National Spaceport Testbed

Kevin R. Brown
Command and Control Technologies
Titusville, Florida
www.cctcorp.com

Carey M. McCleskey
NASA John F. Kennedy Space Center
www.ksc.nasa.gov

37th Space Congress
May 3, 2000
Cocoa Beach, Florida USA

COMMAND AND CONTROL TECHNOLOGIES
CORPORATION

National Spaceport Testbed

Kevin R. Brown
Command and Control Technologies
1311 N. U.S. Highway 1, Suite 129
Titusville, Florida 32796 USA
brownkr@cctcorp.com

Carey M. McCleskey
NASA John F. Kennedy Space Center
Mail Code PH-K
KSC, Florida 32899 USA
Carey.McCleskey-1@ksc.nasa.gov

http://www.cctcorp.com/testbed

ABSTRACT

The U.S. space industry continues to struggle to turn space business into successful business. Sensing this, both NASA and the state of Florida are exploring ideas for engaging their technological and economic resources in solving this grand challenge. This paper proposes just such an idea: a revolutionary new facility called the National Spaceport Testbed that would be dedicated to testing, certifying, and licensing new space transportation technology. The one-of-a-kind testbed would allow space entrepreneurs to carry out ground and flight tests at reduced costs; allow NASA to apply federal resources to technical risk reduction; and allow Florida to attract and retain new space business.

The testbed notion is a key step in the evolution of the newly designated Cape Canaveral Spaceport. This world class facility operates only nine of its 37 Florida-based launch pads, so it is only natural to consider how some of the unused pads could be engaged to help the U.S. space industry realize its full economic potential.

The National Spaceport Testbed plan proposed in this paper calls for the U.S. government to join forces with the state of Florida to help bridge the gap between risky R&D and commercial space transportation operations. The plan allows NASA to invest in development of safer, more reliable, and cheaper launch vehicle technologies while helping boost the competitiveness of the U.S. space industry. The approach would provide a means for the U.S. Department of Transportation to conduct commercial space transportation licensing. The plan also allows Florida to retain and substantially expand its position as a world-class leader in the space industry. Most importantly, the concept gives the commercial space industry a process for moving their ideas from the lab to the launch pad and on to licensed operations more quickly and with greater confidence.

The National Spaceport Testbed would be perhaps the world's largest laboratory extending all the way to low earth orbit. This paper describes how such a laboratory could be developed and utilized by government and private industry.

INTRODUCTION

The entire space industry is galvanized in its pursuit of cheap and reliable access to space but fractured in its approach. For years, NASA has been experimenting with a variety of flight concepts and multi-phase roadmaps. Florida is now mapping out its future in retaining and growing the regional economic impact of the space industry. Space transportation entrepreneurs are struggling

Flight	Ground	Operations	Regulatory
▪ Integrated vehicle health management	▪ Real-time range surveillance	▪ Turnaround/cycle time improvement techniques	▪ Standard license application data packages
▪ Thermal material tests (orbital and suborbital)	▪ Definition of standard interfaces	▪ Abort modes (simulation and flight test)	▪ Development of standard benchmarks and metrics
▪ Radiation-resistant electronics	▪ COTS ground stations	▪ Air/space traffic control integration	▪ Alternative E_c analysis algorithms
▪ Laser and satellite communications	▪ Cryogenic management	▪ Airport-like operations methods	▪ Component/subsystem certification
▪ Automated landing aids	▪ Weather prediction/impact	▪ Multi-vehicle/fleet operation	▪ Flight test programs
▪ Magnetic launch assist	▪ GPS tracking	▪ Ground-based cockpits	▪ Certification regimes
▪ Towed launch assist	▪ "Smart" range	▪ Internet-aided operations	▪ Licensing regimes
▪ Propulsion technology	▪ Spaceport network	▪ Multi-vehicle launch pads	▪ Reliability testing
▪ New rocket motors	▪ Laser tracking		

Figure 1. Examples of space transportation programs and technologies suitable for demonstration at the NST.

to finance and develop the technology needed to launch a commercially-viable enterprise. Established companies are partnering with the federal government to build new space transportation architectures in the hope of reducing costs. This multifaceted approach brings the benefit of applying diverse perspectives to solving the problem, but is also leading to tremendous expenditures and duplicity that congress and private investors are increasingly reluctant to support. Therefore, identifying and developing opportunities to align these interests in achieving the common goal of affordable space access while preserving an environment that encourages diverse technical approaches will become an increasingly essential part of the industry.

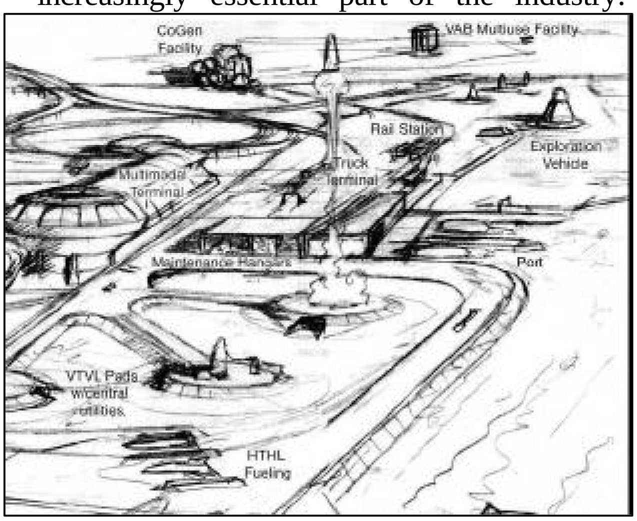

Figure 2. National Spaceport Testbed – Artist's concept of a facility for pooling and focusing the resources of the United States, government, commercial and academic, on solving the challenge of affordable space access.

Courtesy Vision Spaceport/SAIC.

The national spaceport testbed proposed in this paper is an early example of how shared investment could benefit all without stifling innovation, competition, or further private investment.

The testbed would be a government-funded facility built at the Cape Canaveral Spaceport in Florida that supports ground and flight testing of new space transportation technologies. Open to all space transportation companies, the National Spaceport Testbed, or NST, is a dedicated flight test facility akin to flight test ranges used for testing of experimental aircraft. The primary objective of the facility is to demonstrate safety or reliability of new space transportation technologies through ground and flight testing, leading to certification* or other regulatory approval as appropriate.

The NST would be constructed at one or more of the 28 abandoned launch pads at the Cape Canaveral Spaceport (CCS). Users will gain access to simulators and flight test equipment through innovative joint research partnerships in which costs are shared by industry and government. The facility will be suitable for both flight (vehicle) and ground (spaceport and range) technology experiments. Upon certification from the testbed, users will have the convenient option of relocating to the nearby operational area of the CCS.

* In this paper, "certification" is used in the broad sense implying governmental approval of new systems, whether through licensing, certification, or other regulatory means.

The fundamental rules of the NST include:

- No paying payloads – the facility is not to compete with commercial spaceports.
- All users pay a minimum fee to cover facility operational costs – users must demonstrate financial commitment to their program.
- Open to all users – the facility is available on a noncompetitive basis to all users willing to pay the usage fee. Non-competitive access avoids the need for the government to "pick winners," however, government cost sharing would be available.

NATIONAL SPACEPORT TESTBED CONCEPT

The proposed NST is a designated self-contained facility at CCS comprised of a simulation center, launch pads, landing strip, a test control center, and off-line vehicle preparation maintenance facility. Many of the inactive or dismantled pads and hangars at the CCS could serve as a starting point for the facility; Spaceport Florida has expressed interest in designating Complex 20 as an NST site.

The facility would allow new technologies to be tested and demonstrated in a variety of flight test environments. New vehicles and new flight technologies would be tested using equipment, simulators, instrumentation, and data links that were provided by the testbed facility. Use of the testbed would be restricted to ground and flight tests of new and modified launch vehicles not involving paying payloads.

The spaceport testbed would also experiment with and demonstrate new ground system technologies. New technologies associated with range operations, propellant management, spaceport control, ground stations, communications, and flight system test and servicing could be certified at the facility with either simulated or actual flight test articles.[1] In mature cases, both ground and flight technologies are to be demonstrated together. These demonstrations provide the ability to improve technical and economic performance before committing to commercial use.

The testbed would be available for testing new operations concepts as well. Operational approaches typically used at commercial airports could be employed at the testbed. For instance, a demonstration of how a spaceport could be operated with the same size ground crew that prepares a commercial jetliner for flight can be carried out in a controlled testbed type environment, perhaps in conjunction with airport operations experts.

Figure 3 below gives a notional perspective of how the NST could be integrated into the Cape Canaveral Spaceport. Area 1 is comprised of the planned EELV complexes and Complex 39 in the north area of the spaceport. Area 2, located to the south of Area 1, would be dedicated to commer-

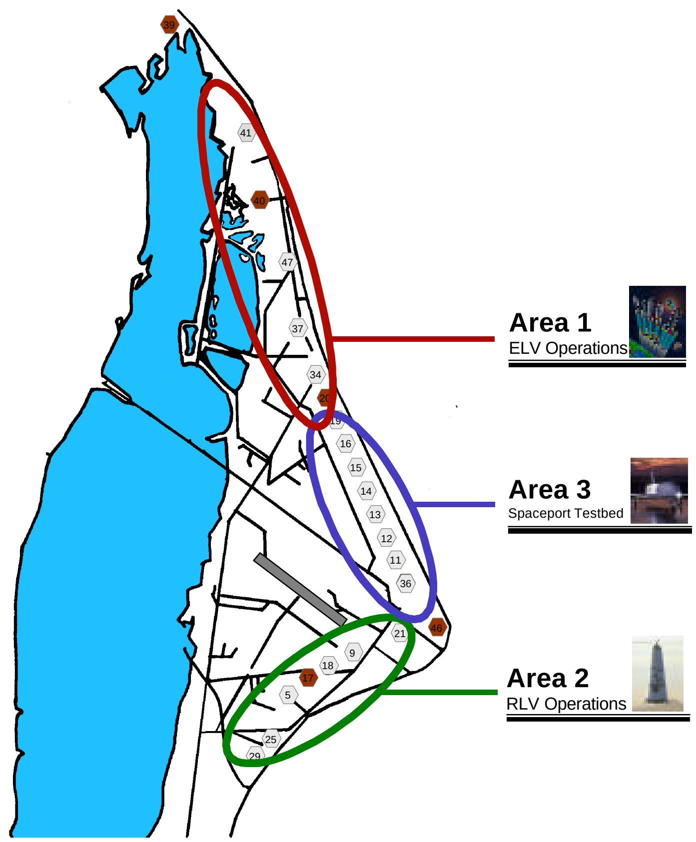

Figure 3. A notional concept for the CCS shows how experimental programs could easily be relocated from the NST to a nearby operational area once the test program is completed.

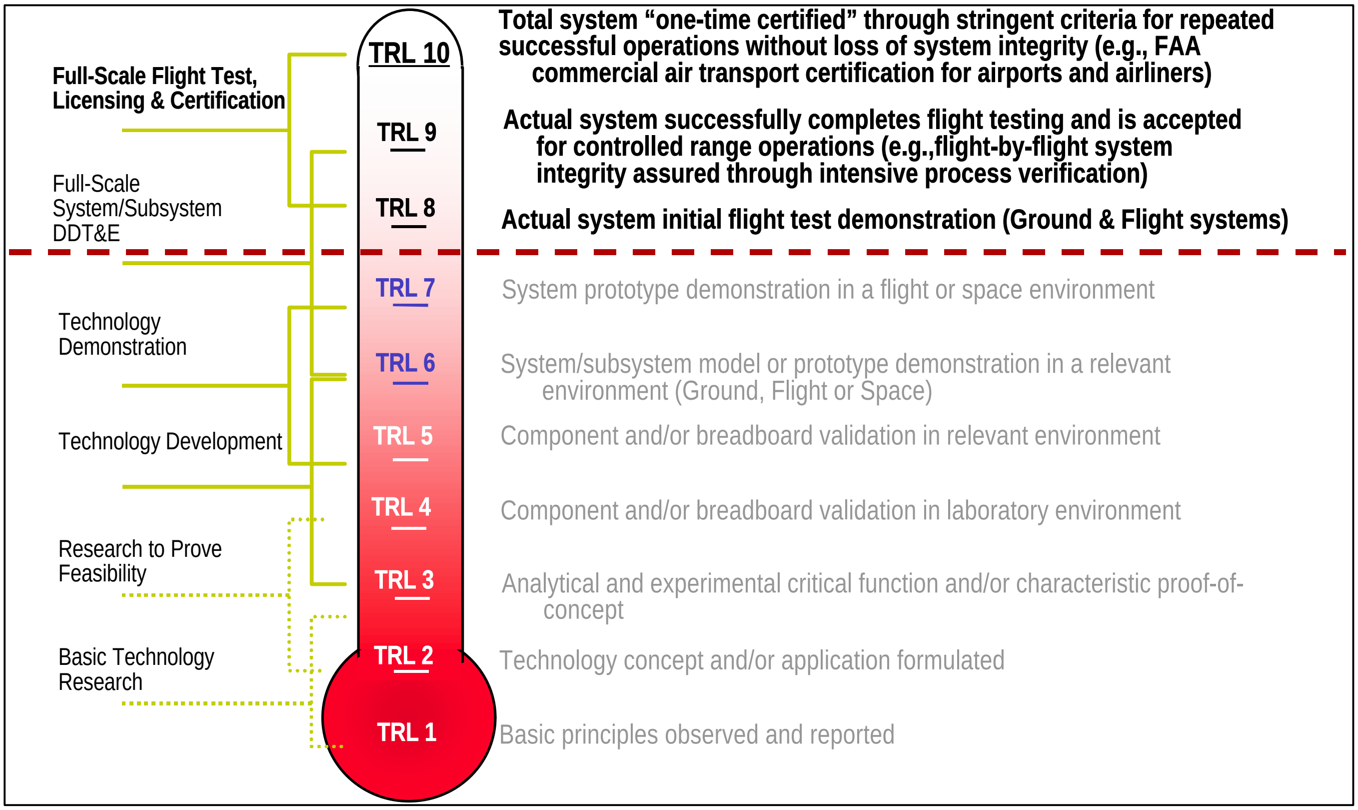

Figure 4. Testbed stages are roughly analogous to NASA's Technology Readiness Level (TRL) scheme, a modified version of which is shown above. The authors propose a new TRL, level "10," to denote flight-certified maturity – as distinguished from TRL level 9 denoting flight-by-flight licensing – and slightly modified definitions of TRL 8 and 9.

cial operations of users that have graduated from the NST. Area 2 could include Spaceport Florida's Complex 46, sharing the runway with Area 3 to the south. Area 3 is the NST, perhaps based in Hangar C near the skid strip. This physical separation of traditional operations from experimental tests would facilitate range scheduling. Such an arrangement should be considered in NASA's future master planning activities at the spaceport.[2]

In summary, the NST would provide a facility for experimenting with and gaining regulatory approval for new flight, ground, and operational concepts in a controlled environment. The facility would nourish partnerships between private industry and government and academia, leading to economic dividends across the industry.

Demonstration Stages

The NST concept is based on a series of certification steps that, roughly paralleling NASA's "Technology Readiness Level" scheme (Figure 4), allow technology developers to incrementally progress from early laboratory testing to full flight demonstrations, including orbital launches and landings (Figure 5). A testbed user would begin at the stage most appropriate for the maturity of the technology under test. As the technology matured, testing would move from early demonstration facilities to more advanced flight operation facilities. The process, which could be coordinated with NASA and the FAA Office of Commercial Space Transportation at various stages or milestones, would culminate in a series of one or more certification flights. Successful completion of the required flight demonstrations would lead to, or perhaps result in, appropriate certification of the vehicle, at which point the user would "graduate" from the testbed and move newly certified systems and procedures to the operational area of the Cape Canaveral Spaceport or other compatible spaceport.

	Stage	Purpose	User
Simulation	**1.** Processor-in-the-loop (PILS) Simulation	Laboratory simulation of flight conditions for component technologies	Early stage technology developers requiring operational simulations for prototype components
	2. Hardware-in-the-loop (HILS) Simulation	Hangar simulation of flight conditions for prototype systems	Ground and flight system developers that need to simulate flight conditions for complete systems
Flight Operations	**3.** Pad/Field Demonstrations	Operational testing of systems not yet ready for flight	System developers that require a method for testing systems in realistic ground operations environment
	4. Initial Flight Demonstrations	Flight testing of new systems	System developers ready for sub-orbital or orbital flight testing
	5. Operational Performance Demonstrations	Certification of operational effectiveness	Advanced systems developers ready for operational deployment

Figure 5. Testbed Demonstration Stages.

Simulation Stages

A simulation capability for the NST is provided in two stages. The first stage involves computer simulation of missing elements including generation of appropriate stimuli to the test article. Referred to as processor-in-the-loop simulation (PILS), this relatively low cost activity is typically used to repeatedly test and adjust individual system components to ensure they meet specifications. PILS testing is useful in exploring operations concepts, verifying communications interfaces, software development and test, command and control system testing, ground system modeling, mission planning, and operator training in a cost effective fashion.

The second simulation stage would consist of a high fidelity ground based simulator commonly known as hardware in the loop simulation (HILS). A HILS facility typically consists of communications gear, navigation equipment (INS and GPS), real-time computer electronics that emulate flight computers, vehicle subsystem interfaces, and flight software. The simulation facility would allow a complete set of operations, including a flight profile, to be executed on the ground to test all components of the space transportation system. This type of simulation is a common early stage element of testing that is repeated to identify problems in the system or with experimental components, effect changes, and retest the changes. This is a key capability required to establish the quality and dependability needed to field a safe and efficient system. The simulator could be used for both flight and ground based technologies.

The simulation capability would be designed to accommodate a variety of launch vehicle configurations and ground systems technologies. The NST would generate signals that simulate operational conditions to the hardware under test. The simulator could simultaneously test multiple vehicles of the same fleet, allowing various operations scenarios to be tested under different launch demand conditions. The simulator would be con-

Figure 6. The testbed's simulation facility would allow components and entire vehicles to be cycled before incurring the risk and expense of flight testing.

Courtesy Vision Spaceport/SAIC.

figured to ease transition from the simulation environment to the flight test environment.

The simulation facility allows technology developers to run FAA mandated scenarios that demonstrate the safety of their systems under varying conditions. The facility would give the FAA insight needed to assess the safety characteristics of the flight concepts as well as the practicality and suitability of the government's evolving flight safety certification requirements. Technology developers would be allowed to move to the flight test facility only upon successful completion of simulation tests.

Flight Operations Stages

The flight operations phase would involve ground launch operations with flight hardware progressing toward actual suborbital and orbital flights, flown repeatedly in a variety of profiles starting with return to launch site for RLV's. The operations phase would begin with static (i.e., non-flight) tests of systems in realistic operational environments. Once proven in a static configuration, testing would proceed to initial flight demonstrations that assess performance, safety, and operational efficiency. Adjustments made to address the findings from the initial flight tests would be demonstrated in a series of operational performance demonstrations.

Remote Access

Both the simulation and operations facilities would have extensive internet-based connections allowing the user's engineering team to remotely plan, monitor, and analyze testing activities, similar to that provided by many national laboratories. Flight planning, simulation scenarios, and post-test analysis activities could be performed by the engineers in their home offices where they have ready access to their tools. Remote access capability would decrease the number of personnel required on site to support the test while bringing the critical data closer to the experts and their tools. This communications arrangement could be based on the recently proposed Global Spaceport Network[3] and a well-planned spaceport information system.[4]

Ground Systems Technology

The spaceport testbed would provide an ideal facility for experimenting with and certifying new ground systems technologies. Free from the strict operational or regulatory limitations associated with operational launch facilities, the testbed could be configured in an endless variety of ways to test and certify new ground technologies without impacting operational missions. Further, at an advanced stage the testbed could offer simulated flight conditions including simulated countdowns and simulated missions that could be used to demonstrate how new ground technologies would interact with the flight segment and improve spaceport and launch operations.

For example, artificial intelligence could be used to experiment with the notion of a "smart range." Self configuring instrumentation, automated tracking solvers, smart vehicle monitors, and intelligent real-time controllers could lead to launch range systems that are operated by dramatically fewer personnel than today's systems – potentially leading to a spaceport tower concept similar to what is found at airports that have no conventional "range." The techniques and technologies associated with this smart range could be explored at the testbed facility using simulated op-

Figure 7. The NST will provide facilities for testing new ground-based technologies, perhaps in conjunction with flight demonstrations. A facility for simulating operations to test new ground systems technology, coupled with a standard certification process, would reduce the economic risk of developing new ground segment products.

erations. Intense experimentation with such technology is simply not practical at today's operational spaceports. Once the value and reliability of the new technologies are proven in a simulated launch environment they could be made available to commercial spaceports in Florida and elsewhere to improve commercial space transportation performance.

It is also conceivable that joint demonstrations involving a combination of new ground and flight technologies be carried out at the testbed. A launch vehicle company, for instance, may be interested in testing some of the experimental smart range techniques. The flight system company and ground system company would strike an arrangement in which each receive the benefits of proving their technologies in conjunction with others. Mutually beneficial arrangements could include reduced or no cost use of the other's technology. New supporting industries would likely develop from such activities.

New Operations Concepts

Just as new ground systems technologies could be tested at the new facility, so could new operations concepts. Operation approaches that demonstrate how flights can be prepared and launched reliably and safely with fewer personnel, fewer ground facilities or other changes are simply too risky or unaffordable to be demonstrated without being evaluated at operational facilities. For instance, some in the industry would like to see a commercial airport engage with the testbed to show how airport flight operations methods could be applied to spaceport operations. No place other than a spaceport testbed can safely host such an experiment.

Figure 8. Experiments with new operations concepts that lead to third generation spaceports could conducted at the NST, perhaps in coordination with airport officials.

STAKEHOLDERS

Fundamental changes at the spaceport

The major organizations involved at the Cape are each exploring profound changes in the structure of the spaceport and its functions. The NST provides one path for evolving NASA's role toward the R&D associated with overall agency goals. Today, the U.S. Air Force is examining its involvement in the day to day operations of the launch range at the Eastern Range and searching for a means to unblock and perhaps engender space launch growth in the emerging commercial space transportation industry without compromising national security. In addition, the White House, through the Office of Science and Technology Policy, has proposed fundamental changes to the operation of the spaceport and the role that federal agencies currently play. The state of Florida, sensing a new day in the space launch business, recognizes the opportunity that these changes pose for the state. Coming at the same time as the startup of several entrepreneurial launch vehicle designs as well as the VentureStar™ initiative, this opportunity frames a high stakes economic game that the state simply cannot afford to ignore. There's no better time to consider the feasibility of a major new spaceport component such as the proposed National Spaceport Testbed as such broad and profound levels of change are unfolding at the Cape and throughout the industry.

NASA

NASA Administrator Dan Goldin is seeking revolutionary new launch systems. The agency maintains it is ready and willing to fund the technical risk reduction once private industry steps up and provides the "spark" for revolutionary risky change. Mr. Goldin has put out a loud and clear call for industry to bring new ideas that NASA can work with.[5]

The NST is a bold new idea. The NASA-owned facility would be set up in coordination with the Air Force to fund technical risk reduction without subsidizing industry or picking winners. The mere existence of an NST would make it far easier for companies to justify experimentation with revolutionary new technologies and new ideas in partnership with NASA. The facility would also provide a ready conduit for applying NASA expertise and technologies to companies developing new launch systems through strategic public-private partnerships. And to ensure the successful experiments do not stop at the laboratory stage but are fully commercialized and turned into successful business, the NST will maintain an entrepreneurial spirit at its heart. Companies will share the risk and commit private funds before using the NST.

NASA's space transportation technology strategy is based on a three-tiered roadmap. Core technologies, forming the foundation tier, are demonstrated on narrowly focused "Pathfinder" flights. Driven by technology, these second tier demonstrators are to take no more than 3 years and $100 million to complete their flight objectives. Successful Pathfinder technologies can then move to large scale ground testing, or to the third tier of flight testing, designated "Trailblazer" demonstrators. Trailblazer demonstrators are performed when required by a particular mission to verify operability and programmatic viability.[6]

Within this strategic framework, NASA has developed an integrated space transportation plan based on a series of projects from shuttle upgrades, to a second generation RLV, leading to a third generation vehicle (shown in Figure 9). Shuttle upgrades require near-term (by 2005) technology advances in vehicle health management, electrical auxiliary propulsion, cockpit safety, and other areas. The second generation RLV is to lower access to space costs by one order of magnitude. This may require new technology in areas such as crew escape, non-toxic subsystems, robust abort capability, intelligent data analysis, and electromechanical actuators. Further down the road, third generation vehicles require dramatic reductions in cost and improvements in safety. NASA's Spaceliner 100 technology program is to explore revolutionary advances in technology including propulsion performance, low drag aerodynamic structures, adaptive intelligent systems, and spaceport range operations. *At some point, every single one of these new technologies will require simulation and flight testing to demonstrate progress toward the desired capabilities.* The proposed NST would be the ideal facility for carrying out the Spaceliner 100 technology development program and other Pathfinder and Trailblazer flight tests.[7]

The strategic purpose of NASA's technology

Figure 9. NASA's Integrated Space Transportation Plan includes three "generations" of reusable launch vehicle technology. All associated technology will require simulation and/or flight testing to demonstrate technical feasibility.

program is to fill the investment gap created by the huge investment and long development cycle time required for new space transportation system development. This program is essential for the industry to realize the necessary revolutionary technology development to achieve safe and affordable space access needed for space commerce. The NST would form a key link in the success of this program, helping bridge the gap now limiting space launch development.

Closer to home, the Kennedy Space Center has been established as the nation's "Spaceport Technology Center" (STC). The center would increase the use of its expertise in developing new space systems in partnership with other entities. According to an STC concept paper, "the STC, comprised of a knowledgeable and experienced workforce utilizing world-class facilities and equipment, will provide technologies and processes to private business and government agencies who propose to build and operate spaceports and associated ranges."[8] To successfully experiment and demonstrate the resulting technologies, the STC will require world-class testbed facilities that leap well beyond current capabilities such as the Launch Equipment Test Facility. In fact, as the concept paper notes, the Office of Technology Assessment recommended over 10 years ago that NASA establish a space transportation operations test center to demonstrate innovative approaches to space launch operations.[9]

The STC is currently envisioned with three "pillars":

1) Launch and launch vehicle processing systems,

2) Payload and payload carrier processing systems, and

3) Landing and recovery systems.

Technology development in these pillars could make use of the NST in each of the development initiatives and technology areas defined in the concept paper:

- Command, control, and monitor systems
- Range systems
- Fluids and fluid systems
- Materials evaluation
- Process engineering
- Information systems
- Simulation
- Biological payload processing systems

At the March 16, 1999 U.S. Chamber of Commerce Forum on the Future Development of Space, Mr. Goldin used an example of how NASA is successfully partnering with industry to push the frontiers of technology in what serves as a precedent for the NST:

> *"Under the leadership of the NASA Ames Research Center, we are putting together a high-tech research park in Sunnyvale, the heart of Silicon Valley. We will partner with the unbelievable talents in the area to develop the next generation electronics and information technologies. We will work with customers, clients, and other stakeholders from day one. We will make it a joint development with each party being able to concentrate on what they do best. This is synergy at work from the get go."*

With NASA's Pathfinder/Trailblazer strategy applied to three generations of NASA launch vehicle development, the advent of the STC concept, the blossoming entrepreneurial space community that remains hungry for financial assistance to reduce the tremendous technical risks, and the availability of land and equipment at the Cape Canaveral Spaceport, the time has come for a high-tech space transportation research facility on the Space Coast. With joint projects that bring together the strengths of various parties – NASA, FAA, Air Force, RLV companies, spaceport companies, and academia – an unprecedented level of synergy can be applied to the most vexing problem facing the space industry today: affordable space access.

U.S. Air Force

While NASA is determined to reduce space access costs for its exploration and science missions, the U.S. defense department strives to reduce those costs to integrate earth orbit into military strategy and battlefield operations. Spacelift 2025, an Air Force initiative to define how space assets will be used in future conflicts, calls for the ability to "launch on demand."[10] Maintaining quick access to space is a critical aspect of national security; reducing its cost is just as critical in the face of reduced defense budgets.

Several recent events reflect the defense department's determination to reduce costs while enhancing the use of space for military purposes. The Air Force Research Laboratory is "working much more aggressively toward space and less toward aircraft."[11] The X-40A military spaceplane program is due to begin drop tests from a B-52 carrier aircraft in late 2000. This vehicle is a scale model of a low cost reusable "satellite bus" proposed for rapid military satellite deployment.[12] The Air Force also conducted a year-long analysis of the readiness of commercial space products in 1999, seeking to replace expensive build-to-order contracts with much cheaper off-the-shelf products. In addition, the Evolved Expendable Launch Vehicle program has been structured to substantially reduce the cost of launching military satellites.

The drive to reduce launch costs is occurring at the same time the federal government considers changes to the fundamental precepts governing federal launch ranges. Both the White House Office of Science and Technology Policy[13] and the National Academy of Sciences[14] have conducted studies on the future use and organization of the launch ranges. The results of these studies, combined with the Air Force vision of turning most range operations over to private industry, could lead to some of the most dramatic changes at the ranges in a generation. With the modernization stemming from the Range Standardization and Automation program, the Range Operations Control Center, and the Spacelift Range Services project, the opportunity to develop a world class space flight testbed and research facility at the Eastern Range is very timely.

To put the NST concept in context from the military point of view, it is important to recognize the tremendous test facility assets already available to the U.S. military. Major aircraft test and training facilities are located at the White Sands Missile Range and Test Facility and Holloman Air Force Base in New Mexico, Edwards Air Force Base in California, Kwaijelein Atoll in the Pacific, and many other sites worldwide. The X-40A test article began flight tests in 1998 at Holloman Air Force Base, for example. The Eastern Range is technically a test range, although over half of the launches conducted from the range are commercial flights.

The proposed NST would be an ideal complement to existing military facilities, providing at least two key benefits to the military that current test ranges cannot. First, the NST would be dedicated to space-related activities. There would be no conflict with aircraft or missile testing as is commonly the case at existing test ranges. New concepts for operating commercial spaceports cannot be fully realized at military installations due to security regulations and statutory limitations on the use of associated facilities for commercial purposes. Secondly, and perhaps more importantly, the juxtaposition of military space testing with commercial space technology R&D at the NST could lead to new partnerships and synergies between the defense department and private industry beyond the traditional defense industry contractors. This potential synergy is precisely the aim of the recent Air Force Commercial Space Opportunities Study[15] and other initiatives to apply commercial space capability to military applications.

Dr. John Borky, vice chairman of the Air Force Scientific Advisory Board, reported to congress on the Air Force roadmap[16] developed last year. This roadmap includes the recommendation for outsourcing range operations in coordination with technological activity such as deploying GPS-based tracking. The roadmap also calls for moving in the direction of national or regional spaceports, potentially including “the creation of a National Spaceport Authority analogous to the FAA.” Major changes are brewing in the Pentagon relative to the military role in space range operations; the proposed NST would be an ideal facility for exploring many of the proposed technological and operational changes.

Federal Regulatory Agencies

The U.S. Department of Transportation is very interested in establishing a spaceport launch licensing or certification mechanism that provides maximum flexibility to spaceport launch operations while ensuring the safety of the surrounding personnel and property. Today, the agency licenses spaceports and launch vehicles independently on a case by case basis. The NST could be used by the FAA to more formally structure the process of granting commercial space operations licenses, perhaps paving the way to realizing true airline-like “type certifications” in the future. The testbed would be an ideal facility for collecting specific performance data in standard formats for inclusion in launch application packages. The demonstration of key onboard safety and ground system technologies in the testbed environment could also comprise part of a future certification regime for the space transportation industry.

Performance data derived from simulated and actual flights are a key element of the launch application process. Vehicle manufacturers would initially conduct simulations or flight tests as appropriate to collect data needed to refine their technology. When ready to begin the certification process, the manufacturers would use the testbed to prepare a more extensive data package for the FAA – some of the data would be generated from simulations and some from flight tests. Applicants may be expected to prove the validity of simulation-generated data. This approach could quickly lead to development of standards for FAA data packages.

The FAA has identified several emerging technologies[17] they believe will influence space transportation operations. These include dynamic airspace reconfiguration, enhanced weather prediction, trajectory modeling, simulation, information exchange tools, cockpit displays, and decision support systems, all of which could be developed and tested at the NST.

The FAA may also be interested in using the testbed facility to explore the problems and potential solutions to integrating reusable launch vehicle traffic with the national airspace system. In an advanced scenario, the FAA and NASA could jointly explore the potential of using “space traffic corridors,” sometimes referred to as “spaceways,” to manage launch vehicles passing through the national airspace system. Working in a shadow mode to traditional range safety, a space traffic control “tower” linked to satellite tracking technology and regional air traffic controllers could experiment with managing the space traffic corridors in coordination with the national airspace system.

This effort could lead to a true aerospace traffic control mechanism in which launch operators notify the tower with launch parameters. The con-

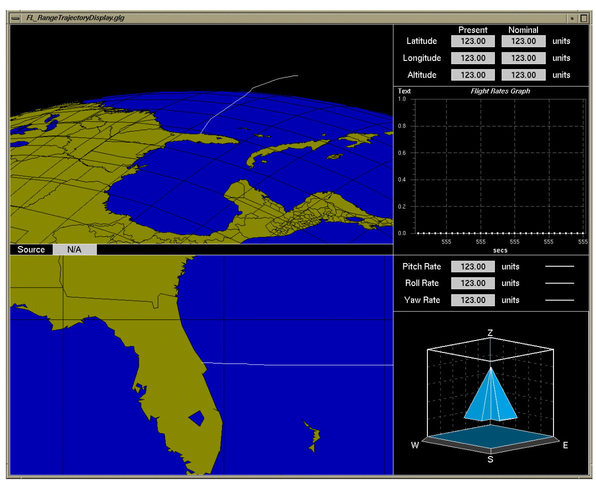

Figure 10 Standard test range safety technology will be used for expendable vehicle tests. Tests of reusable and piloted vehicles will require commercially-oriented safety features similar to that used for the commercial launch facility in Kodiak, Alaska and for piloted test aircraft, as well as new approaches to assessing E_c.

trollers would assign a corridor and time slot for ascent; as long as the operation takes place within the corridor time-space, no range interaction would be required. A similar scenario would take place for managing the return flight. This approach would eliminate the need to close nearby air traffic corridors for days at a time during launch events. Clearly, many technical and operational issues must be explored and addressed before such a scenario can even be attempted; the NST would provide an ideal facility for this kind of exploration. Once proven, this capability would draw new reusable launch vehicle companies to the spaceport.

In addition, RLV developers are lobbying the FAA to create innovative certification processes that would allow them to streamline development and test flight activity.[18],[19] The FAA could utilize the NST to demonstrate the feasibility of proposed new certification processes, allowing the agency to make their case for new regulatory legislation or policy as appropriate.[20] An informal survey of the leading U.S.-based RLV developers revealed the top operational issue was the FAA licensing process and the large number of test flights required in the agency's proposed RLV safety rules.[21] Many of the developers specifically indicate a desire to replace some of the test flights with ground-based analysis or simulation. In order for the FAA to consider such a change to the proposed rules, the agency would require evidence that substituting simulation for flight testing would not impact the safety of certified vehicles. With careful planning of a test program, the NST could be used to gather that evidence, benefiting both government and private industry.

RLV Companies

Many of the space transportation entrepreneurs in the United States are having difficulties raising capital to complete their development efforts. Some of them cite NASA's funding of the X-33 as a stumbling block with potential investors because the investors are reluctant to finance enterprises that compete with a government funded program such as the X-33. Many of these same entrepreneurs have expressed interest in government financed facilities that were equally accessible to all of them in a way that did not favor any one particular concept. The testbed facility, for example, would provide the opportunity for the government to assist in technology development across the industry without discouraging investment in any one particular enterprise since it would be available to all paying users. In fact, government support in such an equal access fashion would be seen as a means of leveraging private investment and therefore make the space transportation enterprises more appealing to potential investors.

Today, developing a commercial space launch vehicle is one of the most difficult business plans to sell to private investors. The upfront investment requirements are tremendous. The time required to move from initial investment to revenue generation is unusually long and the investment horizon is much longer than other high technology enterprises. Launch vehicle entrepreneurs tend to deal with the situation by funding their enterprises in stages; it has become clear that raising private funds for later stages is even more difficult than initial investment rounds due to the ever-increasing clarification of the technological risks associated with launch vehicle development. The design and prototype construction phases are typically within the scope of early rounds of investment, but by the time the program is ready to begin serious flight testing the initial investment is usually consumed and subsequent rounds of financing are very difficult to come by. Launch vehicle firms that have reached the stage of developing a vehicle prototype suitable for flight testing have demonstrated their owner's commitment to the program and the assumption of a very large portion of the technological risks associated with the enterprise; many such companies would likely welcome a partnership with government that leveraged additional private investment rounds to fund their final flight testing program leading directly to revenue generating operations.

Making this situation even more difficult, the flight test stage has the highest risk of the entire vehicle development program. Investors that were willing to assume the risk associated with earlier stages may not be willing to shoulder the flight-test risk alone. This situation offers an opportunity for the federal government to share some of the risk at the riskiest point in the program. Government risk sharing would give entrepreneurs a strong tool in securing additional private financing to complete their development programs.

The government contributions can take any of several forms. Cash contributions are always an option. However, the government may find it more practical and more valuable to contribute time and expertise associated with the test flight facility that would reduce the burden on the entrepreneur to finance a complete launch operations flight team while the full engineering staff is still on the payroll. With a package of government provided test facility time and cash contributions, the entrepreneur will hold a strong hand in approaching private investors to fund the high-risk flight-test portion of the development program. Plans to conduct the flight test from a proven, safe, and technologically state-of-the-art facility combined with a clear plan for achieving FAA approval would also strengthen his case. The proposed NST management structure, discussed later, would support cost sharing arrangements as well as 100% user-paid programs.

Established Launchers

Companies that conduct launch operations today with proven vehicles are continuously striving to engineer more efficient subsystems, more affordable components, and more productive operations. These firms typically employ dozens to hundreds of engineers that apply new technology to advance the performance or affordability of their vehicles. New computer technology leads to “smarter” avionics and safer more reliable vehicles. New materials lead to lighter structures, improving design margins and increasing payload capacity, or more efficient rocket engines. A common thread that runs through all of these projects is the need to ground test and flight test new technologies and new components. The NST offers these companies the opportunity to experiment with proposed improvements to their vehicle and operations without risking one of their operational vehicles or interfering with manifested schedules: the new component or technology could be demonstrated either in the simulation facility or on a test flight of another company’s vehicle. The Spaceport Florida Authority, with its large inventory of test rockets, would also be in a position to work with industry to demonstrate new technology on their test rockets.

Ground Systems Companies

The importance of ground systems and related technologies is often overlooked when devising new space transportation architectures. This phenomenon puzzles many in the ground segment community because, in the long run, the ground systems and related operations make up a very large portion of the cost of a space mission. Developing new ground systems, technologies, and operations techniques that enhance safety and reliability, and lead to lower costs, is critical to maintaining a competitive position in the space launch industry. The NST could play a pivotal role in the development of such technology.

Companies that focus on spaceport technologies, such as Command and Control Technologies Corporation (CCT), have long recognized the opportunity to build a business around products and services that streamline launch and mission operations. The challenge these companies face is to develop affordable products and systems that truly offer long-term benefits to spaceport and launch vehicle operators. With today’s limited market for such products (there are about 20 operational launcher families in the world), it is very difficult to raise private capital to develop them. This problem is particularly acute in developing technologies with the highest potential payoff since more investment is required to develop high-risk high-potential technology. The earlier example of the benefits of applying intelligent systems technology to launch range operations is a case in point. Significantly reducing range configuration time to allow concurrent mission flows and automated flight processing is essential to substantially increase the capacity of U.S. launch ranges and thus lower the costs of using them. However, obtaining the substantial financing to develop this technology privately is not likely in face of its limited potential market today and resulting long term payoff.

The NST concept offers an ideal solution to this dilemma. Joint industry/government funding helps overcome the financial hurdles; demonstration of the technology at an actual launch site shows the benefits of employing resulting products to operational spaceports, thus helping to create a potential customer base for the developer; the availability of a

Figure 11. The recently unveiled KSC Cryogenics Testbed is an example of how government facilities can be used to reduce technical risk of developing commercial space transportation systems.

simulation facility lowers the risk of development; and the opportunity to demonstrate the technology during actual testbed flights, say, by another testbed user demonstrating flight technologies, substantially boosts its credibility if successful. The government wins, the entrepreneur wins, the potential customers win. In the end, the benefits of demonstrating ground systems technology at the NST may be even more compelling than that for flight systems.

Florida

Florida is already home to one of the premier launch sites in the world. The state, however, recognizes that its premier position is by no means guaranteed as the space shuttle program enters its sunset period in the next decade. A recent study by a U.S. Department of Transportation think tank echoed these observations and recommended the state adopt a two-fold strategy: build a world-class spaceport and diversify industry by investing in space R&D.[22] With the Air Force and NASA diminishing their operational roles at the Florida launch site, the state recognizes the need for substantial state level involvement to maintain recognition of the world class facility at the launch site. Creation of a national spaceport testbed facility – the only one of its kind in the world dedicated to commercial launch vehicle and ground system testing – would boost the global prominence of the Florida launch site and form a catalyst for new R&D activity. Such a facility could well provide the cornerstone of a comprehensive "world class" Cape Canaveral Spaceport as envisioned by the state's spaceport authority.[23]

With careful master planning, the proposed testbed could evolve into an incubator of sorts in which launch vehicle entrepreneurs who successfully completed their test flight program would graduate from the test area and move their operation just a few miles to the commercial operations area of the spaceport. This strategy would save much of their investment in local facility, personnel, communication links and other infrastructure. The facility would thus give Florida a mechanism for capturing new space launch operators in a very economical way. Economic development interests in the state would have the opportunity to contribute resources to fledging launch operators in an effort to retain them upon completion of their flight test program, perhaps through an association with the Florida/NASA Business Incubation Center located in Titusville.[24] The proximity of the test area to an operation area would be a clear advantage that the state of Florida would hold over all other candidate launch sites.

Financiers

Current space launch performance has made it clear to the space financial community that a means for creating higher standards for safety, reliability, and throughput are desperately needed. The NST concept fulfills this critical national requirement.

In fact, a relationship between investors and the NST could take any of a number of forms to open up unprecedented opportunities in the fledgling space entrepreneur community. The NST would provide space companies an opportunity to demonstrate their technology to potential investors. The investment community would have an opportunity to observe other companies involved at the NST, some of which may represent promising investment opportunities. Partnerships that are already in place such as the agreement between NASA and SpaceVest,[25] a private equity organization, could serve as the foundation upon which to forge more aggressive and productive pacts.

Venture capitalists and other financiers would get to see their management teams in action for perhaps the first time in an operational environment. Observing the team's reaction to failures and successes during flight testing offers investors unique insights into their companies. And as professional dealmakers, investors may find opportunities to create partnerships between independent NST users to create more robust enterprises, or fill key management positions with individuals who demonstrate special abilities during NST operations.

Benefits of technology demonstrations would be shared between investors and entrepreneurs. These demonstrations allow the developers to judge the market's reaction to their new technology as it makes its way through the testbed stages. Adjustments to the technology can be incorporated early – when it is much cheaper to do so – and marketing strategies can be developed based on the reactions. Overall, this allows investors to gauge the potential payoff of later round financing in a particular company or technology.

Perhaps most importantly, the NST offers the investor an opportunity to learn more about the space industry. Business principles and management decisions take on a unique flavor when mixed with space flight operations; companies conducting demonstrations at the NST would be able to expose their investors to this environment very early, paving the way for what will certainly be even more challenging times when paying payload customers are involved.

Universities and Academic Research

The NST could provide an ideal vehicle to engage the academic research capacity of the entire state in space technology. With a variety of ground and flight experiments taking place at various levels of advancement, opportunities for university researchers to join forces with private industry would proliferate. The trend towards increased research dollars granted in the state that are earmarked for space-related projects would make academic involvement even more attractive to private companies seeking assistance in early-stage experiments and in resolving particularly vexing technical problems. Organizations like the Florida Space Grant Consortium[26] and the Florida Space Research Institute[27] would find ideal proving grounds at the NST for new technologies devised by their researchers.

There would also be an educational element to NST operation. While established operational launch operators are unlikely to involve large numbers of students in their day-to-day operations, the NST could be arranged to include a substantial hands-on student element. Engineering, scientific, and business students alike may benefit from their involvement with the facility. This concept has been demonstrated successfully with satellite development by the Florida Space Institute.[28] The FSI is the obvious choice for playing a leading role in this area for the NST.

Others

Space and brevity does not permit an in-depth analysis of all potential NST stakeholders, users, and associates. A few others include spaceport operators who may find it useful to experiment with innovative operational techniques at the NST prior to implementing them at their own facility. Such demonstration may help pave the way to an FAA Launch Site Operator's license, making the spaceport a much stronger contender for launch business.

Airports may find it useful to monitor some of the activities at the testbed since air traffic routinely encounters interference during space launches. Studies[29] are underway to develop tools that integrate space "corridors" into the national airspace system in a way that is consistent with the proposed FAA concept of operations for reusable launch vehicles.[30]

Lastly, local and regional economic development agencies in Florida could focus their recruitment efforts on the NST, allowing the somewhat splintered approach that prevails today to stabilize into a strong and continuous initiative in which federal government, state government, local government, and universities all have defined roles that complement one another.

MANAGEMENT & FUNDING

In what could be the most revolutionary aspect of this concept, a new NASA partnership arrangement would be used to combine government and user funding for NST projects. NASA has recently created an innovative partnership mechanism under Space Act authority that is proven to be ideally suited to joint research and development activity in the space and aircraft industry. The mechanism, known as the Joint Sponsored Research Agreement, is a reimbursable Space Act partnership between NASA, private firms, and other organizations in which each participant contributes resources to a common goal and where each participant realizes certain benefits from the common effort.

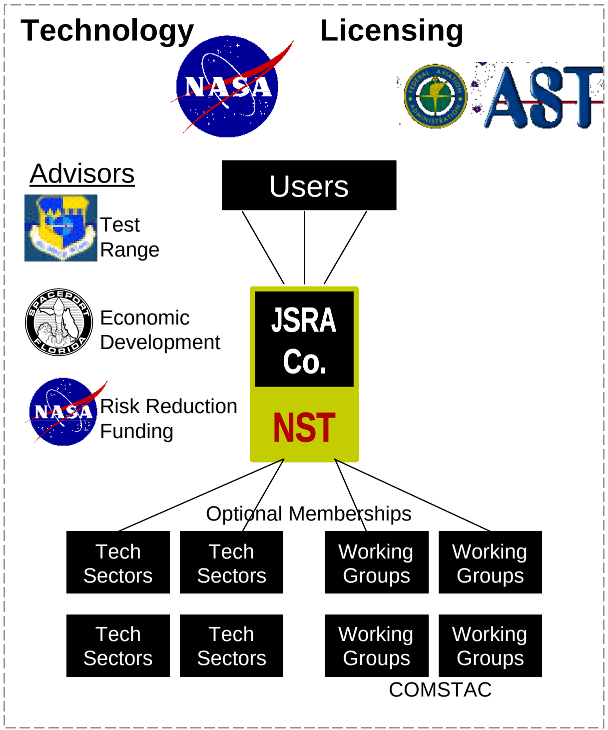

Figure 12. The NST could be managed by a small non-profit company established through a Joint Sponsored Research Agreement.

The JSRA mechanism has been used successfully on the Vision Spaceport project administered out of NASA's John F. Kennedy Space Center in which spaceport transportation system analysis technology has been produced by a government/industry/ academia consortium.[31] The mechanism has also been used on a much larger scale at Langley Research Center. The Advanced General Aviation Transport Experiments project is a consortium of over 70 government, industry and university organizations formed in 1994 to develop technologies to increase small aircraft safety, affordability and ease of use. The group is also developing industry standards and certification methods for airframe, cockpit, flight training systems, and airspace infrastructure for next generation small airplanes. This major initiative serves as an outstanding and successful model upon which to base operation of the NST. The group, which includes the Air Force and the FAA, has established a separate non-profit corporation to handle administrative affairs for the consortium.[32]

The JSRA mechanism would allow NASA and the state of Florida, as NST owners, to establish a partnership for potential testbed users – either flight or ground technology companies – whereby each party would contribute resources to the proposed technology demonstration project. The JSRA includes a strong commercialization element that would be closely aligned with the commercialization interests of the testbed user. Government contributions to the partnership would leverage private financing to be obtained by the user.

With this arrangement, NASA is contributing to the reduction of the technology risk associated with new, innovative space transportation technology. The state of Florida is investing in the capture of new space vehicle operators and the space vehicle entrepreneur is receiving financial assistance from the government that may very well be the impetus that allows the entrepreneur to close the deal with the late stage investor.

CHALLENGES

Several policy, organizational, technical, and logistical challenges must be solved to pave the way for the proposed facility. With sufficient foresight and determination, however, none of these obstacles should be insurmountable.

Range safety requirements.

A flight test program by definition requires maximum flexibility in range scheduling, configuration, and safety requirements. The safety requirements spelled out in the *Eastern and Western Range Standard 127-1* would have to be carefully examined and tailored to spaceport testbed activities. Installation of independent onboard safety destruct devices that are controlled by parties other than the vehicle manufacturer may be a part of the solution for ELV flights. For RLV tests, a renewed focus on the technicalities of calculating expected casualty rates (E_c, the historic measure and standard for calculating risk to property and people) will be needed to more precisely quantify risk without undue conservatism in the process.

Location

Many of the unused launch pads at the Cape Canaveral Spaceport will continue to be unusable for the foreseeable future. Many of these pads were located relatively close together according to old vehicle designs and associated hazards. Most of today's launch vehicles are larger and put more spaceport land areas at risk during launch operations due to higher energy and greater quantities of propellant. Today's safety zones, flight hazard areas, and impact limit lines make many of the unused pads unavailable during certain launch operations at other facilities.

One option may be to locate the simulation and any other non-launch functions away from the established launch pads (possibly on KSC property).

Operational Impacts

One of the chief challenges of conducting tests at an operational range is dealing with the inevitable scheduling conflicts that arise when unplanned test activities interfere with pre-planned operations elsewhere on the base. Test activities are by their very nature unpredictable: a test that is delayed a few days due to last minute adjustments often is delayed even longer because another activity has "reserved" the later time. One way to address this is to designate a large area of the spaceport for flight testbed operations as outlined in the Master Planning section earlier. Operations in this area could be carried out somewhat independently of other areas.

Remaining responsive to the entrepreneurial community.

Today's Florida spaceport suffers from a widespread image of fostering bureaucratic administration and catering to large business and government programs. The image of the spaceport must be restored to one that not only supports innovative enterprises outside the traditional aerospace culture but welcomes them. Assigning NST administrative and operational duties to a small business would go a long way toward keeping the entrepreneurial spirit at the heart of the operation.

Multi-Use Launch Facilities

Existing and planned space transportation system architectures require unique ground facilities and support equipment. Vertical launch systems, for example, generally require a concept-unique launch pad, access points, transporter/crawler, erector, and other large infrastructure items. Horizontal launchers require unique processing facilities with different requirements for various fluids and ground support equipment. Creating a single launch facility to handle a variety of space transportation systems would be an unprecedented and potentially historic advancement in the industry.

Part of the solution may be separate facilities for horizontal and vertical takeoff (and landing) architectures. The horizontal facility would be the easier of the two, requiring a hangar and runway. The vertical facility would be more difficult.

In addressing this issue over the long term, the industry may find some benefit in defining standard launch facility interfaces for vertical takeoff vehicles. The time will eventually come to create a "standard" launch pad. If new vehicles were designed to work with the standard launch pad (just as aircraft are designed to work with standard runways, jetways, cargo loading equipment, etc), airport-like spaceports could become a reality in which fleets of reusable vehicles could launch and land at multiple locations.

Similarly, NST processing facilities (fluid services, access stands, transportation/crawlers, hazardous operations, etc) for both horizontal and vertical systems would be designed with flexibility in mind - and with all interfaces and capabilities published. As a result, the NST could serve as an early de facto standard for such facilities, and new vehicle designers would make a business decision whether to build to the standard. Manufacturers could use the NST simulation and test flight facilities right away if the new vehicles were built to these standards.

An argument could be made that this approach would stifle innovation, however, any alternative would lead to continued production of vehicle designs that require unique ground facilities, a situation that will significantly limit operational cost reductions for space access.

The long term direction of space transportation technology is another consideration.. As with aircraft, the launch vehicle industry will eventually converge upon an optimal design (compare the wildly assorted aircraft designs of the early 1900's with the relatively homogenous designs of today's aircraft from Boeing and Airbus – the aircraft industry has converged upon the optimal design for today's technology). The notion of launching multiple types of vehicles from a single type of "pad" must be predicated upon emergence of common interfaces and standard access styles that can only come from relatively homogenous designs across the industry. From a business viewpoint, such homogeneity can only spring from achievement of near-optimal designs – a goal that will require advanced testing facilities such as the NST proposed here.

Practically speaking, and in the nearer term, the NST should start with a focus on the simulation facilities. This will allow time to develop a solution to the larger "launch pad commonality" problem and perhaps allow early standards to emerge.

Engaging charter partners.

Frankly, the history of cooperation among the major space institutions in Florida – NASA, the Air Force, and Spaceport Florida – has been sporadic and has achieved mixed results. Differing agendas have precluded these organizations from forming strong synergistic bonds that would advance them as a whole. However, some recent progress is promising: the Air Force and NASA established the Joint Base Operations Support Contract in 1998, and more recently have joined with Spaceport Florida to form the Spaceport Management Council. NASA and the Air Force are currently developing a proposed inter-agency organization to run the newly designated Cape Canaveral Spaceport.[33] Cooperation between these three agencies, and, more to the point, establishment of a shared vision for space operations in Florida is essential for the success of this proposal. Indeed, it is essential for the very success of space business in the state.

Conclusion

This paper introduces a concept for a dramatic new use of the assets at the Cape Canaveral Spaceport. Events unfolding today in the commercial space transportation industry call for bold ideas and bold leadership to keep hold of U.S. prominence in this vital area of commerce and technology. The proposed NST is such a bold idea. It is up to government and industry leaders to embrace the idea and make it happen before most space transportation business relocate out of the state, or worse, out of the country.

Acknowledgements

The authors would like to express our gratitude to Renee Ponik and Maylene Duenas of NASA for review of early drafts of the paper, as well as Kistler Aerospace, the Air Force 45th Space Wing, the FAA office of the Associate Administrator for Commercial Space Transportation, and the Vision Spaceport team for insightful comments and suggestions

References

[1] Zapata, E., "Reusable Launch Vehicle Certification," 33rd Space Congress, Canaveral Council of Technical Societies, Cocoa Beach, Florida, April 1996. (See http://www.ksc.nasa.gov/shuttle/nexgen/rlvhq14.htm)

[2] Ponik, Rene, "Master Planning at the Cape Canaveral Spaceport," 37th Space Congress, Cocoa Beach, Florida, May 1, 2000.

[3] Brown, K.R., "Linking Information Systems Between Independent Spaceports," TechEast '99, Miami Beach, Florida. November 3, 1999.

[4] Brown, K.R., "A Ground Information Infrastructure for Spaceport Operations," First International Symposium on Reduce the Cost of Ground Operations, Oxfordshire, U.K. 1995.

[5] Dan Goldin, remarks at AIAA luncheon, May 3, 1999.

[6] Rogacki, Dr. Row, *Overall Approach/Organization* briefing, NASA Space Transportation Day. October 27, 1999.

[7] Smith, Dennis and Cook, Steve, *Integrated Space Transportation Plan* briefing, NASA Space Transportation Day. October 27, 1999.

[8] NASA-KSC, *Spaceport Technology Center Concept*. 1999, undated.

[9] U.S. Congress, Office of Technology Assessment, *Reducing Launch Operations Costs: New Technologies and Practices*, OTA-TM-ISC-28. September 1988.

[10] See http://fas.org/spp/military/docops/usaf/2025/v2c5/v2c5-1.htm and http://fas.org/spp/military/program/launch/lodi/sld011.htm

[11] Covault, Craig, "USAF Shifts Technology for New Future in Space," p. 43, Aviation Week & Space Technology. August 17, 1998.

[12] See http://www.boeing.com/defense-space/space/futurex/X40/].

[13] OSTP, "Future Management and Use of U.S. Space Launch Bases and Ranges," Commerce Business Daily. May 11,1999.

[14] National Academy of Sciences, "Space Launch Range Safety," Project ASEB-J-99-02-A. National Research Council Library, Washington DC. 1999.

[15] U.S. Air Force, "Commercial Space Opportunity Study Final Report" to be released. See http://www.losangeles.af.mil/SMC/XR/CSOS/main.htm

[16] U.S. Air Force, "A Space Roadmap for the 21st Century Aerospace Force." See http://www.house.gov/science/borky_062999.htm.

[17] Federal Aviation Authority Office of Commercial Space Transportation, *Concept of Operations in the National Airspace System in 2005*. February 8, 1999.

[18] Commercial Space Transportation Advisory Committee, RLV Working Group, "Final Report on RLV Licensing Approaches," April 29, 1999.

[19] Boyland, J., and the Commercial Space Transportation Advisory Committee, Draft Working Group Report, May 1, 2000.

[20] See Space News issue 9/13/99: Steve Wurst interview, page 6.

[21] Federal Aviation Administration, Interim Safety Guidance for RLV's (draft). January 4, 1999.

[22] U.S. Department of Transportation John A. Volpe National Transportation Systems Center, "Building on Florida's Strengths in Space". December 6, 1999.

[23] Spaceport Florida Authority, *Next Steps to the Stars*. February 1999.

[24] See http://www.fnbic.org

[25] SpaceVest/NASA Memorandum of Understanding. October 14, 1997.

[26] See http://www.astro.ufl.edu/~fsgc

[27] Florida Statutes, Chapter 99-256, 1999 Florida State Legislature.

[28] See http://fsi.ucf.edu/.

[29] SBIR 99-1 01.02.5282, "A Planning and Simulation Tool for Air Traffic Management of Reusable Launch Vehicles," Command and Control Technologies, awarded by NASA October 1, 1999.

[30] U.S. Federal Aviation Administration, *Concept of Operations in the National Airspace System in 2005*. February 8, 1999.

[31] NASA John F. Kennedy Space Center, *Joint Sponsored Research Agreement: The Vision Spaceport Project*, NCC10-0030. January 1998. See http://www.VisionSpaceport.org.

[32] See http://agate.larc.nasa.gov/.

[33] Stone, Dave. Briefing to the Technology 2009 National Conference. November 1, 1999.