CZECH TECHNICAL UNIVERSITY IN PRAGUE

FACULTY OF TRANSPORTATION SCIENCES

Jakub Michalička

SUPERSONIC BUSINESS JETS OPERATION SPECIFICATION

Bachelor’s thesis

2015

CZECH TECHNICAL UNIVERSITY IN PRAGUE
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K621...**Department of Air Transport**

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(PROJECT, WORK OF ART)

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- New Approaches to Supersonic Transport Issues
- Current Legislation
- Flight Planning Criteria and Aspects
- Flight Durations and Time Savings Analysis
- Conclusion

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I confirm assumption of bachelor's thesis assignment.

Jakub Michalička
Student's name and signature

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Při zpracování bakalářské práce se řiďte osnovou uvedenou v následujících bodech:

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- Historický vývoj nadzvukové dopravy
- Nové přístupy v oblasti nadzvukové dopravy
- Současná legislativa
- Problematika plánování letů
- Analýza časových úspor a doby trvání letů
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Potvrzuji převzetí zadání bakalářské práce.

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V Praze dne .... 24. října 2014

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Prohlašuji, že jsem předloženou práci vypracoval samostatně a že jsem uvedl veškeré použité informační zdroje v souladu s Metodickým pokynem o etické přípravě vysokoškolských závěrečných prací.

Nemám závažný důvod proti užívání tohoto školního díla ve smyslu § 60 Zákona č. 121/2000 Sb., o právu autorském, o právech souvisejících s právem autorským a o změně některých zákonů (autorský zákon).

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Jakub Michalička

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Bachelor's thesis
August 2015
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ABSTRACT

The thesis is generally concerned with the current situation in the field of supersonic air transportation. It briefly describes its history, creates a comprehensive summary of supersonic aircraft projects and discusses crucial issues related to this segment of aviation. A flight planning analysis, primarily focused on supersonic travel time savings and possible route alternatives, is also included in the thesis.

Keywords:

Supersonic transportation, speed of sound, sonic boom, aviation regulations, flight planning, time savings

ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE

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SPECIFIKACE PROVOZU NADZVUKOVÝCH BUSINESS JETŮ Z OPERAČNÍHO HLEDISKA

Bakalářská práce
Srpen 2015
Jakub Michalička

ABSTRAKT

Práce se z širšího hlediska zabývá problematikou letecké nadzvukové dopravy. Ve stručnosti popisuje její historii a dává si za cíl vytvořit ucelený přehled o současné situaci v této oblasti letectví. Shrnuje a stručně popisuje současné projekty nadzvukových letounů a zabývá se zásadními problémy spojenými s jejich provozem. Součástí práce je také simulace plánování vybraných letů, která se primárně zaměřuje na časové úspory vzniklé při užití nadzvukového letounu. Sekundárně pak simulace ukazuje na možné rozdíly mezi plánováním tratí nadzvukových a podzvukových letounů.

Klíčová slova:

Nadzvuková doprava, rychlost zvuku, sonický třesk, letecké předpisy, plánování letů, časové úspory

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Abbreviations

A/C	*Aircraft*
BA	*Business Aviation*
BBJ	*Boeing Business Jet*
BJ	*Business Jet*
CAEE	*Committee on Aircraft Engine Emissions*
CAEP	*Committee on Aviation Environmental Protection*
CAN	*Committee on Aircraft Noise*
CFPR	*Carbon-Fibre Reinforced Polymer*
CFR	*Code of Federal Regulations*
CS	*Certification Specification*
DAPRA	*Defence Advanced Research Projects Agency*
EASA	*European Aviation Safety Agency*
EBAA	*European Business Aviation Association*
EU	*European Union*
FAA	*Federal Aviation Administration*
FL	*Flight Level*
HSCT	*High Speed Civil Transport*
IBAC	*International Business Aviation*
ICAO	*International Civil Aviation Organization*
ISA	*International Standard Atmosphere*
JAA	*Joint Aviation Authorities*
JAXA	*Japan Aerospace Exploration Agency*
MSL	*Mean Sea Level*
MTOW	*Maximum Take-Off Weight*
NACA	*National Advisory Committee for Aeronautics*
NASA	*National Aeronautics and Space Administration*
NAT	*North Atlantic Tracks*
NBAA	*National Business Aviation Association*
NGST	*Next Generation Supersonic Transport*
QSST	*Quiet Small Supersonic Transport*
R&D	*Research & Development*
RAC	*Raytheon Aviation Company*
SAI	*Supersonic Aerospace International*
SARP	*Standards and Recommended Practices*
SCIA	*Supersonic Cruise Industry Alliance*

SFC	*Specific Fuel Consumption*
SNLF	*Supersonic Natural Laminar Flow*
SSBJ	*Supersonic Business Jet*
SST	*Supersonic Transport*
SSTG	*Supersonic Task Group*
ZEHST	*Zero Emission Hyper Sonic Transport*

Introduction

It was over a decade ago when the last civil supersonic aircraft could be seen airborne. Since then, not only no passenger supersonic airplane has taken off, but also the development of almost all supersonic airliners has been terminated.

After the pioneering era of the first supersonic aircraft generation consisting of Concorde and the Tupolev Tu-144 which were rather the result of the technology and prestige race among the world powers in the second half of the 20th century, aircraft manufacturers have mostly abandoned the idea of supersonic travelling, due to a broad range of issues related to supersonic transport. Despite an indisputable progress in the field of aviation and aerospace, supersonic aircraft designers would still have to deal with significant technological, operational and legislative obstacles, often requiring complex and expensive solutions, which would mostly result in an economic uncompetitiveness among other contemporary aircraft.

A huge benefit of supersonic aircraft, though, would be the reduced time spent on travelling. In aviation, especially in the business aviation, time is an extremely valued thing and some people are willing to give a fortune for any travel time savings. But how much time would such aircraft really save and is it worth it when expenses are taken into account?

Several surveys imply that the world aircraft market could be ready for a supersonic business jet (SSBJ), around the year of 2020. There are several companies, some sponsored by multi-billionaires, some having a long history of aircraft production, that are well aware of this fact and that have been investing a lot of effort and money into research and development in order to make the first supersonic aircraft of the new generation.

The thesis has three main objectives. The first one is to make an inquiry about the contemporary supersonic aircraft projects and to summarize and compare basic information and specifications about them. The following goal is to create an extensive analysis of current situation in the field of supersonic air travelling, including legislative, technical and operational aspects, and thus thoroughly describe conditions that would the SSBJs have to deal with at present. Since the time reduction is the key to success, the last thesis objective is to make a time savings analysis consisting of several route simulations and a travel time comparison between a subsonic and a supersonic business jet.

1 Speed of Sound

The thesis often refers to the speed of sound and subsonic, supersonic and hypersonic speeds, so these terms should be defined in the first place.

The speed of sound, simply said, is the speed of sound waves moving through an actual environment. The speed of sound is not a constant speed and it varies accordingly to this equation [1]:

$$a = \sqrt{\kappa \cdot R \cdot T} \qquad \text{[Equation 1]}$$

Where:

a	Speed of sound	$[m \cdot s^{-1}]$
$\kappa = \frac{c_p}{c_v} = 1.4$	Adiabatic index (for dry air)	[non-dimensional]
c_p	Specific heat capacity at constant pressure	$[J \cdot kg^{-1} \cdot K^{-1}]$
c_v	Specific heat capacity at constant volume	$[J \cdot kg^{-1} \cdot K^{-1}]$
$R = 287.1$	Gas constant for dry air	$[J \cdot kg^{-1} \cdot K^{-1}]$
T	Absolute temperature	$[K]$

When the listed constants are substituted into the equation 1, we get:

$$a \sim 20 \cdot \sqrt{T} \qquad \text{[Equation 2]}$$

In the aviation branch, the atmosphere specifications have been standardized for general calculations into the International Standard Atmosphere (ISA), which defines the average mean sea level temperature (T_0) as [2]:

$$T_0 = 288.15\ K\ (15\ °C) \qquad \text{[Equation 3]}$$

And its change with the altitude (up to a tropopause) as:

$$T = T_0 - 0.0065 \cdot h \qquad \text{[Equation 4]}$$

Where:

h … Altitude $[m]$

From the altitude of about 11 000 m the temperature remains (according to ISA) the same up to the height of approximately 20 000 m above the sea level.

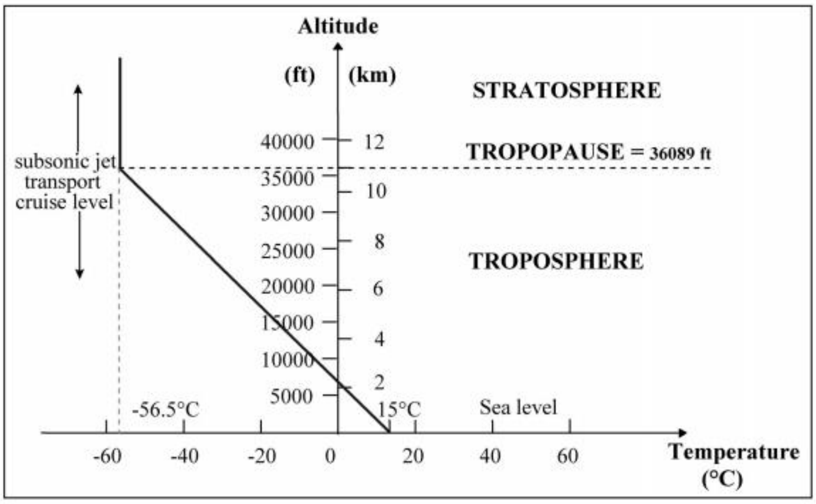


Figure 1: Temperature gradient according to ISA [2]

The speed of fast moving objects (airplanes) is often expressed in Mach numbers [*M*], which represent the ratio of the velocity of an object (airplane) and the speed of sound in an actual environment:

$$M = \frac{v}{a} \qquad \text{[Equation 5]}$$

Where:

M	Mach number	[non-dimensional]
v	Velocity of an object	$[m \cdot s^{-1}]$
a	Speed of sound in an actual environment	$[m \cdot s^{-1}]$

Two examples of the speed of sound in different altitudes are computed below. It shows that M 1.0 is not the same in the altitude of 36 000 feet as M 1.0 in the mean sea level (MSL):

MSL ($t = 15\ °C$):

$$a = 20 \cdot \sqrt{288.15 - 0.0065 \cdot 0} = \mathbf{340\ m/s} = 1224\ km/h = \boldsymbol{M\ 1.0} \qquad \text{[Equation 6]}$$

>FL360 ($t = -56.5\ °C$):

$$a = 20 \cdot \sqrt{288.15 - 0.0065 \cdot 11\ 000} = \mathbf{295\ m/s} = 1062\ km/h = \boldsymbol{M\ 1.0} \qquad \text{[Equation 7]}$$

Where:

MSL	Mean Sea Level ($h = 0$)
FL360	Flight Level at 36 000 feet (approx. 11 000 m)

With regard to the Mach number, we recognize these categories of speeds: [1]

- Subsonic – below M 1.0
- Supersonic – between M 1.0 and M 5.0
- Hypersonic – over M 5.0
- (Transonic – approximately between M 0.8 and M 1.2)

The transonic speed is a special speed category partly involved in the subsonic and partly in the supersonic speed categories. Further details and the issues related to its effects on aircraft are explained section 6.1.

2 Historical Development of Supersonic Transport

2.1 Outset

Due to a relatively fast development in the fields of aeronautical and rocket engineering after the Second World War, the first manned flight, that has been officially regarded as supersonic (speed over Mach 1.0), was made on October 14, 1947. [3] This achievement was accomplished in the experimental airplane X-1 Bell, which was a joint venture of the National Advisory Committee for Aeronautics (NACA) and the U.S. Air Force controlled by the test pilot Charles Elwood "Chuck" Yeager. The aircraft reached a speed of M 1.06 in a horizontal flight at an altitude of 43 000 ft (approximately 13 100 m). [4]

Figure 2: Experimental Bell X-1 [5]

Leading world powers such as the United States, the Soviet Union or some European countries that were due to a post-war situation substantially pushed to invest in new technologies, were well aware of the importance of the supersonic transport in both military and civil sectors. Hence, it is no surprise that thanks to even faster subsequent development in this field, the first military supersonic aircraft started crossing the sky only a half of a decade after the Yeager's record-breaking flight. The earliest ones were namely: Saab 32 Lansen (Sweden, 1952), F-100 Super Sabre (USA, 1953) and MiG-19 (Soviet Union, 1953).

Operating in supersonic speeds has soon become a standard requirement for military fighter jets and later bombers. As an acme of the technological progress, which had been noticeably curtailed when long-range missiles came to the scene, can be perceived United States' strategic reconnaissance aircraft Lockheed SR-71 Blackbird (introduced in 1966), that has held the air speed record as the fastest "manned air breathing jet aircraft" so far [6]. Nevertheless, military aircraft development and comparison are not the main topic of the thesis and thus will not be more thoroughly discussed.

Figure 3: Lockheed SR-71 Blackbird [7]

Aircraft designers were well aware of the fact that civilian supersonic airliners would be, in a comparison to relatively small fighter jets, much more complicated. It was quite evident that the manufacturing of such an aircraft should be technically and technologically possible but because of its huge proportions there were severe doubts if such a project would be also feasible from the financial point of view. But since it was generally thought that supersonic transport would soon and inevitably take a strong position in air transportation in general and since the civilian airliner could be also considered to be a potential predecessor of military supersonic bombers, some governments decided to take a risk.

The first projects that eventually emerged from designers' drawing-boards, were the British Bristol Type 223 (Bristol Aeroplane Company) and the French Super-Caravelle (Sud-Aviation). Two projects that after a few years merged into a joint venture called Concorde.

2.2 Concorde

Concorde (fully named the Aérospatiale-BAC Concorde) is now a retired civil supersonic aircraft, one of two SST projects that have ever been successfully finished. The aircraft with a typical drooping nose and slender "ogival delta wing" was able to reach the maximum speed of Mach 2.04 (2 170 km/h) in the operational altitude of 60 000 ft (18 300 m) with up to 128 passengers on board. [8]

Since the beginning, the Anglo-French project had to face many challenges especially in terms of the technology and finances. It was believed that supersonic airliner, if successful, would soon supplant all the long-haul subsonic transport (such as trans-Atlantic flights etc.), therefore British and French governments were keen to financially support even such an expensive project as Concorde. The development cost was firstly estimated to be around £150 million [9], but until the first commercial flight was performed in 1975, the costs had increased to approximately £1.3 billion, because the technical demands had turned out to be a way higher than primarily expected. [10]

In addition, during the period of the development it also turned out that the supersonic transport's potentiality had been overestimated, and despite the fact that there had been already 74 Concorde pre-orders from 16 airlines in total, most of them were finally cancelled. [11] The only remaining airlines still interested in Concorde were British Airways (BA) and Air France (AF), British and French national air carriers. There were many reasons why such a wave of cancellation suddenly appeared, but it can be assumed that acquisition and operational costs played a major role in this case and thus Concorde, having been every year more and more expensive, finally drove away potential buyers. This fact only intensified with the oil crisis in 1973 and the accident of the Tupolev 144, Concorde's supersonic competitor, at the Parisian airport LeBourget in the same year. This seemingly unrelated event had a great impact on the public in terms of safety, even though Tupolev was substantially different from Concorde. [8]

In spite of these struggles, the Concorde's first test flight was successfully performed on March 2, 1969 and it finally entered service seven years later, on January 21, 1976. [8] The total aircraft production made 16 units (plus 4 experimental), the half of them operating in the colours of BA, the other half of AF, and even though British Airways reportedly made the flights profitable for some years, the project of Concorde as the whole was an economic disaster. On the other hand, Concorde remained popular for diplomatic and VIP charter flights, so the airplanes often served as a private jet for the royal family or the French president and they were also leased to other airlines a couple of times, i.e. Singapore Airlines or Braniff International Airways [12].

Both operators, BA and AF, decided to get Concorde grounded in 2003, after more than 27 years of an operational history. [8] This was an unsurprising result of many factors; first of all, due to age and obsolete technology, maintenance costs rose to intolerably high levels. Another reason for Concorde termination was a sequence of two accidents: The first one (and the only one of Concorde) happened on July 25, 2000 at the Paris Charles de Gaulle airport and ended fatally for everybody on board (100 passengers and 9 crew members). And the second accident, the terrorist attack on the World Trade Centre in 2001 – despite no direct connection to Concorde operations – considerably undermined trust in safety of air transportation in general, including Concorde's one. Besides some other concerns such as noise and exhaust emissions or the fact that both BA and AF earned much more money from "classic" (subsonic) first class air-tickets (when flying with Concorde this clientele usually barely covered the maintenance costs), this was the last straw for Concorde. The last Concorde flight was performed on November 26, 2003. [8]

Figure 4: Aérospatiale-BAC Concorde [13]

2.3 Tupolev Tu-144

The Soviet Tupolev Tu-144 is the second of the aforementioned finished SST project and was supposed to be a main competitor to Anglo-French Concorde. The aircraft was allegedly capable to reach the speed of Mach 2.35 (approximately 2 500 km/h) and fly at the altitude of 65 000 ft (20 000 m) with up to 140 passengers on board [14].

The main reason why the Tu-144 has been ever built was the competition among dominant world powers in the post-war age. According to Trubshaw [8], the main goal of the Soviets was not only to come up with a comparable aircraft to Concorde, but to create a better one in terms of size, speed and in addition, they needed to be the first. However, it should be pointed out that Soviets really achieved all of these goals. The first Tupolev flight took place on December 31, 1968 (two months before Concorde) and the aircraft was faster and bigger than its Anglo-French rival. On the other hand, it cannot be inferred that Tupolev had been more successful. Moon [15] has written that the chase to be first had taken precedence over every other aspect (including safety), so the aircraft then suffered from an unbelievably high number of technical problems and malfunctions. For example, there is an evidence that during one flight in 1978, 22 to 24 on-board systems failed and did not work. The flight was finished only in order to avoid an international embarrassment of cancellation. [17]

Technical issues were apparently so significant that Soviets were not able to find appropriate solutions only by themselves. They even asked the British for help with the most serious problems (such as engine inlets for instance), but the plea was rejected with the statement that Soviets could abuse this technology for further military aircraft. [15] The Soviets then probably decided to follow the plans anyway, so it was not such a surprise when Sergei Pavlov, officially standing as an Aeroflot representative, was arrested in Paris in 1965 with complete plans of landing gear, braking system and the airframe of Concorde. [16] Therefore, the Tu-144 was in the western countries called “Concordski”, referring to its similarity with Concorde. It must be admitted that except for some minor differences (i.e. retractable canard surfaces in the bow of the fuselage) Tupolev design was very similar to Concorde.

Neither the operational history of the Tupolev Tu-144 was successful. The aircraft served as a freighter (transporting mail) from December 26, 1975, when it entered service on the line: Moscow – Almaty (former Alma-Ata). After two years of cargo operations, the aircraft was allowed to carry passengers between the very same two cities (from November 1, 1977), nevertheless civilian operations lasted only short time. After another accident in 1978 of the experimental Tu-144D (the first was the one in Paris, 1973) the civilian transport was “temporarily suspended” on June 1, 1978 and it has never been restored. Shortly after the mail transport was also terminated and the aircraft then served only as flying laboratories or training simulators for Buran space shuttle astronauts. The last flights were made by the NASA in 1998 as a part of the Russian-United States joint SST research programme. [17]

Figure 5: Tupolev Tu-144 [18]

2.4 Boeing B-2707

The Boeing B-2707 was a winning project of an open competition organized in January 1964 in the United States, which was seeking the best design for a future American supersonic airliner. In this competition, Boeing prevailed over the Lockheed and North American with the project which was planned to be much bigger and faster than Concorde or Tupolev (the airplane was designed to be able to transport up to 277 passengers at a maximum speed of around M 3.0). [19] The project was eagerly funded by the American government, but 7 years later, when over a half a billion dollars had been already spent without any substantial progress, the House of Representatives decided (in May 20, 1971) to stop any further funding. Unlike other countries, environmental concerns played an important role in considering the SST’s future in this case, especially the phenomenon called a sonic boom (see section 5.2) and a depletion of the ozone layer (which was later proved to be baseless). There is an interesting fact that even though Boeing designers had never progressed beyond a draft and computation stage, the company had, by October 1969, 122 aircraft orders from a total of 26 airlines [20].

Figure 6: Plan of the Boeing 2707 [20]

Basic specifications of all of the described supersonic aircraft are listed in the attachment 1.

3 “Dark Age” for Supersonic Transport

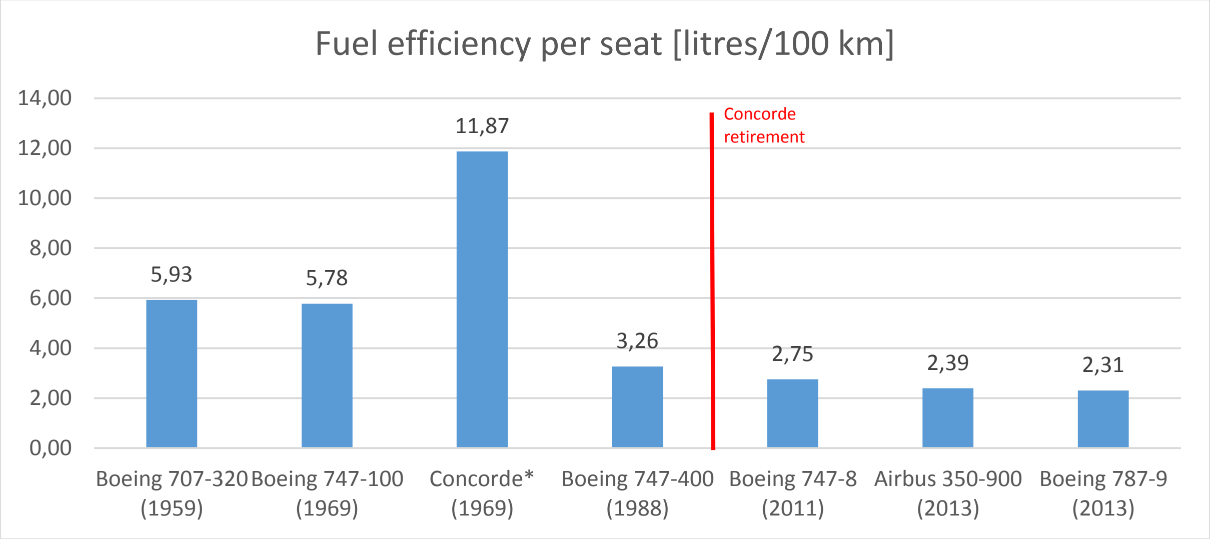
3.1 General

In the second half of the 20th century it was widely believed, that Concorde and the Tupolev 144 were pioneering aircraft projects that would be soon followed by tens of others and that SST would inevitably expand into a vast majority of long-haul air transportation all around the world. On the contrary, the last supersonic flight of a non-military aircraft was performed in 2003 by Concorde and even though a lot of research and development has been carried out in this field since the 1990s, neither aircraft manufacturers nor governments have succeeded in developing any economically viable supersonic project since that time.

Nevertheless, in late 1980s, aircraft designers were still optimistic. The ‘High speed civil transport study’ produced by the Boeing Company in a cooperation with NASA in 1989 [21] concluded that albeit the contemporary technologies were not adequate for a viable SST due to many reasons, if ‘an aggressive technology development’ was undertaken, another supersonic airliner could be flying by the year of 2000. Alongside with the conclusion the study brought an auspicious market research which said that by this time the market would have had a potential for up to an amount of 1 050 supersonic aircraft with the capacity of 250-300 passengers and a cruise speed between M 2.0 – 3.0.

Encouraged by this enthusiasm, in 1990 the ‘High Speed Research’ project was launched in the USA with an obvious goal: to develop a ‘High Speed Civil Transport’ (HSCT), the new generation of supersonic airliner. The project was a joint venture of the NASA and many industrial companies, such as Boeing, McDonnell Douglas, Pratt & Whitney, General Electric, Rockwell-Collins and dozens of others. The research was based on knowledge obtained from previous projects, such as the B-2707, the L-2000, but also Concorde and the Tu-144. In 1995, an airworthy Tu-144 (officially called Tu-144LL) was involved in the program, which was transformed to a flying laboratory and with a support of the Russian Federation and a businesswoman Judith DePaul, a new sponsor of the research, was tested in several experiments. [22] Unfortunately, despite an obvious technical progress, the project had to be officially cancelled in 1999 due to an insufficient funding. [23]

Why it has been so difficult to develop a civil supersonic aircraft, when this goal was successfully met decades earlier? The answer is not simple, but basically the meaning of the phrase ‘successful supersonic aircraft’ has changed significantly since the end of the cold war. In other words, what was perceived as a successful SST in the history (such as Concorde) would be now failing in many aspects, because the requirements that are now demanded as for civil transportation aircraft, substantially differ. A successful civil airliner from today’s perspective usually stands for a fuel efficient, low-maintenance and environmentally benign vehicle which has to be primarily lucrative from an economic point of view. That means the point of view where both Concorde and the Tu-144 were disastrous. The fuel efficiency comparison between Concorde and other subsonic aircraft is shown in the graph below (in the parentheses there are the dates of the first flights).



Graph 1: Aircraft fuel efficiency per seat [24] [25] [26] [27]

In general, apart from many other eclectic problems, any form of the SST is with contemporary technologies relatively expensive and inefficient. As the HSCT project has shown, developing a viable supersonic airliner is a real issue and this fact can be proved e.g. by the fact that there is just two projects of a high-capacity SST these days which are furthermore not planned to rollout before the year of 2050. [35] In addition, the history shows that similar predictions are usually overoptimistic.

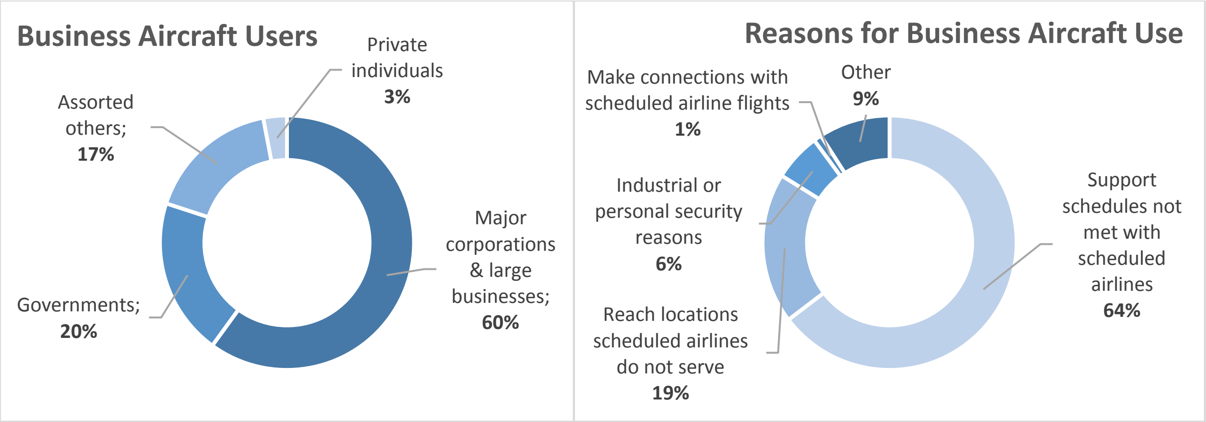
However, exclusion of airliners as a possibility for the SST in the near future does not necessarily result in complete abandoning of the idea of the supersonic travelling. Previous paragraphs suggest that paying loads of extra money just to be sooner in the final destination when travelling by an aircraft would be, for most people, unacceptable. Nevertheless, there are customers (billionaires, corporations, governments etc.), who are willing to pay much more in order to reach their specific demands as for air transportation. A special segment of aviation is commonly focused on this kind of clientele – the business aviation.

3.2 Business Aviation (BA)

Several definitions of the business aviation can be found on the Internet or in the dictionaries and they, in many cases, considerably differ from each other. The definition by the International Business Aviation Council (IBAC) (one of those more comprehensible) defines the BA as:

"That sector of aviation which concerns the operation or use of aircraft by companies for the carriage of passengers or goods as an aid to the conduct of their business, flown for purposes generally considered not for public hire and piloted by individuals having, at the minimum, a valid commercial pilot license with an instrument rating." [28]

In other words, the business aviation usually serves for major corporations or governments as the means of a fast and flexible transportation when needed or/and as an efficient business tool. The distribution of business aircraft users and the reasons for the usage is shown in the graphs below:



Graph 2 and 3: Distribution of business A/C users (left) and reasons for its use (right) [29] [30]

The business aviation can be generally divided into many categories with respect to an aircraft's type of the power plant but since the jet engine has been the only one capable of reaching the supersonic speed so far, the thesis will be mostly focused on the category of business jets (BJ) (a.k.a. private jets or bizjets). Other categories such as turboprop aircraft or helicopters are not going to be discussed any further.

Business jets are mostly aimed to transport individuals, small groups of people or smaller cargo. As a consequence, contemporary bizjets are usually much smaller (when compared to scheduled airlines' jets) in order to benefit from the size (higher reachable altitudes, smaller minimal runway lengths, etc.), but still to fully cover the customers' demands as for comfort etc. Concerning the most important manufacturers there are such companies as Gulfstream Aerospace, Dassault Aviation, Cessna Aircraft Company, Embraer and many others. A typical appearance of the BJ can be represented for instance by the Gulfstream G650, one of the most modern business jets in these days.

Figure 7: Gulfstream G650 [31]

Private jet owners or customers can, when compared to scheduled flights, mostly benefit from these BJ features:

- Flexibility
- On demand
- Prestige
- Security
- Comfort & Service
- Other

3.2.1 Flexibility

As the graph 3 indicates, more than four fifths of the respondents' answers were related to inflexibility of scheduled airlines' flights. Business aircraft in this case can usually offer more suitable option to fulfil customers' needs.

3.2.2 On demand

Another important aspect highly appreciated by the BA users is the fact that they can fly whenever they want, wherever they want and that they can fly (almost) immediately. This is a huge time saving factor that has no relevant alternative in transportation for longer distances.

3.2.3 Prestige

Prestige is defined by the Oxford dictionary as: *“Widespread respect and admiration felt for someone or something on the basis of perception of their achievement or quality”.* [32] Even renting of a business jet is ordinarily perceived as a proof of an unusual wealth (for the most of the people an indicator of success), which automatically results in higher prestige. Large corporations, where company image is an essential part of the marketing strategy, are very well aware of that.

3.2.4 Security

Two particular issues fall into this category. First of all, we distinguish aviation security, i.e. general protection against unlawful interferences (such as terrorist attacks), and it might be asserted that the level of quality of this kind of security does not significantly differ from the scheduled airlines ones. [29]

The second meaning of the security, the industrial security, is rather concerned with passengers and payload itself. It is not a rare case when a business jet is used as to ensure secrecy of objects or personnel carried on board. According to the graph 3, six out of one hundred flights are made for this purpose.

3.2.5 Comfort & Service

The last but not least significant beneficial feature of the vast majority of the BA is a high level of provided service and overall comfort. Not only is the aircraft many times furnished as to be at least comparable to scheduled airlines first class compartments (in terms of comfort), but a range of other advantages, such as faster check-in and customs procedures at airports are commonly provided as well.

In summary, these aspects can be undoubtedly beneficial for the clients but there is still the prize. It is not a surprise that flying with bizjets is an expensive business, but still, there is an increasing demand for this means of transport and the customers are willing to pay huge loads of money for these benefits because they simply value them over the costs. [30]

This is actually the main reason why aircraft manufacturers with supersonic ambitions have decided to focus more on the BA. Next to the aforementioned advantages, particular time savings could be included with an entry of a new SSBJ, i.e. time savings that would result directly from the duration of flights, resulting from faster cruising speed not only from flexibility or better accessibility of the BA. Another motivation for aircraft manufacturers might be potential impacts of creating of the SSBJ. First it would assuredly guarantee them a unique position among other manufacturers, and second the technology developed for the aircraft could be used on further projects, not only in the aviation field. Many supersonic business jets have been presented to public in the new millennium however there are still several issues which have precluded a successful rollout of the SSBJ so far. Most of them will be more thoroughly discussed in the next sections.

4 Contemporary SSBJ Projects

As the business aviation has started to be regarded the promising option in the chase after the new generation of the SST, the majority of aircraft manufacturers with ‘supersonic dreams’ have mostly excluded large airliners from their plans and rather redirected their effort into designing usually much smaller SSBJs. This fact can be easily demonstrated by means of listing all the SST projects revealed or being considered as viable (for at least some time) since the year 2000.

Business Jets	Airliners
Aerion AS2	*Next Generation Supersonic Transport*
Aerion SBJ	*Zero Emission Hyper Sonic Transport*
Dassault Falcon SST	
Gulfstream X-54	
HyperMach SonicStar	
Raytheon Low-Boom	
Raytheon High-Boom	
Tupolev Tu-444	
SAI QSST	
Spike S-512	
Sukhoi S-21	

***Table 1: New generation of SST projects**[1]*

Hypersonic aircraft[2] projects, such as LAPCAT A2 (Reaction Engines) or Spaceliner (German Aerospace Center), have been omitted in the table for two reasons: First, hypersonic travelling for civil purposes will not be most likely feasible in decades to come due to many serious technological difficulties. Second, because of a significant difference from the subsonic and lower-supersonic speeds, it is not clear if hypersonic aircraft would be even similar to recent aircraft and their way of travelling. For instance, the Spaceliner project is planned to fly up to 80 kilometres above the ground (5 - 8 times more than contemporary subsonic airplanes) and the overall appearance of the designed project is rather similar to NASA’s Space Shuttles (vertical take offs, removable rocket parts, etc.). [33] The thesis results will not be thus probably applicable to this or any other kind of hypersonic transport.

Despite the omission of two hypersonic airliner projects in the table, the SSBJ projects evidently outnumber the supersonic airliners. Moreover, these two – Next Generation

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[1] Excluding hypersonic projects.

[2] Cruising speed over M 5.0.

Supersonic Transport (NGST) and Zero Emission Hyper Sonic Transport (ZEHST)[3], led by the JAXA (Japan Aerospace Exploration Agency) and Airbus Group respectively – are rather only ideas or concepts at this time because the ZEHST's first flight is planned for the year of 2050 and the NGST has no official scheduled time frame at all. In the thesis neither of these will be discussed in detail. [34] [35]

Eleven SSBJ projects from the table 1 are assigned to their companies and are shortly described below.[4] The companies are listed in the alphabetical order:

4.1 Aerion Corporation

Aerion Corporation was founded in 2002 in Reno, Nevada (USA) by the contemporary chairman Robert Bass – an aviation enthusiast and a multi-billionaire whose investments into the company's research and development (R&D) have already exceeded $100 million so far. [36]

The Aerion's potential lies mostly in advanced research concerning 'Supersonic Natural Laminar Flow' (SNLF). The research is led by Dr. Richard Tracy, at present the Aerion's chief technology officer, who has been working on this project since 1990. The groundwork of the technology is described in the section 5.3. [37]

In September 2014 the Aerion Corp. announced technology cooperation with the Airbus Group. Airbus, an experienced aircraft manufacturer of both civil and military aircraft of all sizes, offers its engineers and the know-how to Aerion in order to help the company with various 'usual' technological issues so that the final product would comply with all the stringent rules and regulations applied to contemporary civil aircraft (e.g. flight control systems, safety management, materials, etc.). In return, the technology and design tools developed by Aerion will be provided to Airbus, most importantly including the results of the research on the SNLF, which might be one day applicable on large subsonic airliners as well. [38]

The Aerion SBJ has been the Aerion's first announced SSBJ project. The aircraft is based on the Lockheed F-104 Starfighter and has been adjusted to suit the SNLF and many other BA's needs. The company has already got 50 letters of intent, each with a $250 000 deposit. The project was terminated by the time of unveiling a new aircraft version – the AS2. [39]

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[3] The name suggests that the aircraft will fly hypersonically and thus should not be shown in the table, but according to JAXA official websites [35], the airplane's maximum cruising speed is planned to be 'only' M 4.0, which is, by definition still the supersonic speed.

[4] The most auspicious SSBJ projects are compared with Concorde and Gulfstream G650 in the attachment 2.

Aerion SBJ

Max. Cruise Speed	*M 1.8*	***Length***	*41.33 m*
Normal Cruise Speed	*M 1.7*	***Wingspan***	*19.57 m*
Service Ceiling	*51 000 ft (15 500 m)*	***Passengers***	*8 - 12*
Max. Range	*4 200 – 4 600 nm*	***First Expected Flight Test***	*-*
Unit Cost (Targeted)	*US $60 - 80 mil*	***Scheduled Enter Service***	*-*

Table 2: Specifications of Aerion SBJ [40]

Figure 8 and 9: Aerion SBJ [41] [42]

AS2 is the Aerion's second SSBJ design that was officially announced in September 2014. This version has been evolved from the Aerion SBJ and should be more adjusted to customers' demands. Being compared to its predecessor the AS2 is generally bigger, a little slower and has three engines instead of two. The 50 aforementioned pre-orders for the Aerion SBJ have been automatically converted to this version.

Aerion AS2

Max. Cruise Speed	*M 1.5*	***Length***	*51.80 m*
Normal Cruise Speed	*M 1.4*	***Wingspan***	*18.6 m*
Service Ceiling	*51 000 ft (15 500 m)*	***Passengers***	*8 - 12*
Max. Range	*4 750 – 5 300 nm*	***First Expected Flight***	*2019*
Unit Cost (Targeted)	*US $120 mil*	***Scheduled Enter Service***	*2021*

Table 3: Specifications of Aerion AS2 [43]

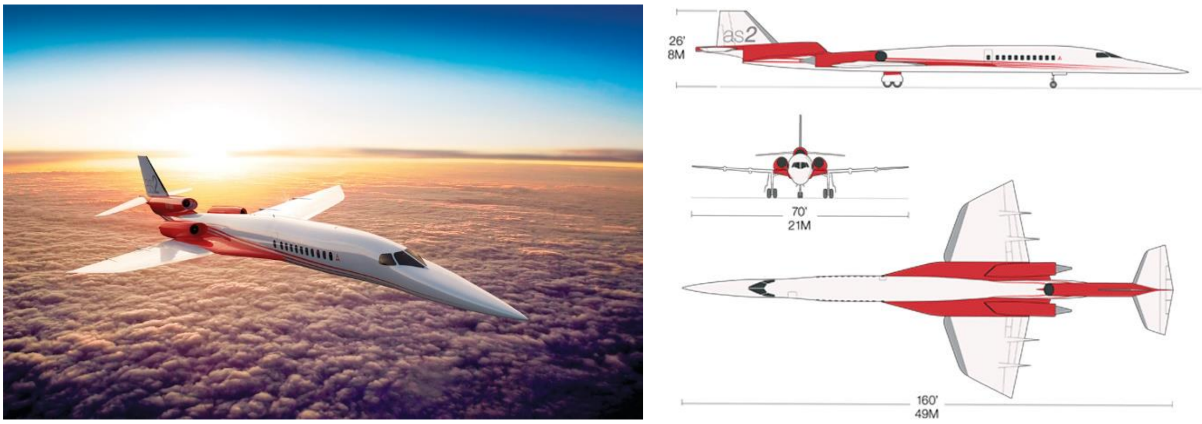


Figure 10 and 11: Aerion AS2 [44]

4.2 Gulfstream Aerospace Corporation

The Gulfstream Aerospace, a subsidiary of the General Dynamics, is a well-established aircraft manufacturer focused solely on the BA. The company has more than 13 000 employees and the number of produced and sold aircraft has already exceeded 2 000. [45] [46]

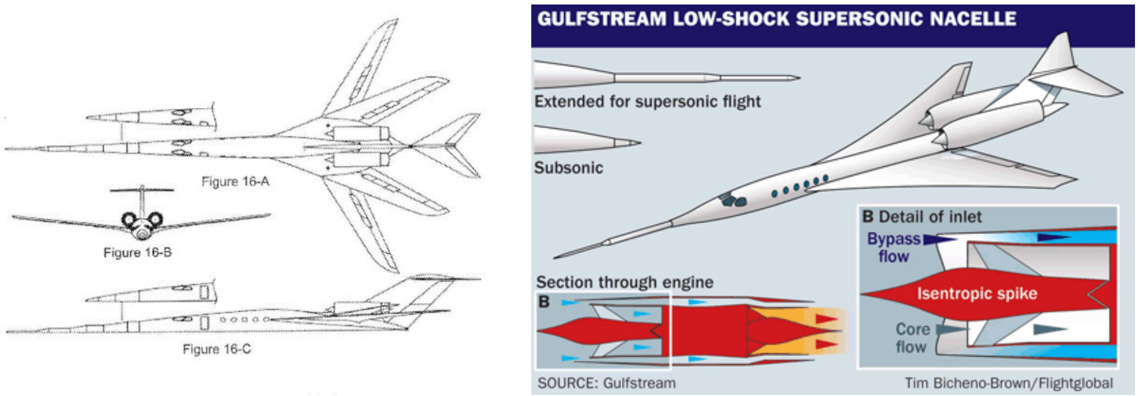
Since the end of a short collaboration with the Sukhoi Company on the S-21G project (described below), the Gulfstream Aerospace has been continuously working on some key issues related to the SST, finally resulting in a new project called Gulfstream X-54. As the name suggests, the Gulfstream co-operates with NASA and the company now focuses on developing pivotal aircraft segments needed to overcome SST's problems such as supersonic shockwaves, overall noise etc. Reportedly, the company is now 'very close' to successfully finish the necessary development. The rest, i.e. the aircraft completion itself, is considered by the Gulfstream to be 'an easy task'. [47]

Among the mentioned important aircraft segments belong some distinctive improvements, such as telescoping nose, highly-sloped fuselage or variable-sweep wings. Some of these features are described in detail in chapter 5.

Gulfstream X-54

Max. Cruise Speed	*Not known*	***Length***	*Not known*
Normal Cruise Speed	*Over M 1.4*	***Wingspan***	*Not known*
Service Ceiling	*50 000 ft (15 240 m)*	***Passengers***	*Not known*
Max. Range	*Not known*	***First Expected Flight Test***	*Not known*
Unit Cost (Targeted)	*Not known*	***Scheduled Enter Service***	*Not known*

Table 4: Specifications of Gulfstream X-54 [48]



SOURCE: Gulfstream

Tim Bicheno-Brown/Flightglobal

Figure 12 and 13: Gulfstream X-54 [49] [50]

4.3 HyperMach

HyperMach is a company founded in 2008 in the United Kingdom with one sole objective – create a SSBJ. Its distinctive feature is very courageous attitudes towards aircraft designing and aeronautical technologies. [51]

The company’s flagship project called SonicStar is a draft of a SSBJ that significantly differs from all its competitors. The HyperMach has focused (as well as Gulfstream Corp.) on developing the technology that would allow the aircraft to avoid the most severe issues related to supersonic travelling. One of the most interesting approaches is, for instance, a proposal of a hybrid engine (gas & electric), designed by the sister company SonicBlue, which includes elements like magnetic levitating turbines or ‘superconducting ring generators’, which should be able to cover most of the aircraft’s electricity demands during a flight. Another interesting idea is the ‘electromagnetic drag reduction technology’, which should considerably mitigate the power of supersonic shockwaves. [52]

Nevertheless, even though the SonicStar’s first flight has been scheduled to 2021, the company’s ability to fulfil the plan is at least questionable, since manufacturing such a pioneering aircraft from the scratch would be not only astronomically expensive, but also very difficult in terms of gaining licenses from civil aviation authorities. [53] In recent years the company has been seeking investors for the R&D.

HyperMach SonicStar

Max. Cruise Speed	*M 4.0*	***Length***	*68.78 m*
Normal Cruise Speed	*M 3.6*	***Wingspan***	*22.60 m*
Service Ceiling	*60 000 ft (18 900 m)*	***Passengers***	*20*
Max. Range	*6 000 nm*	***First Expected Flight***	*2021*
Unit Cost (Targeted)	*US $180 mil*	***Scheduled Enter Service***	*2025*

Table 5: Specifications of HyperMach SonicStar [54]

Figure 14: HyperMach SonicStar [55]

4.4 Raytheon Aircraft Company (RAC)

Raytheon Aircraft Company is a former subsidiary of the Raytheon Company, one of the biggest U.S. contractors that specialize in the variety of military products, such as guided missiles, radars, defence systems etc. In 2007, the RAC was bought by Hawker Beechcraft, an experienced general and business aircraft manufacturer. [56]

In 2003, the Raytheon presented its intention to make a SSBJ and revealed its research on two simultaneous projects – the 'low-boom' and the 'high-boom' version. However, since the time of the project introduction, no further information has been provided to public and thus it can be assumed that the projects have been terminated. [57]

Raytheon Low-Boom / High-Boom[5]

Max. Cruise Speed	*Not known*	***Length***	*50.44 m*
Normal Cruise Speed	*M 1.8*	***Wingspan***	*21.03 m*
Service Ceiling	*Not known*	***Passengers***	*6*
Max. Range	*5 000 nm*	***First Expected Flight Test***	-
Unit Cost (Targeted)	*Not known*	***Scheduled Enter Service***	-

Table 6: Specifications of Raytheon Low-Boom / High Boom [57]

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[5] The shown parameters are the same for both prototypes.

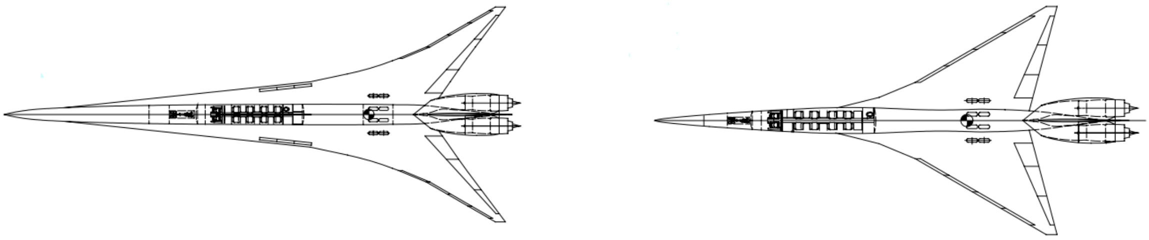

Figure 15 and 16: Raytheon Low-Boom (left) and High-Boom (right) [57]

4.5 Spike Aerospace

The Spike Aerospace is another company with SSBJ ambitions, based in Boston, Massachusetts (USA).

The Spike unveiled its SSBJ design in January, 2013. The project has been named S-512 and the first roll out has been scheduled to the year 2018. Unfortunately, only little information has been officially released about the aircraft so far (except for one ‘interesting feature’ – a windowless cabin for passengers). [58]

The company website fell almost silent in the beginning of the year 2014 and showed no real progress till June 2015, when Spike released a few up-to-date information about the “new S-512”. Besides slightly modified aircraft specifications, the aircraft overall appearance has been significantly changed (especially the wings, now having a delta shape). Any other information though, related to the project’s funding or the first planned flight, have remained unknown. [59]

Spike S-512

Max. Cruise Speed	*M 1.8*	***Length***	*37.00 m*
Normal Cruise Speed	*M 1.6*	***Wingspan***	*17.70 m*
Service Ceiling	*50 000 ft (15 240 m)*	***Passengers***	*18*
Max. Range	*4 050 – 5 580 nm*	***First Expected Flight Test***	*Dec. 2018*
Unit Cost (Targeted)	*US $60 – 80 mil*	***Scheduled Enter Service***	*2021*

Figure 17: Specifications of Spike S-512 [60]

Figure 18 and 19: Spike S-512 [61] [62]

4.6 The Sukhoi Company

The Sukhoi Company is a Russian, primarily military aircraft manufacturer. The company also has broad experience with civil aircraft (e.g. Superjet 100 RJ) and small aerobatic planes (Su-26 or Su-31). In the 1990s Sukhoi also experimented with designing a SSBJ, but after this era, all 'supersonic intentions' have been abandoned. [63]

The Sukhoi Company once attempted to create a supersonic project called Sukhoi S-21, originally named Sukhoi-Gulfstream S-21G, because in 1989 the project started as a joint venture with the Gulfstream. The cooperation, though, lasted only three years, after which Gulfstream decided to forgo its share in the development. [63]

In 1993, Sukhoi got $25 million from Russian investors, thus the R&D on S-21 could continue. The S-21 was presented at the Le Bourget air show in 1999 and four years later a deal of the cooperation was signed between the Sukhoi and Dassault, another front-running business jets' manufacturer. [63]

The Dassault already had its own SSBJ project called Falcon SST but it was due to non-availability of suitable engines terminated in 2000. The consequent deal with the Sukhoi should have merged the effort of both companies into one aircraft. More details were expected to be released in October 2003 but no such release took place and no updates about any further progress have been available since that time. [63]

Apart from some pictures, there is almost no information about the Falcon SST project, neither before nor after its fusion with Sukhoi.

Sukhoi S-21

Max. Cruise Speed	*M 1.8 – 2.2*	***Length***	*37.86 m*
Normal Cruise Speed	*Not known*	***Wingspan***	*19.93 m*
Service Ceiling	*63 900 ft (19 477 m)*	***Passengers***	*6 – 10*
Max. Range	*4 600 nm*	***First Expected Flight Test***	*-*
Unit Cost (Targeted)	*US $40 - 50 mil*	***Scheduled Enter Service***	*-*

Table 7: Specifications of Sukhoi S-21 [64]

Figure 20 and 21: Sukhoi S-21 (left) and Dassault Falcon SST (right) [65] [66]

4.7 Supersonic Aerospace International (SAI)

The SAI is a U.S. company established in 2000 by Michael Paulson, a son of Allen Paulson, the founder and the former CEO of the Gulfstream. [67] In 2001, the company started to cooperate with Lockheed Martin (an aircraft manufacturer) to design a SSBJ. The companies collectively invested over US $80 million into the R&D including 19 wind-tunnel tests and in these days hold over 20 patents related to SST. [68]

The intention to produce a SSBJ has been officially announced in 2004 and the project was called Quiet Small Supersonic Transport (QSST). As the name suggests, the SAI main goal was, similarly to the Gulfstream’s approach, to suppress sonic boom and noise emissions as much as possible. [67]

The QSST project was temporarily stopped in 2010 due to a problematic financial situation in the firm after the global economic crisis. Nonetheless, in 2013 the company unveiled a new SSBJ project called QSST-X, which has evolved from the previous version and now SAI seeks $400 million of investments for an advanced study phase. In case of success, the estimated price of the subsequent development and certification process is expected to be up to $6 billion. [67]

SAI QSST-X

Max. Cruise Speed	*M 1.8*	***Length***	*Not known*
Normal Cruise Speed	*M 1.6*	***Wingspan***	*Not known*
Service Ceiling	*60 000 ft (18 300 m)*	***Passengers***	*20 - 30*
Max. Range	*4 500 nm*	***First Expected Flight Test***	*Not known*
Unit Cost (Targeted)	*Not known*	***Scheduled Enter Service***	*Not known*

Table 8: Specifications of SAI QSST-X [69] [70]

Figure 22 and 23: SAI QSST (left) and SAI QSST-X (right) [70] [71]

4.8 Tupolev

Tupolev is a Russian aerospace firm with its headquarters in Moscow that has broad experience with SST stemming from its former supersonic airliner Tu-144. The company also planned (or plans) to design a SSBJ, Tu-444, which is based on its predecessor, but unfortunately no further information about the project is now available on official websites or other relevant sources. It is hence unclear if the development of the project is still in a progress or not. [72]

Tupolev Tu-444

Max. Cruise Speed	*Not known*	***Length***	*36.00 m*
Normal Cruise Speed	*M 2.0*	***Wingspan***	*16.20 m*
Service Ceiling	*Not known*	***Passengers***	*6 - 10*
Max. Range	*4 000 nm*	***First Expected Flight Test***	-
Unit Cost (Targeted)	*Not known*	***Scheduled Enter Service***	-

Table 9: Specifications of Tupolev Tu-444 [73]

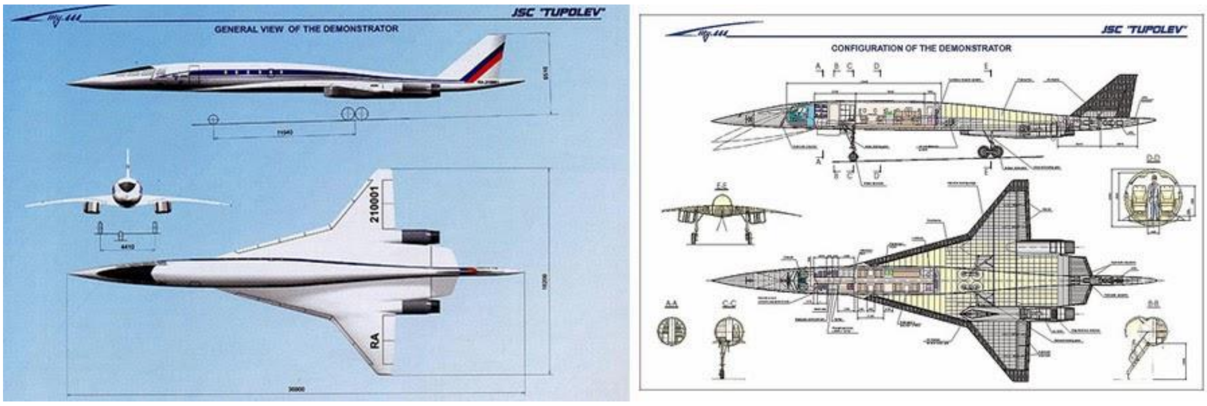

Figure 24: Tupolev Tu-444 [74]

4.9 Other Research and Development Programs

Beside the listed SSBJ projects there exist many other research and development groups and programs that are more or less concerned with the supersonic transportation. These groups are not described in detail in the thesis, but some of the development results are covered in chapter 5. Among the most the most eminent R&D projects belong:

- Environmentally Friendly High Speed Aircraft (HISAC)
  - *EU, Dassault, Airbus, Rolls-Royce, Sukhoi, …*
- Non-symmetrically Distributed Sonic Boom (D-SEND); Silent Supersonic Concept Model (S3CM)
  - *JAXA*
- Quiet Supersonic Platform (QSP); 3rd generation of SST
  - *NASA + DAPRA (Defense Advanced Research Projects Agency)*
- Supersonic Cruise Industry Alliance (SCIA)
  - *NASA + 'Super 10': 3 engine manufacturers, 6 aircraft manufacturers, 1 fractional ownership company*

5 SST Technical Issues and Solutions

As the Concorde era has proven to the world, a successful commercial usage of the civil SST is not an easy task whatsoever. Besides many designing and operating issues applied to every civil aircraft, the SST designers have to face a range of other, additional problems, requiring complex approaches and solutions. The thesis has identified 4 cardinal issues related solely to the SST:

- Exceeding the Speed of Sound
- Sonic Boom
- Wide Range of Operating Speeds
- Temperatures and Used Materials

5.1 Exceeding the Speed of Sound

When a new supersonic aircraft is planned to be designed, the basic assumption is that the aircraft should be primarily able to reach the supersonic speed itself. Contemporary airliners cannot do so, even though their operating speeds is usually quite close to the speed of sound, usually between M 0.7 and M 0.9. The main obstacle that prevents these aircraft from flying faster, is a special form of a drag called wave drag, which appears in the speed of about M 0.8 (lower boundary of transonic speeds), then rapidly increases and is the strongest slightly over the speed of sound. Then, when this speed is overcome, it drops back again to approximately one half of its peak strength. [1]

A drag, in general, is divided into several categories with respect to its origin and can be defined as:

"A rearward, retarding force caused by disruption of airflow by the wing, rotor, fuselage, and other protruding objects. Drag opposes thrust, and acts rearward parallel to the relative wind." [75]

Subsonic aircraft normally deal with two types of drag – a parasitic and an interference drag. The first one is called parasitic because of the only negative effects it has on aircraft. It consists of three sub-types – form drag, skin friction and interference drag – and is dependent on the shape and directly proportional to the size and the velocity of aircraft moving through the air. The induced drag, on the other side, results from lift-making objects such as wings and the tendency of the air around them to equalize the pressure difference and to flow around the wingtips. This type of drag can be partially limited by placing winglets on wings. [76]

The third type of the drag, negligible during subsonic speeds up to the speed of approximately Mach 0.8, is the wave drag. In supersonic speeds, the lift generated on wings works on different aerodynamical principles than in the case of subsonic speeds. During a supersonic cruise, the wings create 3-dimensional shockwaves, which are only thin layers representing a massive pressure leap between two masses of air. The “usual” shockwaves (a bow and a tail wave) are shown in figure 26. [1]

The wave drag is the result of the (energy consuming) formation of such waves and starts to be perceptible during transonic speeds, when some air molecules start to move supersonic. Consequently, the shockwaves appear. [77]

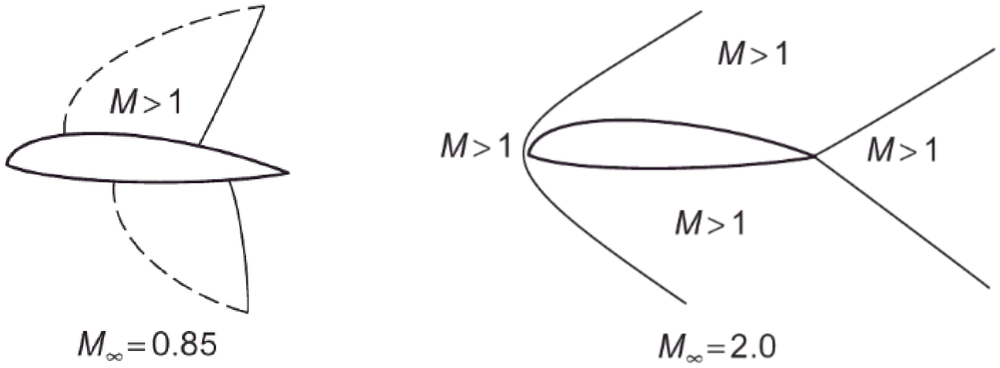

Figure 25 and 26: Shockwaves formation at transonic (left) and supersonic (right) speeds [77]

The graph below shows the progress of a total drag coefficient[6] (C_D) as a function of aircraft speed.

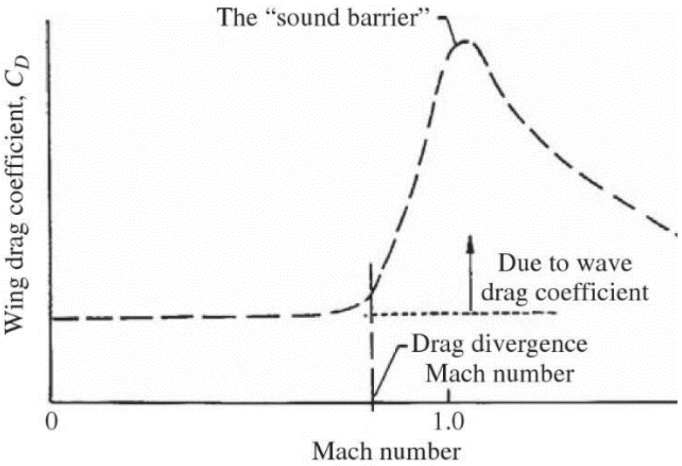

Figure 27: Drag coefficient [78]

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[6] Drag coefficient = *“Dimensionless quantity that is used to quantify the drag or resistance of an object in a fluid environment.”* [131]

As a consequence of an existence of the wave drag, the STT has to face two serious issues, concerning:

- Supersonic fuel efficiency
- Power of engines

The supersonic fuel efficiency is rather an operating issue and will be more closely described in section 7.2.

The second issue is the power of engines needed for overcoming the “sound barrier” that the wave drag creates. The problem is not only to find a powerful engine that would be able to exceed the speed of sound, but it also has to be effective for a variety of speeds and silent enough in order to comply with current noise regulations.

The vast majority of contemporary commercial jets use turbofan engines with high bypass ratios, but these engines would not be most likely usable for a supersonic cruise due to a lack of power and a huge drag it would create over the speed of M 1.0 (see section 7.2, figure 53). Another option could be a turbojet or a turbofan variant with a low-bypass ratio developed from a military aircraft, but the noise restrictions could be still a real issue in this case, as we know the noisiness of military jets on air shows or in vicinity of military airports.

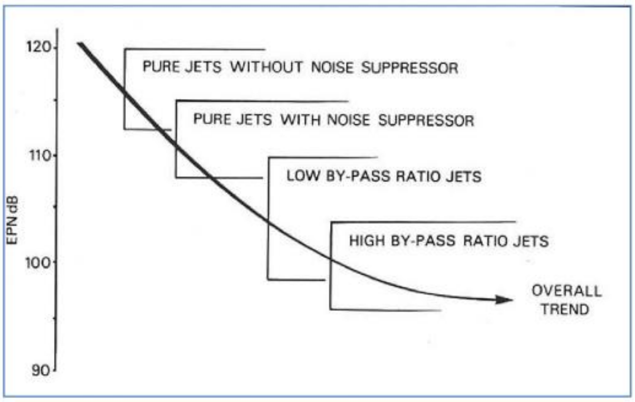

Figure 28: Engine types noisiness [79]

For example, Aerion Corp. originally planned to use an improved Pratt & Whitney JT8D engine (first ran in 1960, used for Boeings B727, B737 100/200, etc.) for the AS2 project, but due to unacceptably high noise levels and exhaustion emissions, the idea has been abandoned. [39]

Additionally, Concorde, the Tu-144 and the most of supersonic military aircraft use or have used a so called afterburner, which allows an extra fuel to be injected to an engine combustion chamber, so it could provide a power increase of about 50%, despite a significant fuel loss. Concorde, for example, used an afterburner as a support for take-offs and for exceeding the speed of sound (the sound barrier). [80] Unfortunately, along with the provision of the extra power, the afterburner emits very high noise levels and it is questionable, if a civil aircraft equipped with the afterburner would be now approved by civil aviation authorities.

The last possible way would be developing a brand new engine tailored to the SST (SSBJ) needs. Even though this option would be probably the most suitable in terms of the power and the noise requirements, the developing costs can be expected very high with no real guarantee of a future success.

5.2 Sonic Boom

The sonic boom is the term defining a very strong noise resulting from a shockwave, made by any object moving faster than the speed of sound. To human, the sonic boom is sensed as an unpleasant or even painful crack-like noise, quite similar to a boom of a thunder. [81]

During subsonic speeds, the sound made by aircraft spreads in all directions. But when an aircraft flies faster than the speed of sound, the sound waves can spread only backwards (with respect to the flight direction), in a cone being circumscribed by shockwaves. The shockwaves actually represent a rapid compression of air particles within a very small space, resulting in a significant leap of pressure and thus creating a very intense noise – the sonic boom. [81] The visualized propagation of sound waves spreading accordingly to the object's speed is shown in figure 29:

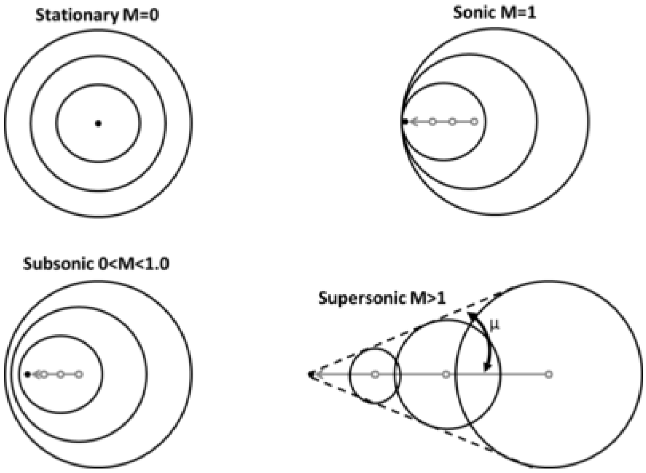

Figure 29: Propagation of sound waves [82]

Simply said, if any aircraft flying supersonic was heading towards us, we would not be able to hear it, because it would be approaching faster than the sound it creates. However, soon after this aircraft passed by, the cone made by a shockwave would reach us and we would hear a very strong, thunder-like noise, called the sonic boom.

Loudness of the sonic boom may be described as an acoustic pressure or as an acoustic intensity interconnected in accordance with this equation [83]:

$$L_{dB} = 20 \cdot \log\left(\frac{p}{p_0}\right) \qquad \text{[Equation 8]}$$

Where:

L_{dB}	Acoustic intensity	[dB]
p	Acoustic pressure	[Pa]
$p_0 = 2.8 \cdot 10^{-5}$	Reference acoustic pressure	[Pa]

The acoustic intensity expressed in decibels is a logarithmic function, meaning that (in this special case) for every 6 dB increment, the acoustic pressure has to be roughly doubled. The ultimate sound (acoustic) intensity depends on several aspects such as size, shape, altitude and the actual speed of an aircraft. But according to Orlebar [84], Concorde produced an acoustic pressure of abound 93 Pa during the flyover in the altitude of 52 000 ft (approximately 15 500 m), flying the speed of M 2.0. This corresponds to the sound intensity of slightly over 130 dB, while the human's pain threshold is between 115 and 140 dB.

In general, we can recognize two types of sonic booms:

- N-type
- U-type

The N-type is a "usual sonic boom" created during a steady supersonic flight. It has been named the N-type because of the "N" shape of the pressure progress made by the aircraft, which is displayed in the next figure:

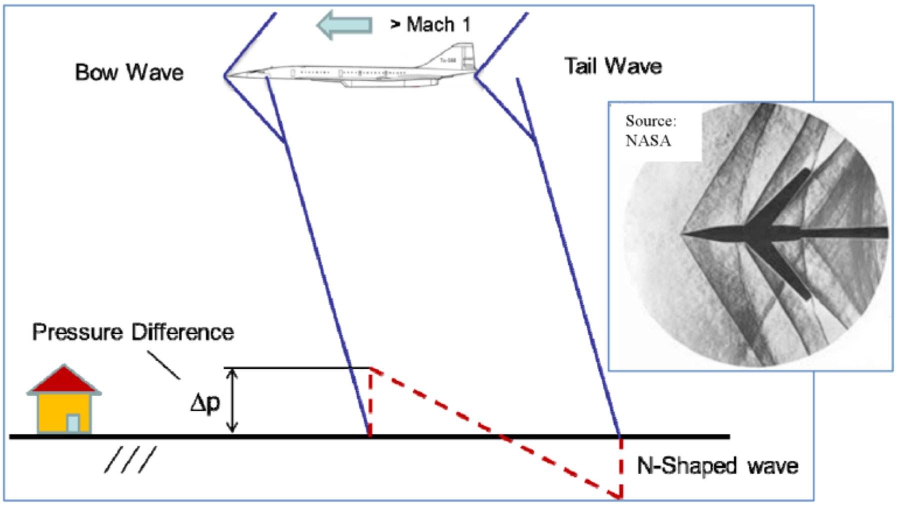

Figure 30: N-shape sonic boom [72]

From this picture it can be seen that the actual noise that reaches the ground is in fact a double-boom. The first one is made by the overpressure in a bow wave and the second one, following the first one in a short time, originates from the underpressure in a tail wave. The short interval between the two booms, though, is almost imperceptible to human ear. [85]

The second type of the sonic boom, the U-type, is characteristic for aircraft transient manoeuvres such as changes in directions or in climbing or descending rates. The “U” shape is (again) in accordance with its pressure diagram, but the pressure peak can be up to five times higher than the peaks of the N-type. Fortunately, this type of the sonic boom affects only a very narrow strip of a land beneath aircraft. Operational issues related to both types of the boom are described in chapter 7. [85]

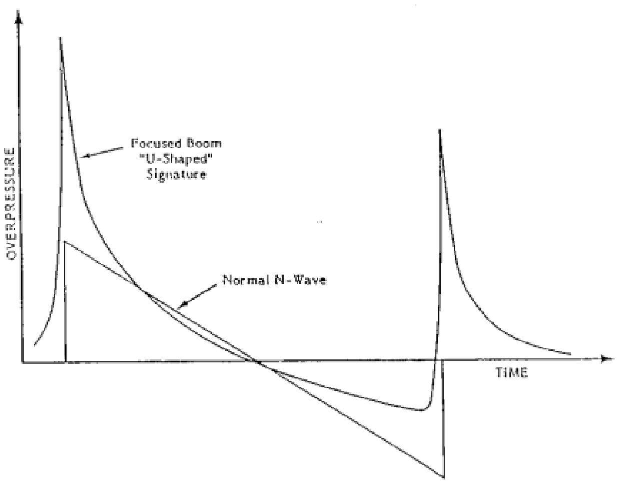

Figure 31: U-shape and N-shape sonic booms [85]

In general, the sonic boom represents one of the biggest issues that the SST designers have to face. As Concorde has shown, the noise made by supersonic aircraft is so intense that the populated areas simply cannot be exposed to such extreme phenomena.

On the other hand, as it was mentioned earlier, the intensity of the sonic boom depends on several aspects, most importantly on: size, shape, altitude and the actual speed of an aircraft. If these four points were applied to currently planned SSBJ projects then [81]:

5.2.1 Size

The size (and even the weight) of aircraft is directly proportional to the emitted sound intensity, due to a larger mass of air that needs to be displaced. Most of the current SSBJs are planned to be much smaller that Concorde or the Tu-144, so from this point of view, the ultimate strength of the sonic boom may be expected less severe.

5.2.2 Shape

There is a variety of shapes among the planned SSBJs, but at least for the most promising and developed projects, the overall appearance is not so much different from conventional airplanes. If an aircraft is not specially adjusted for a sonic boom reduction (described below), the aircraft shape would not probably make a difference in the sonic boom intensity (e.g. when compared to Concorde).

5.2.3 Altitude

Another factor, the altitude, is rather a disadvantage for the planned SSBJ projects. While the altitude (in a combination with weather conditions) is the most important factor in terms of the sonic boom intensity on the ground, the SSBJs are mostly planned to fly in altitudes of “only” between 50 000 and 60 000 feet (approximately 15 200 and 18 300 meters). Both Concorde and the Tu-144 were able to operate in altitudes of about 60 000 feet, so the boom intensity could have been mitigated a little more.

5.2.4 Speed

The last aforementioned contributor to the sonic boom noisiness is the actual speed of aircraft. Unfortunately for the SSBJ projects, whose maximum speed is usually planned to be below M 1.8, which makes them slower than Concorde or the Tu-144, the sound intensity increases only to the speed of about M 1.3 and then remains almost the same (with the increase of velocity). Then, only weak sonic boom reduction originating from lower operating speeds can be expected.

In total, in a comparison to Concorde and the Tu-144, it is uncertain how powerful the sonic boom of the future SSBJ will be. It is quite likely, though, that the difference in sonic boom noisiness between the planned supersonic projects and their predecessors will not be so significant without further improvements or other solutions.

Because SSBJ designers are very well aware of this fact many research programs and tests have been conducted in order to mitigate future sonic boom intensity. Among the most usual approaches belong the aircraft fuselage and wings shape research so that the pressure leap on the nose and the tail of an aircraft would not happen so suddenly (in a shockwave), but it would be rather progressively distributed in a bigger area. A good example of such research is the NASA Shaped Sonic Boom Demonstration program that started in 2003 and lasted for two years. The main goal was to mitigate the sonic boom with a special fuselage shape of the modified fighter jet F-5E, as shown in figure 32. The result of the tests is shown in figure 33. [86]

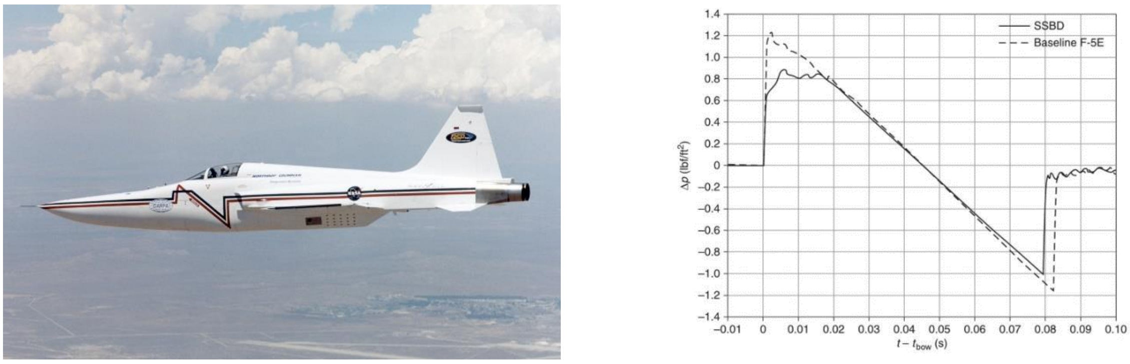

Figure 32 and 33: Shaped Boom Demonstration: F-5E (left) and its results (right) [87] [88]

Another approach to this issue chosen by the Gulfstream Aerospace comes up with a special retractable nose that would at first, “hide” the rest of the aircraft in the cone of the shockwave resulting in a lower drag, and more importantly at second it would significantly reduce the area of the very top of the plane which is another important contributor to the sonic boom intensity. The tested retractable nose in figure 34 is a part of the Quiet Spike research and its expected results are shown in figure 91. [89]

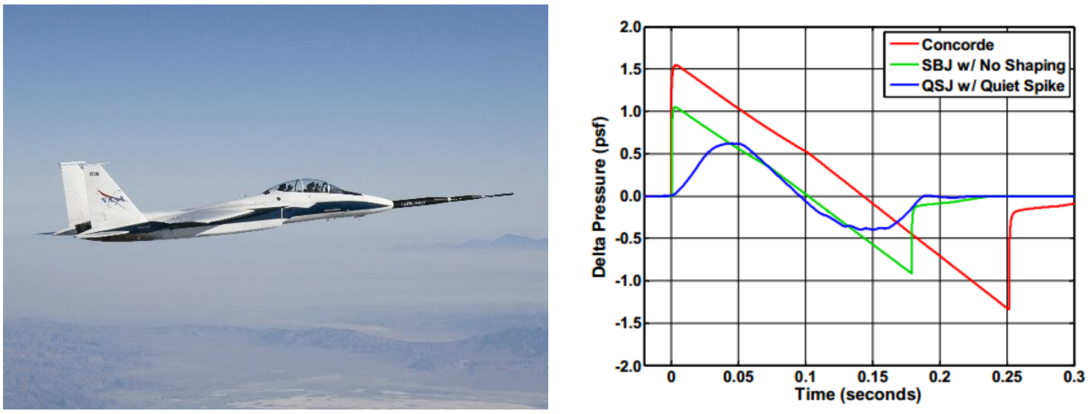

Figure 34 and 35: Quiet Spike: Retractable nose (left) and its expected results (right) [90] [91]

A quite different solution has been proposed by the HyperMach Aerospace whose SonicStar project is planned be able to “absorb” shockwaves and hence prevent the sonic boom from propagating any further. The key for this approach is to be an “electromagnetically induced plasma wave technology” being a part of aircraft hybrid engines (S-MAGJETs by SonicBlue) which are supposed to create “counter-waves” and thus to neutralize supersonic shockwaves. Unfortunately, no closer information about the technology is available at the moment. [55]

After all, the success of any of the SSBJ projects is quite uncertain due to the remaining question, i.e. if the supersonic transport was one day allowed to fly overland. There would be probably no problem if sonic booms were completely eliminated from all supersonic flights, but this possibility is very unlikely, at least in the near future. If the sonic boom was “only” weaker yet still noticeable, the question would arise if the society was able to accept it in their everyday lives. Imagine the situation where every single aircraft crossing the sky would emit noise of a weak thunder. With a regard to a volume of contemporary air traffic, the noise could be heard ten or even hundred times a day. Considering this possibility, the future SSBJ operations could be, even with a quieter sonic boom, ultimately forbidden over a land by aviation authorities.

5.3 Wide Range of Operating Speeds

Even though the range of speeds may not sound so problematic from the technical point of view, the development of a proper wing for Concorde, for example, was enabled only due to several years of preceding research of an air flow and it still remains a key concern of all SST designers.

It might seem as an easy task to design a wing for an airplane, because most of the wings of the contemporary civil aircraft look quite similar (especially the airfoil does), despite a wide range of different operating speeds that they had been made for. But as it was mentioned earlier, the air flow behaves much differently during subsonic and supersonic regimes due to a difference in air compressibility (in subsonic speeds air behaves as an incompressible fluid unlike supersonic speeds when it is the opposite), the formation of shockwaves etc. [1] As a result, an ideal subsonic airfoil is far away from an ideal airfoil for supersonic speeds. Moreover, neither of these is suitable for the other category; the subsonic version creates a very high drag when flying supersonic, while the supersonic one provides only a small lift at subsonic speeds, mostly insufficient during take-off and landing regimes, when the aircraft speed is relatively low. Both ideal airfoils are displayed in the figures below.

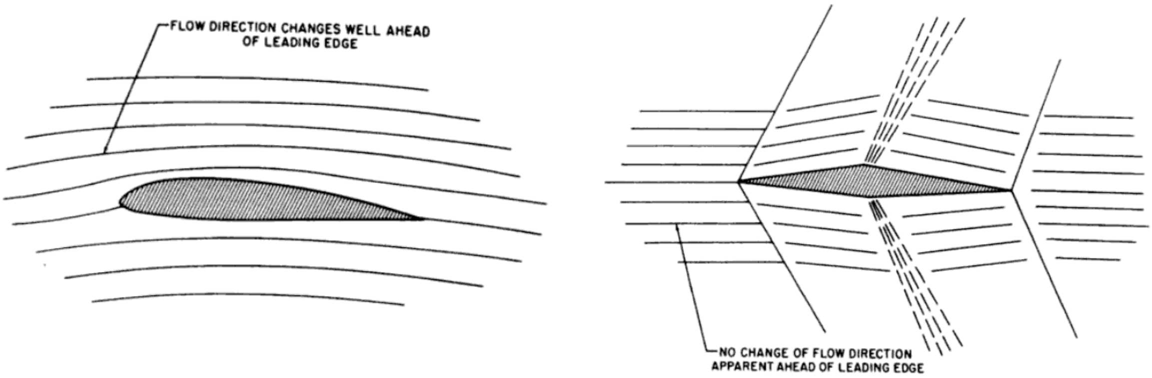

Figure 36 and 37: Ideal airfoil for subsonic (left) and supersonic (right) speeds [92]

Supersonic aircraft, logically, has to be able to operate in both subsonic and supersonic speeds, which is why it needs some kind of a compromise between the two airfoils or a completely different approach. Concorde designers came up with an idea of a “slim double ogee delta” wing, the design of which was rather better for supersonic speeds, but it still generated a sufficient lift for the aircraft flying subsonic. The biggest advantage of this wing was its usability during take-offs and landings. The wing itself would not provide a needed lift during such low-speed regimes, but due to its special and very complex shape, it enabled the aircraft to increase an angle of attack in such a way that the desired lift could be reached. Normally, such high angles of attack would result in separating upper layers of the air flow from the wings, leading to a loss of the lift and the consequential stall of an aircraft. Concorde wings prevented this from happening by creating relatively stable air vertices that maintained a desired underpressure on the upper half of wings, even though it worked on a completely different principle. [93] The vertices are visualized in figure 39.

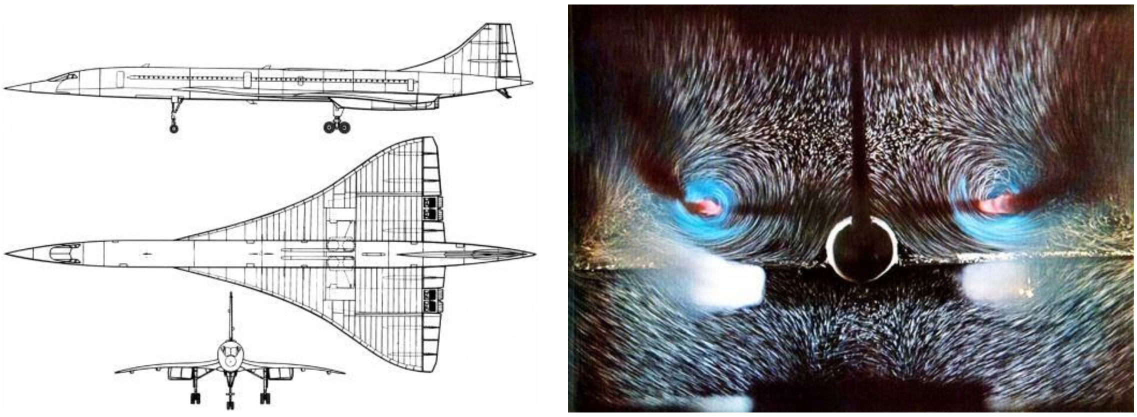

Figure 38 and 39: Concorde wings shape (left) and the visualised air flow (right) [94] [93]

The Aerion Corporation has also invested a lot of effort and money to its wing shape research which finally resulted in new findings and extensive knowledge in this field. The main subject of the research is a so called “supersonic natural laminar flow” (SNLF) and it should, besides making the sonic boom quieter and the aircraft operations more fuel-effective, primarily maintain a laminar air flow around almost the whole wings’ area (instead of a turbulent air flow recognizable on other aircraft wings) and thus make the wing usable for both subsonic and supersonic speeds. The technology is supposed to be crucial for a future success of the AS2 project, but according to company’s official websites [37] most of the test flights related to the SNLF have been already successfully finished.

Figure 40 and 41: SNLF technology testing (left) and Aerion AS2 wings (right) [95] [96]

Another possible approach chosen by the Gulfstream Aerospace is the variable wing geometry. There is at present only little information known about the Gulfstream X-54 project, but from officially released pictures and drafts so far, variable-sweep wings will be most likely included in the future Gulfstream SSBJ. The benefit of such technology is the possibility of controlling the lift and the drag of the aircraft to a certain extent. As it was mentioned earlier, the drag reduction is mainly desired when flying supersonic, while the lift has to be strong enough to be able to carry the aircraft during slow speed regimes. Hence, a swept wing is suitable for higher speeds, because the drag (and the lift) is lower. An unswept wing, on the other hand, provides a sufficient lift, while the drag remains acceptable. [97]

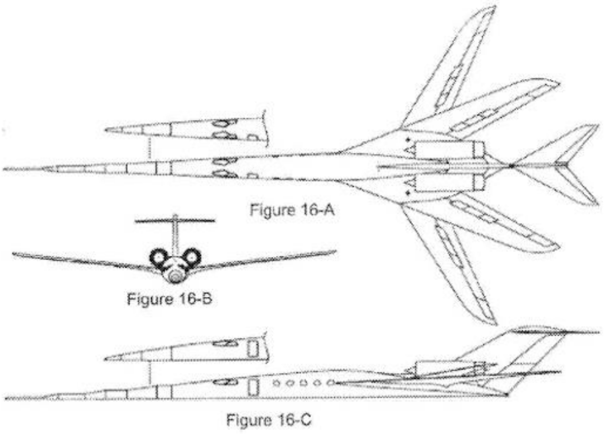

Figure 42: Gulfstream X-54 [49]

The last solution chosen by some SSBJ designers is a further development of the Concorde's slender delta wing. Unlike other aforementioned possibilities this approach is time-tested and it seemed to be very successful in the past. From contemporary SSBJ projects, the upgraded version of the Spike Aerospace S-512 is to be equipped with a delta wing as well as the SonicStar developed by the HyperMach Aerospace.

5.4 Temperatures and Used Materials

The last listed SST technical issue described in detail is related to temperatures that supersonic aircraft have to face. According to the International Standard Atmosphere, the air temperature in the altitude of over 11 km equals to -56.5 °C, while average temperatures at some airports can exceed even 40 °C. That is why the material thermal expansion has to be considered very carefully.

More importantly though the SST will have to deal with the issue of an aircraft nose and leading edges warming during high-velocity flights. As air molecules slow down when “flying” close to aircraft (when the aircraft is considered stationary and the air is moving around it), a significant part of the energy is transformed to heat which results in aircraft surface warming. The issue is significant neither for subsonic nor lower supersonic speeds, but it needs to be taken into account in speeds from about M 2.0, since the surface temperature raises with the square of the velocity (as shown in the equation below) and some usually used aircraft materials cannot operate in such conditions. [1]

$$\frac{v^2}{2} + c_p T = c_p T_0 \;\rightarrow\; \Delta T = T_0 - T = \frac{v^2}{2 \cdot c_p} \qquad \text{[Equation 9]}$$

Where:

v	Velocity of an aircraft	$[m/s]$
$c_p = 1005$	Specific heat capacity at constant pressure	$[J \cdot kg^{-1} \cdot K^{-1}]$
$T_0 = 216.65$	Absolute temperature in the altitude of 11 000 m	$[K]$
T	Temperature of an aircraft leading edge surface	$[K]$
ΔT	Change of temperature caused by the air friction	$[K]$

When the equation 9 is applied for different velocities, we get these results:

$$M\ 1.4\ (v = 413\,m/s) \ldots\ \Delta T = 85\ K \ldots t = 29\ °C$$

$$M\ 2.0\ (v = 590\,m/s) \ldots\ \Delta T = 174\ K \ldots t = 118\ °C$$

$$M\ 3.0\ (v = 885\,m/s) \ldots\ \Delta T = 391\ K \ldots t = 335\ °C$$

Where:

t	Temperature of an aircraft leading edge surface	$[°C]$

It is quite obvious from these results that for most of current SSBJ projects such as the Aerion AS2, the operating speed of which is planned to be about M 1.4, the surface warming should not be an issue at all. But for some other projects, in contrary, that are planned to fly much faster (e.g. HyperMach SonicStar), the surface temperature may represent a real obstacle.

The Concorde speed, for example, was limited to M 2.04 just because of the wings leading edges warming, which could result in a substantial degradation of aluminium alloys that the wings were made of, in the case of exceeding the temperature of 127 °C. [98]

Even the thermal dilatation could cause serious troubles. Concorde, for instance, had been regularly prolonged up to 300 mm (due to the high temperature), which was sometimes perceptible with a bare eye from the aircraft back seats. [99] This could be an issue as well since the aircraft could be changing its shape uncontrollably as well as cause damage in connections between thermally stable and unstable materials.

In general, there are four most basic materials that the nose tip or wing leading edges could be made of (or at least covered with as a protection) and then literally thousands of its possible alloys, variants and derivatives. There also exists a long list of other advanced materials, some of them will be mentioned later, but these are still mostly not in use in the civil aviation. Four possible, heat-resistant materials are listed in the table below, including their biggest advantages and disadvantages.

Material	Advantages	Disadvantages
Aluminium (alloys)	Lightness, strength, low price	Material degradation when $t \sim 120$ °C
Titanium (alloys)	Strength, thermal stability, heat and corrosion resistance	Very high price
CFRP[7]	Stiffness, lightness, heat resistance	Complex manufacturing process
Stainless steel	Heat resistance	High weight

Table 10: Basic materials usable for SST [100]

It should be noted that the table above serves only as a rough description of the listed materials and exceptions may occur in some of the materials' alloys or variants.

The results of Huda work [100], who considered all of the possible material variants usable for supersonic and hypersonic aircraft, are much more detailed. The author divided cruising speeds into three categories – up to M 2.0; M 2.0 – M 4.0; over M 4.0 – and recommended a suitable option for each of them for main aircraft components. A method called *Weighted Relative Property Rating Procedure* has been used in order to find the best solutions, considering materials' mechanical and temperature characteristics and a price of each possible option. The whole table with the results is shown below.

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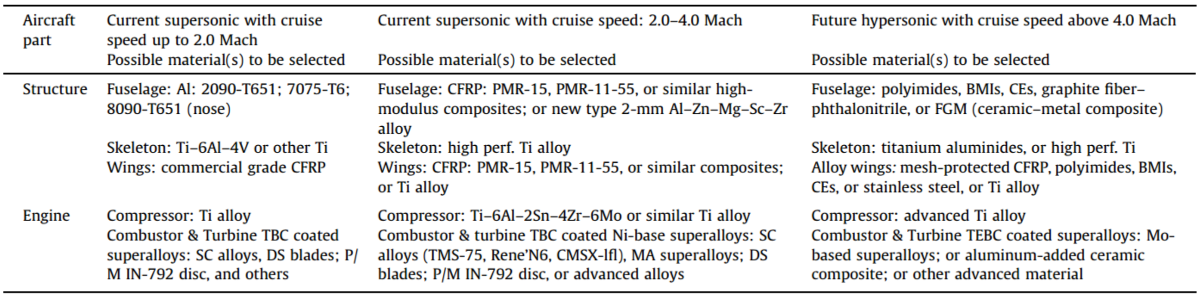
[7] CFPR = Carbon-Fibre Reinforced Polymer.



Aircraft part	Current supersonic with cruise speed up to 2.0 Mach Possible material(s) to be selected	Current supersonic with cruise speed: 2.0–4.0 Mach Possible material(s) to be selected	Future hypersonic with cruise speed above 4.0 Mach Possible material(s) to be selected
Structure	Fuselage: Al: 2090-T651; 7075-T6; 8090-T651 (nose) Skeleton: Ti–6Al–4V or other Ti Wings: commercial grade CFRP	Fuselage: CFRP: PMR-15, PMR-11-55, or similar high-modulus composites; or new type 2-mm Al–Zn–Mg–Sc–Zr alloy Skeleton: high perf. Ti alloy Wings: CFRP: PMR-15, PMR-11-55, or similar composites; or Ti alloy	Fuselage: polyimides, BMIs, CEs, graphite fiber–phthalonitrile, or FGM (ceramic–metal composite) Skeleton: titanium aluminides, or high perf. Ti Alloy wings: mesh-protected CFRP, polyimides, BMIs, CEs, or stainless steel, or Ti alloy
Engine	Compressor: Ti alloy Combustor & Turbine TBC coated superalloys: SC alloys, DS blades; P/M IN-792 disc, and others	Compressor: Ti–6Al–2Sn–4Zr–6Mo or similar Ti alloy Combustor & turbine TBC coated Ni-base superalloys: SC alloys (TMS-75, Rene'N6, CMSX-lfl), MA superalloys; DS blades; P/M IN-792 disc, or advanced alloys	Compressor: advanced Ti alloy Combustor & Turbine TEBC coated superalloys: Mo-based superalloys; or aluminum-added ceramic composite; or other advanced material

Figure 43: Material possibilities for SST [100]

By means of the table above we may illustrate that the best material option for an aircraft construction in the first category (up to M 2.0) would be a combination of an aluminium alloy for a fuselage, a titanium alloy for a skeleton and a CFRP for wings. The CFRP represents a modern approach to aircraft constructions in general which is now used in the subsonic segment as well. For example, a considerably big part of the Boeing B-787 Dreamliner or the Airbus A350 XWB is made of the CFRP.

The second category (M 2.0 – 4.0) differs from the first one due to a greater use of the CFRP and the titanium, while the aluminium would not be usable any more due to high temperatures.

The materials for the last category (over M 4.0) still need some development due to very strict requirements caused by such extreme conditions. But it seems that besides titanium alloys a so called mesh-protected CFRP or other very-high temperature resistant materials, such as polyimides, bismaiemides (BMIs), cyanate esters (CEs) or a few others, could be used in the future. [101]

The material choice of current SSBJ projects has not been mostly announced yet, but for a majority of them, due to their relatively small operating speeds in terms of material boundaries (below M 2.0), no significant future research will be probably needed. The Aerion Corporation has already stated that for the construction of the AS2, solely currently available materials (primarily CFRP) will be used and that no further development would be required. [37]

Some other projects, on the other hand, that are planned to fly faster (such as the HyperMach SonicStar with its operating speed of up to M 4.0) will have to probably invest a lot of effort to further material research.

6 Current Legislation and Regulations

Civil aviation regulations in general represent one of the biggest issues that the supersonic aircraft manufacturers will have to deal with. Especially noise and engine emissions have concerned the public, and thus the aviation authorities, since the beginning of the Concorde era and were topics of extensive environmental discussions. Overcoming these issues, hence, seems to be crucial for the future success of SSBJs. Despite the fact that people could have seen Concordes crossing the sky up to the year of 2003, the requirements for a new SSBJ (or any new SST) may be expected, due to an ongoing trend of tightening environmentally oriented regulations, much stricter. In other words, if Concorde or the Tu-144 were completely new types of aircraft planning to enter service in these days, neither of them would be allowed to fly.

In general, within the current regulatory system we can identify two different categories having impact on the SST.

First, there exists a broad spectrum of regulations, related to noise, engine emissions, air operations, airworthiness etc. These are the standards applicable to all aircraft certified to fly with the potential SST included. Even though some exceptions for the SST might appear in these regulations in the future (as it happened with Concorde, for example), the regulations should be perceived as a guideline for all SST manufacturers as well.

Second, because of some considerable differences between supersonic and subsonic aircraft, some regulations have been focused exclusively on the SST. Due to absence of any airworthy supersonic aircraft at present, though, these regulations are mostly useless or having no text at all and they serve rather as a space reserve among other regulations prepared for future changes. However, noise limitations, particularly due to sonic boom effect, can be expected to be a principal concern of future SST regulations.

The thesis mentions regulations and activities of the four most significant civil aviation organizations (in terms of the rule-making process) regarding the SST or the environmental protection in general. These are:

- ICAO (International Civil Aviation Organization)
    - CAEP (Committee on Aviation Environmental Protection)
- FAA (Federal Aviation Administration)
- EASA (European Aviation Safety Agency)

6.1 ICAO (International Civil Aviation Organization)

The ICAO is the highest civil aviation authority, headquartered in Montreal and established in 1947 as a part of the Convention on International Civil Aviation (also known as "Chicago Convention"), which represents the United Nations in the field of the civil aviation. The organization consists of 191 member states and its general goal is an ongoing work and research as for the growth, development and safety in the world air traffic. [102]

One of the ICAO's regulatory tools are so called Standards and Recommended Practices (SARPs) that unify member states national regulations to a certain minimum level. In fact, only *Standards* are by definition mandatory (member states have to notify ICAO in case of discrepancies between their national and ICAO regulations), while the adoption of the *Recommended Practices* is only highly recommended. On the whole, the member states are obliged to unify the national regulations with accordance to the SARPs "*to the greatest possible extent*". [103]

The most important documents included in SARPs are regulations called Annexes numbered from 1 to 19. Annexes set up an essential basis of all member states national regulations and may be further extended by individual national authorities when necessary. [103]

6.2 CAEP (Committee on Aviation Environmental Protection)

The CAEP was established as a part of the ICAO in 1983 in order to support the rule-making process related to environmental protection resulting in new ICAO standards and policies, such as SARPs. The organization has merged with a number of ICAO sub-organizations concerning of the environmental protection (Committee on Aircraft Noise (CAN), Committee on Aircraft Engine Emissions (CAEE) etc.) and now consists of several different branches. [104] The organization structure of the CAEP is shown in the picture below:

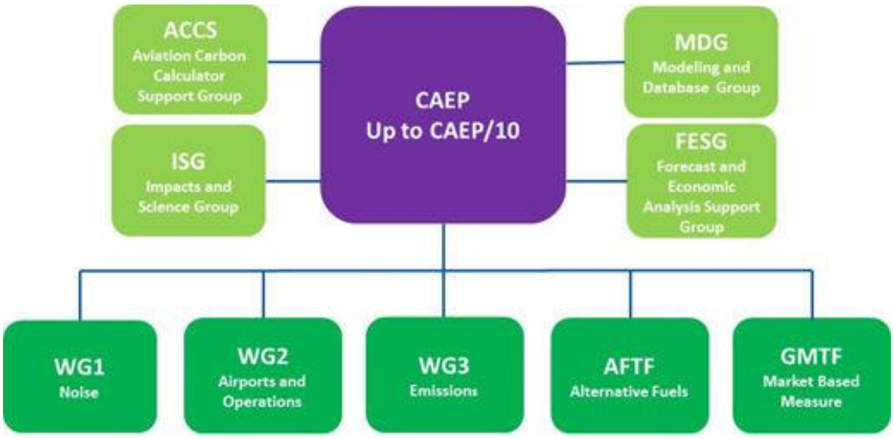


Figure 44: CAEP Structure [104]

The CAEP publishes its recommendations and results every 3 years, having had the last session – CAEP/9 – in the year of 2013. The number in the abbreviation stands for the number of the meeting.

In terms of the SST, the most important segments of the CAEP are the so called Technical Working Groups (WG), especially WG-1 (Noise) and WG-3 (Emissions), whose goal is to monitor a research and a technological progress of member states, to evaluate the results and accordingly to develop new or to modify current ICAO regulations. The biggest contributors to the monitoring programs are these countries: USA, EU, Japan, Canada, Russia and Brazil.

The Supersonic Task Group (SSTG) is included in the WG-1 and is expected to publish its position towards the SST noise issues during the next session in 2016. [105] The monitored SST research projects are shown in the picture below:

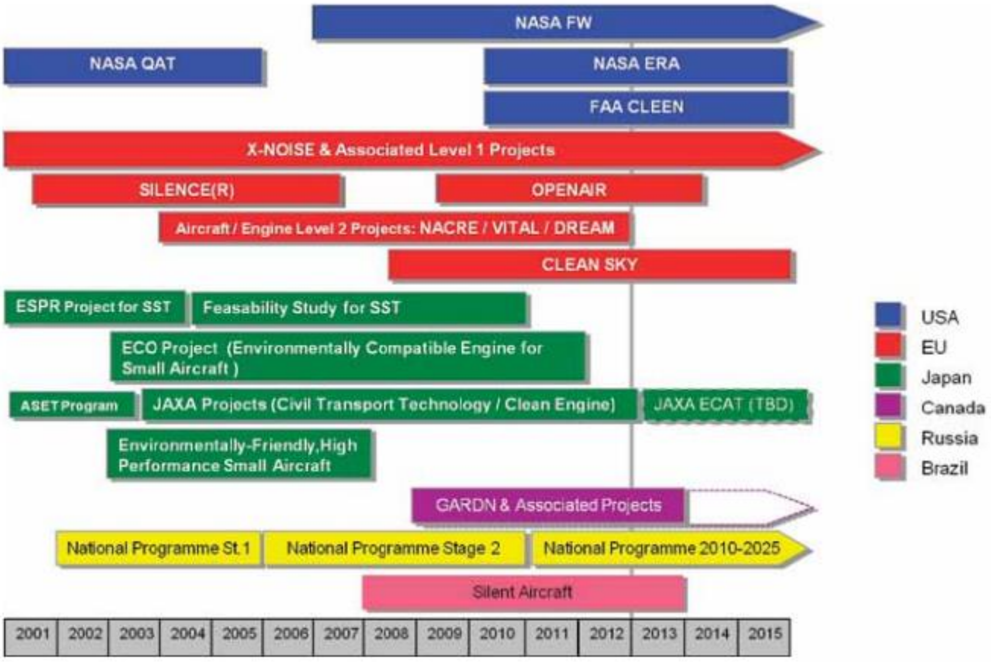


Figure 45: Monitored SST research projects [105]

6.2.1 Annex 16 Volume I – Environmental Protection, Aircraft noise

Annex 16 Volume I is dedicated solely to aircraft noise, defining measurement methods, testing procedures and maximum noise levels of civil aircraft with respect to the dates of applications for type certifications, the number and the types of engines etc. In terms of the future SSBJ, Chapters 4, 12 and 14 will most likely play an important role in the possible SSBJ's future certifying process.

6.2.1.1 Chapter 12 – Supersonic Aeroplanes

Chapter 12 directly regulates noise requirements for the SST, but the only one paragraph concerning new supersonic aircraft states:

“Standards and Recommended Practices for these aeroplanes have not been developed. However, the maximum noise levels of the Part that would be applicable to subsonic jet aeroplanes may be used as a guideline. Acceptable levels of sonic boom have not been established and compliance with subsonic noise Standards may not be presumed to permit supersonic flight.” [106]

The up-to-date form of this section is the result of the needlessness of such regulations at the moment as well as the uncertainty of the closer specifications of the future SST. In other words, nobody knows now how noisy the supersonic aircraft will be. This paragraph is expected to be changed when new supersonic aircraft was likely to enter service. Additionally, it seems that some changes will come with the next CAEP session – CAEP/10 – in 2016. [105]

The rest of the Chapter 12 refers to supersonic aircraft having the application for type certificate submitted before the year of 1975 – Concorde and the Tu-144 – and allows them to operate under certain conditions, closer described in the Chapter 2 of this Annex.

6.2.1.2 Chapter 4, Chapter 14

The Chapters 4 and 14 regulate noise requirements for new subsonic aircraft. The Chapter 4 is dedicated to a propeller and jet aircraft with the MTOW over 55 000 kg referring to type certificate before the end of the year of 2017 and to a propeller and jet aircraft with MTOW below 55 000 kg referring to type certificate before the end of the year of 2020. The rest of the aircraft that do not fit into this group (the applications sent after) is covered in the Chapter 14. [106]

Along with the Chapter 4 and 14, there are also Chapters 2 and 3, all setting up maximum noise levels of airworthy aircraft, each one concerning different ages of types of airplanes and having different requirements for them. There has been an evident trend of reducing noise levels in the last decades as it is shown in graph 4.

One of the most revealing tests that reflect aircraft noisiness is a so called cumulative noise, measured in EPNdB[8]. This test consists of the sum of three noise measurements from different measurements points. These are:

- Lateral full-power noise level – measured during the take-off in the distance of 450 m aside
- Approach noise level – measured 2 000 m in front of the landing point
- Flyover noise level – measured 6 500 m behind the take-off (from the brake release point)

Due to expected power demands for engines that would be applied as for supersonic aircraft in the future, the strict noise limits could be a serious issue for SST manufacturers even for subsonic speeds. If the regulations for subsonic aircraft ultimately serve as a guideline for the supersonic transport, the situation for the Aerion AS2, the MTOW of which is expected to be slightly below 55 000 kg (54 884 according to the official websites), will be following[9]:

AS2 maximum cumulative noise level according to:

- Chapter 4 (type certification sent before 2020) … 277.74 EPNdB
- Chapter 14 (type certification sent after 2020) … 270.73 EPNdB

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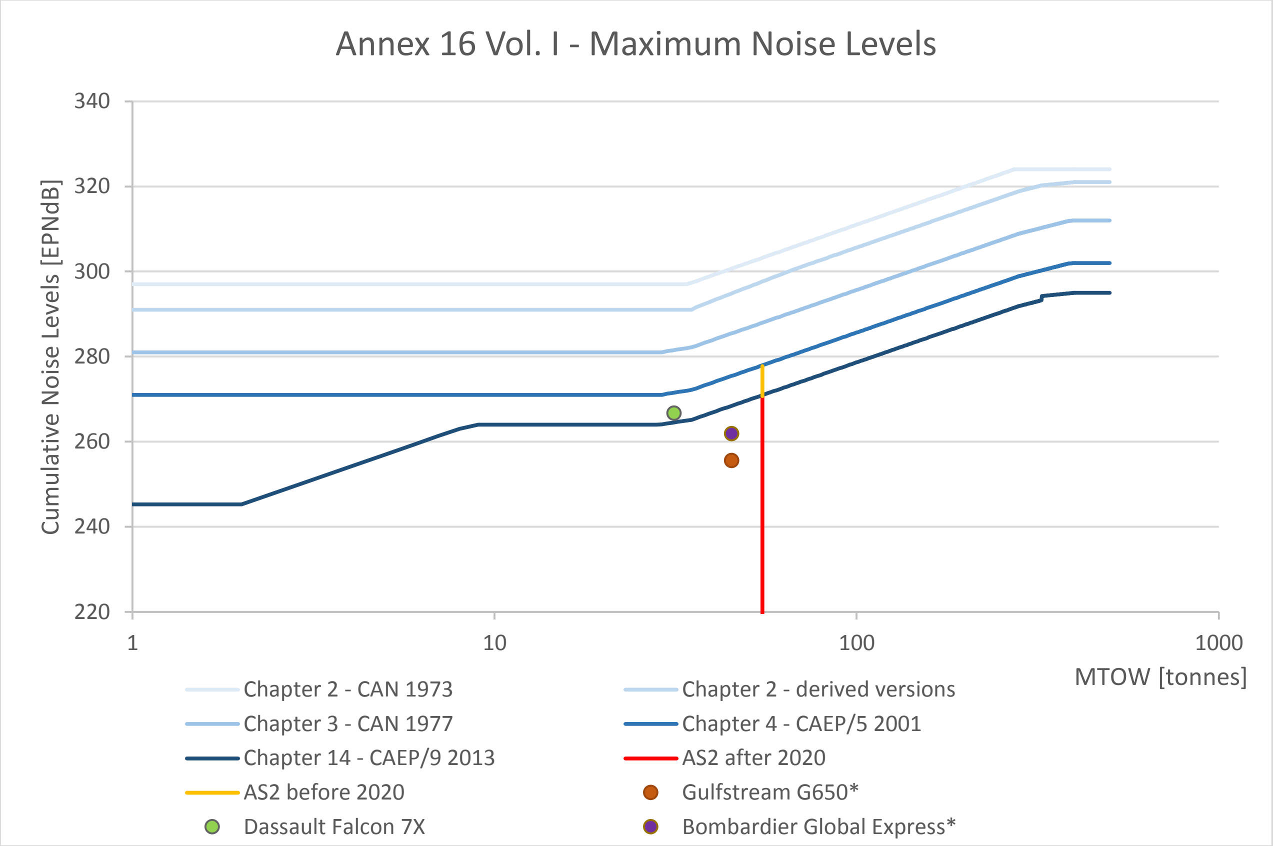
[8] *„EPNdB is a measurement of human annoyance to aircraft noise which has a special spectral characteristics and persistence of sound. Certification quality of EPNdB cannot be directly measured, it has to be calculated as described in the Annex 16."* [130]

[9] Computed in accordance with equations stated in the Annex 16, vol. I, Attachment A – Equations for the Calculation of Noise Levels as a Function of Take-off Mass [106].



Graph 4: Maximum aircraft noise levels*[10] *[107] [108] [109]

6.2.2 Annex 16 Volume II – Environmental Protection, Aircraft engine emissions

The second volume of the Annex 16 is dedicated solely to engine emissions. It defines types of monitored gases (mainly carbon monoxide (CO), oxides of nitrogen (NO_x), unburned hydrocarbons (HC) and the amount of exhausted smoke), limits and the maximum amounts of vented gases, means of measurements and emission evaluations, etc. All these aspects are specified individually both for subsonic and supersonic aircraft (Part III. Chapter 2 and 3 in particular). [110] The trend of reducing engine emissions (NO_x in this case) is shown in the picture below:

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[10] The graph is computed for 3-engine aircraft only, the G650 and the Global Express have only 2.

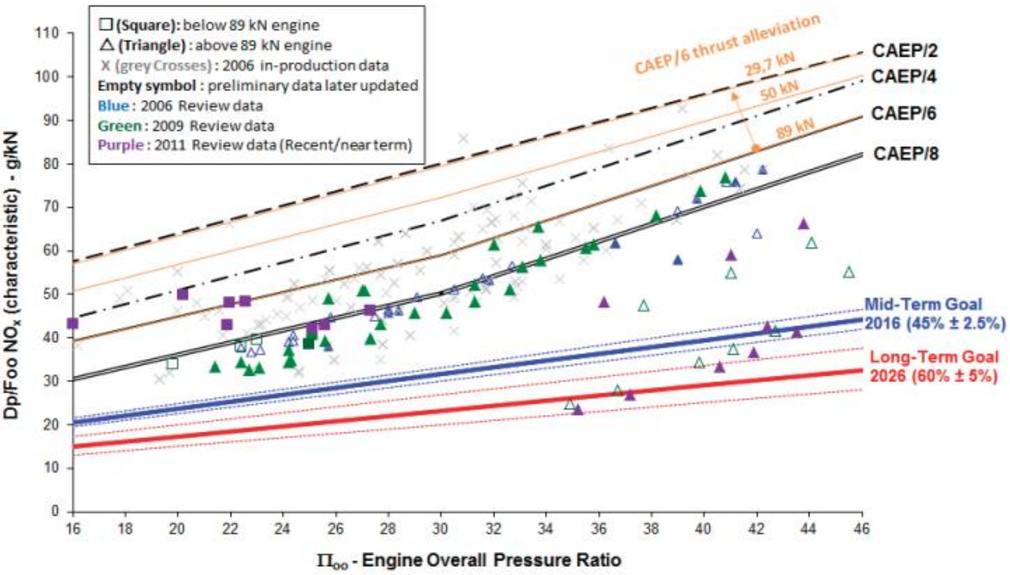

Figure 46: Maximum NO_x aircraft emissions [105]

6.3 ICAO Assembly Resolutions in Force (as of 4th October 2013)

The ICAO Assembly is the highest organ of the organization and usually meets only once in three years. The document sums up all ICAO Assembly resolutions from its 38th session and contains the most up-to-date information related to the SST officially released by the ICAO. The Appendix G of the document states:

“Whereas since the introduction of supersonic aircraft in commercial service action has been taken to avoid creating unacceptable situations for the public due to sonic boom, such as interference with sleep and injurious effects to persons and property on land and at sea caused by the magnification of the sonic boom;” [103]

Since the aforementioned Annex 16, Vol. I has established no real noise requirements for the future SST, the assembly resolution offers at least a hint of the possible noise limit for it. The quoted paragraph indirectly says that the approval of the SST transport by ICAO will be most likely conditioned at least by avoiding sleep interferences and, needless to say, any possible injuries or property damage a sonic boom effect.

This statement, though, opens the door for the SSBJ manufacturers, since first, supersonic aircraft might be allowed to fly over the land in case that the sonic boom caused by the shockwave would not be too strong on the ground, and second, the mentioned conditions would not be breached in any point over uninhabited areas, such as the oceans or deserts. Nevertheless, further discussions about the issue can be expected in the future.

6.4 FAA (Federal Aviation Administration)

Federal Aviation Administration is the national aviation authority of the United States of America, established in 1958 in Washington D.C. (originally named Federal Aviation Agency). As a part of the U.S. Department of Transportation, its main goal is to oversee and regulate all segments of the civil aviation in the U.S. territory. As an aviation authority of one of the most developed air transportation regions, the organization has a strong position in the rule-making process and its collection of regulations serves as a model for many other countries. [111]

6.4.1 14 CFR 91 – General Operating and Flight Rules

The document 14 CFR 91 contains general operating and flight rules that mostly come out from the ICAO SARPs. However, it is the right of any national civil aviation authority to make the regulations more stringent, and when it comes to operations of the SST, the rules are, at least for now, entirely prohibiting. The § 91.817 (Civil aircraft sonic boom) states:

"No person may operate a civil aircraft in the United States at a true flight Mach number greater than 1 except in compliance with conditions and limitations in an authorization to exceed Mach 1 issued to the operator under appendix B of this part." [112]

The § 91.817 also mentions the ban on flying any civil aircraft that can reach a maximum operating speed limit of M 1.0, except for emergency and test flights, the last one being the subject of the mentioned Appendix B. Two other paragraphs concerning the SST – § 91.819 (Civil supersonic airplanes that do not comply with part 36) and § 91.821 (Civil supersonic airplanes: Noise limits) – are rather complementary regulations making an exception for flying of Concordes over the USA and regulating their noise requirements (at least "Chapter 2" noise requirements needed).

6.4.2 14 CFR 36 – Noise Standards: Aircraft Type and Airworthiness Certification

An important regulation concerning aircraft noise in general is the 14 CFR 36. The subpart B of the regulation is dedicated to subsonic aircraft and the subpart D to the SST. Subpart D consists of only one paragraph – § 36.301 (Noise limits: Concorde) – making it legal to fly Concordes over the United States territory. [113]

The subpart B is divided into sections similarly as the ICAO Annex 16, Vol. I, only maximum noise limits are defined as Stages numbered from 2 to 4. While the Stage 2 and Stage 3 differ slightly from their ICAO equivalents, the Stage 4 has been completely unified with the ICAO

Chapter 4. At the moment there is no equivalent to the ICAO Chapter 14, but it may be expected to be the same again in the future.

6.4.3 14 CFR 34 – Fuel Venting and Exhaust Emission Requirements for Turbine Engine Powered Aircraft

The document 14 CFR 34 regulates engine emissions requirements for all aircraft with turbine engines. All of the contemporary requirements are the same as in the ICAO SARPs (Annex 16, Volume II). [114]

6.5 EASA (European Aviation Safety Agency)

The EASA is the European supreme aviation authority headquartered in Cologne, Germany, established in 2003 by the European Union in order to improve and unify standards related to safety in aviation across the European countries. Its sphere of activity was limited only to airworthiness of aircraft and all related parts, but in 2008 the EASA took over all responsibilities from the former Joint Aviation Authorities (JAA). These are associated mainly to air operations, air staff and a supervision of air operators from the third countries. [115]

As a part of airworthiness certification processes, the EASA has a broad collection of regulations concerning aircraft specifications requirements. Nevertheless, no regulation is nowadays directly related to the SST and all noise and engine emissions regulations, such as CS-34 (Aircraft Engine Emissions and Fuel Venting) and CS-36 (Aircraft Noise), are very similar to the American 14 CFR 34 and 14 CFR 36, and hence fully in accordance with the ICAO SARPs (ICAO Annex 16, Volume I and II).

7 Operational Aspects of the SST

The chapter is dedicated to the description of the operational aspects related solely to the SST, often resulting from the technical issues and regulations described in the two previous chapters. The thesis identifies these important aspects:

- Sonic Boom Ground Effects
- Cruise Efficiency and Range
- Use of Airspace
- Airport Specifications

In the thesis, the Aerion AS2 is considered as the representative of the SSBJ projects due to its progressed development and the expectations of being the first SSBJ to enter service in the future. Hence, the chapter is a little modified to the AS2 specifications.

7.1 Sonic Boom Ground Effects

Even though the SSBJ designers try to deal with the issue of the sonic boom in many possible ways (see also chapter 5.2), it is still quite likely that a certain (perhaps weaker) form of this thunder-like noise, will be still produced by supersonic aircraft in the near future. It is a question though, if such a reduced boom intensity would be acceptable to people on the ground. With regard to current technologies, the experience with Concordes and the ongoing trend of tightening the noise regulations, it would be better to expect only the negative answer. Consequently, the shockwaves should avoid all inhabited areas and so prevent the human annoyance by all means.

The AS2 designers are well aware of this fact (after all the aircraft is not designed to reduce the boom intensity so significantly), so the aircraft will operate, as well as some other SSBJ projects such as the Gulfstream X-54 or the Spike S-512, in three speed regimes:

- Subsonic
- “Boom-less” supersonic
- Supersonic

The first, subsonic regime is quite self-explanatory. Some countries, including the United States, strictly prohibit new civil aircraft from flying supersonic overland with almost no exceptions. The situation could be changed in the future, but at least for the first years of the supersonic aircraft’s service, the regulations will probably remain in the current, prohibiting form. For this case, the AS2 is planned to operate in the speed of M 0.95, [43] which is still a little more than the maximum speed of the fastest contemporary civil airplane, Cessna Citation X+, which can reach the speed of "only" M 0.935. [116]

The second listed regime, the "boom-less" supersonic cruise represents a new approach in the field of air operations, even though the effect of the so called "Mach cut-off" is well known for over a half of the century. Basically, an aircraft flying only slightly over the speed of sound does not have to be necessarily heard on the ground (in terms of the sonic boom). The principle of this exception works due to different speeds of sound in different altitudes (caused by temperature and density changes), so when the aircraft speed is only about M 1.15 in the altitude of 50 000 feet (in standard atmosphere), the produced shockwaves do not even reach the ground (at sea level). The shockwaves are either bent upwards or refracted on their way down to the ground in this case (shown in figure 47). The only result of such a phenomenon is a negligible evanescent wave, supposedly barely perceptible on the ground. [117] Hence, after an aviation authorities' approval, this low-supersonic regime could be once used for operations overland.

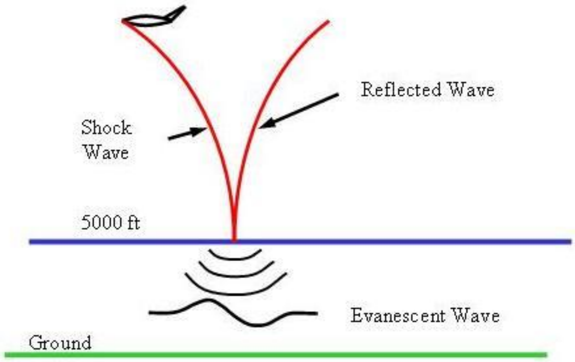

Figure 47: Shockwave reflection [118]

The "boom-less cruise" has not been commonly utilized by commercial aircraft, since the regime is very ineffective in terms of fuel consumption (see also the section 5.1 about the wave drag), so Concorde and the Tu-144 intentionally avoided operations in such speeds. In the case of business jets, though, sometimes the time is by far the most important aspect from its users' perspective, so the aircraft could save tens of minutes by flying overland in this regime.

The third and the last of the listed speed regimes – the "normal supersonic" regime – consists of all of the speeds producing shockwaves that can reach the ground (usually over M 1.15). The AS2 and a few other projects are planned to operate in the speeds of about M 1.4 and despite an expected sonic boom reduction (see figures 33 and 35 in section 5.2), the shockwaves will be probably still strong enough to annoy people on the ground. So the question is not only how strong the sonic boom will be (for this chapter the answer is “unacceptably strong”), but also how big area of the ground would be affected and how far from a land should supersonic aircraft fly, so that the shockwaves would not reach its borders.

In general, when shockwaves are produced by an aircraft to all directions, some of them hit the ground, but the rest of them is redirected back to the atmosphere due to the (aforementioned) temperature and density gradients (figure 48), so the sonic boom can be heard only in a quite clearly circumscribed area, called the sonic boom carpet. Its visualized appearance is displayed in figure 49.

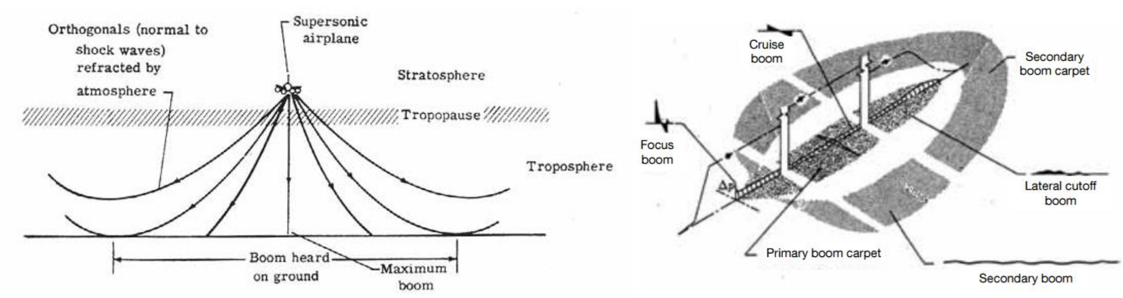

Figure 48 and 49: Lat. shockwaves propagation (left) and sonic boom carpet (right) [119] [105]

In terms of air operations, the lateral propagation of shockwaves and mainly the width of the sonic boom carpet is the main issue in this case, because it directly relates to the total boom-affected ground area. The carpet width is dependent on the atmosphere conditions and the aircraft actual altitude and speed, but the speed is an important aspect only to about M 1.3 and then it has only little influence. [81] Unlike the boom intensity, the size of the carpet is not dependent on the aircraft size, weight and shape.

7.1.1 Altitude

When solely an altitude is taken into consideration, there exists a simplified rule saying that for every 1 000 feet of height, the sonic boom carpet widens for roughly one statute mile ($1\ sm \sim 0{,}87\ nm \sim 1{,}6\ km$). [81] That means that for an aircraft flying supersonic in the altitude of 51 000 feet, which corresponds to the service ceiling of the AS2, the affected area beneath it would be roughly 51 miles wide (about 82 km).

The mentioned rule applies only to the N-shape boom, while the U-shape (focused) boom, which is usually much stronger, penetrates through the air in a different manner. Fortunately, it usually creates only a narrow strip of an amplified noise beneath the aircraft’s flown route, which is only about 100 to 200 meters wide and so remains completely hidden in the sonic boom carpet (see figure 49). [85] On the other hand, if the SSBJ manufacturers were successful in a significant N-shape boom reduction, the noise made by the U-shape shockwaves could be still an issue, preventing the aircraft from flying overland.

7.1.2 Atmosphere - Wind

An atmosphere, especially the wind and temperature conditions, is the second element having a strong influence on the sonic booms carpet.

The direction and the strength of the wind, as the first of the listed aspects, change not only the shape and the size of the sonic boom carpet, but also determine the maximum usable speed for the supersonic boom-less cruise. While the side wind has no real effect in this case (for the boom-less cruise), the tailwind of the speed of only 87 knots (about 160 km/h or 45 m/s) reduces the cut-off speed to M 1.0. The headwind, on the other hand, increases the speed of the "Mach cut-off" similarly as the tailwind decreases it. As a result, for supersonic boom-less flights the wind roughly neutralizes its usual effects on aircraft in terms of faster or slower travelling, since the faster the tailwind is, the slower the aircraft would be allowed to fly due to the cut-off limit and vice versa. The maximum boom-less speed as a function of the wind strength is shown in figure 50. [120]

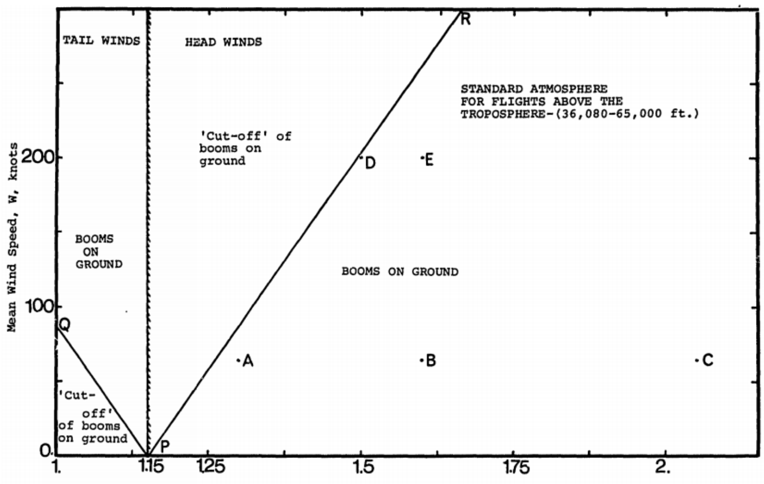

Figure 50: Winds required for "Mach cut-off" [120]

The second direct effect of the wind is related to “normal” supersonic cruises – it changes the shape and the size of the sonic boom carpet. The strips in figure 51 represent the width and the position of the affected ground area (with respect to the aircraft flight direction), which change accordingly to the aircraft speed as well as the strength of the wind. In general, as the graph shows, the tailwind widens the affected corridor, the headwind makes it narrower and the side wind only shifts the whole region to the side of the wind’s direction.

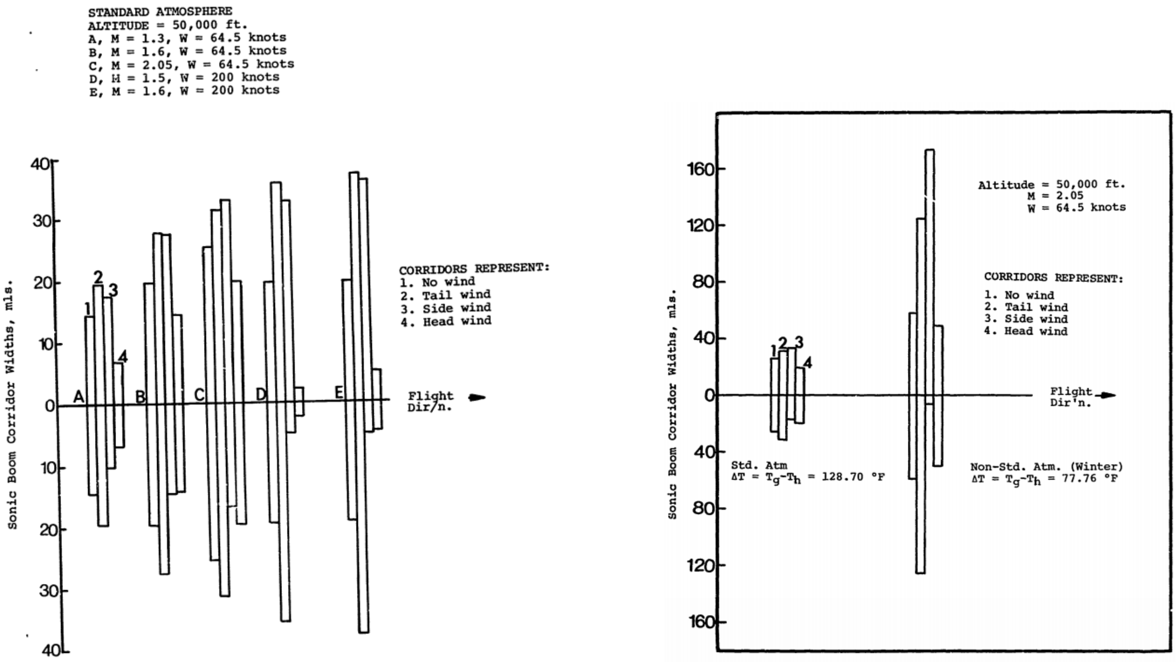

Figure 51 and 52: Effects of wind and temperature on sonic boom corridor [120]

7.1.3 Atmosphere – Air Temperature

The air temperature is an even more important aspect in terms of the size of the supersonic boom carpet. The aforementioned altitude has its boom reducing effects primarily due to a temperature gradient, making the air colder with higher altitudes. In other words, the bigger the temperature difference is (between a flown altitude and the ground), the smaller is the affected boom corridor and vice versa. Hence, cold winter conditions are “the worst” in terms of the sonic boom carpet width, making it even several times wider. Figure 52 is a result of a simulation made by Onyeonwu [120], which combines non-standard weather conditions, represented by an environment in a small Canadian town (Maniwaki, Quebec) during an average wintertime. The mean wind speed in the altitude of 50 000 feet is 64.5 knots (about 33 m/s) and the mean ground temperature (in January) is about -12 °C. The combination of such conditions, may result in the sonic boom being heard in the distance of over 160 miles (about 260 km) away from the flight path (the side wind situation). [120]

So, the related issue is not only about the existence of the sonic boom carpet, but also about its changing size, which may vary from units to hundreds of kilometres and hence cause troubles to aircraft operators in terms of flight planning. If the sonic boom will remain banned from reaching a land, it will be difficult to find the distance, where aircraft would be allowed to fly safely without any ground disturbances. Generally, three possible solutions would be:

- To set a general distance from coasts that would ensure an almost 100% probability that the sonic boom would not reach the ground in any conditions in the world. The problem is that such an established distance could be immense and it would pointlessly prevent aircraft from supersonic operations over some areas (e.g. Mediterranean Sea) or force them to fly much longer distances in the case of a land detouring.

- To regularly compute and publish weather conditions for larger regions, so that the operations could be adjusted accordingly. For example, the atmosphere conditions in Italy during summertime would be probably much kinder to the SST (in terms of the sonic boom carpet) than the weather conditions somewhere in northern Canada. This solution would lead to the higher operational effectivity, but some kind of a special weather monitoring would be a necessity.

- To monitor or guess the actual weather conditions exclusively for each flights' "critical points" (aircraft leaving, approaching to or passing by a land) and adjust the flights correspondingly. This option would be probably the most flexible and time-effective one, but the calculations and forecasts for each separate flight could be overly complex.

All of these solutions could serve well to its primary purpose – to prevent sonic booms from reaching the ground – but the real costs and benefits of each of them should be considered in the first place, with respect to the ultimate volume of the supersonic traffic.

7.2 Cruise Efficiency and Range

The cruise efficiency and (more importantly) the associated aircraft range, will be crucial operational aspects for the future SSBJs. Due to a wave drag (described in chapter 5.1), it can be expected that flying supersonic would remain relatively costly in terms of fuel consumption, which would result in a reduction of the operational range of aircraft. Even though the SSBJ designers have not released the detailed specifications about their projects' fuel consumptions yet, the already announced operating ranges, being usually between 4 000 to 5 000 nautical miles, only confirm the previous assumption.

If we wanted to make a supersonic cruise more fuel efficient and thus to extend the SST operational range, there are three main segments that can be improved. These are [121]:

- Aerodynamic efficiency
- Propulsion efficiency
- Weight of an aircraft

All of them can be written down into one simple equation (Breguet range equation for jets), resulting in aircraft operational range [121]:

$$R = \frac{V}{SFC}\frac{L}{D}\ln\left(\frac{W_i}{W_f}\right) \qquad \text{[Equation 10]}$$

Where:

V	Cruise velocity	$[m/s]$
$SFC = \frac{Fuel\,flow}{Thrust}$	Specific fuel consumption	$\left[\frac{kg/s}{N}\right]$
$\frac{L}{D} = \frac{Lift}{Drag}$	L/D ratio	[-]
W_i	Initial aircraft weight	[kg]
W_f	Final aircraft weight	[kg]
($W_i - W_f$	Fuel burned airborne	[kg])

An aerodynamic efficiency can be expressed as a lift-to-drag ratio (L/D ratio) – the coefficient representing how many times an aircraft's lift exceeds its drag. Despite an unavailability of such information about the SSBJ projects, it is at least possible to demonstrate the influence of the wave drag on Concorde, compared with other subsonic aircraft from the second half of the 20th century (see figure 53). As we can see, not only is the Concorde's L/D ratio much smaller than the other aircraft ones, but also its operating speed M 2.0 was much better in terms of the drag coefficient in a comparison to the Aerion AS2's M 1.4 (see figure 27 in the section 5.1).

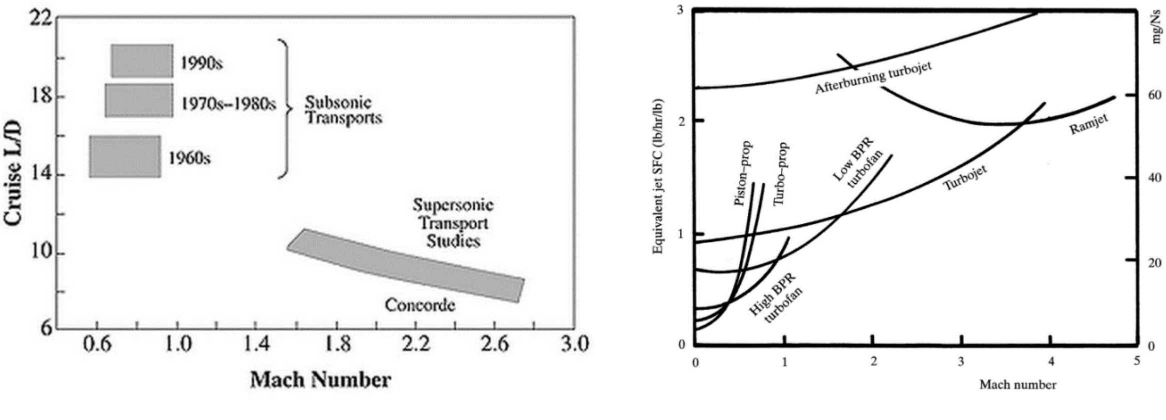

Figure 53 and 54: Cruise L/D ratio (left) and SFC for different engine types (right) [122] [121]

The second aforementioned aspect – the jet propulsion efficiency – should not represent such an issue in terms of the SSBJ's fuel consumption. Admittedly, though, the two possible types of engines for the AS2 (a low-bypass ratio turbofan and a turbojet) would be still less fuel-effective than their subsonic competitors as shown in figure 54 (the lower SFC, the better fuel efficiency).

The last aspect – the weight of the SSBJ – is going to be comparable to current subsonic business jets, making no real difference in the range computed by the Breguet equation.

As it was mentioned earlier, the most of the currently planned SSBJs is going to have their maximum operational range between only 4 000 to 5 000 nautical miles (about 7 400 to 9 300 km), primarily due to the lower supersonic cruise efficiency and also the lack of space for voluminous fuel tanks inside the aircrafts' thin supersonic wings (see attachment 2). This range is, in a comparison to their subsonic competitors that can fly to the distance of up to 7 500 nm (about 13 900 km), considerably low. According to Hans-Reichel [72], the 4 000 nm is simply a must from the potential customers' perspective, since the SSBJ would be used mostly for transoceanic flights (where the supersonic cruises worth it) and hence it should be able to at least cross the Atlantic Ocean (London – New York is about 3 000 nm) or the Pacific Ocean with a fuel stop (the longer leg Honolulu – Tokyo on the track starting from Los Angeles has about 3350 nm).

The Aerion AS2 should be able to offer the maximum operational range of 4 750 nm for supersonic and 5 300 nm for subsonic flights. The problem is that when flying to the distance between 4 750 and 7 500, the AS2 would have to make a fuel stop, while the Gulfstream G650, for example, would reach the destination in one go and the benefit of the time savings from the supersonic flight would be neutralized.

7.3 Use of Airspace

The first problem related to the use of airspace is about sonic booms and its effects on other aircraft. The sonic boom intensity discussed in the previous chapters was only about the strength of the sound experienced on the ground, but the noise level is much higher near the source of the shockwaves. The recent tests show that the pressure difference of the shockwaves near a supersonic aircraft is about 1 000 Pa, which equals to the acoustic intensity of about 151 dB. The strongest shockwave ever measured (produced by a military F-4 flying only 30 m above ground and slightly over the speed of M 1.0) was 7 000 Pa strong, which equals to 168 dB. [123]

When flying over the Atlantic Ocean, for example, the RVSM (Reduced Vertical Separation Minima) rules are applied in the North Atlantic Tracks (NAT), meaning that the minimum distance between aircraft is 1 000 or 2 000 ft (300 and 600 m), depending on the airplane's altitude. [103] When a sonic boom is taken into consideration, even 2 000 feet is very close to the source of the shockwave and the noise intensity of up to 150 dB could be experienced by an aircraft nearby. While the wave of the pressure cannot cause any damage to it, since all aircraft are commonly exposed to much stronger forces and pressures, the noise made by the shockwave could be an issue for the people inside.

An aircraft fuselage reduces the noise level from outside by about 10 dB (Airbus A321 emits 96 dB during take-offs [124], while the measured peak noise levels inside the cabin is about 85 dB). [125] When the noise intensity of 150 dB would be made by a SSBJ, it may be assumed that inside the cabin of the second aircraft flying 2 000 feet below the first one could appear a reduced sonic boom of the intensity of about 140 dB. This strength, though, is on the very edge of the human's noise tolerability and could cause an immediate hearing damage. [126]

Unfortunately, no relevant data or other research related to this issue have been found for the thesis and it is likely that they do not exist at all. It could be so, because Concorde has always flown supersonic only in specially established tracks, quite far from any other traffic, so the issue has not been solved yet. However, a further research (if there is not any) should take place before the SSBJs entry service in order to avoid the aforementioned problems and to prevent hearing injuries.

Another issue is related to the speed of the SST. A supersonic aircraft could cause problems, when flying in an airway, just by the fact that it travels faster than other subsonic airplanes. With respect to the volume of the commercial air traffic in these days, especially between some city pairs, air routes may be sometimes so overcrowded, that fitting in a supersonic aircraft, which would fly about 50% faster and hence require some appropriate space adjustments, might be a difficult task.

Fortunately, all of the current SSBJ projects are planned to be able to operate in the altitude of over 50 000 ft (about 15 200 m), which is far above the most of the commercial civil airplanes' service ceilings. The most modern airliners, such as Airbus A350 XWB or Boeing B-787 Dreamliner, have their service ceilings around the altitude of 43 000 feet (13 100 m), so the commercial traffic in such heights would consist of only other business jets. The three possible SSBJ's competitors – the Gulfstream G650, the Dassault Falcon 7X and the Bombardier Global Express – can operate identically in 51 000 feet (15 500 m).

As a result, no real problems with an overcrowded airspace may be expected by the SSBJ future users. Furthermore, over some areas aircraft do not have to fly in airways (flying directly point-to-point is allowed), so some flexible route changes would be possible in order to avoid other traffic. Among these areas belong all oceans and seas (with a few exceptions such as the North Atlantic Tracks (NAT), established in the altitudes from FL290 to FL410) as well as some single countries such as the United States in the altitudes from FL450 and above or (newly) the whole Hungarian airspace, for instance. This should make the SSBJ operations even easier. [103]

7.4 Airport Specifications

Even though one would think that the future SSBJs would require some kind of a special treatment at airports, so far it seems that nothing like that would be ultimately needed. The AS2 makes no exception and according to the official websites, the aircraft should have no special requirements for airport operations. [127]

The only one possible obstacle could be a longer minimum take-off distance, since the SSBJs' wings have to be operative in a large range of speeds (see also section 5.3), which makes them a little less effective at lower speed regimes. The AS2 is expected to need 7 500 feet (about 2 300 meters) for a take-off at sea level, which is slightly more than the conventional subsonic jets now require (usually about 6 000 feet).

The approaching speed of the AS2 is to be 135 knots, which is also a little more than the approaching speeds of other business jets (from about 100 to 120 knots), but this aspect should not be an issue at all.

8 Flight Durations and Time Savings Analysis

Despite all of the issues related to the SST described in the previous chapters, the SSBJ main benefit – the little time spent by traveling – seems to be an extremely valued attribute for a certain group of customers, which are willing to pay a lot of money for such a "time-saving aircraft". But the main question is how much time will the SSBJ actually save and the answer will be sought in this chapter.

The goal of this section is to make a few simulations of the SSBJ route planning, primarily focused on the track alternatives and flight durations, and to compare the results with a contemporary subsonic business jet.

8.1 Aircraft Used for Simulation

It may be expected that a SSBJ would be very expensive in all aspects, maybe the most expensive business jet on market (except for specially modified airliners such as Boeing Business Jets (BBJ) etc.), so it should be compared with the most modern and developed subsonic competitors. The newest product of the Gulfstream Aerospace, the G650ER, is an appropriate option, since at first, it is a brand new aircraft (certified in October 2014) [128], and second, the Gulfstream airplanes have the history of being ranked among the best business jets on Earth in the last decades.

The category of the SSBJs will be represented (as in other chapters) by the Aerion AS2, which could be, due to the advanced progress in the aircraft development, the first business jet flying supersonic.

The basic specifications of both compared aircraft are shown in the table below:

	Gulfstream G650ER	**Aerion AS2**
Operating Speed	M 0.85	M 0.95 / 1.1 - 1.2 / 1.4
Max. Operating Speed	M 0.925	M 1.5
Max. Altitude	51 000 ft	51 000 ft
Max. Range	7 500 nm	4 750 (5 300)[11] nm
MTOW	46 992 kg	54 884 kg
PAX	8 - 18	8 - 12
Unit Cost	$66.5 mil	$120 mil

Table 11: Gulfstream G650ER and Aerion AS2 comparison [43] [107]

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[11] When flying subsonic.

In terms of the speed, the situation with the Gulfstream G650ER is quite simple, because it has just one standard operating speed – M 0.85. But the AS2 is planned, due to the regulations and restrictions related to the SST, to operate in three different speed regimes (described more in detail in chapter 7.1), so the simulation will count with these variants:

8.1.1.1 Subsonic (M 0.95)

Used in the airspace of countries with a complete ban of civil supersonic flights (exceeding Mach 1.0) with no exceptions, regardless the possibility of supersonic boom-less cruise.

8.1.1.2 Boom-less supersonic (around M 1.15)

Possible for any airspace over a land unless otherwise stated by local regulations. With regard to the complexity and the number of aspects affecting the maximum boom-less speed (see also chapter 7.1), it is unlikely that the SSBJ operators would be able to forecast all of them precisely enough (wind, temperature etc.). And due to the character of the shockwaves and their effects on the ground, a rather cautious approach from these operators might be expected. Hence, the simulation counts with the speed of only M 1.1 in order to ensure that the shockwaves do not reach the ground.

8.1.1.3 Supersonic (M 1.4)

May be used only over uninhabited areas. But since there exists no official lists or maps determining which area is and which is not inhabited, this speed regime is used only over oceans and seas in the simulation. Furthermore, the range of the sonic boom carpet made by an aircraft flying in the altitude of 50 000 feet is about 40 kilometres to all directions (without wind), but due to the carpet shape and size variability (see chapter 7.1), a sufficient space reserve between the land borders and the sonic boom carpet has to be included.

8.2 Tracks in Simulation

The simulation should primarily lead to the computation of the time savings resulting from the usage of a SSBJ when compared to a subsonic aircraft and secondarily to demonstrate that quite radical route changes avoiding the airspace over a land will be possible in order to reduce the flight time of a SSBJ even more. The simulation consists of three popular city pairs in the distance of between 3 000 and 4 000 nautical miles, each requiring a different approach in terms of speed regimes and track planning.

The tracks were planned for random weather conditions, being real in August 9, 2015. An online flight planning software *SkyVector* [129] was used for the simulations including their maps, weather forecasts, computing system and other related information. The aircraft operating altitude had to be set manually into this system, which is incapable of suggesting ideal vertical route profiles (established accordingly to the actual weather conditions such as wind, temperature, etc.), so with regard to the maximum service ceilings of both aircraft, the FL490 or the FL500 were used as operating altitudes for all of the flights. Nevertheless, the main purpose of the simulation is not to count the ultimate time spent by travelling, which is always a little different due to the changing weather or other operating aspects, but to make a comparison between a supersonic and a subsonic business jet flying in the same conditions, so the unified altitude is actually desired, even though it could be slightly disadvantageous for both aircraft in a given case.

The chosen city pairs and the simulated tracks are described below:

8.2.1 City pair A (over a land without supersonic alternatives)

Moscow (Russia, Sheremetyevo Airport – UUEE) – Beijing (China, Capital Airport – ZBAA)

See attachments from 4 to 6.

This variant is expected to be the least time-effective from the SSBJ point of view, since the whole track leads over a land with no land-avoiding alternatives for a supersonic aircraft. Since none of the overflown countries directly ban the supersonic travelling over their territory, the boom-less speed regime could be theoretically used for the whole track. However, the mountainous and inhabited terrain over a part of Mongolia (Khangai and Sayan mountains) with the highest peaks over 4 000 m above the sea level, prevents the AS2 from operating in the boom-less speed regime in this part of the track (the boom would most likely reach the ground in such heights), so the aircraft has to slow down to the speed of M 0.95 at waypoint DEKAN and safely accelerate again to the Mach 1.1 at waypoint SUDAL.

8.2.2 City pair B (over a land with a supersonic alternative)

Miami (USA, Miami International – KMIA) – Buenos Aires (Argentina, Ministro Pistarini Airport – SAEZ)

See attachments from 7 to 11.

This is the special case, where a large proportion of the direct route leads over a land, but the supersonic aircraft has a possibility to fly a different route mainly over an ocean and thus save a lot of flight time despite the fact that the alternative track is over 400 nautical miles longer.

As in all other cases, the Gulfstream's track leads along the beeline between the two cities, reducing its distance to the maximum possible extent, and flying M 0.85 for the whole time with no restrictions.

The same direct track is also simulated for the AS2 in order to make a comparison to the supersonic alternative track. The only one difference from the G650ER is the operating speed, which is M 1.1 (instead of the Gulfstream's M 0.85) for almost the whole track, except for a small part inside the United States' airspace, where all civil supersonic operations are banned. The acceleration to the boom-less supersonic speed would be allowed at waypoint URSUS.

The alternative supersonic track has an identical beginning with the direct route up to the waypoint URSUS. Then the track turns more southwards and shortly behind Cuba it accelerates to "normal" supersonic speed of M 1.4 (waypoint GABAN). In this regime it can continue up to the Isthmus of Panama, where it needs to slow down again to M 1.1 (waypoint MARMA) and then accelerate to the speed of M 1.4 close behind it (waypoint DABOR). When the aircraft passes by Ecuador and Peru, the alternative track leads quite close to the land borders, but the distance does not decrease below 40 nm (~ 74 km), which is about 34 kilometers more than the sonic boom can reach in normal weather conditions. A moderate north-west wind reduces this reserve a little, but an unusually high temperature differences between the ground in August 9, 2015 (20 – 30 °C) [132] and the altitude of the SSBJ at the same time (waypoints ITATA, MIBAR, ATIPU, ATENO, DOLGA) of about 100°C holds the sonic boom carpet still sufficiently far from the land. Then, when the aircraft approaches the shores again, it needs to slow down to the subsonic regime (waypoint NUXUP), because the Andes with its peaks of over 4 000 meters have to be overflown (the same situation as with Mongolian mountains in the previous city pair), behind which it can accelerate again to M 1.1 (waypoint JUA) and continue to Buenos Aires.

8.2.3 City pair C (over an ocean)

London (UK, London Luton Airport – EGGW) – New York (USA, Newark Liberty International – KEWR)

See attachments from 12 to 15.

The third simulated track is expected to be the most time-effective for the SSBJ, since it mostly leads over an ocean, where supersonic flights are not restricted at all. The track for the AS2 is only slightly different from the subsonic one as for remaining in the supersonic regime as long as possible, but the tracks are basically parallel and very similar to each other.

As it was mentioned in section 7.3, the airspace between Europe and North America is characterized by a very dense traffic, so the aircraft flow has to be regulated by the North Atlantic Tracks (NAT), being regularly established between FL290 and FL410 (shown in attachment 12 – green lines are westbound tracks, blue lines are eastbound tracks – in August 9, 2015). Fortunately, both aircraft (the G650ER and the AS2) are planned to fly in the altitude of 50 000 feet, which is 9 000 feet over the highest NAT, hence completely avoiding most of other traffic.

Nonetheless, it is still not sure, if the sonic boom would have any influence on other traffic (aircraft in the NAT in this case). If yes, a complex cooperation between the SSBJ and the ATC would be required, so that the supersonic aircraft would must not ever appear in a close vicinity of other aircraft, or the SSBJ route would have to be completely changed.

The (almost) only one AS2 speed regime in this route is the “normal supersonic”, accelerating from the speed M 1.1 behind the United Kingdom’s borders (waypoint 5110N) and slowing down again near the United States’ airspace to the speed of M 0.95 (waypoint VITOL).

8.3 Time Savings Analysis

The results of the described simulations are summarized in attachment 3:

The primary purpose of this simulation was to show the time savings resulting from the usage of a SSBJ. The results, which can be found in the two last columns in the attachment 3 show that on tracks of the length between 3 000 and 4 000 nm, the absolute time reductions would be between one to two and a half hours, depending mainly on the overflown area and the route chosen by supersonic aircraft operators. This corresponds to approximately 15 - 35 % of the total flight time saved stemming from SSBJ flights, in this case represented by the Aerion AS2.

The secondary goal of the simulation was to demonstrate that for the future SSBJs, some track alternatives can be even more time-efficient, despite an extra length that needs to be flown. Quite surprisingly, though, the alternative track chosen for the City pair B did not result in such a significant time reduction, when compared to the direct supersonic track (12 minutes only). Hence, operators of the SSBJ would have to decide, whether it worth it to fly over 400 extra miles in order to save just a few minutes of the flight time. Except for some really urgent flights (emergency, etc.) the fuel consumption of the AS2 (which is still unknown for individual speed regimes), could be the main determining factor in this case.

Conclusion

The thesis had three main objectives. The first one was to make an inquiry about the current supersonic aircraft projects and to summarize and compare their basic specifications. The second objective was to analyse current conditions and issues for a SSBJ hypothetical entry service at present including technological, operational and legislative aspects. With regard to the importance of travel time reductions in terms of future SSBJ success, a time savings analysis consisting of several route simulations and a travel time comparison between a subsonic and a supersonic business jet was the thesis last goal.

The thesis discusses eleven different SSBJ projects unveiled or being considered as viable (at least for some time) since the year 2000. Despite a huge amount of optimistic information about the inevitable future of supersonic travelling regularly released by media, only five projects are still theoretically in progress: Aerion AS2, Gulfstream X-54, Spike S-512, HyperMach SonicStar and SAI QSST-X. Their specifications (those available) are compared in attachment 2. It can be seen that an average SSBJ project has the operating speed about M 1.4 – 1.8, the service ceiling over 50 000 feet and the maximum range between 4 000 and 5 500 nautical miles. The price for a SSBJ has been changing rapidly in the last years, but from the most actual data it seems very likely that $100 million will be exceeded, which is almost twice the price of the most modern and luxurious subsonic business jets at present. The first test flights could theoretically take place from the year of 2018, but when the history of postponements of all SSBJ projects is considered, this date is not likely to be definitive.

The SST operational and technical aspects and issues identified by the thesis are described in detail in chapters 5 and 7. Among the most significant issues that the SSBJ designers have to face belong: the sonic boom and its effects on ground, the wave drag and the wide range of operating speeds leading to a problematic engine and wing selection, the cruise efficiency and the associated limited operating range, the aircraft surface heating and the usage of materials for supersonic speeds. Possible solutions and new approaches to most of these issues have been described in the two chapters, but the key to success will depend not only on overcoming the issues, but also on finding a way how to maintain the aircraft affordable and financially attractive for its potential users.

In chapter 6, which is dedicated to the legislation related to the SST, the regulations of three most influential civil aviation authorities – ICAO, FAA and EASA – are thoroughly discussed. It has been found out that these regulations are mostly obsolete or meaningless in these days, because they have not been necessary since the last flight of Concorde. However, further changes in all of these regulations may be expected in the near future, since several hints from eclectic sources can be observed. Additionally, the CAEP (an ICAO sub-organization oriented to environment protection, which also prepares the groundwork for future SARPs) has been newly working on the SST issues from the legislative point of view. Nevertheless, it can be assumed that the current regulations for subsonic aircraft will most likely serve as a guideline for the future SST regulations, so the noise requirements for the Aerion AS2, which are expected to be the biggest issue for a SSBJ, have been computed and compared with other subsonic business jets in the thesis (shown in graph 4).

The last chapter is dedicated to the time savings analysis consisting of several route simulations and a travel time comparison between a subsonic and a supersonic business jet (Aerion AS2 and Gulfstream G650ER). Random weather conditions have been chosen for all simulated flights (being real in August 9, 2015), though every time the same for both aircraft, and the online flight planning software SkyVector has been used for the simulations.

The analysis was primarily focused on the travel time savings resulting from the usage of a SSBJ instead of a subsonic jet. The results (shown in the attachment 3) have revealed that the flight time reduction would be only from about 15 to 35 percent, depending on the actual track and overflown terrain. The tracks leading over a land are the least time-effective, while the tracks over oceans and seas are the fastest ones from the SSBJ perspective. Additionally, the results are applicable only to the distance of about 4 700 nautical miles or less, since the AS2 (and the most of the other SSBJ projects listed in attachment 2) are planned have a relatively short operational range. In a comparison to the Gulfstream, the time saved by a supersonic travelling would be lost on a fuel stop on tracks from 4 500 to 7 500 nautical miles long.

The secondary goal of the chapter was to demonstrate that the usage of some alternative tracks, which would not follow the beelines between certain city pairs, could be another important travel time reducing factor in the case of the SST. An alternative track has been planned for the City pair B in the simulation and even though the track was over 400 nautical miles longer, the simulated flight was about 12 minutes faster than the direct route.

The author believes that the knowledge and findings from this Bachelor’s thesis could be later used for his future works and theses.

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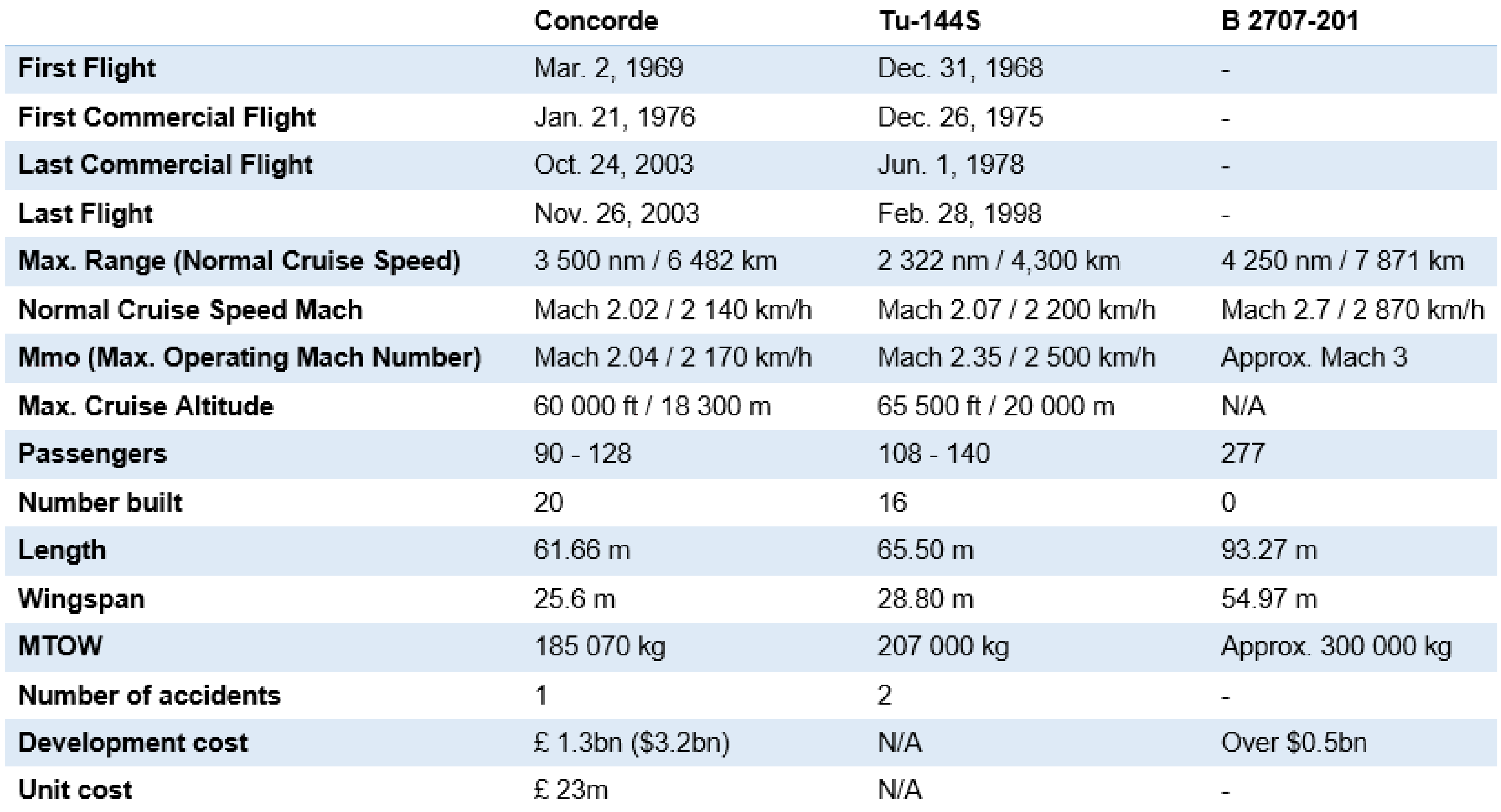
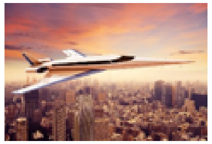
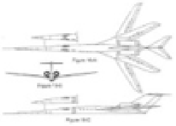
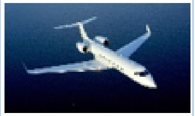
Attachments

Attachment 1: Concorde, Tu-144S and B 2707-201 Comparison [8] [14] [20]



	Concorde	Tu-144S	B 2707-201
First Flight	Mar. 2, 1969	Dec. 31, 1968	-
First Commercial Flight	Jan. 21, 1976	Dec. 26, 1975	-
Last Commercial Flight	Oct. 24, 2003	Jun. 1, 1978	-
Last Flight	Nov. 26, 2003	Feb. 28, 1998	-
Max. Range (Normal Cruise Speed)	3 500 nm / 6 482 km	2 322 nm / 4,300 km	4 250 nm / 7 871 km
Normal Cruise Speed Mach	Mach 2.02 / 2 140 km/h	Mach 2.07 / 2 200 km/h	Mach 2.7 / 2 870 km/h
Mmo (Max. Operating Mach Number)	Mach 2.04 / 2 170 km/h	Mach 2.35 / 2 500 km/h	Approx. Mach 3
Max. Cruise Altitude	60 000 ft / 18 300 m	65 500 ft / 20 000 m	N/A
Passengers	90 - 128	108 - 140	277
Number built	20	16	0
Length	61.66 m	65.50 m	93.27 m
Wingspan	25.6 m	28.80 m	54.97 m
MTOW	185 070 kg	207 000 kg	Approx. 300 000 kg
Number of accidents	1	2	-
Development cost	£ 1.3bn ($3.2bn)	N/A	Over $0.5bn
Unit cost	£ 23m	N/A	-

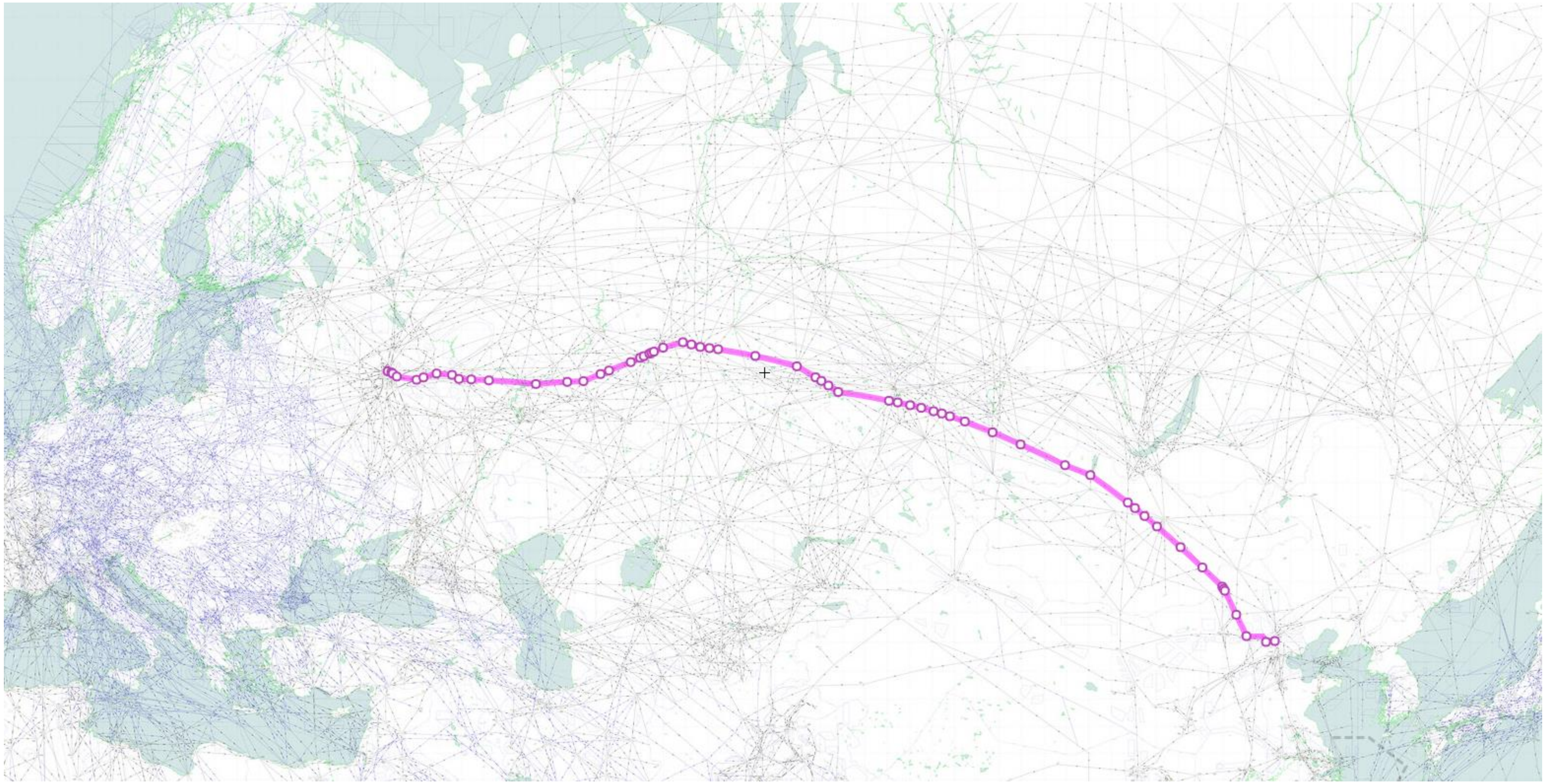
Attachment 2: Current SSBJ Projects Comparison [8] [43] [48] [55] [60] [69] [70]

	Aerion AS2	Spike S-512	Gulfstream X-54	HyperMach SonicStar	SAI QSST-X	Gulfstream G650	Concorde
							
Max. operating speed	M 1.5	M 1.8	over M 1.4	M 4.0	M 1.8	M 0.925	M 2.04
Normal cruise speed	M 1.4	M 1.6	over M 1.4	M 3.6	M 1.6	M 0.85	M 2.02
Service ceiling	51 000 ft (15 500 m)	50 000 ft (15 240 m)	50 000 ft (15 240 m)	60 000 ft (18 900 m)	60 000 ft (18 300 m)	51 000 ft (15 500 m)	60 000 ft (18 300 m)
Max. range	4 750 – 5 300 nm	4 050 – 5 580 nm	N/A	6 000 nm	4 500 nm	7 000 nm	3 500 nm
Length	52 m	40 m	N/A	69 m	N/A	30 m	62 m
Wingspan	19 m	18 m	N/A	23 m	N/A	30 m	26 m
Unit cost (target)	US $120 mil	US $60 - $80 mil	N/A	US $180 mil	N/A	US $64.5 mil	-
Passengers (Max.)	12	18	N/A	20	20 – 30	18	128
First (expected) flight tests	2019	Dec. 2018	N/A	2021	N/A	Dec. 2012	Mar. 1969
Scheduled enter to service	2021	N/A	N/A	2025	N/A	Nov. 2009	Jan. 1976

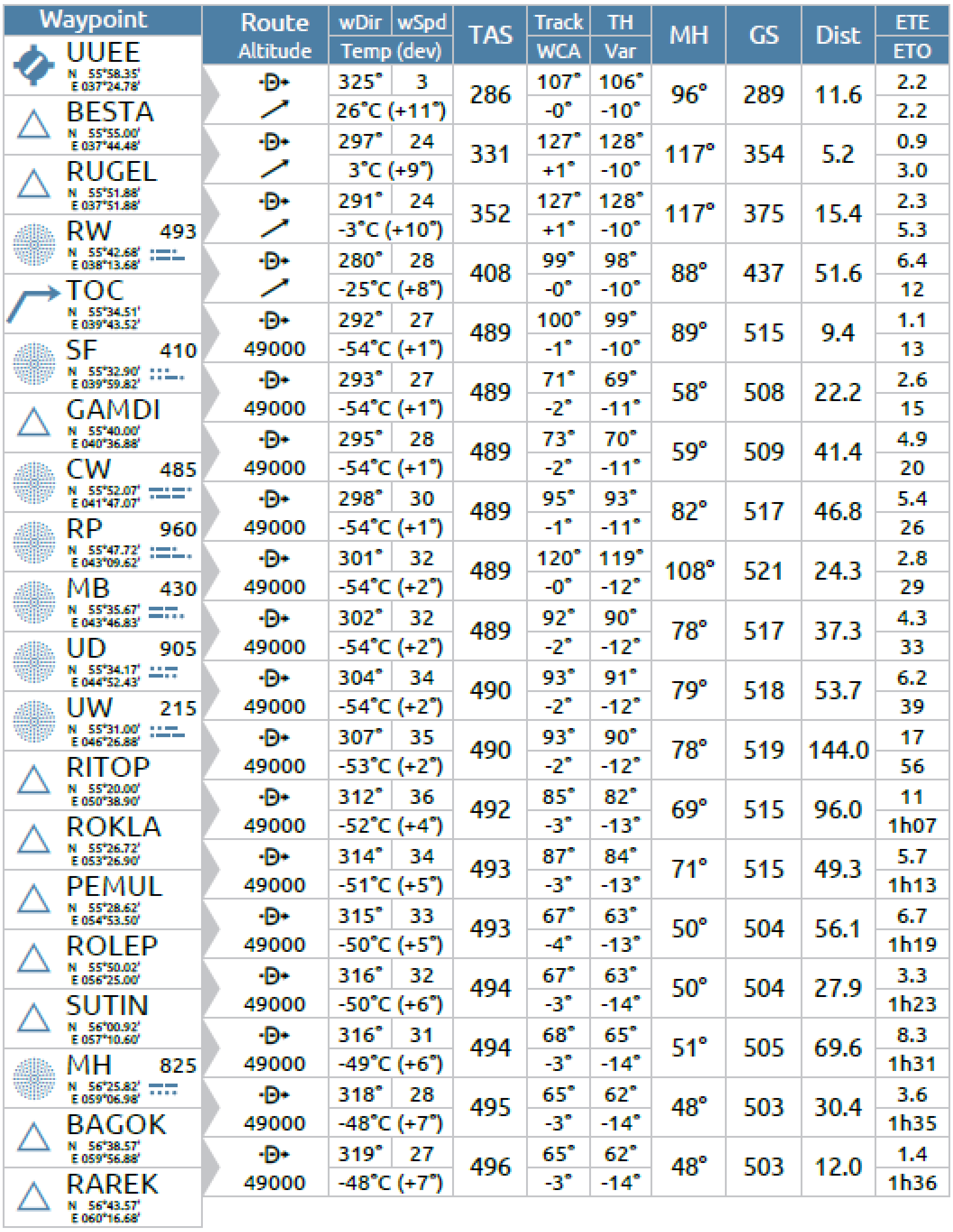
Attachment 3: Time Savings Analysis

Track	**Aircraft**		**Great Circle Distance [nm]**	**Track Distance [nm]**	**Track Distance Difference [nm]**	**Flight Time**	**Time Difference $(t_2 - t_1)$**	**Flight Time Ratio (t_2/t_1)**
City pair A *Moscow – Beijing* *(UUEE – ZBAA)*	Gulfstream G650ER		3138	3 255	0	6h 27min	*1h 11min*	*0,816*
	Aerion AS2			3 255		5h 16min		
City pair B *Miami – Buenos Aires* *(KMIA – SAEZ)*	Gulfstream G650ER		3828	3 858	413	7h 52min	*1h 39min*	*0,790*
	Aerion AS2	The same track				6h 13min		
		Alternative track		4 271		6h 01min	*1h 51min*	*0,765*
City pair C *London – New York* *(EGGW – KEWR)*	Gulfstream G650ER		3007	3 118	32	6h 49min	*2h 19min*	*0,660*
	Aerion AS2			3 150		4h 30min		

Attachment 4: Moscow – Beijing: Route Map (G650ER and AS2) [129]

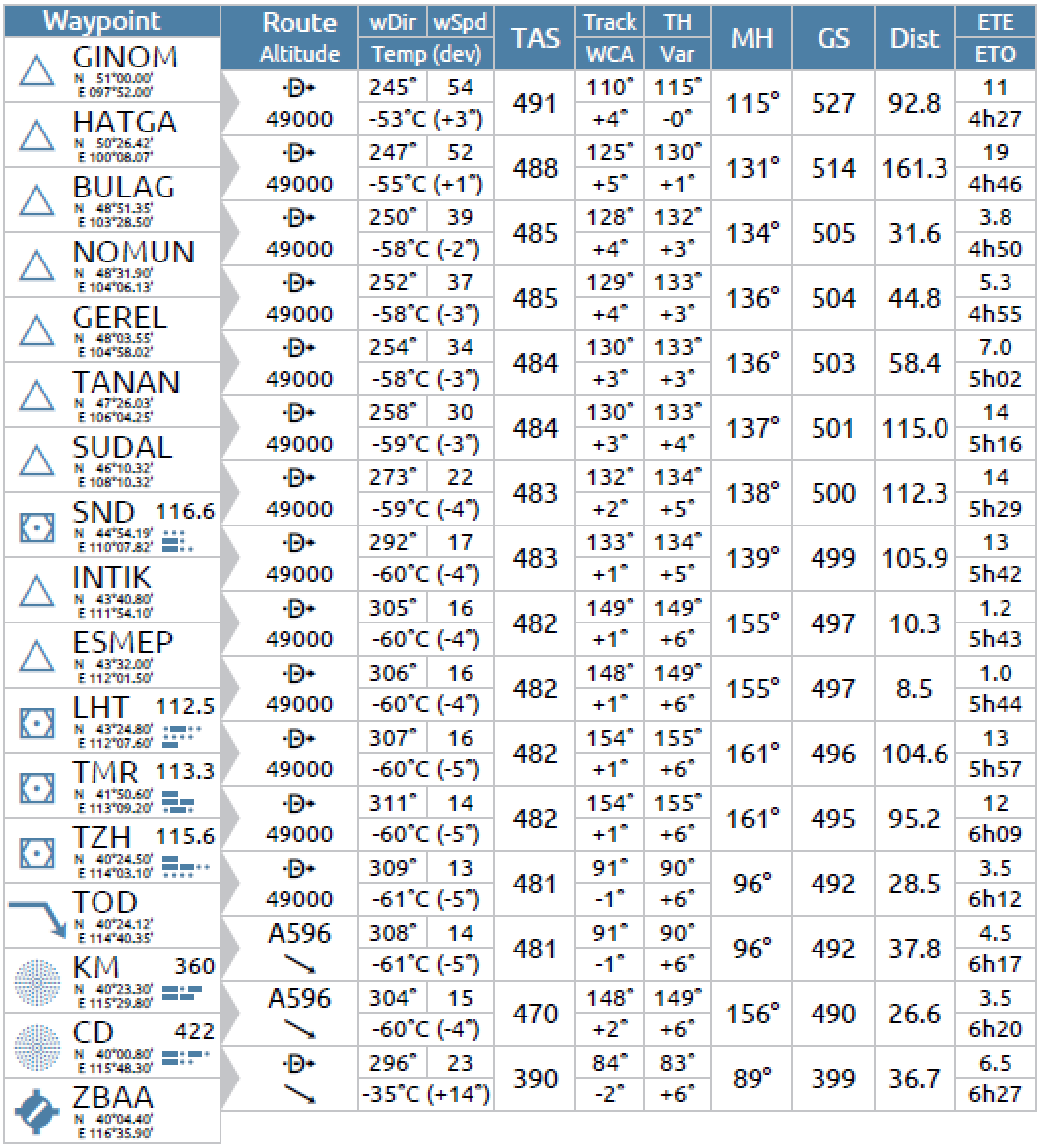


Attachment 5: Moscow – Beijing: Navigation List (G650ER) [129]



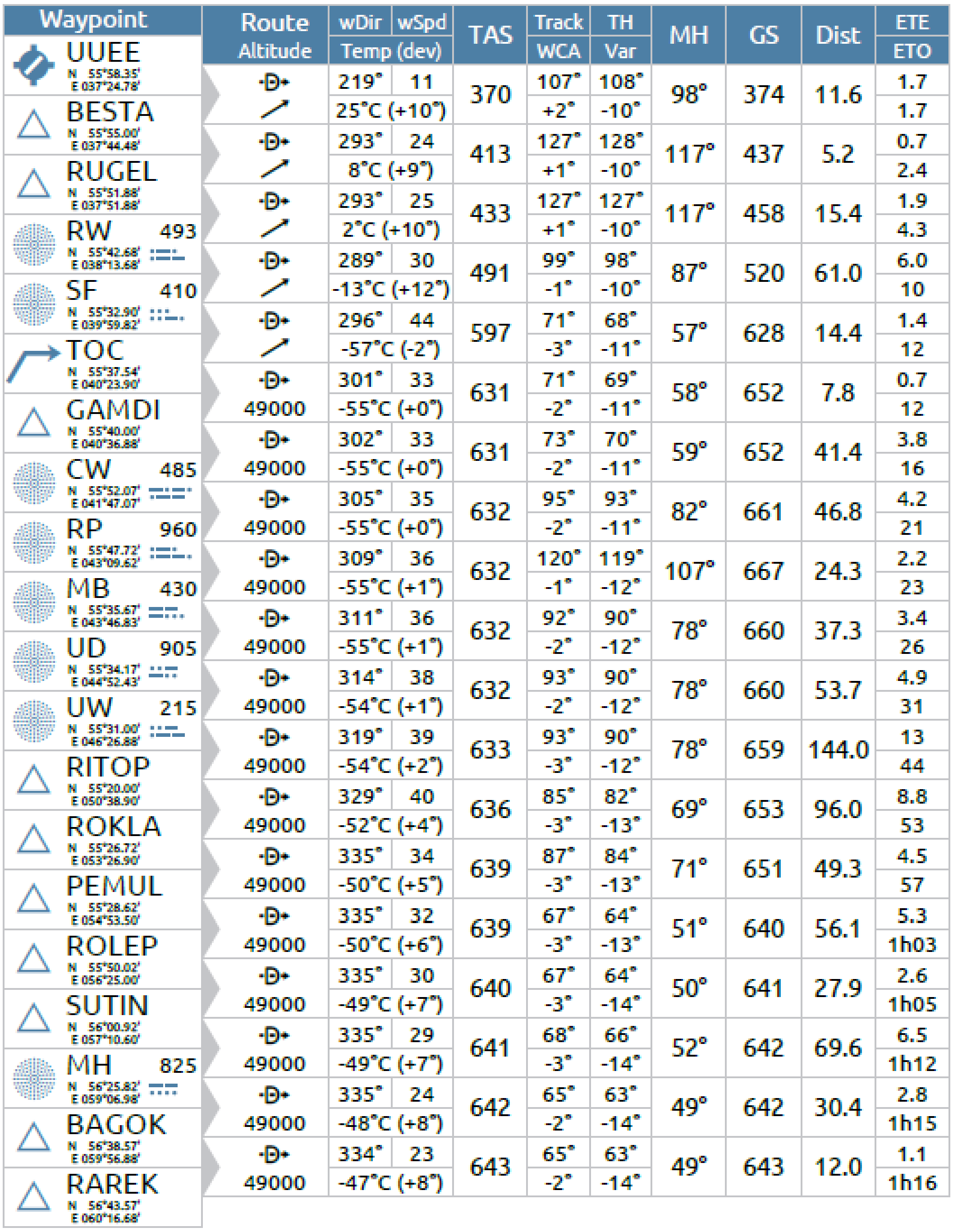
Waypoint	Route Altitude	wDir Temp (dev)	wSpd	TAS	Track WCA	TH Var	MH	GS	Dist	ETE ETO
UUEE N 55°58.35' E 037°24.78'										
	↗	325° 26°C (+11°)	3	286	107° -0°	106° -10°	96°	289	11.6	2.2 2.2
BESTA N 55°55.00' E 037°44.48'										
	↗	297° 3°C (+9°)	24	331	127° +1°	128° -10°	117°	354	5.2	0.9 3.0
RUGEL N 55°51.88' E 037°51.88'										
	↗	291° -3°C (+10°)	24	352	127° +1°	128° -10°	117°	375	15.4	2.3 5.3
RW 493 N 55°42.68' E 038°13.68'										
	↗	280° -25°C (+8°)	28	408	99° -0°	98° -10°	88°	437	51.6	6.4 12
TOC N 55°34.51' E 039°43.52'										
	49000	292° -54°C (+1°)	27	489	100° -1°	99° -10°	89°	515	9.4	1.1 13
SF 410 N 55°32.90' E 039°59.82'										
	49000	293° -54°C (+1°)	27	489	71° -2°	69° -11°	58°	508	22.2	2.6 15
GAMDI N 55°40.00' E 040°36.88'										
	49000	295° -54°C (+1°)	28	489	73° -2°	70° -11°	59°	509	41.4	4.9 20
CW 485 N 55°52.07' E 041°47.07'										
	49000	298° -54°C (+1°)	30	489	95° -1°	93° -11°	82°	517	46.8	5.4 26
RP 960 N 55°47.72' E 043°09.62'										
	49000	301° -54°C (+2°)	32	489	120° -0°	119° -12°	108°	521	24.3	2.8 29
MB 430 N 55°35.67' E 043°46.83'										
	49000	302° -54°C (+2°)	32	489	92° -2°	90° -12°	78°	517	37.3	4.3 33
UD 905 N 55°34.17' E 044°52.43'										
	49000	304° -54°C (+2°)	34	490	93° -2°	91° -12°	79°	518	53.7	6.2 39
UW 215 N 55°31.00' E 046°26.88'										
	49000	307° -53°C (+2°)	35	490	93° -2°	90° -12°	78°	519	144.0	17 56
RITOP N 55°20.00' E 050°38.90'										
	49000	312° -52°C (+4°)	36	492	85° -3°	82° -13°	69°	515	96.0	11 1h07
ROKLA N 55°26.72' E 053°26.90'										
	49000	314° -51°C (+5°)	34	493	87° -3°	84° -13°	71°	515	49.3	5.7 1h13
PEMUL N 55°28.62' E 054°53.50'										
	49000	315° -50°C (+5°)	33	493	67° -4°	63° -13°	50°	504	56.1	6.7 1h19
ROLEP N 55°50.02' E 056°25.00'										
	49000	316° -50°C (+6°)	32	494	67° -3°	63° -14°	50°	504	27.9	3.3 1h23
SUTIN N 56°00.92' E 057°10.60'										
	49000	316° -49°C (+6°)	31	494	68° -3°	65° -14°	51°	505	69.6	8.3 1h31
MH 825 N 56°25.82' E 059°06.98'										
	49000	318° -48°C (+7°)	28	495	65° -3°	62° -14°	48°	503	30.4	3.6 1h35
BAGOK N 56°38.57' E 059°56.88'										
	49000	319° -48°C (+7°)	27	496	65° -3°	62° -14°	48°	503	12.0	1.4 1h36
RAREK N 56°43.57' E 060°16.68'										

Waypoint	Route Altitude	wDir Temp (dev)	wSpd	TAS	Track WCA	TH Var	MH	GS	Dist	ETE ETO
RAREK N 56°43.57' E 060°16.68'	-D- 49000	319° -48°C (+8°)	26	496	66° -3°	63° -14°	49°	503	17.8	2.1 1h38
LEBLA N 56°50.75' E 060°46.33'	-D- 49000	319° -48°C (+8°)	25	496	66° -3°	63° -15°	49°	503	6.7	0.8 1h39
ANATU N 56°53.43' E 060°57.47'	-D- 49000	319° -48°C (+8°)	25	496	67° -3°	64° -15°	49°	503	7.5	0.9 1h40
BEGMA N 56°56.40' E 061°10.05'	-D- 49000	319° -48°C (+8°)	24	496	66° -3°	64° -15°	49°	503	29.8	3.6 1h43
SOPUS N 57°08.12' E 062°00.12'	-D- 49000	319° -47°C (+8°)	22	497	74° -2°	72° -15°	57°	506	59.4	7.0 1h50
GIBUL N 57°23.82' E 063°45.62'	-D- 49000	317° -47°C (+9°)	19	497	105° -1°	103° -15°	88°	513	25.5	3.0 1h53
GINPA N 57°17.30' E 064°31.10'	-D- 49000	315° -47°C (+9°)	18	497	105° -1°	104° -15°	89°	513	27.0	3.2 1h57
TINRI N 57°10.12' E 065°18.92'	-D- 49000	314° -47°C (+9°)	17	497	97° -1°	95° -14°	81°	511	27.0	3.2 2h00
NAPOR N 57°06.88' E 066°08.17'	-D- 49000	312° -47°C (+9°)	16	497	97° -1°	96° -14°	82°	511	25.7	3.0 2h03
LEBED N 57°03.52' E 066°54.92'	-D- 49000	311° -47°C (+9°)	15	497	99° -1°	98° -14°	84°	510	110.5	13 2h16
RUBOR N 56°44.02' E 070°13.33'	-D- 49000	294° -46°C (+9°)	12	498	102° -0°	102° -14°	88°	509	127.0	15 2h31
ML 740 N 56°13.55' E 073°55.77'	-D- 49000	271° -46°C (+9°)	11	498	120° +1°	120° -12°	108°	508	65.6	7.7 2h38
BEDNI N 55°40.33' E 075°36.27'	-D- 49000	265° -46°C (+9°)	13	498	121° +1°	122° -12°	110°	508	20.6	2.4 2h41
UTARU N 55°29.63' E 076°07.25'	-D- 49000	264° -46°C (+9°)	14	498	123° +1°	124° -11°	112°	508	25.9	3.1 2h44
OLAPA N 55°15.53' E 076°45.35'	-D- 49000	263° -46°C (+9°)	15	498	123° +1°	124° -11°	113°	509	36.1	4.2 2h48
ABESA N 54°55.63' E 077°37.65'	-D- 49000	261° -46°C (+9°)	16	498	98° +1°	98° -11°	88°	513	160.2	19 3h07
PERUG N 54°28.63' E 082°09.85'	-D- 49000	253° -46°C (+9°)	23	498	101° +1°	102° -9°	94°	518	27.5	3.2 3h10
NR 750 N 54°23.25' E 082°56.03'	-D- 49000	252° -46°C (+9°)	25	498	102° +1°	103° -8°	95°	519	40.0	4.6 3h15
LAGOP N 54°14.65' E 084°02.75'	-D- 49000	251° -46°C (+9°)	27	498	103° +2°	105° -8°	97°	520	35.9	4.1 3h19
NILAN N 54°06.43' E 085°02.17'	-D- 49000	250° -46°C (+9°)	29	498	105° +2°	106° -7°	99°	521	40.6	4.7 3h23
GIMUK N 53°55.95' E 086°08.70'	-D- 49000	249° -46°C (+9°)	31	498	105° +2°	108° -7°	101°	523	27.0	3.1 3h27
NOSPI N 53°48.63' E 086°52.67'	-D- 49000	248° -46°C (+9°)	33	498	108° +2°	111° -6°	104°	523	26.9	3.1 3h30
SURUB N 53°40.07' E 087°35.67'	-D- 49000	248° -47°C (+9°)	35	498	109° +3°	111° -6°	105°	523	50.7	5.8 3h35
DEKAN N 53°23.23' E 088°55.87'	-D- 49000	247° -47°C (+9°)	38	497	110° +3°	113° -5°	108°	524	95.8	11 3h46
TISUP N 52°48.52' E 091°23.90'	-D- 49000	246° -48°C (+8°)	43	496	112° +4°	116° -4°	112°	525	100.1	11 3h58
TR 980 N 52°09.00' E 093°54.30'	-D- 49000	245° -49°C (+6°)	48	495	113° +4°	118° -2°	115°	525	163.6	19 4h17
GINOM N 51°00.00' E 097°52.00'										



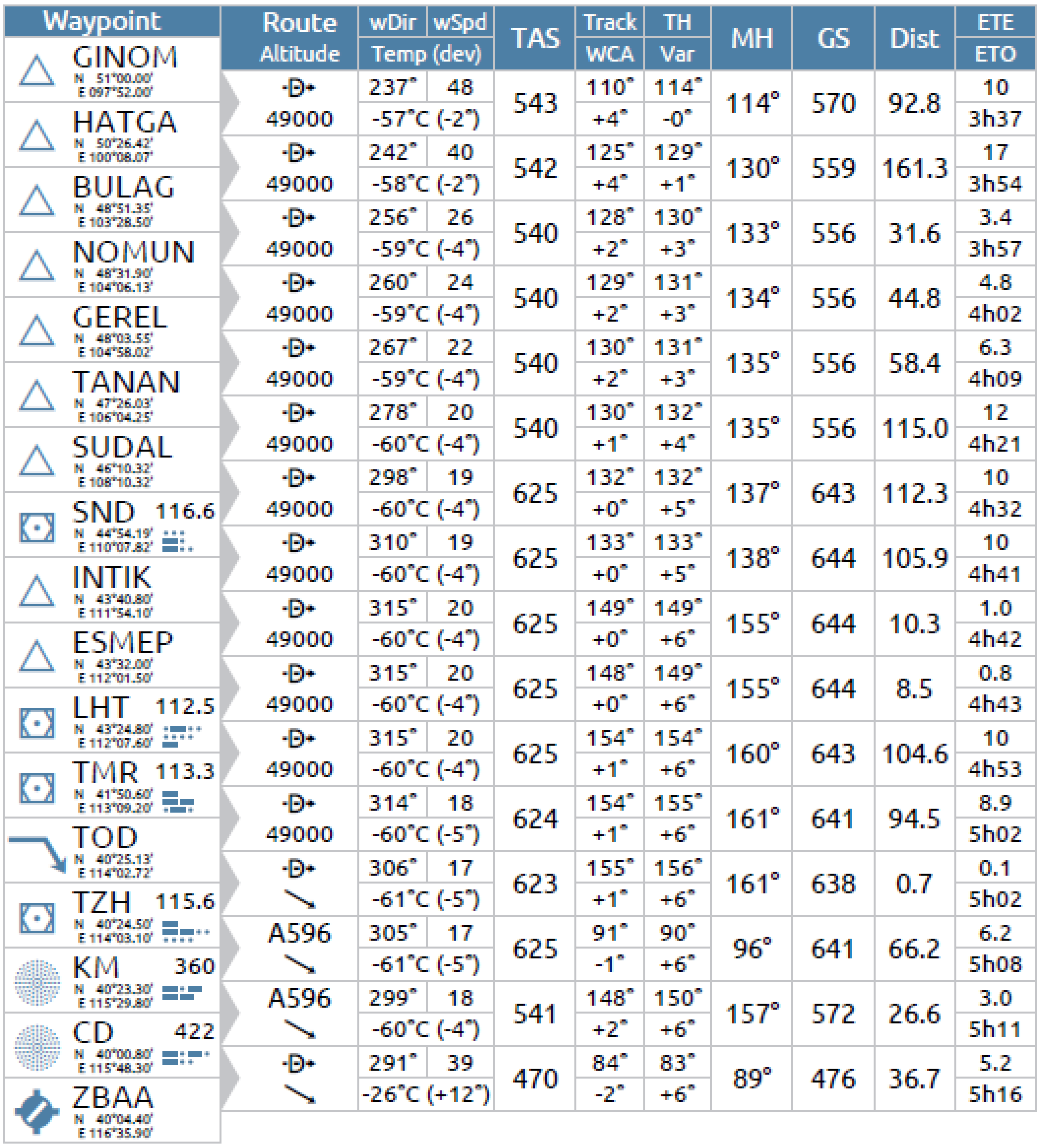
Waypoint	Route Altitude	wDir	wSpd	TAS	Track WCA	TH Var	MH	GS	Dist	ETE ETO
		Temp (dev)								
GINOM N 51°00.00' E 097°52.00'										
	49000	245° -53°C (+3°)	54	491	110° +4°	115° -0°	115°	527	92.8	11 4h27
HATGA N 50°26.42' E 100°08.07'										
	49000	247° -55°C (+1°)	52	488	125° +5°	130° +1°	131°	514	161.3	19 4h46
BULAG N 48°51.35' E 103°28.50'										
	49000	250° -58°C (-2°)	39	485	128° +4°	132° +3°	134°	505	31.6	3.8 4h50
NOMUN N 48°31.90' E 104°06.13'										
	49000	252° -58°C (-3°)	37	485	129° +4°	133° +3°	136°	504	44.8	5.3 4h55
GEREL N 48°03.55' E 104°58.02'										
	49000	254° -58°C (-3°)	34	484	130° +3°	133° +3°	136°	503	58.4	7.0 5h02
TANAN N 47°26.03' E 106°04.25'										
	49000	258° -59°C (-3°)	30	484	130° +3°	133° +4°	137°	501	115.0	14 5h16
SUDAL N 46°10.32' E 108°10.32'										
	49000	273° -59°C (-4°)	22	483	132° +2°	134° +5°	138°	500	112.3	14 5h29
SND 116.6 N 44°54.19' E 110°07.82'										
	49000	292° -60°C (-4°)	17	483	133° +1°	134° +5°	139°	499	105.9	13 5h42
INTIK N 43°40.80' E 111°54.10'										
	49000	305° -60°C (-4°)	16	482	149° +1°	149° +6°	155°	497	10.3	1.2 5h43
ESMEP N 43°32.00' E 112°01.50'										
	49000	306° -60°C (-4°)	16	482	148° +1°	149° +6°	155°	497	8.5	1.0 5h44
LHT 112.5 N 43°24.80' E 112°07.60'										
	49000	307° -60°C (-5°)	16	482	154° +1°	155° +6°	161°	496	104.6	13 5h57
TMR 113.3 N 41°50.60' E 113°09.20'										
	49000	311° -60°C (-5°)	14	482	154° +1°	155° +6°	161°	495	95.2	12 6h09
TZH 115.6 N 40°24.50' E 114°03.10'										
	49000	309° -61°C (-5°)	13	481	91° -1°	90° +6°	96°	492	28.5	3.5 6h12
TOD N 40°24.12' E 114°40.35'										
	A596	308° -61°C (-5°)	14	481	91° -1°	90° +6°	96°	492	37.8	4.5 6h17
KM 360 N 40°23.30' E 115°29.80'										
	A596	304° -60°C (-4°)	15	470	148° +2°	149° +6°	156°	490	26.6	3.5 6h20
CD 422 N 40°00.80' E 115°48.30'										
		296° -35°C (+14°)	23	390	84° -2°	83° +6°	89°	399	36.7	6.5 6h27
ZBAA N 40°04.40' E 116°35.90'										

Attachment 6: Moscow – Beijing: Navigation List (AS2) [129]



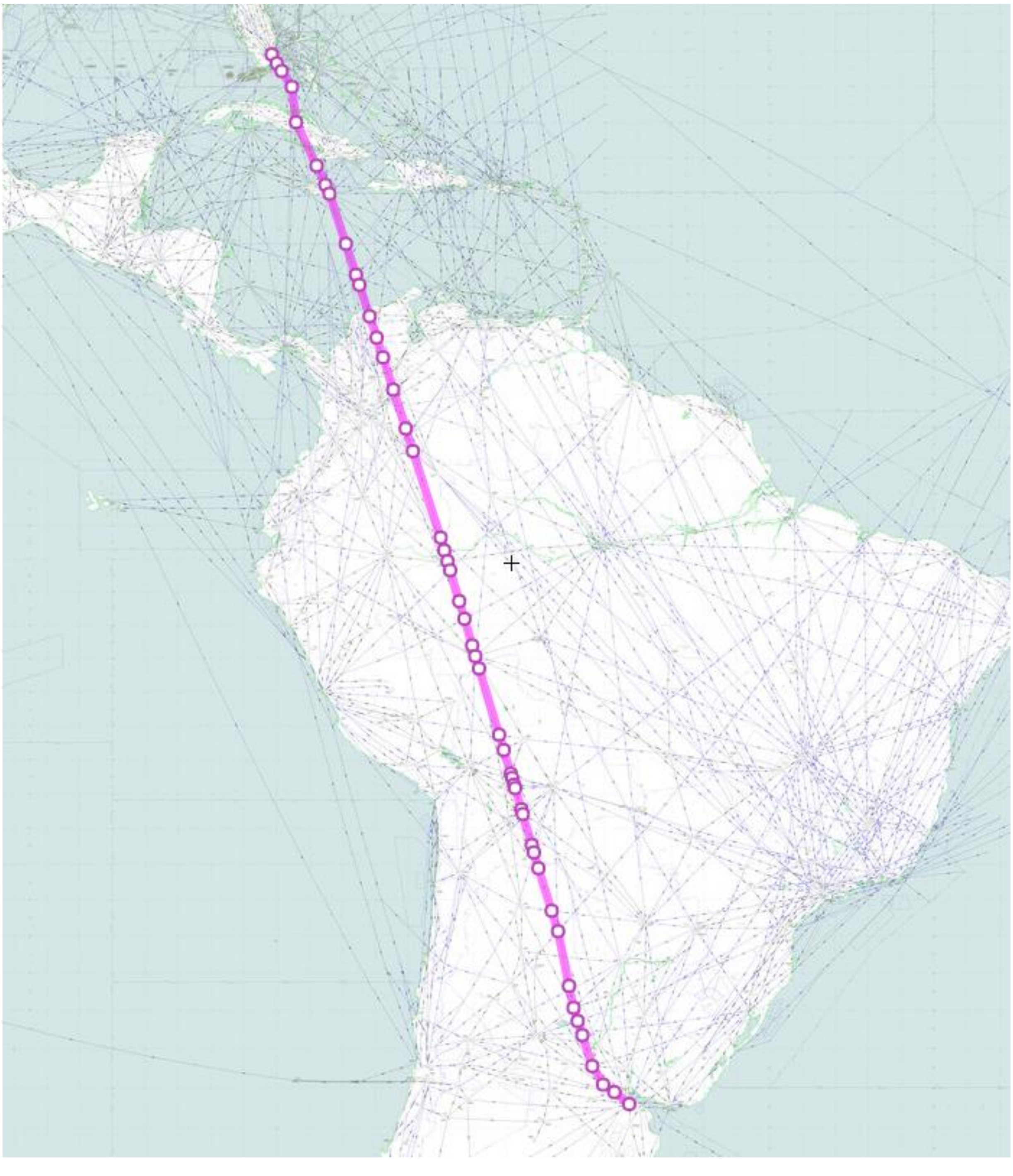
Waypoint	Route Altitude	wDir	wSpd	Temp (dev)	TAS	Track	WCA	TH	Var	MH	GS	Dist	ETE	ETO
UUEE N 55°58.35' E 037°24.78'														
	↗	219°	11	25°C (+10°)	370	107°	+2°	108°	-10°	98°	374	11.6	1.7	1.7
BESTA N 55°55.00' E 037°44.48'														
	↗	293°	24	8°C (+9°)	413	127°	+1°	128°	-10°	117°	437	5.2	0.7	2.4
RUGEL N 55°51.88' E 037°51.88'														
	↗	293°	25	2°C (+10°)	433	127°	+1°	127°	-10°	117°	458	15.4	1.9	4.3
RW 493 N 55°42.68' E 038°13.68'														
	↗	289°	30	-13°C (+12°)	491	99°	-1°	98°	-10°	87°	520	61.0	6.0	10
SF 410 N 55°32.90' E 039°59.82'														
	↗	296°	44	-57°C (-2°)	597	71°	-3°	68°	-11°	57°	628	14.4	1.4	12
TOC N 55°37.54' E 040°23.90'														
	49000	301°	33	-55°C (+0°)	631	71°	-2°	69°	-11°	58°	652	7.8	0.7	12
GAMDI N 55°40.00' E 040°36.88'														
	49000	302°	33	-55°C (+0°)	631	73°	-2°	70°	-11°	59°	652	41.4	3.8	16
CW 485 N 55°52.07' E 041°47.07'														
	49000	305°	35	-55°C (+0°)	632	95°	-2°	93°	-11°	82°	661	46.8	4.2	21
RP 960 N 55°47.72' E 043°09.62'														
	49000	309°	36	-55°C (+1°)	632	120°	-1°	119°	-12°	107°	667	24.3	2.2	23
MB 430 N 55°35.67' E 043°46.83'														
	49000	311°	36	-55°C (+1°)	632	92°	-2°	90°	-12°	78°	660	37.3	3.4	26
UD 905 N 55°34.17' E 044°52.43'														
	49000	314°	38	-54°C (+1°)	632	93°	-2°	90°	-12°	78°	660	53.7	4.9	31
UW 215 N 55°31.00' E 046°26.88'														
	49000	319°	39	-54°C (+2°)	633	93°	-3°	90°	-12°	78°	659	144.0	13	44
RITOP N 55°20.00' E 050°38.90'														
	49000	329°	40	-52°C (+4°)	636	85°	-3°	82°	-13°	69°	653	96.0	8.8	53
ROKLA N 55°26.72' E 053°26.90'														
	49000	335°	34	-50°C (+5°)	639	87°	-3°	84°	-13°	71°	651	49.3	4.5	57
PEMUL N 55°28.62' E 054°53.50'														
	49000	335°	32	-50°C (+6°)	639	67°	-3°	64°	-13°	51°	640	56.1	5.3	1h03
ROLEP N 55°50.02' E 056°25.00'														
	49000	335°	30	-49°C (+7°)	640	67°	-3°	64°	-14°	50°	641	27.9	2.6	1h05
SUTIN N 56°00.92' E 057°10.60'														
	49000	335°	29	-49°C (+7°)	641	68°	-3°	66°	-14°	52°	642	69.6	6.5	1h12
MH 825 N 56°25.82' E 059°06.98'														
	49000	335°	24	-48°C (+8°)	642	65°	-2°	63°	-14°	49°	642	30.4	2.8	1h15
BAGOK N 56°38.57' E 059°56.88'														
	49000	334°	23	-47°C (+8°)	643	65°	-2°	63°	-14°	49°	643	12.0	1.1	1h16
RAREK N 56°43.57' E 060°16.68'														

Waypoint	Route	Altitude	wDir	wSpd	Temp (dev)	TAS	Track	WCA	TH	Var	MH	GS	Dist	ETE	ETO
△ RAREK N 56°43.57' E 060°16.68'	-D→	49000	334°	22	-47°C (+8°)	643	66°	-2°	64°	-14°	50°	643	17.8	1.7	1h17
△ LEBLA N 56°50.75' E 060°46.33'	-D→	49000	334°	21	-47°C (+8°)	643	66°	-2°	64°	-15°	50°	643	6.7	0.6	1h18
△ ANATU N 56°53.43' E 060°57.47'	-D→	49000	334°	20	-47°C (+8°)	643	67°	-2°	65°	-15°	50°	644	7.5	0.7	1h19
△ BEGMA N 56°56.40' E 061°10.05'	-D→	49000	334°	20	-47°C (+8°)	643	66°	-2°	65°	-15°	50°	644	29.8	2.8	1h22
△ SOPUS N 57°08.12' E 062°00.12'	-D→	49000	333°	18	-47°C (+9°)	643	74°	-2°	72°	-15°	58°	647	59.4	5.5	1h27
△ GIBUL N 57°23.82' E 063°45.62'	-D→	49000	331°	15	-46°C (+9°)	644	105°	-1°	104°	-15°	89°	654	25.5	2.3	1h29
△ GINPA N 57°17.30' E 064°31.10'	-D→	49000	329°	13	-46°C (+9°)	644	105°	-1°	104°	-15°	90°	654	27.0	2.5	1h32
△ TINRI N 57°10.12' E 065°18.92'	-D→	49000	327°	12	-46°C (+9°)	644	97°	-1°	96°	-14°	81°	652	27.0	2.5	1h34
△ NAPOR N 57°06.88' E 066°08.17'	-D→	49000	324°	11	-46°C (+10°)	645	97°	-1°	96°	-14°	82°	652	25.7	2.4	1h37
△ LEBED N 57°03.52' E 066°54.92'	-D→	49000	322°	10	-46°C (+10°)	645	99°	-1°	98°	-14°	84°	652	110.5	10	1h47
△ RUBOR N 56°44.02' E 070°13.33'	-D→	49000	311°	9	-45°C (+11°)	646	102°	-0°	102°	-14°	88°	654	127.0	12	1h59
◎ ML 740 N 56°13.55' E 073°55.77'	-D→	49000	272°	9	-44°C (+11°)	647	120°	+0°	120°	-12°	108°	655	65.6	6.0	2h05
△ BEDNI N 55°40.33' E 075°36.27'	-D→	49000	258°	12	-44°C (+12°)	648	121°	+1°	122°	-12°	110°	656	20.6	1.9	2h06
△ UTARU N 55°29.63' E 076°07.25'	-D→	49000	255°	14	-44°C (+12°)	648	123°	+1°	124°	-11°	112°	657	25.9	2.4	2h09
△ OLAPA N 55°15.53' E 076°45.35'	-D→	49000	252°	15	-44°C (+12°)	647	123°	+1°	124°	-11°	113°	657	36.1	3.3	2h12
△ ABESA N 54°55.63' E 077°37.65'	-D→	49000	249°	18	-44°C (+11°)	647	98°	+1°	99°	-11°	88°	663	160.2	14	2h27
△ PERUG N 54°28.63' E 082°09.85'	-D→	49000	238°	25	-45°C (+11°)	647	101°	+2°	103°	-9°	94°	665	27.5	2.5	2h29
◎ NR 750 N 54°23.25' E 082°56.03'	-D→	49000	236°	27	-45°C (+11°)	646	102°	+2°	104°	-8°	95°	665	40.0	3.6	2h33
△ LAGOP N 54°14.65' E 084°02.75'	-D→	49000	233°	29	-45°C (+10°)	646	103°	+2°	105°	-8°	97°	664	35.9	3.2	2h36
△ NILAN N 54°06.43' E 085°02.17'	-D→	49000	231°	31	-45°C (+10°)	645	105°	+2°	107°	-7°	99°	664	40.6	3.7	2h40
△ GIMUK N 53°55.95' E 086°08.70'	-D→	49000	230°	34	-46°C (+9°)	645	105°	+2°	108°	-7°	101°	663	27.0	2.4	2h42
△ NOSPI N 53°48.63' E 086°52.67'	-D→	49000	229°	35	-46°C (+9°)	644	108°	+3°	111°	-6°	105°	661	26.9	2.4	2h44
△ SURUB N 53°40.07' E 087°35.67'	-D→	49000	229°	37	-47°C (+9°)	643	109°	+3°	112°	-6°	106°	661	50.7	4.6	2h49
△ DEKAN N 53°23.23' E 088°55.87'	-D→	49000	230°	40	-48°C (+8°)	554	110°	+4°	114°	-5°	109°	573	95.8	10	2h59
△ TISUP N 52°48.52' E 091°23.90'	-D→	49000	230°	43	-50°C (+6°)	552	112°	+4°	116°	-4°	112°	571	100.1	11	3h10
◎ TR 980 N 52°09.00' E 093°54.30'	-D→	49000	231°	47	-52°C (+3°)	549	113°	+4°	118°	-2°	115°	569	163.6	17	3h27
△ GINOM N 51°00.00' E 097°52.00'															

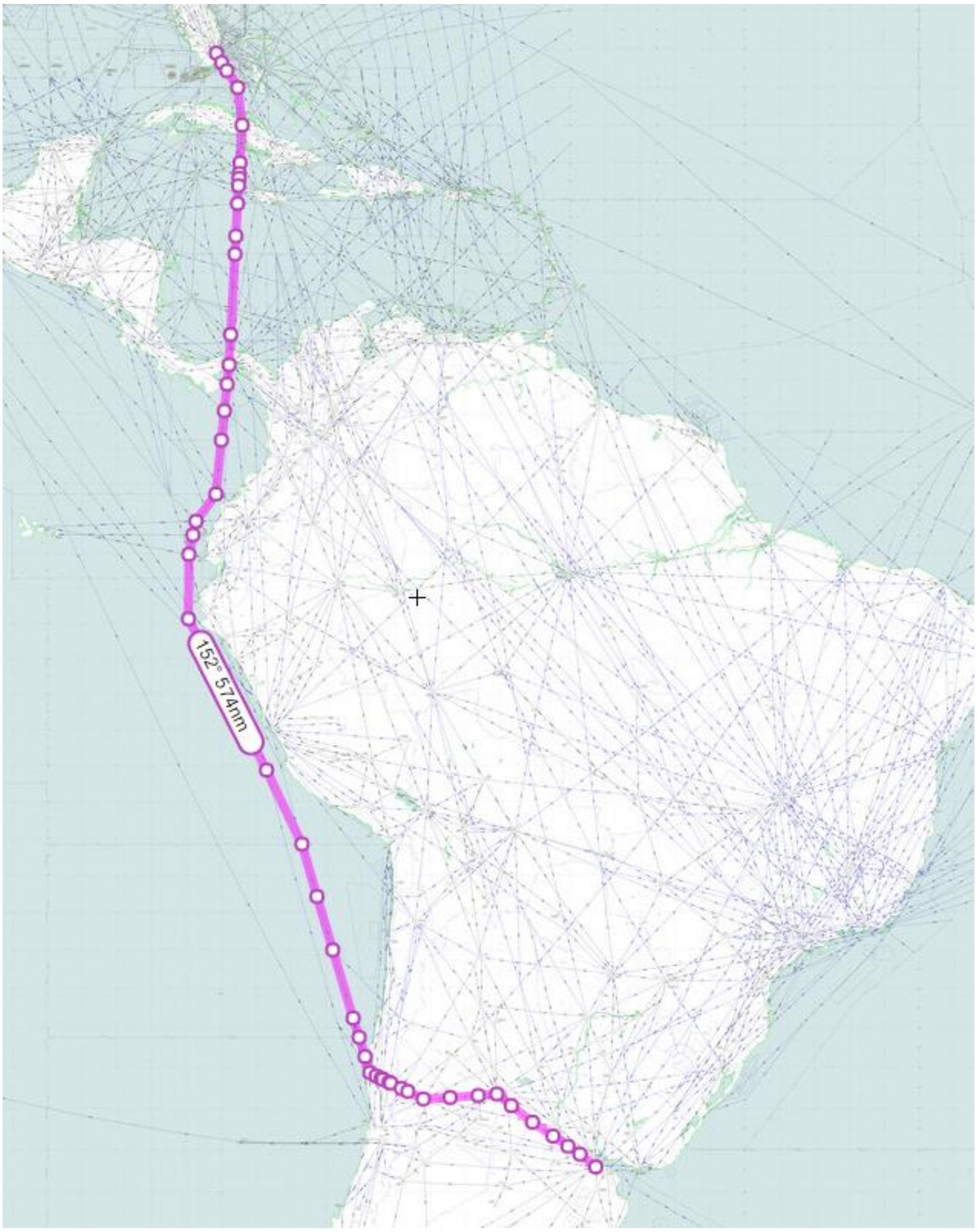


Waypoint	Route Altitude	wDir Temp (dev)	wSpd	TAS	Track WCA	TH Var	MH	GS	Dist	ETE ETO
GINOM N 51°00.00' E 097°52.00'										
	·D→ 49000	237° -57°C (-2°)	48	543	110° +4°	114° -0°	114°	570	92.8	10 3h37
HATGA N 50°26.42' E 100°08.07'										
	·D→ 49000	242° -58°C (-2°)	40	542	125° +4°	129° +1°	130°	559	161.3	17 3h54
BULAG N 48°51.35' E 103°28.50'										
	·D→ 49000	256° -59°C (-4°)	26	540	128° +2°	130° +3°	133°	556	31.6	3.4 3h57
NOMUN N 48°31.90' E 104°06.13'										
	·D→ 49000	260° -59°C (-4°)	24	540	129° +2°	131° +3°	134°	556	44.8	4.8 4h02
GEREL N 48°03.55' E 104°58.02'										
	·D→ 49000	267° -59°C (-4°)	22	540	130° +2°	131° +3°	135°	556	58.4	6.3 4h09
TANAN N 47°26.03' E 106°04.25'										
	·D→ 49000	278° -60°C (-4°)	20	540	130° +1°	132° +4°	135°	556	115.0	12 4h21
SUDAL N 46°10.32' E 108°10.32'										
	·D→ 49000	298° -60°C (-4°)	19	625	132° +0°	132° +5°	137°	643	112.3	10 4h32
SND 116.6 N 44°54.19' E 110°07.82'										
	·D→ 49000	310° -60°C (-4°)	19	625	133° +0°	133° +5°	138°	644	105.9	10 4h41
INTIK N 43°40.80' E 111°54.10'										
	·D→ 49000	315° -60°C (-4°)	20	625	149° +0°	149° +6°	155°	644	10.3	1.0 4h42
ESMEP N 43°32.00' E 112°01.50'										
	·D→ 49000	315° -60°C (-4°)	20	625	148° +0°	149° +6°	155°	644	8.5	0.8 4h43
LHT 112.5 N 43°24.80' E 112°07.60'										
	·D→ 49000	315° -60°C (-4°)	20	625	154° +1°	154° +6°	160°	643	104.6	10 4h53
TMR 113.3 N 41°50.60' E 113°09.20'										
	·D→ 49000	314° -60°C (-5°)	18	624	154° +1°	155° +6°	161°	641	94.5	8.9 5h02
TOD N 40°25.13' E 114°02.72'										
	·D→ ↘	306° -61°C (-5°)	17	623	155° +1°	156° +6°	161°	638	0.7	0.1 5h02
TZH 115.6 N 40°24.50' E 114°03.10'										
	A596 ↘	305° -61°C (-5°)	17	625	91° -1°	90° +6°	96°	641	66.2	6.2 5h08
KM 360 N 40°23.30' E 115°29.80'										
	A596 ↘	299° -60°C (-4°)	18	541	148° +2°	150° +6°	157°	572	26.6	3.0 5h11
CD 422 N 40°00.80' E 115°48.30'										
	·D→ ↘	291° -26°C (+12°)	39	470	84° -2°	83° +6°	89°	476	36.7	5.2 5h16
ZBAA N 40°04.40' E 116°35.90'										

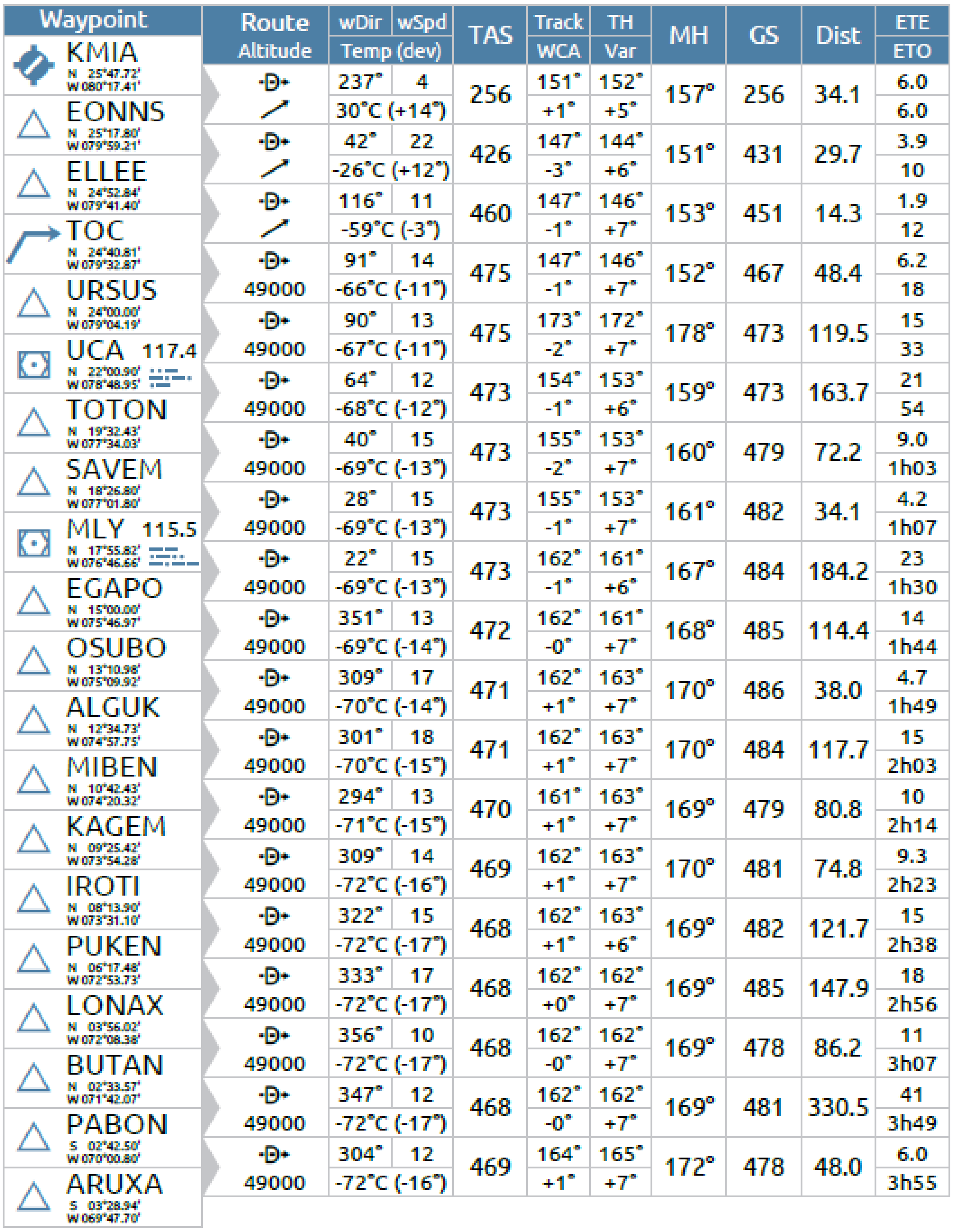
Attachment 7: Miami – Buenos Aires: Route Map (G650ER and AS2) [129]



Attachment 8: Miami – Buenos Aires: Route Map (AS2 Alternative Track) [129]

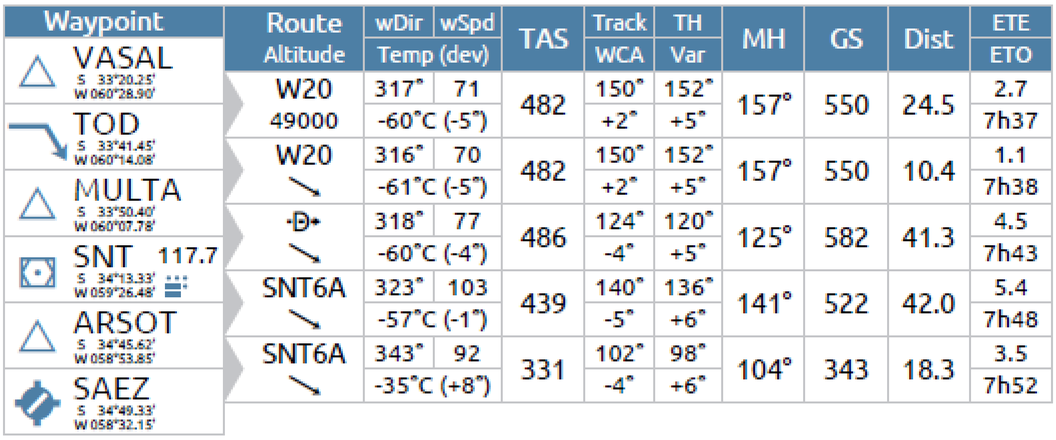


Attachment 9: Miami – Buenos Aires: Navigation List (G650ER) [129]



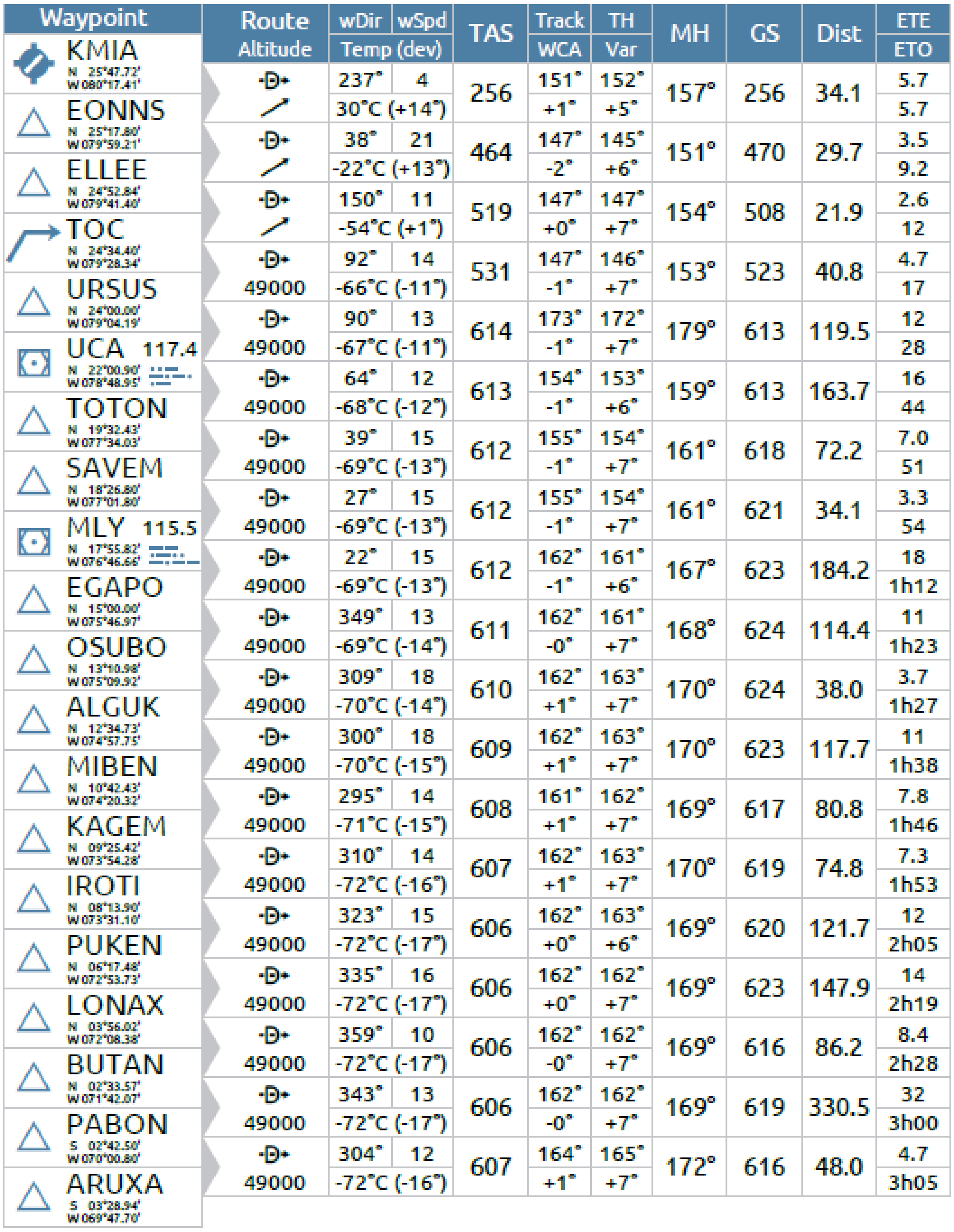
Waypoint	Route Altitude	wDir Temp (dev)	wSpd	TAS	Track WCA	TH Var	MH	GS	Dist	ETE ETO
KMIA N 25°47.72' W 080°17.41'										
	D ↗	237° 30°C (+14°)	4	256	151° +1°	152° +5°	157°	256	34.1	6.0 6.0
EONNS N 25°17.80' W 079°59.21'										
	D ↗	42° -26°C (+12°)	22	426	147° -3°	144° +6°	151°	431	29.7	3.9 10
ELLEE N 24°52.84' W 079°41.40'										
	D ↗	116° -59°C (-3°)	11	460	147° -1°	146° +7°	153°	451	14.3	1.9 12
TOC N 24°40.81' W 079°32.87'										
	D 49000	91° -66°C (-11°)	14	475	147° -1°	146° +7°	152°	467	48.4	6.2 18
URSUS N 24°00.00' W 079°04.19'										
	D 49000	90° -67°C (-11°)	13	475	173° -2°	172° +7°	178°	473	119.5	15 33
UCA 117.4 N 22°00.90' W 078°48.95'										
	D 49000	64° -68°C (-12°)	12	473	154° -1°	153° +6°	159°	473	163.7	21 54
TOTON N 19°32.43' W 077°34.03'										
	D 49000	40° -69°C (-13°)	15	473	155° -2°	153° +7°	160°	479	72.2	9.0 1h03
SAVEM N 18°26.80' W 077°01.80'										
	D 49000	28° -69°C (-13°)	15	473	155° -1°	153° +7°	161°	482	34.1	4.2 1h07
MLY 115.5 N 17°55.82' W 076°46.66'										
	D 49000	22° -69°C (-13°)	15	473	162° -1°	161° +6°	167°	484	184.2	23 1h30
EGAPO N 15°00.00' W 075°46.97'										
	D 49000	351° -69°C (-14°)	13	472	162° -0°	161° +7°	168°	485	114.4	14 1h44
OSUBO N 13°10.98' W 075°09.92'										
	D 49000	309° -70°C (-14°)	17	471	162° +1°	163° +7°	170°	486	38.0	4.7 1h49
ALGUK N 12°34.73' W 074°57.75'										
	D 49000	301° -70°C (-15°)	18	471	162° +1°	163° +7°	170°	484	117.7	15 2h03
MIBEN N 10°42.43' W 074°20.32'										
	D 49000	294° -71°C (-15°)	13	470	161° +1°	163° +7°	169°	479	80.8	10 2h14
KAGEM N 09°25.42' W 073°54.28'										
	D 49000	309° -72°C (-16°)	14	469	162° +1°	163° +7°	170°	481	74.8	9.3 2h23
IROTI N 08°13.90' W 073°31.10'										
	D 49000	322° -72°C (-17°)	15	468	162° +1°	163° +6°	169°	482	121.7	15 2h38
PUKEN N 06°17.48' W 072°53.73'										
	D 49000	333° -72°C (-17°)	17	468	162° +0°	162° +7°	169°	485	147.9	18 2h56
LONAX N 03°56.02' W 072°08.38'										
	D 49000	356° -72°C (-17°)	10	468	162° -0°	162° +7°	169°	478	86.2	11 3h07
BUTAN N 02°33.57' W 071°42.07'										
	D 49000	347° -72°C (-17°)	12	468	162° -0°	162° +7°	169°	481	330.5	41 3h49
PABON S 02°42.50' W 070°00.80'										
	D 49000	304° -72°C (-16°)	12	469	164° +1°	165° +7°	172°	478	48.0	6.0 3h55
ARUXA S 03°28.94' W 069°47.70'										

Waypoint	Route	wDir	wSpd	TAS	Track	TH	MH	GS	Dist	ETE
	Altitude	Temp (dev)			WCA	Var				ETO
△ ARUXA S 03°28.94' W 069°47.70'										
	-D→ 49000	297° -72°C (-16°)	14	469	163° +1°	164° +7°	171°	479	41.1	5.1 4h00
△ DOGLO S 04°08.39' W 069°35.66'										
	-D→ 49000	294° -72°C (-16°)	16	469	164° +1°	165° +7°	172°	479	34.3	4.3 4h04
△ TENUG S 04°41.46' W 069°25.96'										
	-D→ 49000	292° -72°C (-16°)	17	469	164° +2°	165° +8°	173°	479	116.5	15 4h19
△ PUDBU S 06°33.70' W 068°52.83'										
	-D→ 49000	291° -72°C (-16°)	21	469	164° +2°	166° +9°	174°	481	66.2	8.3 4h27
△ ARTIK S 07°37.53' W 068°33.99'										
	-D→ 49000	291° -72°C (-16°)	23	469	163° +2°	166° +7°	173°	483	99.9	12 4h39
△ ESBUK S 09°13.79' W 068°05.28'										
	-D→ 49000	293° -71°C (-16°)	26	469	164° +2°	167° +8°	174°	485	40.1	5.0 4h44
⊡ RCO 116.4 S 09°52.56' W 067°54.32'										
	-D→ 49000	294° -71°C (-16°)	27	470	163° +2°	165° +9°	174°	487	45.7	5.6 4h50
△ ISARA S 10°36.40' W 067°40.60'										
	-D→ 49000	295° -71°C (-15°)	29	470	163° +3°	166° +9°	174°	489	246.0	30 5h20
△ KADOX S 14°32.77' W 066°27.25'										
	-D→ 49000	296° -70°C (-14°)	35	471	163° +3°	166° +9°	175°	495	55.9	6.8 5h27
△ NIRBO S 15°26.53' W 066°10.52'										
	-D→ 49000	299° -69°C (-13°)	34	472	163° +3°	166° +9°	175°	496	86.8	10 5h37
△ LOKOX S 16°50.03' W 065°44.55'										
	-D→ 49000	303° -69°C (-13°)	39	472	163° +3°	166° +9°	175°	501	15.1	1.8 5h39
△ DOLGI S 17°04.53' W 065°40.03'										
	-D→ 49000	304° -69°C (-13°)	39	473	163° +3°	166° +9°	175°	502	24.3	2.9 5h42
△ VAREB S 17°27.88' W 065°32.77'										
	-D→ 49000	305° -69°C (-13°)	40	473	163° +3°	166° +9°	175°	503	12.8	1.5 5h43
△ GELAS S 17°40.20' W 065°28.93'										
	-D→ 49000	305° -68°C (-13°)	41	473	164° +3°	167° +9°	175°	504	76.0	9.0 5h52
△ VALUS S 18°53.38' W 065°06.17'										
	-D→ 49000	308° -68°C (-12°)	43	473	164° +3°	167° +9°	175°	507	17.3	2.0 5h54
△ EGUSU S 19°10.00' W 065°01.00'										
	-D→ 49000	308° -68°C (-12°)	44	473	164° +3°	167° +9°	176°	509	110.0	13 6h07
△ ASETO S 20°55.92' W 064°28.05'										
	-D→ 49000	310° -67°C (-11°)	48	475	164° +3°	167° +8°	175°	514	26.4	3.1 6h10
△ ESMUR S 21°21.38' W 064°20.12'										
	-D→ 49000	311° -67°C (-11°)	49	475	164° +3°	167° +8°	176°	515	55.1	6.4 6h17
△ PUBUM S 22°14.50' W 064°03.60'										
	-D→ 49000	312° -67°C (-11°)	53	475	163° +3°	166° +8°	174°	520	149.1	17 6h34
△ IMBER S 24°37.40' W 063°15.47'										
	-D→ 49000	317° -65°C (-10°)	54	477	163° +3°	165° +7°	173°	525	70.6	8.1 6h42
△ UBRIX S 25°44.97' W 062°52.05'										
	-D→ 49000	319° -65°C (-10°)	56	477	169° +3°	172° +7°	179°	525	181.2	21 7h03
△ MEVUR S 28°43.05' W 062°11.87'										
	-D→ 49000	321° -64°C (-8°)	67	478	168° +4°	172° +7°	179°	537	70.6	7.9 7h10
⊡ ERE 115.5 S 29°52.40' W 061°55.52'										
	-D→ 49000	321° -63°C (-7°)	70	479	162° +3°	165° +6°	171°	544	43.7	4.8 7h15
△ ROMUR S 30°34.10' W 061°40.20'										
	-D→ 49000	321° -62°C (-7°)	70	480	162° +3°	165° +7°	172°	545	46.7	5.1 7h20
△ ISOPO S 31°18.70' W 061°23.63'										
	-D→ 49000	319° -62°C (-6°)	70	481	162° +3°	165° +6°	172°	544	100.4	11 7h31
⊡ ROS 117.3 S 32°54.30' W 060°46.88'										
	W20 49000	317° -61°C (-5°)	71	482	150° +2°	152° +5°	157°	551	30.0	3.3 7h35
△ VASAL S 33°20.25' W 060°28.90'										



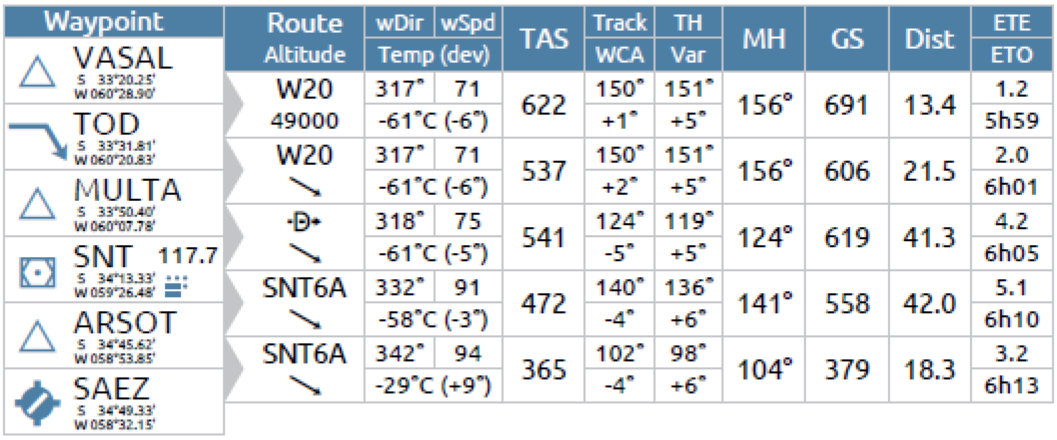
Waypoint	Route	wDir	wSpd	TAS	Track	TH	MH	GS	Dist	ETE
	Altitude	Temp (dev)			WCA	Var				ETO
VASAL S 33°20.25' W 060°28.90'										
	W20	317°	71	482	150°	152°	157°	550	24.5	2.7
	49000	-60°C (-5°)			+2°	+5°				7h37
TOD S 33°41.45' W 060°14.08'										
	W20	316°	70	482	150°	152°	157°	550	10.4	1.1
	↘	-61°C (-5°)			+2°	+5°				7h38
MULTA S 33°50.40' W 060°07.78'										
	·D·	318°	77	486	124°	120°	125°	582	41.3	4.5
	↘	-60°C (-4°)			-4°	+5°				7h43
SNT 117.7 S 34°13.33' W 059°26.48'										
	SNT6A	323°	103	439	140°	136°	141°	522	42.0	5.4
	↘	-57°C (-1°)			-5°	+6°				7h48
ARSOT S 34°45.62' W 058°53.85'										
	SNT6A	343°	92	331	102°	98°	104°	343	18.3	3.5
	↘	-35°C (+8°)			-4°	+6°				7h52
SAEZ S 34°49.33' W 058°32.15'										

Attachment 10: Miami – Buenos Aires: Navigation List (AS2 – The Same Track) [129]



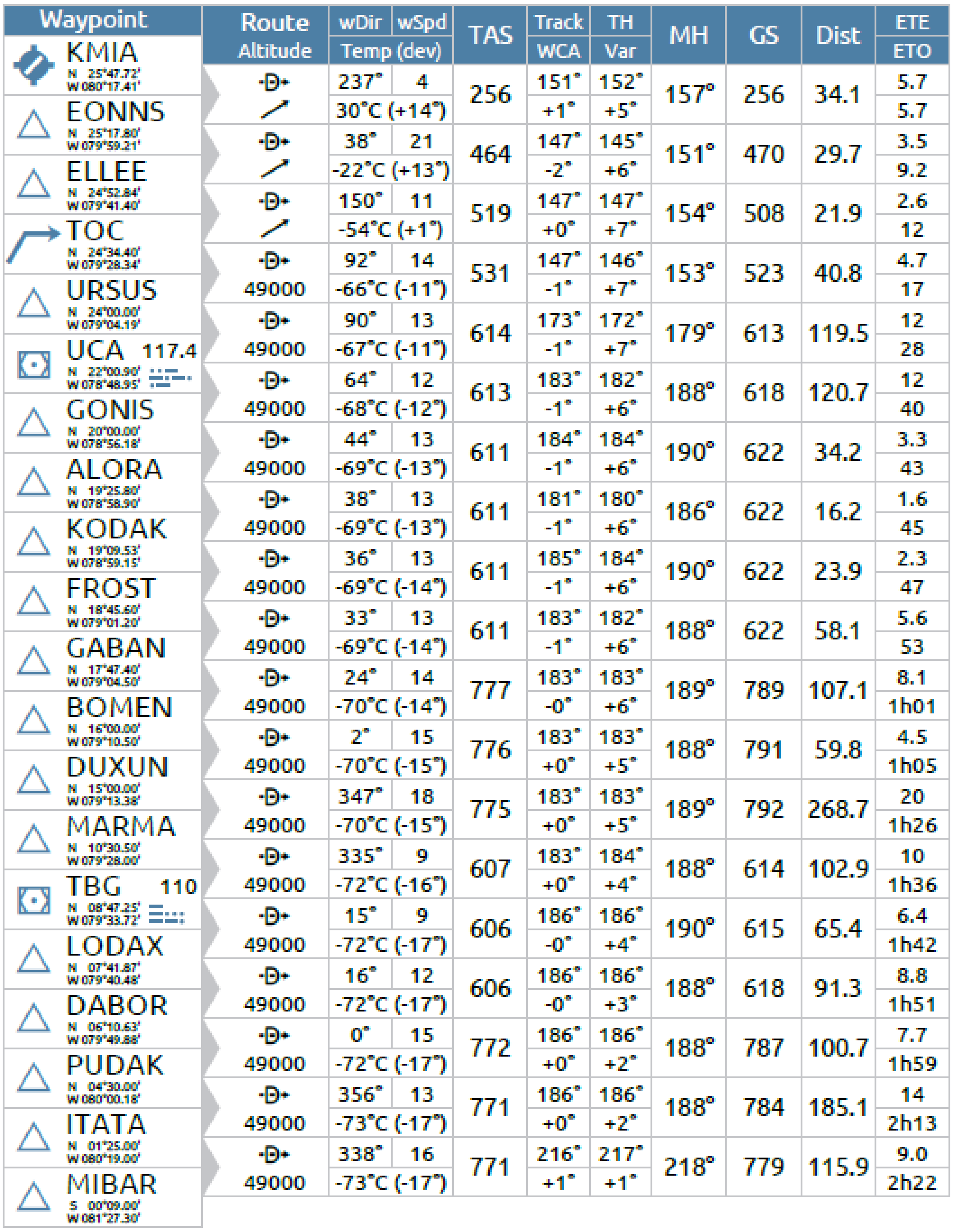
Waypoint	Route	Altitude	wDir	wSpd	Temp (dev)	TAS	Track	WCA	TH	Var	MH	GS	Dist	ETE	ETO
KMIA N 25°47.72' W 080°17.41'															
	-D→	↗	237°	4	30°C (+14°)	256	151°	+1°	152°	+5°	157°	256	34.1	5.7	5.7
EONNS N 25°17.80' W 079°59.21'															
	-D→	↗	38°	21	-22°C (+13°)	464	147°	-2°	145°	+6°	151°	470	29.7	3.5	9.2
ELLEE N 24°52.84' W 079°41.40'															
	-D→	↗	150°	11	-54°C (+1°)	519	147°	+0°	147°	+7°	154°	508	21.9	2.6	12
TOC N 24°34.40' W 079°28.34'															
	-D→	49000	92°	14	-66°C (-11°)	531	147°	-1°	146°	+7°	153°	523	40.8	4.7	17
URSUS N 24°00.00' W 079°04.19'															
	-D→	49000	90°	13	-67°C (-11°)	614	173°	-1°	172°	+7°	179°	613	119.5	12	28
UCA 117.4 N 22°00.90' W 078°48.95'															
	-D→	49000	64°	12	-68°C (-12°)	613	154°	-1°	153°	+6°	159°	613	163.7	16	44
TOTON N 19°32.43' W 077°34.03'															
	-D→	49000	39°	15	-69°C (-13°)	612	155°	-1°	154°	+7°	161°	618	72.2	7.0	51
SAVEM N 18°26.80' W 077°01.80'															
	-D→	49000	27°	15	-69°C (-13°)	612	155°	-1°	154°	+7°	161°	621	34.1	3.3	54
MLY 115.5 N 17°55.82' W 076°46.66'															
	-D→	49000	22°	15	-69°C (-13°)	612	162°	-1°	161°	+6°	167°	623	184.2	18	1h12
EGAPO N 15°00.00' W 075°46.97'															
	-D→	49000	349°	13	-69°C (-14°)	611	162°	-0°	161°	+7°	168°	624	114.4	11	1h23
OSUBO N 13°10.98' W 075°09.92'															
	-D→	49000	309°	18	-70°C (-14°)	610	162°	+1°	163°	+7°	170°	624	38.0	3.7	1h27
ALGUK N 12°34.73' W 074°57.75'															
	-D→	49000	300°	18	-70°C (-15°)	609	162°	+1°	163°	+7°	170°	623	117.7	11	1h38
MIBEN N 10°42.43' W 074°20.32'															
	-D→	49000	295°	14	-71°C (-15°)	608	161°	+1°	162°	+7°	169°	617	80.8	7.8	1h46
KAGEM N 09°25.42' W 073°54.28'															
	-D→	49000	310°	14	-72°C (-16°)	607	162°	+1°	163°	+7°	170°	619	74.8	7.3	1h53
IROTI N 08°13.90' W 073°31.10'															
	-D→	49000	323°	15	-72°C (-17°)	606	162°	+0°	163°	+6°	169°	620	121.7	12	2h05
PUKEN N 06°17.48' W 072°53.73'															
	-D→	49000	335°	16	-72°C (-17°)	606	162°	+0°	162°	+7°	169°	623	147.9	14	2h19
LONAX N 03°56.02' W 072°08.38'															
	-D→	49000	359°	10	-72°C (-17°)	606	162°	-0°	162°	+7°	169°	616	86.2	8.4	2h28
BUTAN N 02°33.57' W 071°42.07'															
	-D→	49000	343°	13	-72°C (-17°)	606	162°	-0°	162°	+7°	169°	619	330.5	32	3h00
PABON S 02°42.50' W 070°00.80'															
	-D→	49000	304°	12	-72°C (-16°)	607	164°	+1°	165°	+7°	172°	616	48.0	4.7	3h05
ARUXA S 03°28.94' W 069°47.70'															

Waypoint	Route	wDir	wSpd	TAS	Track	TH	MH	GS	Dist	ETE
	Altitude	Temp (dev)			WCA	Var				ETO
△ ARUXA S 03°28.94' W 069°47.70'										
	-D→	298°	14	607	163°	164°	171°	617	41.1	4.0
	49000	-72°C (-16°)			+1°	+7°				3h09
△ DOGLO S 04°08.39' W 069°35.66'										
	-D→	295°	15	607	164°	165°	172°	617	34.3	3.3
	49000	-72°C (-16°)			+1°	+7°				3h12
△ TENUG S 04°41.46' W 069°25.96'										
	-D→	293°	17	607	164°	165°	173°	617	116.5	11
	49000	-72°C (-16°)			+1°	+8°				3h23
△ PUDBU S 06°33.70' W 068°52.83'										
	-D→	290°	20	607	164°	165°	174°	619	66.2	6.4
	49000	-72°C (-16°)			+2°	+9°				3h30
△ ARTIK S 07°37.53' W 068°33.99'										
	-D→	290°	23	607	163°	165°	173°	620	99.9	10
	49000	-72°C (-16°)			+2°	+7°				3h39
△ ESBUK S 09°13.79' W 068°05.28'										
	-D→	293°	26	607	164°	166°	174°	623	40.1	3.9
	49000	-71°C (-16°)			+2°	+8°				3h43
⊡ RCO 116.4 S 09°52.56' W 067°54.32' ·–· –·–· –––										
	-D→	294°	27	607	163°	165°	174°	625	45.7	4.4
	49000	-71°C (-16°)			+2°	+9°				3h48
△ ISARA S 10°36.40' W 067°40.60'										
	-D→	295°	29	608	163°	165°	174°	627	246.0	23
	49000	-71°C (-16°)			+2°	+9°				4h11
△ KADOX S 14°32.77' W 066°27.25'										
	-D→	297°	34	610	163°	166°	174°	633	55.9	5.3
	49000	-70°C (-14°)			+2°	+9°				4h16
△ NIRBO S 15°26.53' W 066°10.52'										
	-D→	300°	33	611	163°	165°	174°	635	86.8	8.2
	49000	-69°C (-13°)			+2°	+9°				4h24
△ LOKOX S 16°50.03' W 065°44.55'										
	-D→	303°	38	611	163°	166°	174°	640	15.1	1.4
	49000	-69°C (-13°)			+2°	+9°				4h26
△ DOLGI S 17°04.53' W 065°40.03'										
	-D→	304°	38	611	163°	166°	174°	640	24.3	2.3
	49000	-69°C (-13°)			+2°	+9°				4h28
△ VAREB S 17°27.88' W 065°32.77'										
	-D→	304°	39	612	163°	166°	174°	641	12.8	1.2
	49000	-69°C (-13°)			+2°	+9°				4h29
△ GELAS S 17°40.20' W 065°28.93'										
	-D→	304°	40	612	164°	166°	175°	642	76.0	7.1
	49000	-68°C (-13°)			+2°	+9°				4h36
△ VALUS S 18°53.38' W 065°06.17'										
	-D→	307°	43	613	164°	166°	175°	646	17.3	1.6
	49000	-68°C (-12°)			+2°	+9°				4h38
△ EGUSU S 19°10.00' W 065°01.00'										
	-D→	308°	44	612	164°	166°	175°	647	110.0	10
	49000	-68°C (-12°)			+2°	+9°				4h48
△ ASETO S 20°55.92' W 064°28.05'										
	-D→	311°	46	614	164°	166°	175°	652	26.4	2.4
	49000	-67°C (-12°)			+2°	+8°				4h51
△ ESMUR S 21°21.38' W 064°20.12'										
	-D→	313°	47	614	164°	166°	175°	654	55.1	5.1
	49000	-67°C (-12°)			+2°	+8°				4h56
△ PUBUM S 22°14.50' W 064°03.60'										
	-D→	313°	52	614	163°	165°	173°	659	149.1	14
	49000	-67°C (-11°)			+2°	+8°				5h09
△ IMBER S 24°37.40' W 063°15.47'										
	-D→	318°	52	617	163°	165°	172°	664	70.6	6.4
	49000	-65°C (-10°)			+2°	+7°				5h16
△ UBRIX S 25°44.97' W 062°52.05'										
	-D→	318°	54	617	169°	171°	179°	663	181.2	16
	49000	-65°C (-9°)			+3°	+7°				5h32
△ MEVUR S 28°43.05' W 062°11.87'										
	-D→	321°	64	619	168°	171°	178°	674	70.6	6.3
	49000	-64°C (-8°)			+3°	+7°				5h38
⊡ ERE 115.5 S 29°52.40' W 061°55.52' · ·–· ·										
	-D→	321°	68	620	162°	165°	170°	683	43.7	3.8
	49000	-63°C (-8°)			+2°	+6°				5h42
△ ROMUR S 30°34.10' W 061°40.20'										
	-D→	320°	70	621	162°	165°	172°	685	46.7	4.1
	49000	-63°C (-7°)			+2°	+7°				5h46
△ ISOPO S 31°18.70' W 061°23.63'										
	-D→	319°	70	621	162°	165°	171°	685	100.4	8.8
	49000	-62°C (-6°)			+3°	+6°				5h55
⊡ ROS 117.3 S 32°54.30' W 060°46.88' ·–· ––– ···										
	W20	318°	71	622	150°	151°	156°	692	30.0	2.6
	49000	-62°C (-6°)			+1°	+5°				5h57
△ VASAL S 33°20.25' W 060°28.90'										



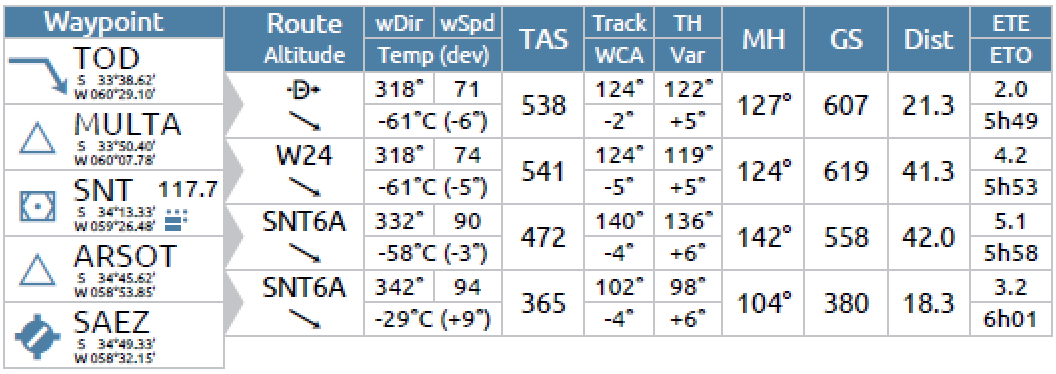
Waypoint	Route	wDir	wSpd	TAS	Track	TH	MH	GS	Dist	ETE
	Altitude	Temp (dev)			WCA	Var				ETO
△ VASAL S 33°20.25' W 060°28.90'										
	W20	317°	71	622	150°	151°	156°	691	13.4	1.2
	49000	-61°C (-6°)			+1°	+5°				5h59
TOD S 33°31.81' W 060°20.83'										
	W20	317°	71	537	150°	151°	156°	606	21.5	2.0
	↘	-61°C (-6°)			+2°	+5°				6h01
△ MULTA S 33°50.40' W 060°07.78'										
	·D→	318°	75	541	124°	119°	124°	619	41.3	4.2
	↘	-61°C (-5°)			-5°	+5°				6h05
SNT 117.7 S 34°13.33' W 059°26.48'										
	SNT6A	332°	91	472	140°	136°	141°	558	42.0	5.1
	↘	-58°C (-3°)			-4°	+6°				6h10
△ ARSOT S 34°45.62' W 058°53.85'										
	SNT6A	342°	94	365	102°	98°	104°	379	18.3	3.2
	↘	-29°C (+9°)			-4°	+6°				6h13
SAEZ S 34°49.33' W 058°32.15'										

Attachment 11: Miami – Buenos Aires: Navigation List (AS2 – Alternative Track) [129]



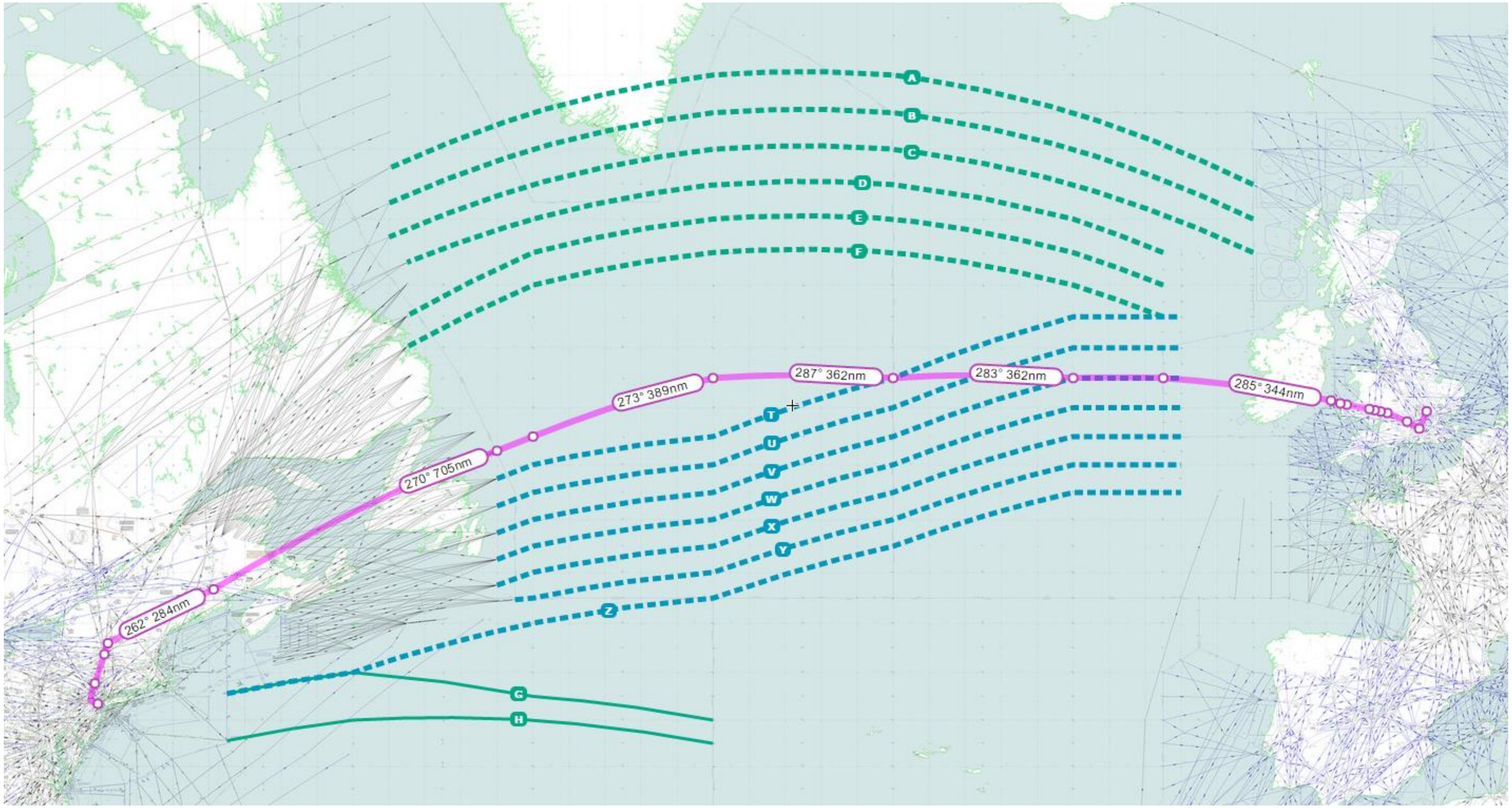
Waypoint	Route Altitude	wDir Temp (dev)	wSpd	TAS	Track WCA	TH Var	MH	GS	Dist	ETE ETO
KMIA N 25°47.72' W 080°17.41'										
		237° 30°C (+14°)	4	256	151° +1°	152° +5°	157°	256	34.1	5.7 5.7
EONNS N 25°17.80' W 079°59.21'										
		38° -22°C (+13°)	21	464	147° -2°	145° +6°	151°	470	29.7	3.5 9.2
ELLEE N 24°52.84' W 079°41.40'										
		150° -54°C (+1°)	11	519	147° +0°	147° +7°	154°	508	21.9	2.6 12
TOC N 24°34.40' W 079°28.34'										
	49000	92° -66°C (-11°)	14	531	147° -1°	146° +7°	153°	523	40.8	4.7 17
URSUS N 24°00.00' W 079°04.19'										
	49000	90° -67°C (-11°)	13	614	173° -1°	172° +7°	179°	613	119.5	12 28
UCA 117.4 N 22°00.90' W 078°48.95'										
	49000	64° -68°C (-12°)	12	613	183° -1°	182° +6°	188°	618	120.7	12 40
GONIS N 20°00.00' W 078°56.18'										
	49000	44° -69°C (-13°)	13	611	184° -1°	184° +6°	190°	622	34.2	3.3 43
ALORA N 19°25.80' W 078°58.90'										
	49000	38° -69°C (-13°)	13	611	181° -1°	180° +6°	186°	622	16.2	1.6 45
KODAK N 19°09.53' W 078°59.15'										
	49000	36° -69°C (-14°)	13	611	185° -1°	184° +6°	190°	622	23.9	2.3 47
FROST N 18°45.60' W 079°01.20'										
	49000	33° -69°C (-14°)	13	611	183° -1°	182° +6°	188°	622	58.1	5.6 53
GABAN N 17°47.40' W 079°04.50'										
	49000	24° -70°C (-14°)	14	777	183° -0°	183° +6°	189°	789	107.1	8.1 1h01
BOMEN N 16°00.00' W 079°10.50'										
	49000	2° -70°C (-15°)	15	776	183° +0°	183° +5°	188°	791	59.8	4.5 1h05
DUXUN N 15°00.00' W 079°13.38'										
	49000	347° -70°C (-15°)	18	775	183° +0°	183° +5°	189°	792	268.7	20 1h26
MARMA N 10°30.50' W 079°28.00'										
	49000	335° -72°C (-16°)	9	607	183° +0°	184° +4°	188°	614	102.9	10 1h36
TBG 110 N 08°47.25' W 079°33.72'										
	49000	15° -72°C (-17°)	9	606	186° -0°	186° +4°	190°	615	65.4	6.4 1h42
LODAX N 07°41.87' W 079°40.48'										
	49000	16° -72°C (-17°)	12	606	186° -0°	186° +3°	188°	618	91.3	8.8 1h51
DABOR N 06°10.63' W 079°49.88'										
	49000	0° -72°C (-17°)	15	772	186° +0°	186° +2°	188°	787	100.7	7.7 1h59
PUDAK N 04°30.00' W 080°00.18'										
	49000	356° -73°C (-17°)	13	771	186° +0°	186° +2°	188°	784	185.1	14 2h13
ITATA N 01°25.00' W 080°19.00'										
	49000	338° -73°C (-17°)	16	771	216° +1°	217° +1°	218°	779	115.9	9.0 2h22
MIBAR S 00°09.00' W 081°27.30'										

Waypoint	Route Altitude	wDir Temp (dev)	wSpd	TAS	Track WCA	TH Var	MH	GS	Dist	ETE ETO
△ MIBAR S 00°09.00' W 081°27.30'										
	-D→ 49000	309° -72°C (-17°)	13	772	193° +1°	194° -0°	193°	777	47.8	3.7 2h26
△ ATIPU S 00°55.87' W 081°37.73'										
	-D→ 49000	302° -72°C (-17°)	15	772	192° +1°	193° +0°	193°	776	68.4	5.3 2h31
△ ATENO S 02°03.02' W 081°52.17'										
	-D→ 49000	296° -72°C (-17°)	17	771	180° +1°	181° -1°	180°	779	220.3	17 2h48
△ DOLGA S 05°44.37' W 081°53.38'										
	-D→ 49000	286° -72°C (-17°)	22	772	153° +1°	154° -1°	154°	787	574.3	44 3h31
△ MOXES S 14°16.48' W 077°25.07'										
	-D→ 49000	272° -68°C (-13°)	45	779	155° +3°	157° -2°	156°	799	270.3	20 3h52
△ IREMI S 18°21.00' W 075°23.00'										
	-D→ 49000	268° -65°C (-9°)	51	786	164° +4°	168° -0°	167°	797	175.6	13 4h05
△ ASEPU S 21°10.35' W 074°31.28'										
	-D→ 49000	273° -61°C (-6°)	50	792	164° +3°	167° -1°	166°	807	176.8	13 4h18
△ ELASA S 24°00.50' W 073°37.00'										
	-D→ 49000	286° -58°C (-2°)	45	799	163° +3°	166° -1°	165°	822	219.9	16 4h34
△ ATEDA S 27°31.70' W 072°26.63'										
	-D→ 49000	303° -55°C (+1°)	47	804	163° +2°	165° -3°	162°	839	60.8	4.3 4h38
△ NUXUP S 28°30.00' W 072°06.42'										
	-D→ 49000	308° -54°C (+1°)	47	546	163° +3°	166° -1°	165°	584	60.4	6.2 4h44
△ DALUS S 29°27.80' W 071°45.98'										
	-D→ 49000	314° -54°C (+1°)	49	547	163° +2°	165° -1°	164°	589	50.1	5.1 4h49
⊕ TOY 260 S 30°15.78' W 071°28.78'										
	-D→ 49000	317° -54°C (+1°)	53	546	118° -2°	116° -4°	113°	596	20.6	2.1 4h51
△ TITKI S 30°25.50' W 071°07.78'										
	-D→ 49000	319° -55°C (+1°)	57	546	117° -2°	114° -1°	113°	598	16.7	1.7 4h53
△ VUNIK S 30°32.97' W 070°50.52'										
	-D→ 49000	319° -55°C (+0°)	62	545	116° -3°	113° -1°	112°	602	5.9	0.6 4h54
△ NIRNU S 30°35.55' W 070°44.37'										
	-D→ 49000	319° -55°C (+0°)	64	545	116° -3°	114° -1°	113°	603	19.9	2.0 4h56
△ SOVSU S 30°44.33' W 070°23.63'										
	-D→ 49000	318° -56°C (-0°)	69	545	117° -3°	114° -1°	114°	608	5.9	0.6 4h56
△ MIBAS S 30°47.00' W 070°17.50'										
	-D→ 49000	317° -55°C (+0°)	69	545	116° -3°	114° -3°	111°	609	34.5	3.4 5h00
△ ILSUR S 31°02.33' W 069°41.57'										
	-D→ 49000	317° -54°C (+1°)	67	546	114° -3°	111° -2°	110°	608	21.4	2.1 5h02
△ REPEV S 31°11.08' W 069°18.80'										
	-D→ 49000	319° -55°C (+1°)	67	546	117° -3°	114° +0°	114°	608	51.1	5.0 5h07
⊡ JUA 113.1 S 31°33.83' W 068°25.28'										
	-D→ 49000	320° -56°C (-0°)	73	631	87° -5°	82° -1°	80°	673	78.8	7.0 5h14
△ ORABA S 31°29.33' W 066°53.22'										
	-D→ 49000	322° -56°C (-1°)	76	630	86° -6°	81° +0°	81°	670	83.0	7.5 5h21
△ PAMAX S 31°23.40' W 065°16.42'										
	W24 49000	324° -58°C (-3°)	76	627	85° -6°	80° +2°	82°	664	55.2	5.0 5h26
⊡ CBA 114.5 S 31°18.79' W 064°12.22'										
	W24 49000	323° -60°C (-4°)	77	624	129° -2°	128° +3°	131°	699	54.4	4.7 5h31
△ UTRAX S 31°53.22' W 063°22.87'										
	-D→ 49000	321° -60°C (-5°)	77	624	128° -2°	126° +3°	129°	699	78.4	6.7 5h38
⬡ MJZ 114.7 S 32°41.17' W 062°09.67'										
	-D→ 49000	320° -60°C (-5°)	74	624	125° -2°	123° +2°	125°	695	71.5	6.2 5h44
△ UDITA S 33°21.65' W 060°59.45'										
	-D→ 49000	319° -61°C (-5°)	72	623	124° -2°	122° +5°	127°	693	30.5	2.6 5h47
↘ TOD S 33°38.62' W 060°29.10'										

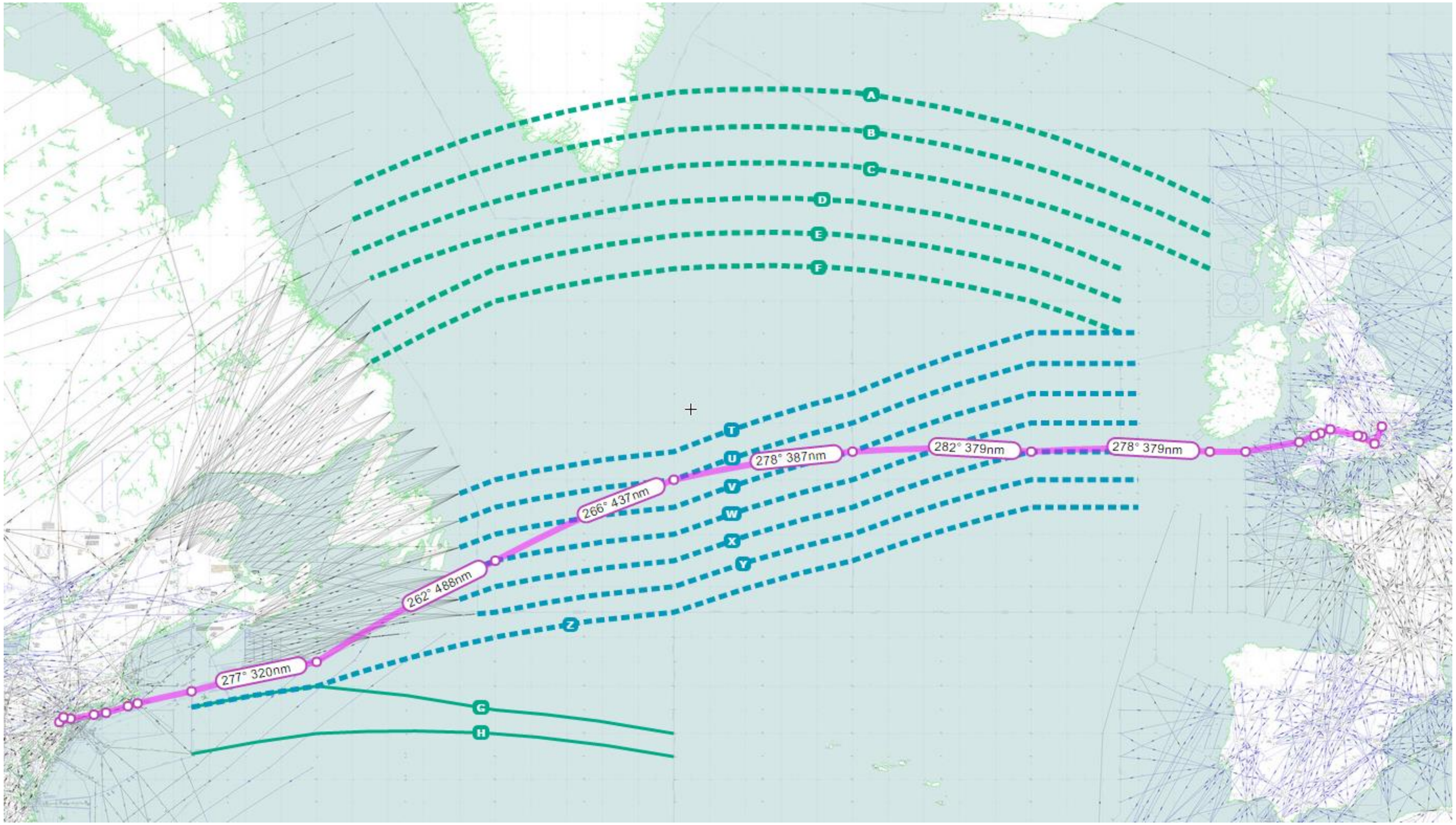


Waypoint	Route	wDir	wSpd	TAS	Track	TH	MH	GS	Dist	ETE
	Altitude	Temp (dev)			WCA	Var				ETO
TOD S 33°38.62' W 060°29.10'										
	·D·	318°	71	538	124°	122°	127°	607	21.3	2.0
	↘	-61°C (-6°)			-2°	+5°				5h49
MULTA S 33°50.40' W 060°07.78'										
	W24	318°	74	541	124°	119°	124°	619	41.3	4.2
	↘	-61°C (-5°)			-5°	+5°				5h53
SNT 117.7 S 34°13.33' W 059°26.48'										
	SNT6A	332°	90	472	140°	136°	142°	558	42.0	5.1
	↘	-58°C (-3°)			-4°	+6°				5h58
ARSOT S 34°45.62' W 058°53.85'										
	SNT6A	342°	94	365	102°	98°	104°	380	18.3	3.2
	↘	-29°C (+9°)			-4°	+6°				6h01
SAEZ S 34°49.33' W 058°32.15'										

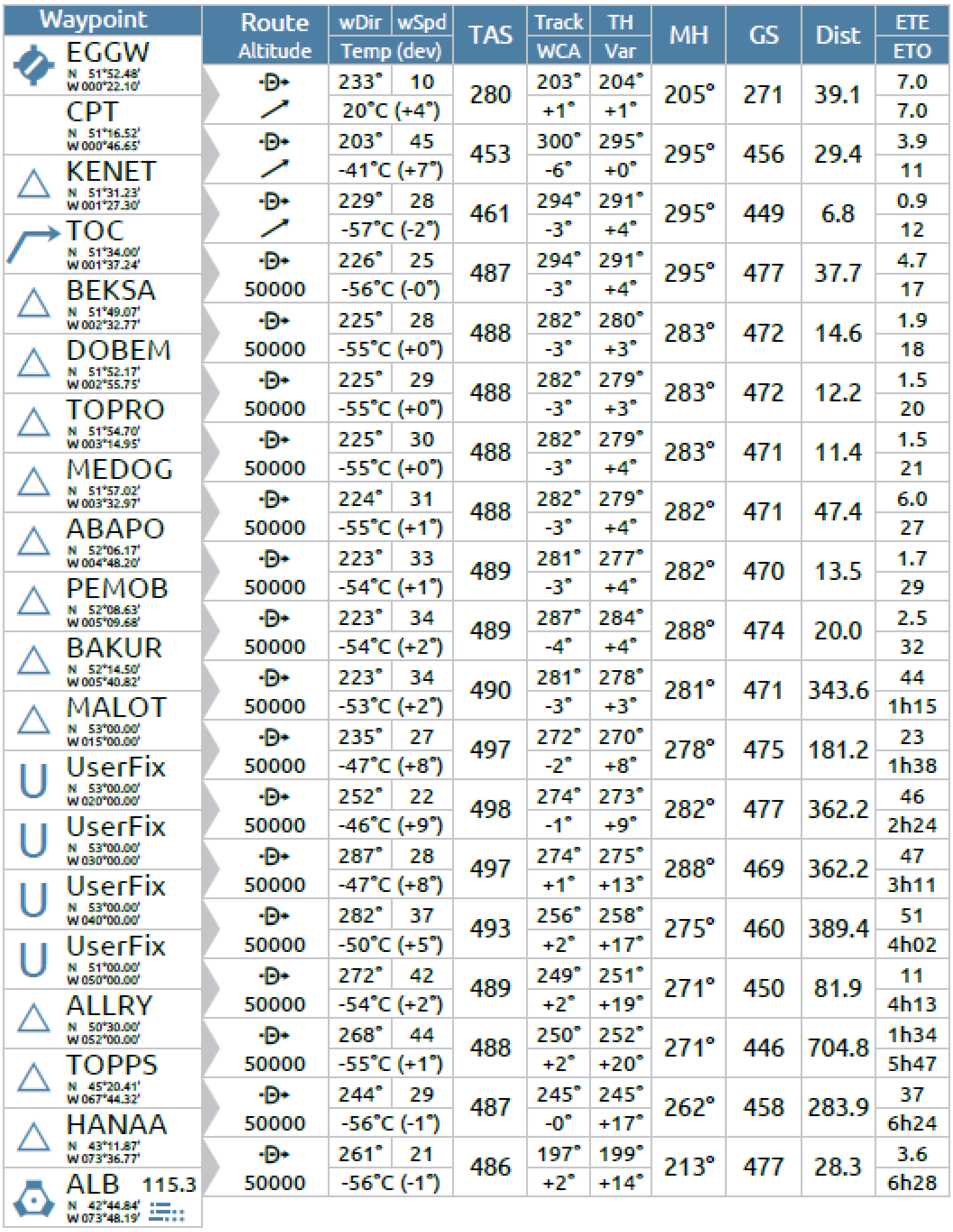
Attachment 12: London – New York: Route Map (G650ER) [129]



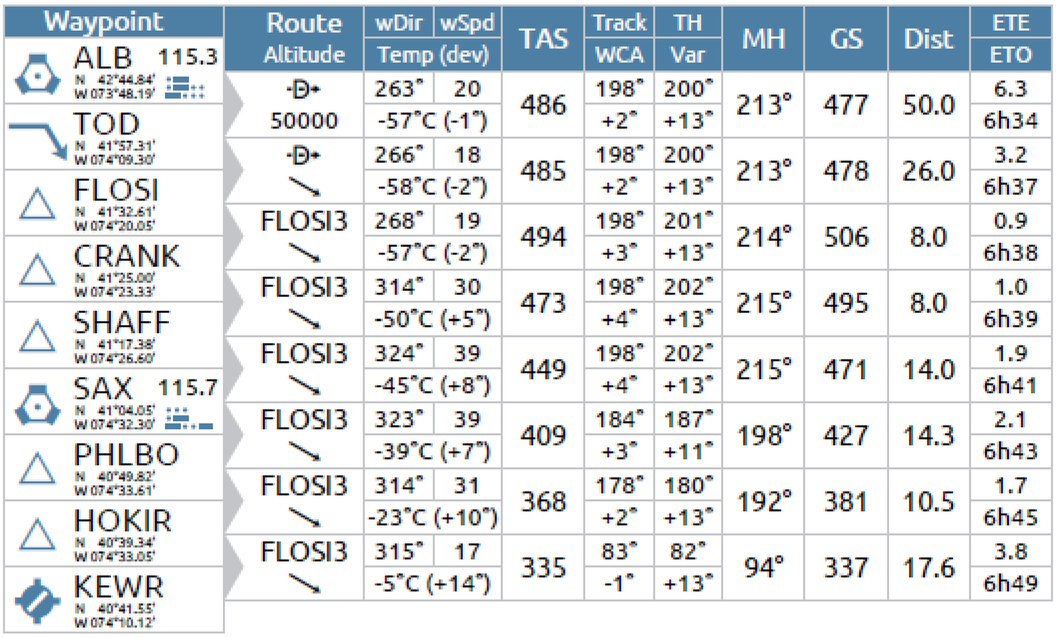
Attachment 13: London – New York: Route Map (AS2) [129]



Attachment 14: London – New York: Navigation List (G650ER) [129]

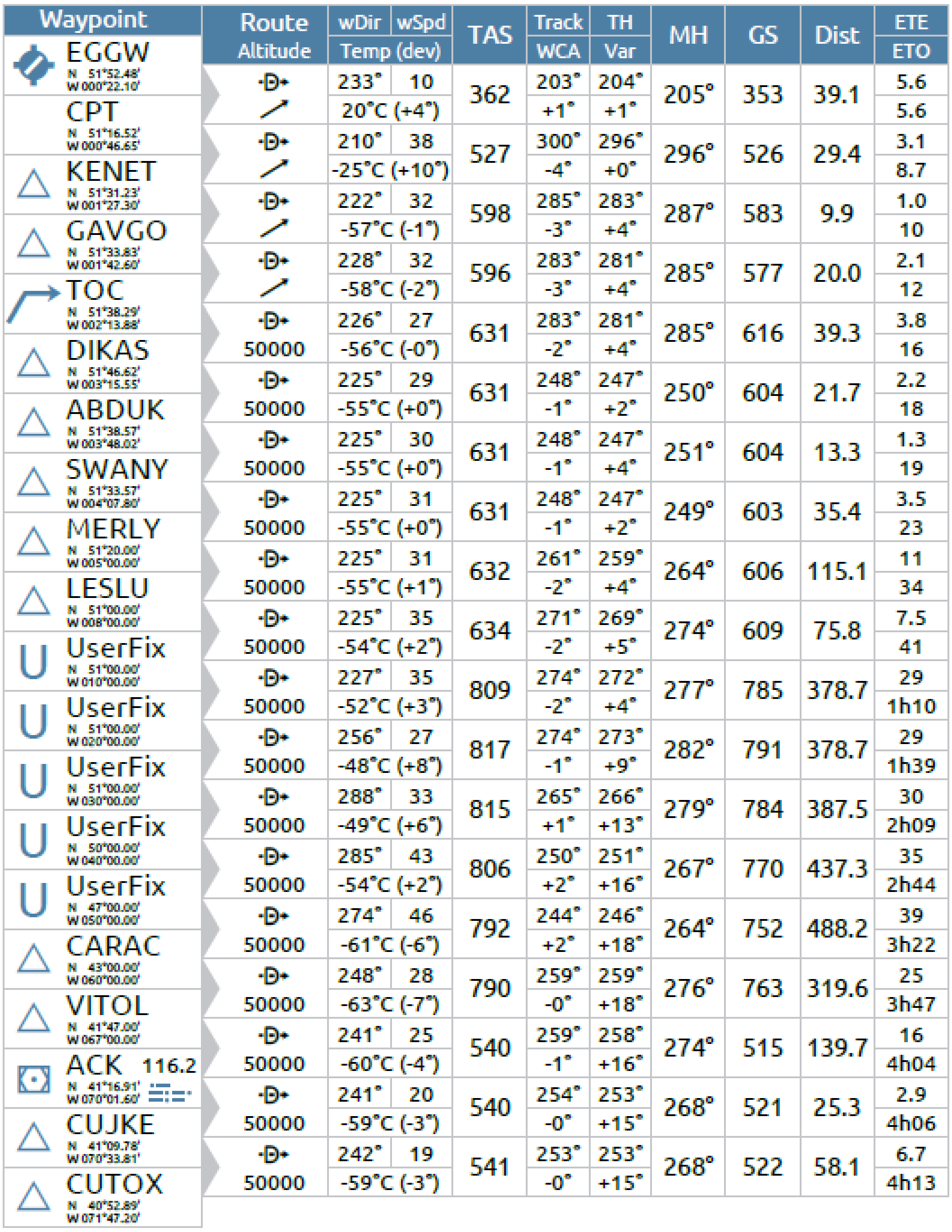


Waypoint	Route	wDir	wSpd	TAS	Track	TH	MH	GS	Dist	ETE
	Altitude	Temp (dev)			WCA	Var				ETO
EGGW N 51°52.48' W 000°22.10'										
	-D-	233°	10	280	203°	204°	205°	271	39.1	7.0
	↗	20°C (+4°)			+1°	+1°				7.0
CPT N 51°16.52' W 000°46.65'										
	-D-	203°	45	453	300°	295°	295°	456	29.4	3.9
	↗	-41°C (+7°)			-6°	+0°				11
KENET N 51°31.23' W 001°27.30'										
	-D-	229°	28	461	294°	291°	295°	449	6.8	0.9
	↗	-57°C (-2°)			-3°	+4°				12
TOC N 51°34.00' W 001°37.24'										
	-D-	226°	25	487	294°	291°	295°	477	37.7	4.7
	50000	-56°C (-0°)			-3°	+4°				17
BEKSA N 51°49.07' W 002°32.77'										
	-D-	225°	28	488	282°	280°	283°	472	14.6	1.9
	50000	-55°C (+0°)			-3°	+3°				18
DOBEM N 51°52.17' W 002°55.75'										
	-D-	225°	29	488	282°	279°	283°	472	12.2	1.5
	50000	-55°C (+0°)			-3°	+3°				20
TOPRO N 51°54.70' W 003°14.95'										
	-D-	225°	30	488	282°	279°	283°	471	11.4	1.5
	50000	-55°C (+0°)			-3°	+4°				21
MEDOG N 51°57.02' W 003°32.97'										
	-D-	224°	31	488	282°	279°	282°	471	47.4	6.0
	50000	-55°C (+1°)			-3°	+4°				27
ABAPO N 52°06.17' W 004°48.20'										
	-D-	223°	33	489	281°	277°	282°	470	13.5	1.7
	50000	-54°C (+1°)			-3°	+4°				29
PEMOB N 52°08.63' W 005°09.68'										
	-D-	223°	34	489	287°	284°	288°	474	20.0	2.5
	50000	-54°C (+2°)			-4°	+4°				32
BAKUR N 52°14.50' W 005°40.82'										
	-D-	223°	34	490	281°	278°	281°	471	343.6	44
	50000	-53°C (+2°)			-3°	+3°				1h15
MALOT N 53°00.00' W 015°00.00'										
	-D-	235°	27	497	272°	270°	278°	475	181.2	23
	50000	-47°C (+8°)			-2°	+8°				1h38
UserFix N 53°00.00' W 020°00.00'										
	-D-	252°	22	498	274°	273°	282°	477	362.2	46
	50000	-46°C (+9°)			-1°	+9°				2h24
UserFix N 53°00.00' W 030°00.00'										
	-D-	287°	28	497	274°	275°	288°	469	362.2	47
	50000	-47°C (+8°)			+1°	+13°				3h11
UserFix N 53°00.00' W 040°00.00'										
	-D-	282°	37	493	256°	258°	275°	460	389.4	51
	50000	-50°C (+5°)			+2°	+17°				4h02
UserFix N 51°00.00' W 050°00.00'										
	-D-	272°	42	489	249°	251°	271°	450	81.9	11
	50000	-54°C (+2°)			+2°	+19°				4h13
ALLRY N 50°30.00' W 052°00.00'										
	-D-	268°	44	488	250°	252°	271°	446	704.8	1h34
	50000	-55°C (+1°)			+2°	+20°				5h47
TOPPS N 45°20.41' W 067°44.32'										
	-D-	244°	29	487	245°	245°	262°	458	283.9	37
	50000	-56°C (-1°)			-0°	+17°				6h24
HANAA N 43°11.87' W 073°36.77'										
	-D-	261°	21	486	197°	199°	213°	477	28.3	3.6
	50000	-56°C (-1°)			+2°	+14°				6h28
ALB 115.3 N 42°44.84' W 073°48.19'										

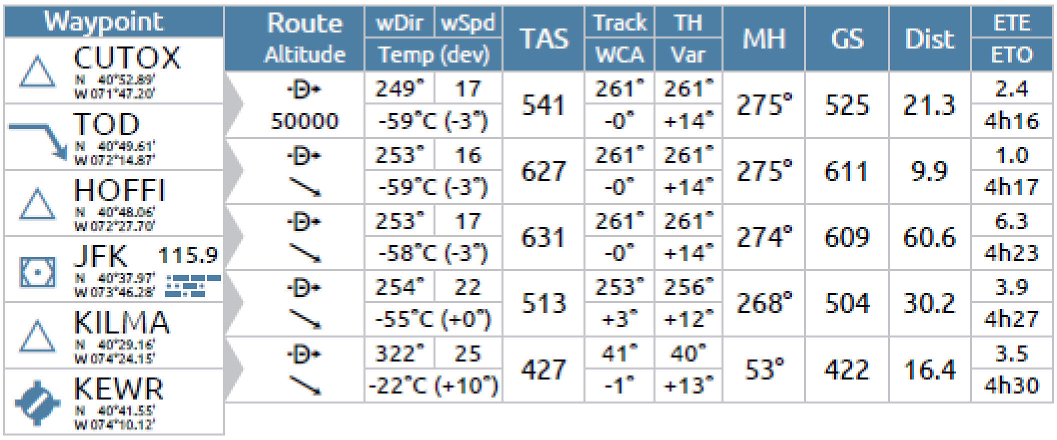


Waypoint	Route	wDir	wSpd	TAS	Track	TH	MH	GS	Dist	ETE
	Altitude	Temp (dev)			WCA	Var				ETO
ALB 115.3 N 42°44.84' W 073°48.19'										
	-D→	263°	20	486	198°	200°	213°	477	50.0	6.3
	50000	-57°C (-1°)			+2°	+13°				6h34
TOD N 41°57.31' W 074°09.30'										
	-D→	266°	18	485	198°	200°	213°	478	26.0	3.2
	↘	-58°C (-2°)			+2°	+13°				6h37
FLOSI N 41°32.61' W 074°20.05'										
	FLOSI3	268°	19	494	198°	201°	214°	506	8.0	0.9
	↘	-57°C (-2°)			+3°	+13°				6h38
CRANK N 41°25.00' W 074°23.33'										
	FLOSI3	314°	30	473	198°	202°	215°	495	8.0	1.0
	↘	-50°C (+5°)			+4°	+13°				6h39
SHAFF N 41°17.38' W 074°26.60'										
	FLOSI3	324°	39	449	198°	202°	215°	471	14.0	1.9
	↘	-45°C (+8°)			+4°	+13°				6h41
SAX 115.7 N 41°04.05' W 074°32.30'										
	FLOSI3	323°	39	409	184°	187°	198°	427	14.3	2.1
	↘	-39°C (+7°)			+3°	+11°				6h43
PHLBO N 40°49.82' W 074°33.61'										
	FLOSI3	314°	31	368	178°	180°	192°	381	10.5	1.7
	↘	-23°C (+10°)			+2°	+13°				6h45
HOKIR N 40°39.34' W 074°33.05'										
	FLOSI3	315°	17	335	83°	82°	94°	337	17.6	3.8
	↘	-5°C (+14°)			-1°	+13°				6h49
KEWR N 40°41.55' W 074°10.12'										

Attachment 15: London – New York: Navigation List (AS2) [129]



Waypoint	Route	wDir	wSpd	TAS	Track	TH	MH	GS	Dist	ETE
	Altitude	Temp (dev)			WCA	Var				ETO
EGGW N 51°52.48' W 000°22.10'										
	→	233°	10	362	203°	204°	205°	353	39.1	5.6
	↗	20°C (+4°)			+1°	+1°				5.6
CPT N 51°16.52' W 000°46.65'										
	→	210°	38	527	300°	296°	296°	526	29.4	3.1
	↗	-25°C (+10°)			-4°	+0°				8.7
KENET N 51°31.23' W 001°27.30'										
	→	222°	32	598	285°	283°	287°	583	9.9	1.0
	↗	-57°C (-1°)			-3°	+4°				10
GAVGO N 51°33.83' W 001°42.60'										
	→	228°	32	596	283°	281°	285°	577	20.0	2.1
	↗	-58°C (-2°)			-3°	+4°				12
TOC N 51°38.29' W 002°13.88'										
	→	226°	27	631	283°	281°	285°	616	39.3	3.8
	50000	-56°C (-0°)			-2°	+4°				16
DIKAS N 51°46.62' W 003°15.55'										
	→	225°	29	631	248°	247°	250°	604	21.7	2.2
	50000	-55°C (+0°)			-1°	+2°				18
ABDUK N 51°38.57' W 003°48.02'										
	→	225°	30	631	248°	247°	251°	604	13.3	1.3
	50000	-55°C (+0°)			-1°	+4°				19
SWANY N 51°33.57' W 004°07.80'										
	→	225°	31	631	248°	247°	249°	603	35.4	3.5
	50000	-55°C (+0°)			-1°	+2°				23
MERLY N 51°20.00' W 005°00.00'										
	→	225°	31	632	261°	259°	264°	606	115.1	11
	50000	-55°C (+1°)			-2°	+4°				34
LESLU N 51°00.00' W 008°00.00'										
	→	225°	35	634	271°	269°	274°	609	75.8	7.5
	50000	-54°C (+2°)			-2°	+5°				41
UserFix N 51°00.00' W 010°00.00'										
	→	227°	35	809	274°	272°	277°	785	378.7	29
	50000	-52°C (+3°)			-2°	+4°				1h10
UserFix N 51°00.00' W 020°00.00'										
	→	256°	27	817	274°	273°	282°	791	378.7	29
	50000	-48°C (+8°)			-1°	+9°				1h39
UserFix N 51°00.00' W 030°00.00'										
	→	288°	33	815	265°	266°	279°	784	387.5	30
	50000	-49°C (+6°)			+1°	+13°				2h09
UserFix N 50°00.00' W 040°00.00'										
	→	285°	43	806	250°	251°	267°	770	437.3	35
	50000	-54°C (+2°)			+2°	+16°				2h44
UserFix N 47°00.00' W 050°00.00'										
	→	274°	46	792	244°	246°	264°	752	488.2	39
	50000	-61°C (-6°)			+2°	+18°				3h22
CARAC N 43°00.00' W 060°00.00'										
	→	248°	28	790	259°	259°	276°	763	319.6	25
	50000	-63°C (-7°)			-0°	+18°				3h47
VITOL N 41°47.00' W 067°00.00'										
	→	241°	25	540	259°	258°	274°	515	139.7	16
	50000	-60°C (-4°)			-1°	+16°				4h04
ACK 116.2 N 41°16.91' W 070°01.60'										
	→	241°	20	540	254°	253°	268°	521	25.3	2.9
	50000	-59°C (-3°)			-0°	+15°				4h06
CUJKE N 41°09.78' W 070°33.81'										
	→	242°	19	541	253°	253°	268°	522	58.1	6.7
	50000	-59°C (-3°)			-0°	+15°				4h13
CUTOX N 40°52.89' W 071°47.20'										



Waypoint	Route Altitude	wDir	wSpd	TAS	Track WCA	TH Var	MH	GS	Dist	ETE ETO
CUTOX N 40°52.89' W 071°47.20'										
	-D- 50000	249° -59°C (-3°)	17	541	261° -0°	261° +14°	275°	525	21.3	2.4 4h16
TOD N 40°49.61' W 072°14.87'										
	-D- ↘	253° -59°C (-3°)	16	627	261° -0°	261° +14°	275°	611	9.9	1.0 4h17
HOFFI N 40°48.06' W 072°27.70'										
	-D- ↘	253° -58°C (-3°)	17	631	261° -0°	261° +14°	274°	609	60.6	6.3 4h23
JFK 115.9 N 40°37.97' W 073°46.28'										
	-D- ↘	254° -55°C (+0°)	22	513	253° +3°	256° +12°	268°	504	30.2	3.9 4h27
KILMA N 40°29.16' W 074°24.15'										
	-D- ↘	322° -22°C (+10°)	25	427	41° -1°	40° +13°	53°	422	16.4	3.5 4h30
KEWR N 40°41.55' W 074°10.12'										