Government Actions to Enable Space Business Parks

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Abstract

The governmental role in the successful development of commercial, large-scale Space Business Parks in low Earth orbit is vital but has not been characterized. This paper presents a specific agenda for such enabling action, tailored for the U.S. Government, in the following four areas: existing NASA programs to be completed; Earth-to-orbit transportation service performance goals to be met; the framework of laws and regulations to be established; and technologies to be developed and demonstrated. Without all these components, significant private investment in commercial space development is foreclosed. This agenda of government actions is presented to help advance the discussion among those government leaders, investors, developers and aerospace professionals interested in working together to establish Space Business Parks as a freely profit-driven focus for human spacefaring activity.

Premise

Four previous papers by the authors' team (Lauer et al 1995a, 1995b, and 1994; Sherwood & Fowler, 1991) have evolved the Space Business Park (SBP) concept by exploring both its market definition, and requirements for its business development, regulation and supporting transportation infrastructure.

Throughout 1995, the SBP concept has received growing attention in space futures conferences, in the press, in Congressional testimony and speeches on the commercialization of space, and in white papers circulated within the aerospace community. The paradigm shift predicted by Sherwood & Fowler (1991)—from pursuing human planetary exploration once the International Space Station (ISS) becomes operational, toward pursuing instead commercial expansion of operations in low Earth orbit (LEO)—has begun to occur. SBPs are increasingly recognized as key components in such commercial LEO development.

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Collective interest is now turning to implementation: how to make SBPs happen. The search for institutional roles has begun. The central issue—how aerospace technology companies, private investors, and existing government agencies can team most productively to achieve a growth SBP industry—will take years to resolve into equilibrium, since the subject is unprecedented within present institutional experience. However, even primitive business analyses have shown that all three entities are vital (Woodcock, 95).

Commercial development means spending private money, in response to market forces, in order to generate wealth—not executing government contracts to pursue public policy objectives. Yet we expect government to use public resources to develop high-risk technologies, infrastructure and a regulatory framework to enable entrepreneurship. Furthermore, existing and emergent space assets—which might facilitate market research and testing to leverage commercialization—are owned by governments anyway. So defining appropriate, helpful or essential roles for government agencies like NASA poses a particularly important challenge.

This paper aims to distinguish between actions which private industry can and would take in developing an SBP industry, and actions which governments alone are able to take. It proposes specific actions—in the form of legislative, regulatory and technology-development needs—which the U.S. Government could take to accelerate and lead SBP development.

Review: SBP fundamentals

For purposes of the present discussion, SBPs are "destination systems" stationed permanently in LEO. Full-scale SBPs provide commercial tenants with a leased mix of pressurized, exposed and unmanned *facilities*; with *utilities* (including stationkeeping, power, thermal management, communications, and life support); and with *services* (including operations, resupply, maintenance, and disposal). Provision of all these needs defines a host of support-business niche opportunities. Probable business sectors include manufacturing, research, entertainment and sporting, and tourism. The objective of an SBP is to make money for its investors by meeting market demand better than competitive services.

Fundamental principles apparently necessary for viable SBP development include:

1. Development practices analogous to terrestrial, mixed-use business parks
2. Business investment conditions attractive to private venture capitalists
3. Reliance on already-demonstrated, preferably standardized technical systems
4. Ability to leverage existing production infrastructure
5. Incremental expansion of capabilities, tied to profitable operation
6. Affordable, regular access.

Governmental action

Governmental action is the principal gate into this extraordinarily promising opportunity both for capital investment and for the private development of orbital infrastructure. In the next four sections, we explore and specify a platform of governmental actions without which SBPs are unlikely to develop freely and vigorously. Four categories of essential U.S. Government action are detailed:

1. Current NASA programs, the completion of which will establish the basic technology proof for SBP development and operation
2. Transportation service performance goals, the attainment of which can unleash significant growth of the SBP industry
3. Legislation and regulations, the establishment of which will allow commitment of significant private money
4. Focused technology programs, the execution of which defines an SBP-driven charter for NASA and other U.S. Government R&D agencies.

We present this draft platform as a basis for discussion particularly by the legislative, investment, industrial and research communities. We do not imagine it to be exhaustive; however, adopting these recommendations would significantly advance SBP development.

Current Enabling NASA programs

Many NASA research initiatives could yield technologies which, when introduced into practice, might significantly enhance operational efficiency and effectiveness of SBPs. However, the following notable programs appear enabling.

1. International Space Station (ISS) - Two areas are paramount: one technical and one programmatic. Technically, expeditious achievement of an operational ISS establishes a manufacturing base capable of producing man-rated integrated LEO destination systems, and also acquires a genuine operations experience database. For potential investors, the mere existence—and therefore credibility—of these data is essential. ISS program continuity can also keep the production capability intact until private demand for further production is established. Programmatically, ISS has broken new ground in international relations. In particular, transfers of U.S. funds to Russia for ISS exceed (at $400M total) any other U.S. Government non-"assistance" funding for Russia (U.S. Congress, 1995). This pathfinding collaboration between the two space superpowers helps stabilize the supply side of the space system market.

2. Reusable Launch Vehicle (RLV) - No LEO destination system can make money if access to it is unobtainable, or too rare, irregular, unreliable or expensive. It has been widely published for years that the three essential conditions for dramatically reduced launch costs are full re-usability of hardware assets, high flight rate, and airline-like turnaround operations. NASA's X-33 program will demonstrate some of the key technologies required for a space transportation system with these attributes. Current typical economic analyses indicate that development of an operational RLV cannot be accomplished without significant government investment.

3. Autogenic Feedback Training (AFT) - The value of SBP business and leisure travelers' time on-orbit warrants solving the problem of Space Adaptation Syndrome (SAS), which compromises the performance of about half of all astronauts for one or two days upon attaining weightlessness in orbit. Ames Research Center is developing a way to train flight crews to self-regulate multiple physiological variables, thereby suppressing SAS symptoms. AFT has been successfully demonstrated on two shuttle flights and is scheduled to be investigated during the Mir 23 mission beginning in late 1996 (Cowings et al, 1995). Tailored AFT could become a routine, extremely valuable part of the pre-flight training regimen for all space travelers.

Enabling Transportation Performance

1. Capacity - Optimal transportation vehicle capacity (per-launch volume and mass, and launch frequency) is directly dependent on SBP configuration and operational design, and so cannot yet be confidently specified. Clearly, payloads as large and heavy as ISS modules and truss sections are necessary for SBP construction, as are more frequent (several times per year) payloads as large as several ISS-racks' worth of equipment throughout SBP operation. Weekly-to-monthly manned, and unmanned resupply, flights are an appropriate target.

2. Price - The acceptable price range is indicated generally by present economic analyses. Reducing the launch price for heavy, human-class payloads from $10k - $20k per kilogram, to roughly $100 per kilogram, over the next 20 years is necessary for profitable SBP operation.

3. Safety - Commercial air transport safety is managed in three categories: risk of catastrophic failure, risk of non-catastrophic but potentially deadly failure, and risk of third-party liability. Type-certification and operating license requirements for commercial jets define the permitted probability of catastrophic failure at 10^{-9}, and third-party liability at 10^{-6}. For rocket travel by paying passengers, catastrophic probabilities greater than 10^{-9} may be admissible—travel demand will be the clearest indicator (current state-of-the-art performance is between 10^{-3} and 10^{-4}). However, relaxing the third-party liability precedent for rocket flight would appear unlikely.

4. Reliability - For airplanes, "schedule reliability" is the percentage of times an airplane is free of mechanical delays and able to leave a boarding gate within 15 minutes of scheduled departure. The 747 achieved 97.7% schedule reliability after 38 months of service; the 767 after 18 months; and the 777 after just three months of revenue service (Boeing, 1995). Something comparable for transportation to SBPs might be: within one year of revenue service, achieving rendezvous on the scheduled day, 95% of the time. Given limited, short launch windows, this is a challenging goal.

Enabling legislation and regulations

Significant private investment simply will not occur before a stable, consistent, documented regulatory environment is defined, and backed up by credible jurisdictional authority. "Capitalists are attracted to open markets where information is readily available, regulatory regimes are stable, fiscal policies are sound, infrastructure is functioning, and politics are predictable" (Siren, 1995). Lenders must be certain that their security interest in an asset can be successfully asserted in case of default or foreclosure. In return, borrowers must be comfortable that lenders cannot instantly claim the asset due to a minor breach of the terms of the loan agreement. Developers must be confident of some protection from liability in exchange for adherence to unambiguous construction standards. Owners must know how, and by whom, taxes will be assessed throughout the life of the asset. And operators must know what laws apply to conduct onboard.

Governance is the central driver for resolving these complex issues. Governance provides the four necessary, inter-related functions of record-keeping, regulation, enforcement, and sovereignty. For SBPs, governance is yet to be established. However, the United States is in the best position, both technologically and in terms of successful and adaptable regulatory precedents, to provide governance for private constructed space assets.

The right of the United States to assert jurisdictional authority over LEO assets deployed and operated under regulations established within the framework of U.S. law is assumed already for all manned and unmanned U.S. satellites. Establishing SBP governance is likely to be a much less contentious issue than developing natural bodies like the Moon. Rather than claiming real property defined by unresolved treaties as the "province of all mankind", the U.S. Government would enter into a consensual agreement with private or public entities to provide governance of human activity onboard personal property, as defined by Lauer et al (1995). Other spacefaring governments could do the same, with conventional treaties then establishing reciprocal recognition of valid ownership and regulatory authority.

Effective U.S. definition of SBP governance will require coordinated legislation, adjustments to the charters of several government agencies, and specification of standards by cross-industry teams. The same act of Congress that explicitly establishes the applicability of U.S. law to SBP assets should also establish the following foundation for a regulatory framework:

1. A Register of Deeds Office in the Department of Commerce, to provide single source public filings for all matters of title, ownership, liens and mortgages, leases, and other securities transactions.

2. A Circuit Court as provided for in Article III of the U.S. Constitution, with appropriate power and jurisdiction for all matters of civil and criminal law.

3. A Uniform Criminal Code, drafted by the Department of Justice and based on known model municipal and state ordinances regarding criminal conduct.

4. A Uniform Commercial Code, drafted by the Department of Commerce and based on known model municipal and state ordinances regulating affairs of civil commerce and personal conduct.

5. A Uniform Construction Code based on known model regulations in the construction and aerospace industries, regulating construction, licensing and issuance of Certificates of Occupancy for manned space facilities. It would be appropriate for the American Institute of Aeronautics and Astronautics to lead the drafting of this Code with participation by space system manufacturers and terrestrial building code experts, and for the Department of Commerce to administer it.

6. A Uniform Orbital Tax Code, drafted and administered by the IRS, providing for collection of revenue by the U.S. Treasury to be placed in a Trust Fund to pay for infrastructure and support costs and provide for long term self-sufficiency. This code should establish expirable tax abatements on profits earned onboard orbital assets, favorable capital gains treatment on sale of ownership interests in orbital assets, and a tax-exempt bonding authority for construction of space operations infrastructure.

7. Space Traffic Control - Finally, both traffic between Earth and SBPs, and the potential orbital interference of multiple operating facilities, must be regulated once the industry grows. Both of these are inherently international in scope and will require treaties to establish reciprocal recognition of licensing authority. The recent establishment of the Office of Commercial Space Transportation within the Department

of Transportation's Federal Aviation Administration enables this authority to evolve following well-understood precedents.

The ability of five alternative, extant models of governance to provide this framework is explored in detail in the companion paper "Analysis of Alternative Governance Models for Space Business Parks" (Lauer et al, 1996).

Enabling technology developments

In supporting the development of profitable, versatile SBPs, government agencies face a significant, focused research agenda which is not currently planned or even necessarily aligned with current agency charters. SBP issues provide ample opportunity for new inter-agency collaboration.

1. Big windows - State of the art is the ISS, with a few 20-inch (0.5 m) diameter window assemblies in some modules, and a hemisphere-viewing operations cupola large enough for two or three people at once. SBPs will have to do much better. Larger windows will be a discriminating amenity for business conferences, and essential for production studio and entertainment facilities, and for leisure travel. This program would develop large-window technology for aluminum pressure vessels, solving the following problems: (1) how to make window assemblies that curve with the module profile and contain atmospheric pressure while still maintaining adequate optical quality; (2) how to make large windows survive the structural-dynamic environment during launch; (3) how to integrate orbital debris protection; (4) .how to mitigate internal reflective glare; (5) how to manage direct sunlight.

2. Space suits that don't require individual tailoring - The number of travelers will far exceed the number of space suits able to be maintained on orbit. Yet operations personnel (unlike leisure travelers who may pay a premium to go EVA) will need suits that enable them to work extensively, for long periods of time. This program would develop suit technology that solves the following problems: (1) quick, on-orbit adaptation to fit anyone; (2) the fatiguing "bent-balloon" resistance imparted against joint motion, including especially hands and fingers; (3) accommodation of the 14.7 psi cabin pressure, to minimize preparation time. This particular combination of requirements is likely to be considered "impossible"; however, the promise of great financial reward from large-scale production should effectively stimulate competition during technology development.

3. Man-rated Orbital Maneuvering Vehicles - Full-scale SBP operations will require man-rated, space-only vehicles for three distinct regimes: (1) proximity operations around habitation and production facilities, for production operations, maintenance operations, and tours; (2) shuttles among habitation and production facilities distributed in flotilla configurations; (3) transportation between widely distributed bases. The last of these will not be required until SBPs are large and multi-use enough that it makes more sense to move people between them than it does to shift the facilities themselves along the orbit track, or unless a plane change is necessary. For the other two regimes, requirements will emerge for vehicles to support one or a few people, and also for vehicles capable of carrying perhaps dozens at a time. This technology program would develop a modular family of space-maintainable spacecraft subsystems (guidance, propulsion, attitude control, power, thermal management, tracking & communications) that could be integrated easily with the standard family of pressurized modules already available.

4. Microgravity food production - NASA's advanced life support programs, including especially those for oxygen recovery and food growth, came about because of the need to conserve crew consumables for long-duration, deep-space exploration missions. ISS is able to avoid closing the oxygen (at first) and food loops because of its combination of frequent supply flights and small crew. But SBPs will be sustaining much larger numbers of people; even with regular resupply for specialty items, they will require food production. This integrated technology program would develop: (1) scaleable methods for the microgravity cultivation of food-producing plants, including light management, heat removal, lightweight substrates, nutrient delivery, health monitoring and intervention, and propagation; (2) , scaleable methods for microgravity husbandry of food-producing fish and small animals, including containment, feeding and waste management, veterinary care and propagation; (3) microgravity harvesting methods for plants, fish and animals, including washing, hulling and threshing, picking, and butchering; (4) microgravity food processing methods, including storage, stabilization, drying, grinding, shredding, filtering, rendering, fermenting and recycling; (5) microgravity food preparation methods, including peeling, measuring, mixing, cooking, serving and cleanup. The USDA might be the lead agency. There is excellent reason to suspect that optimizing this extensive set of techniques for people to do will be far more cost-effective than developing robotic methods.

5. Robotics systems for operations tasks - There will be many mechanistic tasks involved in operating and maintaining SBPs (particularly "outside" and production-specific tasks not dependent on fine manipulation or immediate, complex decision-making) for which robots will be required. This technology program would develop the foundation for commercial development of these diverse systems by solving the following problems: (1) machine vision that works throughout the extreme dynamic range of *chiaroscuro* posed by sunlight in space; (2) reliable tribology of metal, ceramic and plastic mechanisms in the LEO environment of hard vacuum, atomic oxygen ram flux and abrupt cycling throughout a -100 - 170°F temperature range; (3) hierarchical control systems that are self-programming based on modular decision libraries, and can operate on fuzzy problems and learn through experience; (4) coordinated control of multiple complex robots communicating via modulated lasers; (5) active stiffness and vibration control, adaptable for generalized structures; (6) self-reconfiguring hardware, sensing and control systems that can adapt to a wide spectrum of job types and scales.

6. Deployment and outfitting of large pressure vessels - Several real SBP activities—assembling more than twenty people comfortably for meetings or spectator events, producing sports or entertainment events, accommodating large-scale production or maintenance operations requiring controlled environments—will simply require pressure vessels larger than 15-foot (4.4 m) diameter cylinders of any length. Yet foreseeable launch vehicle development will focus on operations parameters like reusability, turnaround cost, safety, flight rate, and schedule reliability, not significantly larger payload volume or even mass capacity than the Shuttle has already. This technology program would *demonstrate*, over several years in four incrementally more challenging phases, practical methods for providing large-dimension, habitable, outfitted pressure vessels in LEO: (1) deployment and subsequent outfitting of volume annexes expanded (e.g. inflated) from a service core already outfitted and tested prior to launch; (2) on-orbit assembly, then outfitting and testing of a system from pre-fabricated, pre-tested parts and subsystems; (3) retrofit of a Shuttle external tank, including orbital safing, interface integration, subsequent outfitting and testing; and (4) fabrication on-orbit of a pressure vessel from material recycled, manufactured or

mined in space, and then outfitted with subsystems launched from Earth and assembled in space.

Conclusion

Large-scale development of the obvious eventual market for space tourism, the apparent market for space-based entertainment and sporting, and the potential market for space-based manufacturing, hinges on private investment There is no shortage of investment capital available to developers, but only if the investment environment is acceptable. Clarity and stability of governance, proof of technological readiness, and availability of the necessary infrastructure are all essential. These three components are uniquely within the power of governments to arrange, and among world governments, the U.S. Government is currently best positioned to arrange them for developing LEO. Doing so will require a mix of persistence in completing existing programs, willingness to focus the priorities of future research programs, and vision in establishing—without any significant present cost—the bold, conducive regulatory framework within which this business sector can grow.

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