AA-1-2008-053
Point-to-Point Sub-orbital Space Tourism: Some Initial Considerations

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Abstract

Several public statements have been made about the possible, or even likely, extension of initial sub-orbital space tourism operations to encompass point-to-point travel. It is the purpose of this paper to explore some of the basic considerations for such a plan, in order to understand both its merits and its problems. The paper will discuss a range of perspectives, from basic physics to market segmentation, from ground segment logistics to spacecraft design considerations. It is important that these initial considerations are grasped before more detailed planning and design takes place.

1. Introduction

Orbital space tourism is now a well-accepted and understood phenomenon. Orbital space tourism began with Denis Tito in April 2001 (or arguably almost a decade earlier with the Japanese journalist Toyohiro Akiyama in December 1990). Up to now, all orbital space tourism flights have taken place using Russian Soyuz vehicles, from the Baikonur space center in Kazakhstan, with a space station as a destination (Akiyama and Sharman both flew to Mir, Tito and all subsequent orbital space tourists flew to the ISS). The two earlier flights were paid for by private agencies; Tito and subsequent true space tourists paid for their flights from their own resources. The general price level is understood, and is of the order of \$20 - \$30M per trip. The orbital space tourists generally remain in orbit for one or two weeks. Several entrepreneurial US companies have been trying to develop an indigenous system that will deliver tourists into orbit (and cargo and astronauts for the ISS), but so far no US flight-proven hardware exists to do this, and no US spaceport has been singled out to host these flights.

Sub-orbital space tourism is about to begin with the Virgin Galactic flights of SpaceShipTwo from Mojave spaceport in California, probably in 2010. Two civilian pilots (Melville and Binnie) have already ridden into sub-orbital space on board the predecessor spacecraft SpaceShipOne during 2004. This sector of the space tourism business is also well characterized now. The price level is of the order of \$100K - \$200K per trip. Take off and landing is from the same spaceport. The apogee of the flight meets the international definition of space at 100km or about 62 miles. Besides Mojave, other spaceports are being developed and licensed to provide a launchingoff point for sub-orbital space tourism (examples include New Mexico and Oklahoma). Several competing systems are being developed to provide options for the sub-orbital space tourist, and they offer a variety of architectures. However, they have in common that the true duration of the spaceflight experience itself is only about 5 minutes near the flight's apogee.

Market surveys have established that commercial demand exists for both orbital and sub-orbital space tourism at these established price levels.

However, an entirely different category of private commercial spaceflight has been proposed, known as *point-to-point sub-orbital* space flight (see Fig 1). The characterization of this kind of space flight is not nearly so well established as is the case for the former two categories. Credible market studies have not been done, or at least published. The optimum technical design has not been established. The ground infrastructure is not in place. Price levels are uncertain. It is not even clear whether such flights are best characterized as tourism or as transportation; whether the passengers would be primarily tourists or business persons on urgent trips; or indeed whether the demand would be primarily military. It is not established whether the market for this capability would be for people or cargo, or for combinations of both. The author believes that it is important that some of these fundamental issues are addressed before work proceeds on detailed design for a vehicle aimed at serving this market. Clearly, the design, and even sizing, of such a vehicle would vary significantly depending upon the resolution of some of these issues. This paper attempts to create a frame of reference for discussing the main aspects of this new sector, in order to provide some clarity for industry planners.

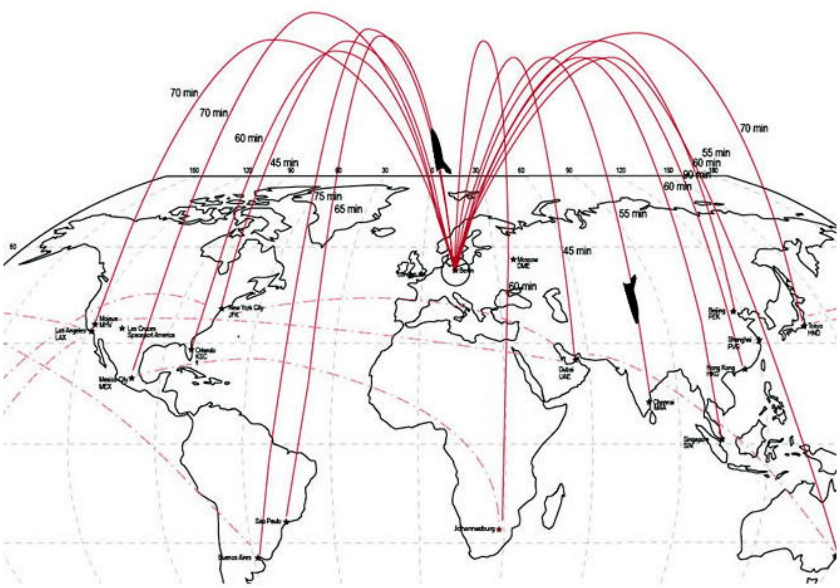

Fig 1 Point-to-Point Sub-orbital Space Travel Routes
(Courtesy Spaceport Berlin and www.spacetransport.de)

2. Basic Physics of Point-to-Point Sub-orbital Spaceflight

There are a number of aspects of the proposed new class of space travel that are constrained by the laws of physics. So it is clearly important to appreciate these limitations before proposing any impossible design objectives.

Perhaps the most basic fact of life is that it takes 90 minutes to orbit the Earth at altitudes of 100 miles or so. As the altitude increases beyond this level, the time period increases, until of course at Geostationary altitude, a spacecraft takes precisely one day to orbit the Earth. We cannot go faster in free fall than the 90 minutes around the Earth, or 45 minutes to go halfway around the Earth (say from London to Sydney).

As a consequence of this, we see that the speed for orbital travel, or shall we say point-to-point hemi-spherical travel, is very high at around *17,500 mph*. This is significantly greater (an order of magnitude greater) than the speed needed for sub-orbital lobs above a spaceport. When the sub-orbital spacecraft reaches its maximum altitude, of say 62 miles, then its horizontal speed is almost *zero*. From this comparison, we can see that the intercontinental point-to-point space travel has more in common with *orbital* travel or ICBM trajectories than with *sub-orbital* lobs. The implications of this, except for the special case of sub-orbital lobs to spaceports in close proximity to the point of takeoff, are discussed in Section 5 below, but include major design challenges for handling the trans-atmospheric and re-entry phases.

To perform an intercontinental point-to-point trajectory, a vehicle must be designed that can both attain the speeds necessary, and manage the thermal environment of transiting the atmosphere both during takeoff and landing. Such a vehicle is generally described as a hypersonic vehicle, and it needs to have engines, thermal control systems, and stability control systems that are considerably more advanced than those needed for sub-orbital lobs.

3. Commercial Market Considerations – is it Tourism or Business Travel?

There are fundamental market issues that are probably so significant that no further work on anything else related to commercial point-to-point sub-orbital space flight is merited until they are resolved.

The first question needing resolution is whether this class of vehicle is needed for cargo, or for passengers? Or just possibly for a combination? If the vehicle is for passenger travel, is it for space tourists, or for urgent travel, presumably related to business? We shall find throughout this paper that the issues are overlapping, and therefore cannot easily be resolved, or even researched, in isolation. For example, to even address the stated market questions, it is necessary to have an idea of the <u>price</u> of a ticket to ride (whether for persons, or cargo). And in order to know the likely region of ticket price, it is necessary to know the cost of building and operating the vehicle and its ground infrastructure. To know the cost of building and operating, one needs to know the size of the vehicle and the number of passengers or amount of cargo, carried, and the number of spaceport destinations. And that presupposes that we know how many people would want to fly in the first place, between any given pair of spaceports. So the argument is circular and iterative. Nevertheless a solution must be attempted.

When the argument is circular, then the best chance at finding a solution is generally to construct a multi-dimensional solution space, in this case covering a range of prices and vehicle sizes, and ground infrastructures. For the case of passenger travel, the solution space will provide a different answer depending on whether the trip is considered as “fast travel” or “space tourism”. A different solution space will emerge in the case of urgent cargo delivery, too. Thus it seems that three sets of results are needed, and they could be presented on three charts as demonstrated by Fig 2, Fig 3 and Fig 4.

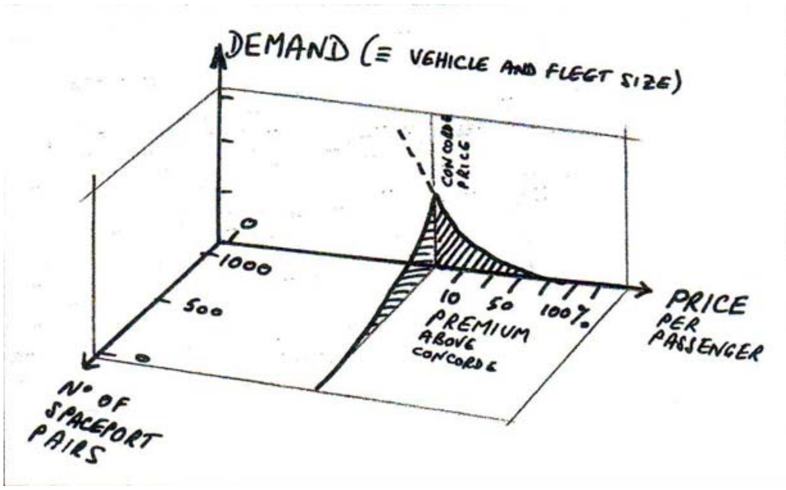

Fig 2 The Case of Urgent Business Travel

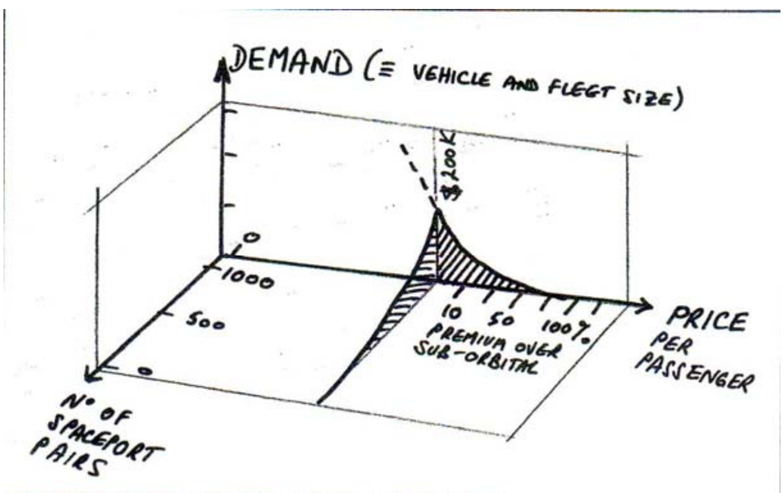

Fig 3 The Case of Extended Sub-orbital Space Tourism Experience

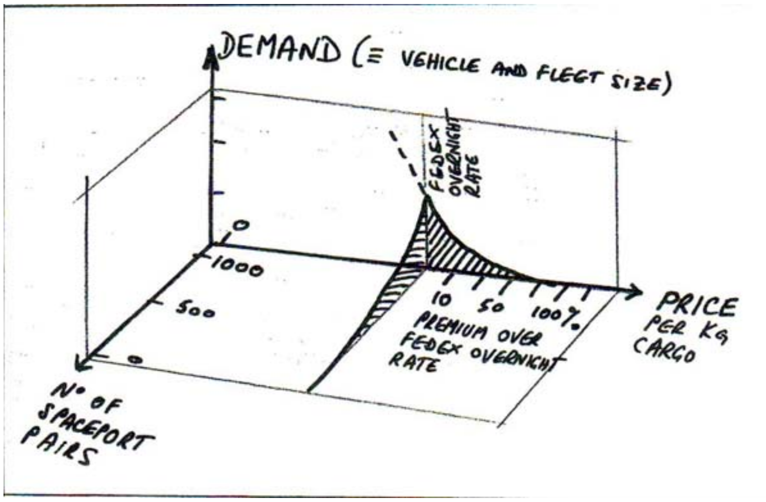

Fig 4 The Case of Fast Cargo Delivery

In order to understand the commercial markets and find data to populate the charts, some credible new market research surveys will be required. No questions about point-to-point sub-orbital space travel were included in any of the previously published robust space tourism surveys (such as the Futron/Zogby Survey, the Adventurers' Survey, the LaTrobe University Survey, or the SEI work.) In exploring the "Urgent business travel" perspective, we can start with Concorde ticket prices and explore the extent to which travelers would pay various premia above those prices to have the benefits of the much shorter journey times of sub-orbital point-to-point travel. For the "Space tourism experience" perspective, we can start with the known prices for straight up-and-down sub-orbital space tourism, and explore how much of a premium would be acceptable for a flight say half way around the Earth in 40 minutes. For the "Fast cargo" perspective, it would be necessary to explore the extent to which folks would pay above the current international "overnight" courier rates to get their cargo to its spaceport destination in say 40 minutes. Of course, for a business case to close, it must be possible to provide the service at costs that are below the assumed prices. So, we suspect that prices will be at least $100K per passenger, and probably much higher.

In all three perspectives, it will be important to obtain additional, more detailed, information from this new survey. For example, in the Fig 2 case, we would benefit from finding out what *kinds* of trips are so urgent, and most importantly what are the *key pairs of spaceports* required. In the Fig 3 example, it would be useful to explore other aspects about the new space tourism experience, eg how to return to base. In the Fig 4 cargo option, we need to understand what *kinds* of cargo would justify the price premium.

In all three cases, however, we need to be aware that the "global" demand solutions will only be approachable if large numbers of spaceports are involved. In the case when only a few pairs of spaceports are assumed to be offering the service, then only a proportionate *share* of the global total market will be achievable (although this may not be so critical in the "Space tourism experience" perspective).

Of course, we should not forget that there may be a government/military demand that operates beyond normal commercial supply and demand constraints.

4. Ground Segment Considerations – How Many Spaceports?

It has been suggested that a variant on the sub-orbital straight up and down space tourism flights from Mojave spaceport in California might be a take-off at Mojave and a landing at a relatively “neighboring” spaceport, such as at Oklahoma. Although, as explained above, no published market data yet exists on incremental demand for this kind of “stretched” sub-orbital space tourism, it does seem that there would be some, depending on price premium. It would not be necessary for many spaceports to operate in order to offer this variant on the space tourism experience, provided that the performance of the sub-orbital vehicle systems can be stretched to provide the trip (but see section 5 below for important limitations in meaning of “neighboring”).

The V-Prize foundation in Virginia, USA, has begun to explore using point-to-point sub-orbital space travel from Wallops spaceport on its Atlantic coast to an, as yet unnamed, single European destination (ref 7.1, 7.2. 7.3). Although the detailed prize rules remain to be finalized, their intention is to encourage development of a craft capable of making international point-to-point trips from their State’s spaceport. To design a craft to carry out intercontinental sub-orbital travel, however, requires some confidence that a commercial market exists for continued use of the vehicle class after the prize has been won. In the case of the X-Prize which was won in 2004, the prize rules envisaged a new class of vehicle capable of providing sub-orbital space tourism. Burt Rutan’s SpaceShipOne was eventually successful, 8 years after the prize was announced, and became the prototype enabling Virgin Galactic to initiate the sub-orbital space tourism industry. What kind of a commercial transportation industry could be initiated by carefully crafted V-Prize rules? We can safely assume that the answer would be “none” if the number of involved spaceports remained at only the Virginia spaceport and its counterpart European site. If the potential new industry is for urgent business travel, or for fast cargo, then it will be necessary to set up <u>an eventual global network of participating spaceports</u> needing to be located near to major population centers.

Why? Because most of the time savings achieved by point-to-point sub-orbital space flight are of no benefit, if the time spent on the ground getting to the new spaceport is just a few hours more than it takes today to get to the local existing international airport. Clearly, one cannot expect the entire world to set up spaceports to parallel its airport locations overnight. And even if it becomes possible to sometimes integrate a spaceport within an existing airport administration and boundary, it would be important to first establish the prime routes. Of course, this inevitably initially restricts the demand to only *a share* of potential global values. One of the results of the new market survey described in Section 3 would be to try to assess what should be the *initial prime route inter-spaceport network*. In exploring the effects of these logistic assumptions on the market demand, we are of course ignoring some rather major questions for subsequent resolution. Questions such as how would the global Air Traffic Control system handle this new vehicle class? Questions such as who would be expected to pay for the establishment of the global network of spaceports? Who would establish global spaceport operating standards? These questions would be capable of answers once a clear commercial market need is established, but they are not minor in nature, and therefore would have a bearing on the likely timeframe for introducing a true global point-to-point sub-orbital space travel industry.

Nor are the ground segment logistics limited to the mere location and number of spaceports. Depending on the kind of travel and/or cargo, a range of infrastructure elements will be needed at the spaceports. Clearly, as with airports today, there will be the need for fuel storage, in this case rocket fuel. Maintenance facilities will be needed for inspection and replacement of key system elements, such as thermal control subsystems and engine parts. Special cargo handling areas will be needed, depending upon the nature of the high-value cargos to be shipped. If transplant organs would be one such cargo category, for example, then extraordinary cleanliness and temperature controls will be needed. Because of the urgency of the (non-tourism) flights, there will be a need for highly efficient loading and documentation and customs procedures.

An important consideration, linked to the overall demand figures, would be the frequency of flights. Someone needing such an urgent flight needs to go *now*, not three or four hours from now. In this kind of operation, the urgent business travel flights would be arranged on a corporate jet travel basis, ie flights would need to go on demand, and *not* according to a pre-arranged schedule. The need for on-demand service is because, if flights are only going twice or thrice a day, say, between two given spaceports, then it would be just as quick and a lot cheaper to fly the person or the cargo on an earlier airline flight the same day. Therefore, unless there are at least about 1000 scheduled point-to-point sub-orbital flights a year between any given pair of spaceports, then the urgent travel customer, or the fast cargo client, will have quicker and cheaper solutions using regular existing aircraft services. There are of course fleet size implications if it is decided to operate an on-demand service

Vehicle design aspects are discussed in Section 5 below, but it is clear that it is easier to fill a smaller vehicle (say 3 passengers) to be able to go at a moment's notice than to fill something, say, Concorde size. This would be an important part of an iterative solution. How many craft of what size would be flying how many times a day between how many spaceports in order to satisfy the demand?

Not until the new market research, described in Section 3 above, has been conducted, can we know if sufficient commercial market demand exists to fill that amount of travel between any two spaceports. Again, we are aware that military facilities could be used to satisfy military demand outside of commercial considerations.

5. Spacecraft Design Aspects

For the special case of a flight from a spaceport to another one in close proximity, (say within a few hundred kilometers), it may be possible to "stretch" the design of a currently planned sub-orbital space tourism vehicle to carry out the mission. The main requirement would be to carry more propellant, or install an auxiliary apogee boost motor, to translate the vehicle horizontally while above the atmosphere. Some simplistic, but nevertheless enlightening, calculations on this approach follow.

We use the data from the SpaceShipOne flights conducted in 2004. In each of its three parabolic flights into space, the spacecraft was first carried to about 50,000 ft by its mother craft White Knight. It was then released, and its rocket motor was fired for about 80 seconds. It then continued to coast upwards to apogee (328,000ft, or 62 miles) for another 100 seconds, thereby achieving its maximum altitude in 3 minutes from the start of motor firing. The spacecraft then took another 3 minutes to fall back to around 50,000 feet again, before its gradual 18 minute glide back to its base at Mojave Spaceport. Thus, if we wish to "stretch" the lob so that it allows for a linear translation, we have only 6 minutes in which to do it before re-entry into the dense atmosphere. Even if we can loft the additional fuel and/or translation motor to make an attempt at point-to-point travel, a simple calculation shows that, traveling at SpaceShipOne's Mach 3, the distance achieved in this time interval with no assumed increase in apogee *can only be of the order of 200 miles*. This is the distance from Mojave to San Diego, or Las Vegas, say, rather than the 1500 miles from Mojave to Oklahoma spaceport, and is certainly not enough for intercontinental travel. A more refined analysis would be unlikely to provide a significantly different outcome for the scale of geographical limitations of this simple "stretched" sub-orbital design concept.

For true intercontinental or "hemispheric" point-to-point sub-orbital space travel, therefore, a new class of vehicle would be needed, the hypersonic transport. They travel at or beyond Mach 7, and crew and/or cargo would experience high-g loadings possibly in excess of 8g. Although at present no such vehicles, nor their engines, have been built, (except for the case of ramjet powered cruise missiles), there are nevertheless a number of theoretical design concepts, starting with the Sanger Amerika transcontinental bomber of World War II. At this conference, one such design is presented by the DLR representatives (ref 7.4, 7.5). Design solutions might include wave-rider technology that allows for skipping along the top of the atmosphere, and combinations of atmospheric and exo-atmospheric transportation. Fig 4 shows the design concept by Planetspace, Inc., known as Silver Dart, arriving at a destination spaceport.

Photo courtesy Planetspace.

Fig 4. The hypersonic transport concept Silver Dart.

Clearly, the sizing of the vehicle is a major determinant of the design. But, as observed in Section 3, we do not know at present whether the commercial market requires a cargo carrier or a passenger vehicle. And in the case of a passenger vehicle, we do not know whether the demand would support a 3-seater or a 100-seater. Notwithstanding the observations in Section 4, we do not know whether they will be flying on daily schedules between hundreds of space ports or whether they will be small craft flying on demand. And most importantly, we do not know the ticket prices (although we do expect that they will probably be at least $100K).

Flight trajectories would of course be coordinated through international air traffic control. Some designs assume glide landings; others assume a landing under power, which latter is clearly a better situation for air traffic control to manage. Special attention is needed to handle the dissipation of heat engendered by hypersonic flight in those phases of the trip that take place in the atmosphere (generally at the start and end of the flight, but possibly also during the flight for skip trajectories). This would require the development of new re-usable thermal control systems, and might be managed by use of high temperature materials, or ablative techniques requiring refurbishment at destination. Engines would probably have to be of Ramjet, or more probably of Scramjet or combined cycle, technology. Engine and thermal system spares would be needed at the spaceports that form part of the network. Because the prime route networks will inevitably traverse populated areas, consideration will need to be given in suppressing the sonic boom for such transports, because the sonic boom was one reason for the limitation of Concorde flights over the USA. Detailed design of a hypersonic transport for commercial point-to-point sub-orbital space travel could proceed if basic parameters such as market requirements can be established.

Of course, we recognize that there would be additional USAF needs that would significantly modify the design specifications if this class of vehicle were to be used for military purposes.

6. Conclusion

Before it can be determined if a new industry sector of commercial point-to-point sub-orbital space travel can be financially viable, some critical new market research is needed, and this paper has described what needs to be surveyed. The objective of the survey must be to determine whether this kind of space travel would serve only as a premium variant on the sub-orbital space tourism experience, or whether it could serve urgent business travel or fast cargo needs. It would also have key implications for vehicle size, flight rates, and the location and number of global spaceports. Quite regardless of vehicle design solutions, the limitations imposed by ground logistics would constrain the use for urgent travel and cargo delivery services. Urgent travel or cargo delivery would require on-demand, rather than scheduled, services. This new market research work is required before any detailed planning or vehicle design for commercial flights can take place. If there emerges a military need for this form of space travel, then of course we could expect that the financial and market constraints would be alleviated.

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