SPACEPORTS: THE NECESSARY INFRASTRUCTURE FOR PRIVATE SPACEFLIGHT

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ABSTRACT

This paper provides an overview of a mechanism to evaluate the viability of a spaceport for commercial space transportation. The current literature in the field of space transportation tends to focus on the vehicle rather than on supportive infrastructure. While several launch sites exist or have been proposed, a structured approach to spaceport evaluation is lacking. To respond to this need a mechanism was created and tested on existing and potential spaceports. The spaceport evaluation mechanism (SEM) contains criteria describing the requirements for the selection, development and operation of a spaceport for commercial space transportation. In the process of the derivation and testing of the SEM, several issues pertaining to the current spaceport industry were identified. Limitations and recommendations for the advancement of the SEM are also discussed. This paper provides an outline of the SEM developed by the Spaceport Team Project at the International Space University (ISU) in its Space Studies Program 2008 in Barcelona, Spain.

INTRODUCTION

The era of government-dominated space activities is now being augmented by private ventures and public-private partnerships[2]. Although in its infancy, the market for spaceports is emerging as a promising enterprise. The number of proposed spaceports around the world aiming to service commercial space tourism and other industries indicates a future market that may be highly competitive. Technologies for commercial spaceflight have been demonstrated in recent years and several companies are independently developing space access vehicles and spacecraft. To incorporate these developments and infrastructure investments into a spaceport, a comprehensive assessment of viability is necessary. In response to this need, a Spaceport Evaluation Mechanism (SEM) was designed and tested[1]. To test the SEM, it was evaluated against two existing and fundamentally different spaceports: Mojave Air and Space Port, California, USA; and Guiana Space Center, Kourou, French Guiana. It was then applied to a case study, analyzing Lleida, Catalonia, Spain as a potential site for a spaceport. Only the Lleida case study is discussed in this paper.

The SEM consists of criteria developed to assess the viability of a commercial spaceport. Application of the mechanism is intended to result in an overall evaluation and a set of recommendations for a given spaceport. It is intended to assist spaceport operators, investors, and policy makers in the evaluation and development process. It is submitted that the SEM is unique due to its international nature, drawing from research and expertise in seven interdisciplinary areas.

For the purposes of this paper, the following definition of a "spaceport" was developed:

An area of land or water that is used or intended to be used for the launch and recovery of space access vehicles, and includes its buildings and facilities, if any.

This paper makes several assumptions. The first is that spaceports can be viable, either currently or in the near future. Second, the use of the SEM is broad in nature and can be applied to all spaceports. Furthermore, the SEM should be viewed as the first published version of the mechanism and used with a clear understanding of its benefits and limitations. Additionally, the conclusions of the evaluation are subject to the accuracy of the information gathered. Updates to the SEM are encouraged to reflect the emergence of advanced technology, new experiences gained, and the evolution of society's acceptance of private spaceflight and commercial space transportation.

The creation and application of the SEM represent the contributions of 41 student professionals from 11 nations at the International Space University Space Studies Program 2008 in Barcelona, Spain.

METHODOLOGY

A literature review on issues relevant to the construction and operation of spaceports resulted in the identification of seven key research areas: technical

infrastructure; facilities; business and commercial; policy and law; safety and security; medical and training; and geography, community, and environment. These areas were addressed by research groups formed according to professional expertise and interest. In addition to this research, there was consultation from industry experts. This process culminated in the development of 58 criteria deemed necessary for the viability of a spaceport. The criteria were consolidated into seven areas of interest and refined to produce the Spaceport Evaluation Mechanism (SEM). The SEM was applied to two existing spaceports, Mojave Air and Space Port in California, USA; and Guiana Space Center, Kourou, French Guiana. These two sites were selected based upon their differing locations, funding structures, regulations, target markets and technical infrastructure. The SEM was then applied to a case study of a possible spaceport in Lleida, Catalonia, Spain. Figure1. Application of the SEM resulted in the formulation of recommendations that could be used to assist the potential development of a spaceport in Lleida.

Prospective users of the SEM may assess the commercial viability of any spaceport model by evaluating the spaceport against the list of criteria. The criteria questions are answered qualitatively as Sufficiently Fulfilled (SF) or Insufficiently Fulfilled (IF). Insufficiently fulfilled criteria may receive suggested recommendations for improvement. A criterion question may be answered as Potentially Fulfilled (PF) if the spaceport has shown that a given requirement is in the process of being fulfilled. If this is the case, the evaluation should then be re-applied at a later date. In the event that the available data is insufficient for the evaluation of a particular criterion, an answer of Not Evaluated (NE) will be recorded. If a certain criterion is perceived as being critical to a spaceport's viability, it is identified with a red flag.

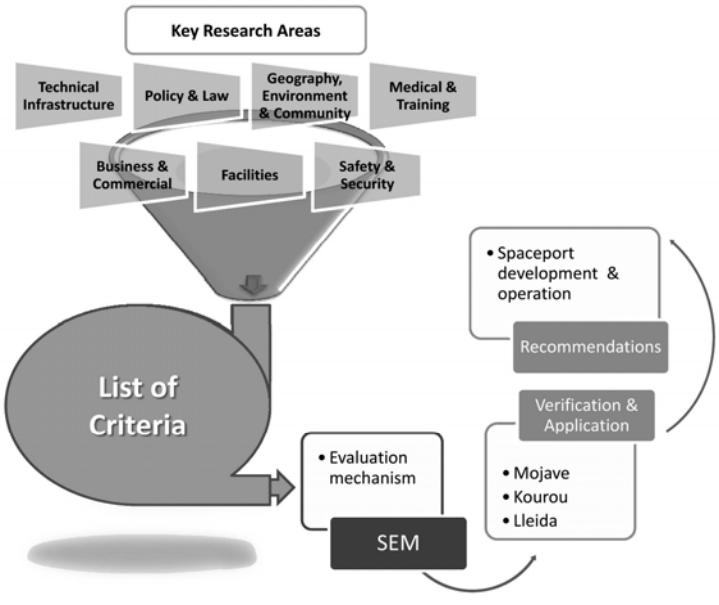

Figure 1 *– Development and evaluation of the Spaceport Evaluation Mechanism (SEM).*[1]

RESULTS

After extensive research, the following areas of interest for spaceports were identified and incorporated into the SEM (Table 1): Business and Commercial; Regulatory Issues; Operational; Infrastructure; Location, Environment and Community; Human Spaceflight; and Cargo and Satellite Operations.

Business and Commercial

Determining the overall commercial viability of a spaceport is based on several factors, including a detailed understanding of the consumer base, the type of orbit offered by the Space Access Vehicle (SAV) operator, and the spacecraft utilized. Other factors include a focus on commercial launches, suborbital transit, orbital launches, or point-to point transportation. Creating multiple sources of revenue is paramount to the financial health of the spaceport. These revenue streams may include space related or terrestrial products and services as well as space and terrestrial tourism opportunities. Having a well developed business plan that outlines financial projections, risks, and liability is needed to establish appropriate contingency plans. As there is a growing number of spaceports under development, having a confirmed commercial spacecraft operator is key in sustaining early development.

Regulatory Issues

Five criteria pertaining to regulatory issues were developed and incorporated into the SEM. Spaceport developers and operators must be aware of and abide by regional and international laws, treaties, and agreements. The location of a spaceport will affect the legal obligations of the spaceport owner or operator. Some of these obligations arise when a State implements national space law. As States are generally accepted as responsible for the space activities of companies established and operating in their jurisdiction, they often put a space sector licensing framework in place to regulate such activities. This framework may require the spaceport to be built to a particular specification, with certain safety and security standards, and in compliance with specific environmental laws and policy. These licenses are usually granted where the space activity is not contrary to national policy or interests, and where adequate insurance and operational plans are in place.

It is also necessary to consider the current lack of specific policy and law, both internationally and nationally, on the ownership and operation of a spaceport. The only comprehensive regulatory framework currently in place is in the United States, where the Federal Aviation Administration's Office of Commercial Space Transportation has begun to directly address regulations for spaceports.

Operations

Spaceport operations involve day-to-day activities to facilitate launching of space vehicles. These activities may include: operations of local infrastructure, human and non human launch activities, and personnel training. The spaceport will provide operational support to each spaceline and ongoing operations of tourism infrastructure with governance by local and state regulations.

Table 1 – *Spaceport Evaluation Mechanism (SEM)*

Number	Criterion	Description
Business		
1 	Have basic business plan areas been addressed?	For a business to be commercially viable, basic business plan areas should be addressed.
2 	Have financiers and multiple revenue streams been identified?	Financing for any large project is an essential element of development. Research has shown that a spaceport will not be profitable if it only focuses on providing space-specific services. Other areas for non-space specific revenue streams must be explored and included in a spaceport business plan e.g. test facility rental or terrestrial tourism.
3	Can the Spaceport secure a substantial share of the spaceport market?	It is a significant advantage if the spaceport has the depth and breadth to be a market leader.
4	Can the spaceport take advantage of a particular customer segment, and/or does it address a specific customer need?	It is an advantage if the spaceport can be the market leader for a particular customer segment, such as vertical take-off or horizontal landing.
5	Are the engineering and development costs plus capital expenditures reasonable based on analogous projects?	Spaceports are large-scale projects requiring significant capital investment.
6	Has an analysis of the business risks and costs of failure, including potential business interruption, been conducted?	A spaceport must evaluate the possibility of failure, including what the failure will cost and whether or not business will be interrupted in the event of a failure or accident.
7	Are there healthy financial ratios and financial figures after the 'breakeven' point?	Financial ratios and financial figures include: revenue - costs, current ratio, debt ratio, debt to equity ratio, free cash flow to operating cash flow, return on assets, and return on equity.
8	Are there manageable quarterly expenses after the 'breakeven' point?	Expenses include Cost of Goods Sold (COGS), sales and marketing expenses, and general and administrative expenses. Some capital expenditures are fixed costs and some are ongoing costs.
9	Is the breakeven point achievable in a reasonable amount of time?	Breaking even represents the point where a commercial venture recovers all of its initial costs. It is recommended for the health of the business that the breakeven point be achieved as soon as is possible.
10	Is a return on investment achievable in a reasonable amount of time?	For a successful business proposition for a spaceport, a prompt return on investment should be forthcoming.
11	Has an exit strategy been defined?	A worst case scenario exit-strategy for the venture should be defined.
12	Is the spaceport well situated geographically to access the orbits/sub-orbits which are desirable to the targeted market?	A geographic area determines orbits which are accessible and can reduce costs by having an optimum launch location.
Regulatory Issues		
13 	Is the Spaceport subject to a regulatory framework?	Lack of a regulatory framework may cause uncertainty in planning and operations. If there is no regulatory framework specific to spaceports or space activities, regulations applicable to aviation should be used as guidelines, and/or consultation with aviation sector/aerospace sector regulators would be necessary.
14 	Does the Spaceport operate in accordance with principles of international and national aviation regulations, concerning, amongst other things, minimizing the effects of operations on air traffic, and obtaining rights of overflight from neighboring States?	Issues that aviation regulations govern include: air traffic management to ensure the space access vehicle has a free and safe airspace corridor, access to space without endangering local communities, and absence of conflict with civil aviation activities. Aviation regulations at national or international level also (depending on the type of space transport) pertain to: infrastructure requirements, warning signage and markings, wind indicators, building evacuation plans; and, the sovereignty of states over their airspace.

15	Are the international obligations of the State within which the Spaceport is located taken into consideration by the Spaceport management?	International obligations (UN Space Treaties) of states often impact space activities and actions of private entities. In the event that there is no specific framework for regulation of space activities, the regulatory authority ought still to respect such obligations in their approach to Spaceports (requiring authorization and supervision through licensing).
16 	Are all local, regional and national laws, including those required for licensing considered?	Environmental and planning laws, health and safety regulations,employment law, and ultimately licensing requirements (if provided for) should be taken into account.
17 	Does the Spaceport provide for communication radio frequency allocation, tracking and telemetry in accordance with international requirements (ITU) with respect to the spaceport airspace?	The spaceport should have its own assigned frequency, and appropriate tracking infrastructure.
Operations		
18	Is there adequate nominal and emergency ventilation?	Ventilation in maintenance facilities and hangars should comply with local health local health and safety/best practices, and ensure the safety of occupants.
19	Does the spaceport have the fire, HAZMAT, and Emergency crews (with access to emergency onsite fire station) to respond to any operational emergencies?	The Spaceport should be equipped with facilities to deal with operational emergencies.
20	Are there built-in redundant power systems for contingency operations?	Certain operational activities must be maintained at all times and will require redundant power systems.
21 	Is there comprehensive emergency medical response plan?	A comprehensive plan would include: onsite triage, immediate emergency facilities, and/or transport for patients to regional facilities with advanced healthcare. Integral to such a plan is the relationship with local authorities.
22	Does the Spaceport emergency health care plan have redundancy in the event of failure, i.e. do they demonstrate fault tolerance?	Emergency response plans require redundancy in accordance with industry standards in the event of systems failure.
23	Are Spaceport personnel performing operations according to applicable occupational health and safety standards?	Given the hazards of spaceport operations, it is necessary to observe applicable occupational health and safety standards.
24	Is there a manifest that will document in real-time the location of users and personnel and their proximity to areas of higher risk?	In the event of mishap involving hazardous materials or operations, emergency response services require real time access to location of all personnel.
25	Can the Spaceport management provide appropriate training to personnel?	Given the uniqueness of spaceport operations, it is essential that jobspecific training infrastructure be provided.
26	Is informed consent obtained from personnel who may be exposed to hazardous areas related to space access vehicle operations and launch?	Given the hazards of a spaceport, it is incumbent on the spaceport authority to inform the users and personnel of the risks.
27	Does the Spaceport have sufficient access to utilities?	Utilities may include, but are not limited to power generation, gas, water, communication, and internet. Resource usage should not affect local community needs.
28	Is there an environmentally sustainable plan for waste management and removal?	A spaceport's proposed waste management plan must be acceptable to the local community and meet applicable environmental and recycling regulations.
29	Is adequate provision made for hazardous and toxic material management?	A hazardous material management plan would prevent environmental contamination.
30	Does the Spaceport have a propellant management plan?	A propellant management plan would include storage, monitoring, and dispensing systems.

31	Does the Spaceport have a security plan?	A security plan includes: security regulations, defined restricted/unrestricted zones, surveillance, liaising with local authorities, protection against espionage, sabotage, theft, vandalism, terrorism or other criminal/unlawful acts. National requirements may also depend on the domestic security policy, as illustrated by requirements at airports.
32	Has the Spaceport management performed a safety risk analysis based on identified risks for prelaunch, launch, and re-entry operations?	Safety risk analysis must be done to mitigate risk of injury, loss of life, and loss of infrastructure.
33	Is there a downrange emergency recovery, search and rescue plan?	In case of downrange emergency, a procedure should be in place to recover a space access vehicle and its passengers/cargo. This plan should include coordination with local and regional authorities.
34	Is the Spaceport located where suitable prevailing weather conditions meet the requirements of the appropriate space access vehicle?	Favorable launch conditions should be present most of the year. Weather criteria pertaining to launch and landing operations of a given space access vehicle should be defined.

Infrastructure		
35 	Does the spaceport launch site support the appropriate space access vehicles?	The spaceport launch infrastructure must be space access vehicle specific. Examples of launch site infrastructure that would support the space access vehicle would be a launch/landing pad, runway, etc.
36	Has an emergency response plan been developed for the contingency situation where a failure occurs within the boundaries of the spaceport?	Emergency recovery plans of the space access vehicles at the spaceport (i.e. emergency landing ability, abort system capability) are necessary to minimize risk to passengers, cargo/payloads, and the community.
37	Does the Spaceport have space access vehicle and payload specific assembly and integration facilities?	The spaceport should have the capability to assemble and integrate payloads with specific space access vehicles.
38	Are there storage and maintenance facilities for space access vehicles?	Storage and Maintenance facilities including hangars, warehouses are necessary for space access vehicle operations.
39	Is there capacity for future infrastructure expansion?	Once the spaceport becomes established in the region and in the market, the capability to accommodate additional facilities and infrastructure will be essential.

Location, Community, and Environment		
40	Is the location of the Spaceport publicly accessible?	Public accessibility can be in the form of public transportation, private road access, etc. If the spaceport has multiple sites or buildings, these should be equally accessible.
41	Is the Spaceport situated near transportation infrastructure that facilitates transport outside the region (national/international)?	Existing transportation links are beneficial as they would reduce costs in shipping of materials relevant to the infrastructure and its operation as a commercial spaceport.
42	Is there existing local tourism infrastructure (hotels, attractions, etc) and can the spaceport absorb seasonal fluctuation in tourism activities?	Existing local tourism would provide an additional revenue stream to the spaceport independent of primary operations, and may alleviate the need to build accommodations for visitors.
43	Does the Spaceport provide or intend to provide entertainment venues and activities for terrestrial tourists?	Facilities such as a visitor center, museum, public launch viewing areas can increase the exposure, publicity and profitability of a spaceport.
44	Is there an expandable commercial airport with a passenger terminal on-site?	Existing terminals should be upgradeable to accommodate space tourism and target specific markets. If the facility supports only ground tourism, an existing terminal could facilitate visitor access and cargo transport.
45	Does the spaceport infrastructure harmonize with the landscape of the location?	To induce a positive visual impact, the infrastructures should harmonize with the landscape of the location and follow local/regional planning guidelines, e.g. ‘green building guidelines'.
46	Is there a wildlife hazard assessment, management, and protection plan?	Both in constructing the spaceport, and in future operations, there should not be a negative impact on local plant and fauna.

47	Has an environmental impact study been completed in accordance with local law?	Local licensing may be dependent upon the acceptable completion of an environmental impact analysis. Additionally, reducing the environmental impact is a beneficial sustainable practice.
48	Does the Spaceport have a plan to minimize noise pollution in local community?	Spaceport noise pollution negatively impacts the local community and should be minimized through sound suppression techniques and distance. Space access vehicle operators licensed to operate at the spaceport must conform to noise limitations.
49	Is there an ethical communication strategy that facilitates community feedback?	The spaceport must accept the responsibility to provide understandable, transparent and relevant information to the public; a process should exist for public interaction, feedback and consultation.
50	Does the Spaceport management have a corporate social accountability plan?	The organization must respect basic civil and human rights, and display commitment to the betterment of community. The organization must honor and respect local culture, language, and knowledge. The requirement of relocating citizens should be avoided where possible.
51	Does the Spaceport promote human resource development within local and regional communities?	The spaceport should utilize local and regional human resources where possible. The spaceport must inspire, engage, educate, and employ local and regional community members.
Human Spaceflight		
52	Is there infrastructure necessary to perform screening and training of passengers and flight crew?	Medical screening and spaceflight training infrastructure is a necessary component of human spaceflight operations and may serve as an additional source of spaceport income.
53	Can the Spaceport provide ground-based in-flight physiological monitoring and medical management?	In the event of medical mishap on board the space access vehicle, the vehicle crew should have the capability to communicate with spaceport based medical staff. Ground-based in-flight physiological monitoring capability is a necessary requirement to perform this function.
54	Is there luggage storage and processing infrastructure?	Luggage storage and processing infrastructure may be used as an additional source of spaceport income. This infrastructure should be securable.
55	Does the Spaceport have onsite food handling and storage infrastructure?	Food handling and storage infrastructure may be used as a source of spaceport income. This infrastructure should comply with applicable food handling standards. additional
Cargo and Satellite Operations		
56	Are there space cargo processing facilities?	Cargo processing facilities should include transport, processing, quarantine, inspection, and customs capabilities. These operations may serve as an additional income source for the spaceport.
57	Does the Spaceport provide testing infrastructure for space access vehicle and payload operations?	Testing infrastructure may be used as an additional source of spaceport income, as spaceport clients typically utilize such facilities in pre-flight verification operations.
58	Does the spaceport have a clean room?	A clean room should be present that meets applicable industry standards for storage, handling, and integration of space access vehicle components and payloads.

Infrastructure

The SEM contains five criteria pertaining to the infrastructure requirements of a spaceport. The present technical infrastructure in government-owned spaceports is not sufficient for the requirements of private spaceflight. Commercial spaceports are being established by private sector and through public-private partnerships[3].

A spaceport that focuses on sub-orbital flights will be very different from one that focuses on orbital flights. The two types of spaceports will have different optimal locations and different facilities. They will also cater to different types of SAVs which rely on different technologies. Sub-orbital flights will primarily be used for space tourism or point-to-point transportation of human passengers or cargo. These flights can co-exist with existing air traffic to minimize the impact on current air infrastructure. Government space

programs tend to focus on end-product delivery and not the reusability of vehicles. For commercial applications such as space tourism, frequent flights are necessary and spaceports must be able to support these types of vehicles.

Orbital spaceflight has higher risks and the amount of power to reach orbit is larger than that required for sub-orbital altitudes[3-4]. Multi-stage vehicles are required for launch from ground, automatically restricting the location of the spaceport to an isolated area or near the ocean due to the possibility of debris falling during stage separation. Most present orbital vehicle configurations use a launcher that deploys the capsule in a parking orbit.

The key technical requirement for the development of spaceport infrastructure is to ensure safe and reliable access to space. The type of SAV, propulsion method, and the launch and recovery modes determine the requirements for the infrastructure. This infrastructure includes runways, launch pads, assembly buildings, and the number of personnel required for operations. Redundant systems must be included in the spaceport to increase reliability. These systems will also maximize safety and minimize the turnaround time needed between launches.

Other important aspects of spaceport infrastructure include the need for an uninterrupted power supply, a safe means for storing and handling propellant, and an efficient and reliable air traffic management system. The infrastructure requirements should take into account the upgradeability of the spaceport to support future traffic such as runways and new installations. Continuous monitoring of the operations is essential in the evolving years for continuous improvement of operational efficiency.

Location, Environment and Community

Twelve criteria were incorporated into the SEM to address a spaceport´s interaction with its community. Issues pertaining to this interaction include: transportation, tourism, social and environmental.

Transportation issues include terrestrial accessibility both to the region, to and within the facilities and are addressed as a trade-off between ensuring security and commercial optimization due to terrestrial tourism revenues.
Tourism issues address questions such as who are the customers of the spaceports and the need of terrestrial tourist activities that require dedicated facilities such as terminals, accommodation, restaurants and entertainment[5]. Tourism activities, space related or not, have an important impact in the regional economy, and, if already existing, can contribute avoiding many costs while taking advantage of an existing tourism market.

Social issues include corporate social accountability to provide a positive economic and social impact on the local community by creating jobs, and generating new revenues to the local companies. An ethical communication plan should ensure transparent information to the public together with an adequate education and outreach program.

Environmental issues identified include items such as landscape integration of

the spaceport, which is relevant both for aesthetic purposes and to provide adequate viewing areas to the visitors. Wildlife is addressed both from a ground operations safety perspective and a protection perspective. Environmental studies are essential in order to minimize impact on the local community by reducing pollution and noise levels.

Human Spaceflight

For a spaceport to support and generate revenue from human spaceflight activities, they must be safe and have manageable risks. This requires the capability to monitor and intervene in participant health during all phases of flight. Although, the health and safety of spaceflight crew and passengers is the responsibility of both the spaceport operator and launch vehicle operator (spaceline), these criteria apply to the spaceport operator only.

To minimize the risk of human spaceflight, pre-flight screening and training infrastructure is necessary to identify at-risk participants who may be unable to endure the physiological stresses of spaceflight and microgravity. Current medical screening guidelines for commercial human spaceflight have been developed (FAA, 2003) and are derived from astronaut and pilot cohorts[6]. Screening and training of flight crew and passengers are the responsibility of the spaceline and may be conducted offsite. However, there is a rationale for onsite screening and training facilities (such as a centrifuge, hypobaric chamber and exercise physiology laboratory) given their multiple benefits. Onsite facilities could serve as a revenue source when leased to the spacelines or when used as an attraction for spaceport visitors. They would also complement onsite medical and occupational health services that are necessary to address immediate problems at the spaceport. Lastly, they are integral to the creation of a center of excellence in human spaceflight research and development that would facilitate ongoing links between industry and academia.

Despite rigid screening and training protocols, adverse events will still occur during human spaceflight. To manage these risks, a spaceport should have the capability to perform in-flight physiological data monitoring and ground-to-space communication to facilitate in-flight medical management. Such systems would act as an early warning system, providing the opportunity to intervene early and prepare for possible post-flight care and transfer. The capability to record this data would also create an expanded cohort for medical research, provided issues of informed consent, data security, and confidentiality have been addressed.

Post-flight medical problems will be addressed by onsite medical services. This will necessitate the presence of trained medical staff including flight surgeons with expertise in space medicine, infrastructure for emergency response, a comprehensive medical emergency response plan that involves local search and rescue, police, fire and health care resources, triage and transfer protocols, and rehearsal and redundancy of onsite emergency medical responses to ensure their effectiveness.

The provision of allied services is also integral to a spaceport's human

spaceflight capability. Food handling and storage that abides applicable regional standards, and luggage processing and storage infrastructure will also be necessary to support human spaceflight.

Cargo and Satellite Operations

There are three criteria necessary for a spaceport to support and generate revenue from cargo and satellite operations. Cargo processing that links with regional transportation infrastructure should be available. Testing facilities that could be utilized by clients in pre-flight verification of their vehicles and payload would serve as a potential source of revenue. Lastly, the spaceport should have a clean room that meets applicable industry standards for storage, handling, and integration of space access vehicle components and payloads. Refer to the section on Infrastructure for further information related to cargo and satellite operation requirements.

Application of SEM: The Lleida Case Study

The SEM was used to assess the feasibility of a potential spaceport to be co-located at the Lleida-Alguaire airport near Lleida, Catalonia, Spain. Because this spaceport is conceptual, not all information relating to our criteria was accessible and most of the details used to complete the SEM were obtained from interviews with representatives from Lleida-Alguaire airport. As a result, most of the criteria in the SEM have not been fulfilled. Specific findings and recommendations are as follows:

- The airport is optimally located with respect to population density
- The airport is easily accessible in an area with developed tourism infrastructure
- The airport has significant capacity for expansion
- The airport infrastructure requires modification to accommodate horizontal take off and landing
- A detailed financial plan including an analysis of potential revenue sources is required
- A national regulatory framework governing commercial spaceport operations is required
- Establishment of on-site facilities to meet the training, medical and residential requirements for spaceflight participants and spaceport employees
- The proposed spaceport must adopt and employ a propellant storing, monitoring and dispensing plan and must encourage the use of non-toxic propellants
- Environmental and community concerns including noise and air pollution should be carefully evaluated and involve local government

The accuracy of the SEM analysis was dependent on the information available at the time of evaluation. The SEM should be re-applied to evaluate the Lleida spaceport as more information becomes available. In addition, however, the SEM may be used to guide spaceport development at Lleida. This evaluation can be re-applied periodically to account for new and evolving trends in industry.

DISCUSSION / CONCLUSION

The SEM is the first comprehensive evaluation mechanism of spaceport

viability to be developed. The application of the SEM to Mojave, Kourou, and the potential Lleida spaceport produced valuable insights and recommendations. The process also highlighted necessary improvements to the spaceport industry and the SEM.

Various issues have been identified that are currently lacking in the area of spaceport industry. For example, spaceport policy and regulation has not been fully developed. Several countries have expressed an interest in spaceports but do not possess a national regulatory body to provide guidelines and framework. Furthermore, such a body could facilitate the adoption of regulations for the spaceport. It would also perform licensing, control and supervisory functions and monitor spaceport activities. These activities would include a mandatory payload review and notification procedures for all spaceport launches. Regulations should also be formulated to negate the impact of spaceports on the environment. Although environmental plans are required for licensing of airports, these regulations do not necessarily extend to spaceports.

Procurement of adequate insurance is an additional requirement for commercial viability. As there are an increasing number of spaceport models, owned and operated by actors other than the traditional public or governmental entities, insurance may become difficult to acquire. As international law designates the ´launching State´ as liable for damage caused by space activities, it is necessary for a regulatory body to impose insurance requirements upon private commercial operations. This insures liability for potential damages caused by activities related to spaceports is assumed by the appropriate party. A private enterprise owning or operating a spaceport would require adequate insurance.

Whilst there are clearly issues that need to be addressed through the implementation of new regulatory frameworks, it is important for law and policy makers to develop them in consultation with industry to minimize the potentially negative effect that excessive regulation can have on a nascent industry.

Future Directions

A generic mechanism (SEM) with high-level criteria applicable to several types of spaceports was developed to make the evaluation process efficient and easy-to-use. Over the course of development, specific sub-groups identified areas of improvement for the SEM. This provides the SEM users with an idea of how the mechanism was developed and its future potential. In the next version of the SEM, a weighting system derived from full statistical analysis should be adopted. The use of a weighting system would allow the criteria to be targeted to different audiences, and a full scoring method similar to that of a statistical Likert scale could accurately assess how well a spaceport meets the stated criteria.

Regarding the financial considerations of a spaceport, additional forms of revenue generation are discussed in the referenced report including advertising, power generation, and terrestrial tourism. These revenue streams are encouraged as a focus in the early stage of spaceport development when costs are high and revenue is low or not yet

existent. Although these revenue streams are important, they do not fully capture the business needs of a spaceport.

Currently, no in-depth business plan has been explored for development of the SEM. A quantitative mechanism, as discussed, would facilitate in-depth cost-benefit analysis. To make such an analysis, additional criteria would need to be added to the SEM. For each potential spaceport infrastructure decision, detailed research would be performed in order to determine the opportunity cost of the decision as well as up-front costs, local taxes, operational costs, and other ongoing costs of the decision. Also researched would be how these costs are offset by potential benefits of the decision. These potential benefits would include estimated yearly revenue and rapid rate of return as well as tangible benefits to the area surrounding the spaceport. These local benefits would be quantified in some way. They could include criteria like job creation, providing a resource for space agencies, drawing international attention to the area, and improving the local economy by bringing people, business, and investment to the area.

Although the mechanism currently includes the criteria and a short description, a more detailed description is appropriate for future development. Another recommendation is to implement a software interface of the criteria evaluation that would allow easier accessibility to industry users and provide a preferred viewing.

Spaceports are the gateway for future space travel just as their airport counterparts opened up the skies to limitless possibilities a century ago. This interdisciplinary project set out to investigate and recommend criteria for commercially viable spaceport infrastructure and operation for the civilian space transportation and tourism industries. Iterations of research, discussion and designs ensued formulating the SEM evaluation mechanism as the deliverable. Verification of the SEM on two operational spaceports, Mojave, USA and Kourou, French Guiana, were conducted. The SEM was also applied to the potential spaceport at Lleida-Alguiare Airport in Spain to determine its viability as a potential spaceport. Lastly, recommendations on further development and use of the SEM were described. This document is aimed at entrepreneurs, investors, governmental entities and spaceport operators. It is the intention of the authors to produce a useful and effective mechanism for evaluating the viability of existing and proposed spaceport projects around the world and to provide a sound rationale for their future development.

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