



COLLABORATION WITH AVIATION - THE KEY TO COMMERCIALISATION OF SPACE ACTIVITIES

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ABSTRACT

The US government's Commercial Space Act of 1998 and commitment to commercialise the International Space Station's operations have changed the direction of space development in the post-cold-war world definitively. During 1998 also the feasibility and great economic potential of space travel by the general public was acknowledged in publications by NASA, AIAA and the Japanese Keidanren. However, crewed space activities are all taxpayer-funded, primarily for scientific research; they have involved only a few hundred people traveling to space to date; and those involved have no experience of commercial passenger service operations.

By contrast, aviation is a global industry, largely commercial, involving the range of activities from engineering design to marketing, and serving more than 1 billion passengers/year. Aviation has very high safety levels developed over decades of experience of carrying billions of passengers. Furthermore, the aviation industry also has extensive experience of operating rocket-powered piloted vehicles: during the 1950s several countries operated such vehicles sufficiently frequently to develop routine operations, maintenance and repair procedures. Consequently, in order to develop safe

and profitable passenger travel services to, from and in space, people, companies and organisations with experience of space activities have a great deal to gain from collaboration with all parts of the aviation industry. Due to the potential economic value of this development, and the high cost to taxpayers of space activities today, governments should take steps to start this collaboration as soon as possible. © 2000 Published by Elsevier Science Ltd. All rights reserved.

INTRODUCTION: AVIATION AND SPACE TOURISM

During 1998 the feasibility and potential economic value of space travel by the general public was acknowledged in NASA Report number NP-1998-03-11-MSFC (1). The American Institute of Astronautics and Aeronautics (AIAA) also acknowledged that "In light of its great potential, public space travel should be viewed as the next large, new area of commercial space activity" (2). The Japanese Federation of Economic Organisations (Keidanren) concluded its report 'Space in Japan' with the sentence "Space tourism is expected to give a strong impetus toward the commercialization of space activities" (3).

These acknowledgements are examples of the growing recognition that only passenger-carrying offers the prospect of creating demand for flights to space

at a rate of tens or hundreds per day. Satellite launches and other government space activities occur at the rate of at most a few per week, and are considered unlikely to reach a rate of even 1 flight/day. However, as in aviation, it is only by operating on a much larger scale than this that space flight services can reach substantially lower costs, through spreading vehicle development costs over thousands of flights, and reducing complex activities to a system of routine procedures.

Passenger-carrying is the main activity of several global commercial transportation industries. Commercially operated ships, trains, cars, buses and aircraft provide travel services to billions of passengers/year. All of these industries have experience that is relevant to a future passenger space travel industry; aviation is technologically the closest to the operation of passenger launch vehicles.

Aviation is a global industry, owned and operated largely by private commercial companies, and forming a seamless network of engineering design, manufacturing, sales, airline operations, customer services, maintenance, repairs, finance, leasing, insurance, marketing, advertising, media and other activities. There is also a comprehensive legal framework, comprising national laws and regulations connected by international treaties, which is under continual revision as the growing industry requires.

The aviation industry's characteristic approach to safety has been extremely effective in reducing the risks of flying progressively for decades to the current level of little more than 1/10,000,000. The reasons for this success are several, but they contrast sharply with

space industry operation of rocket launch vehicles which are typically used only once, like the missiles on which their designs are based; as discussed in (4). It includes an international system for certification of passenger vehicles and their operating procedures, as well as an international system for systematic investigation of accidents and propagation of safety-related information.

As the major activity of civil aviation, passenger-handling has grown to reach a turnover of many hundreds of US\$ billions/year, arising from ticket sales to over one billion passengers/year. These revenues enable the financing of purchases by airlines of hundreds of US\$ billions of aircraft every year. They also support related fields such as airport and passenger facility design and operation, large-scale catering services, passenger entertainment systems, global computerised ticketing systems, and they generate a major contribution to hotel industry revenues.

As a further example of the scale of commercial aviation, the aircraft maintenance, repair and overhaul (MRO) sector alone has a turnover of nearly \$30 billion/year and is growing at an annual rate of some 3%. This activity is sufficiently large that there is a world-wide system for licensing airframe and powerplant (A&P) technicians, and specialised A&P schools for training new staff (5). Thus MRO alone is larger than the commercial space industry today, or than the government-supported space industry. This gives some idea of the promise that passenger space travel offers for future growth of the space industry, provided that it is based on the development and operation of passenger launch vehicles. This vision contrasts sharply with that of

reusable launch vehicles to be used for satellite launch, such as Lockheed-Martin's proposed "Venture Star". The demand for these will be so limited that, by displacing expendable launch vehicles, their operation would greatly reduce the scale of activity of rocket manufacturers and operators, and hence they are seen as unattractive by such companies (6).

Aviation Experience of Rocket Vehicles

In the present context it is of interest that the aviation industry also has long experience of operating piloted, rocket-powered vehicles. During the 1940s and 1950s several countries' military forces operated Rocket-Assisted-Take-Off (RATO), or as then commonly known, JATO - Jet-Assisted-Take-Off) aircraft, as well as aircraft powered by both jets and rockets. These vehicles were flown sufficiently to develop routine operations, maintenance and repair procedures for the rocket engines they used. Anecdotally, the South African Air Force was said to have reached the stage where they flew liquid rocket engines 60 times between overhauls.

In addition to military activities, RATO systems were also used for many years on commercial passenger aircraft, and this experience is a valuable base on which to develop procedures for commercial passenger space travel services. Test-firing certain rocket engines selected as suitable for passenger-carrying vehicles several hundreds of times, while developing test, maintenance and repair procedures in parallel, will lead to high-power rocket engines also being operated in a routine manner like jet engines.

In summary, the fundamental way of thinking in aviation is highly

appropriate for commercialising space activities by developing passenger space travel services.

FAA Activities

In implicit recognition of the above, the US government's Office of Commercial Space Transportation (OCST) was moved into the Federal Aviation Administration (FAA) in October 1995, where the FAA's Associate Administrator for Commercial Space Transportation has started to develop a clear, long-term, vision of a vigorous, commercial space tourism industry that is lacking in the government-dominated space industry. In a speech to the Washington Space Business Roundtable on July 14, 1999, she spoke of developing space transportation "...into a real mode of transportation... when a multitude of entrepreneurs will open space to all kinds of activities: thrill-rides, vacationers, industry and even trips to the Moon and beyond." And she proposed the convening of a summit "...to bring together industry leaders, trade associations and perhaps government to focus on this issue" (7). In furtherance of this objective, the FAA is making progress in several related directions.

1) Space Traffic Control In 1998 the FAA started a study of extending air traffic control to include vehicles in low Earth orbit (LEO) and traveling between Earth and LEO, in order to create a seamless system accommodating both air and space vehicles. This led to the publication of a draft report on this subject in 1999 (8). This report is genuinely path-breaking, proposing a range of initiatives and tackling key issues needed to realise space travel by the general public.

1.1) Space Transition Corridors

A particularly significant proposal in (8) is that of "Space Transition Corridors" (STC) - zones linking an area on the ground to an area in orbit reserved for either a vehicle returning from orbit or a launching vehicle, into which other aircraft are not permitted for the duration. This proposal resolves the potential problem that a returning vehicle such as Kankohmaru (9) will not be able to carry sufficient fuel to be able to manoeuvre significantly within the atmosphere before landing. For example it will not be able to hover for several minutes, nor reroute to another landing site as scheduled airliners can. Kankohmaru's pilot will therefore need to receive irrevocable permission to land at its planned destination airport before departing from the orbiting hotel to which it is docked, as discussed in (9).

The concept of STC solves this problem elegantly: it is not a permanent fixed route like an air-lane, but a temporary zone defined in space and time within a computerised air traffic control system. As such it enables efficient and economical use of airspace and orbital space. Details of such a system remain to be decided, and will require international support to become an international standard.

1.2) International Space Flight

Organisation The FAA has also proposed the formation of a new organisation, the International Space Flight Organisation (ISFO) to play the role of the International Civil Aviation Organisation (ICAO) with respect to passenger space travel. The ISFO would help to coordinate different countries' activities and ensure that agreement is reached on international procedures and standards in a timely

manner. For example, non-US governments have yet to comment on the FAA's proposal of STCs, as they are behind the USA in making plans for the advent of reusable launch vehicles capable of round-trips between the Earth and space. The ISFO could help to make international progress in this matter.

2) Guidelines for reusable launch vehicles The FAA has also published draft guidelines for licensing private space vehicles, including their re-entry into the atmosphere (10). The safety approach is based on the very successful system developed over decades of experience of civil aviation, reducing the risk of accidents to levels that are acceptable to the traveling public, to third parties, and to insurance companies.

3) Medical guidelines for space tourists Under the supervision of Dr Melchior Antunano, draft medical guidelines are currently being prepared for space flight passengers (11). Starting from the fundamental commercial aviation viewpoint that the more people who are able to travel the better, these guidelines are planned to be as liberal as possible, consistent with safety. However, there are a number of issues that require consideration. First, the radiation dose received in low Earth orbit is higher than on Earth, though not sufficiently high to pose significant risk to most people during a trip lasting a few days. However, such exposure would be undesirable for pregnant women, and so it may be suggested that women passengers who may be pregnant should take a test to confirm that they are not before flying to orbit. Second, in weightlessness the blood circulation and the distribution of fluid around the body change significantly,

which may have implications for people suffering from some forms of heart disease. Third, the physiological effects of some types of medication are found to differ in micro-gravity, which may be of significance to passengers taking some forms of medication.

Seen from the point of view of aviation, space tourism is much nearer in the future than is widely appreciated within the space industry - at least in the form of sub-orbital passenger flights to space, to an altitude of 100 km and above. Vehicles capable of such flights could start operations within just a few years, and thereafter commercial passenger flights will start as soon as the regulatory process allows. Overall, the idea of passenger space travel seems readily accepted within aviation, as shown by trade magazine articles such as (12, 13).

Aviation-Related Space Tourism Work in Japan

In this context it is notable that in Japan also much of the work on space tourism has been led by people with primarily aviation experience. The majority of this research has been performed under the Japanese Rocket Society's (JRS) Space Tourism Research Program, which produced the design of the Kankoh-maru launch vehicle (see Figure 1), of which the scenario for development and certification for passenger-carrying has been broadly endorsed by NASA (1). The experts who have chaired the main research committees of the JRS Study Program, namely the Transportation Research Committee and the Commercial Space Transportation Legislation Research Committee have both had careers in aircraft manufacturing and aviation (14).

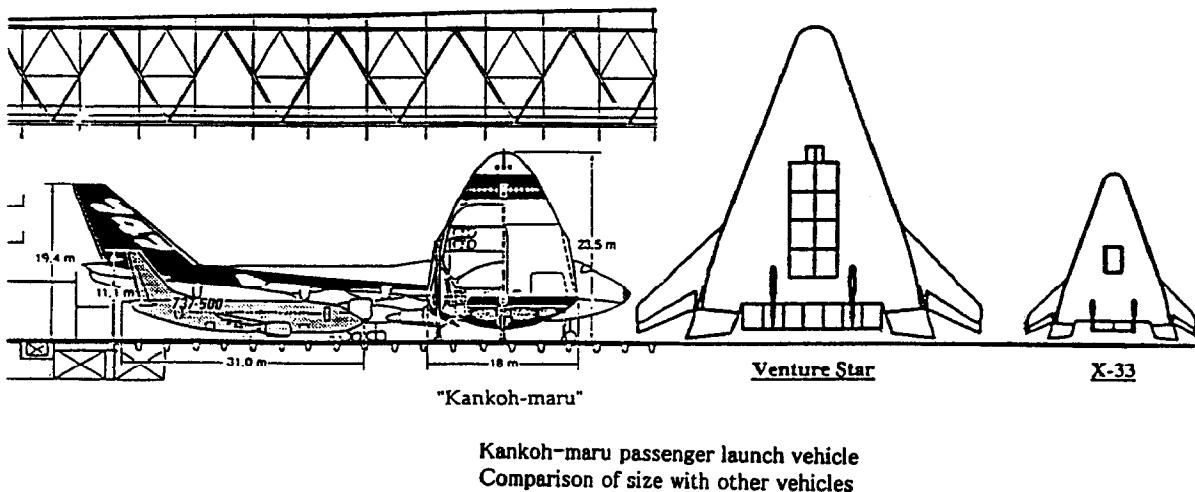


Figure 1: JRS Passenger-Carrying Reference Vehicle Kankoh-maru

In addition, much of the JRS' work is performed with explicit reference to aviation as the precursor. This is true of the work of all three of the JRS

committees, but is particularly true of the Legislation Research Committee (15) and the third phase of the Transportation Research Committee

which is studying issues for "space-worthiness" and certification of the VTOL Kankoh-maru vehicle for passenger-carrying with reference to existing aviation rules (16). These are examples of the wider recognition that the "aviation model" is most appropriate for the broad range of legal and regulatory issues that need to be resolved in order to realise space tourism (17).

SPACE INDUSTRY RESISTANCE TO SPACE TOURISM

Companies and government organisations in the space industry have experience of launching expendable rockets to orbit and beyond, of operating satellites in space by remote control, of launching crewed vehicles to Earth orbit and to the lunar surface, of operating crewed vehicles in orbit, and of re-entry and landing. On a technical level much of this experience, particularly that of crewed space operations, could be of use for developing passenger space travel services.

However, government-funded space agencies have no experience of commercial passenger service operations; they have shown no interest in this objective; and they are currently not devoting significant resources to enabling public access to space. This is in spite of the fact that the investment required to develop commercial passenger travel services to orbit is widely acknowledged to be substantially less than a single year of government space agencies' current expenditure of \$25 billion/year - and that required to initiate sub-orbital space travel services is less than 1% of one year's funding!

In addition, government space agencies

have never performed surveys to evaluate the level of popular interest in space travel, nor market research to estimate the potential economic value of such a development. This lack of concern for the opinions of the public would be inconceivable in commercial organisations of similar size.

After cooperating with the US Space Transportation Association to produce the ground-breaking report "General Public Space Travel and Tourism" which acknowledged that space travel by the general public is a realistic objective and could grow into the largest business activity in space (1), NASA took no action to advance its recommendations, despite its legal responsibility to aid commercialisation of space activities. Furthermore, as of late 1999, this report could not be obtained from NASA - inquiries to its information service were told that the report was "unavailable" (18).

Instead of working towards enabling the public to travel to space, government space agencies carry out a range of activities, a large part of which involves developing and operating wholly or partially expendable launch vehicles. These are not profitable in the normal sense of the word; indeed they return none of the investment in their development to taxpayers. Furthermore, these vehicles are not leading on to the development of profitable or passenger-carrying vehicles, and their operation has little relation to the operation of future passenger space vehicles. Work that is specifically devoted to reusable launch vehicles is confined to unpiloted satellite launchers, such as NASA's X-33 and X-34 test vehicles.

The international space station (ISS) on which space agencies plan to spend

some \$100 billion of taxpayers' money over its lifetime, is an inter-governmental project which will not be profitable, and of which the cost and operations are not a useful model for a commercial facility. In addition, the legal environment is quite different from what is required in a commercial facility and is not appropriate to a commercial passenger industry.

It thus appears that space agencies have chosen to define their role not to include enabling the general public to travel to space and back. However, by taking this position, space agencies are thereby threatening their own futures, choosing to make themselves increasingly irrelevant to the taxpayers who fund them. The growing urgency of this problem is well exemplified by the recent discussion about the lack of missions requiring the space shuttle after the assembly of the international space station (19), and the statement by the US President that he considers that "...benefits to us here on Earth" are more important to the US public than the Mars mission favoured by NASA's leaders (20).

The space agencies' lack of interest in aiding the development of passenger space travel services reflects their history as organisations set up during the cold war to carry out government projects. Their viewpoint contrasts with that of customer-oriented commercial organisations, and is indeed predictable from the theory of the self-interested behaviour of government agencies developed by organisation theorists. It begs the question whether the space agencies now serve a valuable public purpose, in the absence of economic benefits arising from their activities in the form of wealth-creating commercial space

activities. (NB scientific research has a value other than its economically measurable value, but this represents only about 10% of space agencies' activities.)

Space Industry Restructuring

Since the end of the cold war, many industries have experienced vigorous restructuring, which is still continuing as consolidation occurs on a global scale. The space industry has also seen some restructuring, notably consolidation of large aerospace companies due to cuts in defence budgets, and commercialisation of satellite communications activities. But the pattern whereby government funding dominates essentially 100% of human space flight activities remains unchanged.

Despite growing acknowledgment of the potential economic value of space travel by the general public (1, 2, 3), and despite government direction to space agencies to emphasise activities of commercial value, they show great reluctance to make any efforts to assist the realisation of space tourism. Yet this is now a matter of considerable economic importance: if space agencies' budgets continued at their current levels of \$25 billion/year, taxpayers would pay \$500 billion over the next 20 years - but without creating new business turnover of even a small fraction of this amount, since only space travel services are capable of earning a commercial return on crewed space activities.

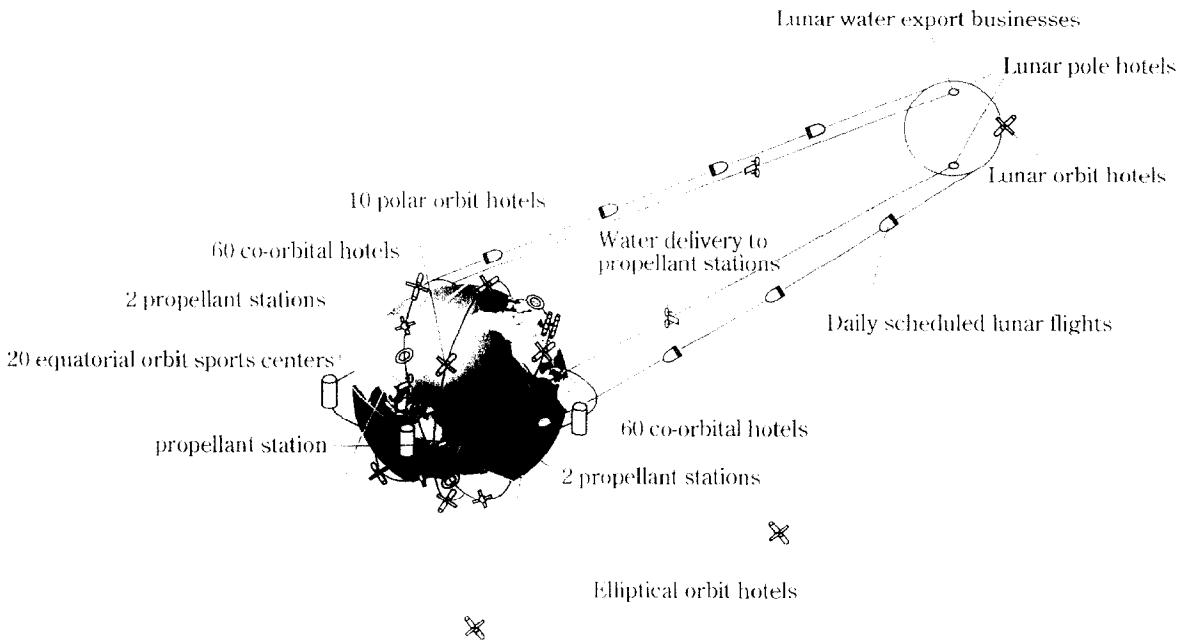
This contrasts strikingly with the economic benefits of developing a space tourism industry: The feasibility of the JRS scenario for space tourism development was referred to favourably in NASA's only ever report on the subject (1), and the JRS's central

argument that orbital tourism services could start within 10 years is supported by Lockheed-Martin (21). Based on this scenario, the investment of just 10-20% of the \$500 billion that space agencies are looking to spend over the next 20 years, if focused on developing space travel services could generate self-sustaining commercial turnover of more than \$25 billion/year by 2020 (6). Furthermore the great majority of this investment would be provided by the private sector. Consequently, failing to develop space tourism while continuing to spend \$25 billions/year on government space activities would be a major error of economic policy, greatly reducing the wealth of the advanced countries, and wasting the opportunity

to create a new industry with unlimited prospects for growth.

Benefit to the World Economy

The world economy is currently threatened by deflation due to serious over-supply in older industries and lack of innovative new fields for economic growth. In this situation it is highly desirable for the more advanced countries to increase their efforts to develop new industries. Since, following the JRS scenario, the commercial space travel industry could grow to a scale within 30 years of employing several million people (6), it is clearly an important candidate for support on grounds of economic policy.



2030 Space Tourism Business

5 million passengers/year Space debris removed
 Orbital population: 70,000 Space salvage law enacted

Figure 2: 2030 Space Tourism Scenario (6)

This leads to the questions of how best to promote the development of space tourism services, and what should be the respective roles of business and government. If government space agencies continue to maintain their present viewpoint that they have no responsibility to help make space accessible to the general public, this is likely to lead directly to their progressive demotion and continuing reduction in their budgets.

In this case the successor organisations to today's space agencies may become research centres to assist the commercial space transportation industry rather than carrying out their own operations. And if they were as successful in aiding the growth of the space travel industry as government aviation research organisations have been in improving airline safety and efficiency, taxpayers and consumers throughout the world will benefit enormously - far more than they would from the continued existence of space agencies in their present form.

SUB-ORBITAL SPACE FLIGHT SERVICES

Following the aviation philosophy of evolutionary improvement, the process of designing, manufacturing, test-flying and operating sub-orbital passenger-vehicles would be an effective means of preparing for the development and operation of orbital vehicles.

Passenger space vehicles capable of reaching 100 km altitude need reach little more than Mach 3, and require technological capabilities not much beyond those of rocket-planes that were tested and flown in several countries during the 1950s, such as the Mach 2 Saunders-Roe SR53. Furthermore, they do not need to be capable of supersonic flight at low altitude like a modern fighter plane, which enables a

much lighter structure to be used, as in Bristol Spaceplanes' "Ascender" (22).

Due to their much lower performance than orbital rockets, sub-orbital passenger space vehicles will cost very much less to develop and operate than orbital vehicles. More specifically, a prototype sub-orbital passenger vehicle could be developed at lower cost than an uncrewed satellite launch vehicle. Indeed, both a VTOL and an HTOL passenger vehicle could probably be developed for less than a single small satellite launch vehicle. In addition, such vehicles could be flown repeatedly for far less than the cost of a single launch to orbit, due to the much smaller propellant requirements. Indeed, the cost/flight could eventually fall to little more than the cost of operating a business jet plus the cost of maintaining a team of engineers.

Repeated operations would generate a wealth of information on which the development of standardised operating procedures for reusable rockets could be based, and reliability and safety could be improved progressively. Such operations would also be valuable for the development of an orbital passenger vehicle, not only concerning engineering matters but also for convincing investors of the feasibility of space tourism, by demonstrating both the necessary safety and cost-levels, and the actual market for passenger space flight. Perhaps most importantly, repeated flights to and from space would change the image of space flight from being an unobtainable, almost unthinkable experience, to becoming a commercial service like air travel available to ever-growing numbers of the general public.

The operation of both VTOL (vertical take-off and landing) and HTOL

(horizontal take-off and landing) sub-orbital passenger vehicles could also contribute greatly to resolving the perennial question of which system is preferable for passenger-carrying - or rather, to helping optimise designs of both vehicle systems for their most appropriate commercial roles.

Both HTOL and VTOL

Among advocates of the development of space tourism, there are different schools of thought concerning the best vehicle configuration to use. Leading candidates are a single-stage-to-orbit (SSTO) vertical take-off and landing (VTOL) configuration such as the Kankoh-maru (23), and a two-stage-to-orbit (TSTO) horizontal take-off and landing (HTOL) configuration such as the Spacecab and Spacebus (22), and there are a wide range of issues relevant to selecting between the two.

In considering sub-orbital systems, HTOL vehicles, being winged, are expected to obtain certification for passenger-carrying more easily than VTOL vehicles, due to their similarity to aircraft, thereby requiring fewer regulatory innovations. HTOL may therefore be the easiest approach to sub-orbital space flight services.

For the same reasons HTOL vehicles may also seem easier to certificate for orbital flight following existing aviation rules. However, in relation to landing requirements VTOL vehicles have an important advantage in that they do not use runways, and in emergency could land on almost any level surface, such as a road or car parking area. Hence there will be no need to require them to carry sufficient propellants to "go round again" and/or divert to an alternate airport, since there will be no realistic situation in which they will not be able to land.

By contrast it may be harder to release HTOL vehicles from the need to carry sufficient propellant to divert and land at an alternate airport, since there will be a non-negligible probability that the runway on which they are planning to land might become unusable during the 30-45 minutes between the time of their making their de-orbit engine burn (9) and the time of landing, due to accidents by other aircraft, weather conditions or otherwise.

However, the choice between these two approaches is not only a matter of engineering. Ultimately it is an economic issue: which system will give operators the lowest costs, given the required levels of safety and comfort? Operating sub-orbital passenger services using both types of vehicle will enable much better estimates to be made of the likely cost of orbital passenger services.

This discussion of the benefits of developing and operating sub-orbital passenger vehicles should not be taken to mean that this would be preferable to developing orbital passenger vehicles directly. The prospects for growth of orbital passenger services are so promising that from the economic point of view investment in realising them should be started as soon as possible. With the potential to reach a turnover of \$100 billion within 30 years, and to create opportunities for profitable employment of millions of people (6), scenarios of space tourism development have strongly positive present values. Consequently for governments to continue to spend \$25 billion/year on space activities that have little commercial value, while not aiding the emergence of a space tourism industry would represent a massive loss of taxpayers' wealth. However, if space tourism is left entirely to the private

sector, proceeding by way of developing sub-orbital space flight services is probably the path offering the lowest risks to investors.

CONCLUSIONS

Passenger space travel is much nearer in the future than is widely appreciated, at least in the form of sub-orbital passenger flights to space, to an altitude of 100 km and above. In this form, the first private space flights could start within a few years, and thereafter commercial passenger flights will start as soon as legal and regulatory issues permit.

In order to develop safe and profitable passenger travel services to, from and in orbit, companies and organisations with experience of space activities have a great deal to benefit from cooperation with companies and organisations in the aviation industry, which has decades of experience of operating advanced aerospace systems profitably and with a high level of safety. Thus vigorous collaboration with the aviation industry in developing passenger space travel services offers the best prospect of putting space activities on a commercial basis.

To date, government-funded space agencies have declined to embrace this fact. If this persists, it would be economically beneficial for government funding of space agencies to be reduced, and for funding of appropriate aviation research to be increased, with the specific task of developing passenger space travel services. For governments not to be actively aiding development of this new field of business is a serious and costly mistake of economic policy, and the sooner that it is corrected the better for economic growth worldwide.

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