Linking Information Systems Between Independent Spaceports

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Confidentiality Statement

ABSTRACT

A concept is presented of linking existing and future spaceports together to enable coordinated operations and reduce duplicity of effort. Information exchange standards and other key elements of the concept are essential to the growth of an economically commercial spaceport industry.

The proposed network is readily automated and has common architectural components that facilitate resource sharing throughout the system. The challenges of crafting an information infrastructure that supports real-time data exchange are explored. Cost reduction opportunities are presented and a model of the network is given. An approach to defining a corresponding information system architecture is also introduced. A brief survey of related work in aerospace, air traffic control, and other fields is included.

INTRODUCTION

There is an opportunity for space operations to enter the mainstream of our daily lives over the next decade in much the way aviation did in the 1950s and 1960s. Just as airlines once struggled to remain commercially viable in the face of rapidly changing technology, substantial risk, and dwindling government subsidies, today's public space agencies are striving to reduce costs as pressures mount to manage spiraling government budget deficits. In addition, the effects of fierce competition now facing the world's airlines will eventually be felt in the commercial space transportation industry. These powerful forces will affect every facet of space operations. They will lead to innovative operations concepts, smaller ground crews, and effective application of modern technology. In addition, spacecraft and launch vehicle designs that focus on operability goals, and, most importantly, a business-oriented approach to the entire spaceport enterprise will be essential to economic survival.

A global spaceport network will be the primary global mechanism for managing space flights of the future. Reusable spaceliners are the key to realizing affordable space access; these spaceliners are by their very nature able to launch and land at any appropriate facility, and, in fact, will often depart from one facility only to return to another. This mode of operation is possible only if the various spaceport facilities coordinate their operations with each other and with their tenant spaceliner operators. A network and corresponding information infrastructure will be required to perform this coordination in a cost-effective manner.

A standard information infrastructure will be required to enable a global spaceport network. Such an infrastructure will be a central element of any initiative to substantially reduce the cost of space operations. Standard integrated information centers must be established that share compatible interfaces, data architectures, and processing models. The complex relationships between flight information, traffic control, range operations, flight and mission planning, and logistics and supportability data can be managed by automation to reduce the magnitude of manual information analysis and planning. This will allow data exchange between spaceports and avoid the need for specialized teams of operators and large sustaining engineering efforts to maintain islands of automation.

This paper first establishes the need for a global spaceport network and a comprehensive ground information infrastructure to enable routine space flight operations from multiple spaceports. A conceptual framework for a spaceport information infrastructure is then introduced, based on information "centers" corresponding to major elements of ground operations such as flight control and logistics. Information system requirements are identified for each center. The technology needed to meet these requirements is also discussed. Finally, an approach to defining a complete information system architecture is suggested, and related work described.

BACKGROUND

Command and Control Technologies (CCT) is a spaceport technology company producing ground data and control systems for launch site operations. The firm and its staff has produced or contributed to several such systems including those for the space shuttle, International Space Station, the Kodiak Launch Complex in Alaska, and a variety of launch vehicle programs at the John F. Kennedy Space Center (KSC) and Cape Canaveral Air Station (CCAS) in Florida. CCT, an independent spin-off of McDonnell Douglas (now Boeing), has created the world's first line of commercial software products designed specifically for spaceport operations. The concepts presented here are derived from this work and from earlier research by the author.[1]

Existing infrastructure at today's spaceports such as KSC and their satellite facilities is a mixture of legacy systems and high-performance technology. In many cases, islands of automation have emerged as new data systems are developed using technology that is incompatible with older or nonstandard systems. Interoperability is also diminished as older systems are replaced element-by-element because budgets are allocated to 12-month periods. These systems are

Table 1: Launch Site Shuttle Information Systems

• Checkout, Control and Monitor System (CCMS)	Primary system for shuttle checkout and launch processing
• Test, Checkout, and Monitoring Systems (TCMS)	Test and checkout system for elements of the International Space Station
• Central Data System	Database support function for CCMS
• Shuttle Processing Data Management System	Scheduling, documentation, and management information support system for shuttle processing
• Payload Data Management System	MIS used to control work authorization documentation, technical documentation, training, and scheduling
• KSC Inventory Management System	MIS for inventory control
• Payload Checkout Unit (PCU)	Spacelab integration and checkout system
• High-Rate Interface Test Set	Interface controllers for PCU
• Partial Payload Checkout Unit	Low-level integration and checkout system for independent payloads
• Cargo Integrated Test Equipment	High-fidelity orbiter simulator for final mission payload integration
• Operations Intercom System	Audio distribution system

generally scattered among launch, administrative, and engineering locations with little regard given to efficient information exchange between the systems *within a particular spaceport*. For example, the shuttle vehicle, payload, and ground operations utilize the variety of launch site information systems listed in Table 1. The resulting infrastructure is complex, requires a specialized maintenance workforce, and employs unique, obsolete, and proprietary technology that is expensive to maintain and operate.

Notably, similar conditions existed in the National Airspace System[2] almost 10 years ago. The emergence of a national airspace information system promises to substantially reduce these conditions.

There are also several mission planning, scheduling, office automation, environmental, and administrative information systems not listed here. Additional systems are located at other NASA sites such as the Mission Control Center at Johnson Space Center and payload operations control centers at Marshall Space Flight Center, Goddard Space Flight Center, and the Jet Propulsion Laboratory. There are very few automated interfaces between these systems: manual file transfers, nine-track tape, and manual data entry are the main mechanisms used to transfer data from one to another. To further complicate operations, various programs use incompatible and unique data formats and media.

Similarly, CCAS employs a variety of information systems (Table 2) to manage the Eastern Test Range in support of commercial, NASA, and Department of Defense missions aboard ELVs and the shuttle. The Air Force uses independently-operated information systems to manage the Western Range, and launch vehicle operators employ separate launch control equipment for each type of vehicle.

This proliferation of information systems makes it difficult for a single site to effectively manage its own information; it makes it almost impossible for one site to efficiently exchange information with another. Large government agencies have historically afforded such arrangements, however, new economically-driven spaceports must rely on alternative, lower cost methods.

Some progress has been made, however. In the past three years, both NASA and the Air Force have embarked on major upgrades to critical launch systems at KSC and CCAS. NASA is developing a new Checkout and Launch Control System for space shuttle launch processing that will completely replace the 20 year old Launch Processing System. This new system will share key architectural elements with the Mission Control System in Houston, including a single configuration database for mission files.[3] The older LPS is an expensive system to maintain, accounting for more monthly problem reports in 1993 than any other spaceport or vehicle element, and twice as many problems as the most error prone component of the flight system (see Figure 1). In addition, NASCOM has

Table 2: Eastern Range Information Systems

• Range Count Control System	Countdown time control and distribution, firing sequencing
• Weather System	Weather observation, modeling, and forecasting; satellite imagery
• Central Computer Complex	Data distribution, range scheduling, and work control
• Central Telemetry Station, Redstone	Telemetry and spacecraft tracking
• Missile Tracking Instrumentation System	Multiple missile tracking network
• Missile Impact Location System	Hydroacoustic system for locating impacts of reentry vehicles
• Splash Activated Deep Ocean Transponder System	Records impact characteristics of reentry vehicles
• Range Safety	Various off-line analysis systems for flyout path determination, trajectory calculations, blast overpressure models, and toxic cloud dispersion prediction
• Range Timing System	Precise central timing, time signal generation and distribution
• Range Safety Display System	Launch vehicle command and control
• Command Destruct System	Range safety flight termination system

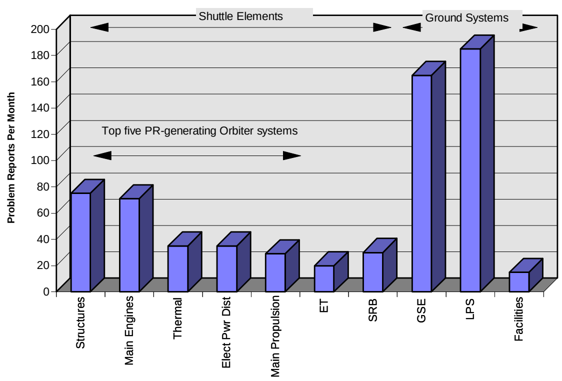

Figure 1: Monthly Shuttle Problem Reports (FY 93)

advanced to the point of supporting virtually all on-orbit NASA operations with command nodes around the country.

The Air Force is in a critical phase of a $1.2 billion replacement to their range automation systems on both the east and west coasts of the U.S.[4] The upgrade will introduce newer computer technology and allow the two launch ranges to exchange data in a standardized fashion.

NEED FOR A SPACEPORT NETWORK

Routine operation of reusable launch vehicles from new spaceports will drive the need for the global network in one form or another. Spaceliners will have the capability to land at many spaceports regardless of their point of departure. Typically spaceliners will depart from the spaceport in which they most recently landed, so all spaceports will need access to the launch information associated with any reusable spaceliner that might land at their facility. Spaceliner schedules, cargo and passenger manifest, launch countdown procedures, safety procedures, trajectory computation algorithms, maintenance and repair activities, and other logistic operations require information that will be shared across the network. Without this information a spaceliner will be stranded at its destination.

NASA's X-33 program serves as a useful illustration of this concept. The X-33, under development by NASA and Lockheed Martin, will eventually launch from California and land in Utah.[5] While this concept illustrates only half of a fully reusable space transportation enterprise, it will serve to develop the notion of a single vehicle operating at two spaceport facilities. Lockheed Martin's VentureStar, a planned reusable spaceliner based on the results of the X-33 project, could launch and land at any spaceport with appropriate facilities.

The development of a wide area information system for the National Airspace System will also require a spaceport network. The FAA will require spaceport personnel to "monitor factors related to the go/no-go decision and assure vehicle safety during ascent." Spaceport operators will need access to key information in order to carry out this mandate.[6]

The global spaceport network would also be an ideal facility for supporting tracking and communications for all spaceliner flights. A global network of communication nodes, both land based and space based, will be required to track the position, status and safety of reusable space-liners. These communication nodes will also be needed to handle downlink telemetry and voice communication and other communication links needed to carry out the objectives of the flight. The nodes of this network must be interlinked to provide communication paths between the on orbit spaceliners and their ground based operation centers, as well as with the national airspace system in the U.S. and its equivalents around the world.

Any spaceport facility with access to the spaceport network would be capable of hosting landings and launches of reusable spaceliners that are on the network. The facilities would also use the network to publish their spaceport schedules and performance information to allow spaceliner operations personnel to match their mission activities with spaceport capabilities.

All launch vehicles require certain information and command structures for preflight preparations and mission operations.

- Telemetry configuration files
- Count down sequences
- Automated health checks
- Flight software
- Flight plan
- Abort plan
- Payload interface configuration
- Safety constraints

In addition to supporting the management and execution of mission critical data and procedures, the spaceport network will provide a mechanism for managing non-flight critical flight information. This information typically includes logistic information, maintenance and repair data, administration information, and engineering and analysis data.

Spaceport operations data would be exchanged with spaceline operations via the network as well. Spaceport information such as launch pad schedules, range schedules and safety requirements, infrastructure, and status would be published by the spaceports and consumed by spaceport users.

INFORMATION INFRASTRUCTURE FRAMEWORK

Spaceport Model. The reference spaceport model is presented here to provide a baseline context for the information infrastructure. In the most general sense, a spaceport brings together the space counterparts of the four operations found at airports, as shown in Figure 2. The spaceport owner – generally a local, state, or federal government agency – is responsible for operating the spaceport facilities and providing services to launch vehicle operators. In this general model, launch vehicle manufacturers provide products and services to the vehicle operators. The vehicle operators, in turn, provide launch services to spacecraft operators and other payload providers. This model is equally applicable to reusable and expendable launch vehicle operations, as well as to manned and unmanned missions.

The operational elements of any spaceport[7] include:

Flight Line Operations

- Flight Operations
- Space Traffic Control
- Ground Support Operations

Flight Preparation Services

- Mission Planning
- Payload Processing
- Engineering and Analysis

Support Services

- Logistics and Maintenance Support
- Spaceport Administration

Flight line operations closely correspond to the activities associated with active flights such as those conducted on runways, aprons, and control towers at commercial airports. *Flight operations* encompass individual flight crews and planning and managing their vehicles. *Space traffic control* manages the in-flight fleet and handles the interface with the Federal Aviation Administration (FAA) and other spaceports to coordinate with aircraft traffic. *Ground support operations* manage all ground-based resources directly associated with active flight vehicles such as fuel farms, communication links, and payload integration and recovery.

Support services provide resources and services required for overall spaceport operations*. Logistics and maintenance support* services focus on spaceport

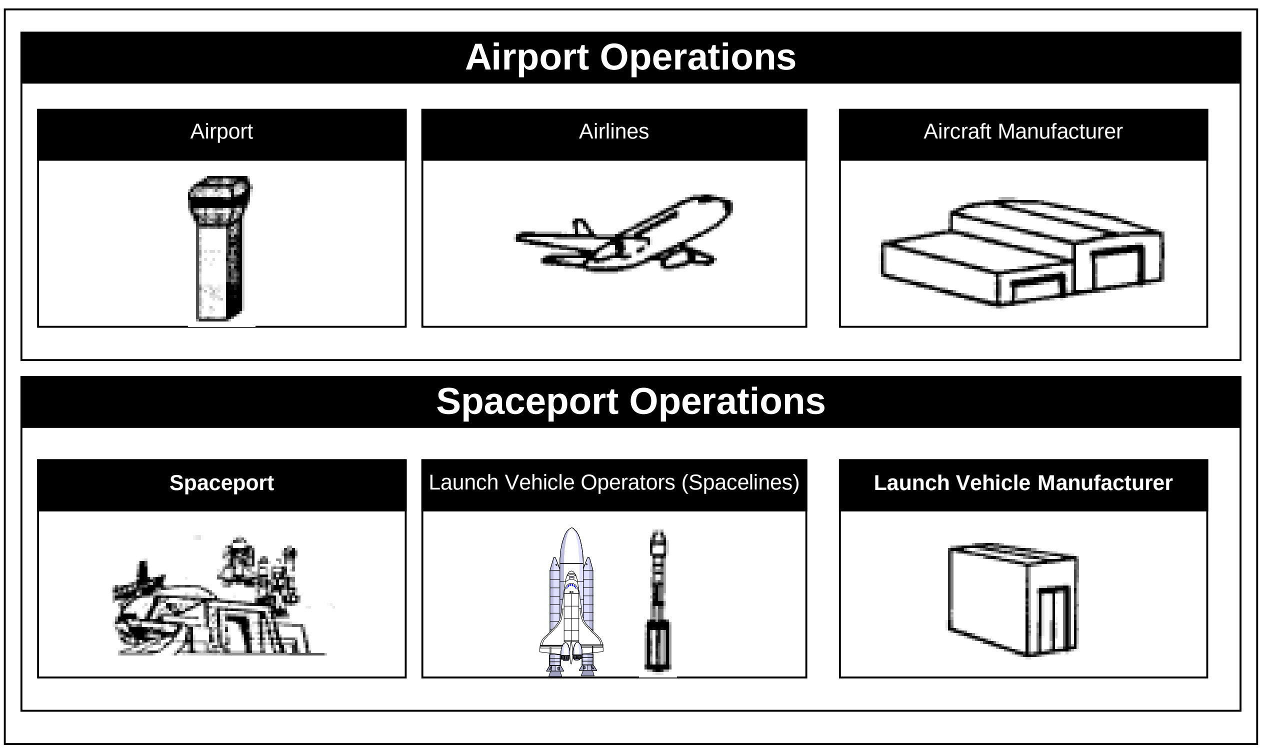

Figure 2. Spaceport Operators

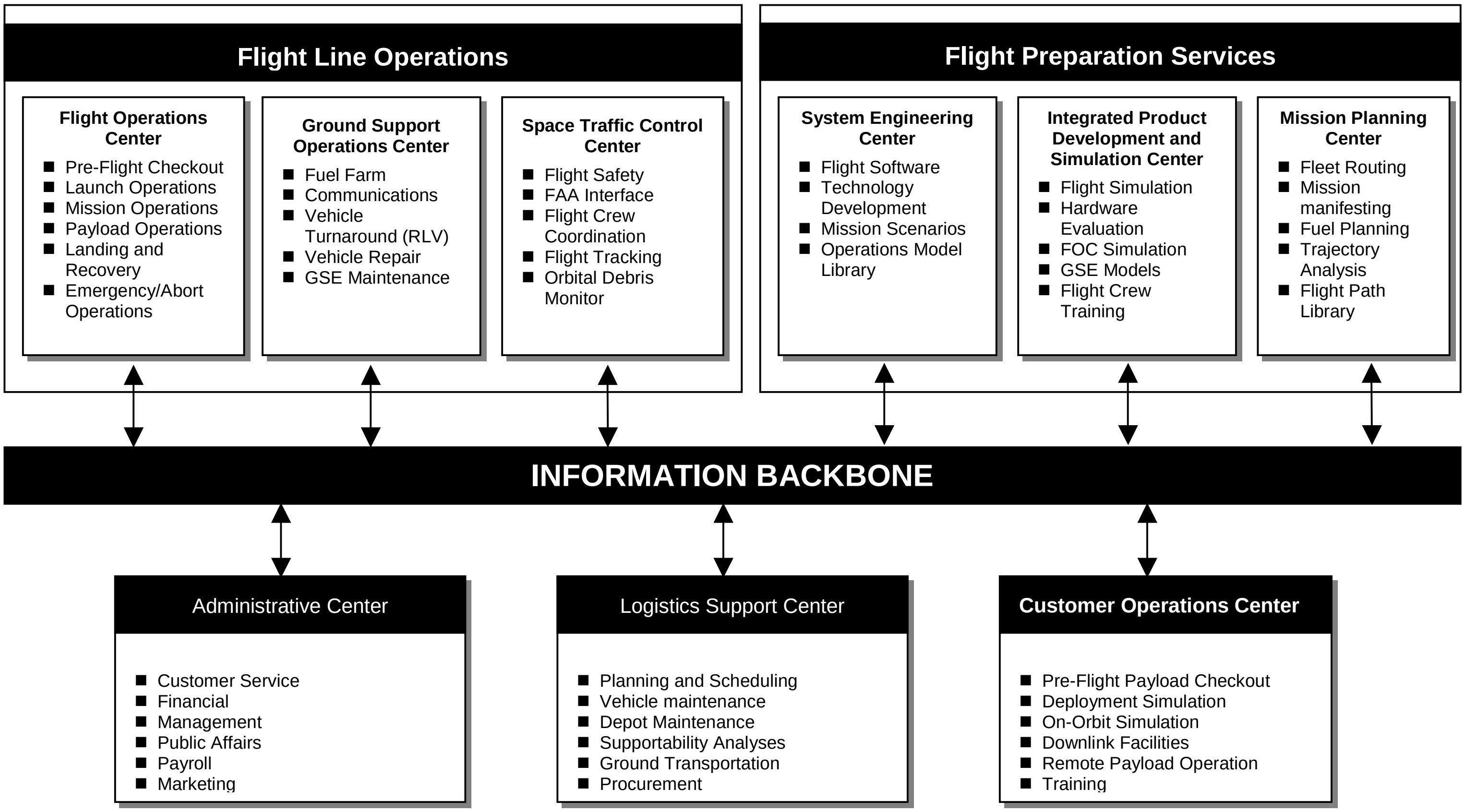

Figure 3. Information Infrastructure Framework

planning and scheduling, maintenance activities, supportability analyses, and quantitative and qualitative mission data analysis. *Spaceport administration* provides general administrative management for the facility and personnel.

These functions can be grouped in other ways to address various spaceport arrangements without affecting the information system considerations discussed here. However, each of these functions is critical and must be supported by any infrastructure. In addition, the scarcity of today's spaceports allows them to operate mostly independently of one another. As more spaceports come on-line, the need to coordinate spaceport operations around the world will pose substantial problems if their information systems are incompatible. Interfaces with the FAA and international airspace regulators will also be complicated if such links are not taken into consideration.

Functional Model. The functional model distributes responsibility for spaceport information requirements to information centers (see Figure 3) supporting key operational elements. In the functional model, these centers correspond to collections of data and activities rather than particular facilities. Satisfaction of the comprehensiveness criteria is traceable to the information requirements allocation to the centers. A summary of the functions and information requirements for each center is described in the following text.

Flight Operations Center (FOC). The FOC, the focal point for flight operations, provides flight crews with the information and control elements required to manage their flights, including preflight operations and planning; in-flight vehicle, crew, and payload management; and post-flight deservicing and maintenance. Flight crews, in planning their own flights, use the FOC to determine clearances, staging, orbit and landing destinations, abort modes, fueling, center of gravity analysis, payload integration and deployment, and weather analysis. The information necessary for these functions must be readily available in the center. The FOC also provides flight plans and real-time flight data to other areas of the spaceport. Real-time data and operations information is used in the FOC for each space flight in much the way flight control data is used on an aircraft flight deck.

The center may support multiple flight crews simultaneously, some of whom may be onboard while others are controlling their vehicle from the ground. ELV and reusable launch vehicle (RLV) operations may be conducted simultaneously. It should be noted that *flight planning* is performed by each flight crew for a particular flight just prior to launch, whereas *mission* *planning* focuses on assignments of payloads to vehicles and on scheduling flights beyond those currently in progress. FOC information requirements are shown in Table 3.

Table 3: FOC Information Requirements

Payload data	Flight planning: mass, orbit/rendezvous requirements, life support requirements Other: Monitor health, determine payload readiness for flight; monitor and control in-flight payload activities
Flight path	Orbit destination and attitude; landing and abort sites; debris avoidance
Weather data	Flight planning: launch, abort, landing, earth observation
Vehicle data	Preflight: vehicle safety checks; flight readiness; fuel planning; payload integration
	Real-time in-flight: vehicle management; abort control, flight profile
	Postflight: vehicle anomaly, maintenance requirements, performance analysis
GSE data	Status and control of ground support equipment (GSE)

Space Traffic Control Center (STC). The primary mission of STC is to ensure safe operation of the spaceport. This mission becomes more complex with multiple launch vehicle operators at a single spaceport and with multiple spaceports in the same region. This function has been provided by government-operated space ranges in the past and this arrangement is likely to continue in much the same way as the FAA controls the national airspace in the U.S. STC operations, based on mission plans produced by launch vehicle operators, include coordination among flight crews, inter-spaceport coordination, and FAA interfaces. Range safety and other government oversight is provided by the STC. Information requirements include:

Table 4. STC Information Requirements

Planning	Mission Planning: flight manifests, mission parameters, spaceport master plans
	Flight Planning: flight clearance requests, weather requirements, flight profile plans, abort modes
Ground Support	Ground operations status, on-field repair and maintenance plans, fuel farm status, weather forecasts
Flight data	Vehicle tracking, vehicle status, flyout patterns, real-time image analysis
Air/space	Air traffic status, orbital debris tracking

Ground Support Operations Center. This center manages operations and maintenance of all ground support facilities, equipment, and consumables in the flight processing area. On-pad vehicle maintenance and repairs, hazardous operations, GSE scheduling, and ground safety operations are all managed from this center. The information required for these activities involves communication and translation of flight and payload requirements to GSE operations. These include:

Table 5. GSOC Information Requirements

Flight planning	Fuel and other servicing requirements; flight schedules; vehicle configuration requirements
Logistics data	Vehicle LRU replacement data; vehicle maintenance scheduling; transportation schedules; GSE maintenance management
Weather data	Fueling operations (hazardous); vehicle protection
Communica-tions	Communication equipment status

Customer Operations Center (COC). The COC centralizes all payload operations, both payload flight preparation and in-flight payload operations, for the convenience of spacecraft operators and to facilitate management of special services provided to customers. Preflight integration and checkout can be managed from the COC either directly or through remote links to the spacecraft operator's or manufacturer's site. In-flight health checks, user commands, and deployment control are provided to the COC through the FOC. Payload/vehicle integration, post-deployment activities, and post-flight servicing can be monitored from the COC as well.

Spacecraft operators frequently wish to connect data processing equipment to the spaceport information infrastructure. The COC should provide an interface for such equipment, and the infrastructure should provide data formats compatible with those commonly used by spacecraft manufacturers.

The information requirements for this operation include:

Table 6. COC Information Requirements

Preflight checkout	Real-time monitor and control data for payload integration and checkout; payload/vehicle integration validation data
Flight planning	flight schedule and profile,
Real-time Mission data	Payload health status; payload management and control data; vehicle flight status
Postflight	mission and payload data reduction and analysis

Logistics Supportability Center (LSC). The LSC is the focal point for spaceport logistics and maintenance management. Supply and depot support, acquisition support, maintenance activities, and transportation are managed by the LSC. Maintenance and repair of active vehicles can be planned using downlink data provided from the FOC. Automated messages can be sent to the GSE center to get repair parts on their way to the landing area before the vehicle arrives (automated maintenance). Failure analysis is also provided by this center.

Planning and scheduling of all spaceport operations can be centralized in this center to ensure a single management point for spaceport operations. The spaceport mission manifest and mission routing are provided by the mission planning center. Combined with GSE and vehicle maintenance schedules, master 30-day, 90-day, and 12-month spaceport plans can be produced and distributed to customers and other centers.

The information requirements for this operation include:

Table 7. LSC Information Requirements

Planning and Scheduling	Vehicles: Fleet operations and maintenance status; facility status Payloads: payload flight requirements and constraints; payload flight preparedness status; customer flight requirements
Transportation	Facility status; ground crew scheduling; vehicle, payload, and GSE transportation requirements
Inventory	spares management, maintenance management and scheduling; consumable requests; acquisition plans and budgets
LRU dispatch	Real-time diagnostics; vehicle and GSE maintenance schedules
Facility management	Vehicle maintenance status and schedule; facility operational status; ground crew status
Maintenance Management	flight hardware maintenance status; LRU failure data; supplier servicing and maintenance requirements

Mission Planning Center (MPC). The MPC provides fleet route and mission plans. Fleet routing provides flight path and trajectory information for spaceport launch, landing, deployment, and abort locations. This data comprises a “flight path library” from which flight crews can select the most appropriate nominal and abort situation profiles for the particular payload, vehicle, weather, and mission circumstances encountered for a flight.

Mission planning produces the spaceport manifest schedule in which specific payloads and vehicles are assigned to missions, dates, and locations. Mission planners work closely with spacecraft operators to define mission parameters, and therefore, prices. Logistics information and the master spaceport plans are available to facilitate mission planning. MPC information requirements include:

Table 8. MPC Information Requirements

Planning	Spaceport plans and schedules; vehicle status; mission parameters
Flight data	Flight profile anomalies requiring flight path updates
Vehicle data	Vehicle characteristics, performance data, status
Payloads	Mission requirements and constraints

System Design and Analysis Center. Flight software and hardware modifications are designed and tested for launch vehicle operators under the direction of this center. Design tools and models are maintained to support development of advanced technology such as image processing, weather modeling, and flyout predictions for spaceport and launch vehicle operators. Information requirements for system design and analysis include:

Table 9. Design/Analysis Information Requirements

Mission planning	Nonroutine flight requirements; launch and landing site status; unplanned abort contingencies
Payload data	Crew or passenger flight constraints; payload deployment requirements; payload flight constraints; special payload interfaces or other services
Maintenance	Flight hardware status; spares status; component maintenance requirements; supplier support requirements

Integrated Product Development and Simulation Center (IPD). This center is closely associated with systems design and analysis. It provides a testbed for analyzing flight hardware and software modifications and for new technology development. System engineers can assemble simulated environments that include FOC, GSE, payload, and vehicle models to analyze the effects of new engineering designs before they are fielded. The IPD center also provides training facilities for flight crews. Information requirements for this activity include:

Table 10. IPD Information Requirements

Fleet configuration	Fleet status, vehicle configurations, master spaceport plans
Maintenance data	Scheduled maintenance requirements; GSE status and configuration

Administrative Center. This center provides base administration functions including marketing, accounting and payroll, budgeting, public relations, and general management. Customer interfaces among the spaceport organizations are administered here. Marketing and public relations information can be provided over a secured Internet platform. The administration information requirements include:

Table 11. Administrative Information Requirements

Budgeting	Consumable, LRU, and maintenance forecasts based on master plans & mission manifest
Payroll	Automated timecard data for spaceport employees
Accounts Payable	Acquisition and contract data, operations status
Public Affairs	Mission plans, flight data, tour schedules, media event opportunities

GLOBAL SPACEPORT NETWORK ARCHITECTURE

The architecture of a global network would consist of the following elements:

- **Space segment**
- **Ground segment**
  - Communications facilities
  - High speed links
  - Data repositories
  - Control Nodes

Discussion of the space segment is left for future work. In the ground segment, communication links in communication facilities are available from commercial providers today. The data repositories and control nodes would be located at each operational spaceport. Data and control elements of the network would be linked to the spaceport command and control systems to provide direct access to mission planning and mission operations data.

Technology Model. The technology model is summarized in Figure 4. Data are produced by a variety of sources – physical, automated, and manual – then transformed, stored, possibly transformed again, and used and reused to carry out spaceport functions. As the infrastructure handles larger quantities and more complex data, system control becomes a more important feature. Thus, the spaceport information infrastructure implementation is essentially an information exchange and application problem.

A few of the applicable technologies are presented in the following text.

Computing Architecture. The computing architecture technology should be based on open distributed computing standards such as the evolving ISO/CCITT Basic Reference Model for Open Distributed Computing. Open computing is a system architect's best hope for facilitating future system expansion, application interoperability, and technology upgrades. Distributed computing is needed to support geographically dispersed spaceport operations as well as to provide system reliability and fault tolerance. All three infrastructure criteria – comprehensiveness, adaptability, and reliability – can be satisfied by such a computing architecture.

Software Architecture. The software architecture can be based a variety of technologies: object-oriented (OO) models, client/server arrangements, relational databases, open software, electronic data interchange, and others. Client/server technology provides the foundation for open distributed computing architecture implementation of the technology model. The application of OO technology to large-scale information systems needs to be studied further to carefully analyze performance considerations of the techniques. The Common Request Broker Architecture (CORBA) may be applicable. Open software standards such as the Open Software Foundation's Distributing Computing Environment (OSF/DCE) will be an important component of the software architecture in support of open distributed computing. Data publishing and subscription models will be useful in managing the distribution of operational data among the centers.

Standards. Even though standards are applicable to many aspects of the infrastructure, the most important application will be in the area of interfaces with spaceport applications. As noted earlier, applications used by the spaceport operators, launch vehicle manufacturers and operators, and payload providers have been historically incompatible, creating automation islands at today's spaceports. Additional work is urgently needed to survey the launch vehicle and spacecraft development industries for definitions of application interface standards. Preliminary work has begun in the AIAA spacecraft control working group,[8] mission operations control for NASA,[9] and in areas of wider scope within ISO.

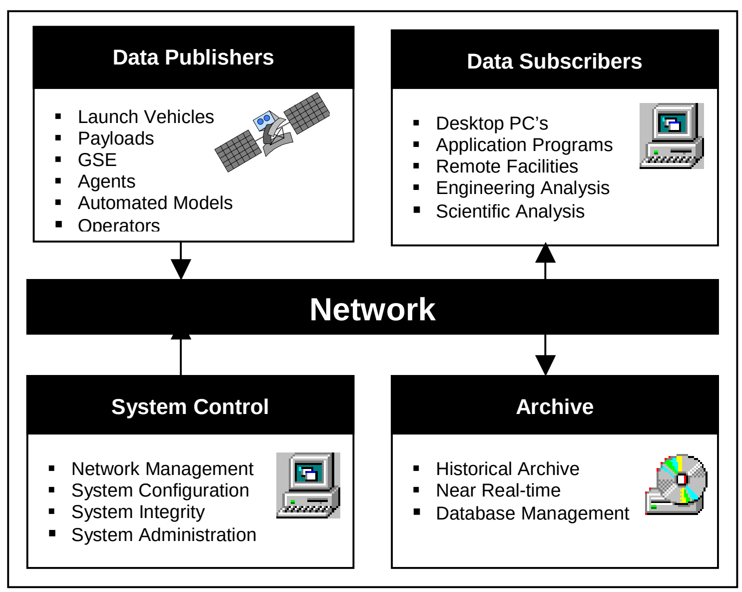

Figure 4: Technology Model

Communications. Asynchronous transfer mode (ATM) technology provides sufficient bandwidth for data, voice, video, and image transmission throughout the spaceport with a reliable data transmission protocol.[10,11] Radio frequency transmissions in various bands provide adequate carriers for space-to-ground and ground-to-space communications. The challenge in this area is to integrate the appropriate combination of communications technology to meet spaceport operational requirements.

Data Management. Data management technology addresses data processing, security, storage, retrieval, and display, as well as a wide variety of other spaceport information requirements. Client/server telemetry and data processing units are available from many commercial suppliers. Information access and security are critical considerations for information system architects. Site, data, and user authentication, data encryption, and electronic commerce protection have been addressed for networked environments.[12] Data warehousing techniques and database technology provide powerful decision support tools. The graphical user interface is the technology of choice for data presentation and display.

Spaceport Applications. Application-specific technology in the areas of weather forecasting and modeling, optics/image processing, surveillance, timing, planning and scheduling, and automated diagnostics and maintenance is relevant to the spaceport information infrastructure. Considerable work has been performed in these areas for many years; automation of these applications within the information infrastructure is the capstone in meeting the information requirements for spaceport operations.

Many examples of partial implementation of this model are operating in spaceport environments[13,14] and related applications.[15,16] Further work is needed to define a technology model that provides a comprehensive architecture for a spaceport information system.

RELATED WORK

NASA-KSC has initiated a program known as the Spaceport Technology Center. This concept includes five spaceport technology development initiatives that will "be the focal point for tying together existing and emerging related spaceport technologies across the agency."[17] Work in the command, control, and monitor systems area will include data exchange and information systems technology and research.

The industry consortium known as the Spaceport Synergy Team has commenced a technology roadmapping effort as part of their Vision Spaceport project.[18] This effort will identify and prioritize key spaceport-related technologies to set the foundation for future technology investment decisions.

Integration of information systems technology into new and existing spaceport enterprises is under study by many organizations. The U.S. Air Force is contemplating a Spacelift Range System that integrates range support assets at both the Eastern and Western Test Ranges.[19] Similar technology is being applied by the space science community in developing information systems to facilitate the exchange of scientific data from the International Space Station.

California Commercial Spaceport Inc. has developed a concept for a virtual spaceport based on automated networks. Spaceport management, operations, and facilities requirements have been defined by the Office for Space Commercialization of the State of New Mexico utilizing a user/tenant-focused operations control center and supporting information system.[20] In addition, the information systems used by the Delta Clipper-Experimental (DC-X) program illustrated the feasibility of operating an airport-like space launch enterprise with a distributed information system.[13,21]

Existing airport information systems provide a rich body of knowledge and experience from which the fledgling commercial spaceport industry can draw. Older studies of the U.S. air traffic control system[16] and air traffic management[2] frame many of the information system issues raised here, including interfacility data interchange; all-weather operations; autoland technology; distributed processing; and remote automated maintenance systems. The relationships between flight crew planning, traffic management, and real-time aircraft status data are being studied to distribute flight management among area control facilities, flight crews, and air traffic control towers. Contrasting these studies with space operations may offer insight into the future of interconnected spaceports. The FAA has taken a noticeable lead in this area with the NAS-WIS and Space and Air Traffic Management System concepts.

CONCLUSIONS

The revolution of affordable space transportation is upon us. Spaceport plans are being assembled at many locations around the world, most of which are focused on commercial customers. New spaceport concept development in Florida, California, Alaska, and other states, as well as in the U.S. Air Force, NASA, and overseas, faces the challenge of integrating information systems and data exchange mechanisms into their business and operational concepts. The information infrastructure needed by these spaceports must be carefully crafted to provide all information necessary to operate the spaceport and to realize the very promise of affordable access to space.

Several suggestions for future work have been offered in this paper, including analysis of the space segment of a spaceport network, advancement of object-oriented spaceport operations models, development of data and technology models, and completion of an ISA. In addition, an expanded survey of relevant research and design concepts being developed for proposed spaceports in countries other than the U.S. would be very beneficial to this field, as international standards are far more difficult to achieve.

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