A FRAMEWORK FOR ANALYZING THE MARKET AND SUPPORTING INFRASTRUCTURE FOR SMALL SATELLITES AND ASSOCIATED SYSTEMS

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ABSTRACT

A comprehensive, conceptual framework within which space programs, projects, and activities can be analyzed is presented. This framework consists of a number of largely functional dimensions. Most important is the division of space-based and space-oriented activity into two major segments: the **space infrastructure**, and **space-derived products** and **services**. The space infrastructure includes the various functions and devices which support space-oriented activity, including launch vehicles, payload and vehicle processing facilities plus those organizational and technological elements which support space-oriented activity, including the institutional support base. Space-derived products and services are those products and services which can only be produced within the space environment, or through the application of space-oriented technology, such as vantage point products (e.g., remote sensing, communications), physical environment products (e.g., materials processing), and others. Other dimensions in the framework include: (1) **time** and **commitment** (e.g., past, present, planned), (2) **scope** (e.g., national, international), (3) **enabling factors** (e.g., enabling technologies), and (4) **providers** and **consumers**.

The small satellite community imay be examined within the context of this conceptual framework. Such an analysis will provide: (1) a limited **snapshot of the current status** of the small satellite community (or industry), and (2) an indication of the areas of interest and concern to the small satellite community -- technical, financial, and institutional. Preliminary analysis (as of this date) indicates that areas of interest and concern to the small satellite community include: (1) continued idenfitication and conceptual definition of applications and potential users, (2) access to space (i.e., space transportation), (3) continued development of enabling technologies (e.g., miniaturization, common buses), and (4) development of policy guidelines and institutional acceptance, among others.

(The purpose of the paper is to demonstrate the use of the conceptual framework as an analytical tool, as well as to present a snapshot of the small satellite industry.)

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INTRODUCTION

In spite of the plethora of space policy studies which have been conducted in recent months, the fields of space policy and space enterprise research lack a well defined conceptual framework in the space policy literature. Such documents as the reports of the National Commission on Space[1] and the Business Higher Education Forum[2], as important and well written as they are, leap immediately into the issues facing space development without fully defining their context. Some works have detailed user and provider relationships for certain segments of the space industry, yet have done so without establishing an overall conceptual framework. Thus, there still exists confusion over the use of such terms as "commercial space", "space business", "space development", and "space infrastructure".

At a recent space conference, one panel session participant stated that it was "up to the government" to provide the "full space infrastructure" in order for private business to be willing to invest in space-oriented projects. Such a statement ignores the many business opportunities open to *commercial* providers of space infrastructure services. However, the problem is not a philosophical difference of opinion as to what sector -- public or private -- should provide such services. Rather, the problem is that there is no well-defined, commonly accepted definition describing precisely what the "space infrastructure" is. In fact, in the report of the National Commission on Space, the development of a "space transportation infrastructure" is presented both as a "critical lead role of government," and as an area in which the private sector should be given free reign in order to provide cost-effective services[3]!

This paper offers a conceptual framework which can be used in analyzing and discussing space activities. Such a framework is particularly important in analyzing a developing area of activity, such as the small satellite community. The purpose of the framework is to enable categorization of the various "impactors" upon a given area of activity, in order to identify potential problems, and areas of opportunity. (This work is an expansion on research conducted by the author on behalf of the Florida Governor's Commission on Space[4-7]).

DEFINITIONS

Before developing the conceptual framework, it is important to establish a number of broad definitions describing space activities:

space project - an organized, space-oriented activity sponsored by an organization or agency, having a specific goal of limited scope, with a budget of time and resources.

space program - a collection of organizationally sponsored space projects, each contributing to the overal goal of the organization.

space development - all activities supporting the *full utilization* of space technology and the space environment, carried out variously by government agencies and the private sector[8]; synonymous with space exploitation.

space exploration - space-oriented activities designed and carried out in order to learn more about the natural and physical environment of space; basic space science research.

space enterprise - space-based or space-oriented business activity which involves space operations, space operations support, or derives from the application of space technology[9]; encompasses private sector companies, entrepreneurs, government and military contractors -- all industries involved in the support of the space infrastructure, or the production of space products and services.

space effort - the totality of programs, projects, and operations which make up space activities, including government civil and military programs, and private space activities.

commercialization - the private development of a product or service.

privatization - transfer of responsibility for a product or service developed by a government agency to a commercial agency or private institution[10].

For example, while NASA has the lead role in the American "civil space program", the American "space effort" includes NASA, the Departments of Defense, Commerce, and Transportation, university researchers, and all domestic private companies involved in space activities.

Having reviewed the above definitions, it is easy to understand where confusion would exist, for example, in a discussion of "space commercialization". Does space commercialization include the marketing of independently developed launch vehicle services to a government agency? In this framework, the answer to this question is, "Yes". Yet, many people feel that commercial space activities exclude government involvement in any way, even as a customer. (This specific example illustrates why the term "space enterprise" is preferable to the term "space commerce".[11])

A CONCEPTUAL FRAMEWORK

Space activity can be divided into two major categories, based generally upon the use of the end product which the activity produces. These are **space-derived products** and the **space infrastructure**:

space-derived products - products or services which are derived directly through utilization of space resources or physical attributes of the space environment, or products and services developed through the application of space-oriented technology (technology utilization, or spin-offs).

space infrastructure - the facilities, institutions, products, and services which directly support space activities.

These form the two primary dimensions of this conceptual framework.

Space-derived Products.

Space-derived products (including services) are those products and services intended for end users who may or may not be concerned or impacted by the fact that the product or service they are using was made possible through space activities.

They are concerned only with the ability of the product or service to meet their needs. The "space connection" is essentially transparent to these users.

Space-derived products can be further categorized as follows:

Vantage Point Products - products and services made possible by taking advantage of the vantage point provided by being in orbit about another body, including:

Communications - transmission of data and information via satellite or satellite network to end users.

Remote Sensing and Observation - passive and active sensing of targets of interest, made possible by being in orbit about, or transitting near, a planetary body, including the observation of some other celestial object (e.g., other than the body being orbitted).

Location and Navigation Services - determination of geographic location on a planetary body or in space, through use of an orbiting satellite or network of satellites.

Physical Environment Products - products made possible by taking advantage of the special physical properties available only in space, or more readily available in space, includng:

Micro-gravity Based - products made possible (or quality of product enhanced) due to elimination of the effects of gravity on the production process.

Vacuum Based - products made possible (or quality of product enhanced) due to the availability of a hard vacuum environment.

Natural Resource Products - products produced in whole or in large part through the utilization of natural resources obtained in space, including:

Energy - produced in space for use as a general commodity.

Material Resources - minerals, compounds, and bulk material mined from extra-terrestrial bodies.

Spin-off Products - products and services made possible through the innnovative and creative application of technology developed for or through space activities.

(It is entirely probable that additional categories or sub-categories will become evident as a result of continued research and development.)

Space Infrastructure.

The space infrastructure makes the production, development, and realization of space-derived products possible. Elements of the space infrastructure include:

Space Transportation Elements - vehicles and devices which enable travel to, through, and from the space environment, including:

Launch Vehicles - devices which enable travel to the space environment from a planetary body, including liquid, solid, and hybrid rockets, expendable and reusable.

On-orbit Transportation - devices which enable travel through the space environment, including orbital transfer vehicles, apogee kick motors, tethers (when used as a means of propulsion), electric propulsion devices, and other devices which enable movement through the space environment.

Return/Re-entry Vehicles - vehicles which enable the physical return of products and cargo from space, including manned and unmanned vehicles.

Hybrid Vehicles - vehicles which perform a major function in multiple regimes of the space transportation operation (such as the space shuttle orbiter).

Earth-based Processing Facilities - all Earth-based operational support facilities which exist to support space operations, including:

Launch and Recovery Processing Facilities - facilities which process the space transportation elements.

Payload Processing Facilities - facilities which process cargo and crew payloads for launch and upon return to Earth.

Extra-terrestrial Facilities - support facilities which are similar to the Earth-based "ground support facilities", which are not Earth-based, including:

On-orbit Facilities - space platforms, stations, and production facilities, orbital refueling stations, orbital research facilities.

Facilities on Other Worlds - support facilities which are based on other planetary bodies, the Moon, and asteroids.

Institutional Support Base - the segments of society and industry which provide the enabling factors (described later) which support space operations, including:

General Policy Making Bodies - government agencies, legislative, executive, and jucicial, and certain advisory committees.

Industrial Support Base - industrial organizations which conduct complex operations in support of space activity.

Economic Support Base - agencies, institutions, and organizations which provide financial resources and services in support of space operations.

Education, Training, and Research Facilities - academic institutions, research centers, vocational and technical training organizations.

Note that these definitions are *functional* in nature. For instance, launch vehicles are classified in the space infrastructure as "space transportation elements," whereas the space transportation industry is a part of the "industrial support base."

Providers and Consumers.

These space-derived products and services, and the space infrastructure, are of interest to the **providers** of the products and services, as well as to the **consumers** of the products and services. The providers and consumers comprise the third dimension of this conceptual framework. Each includes:

Government Agencies - military services and agencies, research agencies, operating agencies, licensing organizations, and others.

Private Companies - companies involved in the space industry or utilizing space-oriented technology.

Academic Institutions - universities, technical training organizations.

Special Purpose Organizations - multi-national organizations, consortia, and others.

Note once again that the categories describe *functional* activities; not all of the categories are mutually exclusive. An organization may be placed in multiple categories to describe its various roles in space activity. For instance, certain government agencies in the executive branch may be considered "policy making bodies" (a part of the space infrastructure) when performing certain regulatory functions, and later may be considered a "government agency consumer" (in the consumers and providers dimension) when purchasing launch services.

Scope.

The fourth dimension of this framework is **scope**. This dimension measures the breadth of impact which any given space activity has. This includes:

Intra-organizational - within a single organization only.

Multi-organizational - involving two or more organizations, including companies, agencies, or governing bodies.

National - involving or impacting many organizations within a nation, usually with respect to the nationally sponsored space program.

International - involving organizations in more than one country, or multi-national organizations.

This dimension is interesting in that, any project which is international in scope also has national (and probably multi-organizational and intra-organizational) implications as well. In other words, projects with broader scope are cummulative with respect to the lower levels in this dimension.

An issue encompassed by the definition of scope is the question, "What is a space organization or a space company?" Obviously, those companies which are based entirely upon space activity, such as American Rocket Company, Orbital Sciences Corporation, and others -- "pure plays", so to speak -- can be classified as space companies. Companies such as McDonnell Douglas, Martin Marietta, and others, which have significant non-space related activities, are nonetheless also thought of as space companies, owing to their heavy involvement in the launch vehicle industry.

Generally speaking, a "space organization" or "space company" can be described as an organization which devotes a significant percentage of its operating budget to space-oriented activity. Further research is warranted in order to outline a continuum of "significant space involvement", based on the percentage of organizational resources committed to space activity. Following such a classification, various financial, organizational, and operational characteristics may be identified for the various types of "space companies."

Enabling Factors.

The fifth dimension of this framework includes the **enabling factors**. These are:

Enabling Technologies - basic and applied technologies which are components of space-oriented projects.

Institutional Capabilities - the capabilities of institutions to support operations of appropriate scale required by space activities, including:

Industrial Production Capabilities - the ability to utilize the basic enabling technologies in successful production projects.

Resource Support Capabilities - the ability of institutions to provide appropriate financial, material, and managerial support to space activities.

Research and Development Capabilities - institutional support for the development of new enabling technologies.

Time and Commitment.

The sixth and final dimension of this framework is **time** and **commitment**. This includes:

Past - historical space activity.

Current - space actitivies currently in progress.

Planned - space activities which are planned and budgeted, but which have not been fully funded or formally initiated, (i.e., immediate future).

Proposed - space activities for which plans are being developed; includes project and program options currently undergoing review by policy making bodies, (i.e., near future).

Projected - space activities which are within the realm of technical feasibility, (i.e., distant future).

This dimension cuts across all others, since each of the other dimensions have different characteristics, depending upon the time frame being considered.

Applying the Framework.

Within this conceptual framework, all space activities can be located and fully described. Two dimensions of this framework -- **space-derived products**, and the **space infrastructure** -- form the central basis of the framework. Any given space activity, at any level (e.g., project, program, industry segment) can be located within one or the other of these dimensions. The remaining four dimensions of the framework - **producers** and **consumers, scope, enabling factors**, and **time** and **commitment** - cut across the previous two, and can be used to fully describe the activity. This relationship is shown if Figure 1.

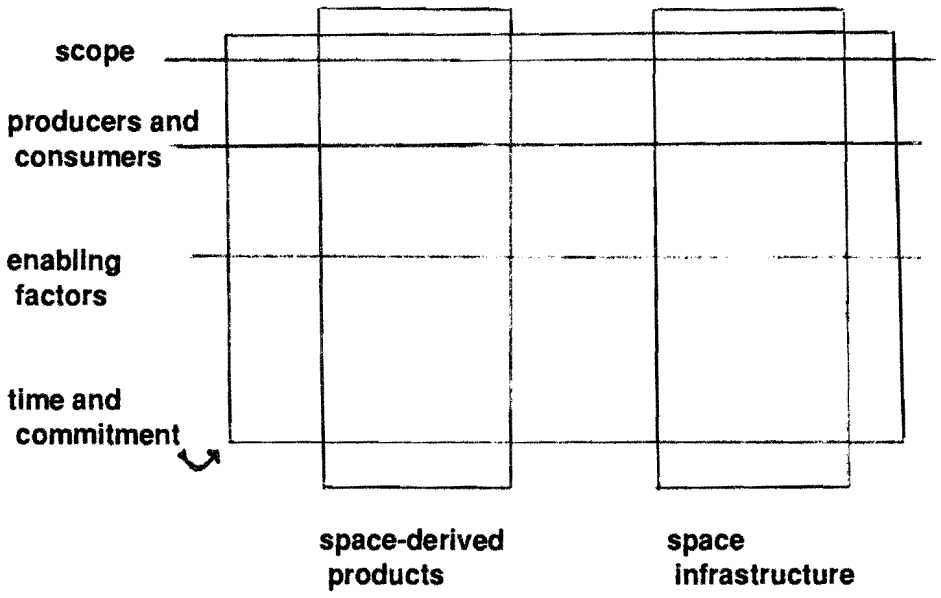

Figure 1. - **The Space Activity Framework.**

Summary.

In general, the **needs of consumers** drive the development of the **enabling technologies**, which are then used by organizations within the **institutional support base** of the space infrastructure -- as a manifestation of their **institutional capabilities** -- to enable **space-derived products** and services to be produced.

A recent example of this framework "in action" is the NASA *Project Pathfinder* initiative[12]. In response to the work of the National Commission on Space, which was an independent policy making body, NASA conducted its own internal policy and program review. This process culminated in the production of the Ride Report, which outlined a broad set of "programmatic objectives" and proposed missions for the nation's space agency.[13] In order to develop the necessary enabling technologies to support these broad mission sets, *Project Pathfinder* was initiated. This program of research has met with a fair amount of funding success. Furthermore, one of the major missions proposed in the Ride Report -- the "Mission to Planet Earth" -- has been adopted as the primary focus of the International Space Year effort[14].

THE SMALL SATELLITE COMMUNITY

Given the framework outlined above, we can begin to develop a comprehensive picture of the small satellite community -- its providers and consumers, the supporting infrastrucuture, enabling (and limiting) technologies -- and the business and policy environment in which it is developing.

Small satellites themselves physically constitute a part of the space infrastructure. Small satellites fall primarily into the sub-category of "on-orbit facilities," although certain designs and applications may take the form of "return/re-entry vehicles." While some studies classify "small capacity payloads" as ranging up to 4,000 pounds[15], a more generally accepted range is between 200-1,500 pounds of payload into orbit, with an overall size of up to 75 cubic feet, exclusive of upper stage propulsion[16,17].

Application areas for small satellites is an area of rapid develoment. Currently planned or proposed applications include "vantage point" and "physical environment products" within the defined conceptual framework. Presently, there is growing interest in the use of small payloads as "test beds" or "busses" for experiments in all of these areas[18]. Small satellites may also be useful in certain experiments in support of the *Project Pathfinder*, in particular in the areas of fault-tolerant systems, optical communications, cryogenic fluids handling, and others[19].

Two areas of particular importance to the small satellite community are (1) space transportation services availability and affordability, and (2) the continued development of enabling technologies. Each of these areas require further in-depth research, in the context of the conceptual framework, in order to describe the current environment, problem areas, and future opportunities.

Given present and projected limitations of large-scale space transportation, particularly for commercial applications and basic scientific research payloads, the future is promising for the continued development and utilization of small-scale packages. NASA is currently studying the use of small satellites, and attached payloads, for use in support of and auxilliary to the space station program[20].

CONCLUSION

The conceptual framework presented in this paper can be a useful tool in analyzing space activity, in order to more fully understand the relationships between the different types of activities, the organizational participants in space activities, the technological and institutional constraints on continued development in a given area of endeavor, and the impact of space policy upon all of the above.

RESEARCH NOTE

In this paper, the author has presented an initial anatomization of the small satellite community within the conceptual framework. Under a recently received grant from the Florida Technological Research and Development Authority, researchers at the Center for Space Enterprise Research are engaged in a further analysis of this industry, and others[21]. The purposes of these research efforts are: (1) further development of this conceptual framework as an analytical tool, (2) the development of a comprehensive business-oriented database on specific segments of the space industry, (3) in-depth analysis of the technological, financial, and business requirements of selected segments of the space industry, and (4) identification of specific areas of importance and opportunity for the continued development of space enterprise in Florida.

Regarding the area of small satellite systems, near-term research goals include: (1) development of a comprehensive snapshot of the small satellite community, within the context of this conceptual framework, including (a) specific provider organizations, (b) specific user or potential user organizations and agencies, (c) identification of specific enabling technologies, and (d) identification of current or planned small satellite research efforts; (2) analysis of the potential market for small satellite systems, including: (a) potential commercial market, and (b) national civil and military operational and research program market; (3) analysis of the business and financial environment facing small satellite companies; and (4) definition of areas of opportunity in the small satellite industry for the state of Florida, including identification of areas in which state-sponsored assistance can lead to a growth in small satellite systems industry within the state.

The author welcomes and encourages comments from readers regarding any of these topics.

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