Intelligent Launch and Range Operations Testbed

Concept Paper

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COMMAND AND CONTROL TECHNOLOGIES CORPORATION

Intelligent Launch and Range Operations Testbed

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INTRODUCTION

Today's space operations rely on a vast network of manual activities and human decisions to safely plan missions, configure systems, conduct flights, and support mission analysis. Literally hundreds of range and launch operations personnel are required to plan and execute each mission. The cost of operations is a significant portion of the total lifecycle cost of space flight, but it is difficult and risky to experiment with new, potentially lower-cost operational approaches during actual space flight operations. A capability for investigating new operational approaches that promise to significantly reduce cost and complexity for future launch vehicles is needed. This paper describes the concept of an "Operations Testbed" that would provided such a capability.

The testbed concept is based on a mockup of a space flight operations control center suitable for experimenting with physical, procedural, software, hardware, and psychological aspects of space flight operations. The testbed would allow researchers to investigate new human performance and operations techniques using a variety of simulated missions, vehicles, flight anomalies, human controller scenarios, and range operations. With this approach, researchers will simulate experimental operations concepts and analyze alternate approaches to system design to better understand human factors and performance issues. As a result, future designers will be able to produce more effective information and decision support systems for launch, range, and flight operations. The ultimate outcome of this project could be replacement of today's space flight procedures and systems with intelligent systems that are highly responsive, safe and can accommodate high flight rates and mixed fleet operations with fewer human controllers at much lower cost.

The Operations Testbed will also provide a framework in which research and operations organizations can work together to address practical problems associated with launch and range operations. The testbed concept includes a collaborative organizational element that will facilitate joint research projects among government, academia, and industry. As a pathfinder initiative, NASA's Ames Research Center is pursuing a collaborative approach with the Kennedy Space Center, academia, and industry to focus the unique resources of these communities on the creation of the Operations Testbed (see Figure 1). Ames' expertise in human centered computing technologies combined with launch and range operations expertise at Ken-

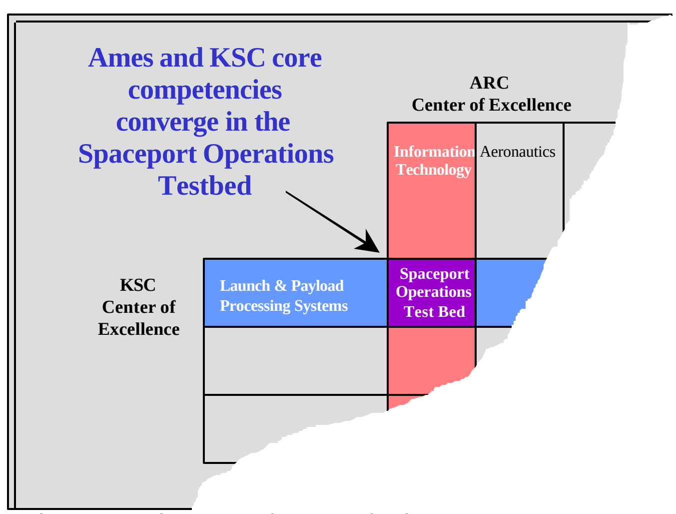

Figure 1. The operations testbed concept represents a common need for Ames and Kennedy missions.

nedy and commercial control center products from CCT form the technological core of the testbed concept.

OPERATIONS TESTBED CONCEPT

The Operations Testbed is full-scale virtual operations control center for simulating launch, range, and mission control scenarios. The facility will be capable of simulating a variety of missions, vehicles, flight anomalies, human controller scenarios, and globally dispersed range operations, allowing new information and human factors technologies to be tested and demonstrated in a variety of simulated ground control environments.

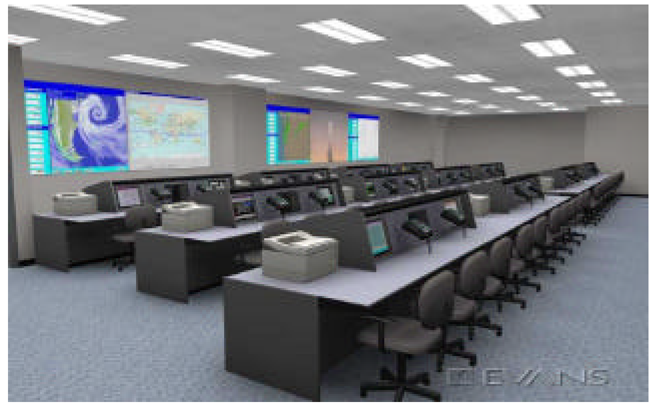

Figure 2. An operations control center mockup is the centerpiece of the testbed concept.

The Operations Testbed concept is comprised of facility and organizational elements. The facility element is a mockup of a space flight operations control center including reconfigurable computer hardware, electronic displays, communications, software, and furniture systems for simulating a wide variety of space transportation scenarios (see artist's concept in Figure 2). These human-centered systems would be designed to support experiments with physical, procedural, software, hardware, and psychological aspects of space flight operations. The function of the proposed facility is similar to that of NASA's FutureFlight Central facility[1] (Figure 3) which simulates airport operations from a virtual control tower.

Management of the facility and research would fall to an organization such as a "Spaceport Operations Research Center" that would manage testbed programs and processes for identifying, prioritizing, and funding research projects. The Center's primary mission would involve fostering collaboration between information technology and operations disciplines to solve multi-dimensional technology problems related to space operations. The collaboration should be manifested in the organization itself to ensure the expertise of each community is available and that the results are shared with designers of future space systems. This organization could support NASA's Advanced Technology Development Center.

Purpose

The objective of the Operations Testbed is to provide a facility for maturing new operational techniques and information technology that could reduce the cost of space transportation operations. Operations and research organizations will collaborate in the testbed to explore the operational issues associated with human performance, human factors and automation, human cognition and human perception in carrying out space flight missions. Research results should lead to more easily-operated information systems for future vehicles and spaceports.

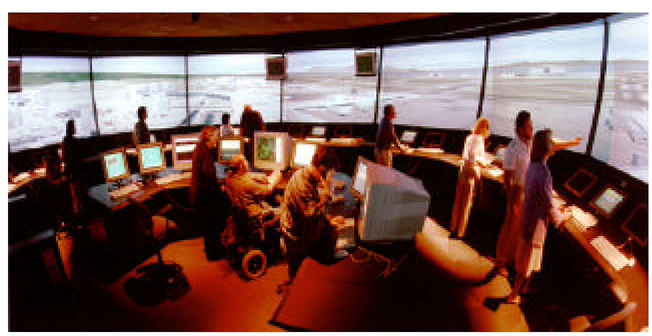

Figure 3. NASA's "FutureFlight Central" is a full-scale virtual airport control tower used to test solutions for potential air and ground traffic problems at commercial airports. The proposed Operations Testbed facility would be similar in function to Flight Central but with a focus on space operations rather than air operations. (image courtesy NASA)

In support of this objective, the testbed project will:

- Develop a space flight simulation facility suitable for experimenting with new human centered computing techniques to improve launch, payload, range, and mission operations.
- Establish a framework for collaborative research that includes space flight programs at NASA,DoD, academia, and industry.
- Influence design of future spaceport information systems to enable space flight operations cost reduction and safety improvement.

Benefits

The proposed testbed would provide opportunities for government and commercial space transportation operators to reduce costs and streamline operations by incorporating new operations concepts, range safety procedures, flight planning and execution processes, and other improvements into their operations. Potential payoffs include new methods for decreasing workload on space and air traffic controllers, distributing highly specialized launch preparation skills beyond the spaceport, and reducing the cost and labor required to recycle the Space Shuttle orbiter between flights.

New technologies associated with range operations, propellant management, spaceport command and control, process engineering, and communications could be explored at the facility. These demonstrations provide the ability to improve technical and economic performance before committing to operational 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.

In summary, the Operations Testbed would provide a facility for experimenting with new ground and operational concepts in a controlled environment. Beginning with increased dialogue between researchers and operators, the facility would nourish partnerships between industry, government and academia, leading to improved space flight operations and economic dividends across the industry.

Increasing Technology Maturity

The primary objective of the testbed is to increase operations and information technology maturity related to space transportation. The Operations Testbed concept is based on a series of technology development steps that, roughly paralleling NASA's "Technology Readiness Level" (TRL) scheme,[2] allows technology developers to incrementally progress from laboratory testing to hardware-in-the-loop prototype demonstrations (Figure 4 below).

As feasibility research matures to the (TRL) 4 stage, researchers are in need of a relevant test environment in which they can explore how their new techniques will work in application. This level of investigation can be enhanced with involvement of operations experts and operations models. The testbed allows laboratory techniques to gain exposure to such an operational environment and operations experts, facilitating a continued move up the TRL scale. It also allows operations system developers to review new techniques coming out of the laboratory, offering opportunities to influence further development and incorporate new techniques in future system development plans.

Commercial and government operators, who are constantly seeking methods to reduce costs and make their enterprises more efficient, typically have a development program at the TRL 6-9 stages. Their development projects are driven by operational requirements and safety and economic objectives. These development programs can often meet or exceed their objectives by incorporating the new methods created at research centers. The challenge is in matching the research results to the operational needs. The Operations Testbed forms the bridge between these communities, facilitating technology maturity from TRL 5 (laboratory validation complete) to TRL 7 (prototype demonstration complete).

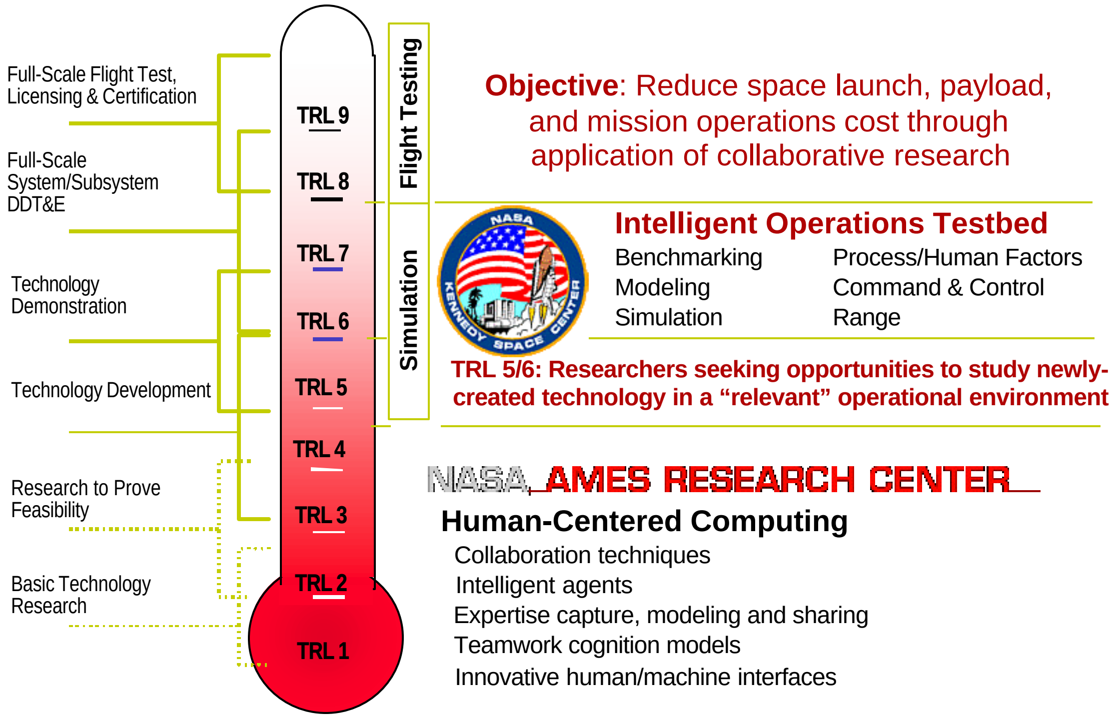

Figure 4. Maturing lab-based research eventually requires additional development in a relevant environment. At TRL 5, this level of research is a vital component of operational NASA centers like KSC. The Operations Testbed will facilitate technology maturation and extraction of research requirements from operational objectives, serving as a two-way "bridge" between the lab and operations.

ARCHITECTURE

The testbed architectural concept is to integrate a virtual space operations facility with a generic capability to model and simulate the dynamic systems, vehicles, and environments found in the spaceport domain. These two architecture segments are integrated via a generic command and control framework that enables multiple operators and agents to interact for computing-centric operational experimentation. The simulation architecture of the testbed is illustrated in Figure 5.

Simulation Stages

The simulation capability for the Operations Testbed is provided in two stages, summarized in Figure 6. The first stage involves computer simulation of missing elements including generation of appropriate stimuli to the test article (TRL 5). 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.

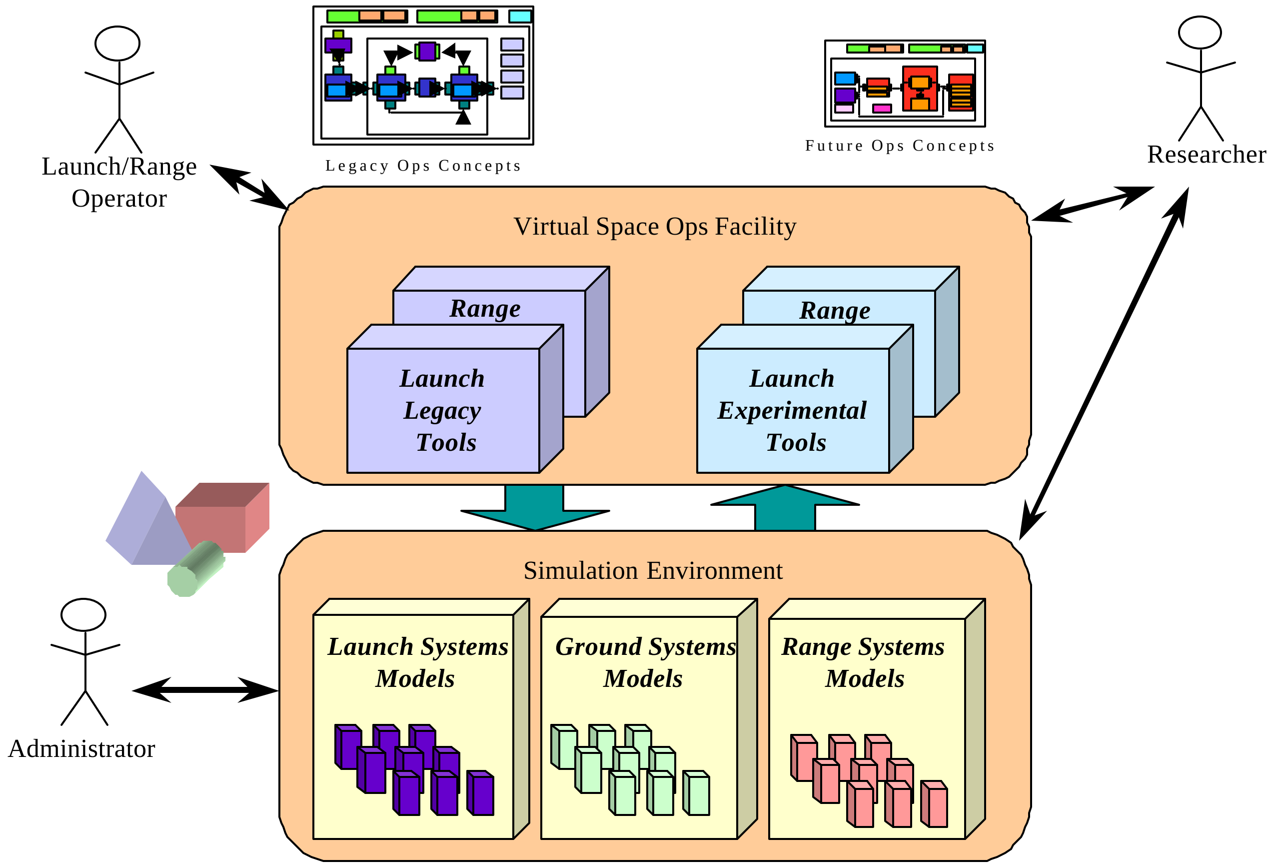

Figure 5. The proposed testbed architecture is based on a virtual space operations facility in which operations experiments are performed (top box) and a simulation environment (lower box) that drives the operations facility.

The second simulation stage (TRL 6) 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, 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. 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.

	Stage	Purpose	User
Simulation	**1.** Processor-in-the-loop (PILS) Simulation (TRL 5)	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 (TRL 6)	Simulation of flight conditions for prototype systems or subsystems	Ground and flight system developers that need to simulate flight conditions

Figure 6. Testbed Demonstration Stages.

Models

The simulation environment is a system of COTS software products and launch, ground, and range systems models hosted on laboratory workstation servers. A few example models are summarized below.

Weather Model

An aggregate weather model includes both atmospheric and solar weather data. The most challenging aspect of the weather model is correlating the different event time lines associated with these data sets. Traditionally solar weather has been collected and analyzed completely separate from atmospheric data.

Traffic Models

The Integrated Airspace model would include data from the airway system fused with launch vehicle data. It integrates standard air traffic data (i.e. flight plans, standard aircraft airways, control center boundaries, and special use airspace) with launch vehicle trajectory data. The Space Traffic model could contain the NORAD data of orbiting spacecraft and debris. This data is updated by NORAD on a scheduled basis and is available via their website. For prediction/simulation, these position data could be integrated within a graphical environment.

Flight Path Prediction Model

For research involving flight path planning (particular range safety research), the output of a flight path prediction model would be a nominal trajectory flight plan and potentially, some abort trajectory files. During flight, this model calculates the present position, determines potential abort trajectories and predicts the rest of the flight path. Sub-level models include vehicle aerodynamic and thrust models that characterize the vehicle and a composite force model that provides $\sum_{n=1}^{n} \vec{F}_n$ in mission planning and during real-time simulation, where the modeled forces include gravity, drag, J_x perturbations, weather, deployment impulses, and rendezvous impulses. The composite effect of the forces provides a much higher fidelity model than the individual effects models that are traditionally employed. This model could, for example, enable an intelligent computer agent to make safe and accurate decisions for range safety.

Range Instrument Model

New techniques for determining the "best" range tracking solution comprise an important research area. A range instrument model would facilitate tracking solution research by simulating ground-based, airborne, maritime and space-based range instruments. Instrument capabilities (e.g. sensor volumes and signal strengths) would be modeled relative to geographic obscura to decide the "best" instrument/system to be used. For example, this model could aggregate the best solution given the characteristics of the instrument, the quality of the data and the "validity" of the solution. A simulated space-based range could be developed to investigate how a constellation of flight tracking, surveillance, and weather satellites could support spaceports anywhere on the planet (see Figure 7).

Cognitive Process Model

Modeling and monitoring human performance metrics are key elements of testbed operations. Developing models for analyzing ground operators performance requires an in-depth understanding of the cognitive process performed by mission planners, safety analysts, and ground controllers. This includes their interaction with computers and software to perform trajectory analysis, safety analysis, and flight operations. The cognitive process model could serve as an inter-disciplinary agent for the other models.

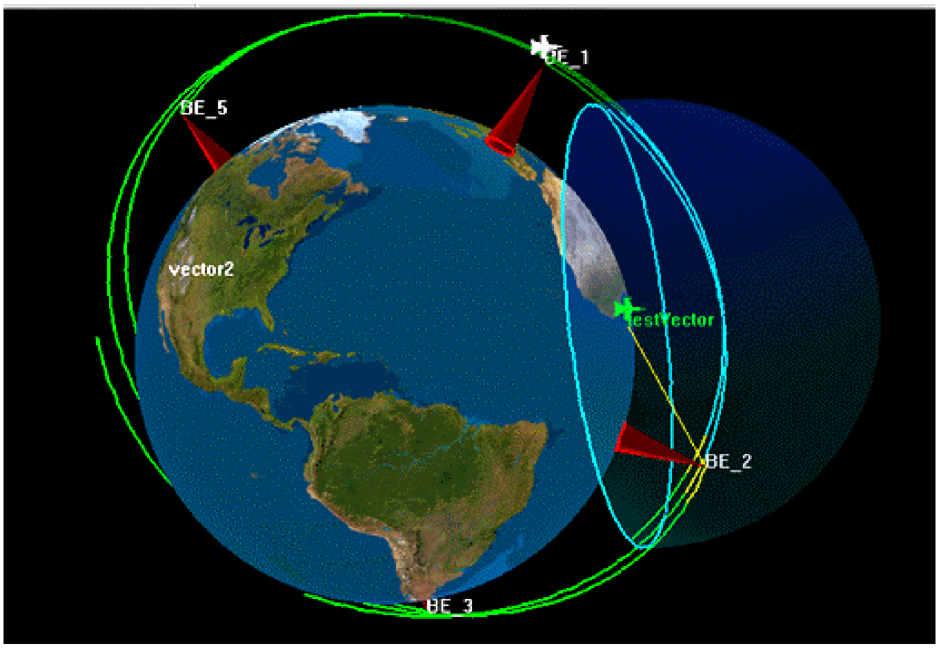

Figure 7. An illustration of a data visualization techniques for depicting on-orbit communication paths and sensor coverage areas for a notional space-based range.

Remote Access

The simulation facility would have extensive internet-based connections allowing the researcher 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 researchers 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.

TESTBED PROTOTYPE

An initial proof-of-concept project is underway to demonstrate the potential of using a testbed for researching human centered computing issues in spaceport and range operations. The prototype, known as the "pathfinder," demonstrates how the testbed can be used to explore concepts for new launch and range processes. The prototype will also help identify future testbed requirements.

The preliminary testbed will be demonstrated using commercial launch operations software and a series of launch and range operations simulations. The real-time command and control framework will process data and commands between simulation models and the HCI, record and analyze data for operations analysis, and provide an open application library and scripting automation for new research. Other key features include:

- Simulation and Modeling Tools - Spaceport and Vehicle End item modeling and scenario control
- Human Computer Interface - Multiuser operations for launch and range control
- Operations Tools - Process, Launch, & Range control

The demonstration will focus on features that will support a sustained research initiative into future human centered computing concepts in the launch and range domain. The demonstration objective is to communicate the intent of proposed follow on work to develop a fully operational testbed.

Demonstration development includes the following major tasks:

- Integration of tools for visualization and operations modeling that support test bed extensibility for a variety of research domains.
- Provide support for scenario control. A capability is being created to dynamically control and monitor operational scenarios via a user interface that allows investigators to select from a menu of scenario options that play nominal and non-nominal end item behaviors. A commercial simulation engine provides a means to create end-item simulation models that exhibit behaviors in response to defined stimulus constraints. The simulation engine also provides mechanisms to dynamically alter model stimulus. Scenario control will support a higher level of abstraction for simulation control that allows investigators to define entry points for scenario variation and invoke them dynamically at runtime.
- Visualization techniques for launch vehicle and ground systems operations. The pathfinder provides HCI tools that can be tailored or replaced to meet various research objectives. A broad range of visualization options will be explored and presented as part of the demonstration scenarios, including the RangeNet™ decision support software for demonstration of range safety functions shown in Figure 8.

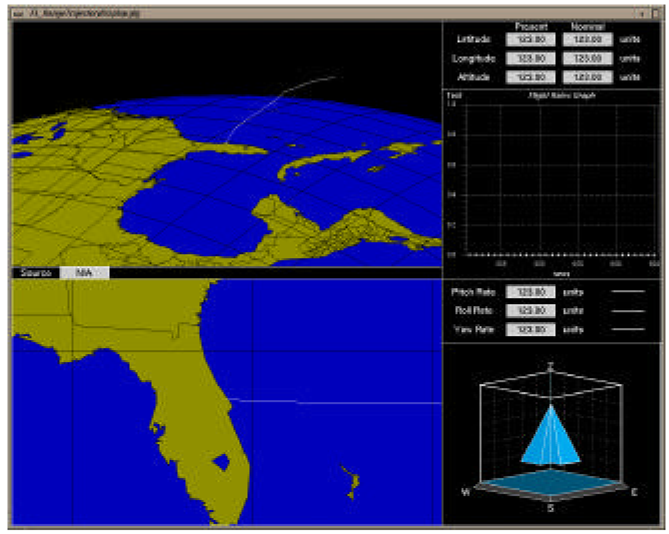

Figure 8. Today's state-of-the-art launch tracking and display programs offer virtually no flight path predictive information. With out this information, controllers must rely on their personal knowledge and training to remain continuously alert to respond to flight anomalies. This precludes a single human controller from managing more than one flight at a time.

- Demonstration scenario creation. In order to demonstrate the testbed capabilities, two realistic operational scenarios have been created: an RLV X-34 roundtrip mission from KSC and an ELV suborbital mission from Cape Canaveral Air Force Station. Both will explore spaceflight operations from pre-flight processing, flight execution, to post mission processing and analysis. The scenario simulation will provide mechanisms for role playing within the scenarios for range safety, launch controllers, mission planners, and flight and ground systems engineers will be supported. Scenario control tools will be used to vary mission parameters and events.
- Investigate integration with DARWIN to provide data mining capabilities.

RESEARCH POTENTIAL

The testbed concept will facilitate operations research for flight, ground, regulatory, and other aspects of space operations. Selected examples are listed in Figure 9 and explained in more detail below.

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

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

Figure 9. Examples of programs and technologies suitable for demonstration at the Operations Testbed.

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 operations. 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 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.

The operations testbed could complement research performed by NASA, DoD, federal regulators, established launchers, ground systems companies, academia, and even specialized segments of the financial industry. Research projects like managing simulated flights of different vehicle types to explore how vehicle architectural characteristics affect human performance, or investigating techniques for determining range readiness, flight safety, and flight termination/abort scenarios, could be performed in a variety of configurations in the testbed. The table shown in Figure 10 describes a few other examples of how the operations testbed could be used to explore new applications of information technology to space flight.

Problem	Objective	Methods
RLV Air Traffic Management Human/Computer Interface		
Space flight increases workload on air traffic controllers	■ Determine optimum decision support presentation methods ■ Reduce special use airspace	■ Benchmark conventional sector control ■ Examine new methods for reducing workload
Payload Operations Expert Advisor		
Shuttle payload certification requires specialized skills that are not widely available.	■ Automate capture of payload test and certification skills	■ Evaluate agent capture options ■ Capture test set knowledge ■ Evaluate effectiveness for novice operators
Half-Size Firing Room		
Shuttle orbiter turnaround is labor intensive, time consuming, and complex to coordinate	■ Apply new automation techniques to reduce launch operations staff	■ Analyze existing systems and approaches ■ Synthesize and demonstrate concept for smaller staff operations ■ Simulate a shuttle countdown (OMI S0007) from six consoles
Orbiter Turnaround Operations Concepts		
Orbiter turnaround hinges on the linkage of complex procedures between the OPF and LCC.	■ Create a localized Orbiter turnaround environment that can act as a testbed for exploring new turnaround operations concepts in a realistic setting	■ Explore command, control, and monitoring functions for a balance between on-board vs. ground control ■ Validate concept in Shuttle Avionics Integration Lab (SAIL)

Figure 10. Examples of how the operations testbed could be used to explore new applications of IT to space flight.

Launch Range Safety

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."[3] Maintaining quick access to space is a critical aspect of national security; reducing its cost is just as critical as more assets require space access. For example, one of the cost drivers of today's range operations is the proliferation of mission, vehicle, weather and other computer-based models. Most of these models are not integrated, requiring repeated manual selection, execution, and analysis of models appropriate for each mission profile. The Operations Testbed could help in defining a decision support architecture that integrates all necessary range models.

The proposed Operations Testbed 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 Operations Testbed 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 Operations Testbed 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[4] and other initiatives to apply commercial space capability to military applications.

Federal Regulatory Agencies

The U.S. Department of Transportation has established a spaceport launch licensing mechanism that provides flexibility to spaceport launch operations while ensuring the safety of the surrounding personnel and property. The testbed would be an ideal facility for collecting specific performance data in standard formats for inclusion in launch application packages.[5]

The FAA has identified several emerging technologies[6] 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 Operations Testbed. 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.

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 Operations Testbed 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.

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 Operations Testbed concept fulfills this critical national requirement. In fact, a relationship between investors and the Operations Testbed could take any of a number of forms to open up unprecedented opportunities in the fledgling space entrepreneur community. Perhaps most importantly, the Operations Testbed offers the investor an opportunity to learn more about the space industry.

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.

Universities and Academic Research

The Operations Testbed 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[7] and the Florida Space Research Institute[8] would find ideal proving grounds at the Operations Testbed for new technologies devised by their researchers.

There would also be an educational element to Operations Testbed operation. While established operational launch operators are unlikely to involve large numbers of students in their day-to-day operations, the Operations Testbed 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.[9] The FSI is the obvious choice for playing a leading role in this area for the Operations Testbed.

POTENTIAL CONTRIBUTORS

At the March 16, 1999 U.S. Chamber of Commerce Forum on the Future Development of Space, the NASA administrator 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 Operations Testbed:

> *"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."*

Ames Research Center

Ames' Intelligent Systems program initiated the Operations Testbed project in 2001 in response to a CCT proposal for an Intelligent Launch and Range Operations Testbed. The initial phase of the project led to creation of the "pathfinder" prototype that has been demonstrated to several NASA audiences, the U.S. Air Force, and space companies.

Dr. Jorge Bardina and Dr. Mike Shafto are leading the pathfinder project. Their teams' expertise in human centered computing methods is essential to fulfill the testbed's potential for creating new operations concepts and technologies that substantially reduce operator workload while maintaining critical safety levels. Applications of intelligent agents and innovative human/machine interfaces could lead to new operations concepts that require far fewer personnel. New expertise-capturing and representation methods could help distribute critical operations skills to a wider domain, while new collaboration techniques under investigation at Ames could improve any operation involving multiple humans.

Kennedy Space Center

The Kennedy Space Center has been established as the nation's "Spaceport Technology Center" (STC) which is to provide technologies and processes to private business and government agencies who propose to build and operate spaceports and associated ranges.[10] Under KSC leadership, several range technology developmental projects are in work including space-based range safety demonstration using Tracking and Data Relay Satellite (TDRS), passive coherent location system and airborne

> **"KSC has a strong track record of teaming with others to apply ground operations expertise, unique facilities, and methodologies to support development of new technologies. This background makes KSC ideal to serve as the focal point for HEDS as an operational development and engineering testbed." –**
>
> Wilbur C. Trafton, (former) Associate Administrator for Space Flight
>
> *November 19, 1997 letter to NASA Center Directors.*

lightning launch commit criteria characterization. Technology development in key strategic areas for KSC shown in Figure 12 could make use of the Operations Testbed.

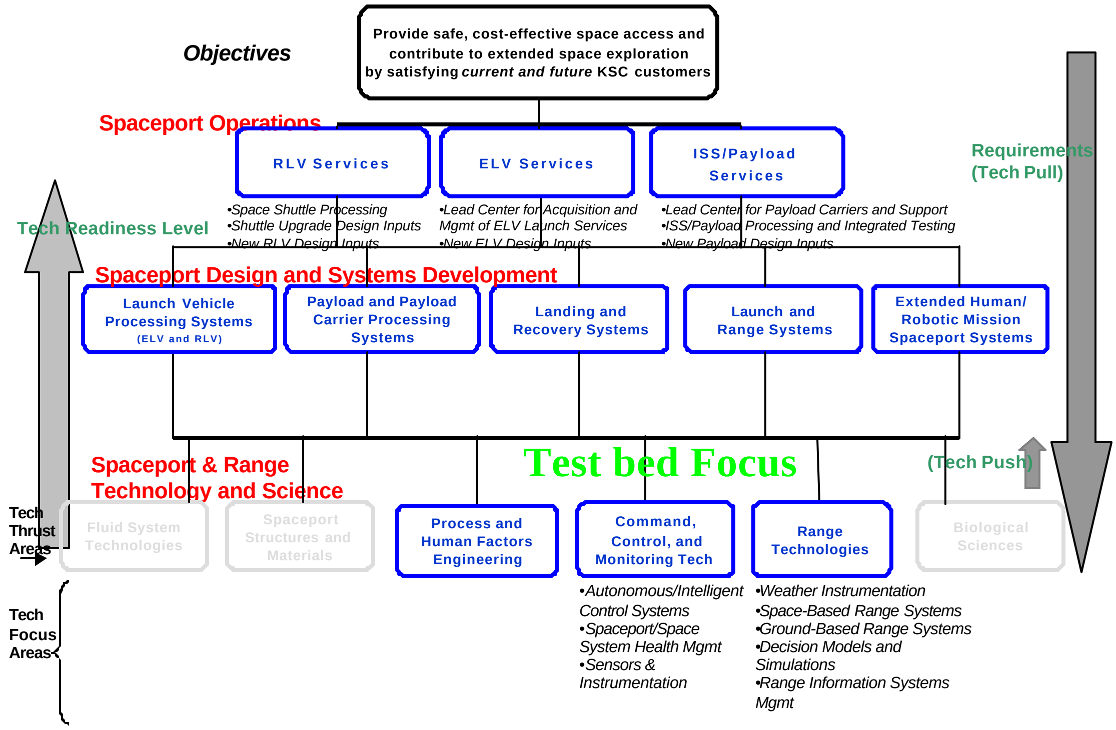

Figure 12. The testbed activities will focus on three key KSC technology development thrust areas: Process and human factors engineering; command, control and monitoring technology; and range technologies.

The center has also established the Advanced Technology Development Center (ATDC) to provide "world class" facilities for research and demonstration of spaceport technologies.[11] The Operations Testbed would provide the information technology component of ATDC with special emphasis on modeling, human factors, and automation techniques.

NASA-KSC could build on concepts developed by their Spaceport Technology Center staff to contribute new concepts and operations analysis to this project. NASA KSC could apply their experience in process engineering, command and control, and range technology development to investigate how new information technology techniques could be utilized to improve space flight operations. KSC could also provide domain expertise in the areas of range operations, telemetry, data acquisition, and instrumentation.

Wallops Flight Facility

WFF is currently building a knowledge model of their mission manager's planning activities and their safety expert's planning, and real-time, decision elements under the Advanced Range Technology Initiative (ARTI). Additionally, ARTI is planning related human/computer interaction analysis and visualization research that can be integrated with this project. This research could be applied to the Operations Testbed to establish methods for measuring human cognition and human/computer interaction levels for various operational scenarios. Mr. Jay Pittman, the Associate Manager of the WFF Real Time Software Engineering Branch, is the ARTI manager.

Command and Control Technologies

CCT and NASA jointly proposed the testbed concept in a published 1999 paper[5] with further clarification of the approach in a 2000 proposal to the Ames' Intelligent Systems program. CCT had made substantial progress in this field at the new Kodiak Launch Complex in Alaska and at Complex 20 for the Spaceport Florida Authority. At Kodiak, CCT created a unique spaceport control system that allows KLC to conduct single launches with a team of six range controllers. However, in designing and deploying the system, CCT recognized that traditional automation methods are insufficient to completely replace the human-oriented processes and culture in today's launch control and range safety operations. The HCC notion of designing human/computer systems by first investigating the cognitive and social processes of humans interacting with technology could provide the breakthrough needed in launch and range system design to support high flight rates with small ground crews. Capitalizing on potential breakthroughs such as this are the heart of commercial enterprise – the Operations Testbed could provide the infrastructure to support the necessary research.

Other companies with expertise in wireless communications, wearable computers, process engineering, and other relevant fields could also contribute to the testbed research infrastructure.

RELEVANCE AND SIGNIFICANCE

Intelligent launch and range operations technology is essential to achieving the twin goals of lowering staffing requirements for mission operations and increasing the capacity of our space transportation system. Every NASA mission requiring transportation to and through space will benefit from lower operations costs and more rapid and more frequent access to space that this technology will enable.

NASA's Space Launch Initiative (Second Generation RLV program) is focused on improving cost and safety by 2-3 orders of magnitude. NASA's analysis shows that the operations architecture holds the second-greatest life cycle cost savings potential (second to propulsion), with operations-focused design, informed maintenance, and other areas ranked as the highest operations payoff technologies.[12] Many of these technologies could be tested and analyzed in the Operations Testbed much more affordably than flight testing.

For the human exploration Enterprise, the Operations Testbed will lead to new capabilities that extend the capacities of ground controllers for human exploration missions. Computer-based agents are required to enable multi-mission operations for human space flights to distant points on earth, orbiting space stations, and planetary destinations, as well as to reduce the size and cost of ground crews. In addition, the need to leverage the cognitive capacity of the on-board crew will grow as the size of the ground control crew shrinks. New techniques pioneered by this research could be applied to in-space navigation, providing astronauts and future space-based traffic controllers with the needed tools to navigate spacecraft through an increasingly crowded near-earth environment. The new techniques could also lead to more autonomous control of life support systems and support combined human and robotic exploration teams through a better understanding of how humans interact with computerized control systems.

For the aerospace transportation technology Enterprise, this research will lead to a new generation of performance support systems that allow ground controllers to perform their functions in a new and much more efficient manner. No launch site or mission control center in the world can control more than one space flight at a time today. Innovative new methods for launch controllers to plan and control the route of launch vehicles through the National Airspace System and in-space are essential to permit multiple flights from a single spaceport. The results of our research may also find applications in the air traffic control system as the workload on controllers increases.

The research will contribute to several other related efforts in NASA and the FAA that are seeking ways to reduce mission staffing while handling more flights. NASA's Pathfinder Program is demonstrating advanced space transportation technologies to dramatically reduce the cost of access to space while defining the future of space transportation. The space traffic control concept driving this proposed research will be a key component of the future of space transportation.

The Operations and Range Technology (ORT) project associated with NASA's Advanced Space Transportation Plan (ASTP) must contribute to the ASTP third generation goal of $100 per pound of payload to orbit by 2025. Substantial range cost reductions are essential to meet this goal since range costs alone exceed this figure for most launches today. The proposed research could also contribute to demonstration of real-time vehicle tracking and best tracking solution computations, a central objective of the ORT project.

The proposed research is also highly relevant to NASA's X-Range effort (based at KSC) to improve range capacity through new technologies and decision models. The research will support the X-Range vision of a space-based range by creating techniques to consolidate ground based resources at the launch site and eliminate the need for downrange assets, as well as creating new launch decision support models that are based on improved computational capability. NASA's Advanced Range Technology Initiative (based at WFF) to identify, prototype and sponsor new and innovative technologies for the launch support environment will also benefit from this research. ARTI is developing a knowledge model of human-centered mission planning and safety activities, and plan to perform analysis of human computer interaction and visualization for range controllers. The proposed cognitive analysis task will complement this ARTI effort.

Finally, the proposed project is also highly relevant to on-going activities in other federal agencies. The results of our experiments will be of significant interest to the technologists associated with the Air Force range modernization program and the Federal Aviation Administration's commercial space transportation office. Both of these organizations are exploring methods for improving the capacity of U.S. launch ranges.

NEXT STEPS

With the Operations Testbed pathfinder complete, a new development plan is needed to chart the path to a fully operational testbed facility. An organization must be created in parallel to manage the research and development activities of the testbed.

It is also important to develop a concept for how the testbed could support NASA's ATDC. A close look at the ATDC development plans, the operations technologies focus of KSC, and the expertise available from Ames and industry need to be combined to formulate a more detailed development plan for ATDC and the testbed. An operations concept and detailed architecture definition for the testbed is also needed. New work is being planned in these areas for 2002.

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