

# AN ANALYSIS OF THE MARKET ENVIRONMENT FOR SUPERSONIC BUSINESS JETS

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## Abstract

This paper is based on scientific work in the DLR proposition „Virtual Integration Platform (VIP) 3 – Small Supersonic Transport“. It intends to show the market potential of future Supersonic Business Jets (SSBJs) and to assess possible modes of operation under consideration of economic, technical and operational framework requirements. For this purpose, business aviation as a whole is analysed, including business jet manufacturers, the current product range and modes of operation. Physical and technical characteristics of supersonic flight and the supersonic overland flight ban are discussed in brief. Furthermore, known SSBJ designs are presented. The main work concerns market analysis for private flight in general and for SSBJs in particular. Calculations of operational expenses of business aircraft are introduced beside statistics on traffic volume and results of a survey among business aviation decision makers. Subsequently, a synthetical estimation is given regarding the market potential of particular modes of operation for SSBJs. At last, basic requirements are deduced for the SSBJ to be designed in the context of VIP-3.

## 1. INTRODUCTION

Since the retirement of Concorde in 2003, there is no more civilian supersonic air transportation. A first in the history of mankind, the top speed of a transportation system has suffered a setback. The reason therefor appears to be quite clear: In spite of essential technical feasibility, none of the concepts was economically sustainable over its whole life cycle. Each of the several great development programs for civil supersonic transports (SSTs) consumed enormous financial resources. Even Concorde which served for 27 years wasn't able to return its development cost to the slightest extent.

The failure of large civilian SSTs has yielded the awareness that before the start of any new program, an economic basis as well as elaborate business and operation models have to be developed that at least render verisimilar the economic viability of such projects. For this reason, so-called supersonic business jets (SSBJs) have been designed predominantly in the last two decades: Small, privately operated aircraft that are assumed to possibly be able to prevail in the marketplace.

Not only is the interest in SSBJs rooted in human drive for progress and speed or in profit seeking. From a scientific perspective, it is technology driven: The know-how regarding civilian supersonic flight has been existing for half a century, and since, basic knowledge has improved greatly: Engine technology with new, high-temperature materials, for instance; or fly-by-wire that had been introduced with Concorde and that is now standard in any modern airliner. Moreover, new development methods have surfaced, among which the meaning of computer aided design and simulation can hardly be overestimated.

In the VIP-3 project, a competency for holistic assessment of small supersonic transports is being developed. This includes not only the ability to design SSBJs, but also

knowledge concerning framework requirements of the air transportation system that such an airplane has to prove itself in. The aforementioned aircraft design environment is being developed at the Institute of Aircraft Design and Lightweight Structures (IFL) at the Technical University of Brunswick, Germany, by adapting the design framework PrADO (Preliminary Aircraft Design and Optimization) for supersonic applications. Furthermore, the Institute of Aerodynamics and Flow Technology of DLR (DLR-AS) engages in flow simulation for low aspect ratio wings.

The present work, assigned to the institution of Air Transportation Systems in DLR (DLR-LY), addresses the investigation of economic, technical, and operational requirements.

## 2. BUSINESS AVIATION

### 2.1. Business jet manufacturers and models

Globally, there are 6 established manufacturers of purpose-built business jets: US-American Cessna, Gulfstream and Hawker, Canadian Bombardier, French Dassault Falcon and Brazilian Embraer.

Except of the latter, no company has managed to gain a foothold in this market for three decades. Grob Aerospace went bankrupt trying, as well as Sino Swearingen and the follow-up association Emivest Aerospace. Several enterprises engage in developing entry models; yet even there, the market hurdles appear to be relatively high as could be seen in the spectacular downfall of promising Eclipse Aviation.

To date, about 40 business jet models are in production, several are in an advanced state of development. Since SSBJs are commonly agreed to become a heavy and very

costly class of airplanes, only the largest business aircraft are interesting as a reference. Among these, so-called ultra long range jets represent the performance leaders. Three manufacturers are contending for this particularly profitable market segment: Bombardier with its Global 6000, Dassault Falcon with the 7X and Gulfstream with its G550. And the next generation is already projected: Gulfstream's G650 is being flight tested and is scheduled for delivery in 2012. With a \$64.5M price tag, it is to become the most expensive business jet ever, and yet, (or as a consequence, respectively,) more than 200 orders have accrued. Bombardier announced the introduction of the Global 7000 and Global 8000 in a few years; they are expected to surpass the G650 both regarding price and performance. TABLE 1 depicts specifications of the most sophisticated business jets at present.

<b>TABLE 1. High end business jets [1]</b>	<u>Bombardier Global 6000</u>	<u>Dassault Falcon 7X</u>	<u>Gulfstream G650</u>
Purchasing price	\$53.25M	\$48.6M	\$64.5M
Service entry	2003	2007	2012
DOC/h	\$2984	\$2085	n/a
Typical crew (flight deck + cabin)	2 + 2	2 + 1	2 + 2
Passengers, typ. / max.	8 / 19	12 / 19	16 / 19
External dimensions (m): length/span/height	30.3 / 28.7 / 7.8	23.2 / 26.2 / 8.0	30.4 / 30.4 / 7.8
Cabin dimensions (m): length / width / height	13.2 / 2.50 / 1.92	11.9 / 2.35 / 1.89	14.3 / 2.59 / 1.95
Max. thrust	2 x 65.6 kN	3 x 28.5 kN	2 x 71.6 kN
Max. takeoff weight	44,450 kg	31,300 kg	45,179 kg
Max. fuel weight	20,170 kg	14,490 kg	20,050 kg
Long range cruise speed	470 kn (870 km/h)	459 kn (850 km/h)	488 kn (904 km/h)
High speed cruise	499 kn (924 km/h)	498 kn (922 km/h)	516 kn (956 km/h)
Max. cruise Mach	0.89	0.90	0.925
Balanced field length	1,887 m	1,693 m	1,829 m
<i>NBAA IFR ranges (200 nm alternate):</i>			
Max. payload	5,756 nm	4,820 nm	n/a
Max. fuel	6,274 nm	5,755 nm	n/a
Reference pax	6,305 nm (4 pax)	5,850 nm (4 pax)	7,000 nm (8 pax)
Ferry flight	6,408 nm	5,930 nm	n/a

It shall not be unmentioned that Airbus and Boeing offer planes for private purposes as well, which are either highly luxurious or fitted with all-business class seats. Those are

predominantly derivatives from 737 or A320 models and their basic price is comparable to the cost of the most expensive business jets. About 15 to 20 so-called bizliners are delivered yearly. Yet, such jets are ordered to satisfy exalted space requirements and thus are not considered apt as a reference for distinctly smaller SSBJs.

## 2.2. Reasons for the use of business aircraft

Business aircraft are valued for their flexibility. An owner or user can fly them to any place, at any time. He is not dependent of fixed airline schedules, and he can change the destination even in the middle of flight.

Moreover, business planes provide for safety, privacy and a good working environment. Usually, the occupants are an associated travelling group which makes it possible to use the time in the "flying office" productively, by having team meetings, for instance.

Also, private jets are said to present adequate ambience for fostering social contacts. The airplane often imposes a lasting impression upon business partners or guests.

But mostly, considerable amounts of time can be saved by using business aircraft which is especially precious for high net-worth individuals or in situations with time pressure. Circumstantial check-ins, security controls and delays at crowded airports are avoided. Destinations can be reached in more direct ways; it is even possible to visit several of them on one day. For these reasons, business jets are occasionally described as "time machines".

## 2.3. Modes of operation for business aircraft

Business jets are, in several aspects, the air travel counterpart to limousines with a driver. They are predominantly flown "on-demand" or "non-scheduled". Quick dispatchability is paramount – the operator often guarantees the owner or customer a maximum duration after which the aircraft has to be available.

Business jets operate on large international airports rather seldom, since slots are preferentially given to airlines. In most cases, general aviation or regional airports like London-Farnborough (FAB), New York-Teterboro (TEB) or Paris-Le Bourget (LBG) are used since they provide for quick access and dispatch and they charge lower fees. Plus, many small airports have specialised for business aviation, offering MRO services.

According the National Business Aviation Association (NBAA), only 550 airports in the US are serviced by airlines, whereas over 5,000 are used by business aircraft. Thus, business airplanes are said to often not replace the airline flight, but to fly routes that airlines don't offer at all.

Below, several modes of operation for business aircraft are presented.

### 2.3.1. In-house flight departments

Most business planes are operated by companies whose business model is not directly attached to the operation of

their airplanes and which run an own flight department [2]. Among those, there are many global enterprises; but most of them are U.S.-American small businesses that incur increased demand for service or consultation.

These so-called corporate flight departments usually lease or own only one or two airplanes. Operations are managed by a proprietary team at an airport near the company and in an own hangar. Maintenance tasks are sometimes given to local MRO suppliers.

### 2.3.2. Governmental flight departments

Most governments of larger countries own and operate own fleets. The aircraft are mostly used for VIP transportation, but also for aerial surveillance, as command bridges in military scenarios and for cargo transportation. Usually, their fleet encompass several aircraft. [2]

### 2.3.3. Charter

Charter airplanes (and helicopters) in air transportation are correlated to taxis in road traffic. The client only names time and destination and subsequently betakes himself in the hands of the charter company. For him, only the cost of operation plus a profit margin are charged, which is particularly attractive in case of low travel demand.

About one quarter of all business jets are run by charter companies. Their fleets often span several planes of different size and make of advanced age. [2]

### 2.3.4. Aircraft management

The occurrence of owner operated aircraft diminishes with aircraft size. Turbine driven jets or turboprops are mostly given to the hands of a company that offers administration, operation and maintenance of third-party aircraft. The client pays a monthly fee and the direct operating cost which is passed on to him without surcharge.

In order to use the airplane productively in non-occupied hours, many clients allow the operator to charter out their aircraft. Since most of the charter companies cannot afford their own airplane, these "managed airplanes" constitute the backbone of the charter industry. The companies keep 15% of the flight charge by default and pass the rest on to the owner. [3]

### 2.3.5. Fractional aircraft management

So-called fractional companies offer a special kind of third-party operation. Clients purchase a fraction or „share“ of an airplane from the company which can be between 1/32 or one half, but mostly 1/16 to 1/4. Aside from ownership cost, a monthly management and maintenance fee is charged, plus a usage fee for the plane and fuel cost.

According to his ownership share, the client gets the same fraction of the yearly occupied hours which are fixed to 800 in total. As a consequence of the business model, clients seldom travel in their own plane as their jet will be in service for another client or in a remote place at most times.

Nearly the whole market is controlled by four U.S. companies: NetJets, Flight Options, Flexjet and Citation-Shares. Among these, NetJets is the biggest, operating 400 of about 1,000 fractional aircraft worldwide, aside from being the only fractional company with branches outside the U.S., namely in Europe.

## 3. SUPERSONIC FLIGHT

### 3.1. Physical characteristics

Flying beyond sonic speed, physical phenomena appear that complicate the technical and economically sustainable feasibility of supersonic flight concepts dramatically and that are ultimately responsible for civilian supersonic flight not having been able to make a breakthrough.

To name the greatest handicaps of supersonic design: Wave drag; entirely different speed regions during flight missions; engine noise at takeoff; hull heating; movement of the aerodynamic center; cabin pressurization. Yet, for operational aspects, the sonic boom is of highest relevance.

As long as an object moves faster than the speed of sound (Mach 1) in the atmosphere, it trails detonation shocks which are perceived as sudden double bangs in some distance. The pressure fluctuation can at worst cause damage to people or buildings on the ground. With airplanes the size of business jets, it can be assumed that physical damages occur utmost seldom. However, the mental effect, namely the shock "out of the blue", is verified to be unacceptable for considerable fractions of the public [4].

### 3.2. The supersonic overland flight ban

By the time the power of Concorde's sonic boom became generally known, nearly all industrial countries enacted laws to constrain supersonic flight over land. Usually, the boom was not allowed to reach the ground, which means that supersonic flight up to the so-called "cutoff Mach number" (about 1.15) is allowed which is the case in Germany (LuftVO §11a), for instance. Only the U.S. ban supersonic civil flight entirely (FAR 91, §817).

This restrictive, albeit quite justified legislation is effective to this day, having highest influence on weal and woe of any supersonic transport. It definitely prohibited a greater success of the Concorde program. Any abolition, relaxation or modification of the regulations is only probable on the long run.

### 3.3. Known SSBJ designs

SSBJs have been studied since the middle of the 1980s. Russian Sukhoi OKB exhibited the design of a plane called S-21 in 1989. It was intended to reach double sonic speed and to transport 8 to 12 passengers over distances of 4000 nautical miles.

In spite of intermittent co-operation with Gulfstream, the project had as little success as several others to follow.

TABLE 2 shows the most serious designs in our eyes.

Remarkably, since those days, the specifications have remained the same: Nearly all designs address the transportation of about 8 persons on ranges of 4000 nm. Speed is never the primary parameter of optimization. It only needs to be well above the speed of sound.

### 3.4. Low-boom design

So-called low-boom jets constitute the most recent trend in SSBJ design. By expert shaping of the aerodynamic hull,

the acoustic signature can be manipulated in a way that the boom is perceived less intensely on the ground [5].

The downside of hitherto existing low-boom concepts is the serious surrender of aerodynamic efficiency which reflects in the takeoff weight of such designs (see TABLE 2). The QSST drafted by Lockheed Martin's Skunk Works for instance was claimed to produce a sonic boom that would have 1/100th the strength of Concorde's. At the same time, its planned takeoff weight turned out to be 70% higher compared to the Aerion's which was designed for about the same mission and payload requirements.

<b>TABLE 2. SSBJ designs</b>	<b>Aerion SBJ</b> {Nat. lam. flow wing} [aerioncorp.com]	<b>SAI QSST</b> {Low boom} [6]	<b>Tupolev Tu-444</b> {conventional} [www.tupolev.ru]	<b>Sukhoi S-21</b> {3 engines/ conventional}	<b>HISAC-A (Dassault)</b> {3 engines/convent.} [hisacproject.com]	<b>HISAC-B1 (Alenia)</b> {Nat. lam. flow wing} [hisacproject.com]	<b>HISAC-C (Sukhoi)</b> {Low boom} [hisacproject.com]	<b>Uni Stanford</b> {Low boom}	<b>Hawker/Raytheon</b> {Low boom} [7]
Design year	2010	2009	?	1993	2009	2009	2009	2010	2009
Purchase price planned (\$)	80M	80M	50M	50M	-	-	-	-	-
Design range (nm)	4000	4000	4000	4000	4000	5000	4000	4000	5000
Design cruise Mach	1.5	1.6	2	2	1.6	1.6	1.8	1.6	1.8
Passengers (typ. / max.)	8 / 12	8 / 12	6 / 10	8 / ?	8 / ?	8 / ?	8 / ?	6 / 8	6 / 8
Length (m)	45.2	40.3	36.0	40.5	36.8	41.6	40.9	38.1	50.4
Span (m)	19.6	19.2	16.2	19.9	18.5	24.0	19.1	20.0	21.0
Max. thrust (kN)	174.4	294.0	190.3	220.7	220.0	313.5	292.6	?	226.0
Max. takeoff weight (t)	40.8	69.4	41.0	51.8	51.1	60.5	53.3	43.1	54.1
Balanced field length (ft)	6000	7500	6000	6500	6266	6119	6375	6255	6000
Sonic boom intensity (dBA)	-	55	-	-	86	85	68.5	77.7	(.4 psf)

## 4. MARKET ASSESSMENT

### 4.1. Business aviation analysis and forecasts

Sales of turbine powered business aircraft totalled \$24B in 2008; more than 1300 planes were rolled out. This was the apex of a boom lasting several years, followed by the shock of the world financial crisis starting in the middle of 2008. However, all serious forecasts [8, 9, 10, 11] are expecting recovery on the long run, mainly driven by the unrelenting demand from booming emerging markets like Brazil, Russia, India and China. The US market appears to be comparatively sated and slow.

Prior to the worldwide economic downturn, the revenue caused by large jets – those costing more than \$24M – traditionally encompassed about half of the total turbine airplane market. In 2009, deliveries for the lower business aircraft segment (\$4M - \$24M) fell a catastrophic 42.8%, whilst for more expensive jets, only 4.1% less were delivered. The upper market proved remarkably immune to economic fluctuations and largely decoupled from the most reliable indicator for the business jet market which is corporate profits. [11]

In the medium term, high end jets are expected to be the most important growth driver regarding worth. Price does not appear to be an obstacle, rather the contrary. Price elasticity is very low in the upper segment; some clients

seem to be willing to pay about any sum just to own the best product the market has to offer. [12]

In 2008, there were 16,000 business jets and 10,000 operators worldwide; thus, the latter are responsible for only one plane in most cases. The U.S. still own more than double as much jets compared to the rest of the world. [11]

Regarding long range jets, only 59% are stationed in the U.S. Since 2007, more than half of the new aircraft have been delivered to the rest of the world. These days, more than 200 long range jets are rolled out yearly (see FIGURE 1).

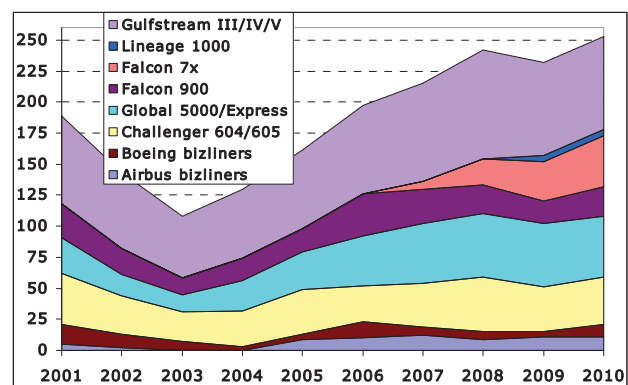


FIGURE 1. Long range business jet deliveries



At this time, about 2,500 high end business jets of newer year of construction (price > \$30M, not built before 2000) are in service. This information was obtained by a data call from the ACAS data base (AirCraft Analytical System, flightglobal.com) on October 25th, 2010. From the same source, the operational figures of some aircraft models could be derived, see TABLE 3.

<b>TABLE 3. Business jet utiliz.</b>	<b>Mean mission block time (h)</b>	<b>Mean yearly utilization (h)</b>
Challenger 604	2,02	342
Global 5000	2,59	248
Global Express	2,73	281
Falcon 2000	1,66	270
Falcon 2000EX	1,68	378
Falcon 50EX	1,59	278
Falcon 900EX	2,17	340
Legacy 600	2,04	289
G450	2,01	216
G550	2,51	329

Obviously, large business jets are predominantly operated way below capacity, regarding mission range as well as regarding utilization. For one, all jets listed are able to cruise for at least 8 hours. Further, fractional companies manage to have their jets flying more than 800 hours per year; airliners usually chalk up 3,000 to 4,000 hours.

## 4.2. Calculation of operating cost

In order to be able to estimate the cost of operation for SSBJs, a semi-empirical model was developed. Its main purpose is not finding exact costs but to provide a means of cost comparison between subsonic and supersonic business jets.

### 4.2.1. Modelling method

The tool created is geared to a well-established software that calculates variable operating cost and yearly fixed cost. With the help of publicly available cost breakdowns of several aircraft types, arithmetical correlations were found for single cost items by regression. However, some items cannot be reproduced without insider knowledge; they had to be obtained by best guessing.

In short, variable cost per hour encompasses fuel, maintenance, engine parts, engine overhaul, landing fees, crew expenses, and catering. Annual fixed cost includes crew salary, hull insurance, refurbishment reserves, a computer maintenance program, and weather service. Depreciation cost is calculated by multiplying a prevalent interest rate with the aircraft price. Total cost is the sum of said items.

The greatest expenses by far when operating SSBJs will certainly result from ownership on the one hand and from fuel consumption on the other hand. These two items are easy to determine for known designs. Thus, results of good validity can be expected regarding cost of SSBJs.

### 4.2.2. Results

In order to compare total cost, calculations were made for

the Aerion jet as well as for the low boom designs HISAC-C and SAI QSST (see TABLE 3), assuming unrestricted cruise speed (Mach 1.5 or 1.8 and 1.6 respectively). Purchasing price was set to \$80M for all SSBJs, fuel price was set to \$5.41 per gallon which was about the average of 2010. As a reference, the 7X by Dassault Falcon and the Global 5000 by Bombardier were chosen.

First, we took the *demand constrained* perspective of a non-commercial owner and user who has a fixed yearly need for travel. This need was assumed to be 200,000 nautical miles which translates to realistic 465 flight hours per year, implying an average flight velocity of 430 knots.

In this case, total cost of travel (cost regarding distance), resulting from variable and fixed cost as well market depreciation, is clearly higher for SSBJs compared to their subsonic counterparts (see FIGURE 2). For a user with limited travelling requirements intending to acquire a SSBJ, the higher speed and the promise of prestige has to outweigh the monetary disadvantage. This correlation has proven to be valid for any magnitude of travel need.

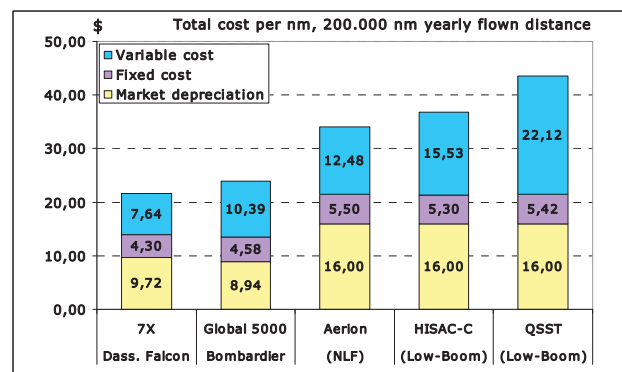


FIGURE 2. Cost of travel, fixed demand

Next, we took a *supply constrained* perspective. Commercial operators usually intend to utilize their aircraft well in order to compensate their fixed cost as soon as possible. For instance, fractional companies aim for 800 block hours yearly on their jets; more hours cannot be attained for operational reasons.

The *cost of operation* (hourly cost) of the supersonic jets is more than double compared to the traditional business jets, presenting a high entry threshold (see FIGURE 3).

The picture changes when looking at *cost of travel*: While it still soars high above all others for the low-boom QSST, it is only slightly higher for the efficient Aerion jet and the moderately boom-optimized HISAC-C compared to the subsonic long range jets (see FIGURE 4).

By means of this moderate rise in travel cost and considering their additional productivity, efficient SSBJs pose an interesting business option for commercial operators. For one, fractional companies would be able to sell about double the aircraft shares, since the user would only require half of the flight time for the same travel need.

Even in the likely case of doubling fuel cost, the ratios presented degrade only marginally to the disadvantage of the SSBJs.

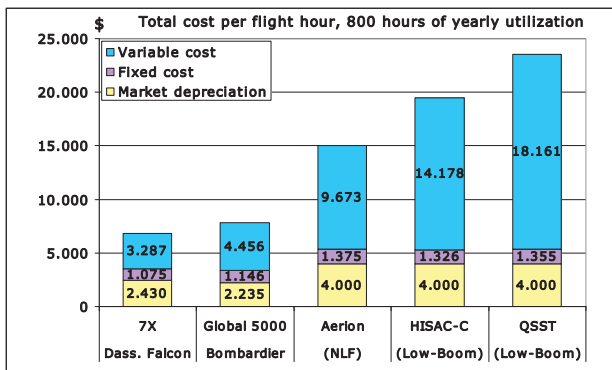


FIGURE 3. Cost of operation, fixed supply

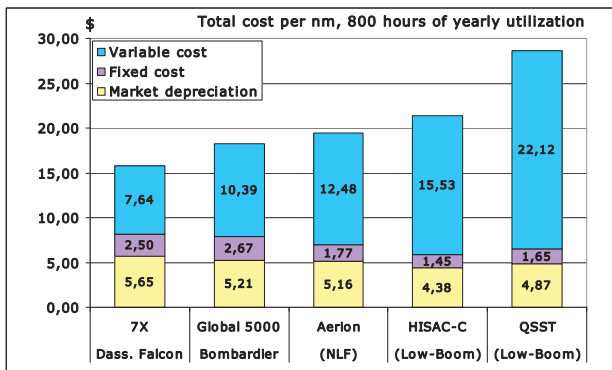


FIGURE 4. Cost of travel, fixed supply

### 4.3. Analysis of traffic volume

European air traffic control agency EUROCONTROL provides exact statistics regarding flight movements in, from, and to Europe. It is even possible to have dedicated business aviation flows. As Europe is too small for long haul flights (supposed to be further than 2500 nm), only incoming and leaving flows were taken into consideration.

Movements between Europe and North America account for the great majority (see FIGURE 5), followed by those to and from Arabia (Saudi-Arabia and UAE). Strong seasonal fluctuations differing between regions can be noted. Also, business flight movements are strongly dependent of the economic situation: From the peak in 2007 until 2009, they slipped about 25% on average (not shown here).

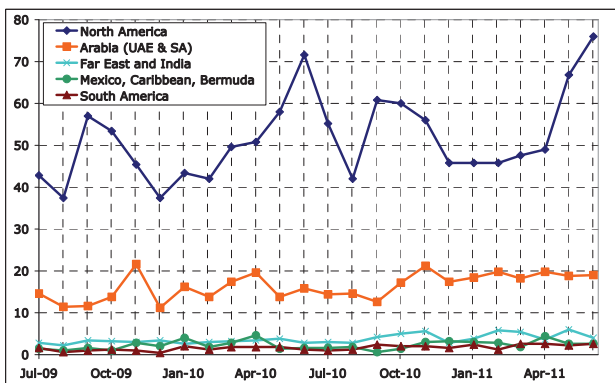


FIGURE 5. Average daily business flights to and from Europe regarding various world regions

For the rest of the world, data about long haul business aviation flows is not available. Yet, considering the fact that North America and Europe account for about 80% of long range jet ownership, we assume that most long haul business flights are taking place in the North Atlantic and that this situation is going to persist for quite some time. The next important region appears to be the Northern Pacific, followed by North America-Middle East flights. All these routes have high overwater percentages. Even flights between the U.S. East Coast and the Middle East are possible with detours of as little as 5% of the great circle distance if routing them over the Mediterranean Sea.

### 4.4. A survey among business jet operators

In order to learn the opinion of decision makers from the business aviation sector and to collect key figures of flight operation, an internet based questionnaire was created. Subsequently, companies were addressed that manage large, long range business jets.

In total, 718 survey invitations were received by the addressees and 93 questionnaires were completed. We were able to gather the following set of data (whereat slight corruption to the favour of the participants, whether committed knowingly or not, should be reckoned with):

- The great majority of long range jets is flown 300 to 600 hours yearly. (Compare to CHART 3.)
- About 60% of the routes flown are less than 3,000 nautical miles of distance. (Compare to CHART 3.)
- On more than 80% of long haul flights, 6 passengers are transported at most; 7 to 9 seats are considered sufficient for most of these flights.
- For a SSBJ, 10 to 13 seats are desired; 7 to 9 are seen as a minimum.
- Regarding the adequate range for most long haul flights, 5,000 nm are given in most cases.
- The ideal range for a SSBJ is more than 5,000 nm in the eyes of most participants; as a minimum, 4,000 nm would be accepted.
- The average overwater percentage of the departments' long haul flights is widely spread, yet it tends to be less than 50%.
- Most of the survey participants guess the chance for their flight department acquiring a SSBJ in spite of an overland flight ban to be zero. In case the ban is lifted, the chance is seen as 50% in most cases, but still tends to be negative.
- As a benchmark, a 10 hours flight in a large cabin, long range jet was given (perhaps a Gulfstream V or a Bombardier Global Express). Subsequently, participants were asked to estimate the monetary benefit of a 7, 6, 5, or 4 hours flight respectively in a midsize cabin SSBJ (comparable to a Gulfstream G200 or a Bombardier Challenger 300 cabin) with regard to the former flight. The benefit of the 7 hours flight is estimated to be 16% on average; in case of 6 hours: 27%; 5 hours: 48%, 4 hours: 74%.

The results gained give valuable insights regarding the operation of current long range jets. Also, they leave the impression that operators are not outright enthusiastic about the prospect of supersonic business jets, even more so assuming that the ones having answered our call belong to the rather positive fraction of the industry.

## 4.5. Potential consumers of SSBJs

### 4.5.1. Corporate flight departments

Given the high cost, it will predominantly be large corporations that will be able to afford a SSBJ. Such firms often possess several aircraft, and a SSBJ would perfect their fleets on the upper end.

However, the management needs to be able to convincingly justify the acquisition of an airplane in front of the board and the shareholders, which might be an issue regarding the poor utility of a speed constrained SSBJ on the one hand and on the other hand, the even higher operating cost as well as possibly bad publicity caused by a low boom jet.

All told, we estimate the possible corporate demand for SSBJs to be rather low.

### 4.5.2. Government agencies

Low boom jets could be the ultimate means of transportation for government officials where time savings are prized much higher than operating cost. Also, power will be represented adequately by a prestigious SSBJ. The military and secret services will doubtlessly have interest in supersonic airplanes for passenger transportation, first and foremost as a means to quickly respond to emerging political developments.

Quite independently from the size of the jet, it can be assumed that at least large industrial and emerging nations are going to order several copies. In case of speed constrained jets, a considerably smaller market has to be expected as time advantages diminish in many cases. The size of the jet is thought to be comparatively irrelevant. Being able to transport a team over long distances in supersonic speed should be reason enough to buy one.

The market potential for governmental use could prove substantial. However, governmental agencies are neither likely to act as launch customers nor to dictate requirements for civil aircraft. For these reasons, this mode of operation should not be considered for the layout of SSBJs.

### 4.5.3. Private individuals

Private individuals buy long range jets predominantly for prestige reasons. They often use them to fly on holidays where flight duration is quite unimportant. Also, they frequently have their plane run and chartered out by management companies to increase its otherwise marginal utilization.

Anyway, a supersonic business jet would pose the ultimate status symbol, similar to a super sports car that can gladly be presented to ones guests and that is not in use very often, while a SSBJ is of a whole different magnitude. One can speculate that many a Russian oligarch, an American billionaire, super rich Chinese, Indians, sheikhs will strive for a copy. In those circles, money plays a subordinate role; the main point is occupying a superlative.

This group represents strong market potential. At the same time, the specifications of a SSBJ should be of low importance as long as it reflects a passable utility. Bigger will certainly be better, but if a small group can be fitted in neatly, that fact should give enough reason to buy one. Consequently, the wishes of this group should not be regarded as direct requirements; yet, their standards for room and comfort need to be taken into account.

### 4.5.4. Charter companies

There are only a handful of charter companies in existence worldwide that operate their own new long range jets. For this reason, their wishes are of little relevance when designing aircraft, the more so as they widely match the needs of private owners. A purchasing demand for SSBJs is estimated to be hardly present.

### 4.5.5. Fractional companies

Since a speed constrained SSBJ will be inflexible and a low boom jet will be all the costlier, in most cases, the benefit will come out too low for a prospective buyer judging upon usefulness so as to aim for full ownership. However, a SSBJ can be of real value, especially when the cost of travel is only slightly higher compared to large long range jets, as has been described in 4.2.2.

This situation renders the fractional model very attractive for supersonic business aircraft. In comparison to full ownership, only a marginal investment is needed for benefitting from supersonic travel on the seldom flown long haul. Especially companies that less care for prestige than for the time of their employees and that do not have the need to fully utilize a SSBJ would probably embrace such an offer.

Under objective circumstances, this business model should be able to support more SSBJs than full ownership. Yet, it is all but certain that the oftentimes loss-making fractional companies would take the risk of an entry investment worth hundreds of million Dollars for a fleet of SSBJs. We estimate that, if anything, a dozen SSBJs will be acquired and deployed in London and New York in order to test the market. Great initial euphoria is not to be expected from the side of fractional firms.

## 4.6. Synthesis of market estimation

Seeing the market share and future potential of long range business jets, a success of a SSBJ program appears to be at least imaginable. 200 of the largest, heaviest and most expensive jets are sold per year, and this segment is thought to have the greatest growth potential. Diverse market analysis [12, 13, 14, 15] justify starting a SSBJ development with a yearly demand of about 20 SSBJs. This number does not seem unrealistic today and even less so for the future. Nevertheless, a sufficient demand is neither certain nor verifiable. Thus, it can be understood why no established manufacturer has ever committed itself to a full fledged SSBJ program.

In any case, one has to assume that none of the modes of operation mentioned will alone suffice to warrant the development of a SSBJ, as has also been denoted by

Chudoba et al. [16]. For this reason, a SSBJ design should always allow for additional applications, as an express cargo transport or as a small airliner, for instance.

Furthermore regarding the sonic boom issue, it is difficult to tell which concept will perform best on the market for small supersonic transports: A design centered upon efficiency (like the Aerion jet) that neglects its sonic boom and thus becomes uneconomic when often used on overland flights? Or a design strictly trimmed for boom reduction (like the SAI QSST) that – in the arguable case of lifted bans – will be deployable worldwide, while being very costly and likely to face strong political headwinds concerning its environmental impact when its excessive fuel consumption becomes widely known?

Given the present socio-cultural mainstream and respective topics (e. g. sustainability, renewable energies, climate change, air pollution, economy crises, executive bashing), it cannot be assumed that in the foreseeable future, parliamentary majorities will gather to lift civil supersonic overland flight bans. Supersonic jets are prone to condemnation as anachronisms.

For this reason, we hold the more promising approach to be an efficient, conventional design that bears less risk and cost and that does not require legislative changes, instead of having to get across to politics and society with a very controversial low boom concept that additionally represents potential nuisance and that will probably be subject to severe regulatory burdens.

Ultimately for jets with strong sonic boom, commercial operation seems to be more likely, ergo done by fractional or charter companies (if not even airlines), where a small supersonic transport can be dedicated to overwater routes and where fuel efficiency overrides flexibility. On the other hand, private individuals, companies, and government agencies that value their freedom to fly supersonic anywhere higher than the extra charge on operating cost will probably prefer a low boom jet.

## 5. SSBJ REQUIREMENTS DEFINITION

Below, the most promising top level requirements for supersonic business jets are presented from our view.

### 5.1. Cruise speed

Regarding cruise speed, requirements from possible modes of operation are less decisive than, in fact, technical feasibilities regarding engine layout. For this reason, cruise speed should adapt to technical conditions within certain limits.

The primary purpose of propulsion is accelerating the airplane through the drag intensive transonic speed regime (about  $0,8 < Ma < 1,2$ ) to its supersonic cruise speed and keeping it there for a longer period of time: The faster the airplane, the higher the necessary exhaust jet velocity and the lower the ideal engine airflow bypass ratio. Simultaneously, high exhaust jet velocities result in loud engines on takeoff. In order to meet present and future

stringent noise abatement regulations, an engine basically needs a bypass ratio as high as possible. This would result in large engine cross sections and consequently in high supersonic drag. These requirements are contradictory: The higher the desired cruise speed, the less probable is complying with takeoff noise limits.

Furthermore, starting at about Mach 1.7, variable engine inlets are required to prevent major total pressure losses and the dwindling efficiency accompanying the former. Variable inlets are complex to develop and to maintain; for this reason, they should be avoided on SSBJs. Besides that, the most efficient flight levels increase with speed, and so does the harmfulness of emissions into the atmosphere. Also for reasons of hull heating, implying the use of non-exotic materials, Mach 1.7 is considered the upper limit.

In the end, a cruise speed as high as possible *between Mach 1.2 and 1.7* should be aimed for. However, future noise regulations will significantly determine the final possibilities.

### 5.2. Cabin and capacity

The mentioned survey showed that private long range flights seldom carry more than 6 passengers. As a minimum, 7 to 9 seats were chosen, which hereby is deemed appropriate.

Double club seating which predominates in medium sized business jets is well suited for this application. Optionally, two seats can be interchanged with a 3 person sofa. The aisle should be at least 1.85 to 1.9 meters high to provide for adequate headroom for people used to larger jets.

### 5.3. Range

The unique selling point of a supersonic jet is its speed. Even if it has to refuel on longer missions, it is still going to arrive a lot earlier than any other civil airplane. The longer the distance, the greater can the willingness of the passengers be assumed to accept a technical stop.

This means that creating a small supersonic airplane for very long distances makes little sense, particularly because technical requirements and costs increase enormously compared to a less ambitious design. Yet, the most important missions should be accomplishable without refuelling to center the maximum benefit of a SSBJ upon this market.

Thus, a SSBJ should at least be able to cover all routes between the U.S. East Coast and Western Europe, as shown in 4.3. For this purpose,  $7,400 \text{ km} = 4,000 \text{ nm}$  is considered adequate. This way, Miami, the most remote East Coast metropolis, can be connected to London, Paris, and Madrid. In the next important region, the North Pacific, a range of at least 7,515 km would be required just to bridge the closest metropolises, Vancouver and Tokyo. Also, a minimum range of 4,000 nm emerged from our survey. We regard said range, flown with 6 passengers and NBAA IFR reserves, as an optimum.



## 5.4. Runway length

For being able to use the same runways as long range business jets, SSBJs need to feature a so-called balanced field length (BFL) of about 6,000 ft (see CHART 1). Considering CHART 2, BFLs between 6,000 and 6,500 ft appear realistic from a technical viewpoint. We shall now assess whether this requirement is really obligatory with regard to operability.

First of all, a SSBJ should be able to operate on as many general aviation (GA) airports as possible. Since a SSBJ can only adequately exert its speed advantage on intercontinental flights, relevant airports should additionally be open to international travel. That means they have to be declared as airports of entry (AoE) and they have to dispose of their own customs office, which becomes increasingly seldom with decreasing airport size and runway length accordingly.

For SSBJs, airports near large economic centers have to be considered in particular, as most long haul business flights will supposedly take place between such areas. A list of several dozens of the most relevant metropolises and their airports was compiled by the authors. It became clear that in most cases, only western cities have proprietary GA AoEs. Yet, all others can be reached by business aircraft via their international hubs, often without slot restrictions. It can be assumed that in the latter case, the runway length will always suffice.

Important GA AoEs with runway lengths short of 8,000 ft are regarded as critical, in case their respective hub requires slots or is remote from the city center or generally sees little business aviation. At least one of these criteria is fulfilled by the following airports:

– Rome-Ciampino	CIA	7,244 ft
– London-Luton	LTN	7,087 ft
– Jorge Newbery (Buenos Aires)	AEP	6,890 ft
– Chicago-Midway	MDW	6,522 ft
– Roskilde (Copenhagen)	RKE	5,900 ft
– Stockholm-Bromma	BMA	5,472 ft
– Seletar (Singapur)	XSP	5,223 ft

London Luton Airport is the most important GA airport of entry nearby the world's most important financial center; from here, a SSBJ should be able to lift off with maximum takeoff weight in any case. In Buenos Aires, slot-free Ezeiza hub could be used to refuel in case of need. The runways of Roskilde, Bromma, and Seletar appear too short anyway; slots will need acquiring. In Chicago, a very important economic area, there is no reasonable alternative to Midway Airport. Yet, it seems exaggerated to postulate a BFL that is 500 ft shorter only for this reason.

In summary, we do not see the necessity for a BFL of 6,000 ft. 6,500 ft are regarded as desirable, a *maximum* of 7,000 ft is definitely essential.

The landing distance of jet aircraft is generally shorter than their BFL. Anyway, it should also be 7,000 ft at most.

As low boom SSBJs tend to require increased flexibility in order to meet the needs of their users, they might have to allow for operation on even shorter runways.

## 6. CONCLUSION

In the present work, the market environment for supersonic business jets (SSBJs) was discussed under consideration of different consumers and modes of operation. The work included analysis and forecasts for the whole business aviation segment, assessment of past SSBJ designs, an operating cost model, air traffic data and a survey among large business jet operators.

We found that both non-commercial entities and commercial operators come into consideration as SSBJ users, the former rather regarding low boom, the latter rather regarding conventional SSBJs. Commercial modes of operation appear to pose a sensible business case, since while being a lot more productive, only a moderate increase in travel cost has to be taken. Yet, there is probably no strong demand from one single application that would justify the development of a SSBJ. Hence, the aircraft should be designed in a way that it can be used miscellaneously.

Following this appraisal, top-level requirements for the SSBJ to be designed within the project VIP-3 were drafted: A cruise Mach number short of 1.7, a cabin for about 8 persons, a still air range of 4,000 nautical miles, and operability on 7,000 ft runways were deemed adequate.

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