with high sped aircraft. Indeed, if the acceleration levels are too small and the mission is too short, it might not even be possible to reach the cruise speed before reaching the end destination.

The cruise altitude is imposed by the best aerodynamic performance (linked to the dynamic pressure), and thus by the cruise speed.

The fuel type is selected according to its energy content, ie its ability to produce the best range, but also according to its cooling capability and climate impact.

Finally, the passenger capacity results from the “Market Equilibrium”, that is the equilibrium between the ticket price (or fare ratio vs subsonic ticket price), the market share, and the number of aircraft produced.

Once the interdepencies are understood, the following step is actually to quantify them thanks to models to be able to determine the recommended value for each requirement. An example of this justification, in the case of the market analysis, is provided hereafter.

2.2 Market and Economic analysis

Network and Traffic Demand

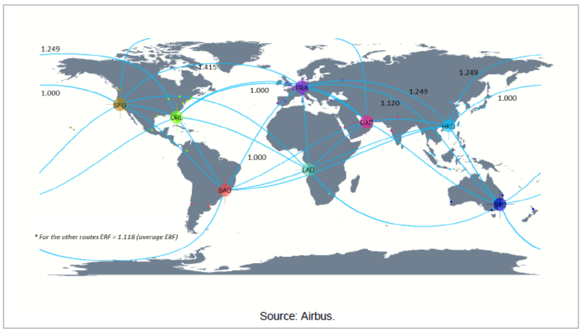

Figure 1.5: Traffic Flow and ERF

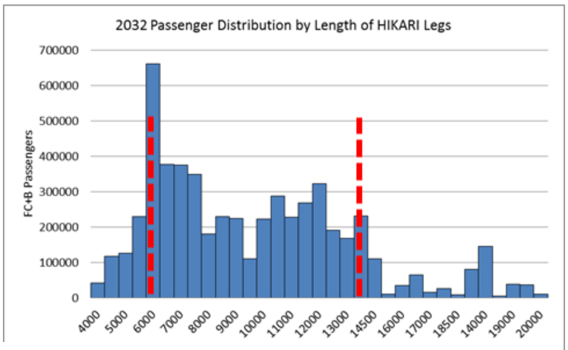

Figure 1.4: Passenger distribution w/ ERF

First, the HIKARI market analysis identified the long-range routes with sufficient business and first class passenger traffic to sustain high speed operations (Figure 1.5). For each route, an Extended Range Factor was computed in order to capture the detour required to avoid supersonic overland flight.

The distribution of the demand according to the distance of the flight was plotted (Figure 1.4), including the ERF, so as to determine a satisfying target range for the aircraft. This chart indicates two peaks of traffic (marked red): the first one around 6000km, corresponding to the transatlantic market, the second, up to 14000km with ERF, corresponding to the Europe-Asia market.

Market Equilibrium

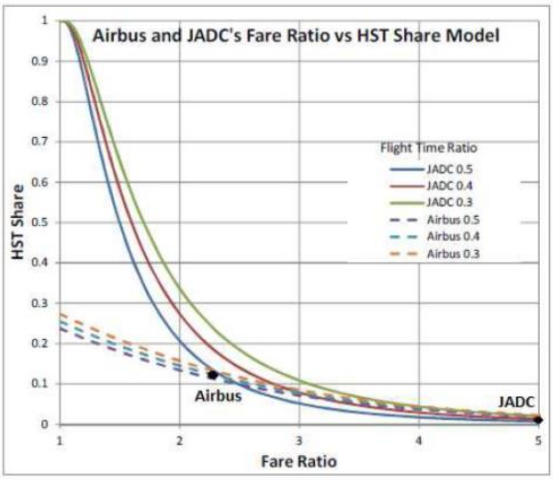

Figure WP3.38: Preliminary outcome for HS market share from JADC and Airbus modelling

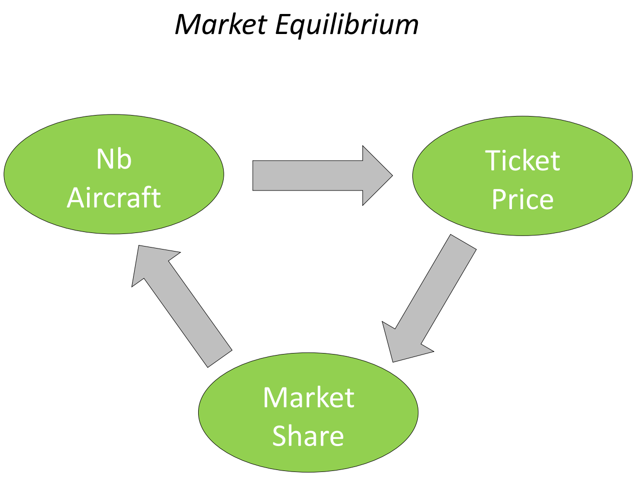

Figure 1.7: Fare Ratio vs HST Market Share

Figure 1.6: Market Equilibrium

Second, the passenger eagerness to pay for time savings ("value of time") was modelled by JAC and Airbus and plotted on **Figure 1.7**, for various speeds. These curves provide the number of passengers willing to travel by HST (market share) according to the ticket price offered by the airline. For instance, if the fare ratio is 3, ie if the ticket price in HST is three times its equivalent subsonic business class ticket, then the HST market share should be around 10%.

This link is one of the three branches of the "market equilibrium" triangle shown in Figure 1.6 . The second link between the market share and the number of aircraft is derived from the network analysis mentioned in the previous paragraph (ie how many routes can be opened, and how many aircraft are required to operate them). The third link between the number of aircrafts and the ticket price results from a simple Direct Operating Costs model (via the depreciation of the program development costs over the fleet).

Global Economic Impact

Finally, a study of the wider indirect impact of high speed transport for the economy, based on econometric evidence, suggest that the wider benefits through trade and international investment would be worth a further €3.5 billion a year (at today's prices). By 2030, HST could generate employment for over 500 thousand across the HIKARI network.

2.3 Key Design Parameters Outcome

Following the investigations on the key trades affecting the high level requirements for a high speed transport aircraft mapped in Figure 1.3, the following recommendation are summarized in Table 1.1.

Table 1.1: Design Parameters Synthesis

Design Parameter	High is good for …	Low is good for …	Recommended Value
Range	Market Capture → # of aircraft sold	Performance / Operating costs – Ticket Price	**13 500 km (including the ERF)** 11 500km (excluding the ERF)
Acceleration	Cruise performance	Comfort/ Engine weight	**Nx= [0.15-0.2] g**
Cruise Speed	Time savings -> Pax appeal –> market share	Technology levels required	**Mach 5**
Cruise Altitude	Emissions : non monotonous behavior		**Optimized for Mach 5**
Fuel Type: H2	Range, Cooling	Cost, Climate impact	**Hydrogen**, but consider alternatives
Pax Capacity	Performance / Operating costs – Ticket Price	Market Capture (flexibility) # of a/c sold Program complexity and costs	**Step-wise growth** Small (10 pax) < 2040 Medium (100 pax) for 2045 Large (>200 pax) beyond 2055

Target Setting

As no vehicle preliminary conceptual study and sizing was covered by the scope of HIKARI, assessing whether a vehicle following the above mentioned technical requirements would make economic sense and meet an adequate "market equilibrium" as shown in Figure 1.6 was difficult, or could only be based on analogies with the concepts inherited from HIKARI "parent-studies".

To provide an additional answer, a target setting exercise was performed in order to compute the fuel burn allowance and the performance target envelope (as show in Figure 1.3) necessary to meet the market equilibrium expectations.
This cross-check confirmed that meeting the expected performance envelope was reachable, based on knowledge developed in the previous concept studies.

3. KEY TECHNICAL FINDINGS

The first main objective of HIKARI was to reach a converged view on the high level requirements for a high speed passenger transport aircraft. The design decisions and the technology selection derived from these requirements to reach an optimal design were not within the scope of the project.

Nevertheless, a second objective of HIKARI was to study promising technologies, and mature them, without necessarily down-selecting them at this stage.

The outcome of this technology research in 3 areas: Environment and Climate, Thermal and Energy, Propulsion and Fuel systems, are presented hereafter.

3.1 Environmental and Climate Studies

From the analysis performed in the field of environment and climate, some recommendations can be provided regarding the general guidelines for highly supersonic aircraft design and the environmental acceptability of such concept.

The first observation is that the water vapor produced by H_2 combustion has a long residence time in the very dry layers of the stratosphere. This generates a high radiative forcing, and thus a high greenhouse effect. Considering H_2 as an alternative to kerosene for purely environmental reasons does indeed make little sense, for the radiative forcing of H_2O in these layers is higher than the one of CO_2.
Regardless of the fuel, and because of water vapor emissions at a high cruising altitude (vs subsonic aircraft), the simulations performed (cf **Figure 1.8**) indicate that significantly more greenhouse gas effect is to be expected compared to a subsonic fleet.
Some further analysis is required to confirm that these GHG effects might decrease above a certain altitude (25km) due to photolysis and that some specific routes (polar routes, single hemisphere routes) might be more favorable.
On the contrails side, high speed operations do not seem to represent a threat.
In order to enable social acceptance for such type of aircraft, some climate tax should be incorporated into the ticket price to compensate for the extra emission vs an equivalent subsonic flight.

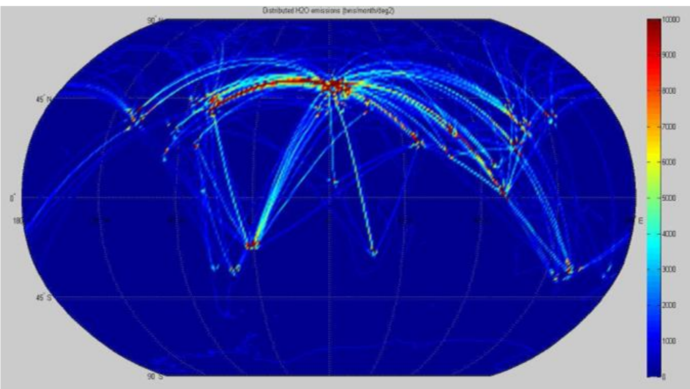

Figure 1.8: Example of emission distribution for HS fleet

Second, the current production process for hydrogen, based on natural gas reforming is associated to a large CO_2 equivalent production. This drawback could however be drastically reduced when considering future hydrogen production based on nuclear powerplant or wind/solar energy associated to high temperature electrolysis (HTE). However, one has to remember that the primary energy to produce, liquefy and store hydrogen remains high, which induces a significant cost penalty.

As a conclusion, the use of hydrogen is not an obvious greener solution than hydrocarbon fuels, and the latter are still good candidates for the high altitude / high speed application.
An investigation of alternative designs using other fuels (liquid hydrocarbon specifically, and possible LNG) with an holistic evaluation method (performance, thermal, costs, climate impact, ground operations) is thus recommended.

3.2 Thermal and Energy Analysis

The objective of the HIKARI thermal and energy analysis was to establish a concept for an innovative on-board thermal and energy management system adapted to the specific needs for high speed air vehicles.
Indeed due to the high heat fluxes entering into the fuselage at hypersonic speed, the airframe structure, equipment, cabin etc. need to be cooled. The only cold source on-board is the fuel but it can only absorb a part of the heat entering the fuselage or produced by the combustion. At the same time, the dual-mode ramjet propulsion system (as one propulsion option for high speed transport) cannot directly provide any electrical energy.
The aim of this research is thus to assess different options based on fuel preheating or on electrical/mechanical energy conversion to capture the entering heat fluxes and apply a methodology to design a complete thermal and energy management system.

A first study has allowed to identify the thermal and mechanical loads and the power sources and cooling capacity inside the airframe to show that they can be balanced (for instance: powerplant to be cooled, passenger cabin to be cooled, fuel pump to be powered etc.) . Moreover, different technologies have been identified to generate, store or use the electricity (thermo-electricity, fuel-cells and electrolysis, electrical discharges for flow control etc.).

Then, different cycles for the airframe cooling were modelled, as shown in Figure 1.9
Running several simulations allowed comparing different types of coolant media, different routes for the coolant fluid and finally demonstrated that sufficient cooling capacity was available in the fuel to ensure stable operations.

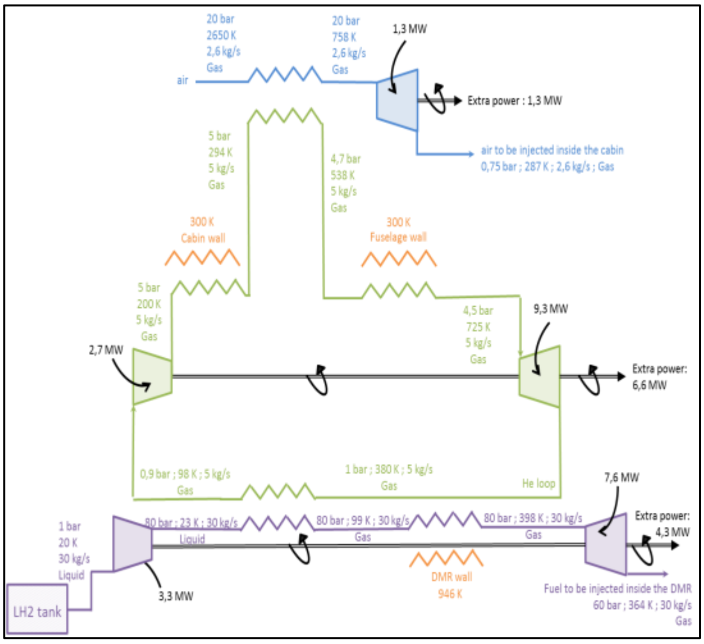

Figure 1.9: Illustration of one possible cooling cycle

A second study, realized in parallel to the first one, consisted on the regenerative cooling of the airframe by means of the fuel vapor boiled-off within the cryogenic fuel tanks and showed that the fuel boil-off could be re-used to cool down the airframe and injected, prior compression, into the combustion chamber.

3.3 Propulsion-related studies: engine, fuel tanks and noise

Within HIKARI, multiple studies were dedicated to investigating alternative technologies to ensure the propulsion function of the high-speed aircraft.

Two propulsion types were specifically considered: the Pre-Cooled Turbojet (PCTJ) and the reusable rocket engine. The fuel system to feed the engines, and especially the tank characteristics were also analyzed, for two fuel types: liquid hydrogen and liquid methane.

The PCTJ is a single type engine capable of ensuring the aircraft propulsion from take-off to Mach 5. In the course of HIKARI, wind tunnel test were conducted at Mach 4 on a small scale model (‘S-engine’) (see Figure 1.10). The S-Engine test-results have allowed to validate the soundness of the main design aspects, and also allowed to anchor the functional mathematical model related to such PCTJ design, which can then be used for predictions.

Figure 1.10: PCTJ Mach 4 Wind-tunnel Test

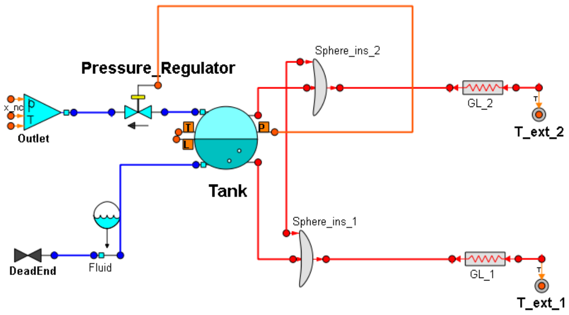

Figure 11: Fuel Tank pressure modelling

Additionally, the noise of an aircraft propelled by this multi-cycle engine has been simulated in the airport environment. First results, prior to any noise reduction procedure, or engine design optimization, indicate noise levels inferior to those of Concorde. Specific emphasis should be made in the coming steps to prepare the noise regulation applicable to high-speed aircraft and to adjust the design and procedure to minimize the noise impact in the airport vicinity.

Furthermore, and though not investigated in the course of HIKARI, the “in-flight noise” caused by the sonic boom should also be one major focus for future studies to help reducing the performance penalty associated to the Extended Range Factor (as shown in Table 1.1).

As an alternative to PCTJ for the acceleration phase of the vehicle, hydrogen and methane powered reusable rockets engines were considered. This included the high level requirements of the engine design itself, but also the staging strategies and the fuel architecture to operate these engines.

Furthermore, to ensure a good mastering of the available technologies for cryogenic tanks, an exhaustive review of the metallic tank technology was performed, considering the functional requirements in terms of safety, storage and operations. Additionally, in conjunction with the thermal studies presented in chapter 3.2, the pressure control management of a tank was simulated (see Figure 11) with an optimization of the insulation thickness to make the best use of the boil-off for the tanks self-pressurization.

3.4 Technology Roadmaps

Finally, an essential mission of the HIKARI project was to derive the required technology roadmaps to support the development of the high speed air transport vehicle, including the maturing process, ground and flight testing.

This overall roadmap is presented in Figure 1.12.

During the first half of the overall roadmap the technology development and maturation is the most important part of the activities and is estimated to have a duration of ~10 to 15 years, according to how fast the program is launched and according to the magnitude of its funding.

At technology level, several roadmaps for *environment, propulsion, thermal control, materials, control aerodynamics, structure, safety/operations/social impact*, and *facilities/tools/capabilities* have been identified within the HIKARI project. Based on the expertise of the HIKARI consortium many of these roadmaps have been detailed and are presented in D2.2.1.

It is important to highlight that many technology maturation streams have synergies with other domains which might support joint developments on European and international level, specifically with Japan (cf chapter 4.3).

As a key validation element of this roadmap, the *Reduced Size Aircraft Demonstrator* should ensure the flight of a reduced scale high speed aircraft with all relevant subsystems integrated, before launching the final sizing and manufacturing of a full scale prototype.

For the question of a shorter term product was raised by METI, an earlier Entry into Service than the one presented here (2050) could be foreseen. This would of course be more easily achievable for a smaller vehicle, for which the necessary resources might be more quickly gathered.
In this scenario, the “Mission and Conceptual Phase” could be shortened by up to 8 years. Two technologies would then get on the critical path and would require specific attention: cryogenic tanks and thermal protection integration into the airframe structure, and the development and testing of combined cycle propulsion concepts (based on turbojets and (sc)ramjets).

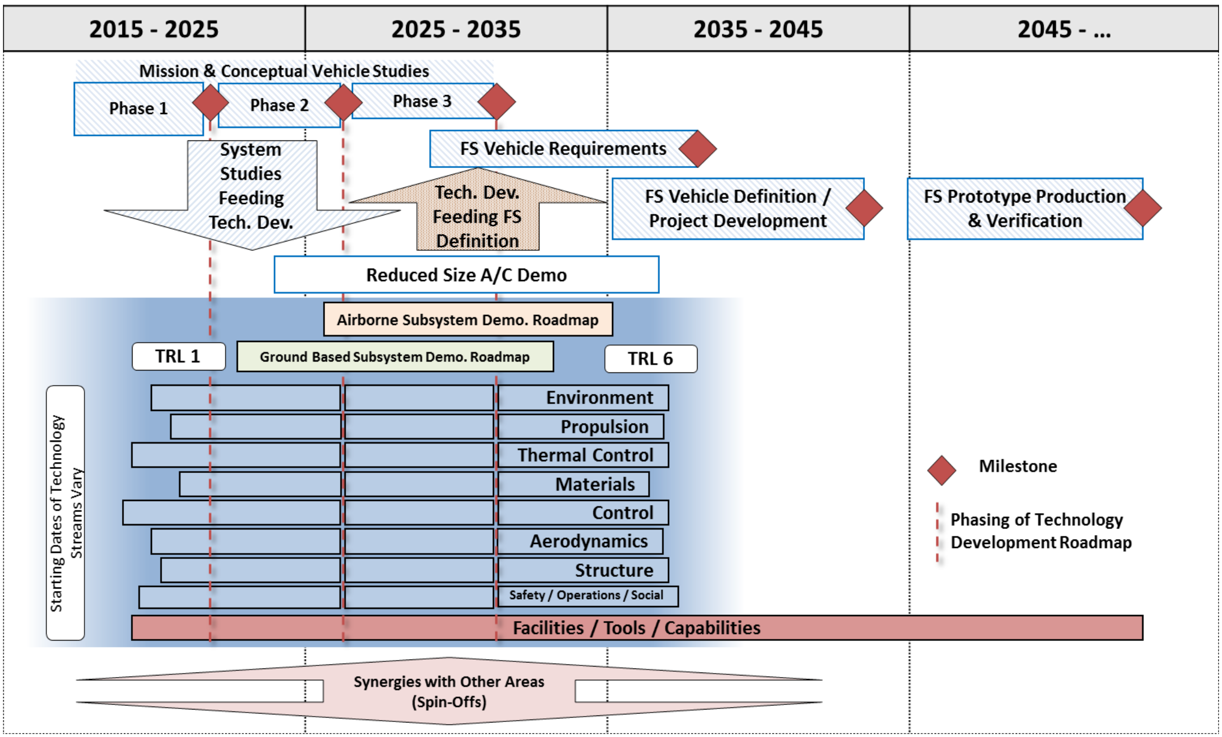

Figure 1.12: HIKARI High Speed Flight Technology Development Roadmap

4. LESSONS LEARNED AND ADDED VALUE

As highlighted in the technical results presented before, HIKARI, as a Europe-Japan project, was a successful cooperation in which each partner learnt to effectively work together to eventually produce a result greater than the sum of the individual contributions. The added value of the project beyond its mere technical outcome is presented in this section.

4.1 Benefit of EU-Japan Cooperation: Knowledge

In most work packages from HIKARI, partners from Japan and Europe were jointly involved. In some cases, like for the guidelines, the aim was to openly exchanges and discuss to progress towards a joint vision. In other work cases, the approach was to initially work in parallel studies, based on different set of assumptions, to be able to confront the results at the end, so as to increase the confidence level in the outcome.

This was for instance the case for the market study where Airbus and JADC performed parallel studies based on a common set of assumptions (except for a few selected ones). For instance, the JADC modelling voluntarily did not integrate the connecting traffic feeding the high speed flights, whether the Airbus modelling did. The comparison of the two brought the very valuable conclusion that a network based on direct flights only (without connecting traffic) was too small for the targeted fleet (~200 aircraft). Integrating the passenger traffic from connecting flights (hub and spoke) is thus essential to have a large sustainable fleet. In the case of the market elasticity to ticket price, JADC and Airbus conducted independent studies that led to converging results (**Figure 1.7**), thus comforting the confidence in this outcome.

On the technical disciplines, the European and Japanese had complementary benefits to the projects. On the propulsion side, the Japanese partners worked on engine types unique to Japan (like the PCTJ), so as to offer an alternative to segregated propulsion types (rocket engine, turbojet based engine or ram/scramjets) considered on the European side.

Likewise, on the environment modeling side, the Japanese partners investigated the impact on the high-altitude atmospheric chemistry for a rich burn mix, whereas the European partners simulated the climate impact of a lean burn mix.

4.2 Benefit of EU-Japan Cooperation: Dissemination and Communication

Thanks to the large representativeness of its consortium, one of the aims of HIKARI was to be able to increase the level of interest and acceptance from the general public, scientific community and decision makers towards hypersonic flight on a global scale.

For the scientific community, technical publications were produced and presented in numerous congresses and conferences worldwide, and not only limited to Europe and Japan. Moreover, two major dissemination events took place, the 1st & 2nd HIKARI Open Workshop in Tokyo and in Brussels respectively. During these events, the technical ambitions and challenges of High Speed Transport derived within the HIKARI project and the established roadmaps were presented to more than 150 key stakeholders; thus increasing awareness and keeping the HIKARI community updated upon the significant research activities of the project.

For the wider public, some information was provided, through the project website and other channels to explain the way that should be followed for making HST a viable scenario, the benefits and usefulness of HST on their future daily life, and the overall impact of HST on technological excellence and on citizens.

The production by Euronews of a TV documentary regarding the research performed within the HIKARI project, aired worldwide for a whole week (22 times) in 13 languages in the FUTURIS program, was a key enabler in this endeavor.

Concluding, the dissemination plan implemented during these 24 months of the HIKARI project achieved its main aim, thus raising public awareness & enhancing societal acceptance about the controversial issue of High Speed Transport and therefore making it a viable scenario both in Europe and in Japan.

4.3 Synergetic Areas with other domains

Even though the research towards high speed air transport is primarily mid-term and long term oriented, with end products not available to the market before at least two decades, the technical and economic value from its work is to be felt in a much shorter term.

Indeed, several topics have been identified where synergies with other economic fields provide opportunities for joint work and much shorter applications, with obvious benefits in terms of costs sharing and risk mitigation.
They are summarized in Table 2.

Table 2 :Synergetic technology areas between high-speed research and other applications

Synergetic topic	Short/Mid-Term application
Mass **H2 production and use, including tanks**	Ground transportation, subsonic aviation (propulsion / fuel cell), space launchers …
Thermal and energy optimization method (including components like lightweight heat exchangers)	More electric subsonic aviation, ground transportation…
High temperature lightweight materials	Subsonic aircraft engines, space re-entry vehicles, space propulsion
High altitude atmospheric and climate modelling	Subsonic commercial flights using polar trajectories (lower stratosphere), business jets…
Design **methods and tools for highly complex and integrated vehicles**	Aerospace vehicle design
Design Rules evolution to allow high performance vehicles (i.e. single pilot, windowless aircraft…)	Subsonic aircraft, sub-orbital vehicles

5. CONCLUSION AND WAY FORWARD

When overlooking passenger transport at the horizon of 2040-2050, a high speed transport design capable of sufficient performance levels to capture a reasonable market share (>10%) and to sustain stable operations seems to be feasible.

An incremental way seems to be the most adequate towards this ultimate objective.

Thus one should tackle the technical and financial complexity in a stepwise approach, but always aiming at vehicles with performance levels capable of guaranteeing a competitive ticket price and market capture. The very first step of this evolution could be a reduced size vehicle (<=100 PAX) with intermediate technical requirements (speed ~Mach 5, maybe more conventional fuel).
In a second step, one could grow towards a 100 pax vehicle, capable of fulfilling all the HIKARI requirements, ie a Mach 5, 14000km range aircraft possibly using cryogenic fuel. Finally, the third step could be a faster and larger plane, for which speed and technology would open the door to further applications (reusable space launchers…).

In this endeavour, the already available designs should be kept alive to be a strong foundation and provide valuable building blocks, as well as a competitive benchmark. Meanwhile, one should also monitor the ongoing evolutions in aerospace which will generate synergies and accelerate this step-wise approach.

The next natural research step on this path towards high speed aviation would be to reach a common design compliant with the HIKARI Guidelines.
This common design should be the product of an integrated team under the leadership of a chief engineer, and should encompass not only the vehicle and the selection of its

technological building blocks, but the system as a whole, including the infrastructure to support the flight and ground operations of a commercial high speed fleet.

Furthermore, to ensure the required performance level of this vehicle and system, each selected technology block should be matured following the HIKARI roadmaps.

Specific emphasis should be made for instance on sonic boom reduction and regulation, which could enable significant vehicle performance gains and operational simplification by allowing direct overland supersonic trajectories.

Technology focus should also be made on topics such as energy and thermal management, community environment, including low speed noise and emissions, and propulsion. Because of their worldwide impact and ambition, all these topics are natural candidates for international cooperation between Europe and Japan, and beyond.

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