HiSST: 2nd International Conference on
High-Speed Vehicle Science & Technology

11–15 September 2022, Bruges, Belgium

CEAS
Council of European Aerospace Societies

Design of Hypersonic Airline Networks with respect to Passenger Demand and Flight Routing

Jens Thöben[1], *Daniel Bodmer*[2], *Bernd Liebhardt*[3], *Volker Gollnick*[4]

Abstract

A methodology is presented to design and assess basic operational aspects of hypersonic airliners. Initially, a database of global airline ticket sales is used to identify promising origin-destination pairings for hypersonic transportation. The encountered demand is pooled to be served by so-called Stratoports that are strategically spread all over the globe. To connect the Stratoports, overwater flight routes are designed with the help of mission simulation and sonic boom carpet computation to identify a noise-optimal global route network guaranteeing that the sonic boom will not hit on landmasses. This work was done in the context of the European Union project STRATOFLY.

Keywords: *Sonic Boom, Business Case, Mission Simulation, STRATOFLY*

Nomenclature

Latin
ECMWF – European Center for Medium-range Weather Forecast
HST – Hypersonic Transport
HTCM – Hypersonic Trajectory Calculation Module
ILT – Institute of Air Transportation Systems
LNAV – Lateral navigation
STRATOFLY – Stratospheric Flying Opportunities for High-Speed Propulsion Concepts
VNAV – Vertical navigation
PAX – Number of premium passengers
a – Quantity (e.g. PAX)
$addInfluence$ – Additional influences
$flighttime$ – Total flight time
n – Number of years
r – Average growth rate [%]
Subscripts
$direct$ – Great circle connection
i – Year of reference
$i+n$ – Projected year
$real$ – Connections including detours
$weighted$ – Weighted

1. Introduction

The Stratospheric Flying Opportunities for High-Speed Propulsion Concepts (STRATOFLY) research project was launched in 2018 to develop a hypersonic airliner with up to 300 seats that has a cruise speed of Mach 8 at an altitude of 113,000 feet to fly an antipodal flight range of up to 19,000 km in about 3 h. Whereas most of the work focuses on technical aircraft design, we draft probable scenarios of airline networks with the help of operational, economic, and technical data.

The analysis of the climate impact of the aircraft has not yet been completed and is therefore not part of this publication. Nevertheless, it can be assumed that this has an influence on public perception and thus on social acceptance.

Since both development and operations of hypersonic aircraft will be expensive because of their nonconventionality, higher technological requirements, and high fuel consumption, this kind of transportation

---

[1] *Institute of Air Transportation Systems (ILT), Hamburg Univ. of Technology, jens.thoeben@tuhh.de*
[2] *Institute of Air Transportation Systems,(ILT), Hamburg Univ. of Technology, daniel.bodmer@tuhh.de*
[3] *Institute of Air Transportation Systems, German Aerospace Center, bernd.liebhardt@dlr.de*
[4] *Institute of Air Transportation Systems,(ILT), Hamburg Univ. of Technology, volker.gollnick@tuhh.de*

will inevitably cost considerably more compared to their subsonic counterpart. Therefore, principally passengers routinely booking premium seats (Business & First Class) can be held able and willing to regularly afford hypersonic flights. Based on the resulting demand data, promising intercontinental pairs of regions and cities are identified that a hypersonic aircraft can operate between.

Supersonic overland flight was banned by most countries in the early 1970s when the loudness of Concorde's sonic boom became public. Even though hypersonic aircraft operate in high altitudes around 20-30 kilometers, they still produce an audible sonic boom whose loudness is probably inacceptable to significant portions of the public. This means that they will probably operate on overwater routes exclusively, at least unless current technological developments with the objective to decrease or even cease the supersonic boom are successful.

2. Global passenger market assessment and flight path design with respect to the sonic boom carpet

Concerning needed vehicles and associated operations, hypersonic transport (HST) is a technically and economically demanding task, which ultimately leads to high ticket prices, in particular due to extensive fuel consumption. These tickets were considered too expensive to gain a relevant interest of the economy class sector in traveling at hypersonic speed as this segment is especially price sensitive. Consequently, it was assumed that mainly business class and first class passengers are expected to use such a service. Therefore, only the latter passengers (PAX), who are understood as "premium passengers" in this paper, were subjects of the conducted analysis. Since these PAX are composed from two customer segments, the compiled metrics are an average.

In addition, it is assumed that PAX do not mind changing between different airports available in their origin or destination metropolitan area, which enables accumulating PAX of all airports within such an area.

The Sabre Market Intelligence database [1] provides detailed information about the airline market including the number of PAX traveling between all worldwide airports. Based on that database, the number of premium passengers for all city pairs were compiled for the year 2017, forming the basis for the investigation of future HST demand.

Table 1. Top 10 city pairs of premium air travel w. r. t. revenue, 2017

Origin	Destination	PAX	Revenue [$]
New York	London	353,000	670,791,000
London	New York	342,000	646,092,000
Los Angeles	New York	321,000	280,740,000
San Francisco	New York	250,000	278,786,000
New York	Los Angeles	318,000	276,765,000
New York	San Francisco	252,000	275,926,000
London	Singapore	101,000	249,702,000
London	Hong Kong	102,000	239,464,000
Hong Kong	London	100,000	239,359,000
Singapore	London	95,000	238,253,000

Table 1 visualizes the top 10 city pairs sorted for generated revenue in the same year. Here, the importance of London and New York becomes particularly clear as both traffic hubs generate more than twice the revenue compared to the subsequent city pair.

To forecast the processed data of 2017 to the year 2050 when a hypersonic air transportation system could be in service, the well-known Current Market Outlook (CMO)[2] issued by Boeing was taken as reference to estimate the expected growth. Even though the CMO presents region growth only until 2037, it was assumed that the same average rate of growth applies to the years between 2037 and 2050. However, as the CMO was prepared before the COVID-19 pandemic and current energy shortages, these growth projections must be viewed with caution. To obtain a future quantity of interest with a given constant growth rate from a year of reference to a specific time in the future, the following formula

$$a_{i+n} = a_i \cdot (1+r)^n \tag{1}$$

was used where a_i is the given quantity in the year of reference, a_{i+n} is the projected quantity, n is the number of years and r is the average annual growth rate [%] during this duration taken from the CMO for each specific region pair (e.g. 3 % for Europe - North America).

Table 2. Predicted top 10 city pairs regarding revenue in 2050

Origin	Destination	PAX	Revenue [$]
New York	London	936,000	1,779,163,000
London	New York	908,000	1,713,652,000
London	Hong Kong	615,000	1,445,941,000
Hong Kong	London	604,000	1,445,301,000
London	Dubai	666,000	1,084,573,000
Dubai	London	654,000	1,049,460,000
Sydney	London	356,000	968,364,000
Hong Kong	New York	259,000	937,568,000
London	Sydney	333,000	923,302,000
New York	Hong Kong	253,000	889,724,000

Table 2 presents the top 10 city pairs sorted by generated revenue in 2050. Comparing this data to the situation in 2017 as shown in Table 1 reveals that especially Asia will increasingly become important in future air travel.

In order to distinguish conventional airports from airports with a hypersonic flight connection, the latter are referred as Stratoports. As a technical boundary condition for the STRATOFLY-MR3, a runway with a minimum length of 4000 m at an altitude of less than 3000 m was determined. Furthermore, Brussels and Sydney were included in the list of possible Stratoports from the STRATOFLY project context, each with a runway length of just under 4000 m. Since the hypersonic aircraft is designed primarily for a hypersonic flight, only a short part of the journey should be over land, and thus, subsonic. Therefore, as a further boundary condition for selecting the initial Stratoports, a maximum distance of 450 km between a Stratoport and the coast of an open sea is considered. The later analysis shows that the sonic boom carpets take widths of at least 50 km. In particular, this limits the flights via straits, e.g. the Strait of Gibraltar as an exit from the Mediterranean, which is why these airports are not among the possible Stratoports from an operational point of view. Of more than 9000 analysed global airports, more than 40 fulfill the technical conditions and are considered to be potential Stratoports for the following economic analysis.

A database with initial hypersonic routes connecting two Stratoports was created including distances and required flight times. To assess the hypersonic flight missions and attain feasible flight times, the Hypersonic Trajectory Calculation Module (HTCM) [3] is used, with a subsonic cruise altitude of 45,000 ft, a cruise altitude of 113,000 ft and a route-depending payload factor (maximum payload 33 t). Additional flight times were estimated based on linear interpolation.

The HTCM is a MATLAB-based simulation tool to calculate 4D flight trajectories based on aerodynamic [4], engine [5] and emission [6] property databases of the STRATOFLY-MR 3 vehicle. These trajectories contain the complete history of MR 3 state variables and are propagated by fast-time Euler forward integration method. The tool is a software derivate of the Trajectory Calculation Module (TCM), a subsonic mission performance tool developed by DLR [7]. Within the HTCM, MR 3 flight dynamics are embedded using a 3-degree-of-freedom point mass model where the geodetic longitude, latitude and height compose the aircraft's position state as well as the true airspeed, course and climb angle represent the aircraft's translation state. Inertial forces of the orbital curvature contribute to the rigid-body equations of motion which are based on an Extend-Total-Energy Model that physically equates the specific excess power (being correlated to the external forces acting on the aircraft) to the total rate of change in potential and kinetic energy. A lateral navigation (LNAV) routine ensures that route waypoints are detected, and curve flights are initiated based on a normal load factor of $n_z = 1.3$. Due to the hypersonic cruise speed of Mach 8, large turn radii of up to 720 km result so that e.g. a course change of 10° requires more than 1 min of flight time making hypersonic flight missions very challenging from an operational point of view. In terms of a vertical navigation (VNAV) routine, target and exit condition of the particular flight segment (e.g. speed and altitude schedule) are monitored and passed to the aircraft control laws. The LNAV routine additionally contains two iterative cycles, which define the transition phase into (from) the supersonic flight regime (Mach 1) at the second (penultimate) route waypoint.

In order to create a hypersonic route between two Stratoports, a flight path containing mission specific route waypoints was first drawn in Google Earth. Considering that the so-called sonic boom carpet (which is the area under the flight path where the sonic boom reaches the earth's surface created at supersonic speed) does not reach any inhabited areas, most hypersonic sections are above the sea at a sufficient distance from the coast. Furthermore, minimum curve radii were taken into account. An example can be seen in Fig. 1.

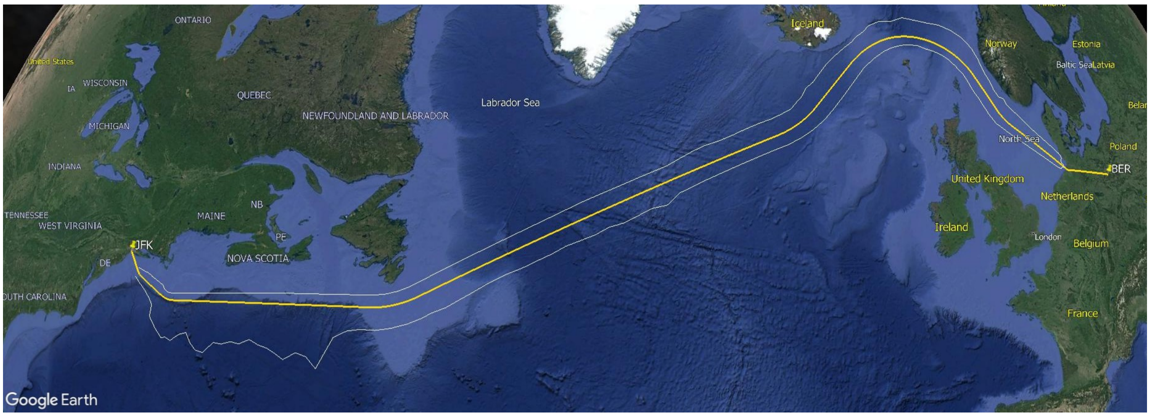

Fig 1. Flight path from Berlin to New York and an associated sonic boom carpet

The flight paths between the Stratoports were transferred to the HTCM, which created 4D flight trajectories. In the next step, a proprietary sonic ray tracing software [8] was used to calculate the geometric sonic boom carpet for the given 4D flight trajectories from the HTCM. The ray tracing software primarily uses Schulten's equations [9] to propagate the rays of the aircraft's Mach cone from operating altitude to the surface of the earth. The ordinary differential equations are solved by a standard Runge-Kutta method. Furthermore, the reference ellipsoid from the World Geodetic System 1984 (WGS 84) is applied to model the earth's spheroid. To test the flight paths robustness to different weather conditions, various sets of globally discretised ECMWF weather data [1] including winds are used. So as to ensure the convergence of the mentioned method, the weather data is interpolated in a manner that the 3D derivatives are continuous.

In order to be able to map the effects of the weather data on the sonic boom carpet as well as possible, the calculations were carried out for different times of the day and seasons. Depending on the weather

---

[1] ERA-Interim data, provided by the European Center for Medium-range Weather Forecast (ECMWF)

conditions, some sonic boom carpets of entire flight sections shift perpendicularly to the flight path, resulting in a wide corridor in which a sonic boom can occur as can be seen in Fig. 2.

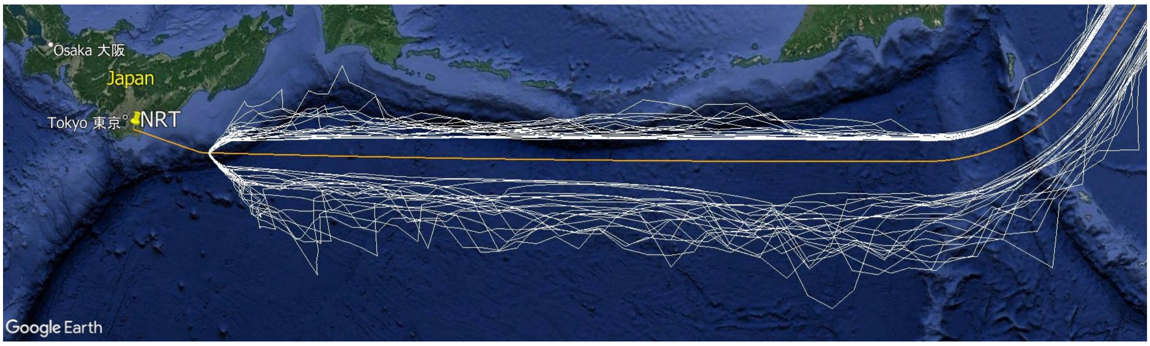

Fig 2. Example of sonic boom carpets for different weather conditions

In order to avoid major detours, the contour calculation of the boom carpet must become part of the pre-tactical flight planning. If necessary, adjusted and optimised flight paths were given back to the HTCM to recalculate the 4D-trajectories and to iterate the process.

Although most flight paths are above the sea and uninhabited areas, this is not always possible. In particular, the connection between the North Atlantic and the North Pacific runs through an extremely sparsely populated part of Siberia as shown in Fig. 3. Due to the width of the sonic boom carpet, more densely populated areas in Alaska, Siberia and on the islands in the Chukchi Sea and Bering Sea would be affected by the noise if an alternative route were taken over water. Since the model of the sonic boom carpet only shows its footprint but not its loudness, further studies are necessary to assess the influence of a supersonic flight on the Siberian population.

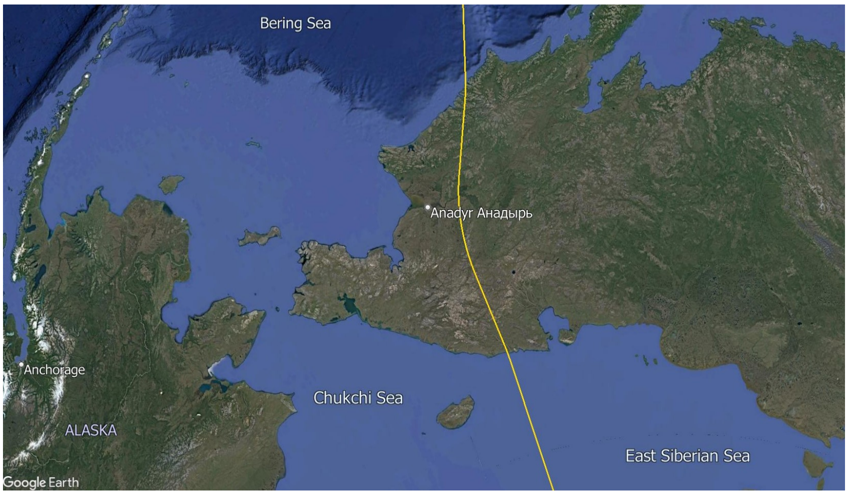

Fig 3. Hypersonic route via Siberia

Since the biggest advantage of hypersonic flight is time saving, the assessment of the global passenger market is based on finding the fastest route between two cities. Our algorithm compares different flight routes for a given city pair and chooses the fastest one out of a subsonic direct flight or a flight via an available Stratoport-to-Stratoport route. The latter are characterised by a subsonic flight from the departure airport to the Stratoport, a hypersonic flight between the Stratoports and a subsonic flight to the final destination. Furthermore, it takes into account a layover time at the Stratoports, if the distance between the airport and the Stratoport exceeds a minimum distance. This approach allows cities further inland to use a hypersonic leg if it is faster than a direct subsonic connection. In the next step, the passengers are assigned to the individual city pairs and the routes are evaluated on the basis of the weighted passenger numbers. Not sufficiently utilised Stratoports and connections between them are removed from the database and the calculation of the fastest route between two cities is restarted with the remaining Stratoport connections. The weighting of passenger numbers considers the time ratio and additional influences according to the following formula:

$$PAX_{weighted} = PAX \cdot addInfluence \cdot \left(1 - \frac{flighttime_{real}}{flighttime_{direct}}\right), \tag{2}$$

where $PAX_{weighted}$ describes the weighted number of passengers which can be expected on the associated hypersonic flight in 2050 per day. PAX describes the number of passengers per day which result from the Sabre database and the extrapolation into the year 2050. $flighttime_{real}$ is the total flight time including hypersonic flight with overwater detours resulting from noise restrictions, layovers and subsonic feeder flights. $flighttime_{direct}$ is the flight time of a subsonic direct flight. The factor $addInfluence$ models the influences that are not covered by the flight time. These include, for example, the ticket price, the lower comfort level and the general approval of passengers for hypersonic flight (e.g. due to health issues). In a survey by the Lufthansa Innovation Hub done in 2019 [10], only 42 % of First Class passengers and 54 % of Business Class passengers were generally interested in paying an additional charge for halving the flight time. On average, Business Class passengers would be willing to pay between 30 and 40 % more, while First Class passengers would only pay up to 25 % more. Besides, we assumed that airlines with subsonic fleets also have an economic interest in continuing to offer subsonic flights and will not abandon individual connections and their premium passengers. They could persuade the passengers with lower ticket prices and greater comfort. Furthermore, a faster flight does not automatically lead to a time benefit for the passenger. It varies very much depending on other factors, namely times of departure and arrival, time shift, journey purpose and duration, biorhythm and work schedules. For instance, a flight that starts in the morning and arrives in the late evening due to time shift, despite being very fast, has limited appeal for business travellers who need to make use of the working hours at their destination (for further information see [11]). In addition to the economic perspective, the impact of hydrogen-powered aircraft at high altitudes on the environment and the resulting social image have not been fully clarified. Companies might have an interest in not letting their employees travel with fuel-intensive aircraft. Since these influences are difficult to estimate for the next 30 years due to current climate movements and the social acceptance of hypersonic flight, a parameter study is conducted, in which the factors are combined into the $addInfluence$ parameter.

3. Results

Since the assessment of future passenger numbers is based on assumptions, parameter studies were carried out to investigate the influence of individual variables.

Fig. 4 shows the influence of the $addInfluence$-factor on the total amount of flights per day, the number of routes between Stratoports and the number of Stratoports. These values are calculated for an aircraft with 300 seats and a load factor of at least 75 %. As the number of passengers per route increases due to the increasing $addInfluence$-factor, the number of routes between the Stratoports and thus the number of flights increases.

To investigate the impact of an aircraft with a load factor of less than 75 % and thus an economically unfeasible flight, the maximum seating capacity was reduced in a further study. Fig. 5 shows the influence of the number of seats per aircraft on the total amount of flights per day, the number of routes between Stratoports and the amount of passengers per day. These values are calculated for the performance data of the STRATOFLY-MR 3, an $addInfluence$-factor of 0.3 and a load factor of at least 75 %. Increasing seat capacity reduces the number of routes because there are not enough passengers on some routes to utilise the aircraft. As a result, the number of flights per day decreases more than can be compensated by the increasing seat capacity. This result is reflected in the decreasing number of passengers.

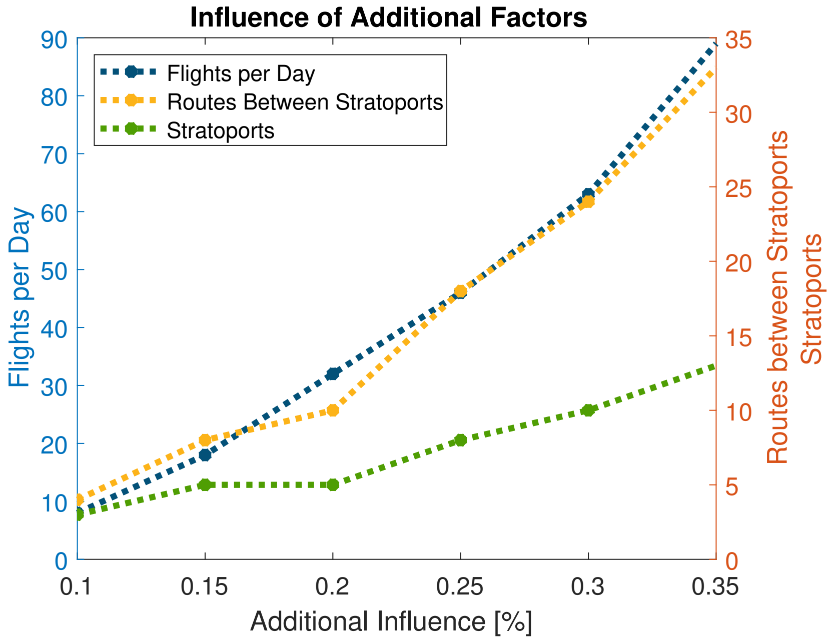

Fig 4. Influence of additional factors

Table 3 and 4 show, for different number of seats and $addInfluence$ combinations, the most promising stratoports and the connections between them. The data shows that due to larger detours, load factors of less than 75 % or too small time advantages compared to a subsonic flight, not all technically possible and from the Sabre database extrapolated connections and Stratoports are included. As passengers are reallocated to the remaining Stratoports in each iteration step, a single Stratoport can gain importance if a neighbouring Stratoport cannot transport enough passengers and loses its status as a Stratoport. These passengers are then assigned to the remaining Stratoports. This changes the order of routes and Stratoports for different parameter variations.

Currently, distances of about 5000 to 20,000 km can be served by the STRATOFLY-MR 3. The time spent at Mach 8 can vary from a few minutes to several hours. Especially with the long routes, the speed advantage can be effectively exploited. However, the long distances can also result from long detours. Due to the high cruise speed, decelerating to the necessary subsonic speed to fly over inhabited areas is not always possible. Therefore the flights are planned with longer detours over water.

In order to explore these effects closer, Fig. 6 and 7 show the number of flights and the detours depending on the distance. This shows that on the one hand the three range segments (5000-7500 km, 10,000-12,500 km, 15,000-20,000 km) are relevant for the business case. On the other hand, it becomes clear that especially the distances in the range of 15,000-17,500 km are mainly caused by a high detour. The detours are related to the great circle distance.

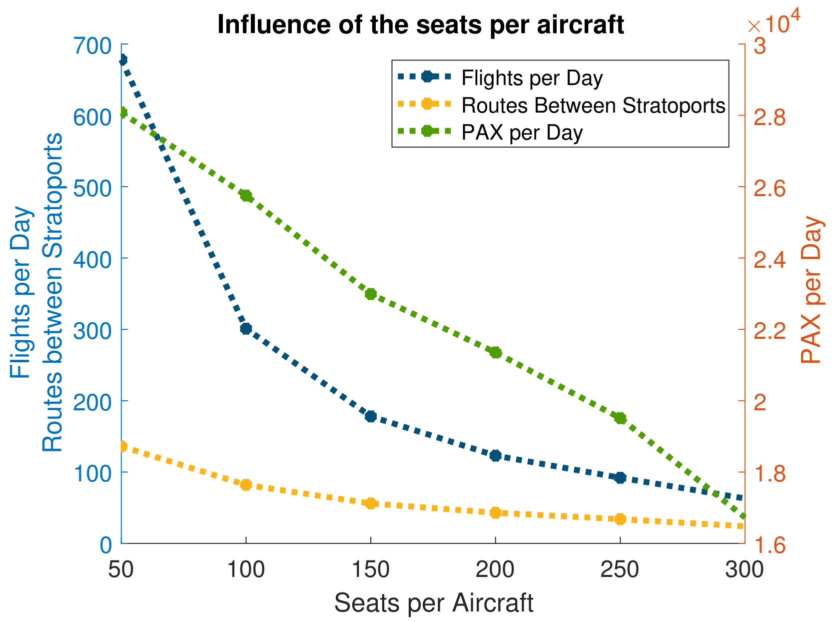

Fig 5. Influence of the number of seats

Table 3. Promising Stratoports

City	**Number of Flights per day (In & Out)**				
	Seats	100	100	300	300
	$addInfluence$	0.1	0.3	0.1	0.3
New York		22	96	4	26
London		24	84	8	24
Shanghai		21	82	4	25
Sydney		12	58	-	14
Yuma		5	40	-	6
Singapore		4	38	-	8
Brussels		10	32	-	12
Tokyo		-	31	-	-
Paris		-	30	-	-
Bangkok		-	23	-	-
Rio de Janeiro		-	16	-	-
Frankfurt		-	16	-	3
Kuala Lumpur		8	15	-	4
Sri Lanka		-	12	-	4
Seoul		-	7	-	-
Windhoek		-	6	-	-
Dubai		-	6	-	-
Berlin		-	6	-	-
Moses Lake, Seattle		-	4	-	-

Table 4. Top 10 connections between Stratoports

			Number of Flights per day				
Origin	**Destination**	**Flight Time**	Seats	100	100	300	300
			$addInfluence$	0.1	0.3	0.1	0.3
London	New York	1.66 h		4	12	2	4
New York	London	1.76 h		4	12	2	4
Sydney	London	3.11 h		4	9	-	3
London	Sydney	3.05 h		4	9	-	3
Shanghai	New York	3.12 h		3	8	-	3
New York	Shanghai	3.14 h		3	8	-	3
Yuma	Shanghai	2.34 h		3	7	-	3
Shanghai	Yuma	2.50 h		2	7	-	3
Shangahi	London	2.78 h		2	7	2	2
London	Shanghai	2.63 h		2	7	2	4

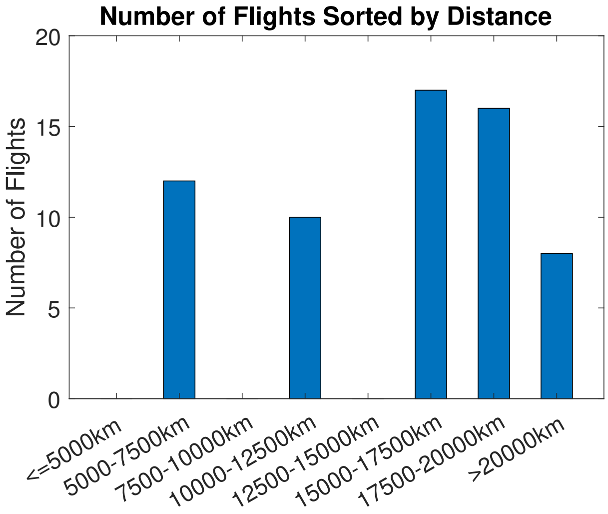

Fig 6. Number of daily flights sorted by distance for 300 seats and an $addInfluence$-factor of 0.3

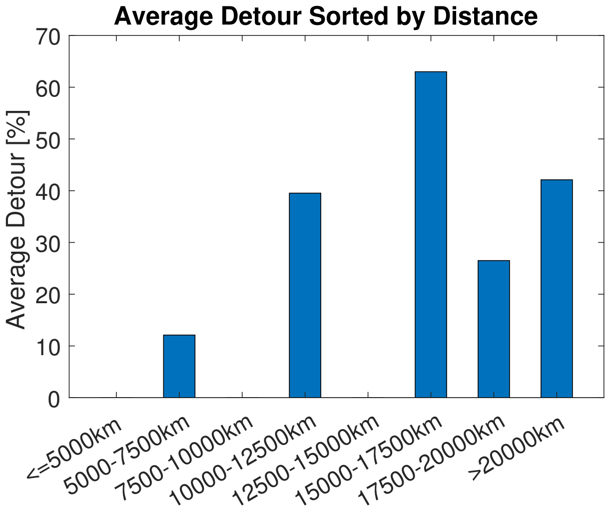

Fig 7. Average detour sorted by distance for 300 seats and an $addInfluence$-factor of 0.3

4. Conclusion

The present analysis preliminarily assesses the global passenger market with respect to the sonic boom carpet.

Based on the premium passenger numbers of the Sabre database and Boeing's CMO, the passenger numbers could be extrapolated into the year 2050, where the city pair London - New York continues to be the most promising connection. The study also shows that Asia is becoming increasingly important over time. The other most promising connections can be found in Table 3 and 4.

The cities' passenger demands were bundled to so-called Stratoports. A database with initial hypersonic routes connecting two Stratoports has been created including flight times based on calculations from the HTCM. For the given 4D flight trajectories from the HTCM, a proprietary sonic ray tracing software has calculated the sonic boom carpet, whereas the strength of the sonic boom carpet was not calculated. By predicting the strength of the sonic boom, adapted flight paths with possibly smaller detours could be feasible in the future. If necessary, adjusted and optimised flight paths were given back to the HTCM to recalculate the 4D-trajectories and to iterate the process.

The flight times from the optimised 4D trajectories were again used as input for the assessment of the passenger market. It was shown that due to layover times and overwater detours, some flight routes are no longer economically feasible. This also shifts the number and order of the promising city pairs and regions. Since the assessment of future passenger numbers are based on assumptions, parameter studies were carried out to show their sensitivity.

The analysis of the STRATOFLY-MR 3 showed that the high speed can lead to a significant time advantage compared to subsonic flight, especially over long distances. However, it also became clear that the long distances were partly necessary due to large detours to avoid the sonic boom reaching inhabited areas. On transatlantic routes in particular, the detours are smaller, but here, too, straits such as the Strait of Gibraltar or the English Channel cannot be flown over, as the sonic boom would fall on inhabited areas. Due to the high airspeed and the associated long acceleration and deceleration phases, it is not possible to switch temporarily to a subsonic speed. This is particularly critical when crossing from the North Atlantic to the North Pacific region. If a flight over the sparsely populated area in Siberia were not allowed for political, social or environmental reasons, numerous connections would not be possible. For this reason, a reduced design speed seems reasonable, so that an efficient subsonic flight and a shorter runway is possible. This could also integrate airports further inland. Currently, flights are limited to airports near the coast, as long subsonic sections from the airport to the coast drastically reduce the range. It should be noted, that during approach, the aircraft must switch to subsonic flight no later than 50 km from the coast, as wind effects, among other things, cause the sonic boom to hit the coast and inhabited areas.

In the design of the flight routes, inhabited islands were avoided if possible. Even if this would only affect a few people on some routes, it would otherwise result in a loss of image for people and companies involved in hypersonic flight, if premium passengers in particular wanted to shorten their travel times at the expense of minorities.

Furthermore, the high seating capacity means, that only a few flights can take place per connection and day. Combined with the goal of keeping the turnaround time as short as possible, it cannot be guaranteed, that the departure and arrival times correspond to the wishes of the passengers. Thus, the actual time advantage and the basis of the hypersonic flight could even disappear. Smaller aircraft could significantly increase the number of flights required. Nevertheless, further studies are needed to map the effect of increasing seat costs.

Overall, based on the current ban on supersonic flights over populated areas and ticket prices in the premium passenger range, the success of a 300-seat Mach 8 aircraft seems questionable. However, further studies are required to analyse the strength of the sonic boom and thereby possibly allow supersonic flight over populated areas.

References

1. Sabre Corporation: Sabre AirVision Market Intelligence (2018)
2. Boeing: Commercial Market Outlook. https://www.boeing.com/commercial/market/commercial-market-outlook/ (2018). Accessed 14 January 2018
3. Bodmer, D.: Trade-Offs and Trajectory Optimization. Final Report GA-769246 STRATOFLY, Hamburg University of Technology (2021)
4. Roncioni, P., Marini, M.: CFD-based Aero-Propulsive Database. Final Report GA-769246 STRATOFLY, Centro Italiano Ricerche Aerospaziali (CIRA) (2021)
5. Saracoglu, B.H., Ispir, A.C., Hurtig, T.: Airframe-integrated propulsion design. Final Report GA-769246 STRATOFLY (2021)
6. Cutrone, L., Saccone, G., Martinez, J., Luis, D., Vincent-Randonnier, A., Nilsson, T., Fureby, C., Ibron, C., Zettervall, N., Nordin-Bates, K., Bodmer, D., Weder, C.M.: Emission and reduction potential. Final Report GA-769246 STRATOFLY, CIRA, DLR, ONERA, LTH, FOI, TUHH (2021)
7. Linke, F.: Ökologische Analyse operationeller Lufttransportkonzepte (Environmental Analysis of Operational Air Transportation Concepts). Ph.D. thesis, Hamburg University of Technology (2016)
8. Liebhardt, B., Lütjens, K., Swaid, M., Müller, M.N., Ladewich, M.: Sonic Boom Carpet Computation as a Basis for Supersonic Flight Routing. In: AIAA Aviation Forum, Dallas, TX (2019)
9. Schulten, J.: Computation of aircraft noise propagation through the atmospheric boundary layer. In: Fifth International Congress on Sound and Vibration (1997)
10. Schunck, K.: The return of commercial supersonic flights. Lufthansa Innovation Hub GmbH. https://tnmt.com/the-return-of-commercial-supersonic-flights/ (2020). Accessed 14 August 2022
11. Liebhardt, B.: Eine Methodik zur Quantifizierung der zeitlichen Güte von Flugreisen aus Passagiersicht (A Methodology for Quantifying the Quality of Air Travel with Respect to Time from a Passenger's Perspective). Ph.D. thesis, Hamburg University of Technology (2016)