A GROUND INFORMATION INFRASTRUCTURE FOR SPACEPORT OPERATIONS

Kevin R. Brown

MCDONNELL DOUGLAS SPACE AND DEFENSE SYSTEMS

KENNEDY SPACE CENTER DIVISION

ABSTRACT

A framework is presented for a ground information infrastructure linking major elements of spaceport operations. This highly integrated framework is readily automated and has common architectural components that facilitate resource sharing throughout the system. Cost reduction opportunities are presented and a model of the framework 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 required

A comprehensive information infrastructure will be a central element of any initiative to substantially reduce the cost of space operations.[1] Integrated information centers must be established that share compatible interfaces, data architectures, and processing models. This will avoid the need for specialized teams of operators and large sustaining engineering efforts to maintain islands of automation. 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 paper first establishes the rationale for using a comprehensive ground information system to reduce operations costs. 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

The Kennedy Space Center (KSC) division of McDonnell Douglas Space and Defense Systems is responsible for ground operations associated with payload processing for the shuttle, space station, and expendable launch vehicles (ELVs) at KSC and Cape Canaveral Air Station (CCAS) in Florida. The KSC division became interested in advanced spaceport concepts as a result of work with NASA, the Air Force, various state spaceport initiatives, and other programs.[*] The concepts presented here are derived from this work.

Existing infrastructure at KSC, CCAS, 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 for 12-month periods. These systems are generally scattered among

---

[*] These include information systems for space station, shuttle payloads, and orbiter simulation[14]; launch site processing analysis[3]; advanced command and control technology for the Delta II ELV[24]; concept definitions for the Southwest Regional Spaceport[5] and the Spaceport Florida Authority[4]; ground control system development for the DC-X technology demonstrator,[13] and others.

[†] Interoperability is the capability to share resources (such as computer programs, hardware, and data) among different data processing environments without modification

Table 1: Launch Site Shuttle Information Systems

• Checkout, Control and Monitor System (CCMS)	Primary system for shuttle checkout and launch processing
• 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

launch, administrative, and engineering locations with little regard given to efficient information exchange between the systems. For example, shuttle vehicle, payload, and ground operations utilize the variety of launch site information systems listed in Table 1.

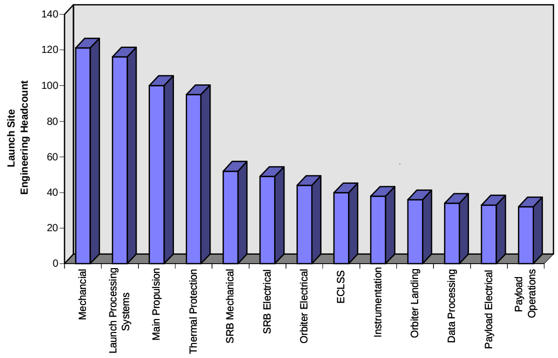

Figure 1: Shuttle Engineering Support

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 exist in the National Airspace System[2] which is used to control air traffic throughout the United States.

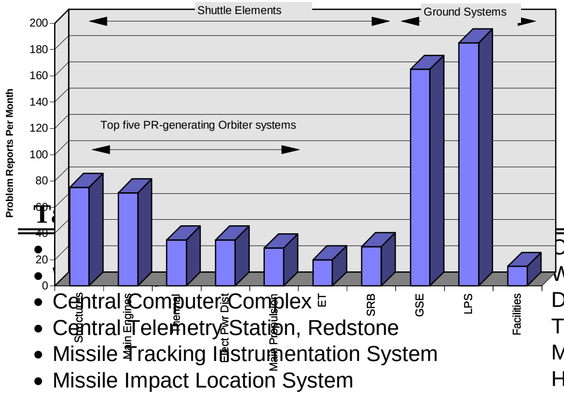

Figure 2: Monthly Shuttle Problem Reports (FY 93)

Ta

• [illegible]	Countdown time control and distribution, firing sequencing
• [illegible]	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

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: file transfers, nine-track tape, and manual data entry are the main mechanisms used to transfer data from one to another.

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.

Our studies show that operational shuttle information systems ("Launch Processing System" and "Data Processing" in Figure 1) consume a major portion of engineering support manpower at KSC. As shown, engineering support for shuttle launch information and command systems accounts for almost 20% of the total support required for the 12 main shuttle subsystems.[3] Further, information systems are one of the largest sources of problem reports (PRs) at the spaceport (Figure 2), accounting for about 30% of all 1993 shuttle PRs at KSC.

Overall, functions such as configuration management, system administration, and data management, performed separately on each system by its own individual support staff, account for as much as 20% to 30% of the engineering support cost. In addition, operations procedures have been developed to deal with the diverse set of incompatible information systems – procedures that involve substantial paperwork and cumbersome manual data transfers, conversion, correlation, and analysis. A robust information infrastructure, designed as a single interconnected system using compatible and interoperable computing technology, would avoid redundant support functions and enable streamlined operational procedures.

Such an infrastructure should be comprehensive, adaptable, and reliable. It should provide the information required to conduct all spaceport operations at appropriate times and locations. Without this characteristic, additional systems will be needed, requiring additional personnel interfaces, increasing operations complexity, and encumbering operators.

The infrastructure should be open to new and unanticipated functions. Open systems provide adaptability and standardized interfaces to accept future unplanned changes. Interconnectivity between spaceports and related organizations will be required to coordinate space transportation activity around the globe. Further, system reliability and maintainability must be measurable and controllable.

The infrastructure framework presented here provides these characteristics with a single interconnected architecture.

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 3. The spaceport owner – historically 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.

A fifth operation is introduced when spacecraft operators are distinct from spacecraft manufacturers. This model is equally applicable to reusable and expendable launch vehicle operations, as well as to manned and unmanned missions. The two primary U.S. spaceport enterprises can be depicted in terms of this model, as shown in Figure 4.

Further analysis of potential spaceport enterprises has been sponsored by the U.S. Air Force under a variety of "dual use" projects and U.S. state spaceport initiatives in Florida, Alaska, New Mexico, and California.[4,5] The common operational elements of a spaceport have been discussed in many of these analyses, as well as within the NASA X-33 program[6] and as part of the U.S. Air Force Range Standardization and Automation program.[7] A common theme in many of these initiatives is the adaptation of airport and aircraft operations to spaceport operations. The operational elements of such a spaceport 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.

Flight preparation services include planning activities and readying flight hardware for future flights. *Payload processing* services, including a provision for remote operations and checkout, are available to spaceport customers (launch vehicle or spacecraft operators) as needed. *Engineering* services produce mission models and flight software to prepare spacecraft for modification,

Figure 4: U.S. Spaceport Enterprises

Figure 3: Spaceport Operators

checkout, and flight. Engineering can also provide special services for particular payloads when required.

Support services provide resources and services required for overall spaceport operations. *Logistics and maintenance support* services focus on spaceport 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 postflight 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 spaceflight in much the way flight control data is used on an aircraft flight deck.

Figure 3: Information Infrastructure Framework

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)

<u>Space Traffic Control Center (STC)</u>. 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, interspaceport coordination, and FAA interfaces. Range safety and other government oversight is provided by the STC. Information requirements include:

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:

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, postdeployment activities, and postflight 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:

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:

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:

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:

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

<u>Integrated Product Development and Simulation Center (IPD)</u>. 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:

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

<u>Administrative Center</u>. 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:

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

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.

<u>Computing Architecture</u>. 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.

Figure 4: Technology Model

<u>Software Architecture</u>. 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 an 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.

<u>Standards</u>. 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.

<u>Communications</u>. 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.

Data Model. A data model, or information architecture, must also be defined to ensure compatibility of data formats and exchange protocols across applications. Definition of the data model is left for future work, possibly based on the information architecture developed for Space Station Freedom.[17]

INFORMATION SYSTEM ARCHITECTURE

A comprehensive information system architecture (ISA) can be composed by defining architectural models using the framework presented by Zachman (1987).[18] Zachman's arrangement relates data, functional, and network architecture to the perspectives of designers, owners, and operators to form enterprise, system, and technology models. Sowa and Zachman (1992) characterize the ISA as "an observation of some (apparently) natural rules for segmenting an enterprise into understandable parts without losing the definition of its total integration."[19] Additional architectures have been proposed for the real-time elements of an information system.[20] This framework suggests an approach for defining a complete spaceport ISA.

RELATED WORK

Integration of information systems technology into new and existing spaceport enterprises is under study by many organizations. The U.S. Air Force is now constructing a Spacelift Range System that standardizes range support assets at both the Eastern and Western Test Ranges[7]. This is one of the most advanced spaceport information system projects in the USA. Similar technology is being applied by the space science community in developing information systems to facilitate the exchange of scientific data. Further, NASA has an X-33 RLV program to encourage industry to develop low-cost access to space.

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.[5] In addition, the information systems used by the Delta Clipper-Experimental (DC-X) program illustrate 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. Studies of the U.S. air traffic control system[16] and air traffic management[2] address many of the information system issues raised here, including interfacility data interchange; all-weather operations; autoland technology; area control computers; distributed processing; consolidated, fully automated stations; remote automated maintenance systems, and reduced overhead. 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.

In addition, the Information Services Policy Board of the State of Maine has adopted a comprehensive set of information architecture principles as part of the Board's effort to establish a state-wide information infrastructure.[22] The principles address interoperability, standards, empowerment (ownership of data), and other aspects of an information architecture within infrastructure, data, application, and organization domains. The definition, rationale, and implication of each principle is applicable to spaceports and other multifaceted information system applications.

Other related work addresses safety critical real-time architectural principles[23] and the importance of empowering operators with information infrastructures.[15]

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. 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.

New spaceport concept development currently in progress in Florida, California, New Mexico, Virginia, and Alaska, as well as in the U.S. Air Force and NASA, faces the challenge of integrating information systems technology into their business and operational concepts.

Several suggestions for future work have been offered in this paper, including analysis of applying object-oriented technology to spaceport operations, 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 existing and proposed spaceports in Canada, South America, Australia, and Asia would be very beneficial to this field. Consideration of interfaces required for existing launch vehicles and their impact on information interfaces for the next generation of ELV and RLV rocketry in a single spaceport is also an important area of future work.

Author contact information:

kevin.brown@ksc.nasa.gov or **BrownKR@aol.com.**

Kevin R. Brown
McDonnell Douglas Aerospace (MDA)
P.O. Box 21233, Dept. F164
Kennedy Space Center, FL 32815

REFERENCES

[1] U.S. Congress, Office of Technology Assessment, *Reducing Launch Operations Costs: New Technologies and Practices,* OTA-TM-ISC-28 (Washington, DC: U.S. Government Printing Office, September 1988)

[2] Nelson, Gary G., "Hierarchical Information Architecture for Air Traffic Management," *First IEEE Conference on Control Applications,* Vol. 1, pp. 474-8, Cat. No. 92CH3000-7, McLean, VA (1992)

[3] Headley, David, *Launch Site Operations Design Data Book,* MDA. NASA-KSC Launch Site Processing and Facilities for Future Launch Vehicles Study, (March 1995).

[4] McDonnell Douglas Space Systems Co., *Multi-Vehicle Processing System Open Systems Applicability Study for the Spaceport Florida Authority,* Kennedy Space Center, FL (1991)

[5] State of New Mexico Economic Development Department, *Dual Use Launch Facility Grant Requirements Study for the Southwest Regional Spaceport,* Report No. G-F0471-93-1-0004/R1, Vols. 1-5. Las Cruces, NM (1995)

[6] NASA, *Cooperative Agreement Notice for Reusable Launch Vehicle Advanced Technology Demonstrator - X-33*, CAN 8-1, Marshall Space Flight Center, AL. (January 1995).

[7] Department of the Air Force, *Range Standardization and Automation II Request for Proposal,* F04701-94-R-0006. (1995)

[8] Hooke, Adrian J., "Industry/Government Partnership Producing an Interoperable Mission Operations Control and Communications Architecture (SuperMOCA and SCPS)," NSIA Satellite Command and Control Conference (presentation), Santa Clara, CA (August 1995)

[9] Ondrus, Paul J., and Carper, Richard D., *The NASA Mission Operations and Control Architecture*, CASI No. 95N17603, SAIC, McLean, VA. (November 1994)

[10] Agrawal, Jagan and Varshney, Upkar, "Architecture and Performance of MLAN: A Multimedia Local ATM Network", *Simulation*, January 1995, pp. 15-27. (1995)

[11] Bujewski, Theodore and Schmidt, Phillip, "Integrating ATM Networks with Spacecraft Command and Control: Problems and Potential", *1995 NSIA Command and Control: Partnerships and Technology Symposium*, Sunnyvale, CA (August 1995)

[12] U.S. Office of Technology Assessment, *Information Security and Privacy in Network Environments*, OTA-TCT-606 (Washington, DC: U.S. Government Printing Office, September 1994)

[13] Voglewede, Steven D., *Single-Stage Rocket Technology - Real-Time Data System*, MDA, Kennedy Space Center, FL (January 1994)

[14] Uhrlaub, David R., *Configurable Technology Development for Reusable Control and Monitor Ground Systems,* MDA, Kennedy Space Center, FL. (November 1994)

[15] Hill, Robert C., "Strategy and Implementation of an Information Infrastructure to Support Contemporary Management Practices," *ISA Transactions* (1994)

[16] Pozesky, Martin T. and Mann, Michael K., "The U.S. Air Traffic Control System Architecture," *Proceedings of the IEEE*, November 1989, Washington, DC (1989)

[17] Easton, C. R., *Standardizing the Information Architecture for Spacecraft Operations*, MDA, Huntington Beach, CA. Undated (circa 1994)

[18] Zachman, J. A., "A Framework for Information Systems Architecture," *IBM Systems Journal,* Vol. 26, pp. 276-292 (1987)

[19] Sowa, J. F. and Zachman, J. A., "Extending and Formalizing the Framework for Information Systems Architecture," *IBM Systems Journal,* Vol. 31 (1992)

[20] Schoch, D. J. and Laplante, P. A., "A Real-Time Systems Context for the Framework for Information Systems Architecture," *IBM Systems Journal,* Vol. 34 No. 1 (1995)

[21] Gaubatz, William A. et al, *A Technology and Operations Assessment of Single Stage Technology Flight Test Program Results*, AIAA-93-4163, AIAA Space Programs and Technologies Conference, Huntsville, AL (September 1993)

[22] Maine, State of, *The Maine Telecommunications and Information Technology Planning Project*, http://mtitpp.maine.edu/mtitpp/homepage.hmtl, World Wide Web (1995)

[23] Lala, Jaynarayan H. and Harper, Richard E., "Architectural Principles for Safety-Critical Real-Time Applications," *Proceedings of the IEEE*, Vol. 82 No. 1, Cambridge, MA (1994)

---

[24] McDonnell Douglas Space Systems Company memo, "Delta User Command and Control System", A91-F164-KRB-M90034 (December 1990).