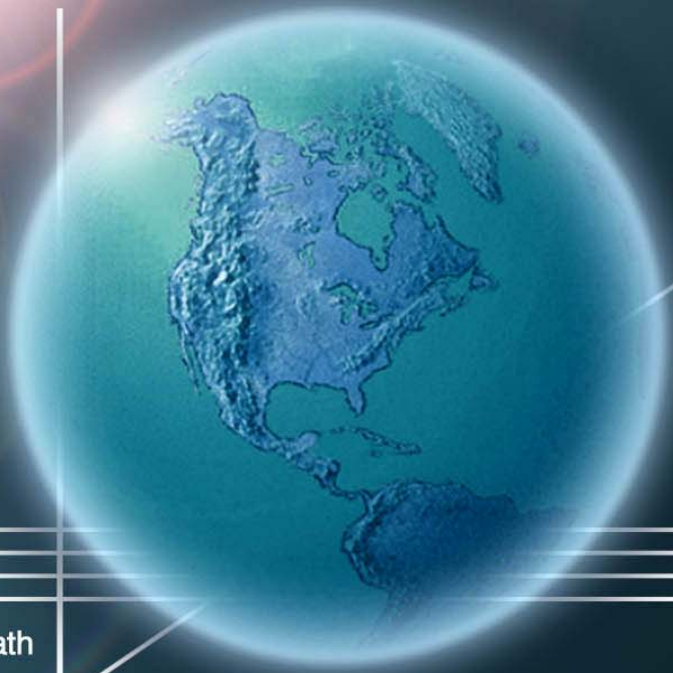
Appendices

ADVANCED SPACEPORT TECHNOLOGIES WORKING GROUP



BASELINE REPORT

November 2003

Charting America's Path Towards Low-Cost, Routine Access to Space

ASTWG

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Appendix A
General ASTWG Membership

U.S. Air Force
114th Range Flight
Edwards AFB
Los Angeles AFB
Patrick AFB
Tinker AFB
Vandenberg AFB
White Sands Missile Range

U.S. Navy
Naval Ordnance Test Unit
Naval Surface Warfare Center

NOAA
National Weather Service

NASA
Ames Research Center
Dryden Flight Research Center
Johnson Space Center
Kennedy Space Center
Marshall Space Flight Center
NASA Headquarters
Wallops Flight Facility

Federal Aviation Administration
Commercial Space Transportation
FAA Aerospace Weather Standards

Academia
Aerospace Development Center
Florida Space Research Institute
New Mexico Space Grant
University of Central Florida
University of Nebraska

States
Aerospace States Association
California Space Authority
Coalition of Spaceport States
Oklahoma Space Industry Development
Florida Space Authority

Industry

ACTA, Inc.
Advanced Technology Group
Aero Thermo Technology, Inc.
Aerospace Industries Association
Aim8 Product Development, Inc.
All Points Logistics
Analex
ASRC-Aerospace, KSC
ATK-ELKTON
BAE Systems
Boeing
Boeing Expendable Launch Systems
Boeing Homeland Security
Boeing SLRSC
Booz Allen Hamilton
CMC Electronics Cincinnati
Command & Control Tech Corp.
Computer Sciences Raytheon
Dynacs Engineering
ENSCO, Inc
Futron Corp.
Harris Corporation
Infoware Systems, Inc.
Institute for Defense Analyses
ITT Industries Systems Division
Knowledge Based Systems, Inc.
LJT & Associates
Lockheed Martin
Lockheed Martin Aerospace Atlas Launch Operations
Lockheed Martin Space
Lockheed Martin Space & Strategic Missiles
Loral Space Comm.
Morgan Research Corp.
North Consulting
Praxair, Inc.
Range Safety Operations, Inc.
Range Systems Design
Reliable System Services Corp.
Research Triangle Institute
Science Applications
Scitor Corp.
Sigmatech, Inc.
Spacelift Range System
SRI International
Swales Aerospace
The Aerospace Corporation
Titan Systems – OATG
TRW
TSI Telsys, Inc.
TYBRIN Corp.
United Paradyne, Corp.
Universal Technology Corporation
Veridian Systems
Wyle Laboratories
X Prize Foundation

Appendix B
Miniretreat Participants

(Technology & Commerce Development)

Technology Miniretreat – Flight and Payload Element Operations
March 10-14, 2003
Kennedy Space Center, Florida

Last Name	First Name	Company
Blanchard	Lyman	NASA
Brown	Kevin	Command Control Technologies
Cook	Bill	Veridian
Fussell	Ron	Boeing
Guidi	Cristina	NASA
Harris	Bill	ASRC Aerospace
Hernandez	Ed	Universal Technology Corporation
Hiatt	Janice	Research Triangle Institute
Huddleston	Tim	National Coalition of Spaceport States
Ingoldsby	Kevin	LMCO
Klock	Paul	VAFB
Kotnour	Tim	University of Central Florida
McCleskey	Carey	NASA
Merritt	Steve	LMCO – Atlas V
Roy	Bill	NASA
Ryberg	Steve	University of Nebraska
Schuling	Roelof	NASA
VanSuetendael	Rich	FAA
Nelson	William	Booz Allen Hamilton

Technology Miniretreat – Enabling Functions
April 14-16, 2003
Kennedy Space Center, Florida

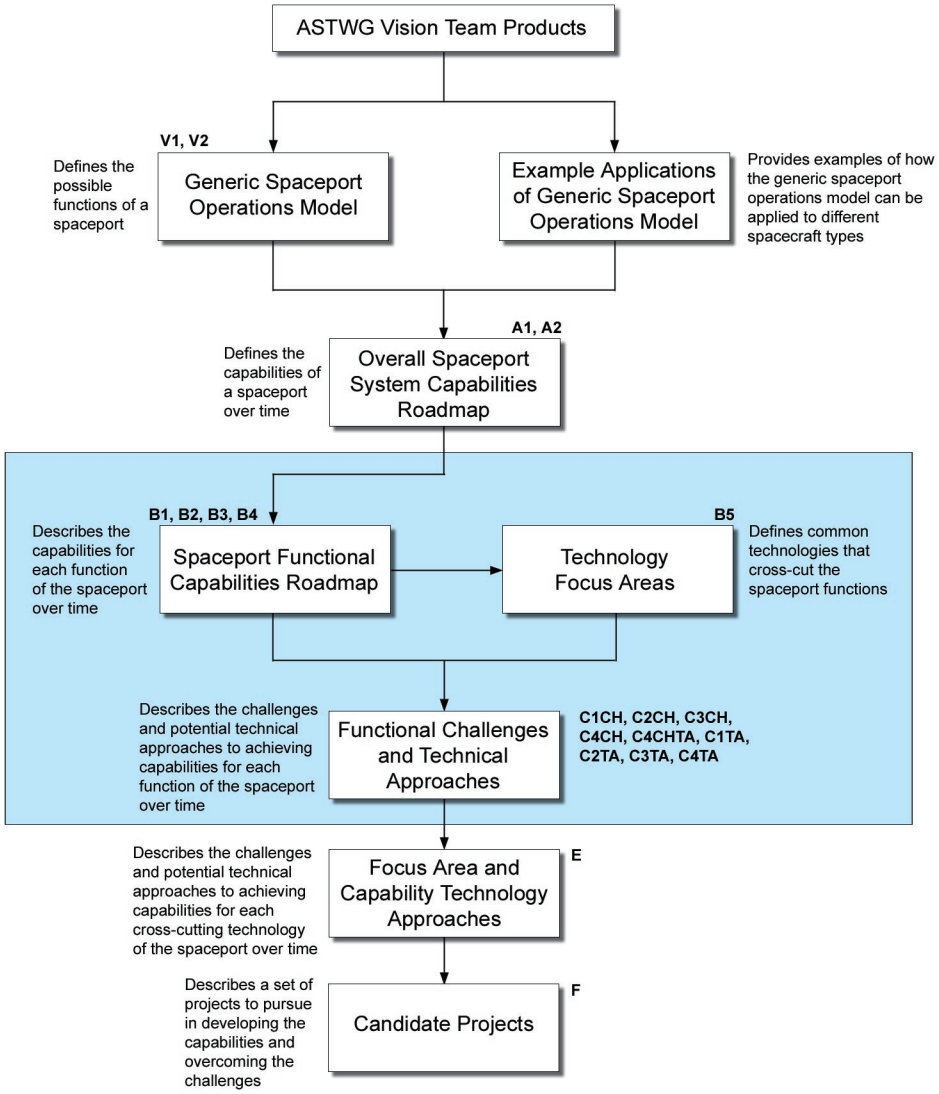
Last Name	First Name	Company
Cunningham	Bob	NASA
Fussell	Ron	Boeing
Guidi	Cristina	NASA
Harris	Bill	ASRC Aerospace
Hernandez	Ed	Universal Technology Corporation
Hiatt	Janice	Research Triangle Institute
Huddleston	Tim	National Coalition of Spaceport States
Ingoldsby	Kevin	LMCO
Kotnour	Tim	University of Central Florida
Littlefield	Maria	NASA
McCleskey	Carey	NASA
Merritt	Steve	LMCO – Atlas V
Schuling	Roelof	NASA
VanSuetendael	Rich	FAA

Commerce Development Miniretreat
August 12-13, 2003
Oklahoma City, Oklahoma

Last	First	Company
Eckert	Paul	Boeing
Edwards	Jay	Oklahoma Space Industry
Feige	Jeff	Aerospace States Association
Gomez	Louis	New Mexico Space Authority
Guidi	Cristina	NASA
Huddleston	Tim	Aerospace States Association
Ingoldsby	Kevin	Lockheed Martin
Kotnour	Tim	University of Central Florida
Lobmeyer	Dennis	Swales Aerospace
Ponik	Renee	NASA
Ryberg	Steve	University of Nebraska – Omaha
Teek	David	Florida Space Authority
Trimble	Paula	FAA-AST
Wells	Joel	NASA

Appendix C
Roadmap Legend/Process

Simplified ASTWG Technology Planning Process



Legend:

V1:	Generic Spaceport Operations Model	C2CH:	Payload Element Challenges
V2:	Plug & Play image	C2TA:	Payload Element Technical Approaches
B1:	Flight Element Capabilities Roadmap	C3CH:	Integrated Operations Challenges
B2:	Payload Element Capabilities Roadmap	C3TA:	Integrated Operations Technical Approaches
B3:	Integrated Operations Capabilities Roadmap	C4CH:	Enabling Functions Challenges
B4:	Spaceport Enabling Functions Capabilities Roadmap	C4TA:	Enabling Functions Technical Approaches
B5:	Technology Focus Areas	C4CHTA:	Enabling Functions Challenges/Technical Approach Combined
C1CH:	Flight Element Challenges	E:	Focus Area Capability and Technical Approaches
C1TA:	Flight Element Technical Approaches	F:	Candidate Projects

Appendix D
Overall Roadmaps and Definitions

A1 – High-Level Time Capabilities Roadmap

Function	Subfunctions	Baseline	Near (2003–2009)	Mid (2010–2016)	Far (2017–2028)	Ideal Characteristics
Flight Element Preflight Operations	Receive and Accept Flight Elements (A1)	• Days to weeks	• Days	• Hours	• Minutes to hours	**Service & Roll** Minimal servicing and/or routine, scheduled turnaround that replenishes consumables only and performs a power-up diagnostics test to quickly reveal faults and anomalies without user interaction.
	Assemble Flight Elements (B1)	• Days (ELV for stacking) • Weeks to months (SRB stack)	• Days	• Day	• Hours to day – noncritical path • No assembly for critical path	
	Service and Checkout Flight Elements (C1)	• Weeks to months	• Week	• Day	• Hours	
Payload Preflight Operations	Payload Element Receipt and Acceptance (A2)	• Week	• Days	• Day	• Hours	**Can & Ship** Containerized payload that is self-sufficient (does not rely on vehicle for its resources) and has standard interfaces for integration to the flight vehicle.
	Assemble Payload Elements (B2)	• Months	• Week	• Days	• 0 hours	
	Service and Checkout Payload Elements (C2)	• Varies based on mission (days to months for complex payloads)	• Balance the standard elements vs. unique (out-of-family) elements • Mission-standardized (days to months for complex payloads)	• Mission-standardized (hours to days)	• Within hours of flight	
Integrated Operations	Integrate Flight System and Payload (D) (Vehicle Perspective)	• Weeks	• Days	• Hours	• Minutes to hours	**Plug & Queue** Simple and standard interfaces that allow for self-aligning surfaces and autonomous and rapid integration of payload and flight vehicle.
	Integrate Flight System and Payload (D) (Payload Perspective)	• Weeks to days	• Days	• Hours	• Minutes to hour	
	Execute Departure Operations (E) (Vehicle Perspective)	• Week to days • 8 hours (ELV) • 4 days (Shuttle)	• Days	• Hours	• Minutes/on-demand	**Gas & Go** On-demand propellant servicing to the flight vehicle and/or payload and quick verification that vehicle is ready to fly.
Mission Operations	Monitor, Control, and Manage the Flight (F) (Vehicle Perspective)	• Lead time to support: 2 days for the range • Departure control set up in weeks	• Range turnaround in less than 1 day • Departure control set up in days	• Range turnaround in an hour • Departure control set up in a day	• Lead time to support: real time for the range • Departure control set up in hours	**Fly & Play** Flexible and responsive departure control and range support.
Postflight Operations	Land/Recover Flight Elements and Payload (G)	• 4 to 6 hours • 3 days • Several hours to 4 days (e.g., boosters) • Weather-dominated	• Hours • 95th-percentile weather-capable	• Hour • 99th-percentile weather-capable systems	• Minutes • All-weather capable systems • Time = get into "hangar" or "staging area" within 1 hour • Quick turnaround – decouple vehicle and payload within 1 hour	**Down & Off** Routine landing with self-safing systems and rapid removal from runway. Shortly after wheel stop the vehicle is immediately (minutes) transported to the next processing location.
	Prepare Flight Elements for Turnaround or Disposal (H1)	• Weeks (21 to 28 days between different Shuttles) — postflight analysis	• Days	• Day	• Hours	**Unload & Return (Flight Element)** Informed maintenance where status of vehicle is communicated to spaceport via power-up diagnostics test to quickly reveal faults and anomalies without user interaction.
	Restore Flight Element (I1)	• Years (SRBs: 18 months)	• Months	• Weeks	• Hours to days	
	Prepare Payload Elements for Turnaround or Disposal (H2)	• 3 days			• 1 day	**Unload & Return (Payload Element)** Rapid disconnect of modularized payload and rapid transfer to customer.
	Refurbish Payload Element (I2)	• Payload-dependent • 6 weeks for complex payloads			• Time = hours to enable the refurb/remfg of the element to take place	
Postflight Refurbishment	Restore/Reservice Ground Systems for Reuse (J)	• Weeks for MLP (7 to12 days at park site + 5 days at launch site)	• Days	• Hours	• Minutes	**Swab & Reload** Robust spaceport ground systems with informed maintenance where status of systems is communicated via power-up diagnostics test that quickly reveal faults and anomalies. Repairs and resets are remotely or autonomously performed without direct user interaction.

A2 – Spaceport Functions Capabilities Summary Roadmap

Function	Baseline	Near (2009)	Mid (2016)	Far (2028)
Spaceport Operations	• Vehicle-centric operations • Unique facilities for each architecture • Suboptimal integration with range • Range not standardized	• High flight rate of a single architecture • Standardization of vehicle and payload processing no matter where (e.g., next -generation EELV) • Standard set of systems (e.g., infrastructure, interfaces, vehicle, payload, SW)	• Multiple vehicles from common spaceport infrastructure • Minimal reconfiguration/modification to spaceport when vehicle changes • Operate multiple vehicles at different locations the same way (deliver payloads)	**Airportlike operations – High flight rate** • Plug & Play – seamless integration into spaceport • Standardized range and safety rules/regulations • Standardized infrastructure to support multiple vehicles and payloads • Integration into current air traffic control
Preflight Operations Flight Element Operations	**Time: Months** • Incremental disassembly, inspection, assembly, test • Time-consuming • Serial operations/processing • Overtesting • Redundancy – duplicate	**Time: Weeks** • Standardized environmental monitoring during transport • Standardized and paperless receipt acceptance • Standardized servicing ports (fluid and electrical • Implement standardized interfaces for each commodity/bulkhead for fluids and electrical connections	**Time: Days** • Standardized receiving process, ground support, and fixtures • Automated acceptance based on integrated health management in transport • Common standards between vehicle and spaceport • Automated fault isolation • Standardized and minimized servicing ports (fluid and electrical) – modular assembly	**Time: Hours** • Element arrives ready to roll for integration • No routine assembly completed at spaceport • Minimal turnaround servicing, requiring only replenishment of consumables • Self-diagnostics with autonomous repair
Preflight Operations Payload Element Operations	**Time: 1 month** "Custom Buildup" • Vehicle reconfiguration between flights – structural service kits • Extensive interface verification	**Time: Days** "Standard Payload Carrier" • Vehicle provides services (power, data, etc.) through standardized launch vehicle common interfaces • Interface verification testing required and common spaceport interfaces	**Time: Day** "Containerized Payloads" • Payload services are self-contained and transparent to launch vehicle • Requires payload structural/ mechanical accommodations intrusive to vehicle mold line	**Time: Minutes to hours** "Piggyback" • Self-sufficient – transparent to launch vehicle • Nonintrusive to vehicle mold line • Self-aligning, remotely actuated attachments for payload carrier mate
Integrated Operations	**Time: Months** • Too much time spent at departure point • External test equipment • Intrusive testing • Interfaces dependent on skilled labor • So many parts	**Time: Weeks** • Design common/universal lifting GSE • Standard interface documented for spaceport and spacecraft communication and umbilical and umbilical identification • Spaceport control software starts to be developed based on abstract interfaces	**Time: Days** • Robotic support for lifting and mate operations • Implement standardized interfaces for each commodity/bulkhead for fluids and electrical connections • Develop hardware interfaces that automatically recognize what it is connected to, configures to interface to operate the attached equipment or system	**Time: Minutes to hours** **Plug & Queue** • Maximize use of automation in integration and testing • Mechanical interfaces only, payloads self-contained in smart pods • Minimal facility/vehicle interfaces **Gas & Go** • Rapid on-demand propellant loading operations • Skeleton crew to perform the entire servicing and launch operation
Postflight Operations Flight Element & Payload Element Operations	**Time: Months** • Time- and labor-intensive safing ops • Intensive postflight inspection and disassembly • Significant recalibration of ground systems • Toxic fluids and handling • Extensive refurbishment of launch site equipment	**Time: Weeks** • Enhanced methods for remote sensing of vehicle for safety • Standardize required support services for recovery operations	**Time: Days** • Automated safing/reconfiguration of vehicle and payload	**Time: Hours** • Autonomous safing/reconfiguration • Universal support equipment for recovery • Autonomous and quick exit of landing area • Autonomous data archiving
Spaceport Logistics	• Manual kitting from paper lists • Too many unique tools • Manually scan item and manually download data into inventory	• Develop paperless integrated logistics systems • Standardize operations and repair manuals • Automatic tracking of inventory	• Automated and integrated paperless logistics systems • Universal tools • Automated collection and analysis of metric data • Autonomous tracking of inventory	• Automated paperless supply chain management integrated with equipment integrated health management • Autonomous asset tracking
Operations Planning & Mgmt	• Limited cost tracking • Budget and documentation databases not connected	• Collect data and input into actual cost model • Collect as-run schedule data from operations • Centralized data repository – integrate databases	• Automatic interactive scheduling of flight vehicle, ground support facilities, and support logistics • Standardized, online documentation (procedures, requirements, configuration management, etc.)	• Business systems and processes integrated into one data management system • Autonomous, adaptive, self-training scheduling system for flight vehicle, ground support facilities, and support infrastructure
Spaceport-Shared Services	• Configurations of comm infrastructure vary • Manual/labor-intensive security/surveillance • Partially integrated emergency services	• Enhance information/comm architecture • Enhanced surveillance and security operations • Integrated emergency services	• Integrated comm system linking several spaceports • Semiautonomous surveillance • Autonomous emergency detection and response system	• Global connectivity to spaceports • Autonomous surveillance • Microeconomy within spaceport

ASTWG Subfunction Definitions

ASTWG Function ID	ASTWG Function Title	ASTWG Function Description
A1	Receive and Accept Flight Elements	Functions that may be needed upon delivery of the flight element to the spaceport, such as from an external supplier or offsite depot (i.e., not routine arrival/recovery from space).
A2	Receive and Accept Payload Elements	Functions that may be needed upon delivery of the payload or cargo element to the spaceport, such as from an external supplier or offsite depot (i.e., not routine arrival/recovery from space).
B1	Assemble Flight Elements	Functions that may be needed to structurally assemble and mate components or segments of a flight element as received at the spaceport or launch area. Also transfers the assembled element to the flight vehicle integration point, if required.
B2	Assemble Payload Elements	Functions that may be needed at the spaceport to outfit and structurally assemble payload/cargo elements.
C1	Service and Checkout Flight Elements	Functions that may be needed to prepare serviceable fluid commodities/systems, mechanical components requiring preflight adjustment and calibration and electrical/electronic preflight preparations. Also includes functional verification through physical assembly.
C2	Service and Checkout Payload Elements	Functions that may be needed to prepare serviceable fluid commodities/systems, mechanical components requiring preflight adjustment and calibration and electrical/electronic preflight preparations. Also includes functional verification through physical assembly.
D	Integrate Flight System and Payload	Functions that may be needed to structurally mate the flight elements and the payload/cargo elements into an integrated launch vehicle and mate to ground support systems. Also transfers the mated vehicle to the launch point, if required by the concept.
E	Execute Departure Operations	Functions that may be needed to provide final preparation, servicing, and payload and/or crew ingress and to launch the flight vehicle into space. Also includes the postlaunch securing and refurbishment of the facilities and equipment at the launch point.
F	Control the Flight	Functions that may be needed to control mated vehicle flight, staged-element flight to space, and element return, if required. Does not include in-space transportation operations (i.e., “control the (space) mission”).
G	Land/Recover Flight/Payload Elements	Functions that include the arrival or return of a flight element and/or cargo/payload elements during the course of a spaceflight. The arrival may be its trip back from space, perhaps a boost or assist stage returning, or a return-to-launch-site abort.
H1	Prepare Flight Elements for Turnaround or Disposal	Postflight functions that may be needed to disassemble flight element segments for refurbishment/remanufacture (e.g., Hangar AF). Also includes planned removal of limited-life items and major components that may require offline preflight activities.
H2	Prepare Payload Elements for Turnaround or Disposal	Postflight functions that may be needed to disassemble cargo/payload element segments for restoration and refurbishment. Includes offload of experiments, removal of racks, breakdown of segments, etc.
I1	Restore/Remanufacture Flight Elements	Functions that may be needed to perform troubleshooting, repair, and replacement of failed or worn parts of flight vehicle elements. Includes element remanufacturing and off-manifest, phased maintenance actions, such as vehicle or vehicle elements.
I2	Restore/Remanufacture Payload Elements	Functions that may be needed to perform payload/cargo element repair and reconfiguration for next flight.
J	Restore/Reservice Ground Systems for Reuse	Functions that may be needed to restore ground systems.
K	Traffic Control and Safety	Functions necessary to monitor and control outbound and inbound space traffic and ground element movements within a spaceport and to protect the public and high-value assets during ground processing and spaceflight operations.
L	Spaceport Logistics	Functions that include shipping, receiving, and repair of flight line-replaceable parts and materials after removal from the vehicle or its ground support equipment. Also includes logistics support for acquisition and distribution of consumables and propellants.
M	Management of Spaceport Operations	Functions that may be necessary to support flight/ground systems processing. May include a variety of host services needed to plan, manage, and control the operation of the space transportation assets, as well as all elements of the supporting ground systems.
N	Spaceport-Provided Support Services	Indirect services or functions that may be needed in support of on-vehicle operations. These may include a variety of host services needed to support flight production.
O	Offline Maintenance, Repair, and Overhaul	Functions required to perform offline periodic inspections and checkout and upgrade of flight vehicles, ground support systems, and common spaceport infrastructure in accordance with a scheduled, phased maintenance plan.
P	Public and Community Support Services	Functions that may be needed to connect to and sustain the overall space transportation architecture and infrastructure.

Appendix E
Flight Element Operations Capabilities Roadmap, Challenges, and Technical Approaches

B1 – Flight Element Operations Capabilities Roadmap

Function	Subfunction	Baseline	Near (2003–2009)	Mid (2010–2016)	Far (2017–2028)	Ideal Characteristics
Flight Element Preflight Operations	Receive and Accept Flight Elements (A1)	• Days to weeks	• Days	• Hours	• Minutes to hours	**Service & Roll** Minimal servicing and/or routine, scheduled turnaround that replenishes consumables only and performs a power-up diagnostics test to quickly reveal faults and anomalies without user interaction.
		• Each shipment is unique – handle each differently • Come in after different times – some items sit and wait • Require preapproval for items (e.g., escorts) • Acceptance modes are weather-dependent (e.g., winds or sea conditions) • Availability of modes to carry (e.g., aircraft not owned or always available) • Special fixtures • Paper-intensive • Receive/unpack/inspect manually	• Standardized environmental monitoring of vehicle elements during transportation • Standardized receipt acceptance • Paperless system for receiving • All components/elements arrive together • Inventory performed electronically (e.g., barcode)	• Automated receipt acceptance • Standard receiving process, ground support, and fixtures • Acceptance based on go/no-go • Integrated health management for transportation • Standard fixtures • Automated accounting for piece-parts • Nonintrusive inspection of piece-parts	• Items show up ready to fly with needed monitoring and commodities in the smart pod container for flight element • Remove item from transporter only – ready for assembly/integration	
	Assemble Flight Elements (B1)	• Days (ELV for stacking) • Weeks to months (SRB stack)	• Days	• Day	• Hours to day for noncritical path • No assembly for critical path	
		• Significant amount of mission and vehicle-unique equipment • Incrementally and serially assemble • Hazardous operations • Spaceport = development + manufacturing + assembly center • Major structural assembly • Requires movement to multiple facilities • Interfaces are inconsistent across vehicles • Lifting operations required • Numerous subsystem/component installations at spaceport	• Design guidelines developed for flight vehicle providers to minimize spaceport integration • Standard interfaces between subassemblies • Standardized assembly procedures • Standardized and reduced manual operations • More integrated – preassembled subassemblies/assemblies • Automated/mechanized assembly	• First vehicle designed for routine spaceport access arrives (move to payload) • Unified development of common standards between vehicle and spaceport (e.g., two-stage to orbit) • Transition to next-generation ground assembly systems • Automatic verification of proper connection (mechanical and electrical) – "green light" – self-verifying interfaces • Foolproof connection/assembly (eg., clocking of connectors) • Items come together as a module	• No vehicle-unique ground equipment – standardized lifting/handling equipment • Minimal to no hazardous assembly operations • Single place of preparation • Concurrent operations – able to assemble more than one at a time (as required) • Comes nearly fully assembled with minimal assembly • Standard interfaces • Certification of subcomponents and streamlined approval process	
	Service and Checkout Flight Elements (C1)	• Weeks to months	• Week	• Day	• Hours	
		• Unique vehicles and elements • Legacy checkout systems, procedures, and equipment for each vehicle • Multilayered testing (test on the way in and on the way out) • Weather-dependent • Fragile and easily damaged hardware • Single-vendor suppliers for consumables and equipments • Impact other operations (e.g., loading fuel impacts other contractors and operations) • Multiple fuels/propellants/fluids • Hazardous operations – clears required • Redundant checkout – check the same thing many times • Incremental checkouts • Intrusive testing – assemble and test, disassemble	• Design guidelines for quick servicing at spaceports delivered to vehicle providers - Use common fluids; standard interfaces - Mold line interfaces • Use standardized service and checkout procedures • Full-system testing (functional) • Standard interfaces • Design common checkout and servicing equipment • Localized gas monitoring for toxic/hazardous fumes/leaks	• Separation of serviceable components from rest of spacecraft (quick assembly of fueled components at launch point) • Automated verification • Implement minimal interfaces • Mold line access for servicing of systems • Testing focuses on the more macro system (e.g., turn the key on the car) • Implement standardized testing and servicing equipment • Multiparameter monitoring for safe environment in servicing area • Centralize interfaces on the mold line of the vehicle	• Decoupling operations • Minimize toxic fluid usage • Maximize remote capabilities • Nonintrusive servicing and checkout • Autonomous testing, self-fault identification, and self-healing • Integrated health monitoring • Standardized and common checkout systems, procedures, and equipment for each vehicle (e.g., product lines) • Eliminate subsystem checking • Checkout is vehicle-controlled • Virtual-presence network monitoring for safe work environment	

Function	Subfunction	Baseline	Near (2003–2009)	Mid (2010–2016)	Far (2017–2028)	Ideal Characteristics
Integrated Operations	Integrate Flight System and Payload (D) (VEHICLE PERSPECTIVE)	• Days to weeks	• Days	• Hours	• Minutes to hours	**Plug & Queue** Simple and standard interfaces that allow for self-aligning surfaces and autonomous and rapid integration to payload.
		• Labor-intensive/hazardous due to lifts • Nonstandardized • Unique each mission • Unique facilities and infrastructure for program • Share limited resources (e.g., range, transportation), which may cause delays/scheduling conflicts • Conflicting requirements • Limited turnaround/reconfiguration of support systems • Use of pyrotechnic separation systems (hazardous ops) • Vehicle reconfiguration between flights for differing payloads • Vehicle provides all payload services • Extensive interface verification • Mechanical payload attachments provided by vehicle • Too many lifts and moves • Complex interfaces and multiple interfaces • Slow process for lifting operations • Visual spotting/positioning of elements • Interrupts other operations	• Enhanced sensing and alignment (e.g., laser or proximity) • Enhanced interfaces (mechanized and standardized) to reduce dependency on craftsmanship • Remote operations and sensing for mating activities • Define interfaces for each commodity	• Self-aligning elements • Robotic support for lifting/mating • Move away from lifts and suspended loads as a method of integration • Flexible orientation facilities and vehicles for integration • Self-guiding/positioning systems • Standard lifting equipment to support multiple vehicles • Universal GSE • Implement standardized interfaces for each commodity	• Share facilities – nonunique • Common, standard facilities • Concurrent operations and offline capabilities • Debrisless separation systems • Nonpyrotechnic separation systems • Automated and highly reliable cranes, lifting devices, air-bearing pallets • Minimal facility/vehicle interfaces • Payload systems are self-contained (no resources from spacecraft required) • Seamless integration of standardized cargo elements into the vehicle • Single set of umbilicals at base • Minimal ground system interfaces • Standardized interfaces	

Function	Subfunction	Baseline	Near (2003–2009)	Mid (2010–2016)	Far (2017–2028)	Ideal Characteristics
Integrated Operations	Execute Departure Operations (E) (VEHICLE PERSPECTIVE) (Close door, disconnect ground power supply, power up vehicle, terminal count, and launch.)	• Weeks to Days • 8 hours (ELV) • 4 days (Shuttle)	• Day	• Hours	• Minutes/on demand	**Gas & Go** On-demand propellant servicing to the flight vehicle and/or payload and quick verification that vehicle is ready to fly.
		• All-encompassing – entire spaceport involved for one vehicle • Do not have concurrent operations • Every departure is custom-designed (e.g., flight SW, orbit insertion, RTLS, weather) – parameters change every day – months to prepare flight plan • Flight plan amendment requires extensive approval • Need special-use airspace, etc. • A lot of interagency coordination • Weather-dependent • Dependent on reliable performance of GSE across many locations • Very labor-intensive – standing army/console operators • Last-minute analysis is custom-designed (e.g., debris patterns and weather, Ec) • All-or-nothing decision • Limited crew/payload escape – emergency egress • Vehicle-specific decision making for go/no-go (e.g., range assets) • Major safety and security issues (e.g., when on the pad and fueled, have limited access) • Vehicle-specific command and control systems – inflexible	• Ground-based, automated checkout and servicing utilizing universal interfaces • Minimize remove-before-flight items (identify how remaining ones could be removed) • Automated system diagnostics • Enhanced servicing process • Situational awareness during loading • Rapid mate/connecting umbilicals • Standardized command and control systems	• Continue to minimize remove-before-flight items • Spaceport traffic control integrated with air-space and space-space traffic control • Autonomous system diagnostics/monitoring • Minimal console operator support – dozens vs. hundreds • Standard servicing interfaces • Automated umbilicals • Shared responsibility between vehicle and spaceport for command and control	• On-demand propellant system • Onboard control of preflight checkout and servicing (minimal, automated ground support) • Move toward rapid and autonomous servicing – relate to Gas & Go concept • Expanded weather capability – weather is not a significant limiting factor • Minimize impact ground systems have on launch • Concurrent operations • Queuing system • Get in and out of line for launch easily – go to a queuing system • Spaceport manages access to shared resources • Standardized, simple, integrated decision process and tools • Flexible abort procedures (e.g., hot-abort on the runway, engine shutdown on pad) • Rapid propellant-loading operations • A few consoles with a few operators • Scheduled flight procedures • File a flight plan (e.g., like an airplane) (includes the COLAs) (seamless integration) • Departure traffic management seamlessly integrated with orbital insertion and beyond (e.g., mission planning and public safety) • Universal departure points (one size fits all) • Shared departure points (multiple users can use the same departure point) – based on business model • Little or no refurbishment of equipment • Highly reliable ground equipment • Eliminate last-minute vehicle test on the ground • Ground systems focus on verifying ground systems ready to go • Eliminate last-minute test and checkout on the vehicle • Passive/active noise abatement • Clearance established across multiple spaceports (flight plan) – integrated resources to support	

Function	Subfunction	Baseline	Near (2003–2009)	Mid (2010–2016)	Far (2017–2028)	Ideal Characteristics
Mission Operations	Monitor, Control, and Manage the Flight (F) (VEHICLE PERSPECTIVE)	• Lead-time to support: 2 days for the range • Departure control setup in weeks (i.e., firing room/blockhouse)	• Range turnaround in less than 1 day • Departure control setup in days	• Range turnaround in an hour • Departure control setup in a day	• Lead time to support: real time for the range • Departure control setup in hours	**Fly & Play** Flexible and responsive departure control and range support.
		• Vehicle-specific • Launch control is separate from mission control (e.g., JSC/KSC operations) • Launch vehicle ascent transitioned to mission control (e.g., JSC/KSC operations) • Limited flight control from the ground (e.g., ELV)	• Minimal ground-based mission control (flight control) • Integrated and coordinated with the National Airspace System and schedule	• Mission controlled from spacecraft • Controlled flight boxes/volumes/ paths • Vehicle-specific mission control is separate from but parallel with the coordinated traffic control	• Seamlessly integrated and coordinated with the national air and space system and schedule • Fleet operations • "Free flight" • Return-after-flight abort	
Flight Element Postflight Operations	Land / Recover Flight Elements and Payload (G)	• Several hours to 4 days (e.g., boosters) • Weather-dominated	• Hours • 95th-percentile weather-capable systems	• Hour • 99th-percentile weather-capable systems	• Minutes • All-weather-capable systems	**Down & Off** Routine landing with self-safing systems and rapid removal from runway.
		• Highly sensitive to weather • Time to get ready (always an emergency) • Around-the-world sites • Labor-intensive • Vehicle operations concept requires dedicated vehicle support equipment • Need to provide environmental and safety protections • Extensive time on runway • Long delay for clearance to approach vehicle after landing • SCAPE suit for approaching vehicle • Expendables with environmental impacts • Large space	• Broaden the environmental envelope for landing and recovery • More accurate weather predictions • Enhanced methods for remote sensing of vehicle for safety • Design guidelines for quick recovery, safing, and deservicing at spaceports delivered to vehicle providers • Use staging area that has no impact on flight operations	• Build ground recovery systems to support immediate and rapid recovery • Vehicle and payload health monitoring provides real-time status and is connected to spaceport response (receive during approach and landing) • Remote sensing of vehicle	• Get off run way "immediately" • Minimize vehicle-specific GSE • Minimize environmental/toxic impacts • Automated safing (vehicle) • Vehicle/payload perform self-safing reconfiguration • Universal support equipment for contingencies • Robotic (unmanned) towing vehicle to safing area (postflight)	
	Prepare Flight Elements for Turnaround or Disposal (H1)	• Weeks (21 to 28 days between different Shuttles) – postflight analysis	• Days	• Day	• Hours	**Unload & Return** Informed maintenance where status of vehicle is communicated to spaceport via power-up diagnostics test to quickly reveal faults and anomalies without user interaction.
		• Labor-intensive and time-consuming • Vehicle-unique equipment • Processing hazardous materials • Decontaminating of hazardous systems • Do for every vehicle and flight • Extensive disassembly and inspection	• Spacecraft designed for minimal postflight servicing/inspections • Minimal inspections planned • Work on "hot tanks" – no need for purge and inert • Smart, in-line analysis of commodities quality at the vehicle	• Maintenance data is combined with timed inspections for postflight servicing • Separation of serviceable components from rest of spacecraft (quick disassembly of fueled components) • Nonintrusive inspection of structures	• Informed maintenance – status of vehicle communicates to spaceport response • Regenerate sorties faster, minimal time • Noninvasive structural examination – "MRI" for vehicles	
	Restore Flight Element (I1)	• Years (SRBs 18 months)	• Months	• Weeks	• Hours-days	
		• Pull elements/components every launch/ flight • Heavy moisture entrapment • Drain and purge elements/tanks • Operational risk management (ORM) drives refurbishment activities – risk aversion • Fragile/unique nature of vehicle systems • Unique elements • Single, one-time-use elements on the vehicle • Hundreds of one-time use items that are removed and replaced each flight • We don't trust HW enough to leave alone between flights	• Eliminate routine disassembly of subsystems • Mitigate the need for disassembly for checkout • Work on "hot tanks" – no need for purge and inert • Collect data from system health to identify appropriate maintenance cycle (trend analysis for informed maintenance) • Service/checkout individual components while installed in vehicle (no disassembly or removal)	• Integrate health monitoring with logistics support to have replacement parts available • Implement informed maintenance – refurbish/restore based on health trend • Automated checkout of system • Frequency of depot-level maintenance decreases as vehicles become more reliable	• Risk management drives refurbishment – informed maintenance • Vehicles designed for operability • Periodic, routine maintenance based on health monitoring and conducted quickly and as needed • Major unplanned maintenance handled offline • Replenish consumables only • Autonomous testing, self-fault identification and self-healing systems	

C1CH – Subfunction Challenges: Flight Element Operations

	Servicing	Handling & Transportation	Assembly & Interfaces	Inspection & Checkout	Command, Control, and Monitor	Planning / Documentation	Analysis / Learning
Receive and Accept Flight Elements (A1)	• Need to purge and maintain environmental controls for active systems • Deservicing after receipt (e.g., draining antifreeze from lines) • Remove protective covers	• Requires special fixtures • Receive from all modes (air, rail, truck, barge) • Availability of modes to carry (e.g., aircraft not owned or always available to bring Atlas V) • Too much special GSE • Every element has a unique interface with GSE • Need to reposition vertically/ horizontally – special facilities to rotate canisters • Continuously reorienting elements • Different transportation modes/equipment for an element along the flow • Need to transport all during certain times (e.g., at night)	• Incrementally receive • Interfaces unique to transporter – need to close out multiple interfaces on the transporter • Need to maintain multiple interfaces	• Unique acceptance criteria for each • Inspection on each element is time-consuming • Unique equipment • Damages in shipping • Mostly visual and manual • Total system • Recomplete factory test at spaceports	• Environmental controls • Facility specific • Plug into environmental system and monitor • Element-unique monitoring equipment • Maintain whole logistics inventory	• Paper process • Documentation methods are hard copy, paper, slow, labor-intensive • Nonstandard approaches • Limited cross-checks	• Time-analyzing records of shipment for off-nominal conditions • Different data formats • Capturing lessons learned • Labor-intensive
Assemble Flight Elements (B1)	• Safety concerns • Lack of blowout capabilities • Too much servicing early in the process	• Requires multiple facilities • Different companies developing unique handling equipment • Special buildings and equipment – program-unique requirements • Moving of hazardous or radioactive elements • Share limited-range resources • Multiple facilities to move to – process-driven – multiple stages of integration across facilities for safety	• Major structural assembly • Requires movement to multiple facilities • Interfaces are inconsistent across vehicles • Slow, incremental approach to assembly • Assembled in multiple facilities • Large clean-room facilities • Impacts on other operations • Unique access requirements • Maintaining single orientation throughout processing • Safety concerns • Many pieces to assemble • Weather-dependent • Different interfaces for each vehicle • Difficult access and installation • Too many interfaces and connections	• Complete some test and checkout due to serially and inter-twined elements – subsystem/bench testing • Time-consuming • Unique equipment • Total system • Very intrusive • Hands-on • Paper trail is heavy • Specialized labor skills – quality assurance staff for this function • Weight of inspection equipment limits ability to place on and integrate with payloads	• Environmental controls • Facility-specific • Plug into environmental system and monitor • Element-unique monitoring equipment • Maintain whole quality assurance and documentation	• Quality sign-offs • Paper needs to move with items — paper trail • Work documentation system is manual and labor-intensive • Lengthy, numerous, conflicting checklists • Work instructions/ styles differ by author • Numerous approvals/ reapprovals • Real-time amendments are difficult • Diverse configuration control systems — weight/balance logs	• Time-analyzing records of shipment for off-nominal conditions • Different data formats • Difficult to capture lessons learned • Labor-intensive • Use processes that depend on craftsmanship of the worker

	Servicing	Handling & Transportation	Assembly & Interfaces	Inspection & Checkout	Command, Control, and Monitor	Planning / Documentation	Analysis / Learning
Service and Checkout Flight Elements **(C1)**	• Multiple fuels/ propellants/fluids • Hazardous operations • Highly trained crew • People in SCAPE suits • Clearing a large area • Impacts on others' operations • Waste stream generation • Numerous grades of same fluids (e.g., 5 grades of water for the Orbiter) • Commodities are kept onsite – own set of infrastructure to store and maintain • Need to certify hoses before use • Use manifolds, isolation valves, drainbacks	• Handling many toxic and hazardous commodities for hyperservicing • Highly trained crew • People in suits • Clearing a large area • Impacts on others' operations • Waste stream generation and handling • Numerous grades of same fluids (e.g., 5 grades of water for the Orbiter) • Commodities are kept onsite – own set of infrastructure to store and maintain • Need to certify hoses before use • Use manifolds, isolation valves, drainbacks • Many storage tanks • Cryogenic pumps • Unique SW – SW validation • Mobile truck fluids • Old systems • Procedures are not up to date • Overregulated within the fence – normalized operations off the Center	• Unique interfaces – vehicle-specific • Closeout of servicing ports • Leaks • Multiple, nonstandard connections/connectors • Preuse certifications • Loss of cryogenics • Gaining access to connections	• Redundant checkout – check the same thing many times • Incremental checkouts • Intrusive testing – assemble and test, disassemble • Unique HW and SW • Difficulty in updates • Limited access during and after fueling • Person controls • Human observation • Subject to error • Humans operating in a very hazardous environment	• Launch Processing System (LPS) • Using launch consoles for checkout and control • Mixed use of resources • Labor-intensive • Stove-piped to systems • HW and SW modifications are difficult • Convoluted systems • Non-real-time data reductions	• Labor-intensive • Subsystem-unique/ centric • Paper system does not capture configuration change information • Procedures have too many optional steps	• Time-analyzing records of shipment for off-nominal conditions • Different data formats • Capturing lessons learned • Labor-intensive
Integrate Flight System and Payload **(D)** (VEHICLE PERSPECTIVE)	• Contamination control • Maintain blanket purges	• Too many lifts and moves • Many lifts and hazards • Changing orientation • Breakover fixtures • Multiple cranes • Fragile packages • Environmental issues • Specialized equipment • Specialized, one-time-only training • 1-g limitations • Big pieces built in separate facilities and need to bring together • Costly ground support • Armed escort • Shared resources • Aging ground equipment	• Hook up and close out interfaces • Elevated umbilicals • Complex interfaces and multiple interfaces • Handling large pieces • Integrating fragile and delicate pieces – slow to do • Interfaces involve additional HW – bridging pieces • Special lifting fixtures and ground support • Risk aversion procedures • Upending or rotating vehicle • Happens on the pad • Too many umbilicals • Too many ground interfaces distributed up and down the vehicle • Use pyrotechnic separation	• Continuous checks • Manual operations • Too many are completed within the critical path – need to complete ahead of time • Too much is a retest – multiple subsystem test • Too many ground and range interfaces • Risk aversion approach • Weather-dependent	• Unique HW/SW • LPS • Using launch consoles for checkout and control • Mixed use of resources • Labor-intensive • Stove-piped to systems • HW and SW modifications are difficult • Convoluted systems • Non-real-time data reductions	• Multiple formats • Multiple sources • Paper-based • Every one is a custom job • Diversity of approvals for procedures and paperwork	• Conducting trend analysis • How many threads exposed to adjustable tip? • Determining out-of-family/out-of-spec issues – risk aversion

	Servicing	Handling & Transportation	Assembly & Interfaces	Inspection & Checkout	Command, Control, and Monitor	Planning / Documentation	Analysis / Learning
Execute Departure Operations **(E)** (VEHICLE PERSPECTIVE) (Close door, disconnect ground power supply, power up vehicle, terminal count, and launch.)	• Final fueling • Time-consuming: getting ready to do, doing, and topping off • Weather-dependent • Last-minute power requirements for last possible moment for vehicle • Volatile commodity top-off • Take up a lot of real estate	• Vehicle at most volatile and hazardous point • Large amount of structure around vehicle to be retracted and stowed • Last-minute handling • Army of support staff • Runway orientation • Need for rapid transfer to departure point and back for contingency • Vertically stacked element movement	• Final component installation – close out door • Crew sits for hours before takeoff • Flight crew systems • Battery activation – last minute – finite resources with limited life span • Final ordnance hookup • Range safety system activation • Number of interfaces and umbilical connections – each introduces potential for problem • Control hazards through brute-force methods (e.g., blast inert purges into cavities to prevent explosive-mixture combinations)	• Final Flight Termination System (FTS) checks • Countdown procedure = final checkout • Manual • People in danger for final inspection (e.g., red crews)	• Loading range safety code is manual • Large distributed team and equipment • Pseudoautomated process – direct touch • Risk aversion approach • Launch control scenario • Dozen control centers involved	• Long-term planning process • Lots of interactions for approval to launch • Mountain of paper • All paper is closed before go • Critical requirements documentation process is massive • Meeting everybody's requirements to fly – extensive analysis completed by committee • Flight plan development (e.g., trajectory) • Need a license to launch if nongovernment	• Recording and processing thousands of measurements and comparison to family and trends – manual • Information shared verbally over comm nets • Limited lessons learned • Training – numerous practice exercises to certify launch team for one flight – limited operational learning opportunities
Monitor, Control, and Manage the Flight **(F)** (VEHICLE PERSPECTIVE) (The transition from E to F is the commit to depart.)	• Airborne servicing in some concepts	• Too many lifts and moves • Many lifts and hazards • Changing orientation • Breakover fixtures • Multiple cranes • Fragile packages • Environmental issues • Specialized equipment • Specialized, one-time-only training • 1-g limitations • Big pieces built in separate facilities and need to bring together • Costly ground support • Armed escort • Shared resources • Aging ground equipment	• Multiple communication architecture paths • Distributed spaceport communications – network of spaceports communicating with each other • Cost of Tracking and Data Relay Satellite System (TDRSS) constellation (see ARTWG)	• Limited ability for onboard abort situation • Light and go (no coming back) – no ability to check in-flight and return if possible (ELV) • Limited onboard inspection (Shuttle)	• Limited ability for onboard abort situation • Light and go (no coming back) – no ability to check in-flight and return if possible (ELV) • Limited onboard inspection (Shuttle)	• All preplanned • Little real-time planning • Flight SW is custom-developed – long lead time to develop • Unique to each mission • Multiple-agency approval • Cumbersome alternative trajectory analysis	• Limited real-time analysis – large number of people and long time to process • Limited onboard data monitoring • Limited bandwidth
Land/ Recover Flight Element and Payload Elements **(G)** (VEHICLE PERSPECTIVE)	• Takes army to service the vehicle • Need for active safing systems while on the ground • Fear of hot tanking operations – risk aversion	• Vehicle operations concept requires dedicated vehicle support equipment • Takes an army to clear the vehicle • Vehicle is toxic and dangerous to handle – time delay • Crew cannot egress • Special equipment • Distance to travel • Sensitivity to FOD, weather, and wildlife	• Destowing time-critical items • Safing systems • Fragile items • Unique portable access equipment • Mobile interfaces to get to hangar • Different hangar interfaces	• A lot of runway inspections • Labor-intensive • Detailed walkaround • Hazardous operations • Landing systems deposit debris on landing area	• Hazardous gas detection • Handoff from mission control to firing room • Single-mission capability • Manual • Lengthy	• Big checklist • Can't change plan easily	• Mapping of Orbiter debris hits developed manually every flight • Manual crew debrief

	Servicing	Handling & Transportation	Assembly & Interfaces	Inspection & Checkout	Command, Control, and Monitor	Planning / Documentation	Analysis / Learning
Prepare Flight Elements for Turnaround or Disposal **(H1)**	• Processing hazardous materials • Decontaminating • Completed in special and separate facilities • Hazardous operations • Labor-intensive • Special equipment	**Vehicle** • Jack and level • Position access • Environmental support • Connect to ground support • Access the access points **Payload** • Sensitive cargo • Live cargo • Hazardous operations • Residual fluids – toxics • Attitude requirements • Shared resources • Unique methods for transport	**Vehicle** • Time-consuming to open up access points • Labor-intensive • Lots of systems to be removed • Many systems to document **Payload** • Lots of interfaces and connections • Diverse and specialized types	• Great use of nondestructive evaluation resources • Labor-intensive inspection • Determining what needs to be serviced • Documenting state of the systems • Checking the damage • Checkout and service entire vehicle • Manual mapping of damage reports	• Bring a lot of GSE to energize flight systems and reposition flight element components • Recalibrating elements on every flight • Power up entire flight system to checkout a single system • Complex scheduling system • Several separate groups involved	• A lot of documentation • Big checklist • Can't change plan easily • Diverse providers/ formats • Diverse system requirements	• Extensive postflight analysis recording quantities of residuals to feed back to systems owners • Manual process
Restore/ Remanu-facture Flight Element **(I1)** (SRBs – every flight, Orbiter – ~ every 5 flights.)	• Completed in special and separate facilities • Hazardous operations • Labor-intensive • Special equipment • Corrosion control	• Specialized handling equipment for each subsystem • Position access • Environmental support • Connect to ground support • Access the access points • Towing the vehicle to multiple facilities • Transportation of subsystem pieces for specific depot work • Different handling and shipping procedures	• Time-consuming to open/ close access points • Labor-intensive • Lots of systems to be removed • Many systems to document • By taking apart, may break things that weren't broken • Lots of interfaces and connections • Diverse and specialized types	• Intensive inspection and changeout • Determining what needs to be serviced • Documenting state of the systems • Checking the damage • Checkout and service entire vehicle • Manual mapping of damage reports • Determine electrical system integrity	• Bring a lot of GSE to energize system and reposition flight element components • Recalibrating elements • Power up entire flight system to check out a single system • Complex scheduling system	• Big checklist • Can't change plan easily • Diverse providers/ formats • Diverse system requirements	• Manual process
Restore/ Reservice Ground Systems for Reuse **(J)** (Pads, runways, GSE, MLP)	• Specialized tooling • Lubrication of mechanical systems • Determining what to repair (unplanned) • Performing routine maintenance • Repair/replacement of components (e.g., seals) • Contamination control • Drainback • Safety and environmental concerns • Commodity replenishment • Trucking commodities in	• Unique/customized handling • Specialized tooling • Aging infrastructure • Handling (transferring) SW between test systems • Costly transportation • Special equipment to transport odd-shaped items • Retaining operators' certification • Not predictable on what needs to be transported • Aging, expensive infrastructure • Need to move large pieces of facility to maintenance areas (e.g., MLP to park site)	• Destroyed during launch • Placing connection savers or covers – ensuring connectors don't get damaged • Restoring to a configuration	• Functional verification • Recertification • Calibrations • Introducing back into the supply system	• Maintaining environmental conditions	• Configuration control – recording rework and alterations made • Determining future needs to stage and configure equipment • Time-consuming to collect and manage detailed maintenance records • Aging systems requiring higher levels of maintenance	• Cumbersome to identify and track discrepancies with current documentation systems • Updating configuration • Updating performance metrics • Initiating corrective actions • "Tribal" knowledge • Stove-piped documentation systems

C1TA – Technical Approaches: Flight Element Operations

	Servicing	Handling & Transportation	Assembly & Interfaces	Inspection & Checkout	Command, Control, and Monitor	Planning / Documentation	Analysis / Learning
Receive and Accept Flight Elements (A1)	• Environmentally sealed elements • Element requirements for purging items • New designs to balance zero- and 1-g environments • Reduce the need for conditioning of lines	• Standardized interfaces • Ready-to-go vehicles • Standard all-weather containers • Horizontal processing capabilities • Standardize transportation modes/equipment throughout the flow • Robust, standardized class of all-weather transporters that provide complete environmental, vibration, and shock protection (e.g., inflatable airbags/containers) • Highly safe transporters	• Transport interfaces are the same for lifting • Use flight attach points for transportation attach points • Optimized attached points • Materials science	• Minimize need to validate and verify SW • Automated testing • Automated inspecting	• Automated tracking ("FedEx") • Automated environmental monitoring • Self-contained and test units • Smart shipping containers (pods) verify integrity and environment since factory acceptance testing – pod arrives, status is checked, and it is ready to install	• Creating a paperless system • Establishing common standard for documentation • "Turbo Tax" • Central repository • Shared information systems • "FedEx" tracking • Multiple access points	• Monitoring in transporter/ automated, real-time analysis • Complete analysis only if there is an off-nominal event • Intelligent analysis • Archive and provide easy access • Trend analysis • Data warehousing
Assemble Flight Elements (B1)	• Modular line units • Move servicing to Gas & Go • Standardized servicing approaches	• Minimize amount of handling • Items come ready to go • Elements do not require unique attitudes • Minimize need for clean room • SMART buildings • Multifunction buildings to limit the need for transportation • Colocation of functions • Standardized transports • Shared standard resources	• Industry-standard approaches for assembly equipment • Smarter designs that eliminate safety hazards and the need to reorientate • Minimize parts count • Modular line replaceable units • Automate, mechanize assembly • Weather- and atmospheric-independent operations to eliminate weather and environmental concerns • Minimize field assembly • Clamshell • Minimize interfaces • Standardized interfaces • Modular and self-verifying interfaces • Centralized interfaces • Easy-access interfaces – equipment bay or mold line • Wireless interfaces	• Minimize need to validate and verify SW • Automated testing • Automated inspecting • Intelligent analysis • Self-verifying, modular interfaces • Integrated health monitoring • MEMS • Nanotechnology	• Automated tracking ("FedEx") • Automated environmental monitoring • Self-contained and test units	• Automated work instructions • Automated check-offs • Standardized format • Paperless work instruction systems • Voice interfaces • Heads-up displays • Human factors analysis • Precertified elements combined with Plug & Play	• Automated, real-time analysis • Complete analysis only if there is an off-nominal event • Intelligent analysis • Archive and provide easy access • Trend analysis • Data warehousing/ archiving • Use generic, smart approach
Service and Checkout Flight Elements (C1)	• Minimize breaking the systems • Automate fluid transfer • New techniques for fluid handling • Robotic fluid transfer • Materials for handling hazardous fluids • Keep lines hot to the vehicle • Push the servicing down the process – just before the launch	• Minimize breaking the systems • Automate fluid transfer • New techniques for fluid handling • Robotic fluid transfer • Materials for handling hazardous fluids • Keep lines hot to the vehicle • Push the servicing down the process – just before the launch • Adopt commercial/industry standards within the fence – throughout the process for transportation	• Self-verifying systems • Move to later in the process • Smart standardized interfaces • Self-sealing quick disconnects • Self-clearing interfaces • Better-insulated fuel tanks • Automatic seals • Standardized access points	• Stereoscopic vision helmets – telepresence inspections • Heads-up displays for inspections and documentations • Nondestructive sensors • Automated and robotic • Integrated health management • Remote sensing	• Automated sensing techniques – remote sensing • Integrated monitoring systems • Advanced hazardous detection systems – tricorders • Spacecraft controls checkout and servicing • Tied in with integrated checkout and maintenance system	• Standard procedures across platforms • Automated implementation • Automated configuration management systems (hardware and procedures) • "Turbo Tax" for procedures – wizard-based	

	Servicing	Handling & Transportation	Assembly & Interfaces	Inspection & Checkout	Command, Control, and Monitor	Planning / Documentation	Analysis / Learning
Integrate Flight System and Payload **(D)** (VEHICLE PERSPECTIVE	• Advanced filtering • Eliminate need while mating elements • Eliminate fluid interfaces between elements • Self-contained flight elements – closed systems – only mating is structural	• Not to handle • Minimize handling • Erector set • Bring in on handling fixture • Factory-packaged for shipping, handling, assembly • Transporter doubles as breakover fixture • Minimize transport where share resources • Standardized transport modes • Minimal transport • Single facilities • Use commercial practices • Minimize institutional support	• Better sensors to tell when getting close and aligned • Minimize number of times to bring pieces together • Fewer connection points • Complete in easier orientation • Incorporate ground-protective shields as part of operation • Relocate process from critical path – perform integration off the critical path/choke point • Run utilities underground to the need point • Wireless • Nonpyrotechnic, debrisless separation techniques • Eliminate T-0 umbilicals – wireless	• Self-verifying • Fault-tolerant system • Integrated health management • Integrated and automated trend analysis • Risk management approach	• Automated sensing techniques – remote sensing • Integrated monitoring systems • Advanced hazardous detection systems – tricorders	• Paperless • Single format • Standardized processes, wizard-based • Automated plan generation and approval • Heads-up display of procedures • Electronic approvals	• Automated go/no-go criteria • Risk management • Data warehouse • Comprehensive health management • Automated, integrated trend analysis
Execute Departure Operations **(E)** (VEHICLE PERSPECTIVE) (Close door, disconnect ground power supply, power up vehicle, terminal count, and launch.)	• Minimize servicing required • Nonvolatile fuels • Advanced fluid system storage and transfer • Robust fluid systems for weather mitigation	• Wireless sensors • "Clean pad" and "clean runway" • Transport under own power to departure point (horizontal) • See Atlas V model • Transport erector/launcher – mobile launch pad (Russian model)	• Minimize to zero • Eliminate by design • Automated • Artificial vision • Use rechargeable batteries • Wireless • Self-healing seals • Sealing technology • Leak detection • Eliminate confined spaces • Eliminate potential leak sources	• Remote sensing • Remove need for closeout photos • Artificial vision and intelligence • Integrated health monitoring • Remote sensors • Onboard sensing • Perform checks earlier in the countdown • Tight configuration control and integrated health monitoring • Fault-tolerant systems	• Launch management scenario • Risk management approach • Centralized launch management • Automated handoff between launch and flight management • Transfer responsibility to crew or autonomous	• Paperless systems • Automated systems • Real-time data reduction, configuration control analysis • File a flight plan – see the FAA's AST con-ops • Risk management	• Automated, intelligent processing • Automated trend analysis – control center-oriented • Data warehousing and archive • Semantic networks and AI tools • Knowledge-based decision tools • Generic crew training • High-fidelity training models
Monitor, Control, and Manage the Flight (F) (VEHICLE PERSPECTIVE) (Transition from E to F is the commit to depart.)		• Established infrastructure – see ARTWG	• Comprehensive communication architecture • See ARTWG for communication architecture	• More robust onboard sensors and health management • Wider abort envelope	• Integrated with National Airspace System (NAS)	• Real-time replanning • Transfer to crew or intelligent autonomous system • Automated flight plan generation and analysis • Automated risk management	• Automatic data reduction • Reduce need for ground communication • "Pilot" in charge • Data compression techniques • Integrated health monitoring with logistics (planned pit stops, just-in-time logistics with integrated health monitoring) • Uplink to crew any important information

	Servicing	Handling & Transportation	Assembly & Interfaces	Inspection & Checkout	Command, Control, and Monitor	Planning / Documentation	Analysis / Learning
Land / Recover Flight Elements and Payload Elements **(G)**	• Self-safing vehicle systems • Self-inert vehicle systems • Mobile purging/safing/ environmental systems • Allow hot tanking operations • Clamshell operations • Provide an environmentally safe area • Standard interfaces	• Pull to a gate • Get to staging area under own power • Robotic towing • Reduce hazardous operations • Automated purging • Autocleaning runways/ auto-FOD detection	• Minimize time to get to gate/unload point • Instrumented tarmac • Wireless • Standardized interfaces	• Delay inspections until get to safe area • Robotic inspections • Advanced imaging systems – wire frame images – electronic imaging • Universal cameras • Holograms • Laser imaging (MRI) for vehicle	• Remote hazards detection (gas, temperatures) • Remote, automated command and control • Automated sequencing	• Automated checklist • Heads-up displays	• Integrated health monitoring from data dump from vehicle to beginning maintenance actions • Data warehousing • Automated data analysis • Automated debrief systems
Prepare Flight Elements for Turnaround or Disposal **(H1)**	• In-place deservicing • Modular deservicing	**Vehicle** • Use standard hangar/ facilities • Standard access points • Movable access platforms: eliminate jack and level; cargo, lift trailers **Payload** • Standardized containers • Clamshell • Self-sustained payload • Common, automated offloading equipment	• Phased inspections, periodic phased maintenance	• Integrated health monitoring • Phased inspection based on performance and real-time health monitoring • Robotic • Integrated logistics and maintenance systems	• Automated scheduling • Automated subsystem test • Integrated health monitoring • Higher-reliability vehicle	• Automated checklist • Heads-up displays • Paperless systems • Standardized documentation	• Automated • Integrated health monitoring • Data warehousing
Restore / Remanufcture Flight Element (I1)	• In-place deservicing • Modular deservicing	• Use standard hangar/ facilities • Standard access points • Movable access platforms: eliminate jack and level; cargo, lift trailers • Common handling and shipping containers/ fixtures	• Phased inspections, periodic phased maintenance	• Integrated health monitoring • Phased inspection based on performance and real-time health monitoring • Robotic • Integrated logistics and maintenance systems • Nondestructive testing • Better methods for inspecting wiring	• Automated scheduling • Automated subsystem test • Integrated health monitoring • Higher-reliability vehicle • Eliminate need for powered depot work	• Automated checklist • Heads-up displays • Paperless systems • Standardized documentation	• Automated • Integrated health monitoring • Data warehousing
Restore / Reservice Ground Systems for Reuse **(J)** (Pads, runways, GSE, MLP)	• Materials that minimize periodic maintenance (materials science) • Commodity production onsite • Onsite commodity distribution • Horizontal launch vehicles	• Standardized fixtures • Advanced storage facilities: vary the cleanliness and performance as needed • Use off-the-shelf tools • Standardized information systems – distributed information systems • Standardized cranes • Flexible platforms • Flexible transporters • Less expensive rail vs. crawler tracks	• Modular, standardized containerized system • Connector covers • Configuration control • Sacrificial interfaces • Horizontal launch vehicles • No T-0 umbilicals • Wireless interfaces • Retracting umbilicals to blastproof compartments	• Self-checking systems • Maintenance on demand		• Configuration control systems • Automated planning tools • “Turbo Tax” • Predictive maintenance approach	• Learning databases/ tools • Configuration management tools • Knowledge capture-based systems • Expert systems

Appendix F
Payload Element Operations Capabilities Roadmap, Challenges, and Technical Approaches

B2 – Payload Element Operations Capability Roadmap

Function	Subfunction	Baseline	Near (2003–2009)	Mid (2010–2016)	Far (2017–2028)	Ideal Characteristics
Payload Preflight Operations	Payload Element Receipt and Acceptance (A2)	• Week	• Days	• Day	• Hours	Can & Ship Containerized payload that is self-sufficient (does not rely on vehicle for its resources) and has standard interfaces for integration to the flight vehicle. Includes automated calibration and self-fault identification. • Reduced number of interfaces • Standard interfaces • Grouping and modularizing interfaces
		• Receive from manufacturer, universities, commercial researchers by various transportation methods (air, rail, ship, truck) • Manual process with cranes and pallets • Custom support equipment – build unique handlers/transportations • Payloads come in with hazardous items (e.g., hydrazine, radioisotopic thermal generators [RTGs]) • Unpack and repack to verify what was received – manual inspection • Assembly required – comes in pieces • Limited use of standard payload pods (e.g., spacehab) • All tasks funded by payload program – including infrastructure – widen roads, relocate power lines • Unique range safety and environmental reviews – time-consuming • Little or no feedback on improving process – application of lessons learned/ metrics (transportation, security, safety) • Certification process unique • Paper-intensive	• Enhanced inspection procedures and techniques (more efficient/fewer inspection points) • Continuous health monitoring throughout the life cycle (e.g., cleanliness, RF, EMI, EMC, load bearings, physical) • Encourage design convention for payloads • Smart pods (containers) developed and integrated with payload at spaceport • Range launch site – plans for typical infrastructure modification to support payload process flow (e.g., widen roads between airstrip landing area and payload facilities) • Range safety and environmental standards – reduced certification process • State-of-the-art support facilities: access platforms, clear rooms, RF/EMI, payload platforms, cranes, standard interfaces • Capability services – fee for service – competitive government/commercial • Process evaluated and briefed compared to acceptable metrics – improvement • Electronic accounting for piece-parts	• Minimal use of hazardous fluids (payload assumption) • Minimize use of custom HW/SW designs • Smart pods developed and marketed to payload providers; validate payload integrity and environment since factory acceptance testing. • Automated accounting for piece-parts • Standardized handling fixtures • Nonintrusive inspection of piece-parts	• Payload comes containerized with no/minimal hazardous items • Automated receipt and inspection • Items show up ready to fly with needed monitoring and commodities in the smart-pod container • Automated acceptance data package (e.g., barcode) and triggered work instruction development and resource scheduling	
	Assemble Payload Elements (B2)	• Months	• Weeks	• Days	• 0 hours	
		• Unique payloads – custom-built • Tailored/custom assembly process • Time-consuming, a lot of engineering, time to troubleshoot, fit checks, inspection of assembly and documentation • High degree of subassembly/component installation at spaceport • Combination of integrated system arrival (ELV) and final assembly completed at spaceport • Little or no feedback on improving process – application of lessons learned/metrics • Unique range safety and environmental reviews – time-consuming	• Standardized assembly process – modular into a payload carrier • More integrated – preassembled subassemblies and assemblies • Standardized interconnects at the experiment and mold line level • Design guidelines developed for payload providers to minimize spaceport integration – standardized launch vehicle interfaces and spaceport interfaces • State-of-the-art support facilities: access platforms, clean rooms, RF/EMI, standard interfaces • Reduce payload GSE needs at launch site – use remote testing from factory to reduce test equipment, fewer personnel required at launch site • Process evaluated and briefed compared to acceptable metrics – improvement	• Major systems arrive assembled • Reduced amount of customized assembly • First spacecraft designed for routine spaceport access arrives • Easy installation of payload into canister • Payload services/resource provided through canister mold line • Standard assembly fixtures	• 0% assembly at spaceport • Standard with adaptable/flexible canister lifting fixtures • Payload is already installed in container	

Function	Subfunction	Baseline	Near (2003–2009)	Mid (2010–2016)	Far (2017–2028)	Ideal Characteristics
Payload Preflight Operations	Service and Checkout Payload Elements (C2)	• Varies based on mission (days to months for complex payloads)	• Balance the standard elements vs. unique (out-of-family) elements • Mission standardized (days to months for complex payloads)	• Mission standardized (hours to days)	• Within hours of flight	
		• Specific, custom-developed payload-related servicing • Unique operations and checkout procedures established by manufacturing • Limited standard checkout equipment (e.g., Orbiter simulator) • Little or no feedback on improving process – application of lessons learned/metrics • Unique range safety and environmental reviews – time-consuming • Unique checkout equipment provided by payload customer • Extensive interface verification	• Common template for procedures • Common design for checkout equipment • Standard quick disconnects and electrical connectors • Standardized commodities and flow rates • Design guidelines for quick servicing at spaceports delivered to payload providers • Reduce payload GSE needs (e.g., reduce payload GSE at launch site) – use remote testing from factory to reduce test equipment, fewer personnel • Use standardized service and checkout • Reduce servicing requirements for components • Process evaluated and briefed compared to acceptable metrics – improvement procedures	• Script testing and servicing scenario • Common interface panel (fluid and electrical) • Centralized interfaces • Separation of serviceable components from rest of spacecraft (quick assembly of fueled components at launch point) • Automated verification • Remote testing capability	• Automated plug-in • Minimal servicing • Standardized connections at mold line • Container has go/no-go gauge to provide payload health information • Distributed, remote as needed • Automated test procedure generation • Flight verification at factory vs. onsite	
Integrated Operations	Integrate Flight System and Payload (D)	• Days	• Day	• Hours	• Hour	**Plug & Queue** The payload has standard interfaces that allow for self-aligning surfaces and autonomous and rapid integration to flight vehicle.
		• Payload becomes integral part of vehicle necessitating repositioning of vehicle fixed mechanisms for access • Movement of vehicle fixed mechanisms for checkout, repair, or servicing impinges upon payload access and operations • Excessive number of unique fluid, mechanical, and electrical interfaces between the flight vehicle and the payload requiring removal, installation, and functional verification • Payload and vehicle design dictates relatively early installation of payload in order to mate and test interfaces, close out payload bay, and then configure payload and vehicle for launch• Custom-designed • Slow, incremental, labor-intensive mating process (spotters for alignment) • Simultaneous mechanicals – put all payloads in at the same time • Electrical connections are incremental • Multiple attach points • Complete at multiple points (e.g., Shuttle – horizontal and vertical) • Little or no feedback on improving process – application of lessons learned/ metrics • Unique range safety and environmental reviews – time-consuming • Range meetings used to disseminate detailed mission status • Time-consuming	• Standardized attach points • Automated retention • Generic integration process • Process evaluated and briefed compared to acceptable metrics – improvement • Range/payload mission detail data status available to launch team in real time (security access issues resolved) – improved planning of shared resources • Vision system assistance for alignment and positioning • Simple (not labor-intensive) attach points/ closeouts	• Standard process for integration • Automatically handling system attaches and inspection • Self-aligning pieces • Self-guiding/positioning system	• Minimal integration • Plug & Play • Rapid mating/integration • Automated integration • Self-verifying interfaces • Autonomous troubleshooting and checkout • Drop container in macro Plug & Play system • Minimal integration • Rapid mating/integration • Automated integration • Payload systems are self-contained (no commodities/resources from spacecraft required) • Seamless integration of standardized cargo elements into the vehicle • Self-fault identification	

Function	Subfunction	Baseline	Near (2003–2009)	Mid (2010–2016)	Far (2017–2028)	Ideal Characteristics
Integrated Operations	Execute Departure Operations (E)	• Resource-limited • Infrastructure-limited • Process is owned by the range • Wheeling and dealing • Vehicle-centric • Providing energy to payload up to the last second – late-count servicing • Payload approved by range to fly • Unique range safety and environmental reviews – time-consuming	• Process owned by the vehicle operator – launch from North America requires government approval • Decouple payload from the range • Continuous monitoring of payload (not through the range) • Process evaluated and briefed compared to acceptable metrics – improvement – weather, security, delays/enhancements	• Decouple payload from vehicle – payload along for the ride • Continuous command and control of payload (not through the range)	• Process owned by the vehicle operator (next-generation space vehicle advanced engines) • Pull up and go • Countdown = 10 minutes and go • Concurrent operations – one operation clearance impacting another – concurrent hazardous operations • Flexible spaceport and range responsiveness to departure • Quick recovery	**Gas & Go** Autonomous command and control of payload.
Mission Operations	Manage/ Monitor Payload During the Flight (F)	• Customer-specific (program-specific) • Limited resources • Control rooms – large and multiple • Range collects data and passes it to customer support room • Little or no feedback on improving process – application of lessons learned/metrics • Evaluation of plan vs. actual	• Process owned by the payload operator • Data provided to customer's factory/ground station in real time • Decouple payload from the range • Continuous monitoring of payload (not through the vehicle) • Process evaluated and briefed compared to acceptable metrics – improvement – data distribution (accuracy/coverage) – helps reduce range data storage requirement	• Decouple payload from vehicle – payload along for the ride • Continuous command and control of payload (not through the vehicle)	• Fully automated and autonomous • 100% mission success • Spaceport provides infrastructure only to payload operators as required • In-flight data reduction • Seamless flight data analysis	**Fly & Play** Flexible and responsive departure control and range support.
Payload Postflight Operations	Land/Recover Flight and Payload Elements (G)	• 4 to 6 hours • 3 days			• Time = get into hangar or staging area within 1 hour • Quick turnaround – decouple vehicle and payload within 1 hour	**Down & Off** Shortly after wheel stop, the vehicle is immediately (minutes) transported to the next processing location. • Automated configuration safing/ archive • Hazard safing • Self-fault identification
		• Sits on runway until payload pieces are removed after vehicle downgrade • Manual; labor-intensive • Can't keep power on vehicle – no mobile power unit • Adapting GSE and platforms • Dependent on vehicle deconfiguration • Impact other vehicle operation functions – conflicts with operations • Equipment-intensive		• Ground control remote for payload safing/reconfiguration/data archive	• Land at choosing • Quickly move payload and vehicle out of landing area for safing – mobility off the runway • Minimal time to ensure payload is safe (e.g., toxics, radiology) • Minimize need for earlier access • Remove payload at the best time • Autonomous safing/reconfiguration • Autonomous data archive from payload operation/experiments • Self-sufficient payload • Automated disconnect and transport • Modularized payload carriers/canisters	
	Prepare Payload Elements for Turnaround or Disposal (H2) (e.g., spacelab/ logistics modules)	• 3 days			• 1 day	**Unload & Return** Rapid disconnect of modularized payload and rapid transfer to customer.
		• Payload accommodations turnaround and flight vehicle ops colocated – causes excessive ops constraints and interface	• Remotely operated data download and archiving	• Rapid download of payload data via port on canister • Modular deservicing	• Return to receiving location • Unplug and move to where needed next • Cargo and vehicle go separate ways • Minimum turnaround • Autonomous data archiving/download • In-place deservicing	

Function	Subfunction	Baseline	Near (2003–2009)	Mid (2010–2016)	Far (2017–2028)	Ideal Characteristics
Payload Postflight Operations	Refurbish Payload Element (I2)	• Payload-dependent • 6 weeks for complex payloads	•		• Time = hours to enable the refurb/remfg of the element to take place	
					• Customer/operator completes minimum amount of work onsite • Interchanging canisters • Open, take out, put new one in, close	
Postflight Refurbishment	Restore/ Reservice Ground Systems for Reuse (J)		•		•	**Swab & Reload** Robust spaceport ground systems with informed maintenance, where status of systems is communicated via power-up diagnostics tests that quickly reveal faults and anomalies. Repairs and retests are remotely or autonomously performed without direct user interaction.
		• See vehicle inputs • Many clean-room requirements (e.g., filters, drain and dry) • Tracking of environment when payload at facility • Throw away consumables every cycle • Need to reconfigure firing and control rooms for every cycle • Highly manual • Payload facility hardware – abandon in place • Little or no feedback on improving process – application of lessons learned/metrics	• Enhanced methods to clean hazardous equipment • Standardized firing and control room SW loads • Storage of high-cost payload GSE or sharing of equipment maintenance (cranes, payload platforms) if cost-effective/business-case • Real-time continuous monitoring of payload environment within clean rooms (alert system)	• No need to reconfigure – common HW/SW between control and firing rooms • Automatic reservicing • Automatic "scrubbing" of clean-room environment	• Continuously ready • Modifications/updates are software-centric • Self-restoring equipment • Quick turnaround – reconfigure facilities for next flight	

C2CH - Sub Function Challenges: Payload Element Operations

	Servicing	Handling & Transportation	Assembly & Interfaces	Inspection & Checkout	Command, Control, and Monitor	Plan/Document	Analysis/Learning
Payload Element Receipt and Acceptance (A2)	• Standard services • Tying different sources together (e.g., 50 vs. 60 Hz)	• Lack of standard approaches • Need to clean payload transporter before moving into controlled facility (i.e., clean room) • Expensive facilities for environmental and contamination control and monitoring • Securing facilities require lots of manpower and/or sophisticated security systems	• Lack of standards • Lack of a national interface control documents/ drawings for payload-to-spaceport interface	• Complex and lengthy inspection process • Each payload is unique – therefore need to retrain workforce for every mission • Lack of standards/ unified approach	• No "shipping" state-of-health data	• Infrastructure is owned by different agencies – impacts ability to develop unified plan • Preparing the ITAR is time-consuming and ill defined • Tracking free trade zone usage • No way to budget because no real-time tracking of actual costs • Extremely early submittal of program requirements document is required; however, this results in lack of clear, concise requirements and is a time-consuming process • Lack of integrated planning and resource scheduling (e.g., for hazardous payloads) • Lengthy safety review process for hazardous payloads (even to determine if hazardous) • Lack of nationalized payload safety criteria – subject to interpretations	• Lack of central repository of initial inspection data
Assemble Payload Elements (B2)		• Unique/customized handling increases procurement and training costs • Costly transportation because nonstandard container/interfaces • Clear under lifts	• Building subassemblies at the launch site vs. mfg. facility – want to build more of the subassemblies at the factory • Installation and checkout of payload test equipment (GSE) unique for each payload • Aligning the components is a manual process • Connector design is unique for each payload	• Need to complete the mfg at the launch site for an iterative verification at launch site – this is labor- and time-intensive • Buried or layered components results in retesting: testing on the way in and the way out without breaking • Human factors tend to be ignored	• Monitoring state of health during assembly is manual • Monitoring industrial safety • Running parallel operations with no collaborative situation awareness	• Verification that have the right components is manual • Inventory tracking and control is manual and distributed • Access to information about the payload is manual and distributed	• Takes time to learn (e.g., each payload is unique and the learning curve is steep) • One-shot deals leave no room for lessons learned
Service and Checkout Payload Elements (C2)	• Keep cryos cold • Loading hazardous commodities/ ordnances • Level of purity needed – multiple filtering for hydrazine • Contamination control • Incremental servicing – time-consuming and increases error probability	• Handling and transportation of hazardous commodities/ ordnances • Physically impossible to handle the equipment due to lack of design for interface • Difficult to setup and move access stands • Under clears – suspended loads	• Unique interfaces/no interface planned • Multiple subsystem interfaces (mechanical and electrical)	• Incremental checkout – time-consuming and labor-intensive	• Commanding the payload during the checkout is unique each time • Monitoring while performing servicing and checkout is a manual process	• Managing many checklists • Lengthy review and approval process • Configuration management and tracking • Ambiguous initial requirements result in: - Requirements creep - Late requirements - Late SW - Late changes - Forgetting requirements – "oops"	• Everything is treated as a unique operation • Catching and using lessons learned as they occur is subjective and manual

	Servicing	Handling & Transportation	Assembly & Interfaces	Inspection & Checkout	Command, Control, and Monitor	Plan/Document	Analysis/Learning
Integrate Flight System and Payload **(D)** (PAYLOAD PERSPECTIVE		• Lifting/mating is done in different orientations – alignment is manual • Unique vehicle interface for each payload • Using same resources across multiple users (e.g., cranes) results in resource/scheduling conflicts • Transporting hazardous materials • Multiple moves increase chance for error • Infrastructure does not support the transportation needs (e.g., moving payloads in vertical position) • Payloads are fragile/ not designed to be moved • Moves have to be controlled and monitored • Weather greatly impacts schedule for moves	• Customized equipment and carrier panels • Complex positioning and lowering • Aligning the pieces is manual • Closeouts and cover plates – put on many pieces • Nonstandard interfaces, unique to each vehicle and payload • Complex interfaces – too many bolts and connections • Too many different connections • Too many dangerous connections (ordnance) • Closeouts and cover plates – many pieces to put on and take off – need to inspect (test way in and test way out) • Connecting to ground support systems • Mechanically connect and then electrically test	• Too many inspection and checkout points • Time-consuming because mostly manual and iterative • Multiple manual and electrical interface verification tests • Gaining physical access once integrated to vehicle for checkout is necessary because many verifications are by eye; however, interface not designed for access	• Each mission/ vehicle has unique control system	• Lack of standardized documentation for all issues • Long-lead-time submittal requirements • Difficult methods to make changes to documents • Integrating requirements with other systems • Diverse responsibilities and organizations	• Verification data reduced after the fact • "Who is in charge?" model of operations
Execute Departure Operations **(E)** (PAYLOAD PERSPECTIVE)	• Final fueling and topping are hazardous operation and require contamination control • Need to condition lines for cryogenics before pump through – time-consuming and manual	• Potential move to final departure point	• A lot of T-0 umbilicals	• Restriction on data – bandwidth-limited	• Many people in the decision loop • Very limited by weather	• Integration of requirements between vehicle owner/operator and payload developer (launch commit criteria) • Modifications for flight data files – hard to get in last-minute changes	• "Who is in charge?" model of operations • Who notifies NORAD and other countries?
Monitor, Control, and Manage the Flight **(F)** (PAYLOAD PERSPECTIVE)	• n/a	• n/a	• n/a	• Making the deploy/ no-deploy decision and communicating the decision are manual and distributed across a variety of networks	• See range • See flight and mission control	• The data the payload operator wants/ needs is defined upfront due to limited bandwidth rather than in response to real-time situation • Getting the information to where they need it is not always feasible in real time because the cognizant decision maker may be "back at the factory"	• Data reduction is completed postmission

	Servicing	Handling & Transportation	Assembly & Interfaces	Inspection & Checkout	Command, Control, and Monitor	Plan/Document	Analysis/Learning
Land/ Recover Flight Elements and Payload Elements **(G)**	• May be hazardous operation • Nonroutine • Removing hazardous commodities/materials	• Transporting hazardous payload • Storing payload • Handling contaminated elements (e.g. leaking payloads) • Payload may be inaccessible • Transporting and disposing of hazardous materials	• Gaining access for safing may be difficult • Too many pieces – how much to disassemble to get out of the vehicle • Complex interfaces – too many bolts and connections • Too many different connections • Too many dangerous connections (ordnance) • Closeouts and cover plates – put many pieces on – need to inspect (test way in and test way out) • Connecting to ground support systems • Mechanically connect and then electrically test	• Hazardous inspection and safing may be nonstandard procedure	• Safing may be nonstandard procedure • Mechanical or physical safing systems • Weather-dependent • Monitoring contamination levels	• Inflexible system not able to handle changes – limited flexibility to adapt to real-time changes • Not always a planned activity	• Learn as you go
Prepare Payload Elements for Turnaround or Disposal **(H2)** (e.g., spacelab/ logistics modules))	• Deservicing is a hazardous operation • Nonroutine • Disposing of hazardous material • Environmental monitoring and control • Weather-dependent	• Lifting and transporting may be done in a contaminated environment • Using same resources across multiple users (e.g., cranes) • Resource/scheduling conflicts • Unique orientation needed for disassembly • Routine methodology may not be able to handle hazardous • May have hazardous or contaminated elements	• Unique methods and tools for disassembly • Breaking connections without breaking the connectors • Hard to gain access	• Hazardous • Time-consuming	• Monitoring of environmental and confined spaces is nonstandard • Hazard control and monitoring		• Determining and documenting the condition of the payload elements is manual and nonstandardized • If contaminated, can't gain access

	Servicing	Handling & Transportation	Assembly & Interfaces	Inspection & Checkout	Command, Control, and Monitor	Plan/Document	Analysis/Learning
Refurbish/ Remanufac-ture Payload Element **(I2)**	• Specialized tooling • Lubrication of mechanical systems • Determining what to repair (unplanned) • Performing routine maintenance to complete • Repair/replacement of components (e.g., seals)	• Costly handling tools • Unique/customized handling • Specialized tooling • Unique storage and packaging requirements • Costly transportation • Special equipment to transport odd-shaped items • Retaining operators' certification • Not predictable on what needs to be transported	• Placing connection savers or covers – ensuring connectors don't get damaged • Restoring to a configuration	• Functional verification • Recertification and calibrations for introducing back into the supply system	• Maintaining environmental conditions	• Configuration control – recording rework and alterations made • Determining future needs to stage equipment	• Manual documentation of discrepancies and no central repository • Updating configuration data – manual • Updating performance metrics – manual • Initiating corrective actions – manual • "Tribal" knowledge not captured

C2TA – Technical Approaches: Payload Operations

	Servicing	Handling & Transportation	Assembly & Interfaces	Inspection & Checkout	Command, Control, and Monitor	Plan/Document	Analysis/Learning
Payload Element Receipt and Acceptance (A2)	• Environmentally sealed payloads • Minimal purging required • Reduce the need for conditioning of lines	• Standardized interfaces • Arrives ready to integrate to standard transport vehicle and flight vehicle • Use standard all-weather container • Robust, standardized class of all-weather transporters that provides complete environmental, vibration, and shock protection (e.g., inflatable airbags/ containers)	• Transport interfaces are the same for lifting • A payload-to-spaceport interface control document is available	• Automated testing – self-contained end test units • Automated inspecting • Smart shipping containers verify integrity and environment since factory acceptance testing – container arrives with self-reporting status	• Automated environmental monitoring • Self-commanding for health	• Cafeteria plan for spaceport services is available for budget planning • Automated ITAR/free-trade-zone documentation • Streamlined/just-in-time requirements definition • Standardized/minimal safety review • Create a paperless system for defining and tracking requirements • Establishing common standard for documentation • Central repository • Shared information systems • "FedEx" tracking of payload location and status • Local and remote access to data and status	• Monitored data is automatically analyzed for fault detection and lessons learned (i.e., intelligent analysis) • Autoarchive with easy access/ retrieval • Data is integrated with trend analysis tools • "Turbo Tax" accounting begins
Assemble Payload Elements (B2)	• Move servicing to Gas & Go • Standardized servicing approaches	• Minimize amount of handling • Minimize need for unique clean room (i.e. design a multilevel clean room) • Smart buildings • Multifunction buildings to minimize transportation (e.g., storage and assembly in one building) • Standardized transport interfaces • Shared standard resources are tracked and scheduled dynamically	• Standardize payload interface to spaceport • Standardize and minimize assembly interfaces • Automate/mechanize any assembly • Weather- and atmospheric-independent operations to eliminate weather/ environmental concerns • Minimize field assembly • Modular and self-verifying interfaces • Easy-access interfaces – equipment bay or mold line • Wireless interfaces	• Automated testing • Automated inspecting • Intelligent analysis • Integrated health monitoring • Self-contained test units • Minimal "hands on" required	• Automated tracking ("FedEx") • Automated environmental monitoring • Integrated health monitoring • Autonomous command and control for response to anomalies encountered in state-of-health data • Real-time status of all parallel operations	• "FedEx" tracking of payload elements location and status • Automated (paperless) work instructions and associated signoff – (e.g., heads-up display) • Flight-certified elements come in to Plug & Play	• Data warehousing/ archiving in real time • Easy local and remote access to data • Ongoing intelligent analysis of data (trends, troubleshooting, recommendations, scheduling of assets, etc.)
Service and Checkout Payload Elements (C2)	• Automate fluid transfer • New techniques for fluid handling • Robotic servicing • Materials for handling hazardous fluids • Keep lines hot to the vehicle – no conditioning • Remote sensing for contaminants • Push the servicing down the process – just before the launch	• Standardize movement within the spaceport • Robotic handling	• Self-verifying systems • Smart standardized interfaces • Self-sealing quick disconnects • Self-clearing interfaces • Automatic seals • Standardized access points	• Stereoscopic vision helmets – telepresence inspections • Heads-up displays for inspections and documentations • Wireless sensors for inspection and state of health • Automated and robotic • Remote sensing	• Automated sensing techniques – remote sensing • Integrated monitoring systems • Advanced hazardous detection systems – tricorders • Payload controls checkout and servicing tied in with integrated checkout and maintenance system	• Automated/autonomous configuration management ("FedEx" tracking) • "Turbo Tax" for monitoring costs/ changes in requirements	

	Servicing	Handling & Transportation	Assembly & Interfaces	Inspection & Checkout	Command, Control, and Monitor	Plan/Document	Analysis/Learning
Integrate Flight System and Payload **(D)** (PAYLOAD PERSPECTIVE)	• Eliminate fluid interfaces between payload and vehicle • Self-contained payload – closed systems – only mating is structural	• Minimize handling • Erector set • Bring in on handling fixture • Factory-packaged for shipping, handling, assembly – only integrate • Minimize transport • Standardized transport modes • Single facility for all integration	• "Sensed" alignment (wireless technology) • Fewer connection points • Nonpyrotechnic, debrisless separation techniques • Eliminate T-0 umbilicals – wireless	• Self-verifying • Integrated health management • Risk management approach	• Automated sensing techniques – remote sensing • Integrated monitoring systems • Advanced hazardous detection systems – tricorders • Autonomous command and control for self-diagnosis and self-healing	• Automated plan generation and approval • Heads-up display of procedures • Electronic approvals • Standardized processes, wizard-based	• Data warehouse • Comprehensive health management • Automated, integrated trend analysis • Risk management intelligence
Execute Departure Operations **(E)** (PAYLOAD PERSPECTIVE)	• Minimize servicing required • Nonvolatile fuels • Advanced fluid system storage and transfer • Robust fluid systems for weather mitigation	• Integrate and fuel at, or as close to, departure point as possible	• Artificial vision • Minimize umbilicals • Use rechargeable batteries • Wireless sensing and commanding • Self-healing seals • Leak detection	• Remote sensing • Artificial vision and intelligence • Integrated health monitoring • Onboard wireless sensing	• Automated go/no-go criteria • Risk management approach • Knowledge-based decision tools	• File COMBO analysis and orbit insertion data similar to flight plan • Risk management	• Real-time data reduction, configuration control analysis • Automated, intelligent processing • Automated trend analysis – control center-oriented • Data warehousing and archive • Semantic networks and AI tools
Monitor, Control, and Manage the Flight **(F)** (PAYLOAD PERSPECTIVE)		• Established infrastructure – see link to range (ARTWG)	• Comprehensive communication architecture • See ARTWG for communication architecture	• More robust onboard sensors and health management	• Reduce need for ground communication	• Real-time replanning • Transfer to crew or intelligent autonomous system	• Automatic data reduction • Data compression techniques • Automated monitoring – throughout all phases/ operations – communicates needs to all appropriate stakeholders
Land / Recover Flight Element(s) and Payload Elements **(G)**		• Mobile purging/safing/ environmental systems (e.g., clamshell operations) • Standard interface • Automated/ autonomous hazard monitoring, assessment and purging	• Transport in mobile servicing unit	• Wireless communication • Standardized interfaces to any transporters	• Safe vehicle "enough" until get to offloading area • Robotic inspections • Advanced imagery systems – infrared, x-ray, etc.	• Wireless sensor network assessment of state (environment, hazards) • Autonomous command and control	• Automated checklist generation based on the reported "state" • Heads-up displays
Prepare Payload Elements for Turnaround or Disposal **(H2)** (e.g., spacelab/ logistics modules)		• In situ deservicing (i.e., in the mobile unit)	• Self-contained payload • Common, automated offloading equipment	• Standard interface to support equipment	• Self-test/self-reporting of status	• Self-diagnosing and healing • Automated scheduling of necessary support	• Automated checklist generation based on state-of-health data • Heads-up displays

	Servicing	Handling & Transportation	Assembly & Interfaces	Inspection & Checkout	Command, Control, and Monitor	Plan/Document	Analysis/Learning
Refurb/ Remanufacture Payload Element (I2)		• Self-contained environment (e.g. shipping container)	• Use standard hangar/ facilities • Standard access points • Standard handling and shipping containers	• Standard interface to support (e.g. container is standard size, weight, power, etc.)	• Integrated health/ self-inspection/self-reporting	• Automated scheduling of any calibration • Self-monitoring/self-healing	• Automated checklist generation based on self-diagnosis • Heads-up displays • Self-generating and standard shipping/ tracking

Appendix G
Integrated Operations Capabilities Roadmap, Challenges, and Technical Approaches

B3 – Integrated Operations Capabilities Roadmap

Function	Subfunction	Baseline	Near (2003–2009)	Mid (2010–2016)	Far (2017–2028)	Ideal Characteristics
Integrate Flight System and Payload (D)	Handling/ Transport	• Weeks to days	• Day	• Hours	• Minutes to hour	Plug & Queue Simple and standard interfaces that allow for autonomous and rapid integration, using common lift points, self-aligning surfaces, autonomous umbilicals, and self-fault isolation and repair techniques.
		• Payload installation can occur in multiple orientations requiring special handling equipment • Hazardous due to lifts – too many lifts and moves – slow process for lifting operations – interrupts other operations • Labor-intensive – visual spotting/ positioning of elements	• Generic integration process • Vision system assistance for alignment and positioning – remote operations and sensing for mating activities • Design common/universal lifting GSE for multiple architectures	• Standard process for integration – common lift points • Robotic support for lifting/mating • Self-aligning flight hardware elements • Self-guiding/positioning system • Standard lifting equipment to support multiple vehicles – universal GSE	• Seamless integration of standardized cargo elements into the vehicle – payload systems are self-contained (no resources from spacecraft required) • Rapid mating/integration using common lift points • Automated integration – self-aligning/guiding system during mate operations • Automated high-accuracy crane/ lifting operations	
	Interfaces/ Connections	• Nonstandardized payload installation process – custom-built – unique every mission • Vehicle provides all payload services (power, fluids, etc.) • Movement of vehicle fixed mechanisms for checkout, repair, or servicing impinges upon payload access and operations • Complex interfaces and multiple interfaces – excessive number of unique fluid, mechanical, and electrical interfaces between the flight vehicle and the payload requiring removal, installation and functional verification • Extensive interface verification	• Standardized mechanical attach points to the flight vehicle • Automated retention/latching of payload to the vehicle • Simple (not labor-intensive) attach points/closeouts to reduce dependency on craftsmanship • Define common interfaces for each commodity at a common location (e.g., bulkhead) for connection to ground infrastructure • Define common location (e.g., bulkhead) for electrical connections to facility	• Implement standardized interfaces for each commodity/ bulkhead for fluids and electrical • Automated umbilicals • Self-latching mechanisms	• Self-verifying interfaces • Minimal facility/vehicle interfaces with self-connecting umbilicals • Standardized interfaces (payload to vehicle and flight element to facility) • Debrisless separation systems • Nonpyrotechnic separation systems • Autonomous umbilical-to-facility connections	
	Inspection & Checkout	• Extensive vehicle reconfiguration between flights – repositioning of vehicle fixed mechanisms for access • Manual/operator-controlled testing after integration	• Tools and techniques to perform the flight readiness verification tasks without disassembling or invalidating the vehicle or GSE • Provide automated diagnostics with high fault detection capability	• Provide self-test diagnostics with high fault detection capability	• Self-fault identification and repair through autonomous troubleshooting and checkout	
	Command, Control, & Monitoring	• Vehicle-specific command and control systems – inflexible • Very labor-intensive – standing army/ console operators	• Remote distribution of checkout system data to users • Develop design guidelines for standardized ground and space vehicle interfaces and data format • Develop standard checkout and control software library modules that may be fused together to support the automatic configuration of a checkout system to the end-item design	• Develop new hardware interfaces that automatically recognize what is connected, configure that interface, and provide checkout and control capabilities to operate the attached equipment or system • Remote access to checkout system	• Software modules that automatically recognize and reconfigure based on flight hardware interfaces	

Function	Subfunction	Baseline	Near (2003–2009)	Mid (2010–2016)	Far (2017–2028)	Ideal Characteristics
	Infrastructure	• Unique facilities and infrastructure for program • Little or no feedback on improving process – application of lessons learned/metrics • Unique range safety and environmental reviews – time-consuming • Range meetings used to disseminate detailed mission status • Limited turnaround/reconfiguration of support systems • Use of pyrotechnic separation systems – hazardous ops • Share limited resources (e.g., range, transportation), which may cause delays/scheduling conflicts	• Process evaluated and briefed compared to acceptable metrics – improvement • Range/payload mission detailed data status available to launch team in real time (security access issues resolved) – improved planning of shared resources	• Flexible orientation facilities and vehicles for integration	• Common, standard facilities that can accommodate multiple architectures (nonunique) • Concurrent operations and offline capabilities	

Function	Subfunction	Baseline	Near (2003–2009)	Mid (2010–2016)	Far (2017–2028)	Ideal Characteristics
Execute Departure Operations (E)		• 8 hours (ELV) / 4 days (Shuttle)	• Day	• Hours	• Minutes/on-demand	Gas & Go On-demand propellant servicing to the flight vehicle and/or payload and quick verification that vehicle is ready to fly.
	Final Assembly & Closeout	• Crew sits for hours before takeoff • Battery activation – last minute – finite resources with limited life span • Limited crew/payload escape – emergency egress	• Minimize remove-before-flight items (identify how remaining ones could be removed)	• Continue to minimize remove-before-flight items	• Last-minute boarding of crew/ passengers	
	Servicing	• Major safety and security issues (e.g., when on the pad and fueled, have limited access) • Servicing of vehicle/payload commodities is incremental with topoff at the last minute • Time-consuming propellant loading process (chilldown of lines, etc.)	• Develop the capability for better leak detection of the gases used on the flight vehicle and associated GSE during loading operations • Design for efficient, zero-loss propellant storage and distribution systems	• Component health management • Rapid propellant system chilldown capability • Reduced boiloff storage capability	• On-demand propellant system for rapid loading operations • Rapid and autonomous servicing operations	
	Interfaces / Connections	• Number of interfaces and umbilical connections – each introduces potential for problem • Hazardous operations performing final ordnance hookup	• Rapid mate/connecting umbilicals (ganging of connectors) • Design for ground-based automated checkout and servicing utilizing universal interfaces • Ground infrastructure interfaces standards provided to vehicle providers	• Standard servicing interfaces based on commodity type • Automated umbilicals (ganging of connections – electrical, fluid, etc.)	• Debrisless separation systems • Nonpyrotechnic separation systems • Autonomous umbilical extend and retract	
	Command, Control, & Monitoring	• Vehicle-specific command and control systems – inflexible • Very labor-intensive – standing army/ console operators • Last-minute manual (operator-controlled) testing of flight systems • Limited visibility in leak detection during loading	• Situational awareness during loading – develop the predictive analysis techniques/capabilities necessary for use of the flight element and associated GSE (this includes direct health status from valves, motors, and other equipment) – automated system diagnostics • Standardized command/control systems • Standardized data types	• Automated process control, using learning systems • Minimal console operator support – dozens vs. hundreds • Autonomous system diagnostics/ monitoring • Continuous command and control of payload (not through the range) • Shared responsibility between vehicle and spaceport for command and control • Temporal/spatial leak monitoring with quantitative capabilities	• Onboard control of preflight checkout and servicing (minimal, automated ground support) • Skeleton crew for departure operations – a few consoles with a few operators to perform the entire servicing and launch operation • Autonomous ground system diagnostics/monitoring and self-repair	
	Decision Support	• Every departure is custom-designed (e.g., flight SW, orbit insertion, return to launch site, weather) – parameters change every day – months to prepare flight plan • Flight plan amendment requires extensive approval • Need a special-use airspace, etc. • Vehicle-specific decision making for go/ no-go (e.g., range assets) • Weather-dependent • Unique range safety and environmental reviews – time-consuming • A lot of interagency coordination – payload approved by range to fly	• Develop and utilize analytical tools to help perform mission analysis more effectively and efficiently (flight dynamics, controls, thermal/ fluids, structural dynamics and environments, structures/stress, EMC/RF). • Localized weather forecasting supporting prelaunch, launch, landing, and range operations (mesoscale comprehensive weather/hazard assessment model)	• Spaceport traffic control integrated with air-space and space-space traffic control	• Process (departure ops) owned by the vehicle operator • Expanded weather capability – weather is not a significant limiting factor • Standardized, simple, integrated decision process and tools • Scheduled flight procedures • File a flight plan (e.g., like an airplane) (includes the COLAs) (seamless integration) • Departure traffic management seamlessly integrated with orbital insertion and beyond (e.g., mission planning and public safety) • Clearance established across multiple spaceports (flight plan) – integrated resources to support	

Function	Subfunction	Baseline	Near (2003–2009)	Mid (2010–2016)	Far (2017–2028)	Ideal Characteristics
	Infrastructure	• Large amount of structure around vehicle to be retracted and stowed • Resource-limited • Infrastructure-limited • Process is owned by the range • Wheeling and dealing • All-encompassing – entire spaceport involved for one vehicle departure operation – do not have concurrent operations • Dependent on reliable performance of GSE across many locations	• Design for universal departure point – standardized transporter/vehicle connections to departure locations (e.g., pad) • Design for minimal interfaces between ground infrastructure and flight elements	• Implement common interfaces between flight elements and ground infrastructure	• "Clean pad" and "clean runway" • Universal departure points (one size fits all) – multiple users can use the same departure point • Minimize impact ground systems have on launch • Concurrent departure operations • Queuing system – get in and out of line for launch easily – go to a queuing system • Flexible abort procedures (e.g., hot abort on the runway/engine shutdown on pad) • Little or no refurbishment of ground support equipment required • Passive/active noise abatement	
Monitor, Control, and Manage the Flight (F)		• Lead time to support: 2 days for the range, days firing room – preflight piece • Departure control setup in weeks (i.e., firing room/blockhouse)	• Range turnaround in less than 1 day • Departure control setup in days	• Range turnaround in an hour • Departure control setup in a day	• Lead time to support: real time for the range • Departure control setup in hours	**Fly & Play** Flexible and responsive departure control and range support.
		• Vehicle-specific • Launch control is separate from mission control (e.g., JSC/KSC operations) • Launch vehicle ascent transitioned to mission control (e.g., JSC/KSC operations) • Limited flight control from the ground (e.g., ELV) • Some flights require mobile comm assets – expensive • Need mobile range information equipment • Limited ability for onboard situational awareness • Determining data needs of payload operator is defined upfront due to limited bandwidth rather than in response to real-time situation • Making deploy/no-deploy decision and communicating decision are manual and distributed across a variety of networks	• Minimal ground-based mission control (flight control) • Incorporate automated reasoning tools	• Mission controlled from spacecraft • Integrated and coordinated with NAS and schedule • Controlled flight boxes/volumes/ paths • Vehicle-specific mission control is separate from but parallel with the coordinated traffic control • Automated mission data feedback (vehicle performance, payload performance, weather and atmospheric information)	• Fleet operations • "Free flight" • Return-after-flight abort • On-orbit traffic coordination	

Function	Subfunction	Baseline	Near (2003–2009)	Mid (2010–2016)	Far (2017–2028)	Ideal Characteristics
Land/Recover Flight Elements and Payload (G)		• Several hours to 4 days (e.g., boosters) • Weather-dominated	• Hours • 95% weather-capable systems	• Hour • 99% weather-capable systems	• Minutes • All-weather-capable systems	Down & Off Routine landing with self-safing systems and rapid removal from runway. • Automated configuration safing/archive • Hazard safing • Self-fault identification
	Support Equipment	• Vehicle landing/recovery operations concept requires dedicated vehicle support equipment (requires mobile power unit, purge units, etc.) • Adapting GSE and platforms to provide access to vehicle/payload	• Combine services (purge, power, etc.) into one unit • Standardize required support services for recovery operations	• Build portable ground recovery systems to support immediate and rapid recovery	• Minimize vehicle-specific GSE • Universal support equipment for contingencies • Robotic (unmanned) towing vehicle to safing area (postflight)	
	Safing & Reconfig-uration	• Extensive time on runway – long delay for clearance to approach vehicle after landing due to potentially hazardous offgassing	• Enhanced methods for remote sensing of vehicle for safety • Minimal time to ensure payload is safe (e.g., toxics, radiology) • Ground control/remote for payload safing/reconfiguration/data archive	• Remote sensing of vehicle • Automated safing/reconfiguration of vehicle and payload • Self-sufficient payload • Vehicle and payload health monitoring provides real-time status and is connected to spaceport response (receive during approach and landing)	• Autonomous safing/reconfiguration • Autonomous data archive from payload operation/experiments	
	Inspection	• Detailed walkaround • Protective equipment (e.g., SCAPE suit) required for approaching vehicle after landing • Geiger tube "sniffer"	• Remotely operated/telerobotic hazardous gas detection	• Robotic "canary" • Remote spectroscopy	• Laser imaging (MRI) for vehicle for structural inspections • Advanced imaging systems – wireframe images – electronic imaging • Robotic inspections	
	Infrastructure	• Sits on runway until payload elements are removed after vehicle downgrade • Around-the-world sites must be activated for contingency purposes	• Move payload and vehicle quickly out of landing area for safing – mobility off the runway		• Get off runway "immediately"	
	Operations	• Highly sensitive to weather • Long time to get ready (always an emergency) • Labor-intensive • Need to provide environmental and safety protections • Impact other vehicle operation functions – conflicts with operations	• Broaden the environmental envelope (weather conditions) for landing and recovery • More accurate weather predictions • Design guidelines for quick recovery, safing, and deservicing at spaceports delivered to vehicle providers		• Minimize environmental/toxic impacts • Land at choosing • Minimize need for earlier access to remove payload from vehicle	
	Payload Removal	• Payload removal is dependent on vehicle deconfiguration			• Remove payload at the best time • Automated disconnect and transport payload to receiving area • Modularized payload carriers/ canisters	

Function	Subfunction	Baseline	Near (2003–2009)	Mid (2010–2016)	Far (2017–2028)	Ideal Characteristics
Restore/Reservice Ground Systems for Reuse (J)	Structures	• Weeks for MLP (7 to 12 days at park site + 5 days at launch site)	• Days	• Hours	• Minutes	**Swab & Reload** Robust spaceport ground systems with informed maintenance where status of systems is communicated via power-up diagnostics tests that quickly reveal faults and anomalies. Repairs and restests are remotely or autonomously performed without direct user interaction.
		• Reactionary maintenance • Refurbish the launch mounts and pads after each flight • Inflexible ground systems – architecture dedicated – rigid, stove-piped ground systems • Ground infrastructure is adapted to support a unique architecture • Using recycled, modified, 40-year-old hardware – breakages due to age	• Develop new materials and coatings that reduce corrosion and are sustainable in the launch environment • Enhanced capability for sound suppression	• Informed maintenance • Integrated health management incorporated into spaceport structures and systems	• Quick turnaround – reconfigure facilities for next flight • Self-restoring equipment	
	Command, Control, & Monitoring	• Use alternative fire rooms for subsequent missions (e.g., Shuttle) • Time-consuming and labor-intensive to reconfigure command and control systems • Outdated, legacy software • Long process (e.g., minimum 48 hours on Eastern Range) to recycle – due to a scrub for ground systems and range – inability to delay windows	• Standardized firing and control room SW loads	• No need to reconfigure – common HW/SW between control and firing rooms	• Modifications/updates are software-centric	
	System Checkout	• Manual/operator-controlled	• Incorporation of health monitoring into ground systems	• Develop character recognition inspection systems for vehicle and ground system inspections (using technologies such as automation/robotics and expert systems/neural networks)	• Self-fault isolation and repair	
	Servicing	• Reload propellants storage vessels – site- and platform-specific requirements • Truck in propellants from remote sites	• Enhanced propellant ground storage replenishment	• Onsite commodity production • Onsite commodity distribution	• Continuously ready	
	Waste Management		• Enhanced processing of contaminated run-off • Develop portable treatment unit for industrial wastewater • Develop the capability to accomplish hazardous waste incineration • Develop alternate processing methods for environmentally safe disposal of hazardous commodities			
	Payload Systems	• Storage of high-cost payload GSE or sharing of equipment maintenance (cranes, payload platforms) if cost-effective/business-case • Tracking/monitoring of environment when payload at facility • Many clean-room housekeeping requirements (e.g., filters, drain and dry) • Payload facility hardware – abandon in place	• Enhanced methods to clean hazardous equipment • Real-time, continuous monitoring of payload environment within clean rooms (alert system)	• Automatic “scrubbing” of clean-room environment		

C3CH – Subfunction Challenges: Integrated Operations

	Servicing	Handling & Transportation	Assembly & Interfaces	Inspection & Checkout	Command, Control, and Monitor	Planning / Documentation	Analysis / Learning
Integrate Flight System and Payload (D) Flight Element and Payload Element	• Contamination control • Maintain blanket purges	• Too many lifts and moves • Changing orientation requiring breakover fixtures and multiple cranes • Need to avoid collateral damage – fragile elements • Specialized lifting fixtures and handling equipment • 1-g limitations • Handling of large pieces • Movement of large elements between facilities for integration • Costly ground support • Armed escort from hardware transport • Using same resources across multiple users (e.g., cranes) – shared resources • Aging ground equipment • Transporting hazardous materials • Moves have to be controlled and monitored – area access controlled/cleared • Transferring hardware in multiple orientations (vertical vs. horizontal)	• Complex positioning and lowering of elements requiring numerous spotters • Elevated umbilicals • Complex interfaces and multiple interfaces – too many bolts, connections, etc., requiring craftsmanship • Customized equipment and carrier panels • Integrating fragile and delicate pieces – slow to do • Interfaces involve additional HW – bridging pieces • Risk aversion procedures • Upending or rotating vehicle • Happens on the pad • Too many umbilicals • Too many ground interfaces distributed up and down the vehicle • Too many dangerous connections (ordnance) • Gaining physical access to payload once inside vehicle	• Too much retest – multiple subsystem and interface tests • Manual inspection and checkout operations • Too many inspections and testing ops are completed within the critical path – need to complete ahead of time • Need approval from range to perform certain tests • Risk aversion approach rather than risk management • Weather-dependent	• Unique HW/SW • Using launch consoles for checkout and control • Numerous console operators required – labor-intensive • Stove-piped/legacy systems designed to accommodate only one architecture • Mission/vehicle-unique control system – major reconfiguration after each mission • HW and SW modifications are difficult • Non-real-time data reductions	• Lack of standardized documentation for all issues (e.g., range safety) • Multiple formats of data collection • Multiple sources of database • Paper-based • Every operations a custom job – new procedures developed • Diversity of approvals for procedures and paperwork • Integrating requirements with other systems • Difficult methods to make changes to documents	• Insufficient trend analysis • Determining out-of-family/out-of-spec issues – risk aversion
Execute Departure Operations (E) Flight Element and Payload Element (Close door, disconnect ground power supply, power up vehicle, terminal count, and launch.)	• Final fueling and top-off operations are time-consuming, requiring system chilldown prior to loading • Weather-dependent • Last-minute power requirements for last possible moment for vehicle • Large area needs to be cleared prior to loading due to hazardous nature of operations – large real estate • High level of commodity purity needed, requiring multiple filtering (eg., hydrazine) • Contamination control of payload during loading operations	• Large amount of structure around vehicle to be retracted and stowed • Army of support staff escorting movement of flight hardware to departure point • Need for rapid transfer to departure point and back to integration location for contingency	• Final component installation – close out door • Last-minute connection of pyrotechnic devices • Crew sits for hours before takeoff • Flight crew systems • Battery activation – last minute – finite resources with limited life span • Range safety system activation • Number of interfaces and umbilical connections – each introduces potential for problem • Control hazards through brute-force methods (e.g., blast inert purges into cavities to prevent explosive mixture combinations)	• Loading range safety code is manual • Manual/operator-controlled • People in danger for final inspection (e.g., red crews, ice inspection) • Bandwidth-limited restriction on data from testing	• Final Flight Termination System (FTS) checks • Countdown procedure = final checkout • Large distributed team and equipment managing terminal count • Pseudoautomated terminal count process – direct touch • Risk aversion approach rather than risk management • Launch control scenario – too much human interaction • Dozen control centers involved	• Planning process is lengthy • Lots of interactions for approval to launch • All paper is closed before go • Critical requirements documentation process is massive • Meeting everybody's requirements to fly – extensive analysis completed by committee • Flight plan development (e.g., trajectory) • Need a license to launch if nongovernment • Integration of requirements between carrier and payload developer (launch commit criteria) is not seamless • Modifications for flight data files – hard to get in last-minute changes	• Large quantity of data needs to be recorded and processed • Analysis of captured data for out-of-family trends is manual • Information shared verbally over comm nets • Limited lessons learned • Training – numerous practice exercises to certify launch team for one flight – limited operational learning opportunities

	Servicing	Handling & Transportation	Assembly & Interfaces	Inspection & Checkout	Command, Control, and Monitor	Planning / Documentation	Analysis / Learning
Monitor, Control, and Manage the Flight **(F)** Flight Element and Payload Element (The transition from E to F is the commit to depart. The commit to depart is based on the vehicle – manage the ascent, not the traverse between spaceports – that is the mission ops.)	• Airborne servicing in some concepts	• Some flights require mobile comm assets – expensive • Need mobile range information equipment • Mothership for some vehicles (e.g., L1011)	• Multiple communication architecture paths • Distributed spaceport communications – network of spaceports communicating with each other • Cost of Tracking and Data Relay Satellite System constellation (see ARTWG)	• Limited ability for onboard abort situation • Light and go (no coming back) – no ability to check inflight and return if possible (ELV) • Limited onboard inspection (Shuttle) • Making the deploy/no-deploy decision and communicating the decision	• Limited ability for onboard abort situation • Light and go (no coming back) – no ability to check inflight and return if possible (ELV) • Limited onboard inspection (Shuttle) • See range • See flight and mission control	• All preplanned • Little real-time planning • Flight SW is custom-developed – long lead time to develop • Unique to each mission • Multiple agency approval • Cumbersome alternative trajectory analysis • Determining the data needs the payload operator wants/needs • Getting the information to where they need it	• Limited real-time analysis – large numbers of people and long time to process • Limited onboard data monitoring • Limited bandwidth
Land/Recover Flight and Payload Element(s) **(G)** Flight Element and Payload Element	• Long delay for clearance to approach vehicle after landing due to potentially hazardous offgassing • Protective equipment (e.g., SCAPE suit) required for approaching vehicle after landing • Connecting active purge/ power support services labor-intensive and time-consuming	• Sensitivity to FOD, weather, and wildlife • Long time to get ready from recovery because it is always considered an emergency • Vehicle operations concept requires dedicated vehicle support equipment • Crew cannot egress without assistance from ground operations • Long distance for vehicle to travel to its servicing point • Removing hazardous payload • Storing payload • Accommodating contaminated situations (e.g., leaking payloads) • Lack of ability to get payload easily	• Special equipment required to gain access to various areas on the vehicle • Unique portable access equipment • Destowing time-critical items • Mechanical or physical safing of active systems	• Takes an army to clear the vehicle for general personnel access • Detailed walkaround involving visual inspection techniques • Hazardous operations • Landing systems deposit debris on landing area	• Hand-off from mission control to ground operations firing room • Single-mission capability • Manual • Lengthy	• Big checklist • Can't change plan easily • Inflexible system not able to handle changes – limited flexibility to adapt to real-time changes	• Mapping of Orbiter debris hits developed manually every flight • Manual crew debrief
Restore / Reservice Ground Systems for Reuse (J) (Pads, runways, GSE, MLP)	• Specialized tooling • Lubrication of mechanical systems • Determining what to repair (unplanned) • Performing routine maintenance to complete • Repair/replacement of components (e.g., seals) • Contamination control • Drainback • Safety and environmental • Commodity replenishment requires transporting commodities via tankers to spaceport	• Unique/customized handling • Specialized tooling • Aging infrastructure • Handling (transferring) SW between test systems • Special equipment to transport odd-shaped items • Retaining operators' certification • Not predictable on what needs to be transported • Aging, expensive infrastructure • Need to move large pieces of facility to maintenance areas (e.g., MLP to park site)	• Infrastructure interfaces are destroyed during launch • Massive refurbishment efforts required to restore to an operating configuration	• Functional verification • Recertification • Calibrations • Introducing back into the supply system		• Configuration control – recording rework and alterations made • Determining future needs to stage and configure equipment • Time-consuming to collect and manage detailed maintenance records • Aging systems requiring higher levels of maintenance	• Cumbersome to identify and track discrepancies with current documentation systems • Updating configuration • Updating performance metrics • Initiating corrective actions • "Tribal" knowledge • Stove-piped documentation systems

C3TA – Subfunction Technical Approaches: Integrated Operations

	Servicing	Handling & Transportation	Assembly & Interfaces	Inspection & Checkout	Command, Control, and Monitor	Planning / Documentation	Analysis / Learning
Integrate Flight System and Payload **(D)**	• Self-contained flight elements – eliminate fluid interfaces between elements	• Transporter doubles as breakover fixture – transfer to spaceport on handling fixture • Standardized transport modes • Minimize handling • Erector set • Flight hardware is factory-packaged for shipping, handling, assembly operations – self-contained hardware • Minimize transport operations by processing all elements in one facility – or Ship & Shoot • Robotic and artificial intelligence/visual element mating • Virtual reality planning and testing • Design guidelines for spaceport infrastructure (e.g., road width/radius and power line height) and support equipment • Simulation models for ground traffic management • Remove need for spin test • Design for horizontal assembly and delivery	• Laser alignment or proximity sensing for positioning of elements for mate ops • Robotic and artificial intelligence/visual payload mating • Minimized and standardized (simplified) interfaces (e.g, interface control documents) • Incorporate ground protective shields as part of operation • Relocate process from critical path – perform integration off the critical path/choke point • Provide underground utilities to need point • Nonpyrotechnic, debrisless separation techniques • Eliminate T-0 umbilical – wireless • Self-contained payload – external payload attachment (e.g., payload is not within the mold line) • Self-verifying connections • Self-latching mechanisms • Clocked electrical connectors – one-way connectors	• Self-fault isolation and repair systems • Fault-tolerant system • Integrated health management • Integrated and automated trend analysis • Risk management approach vs. risk aversion • Noninvasive NDE techniques – remote inspection technologies (e.g., leak visualization, computer tomography) • Automated defect and material characterization systems • Standardized tests • Holistic approach to verifying system functionality – test the entire system at one time rather than individual subsystems	• Automated sensing techniques – remote sensing of hazardous gases • Integrated monitoring systems • Multiparameter temporal/ spatial and quantitative monitoring system • Data fusion – data reduction during testing • Knowledge-based systems • Standard for command, control, and monitoring systems (C4I) • Interoperable systems across the nation – distributed systems • Common command and control descriptor • Automated configuration control for systems • 3-D imaging • Virtual reality systems	• Paperless, wizard-based (electronic) system for document generation and approval • Automated scheduling and deconflicting • Automated, responsive, dynamic requirements management (“Turbo Tax” for requirements) • Heads-up display of procedures	• Simulation models for preplanning • Automated decision models • Data warehouse • Automated, integrated trend analysis

	Servicing	Handling & Transportation	Assembly & Interfaces	Inspection & Checkout	Command, Control, and Monitor	Planning / Documentation	Analysis / Learning
Execute Departure Operations **(E)** **(Close door, disconnect ground power supply, power up vehicle, terminal count, and launch.)**	• Service station approach (bring spacecraft to the propellants) • Advanced filtering • Minimize servicing required • Nonvolatile fuels – less toxic commodities • Advanced fluid system storage and transfer • Low-maintenance fluid transfer lines • Nonintrusive instrumentation for cryogenic system performance (temp sensors, flow meters, etc.) • Robust fluid systems for weather mitigation • Teleoperated or autonomous umbilicals • Leak-free mechanical interfaces (quick disconnects) • Self-cleaning quick disconnects • Automatic deicing • Multiparameter leak detection capability • High-accuracy leak detection systems that provide temporal/ spatial and quantitative information • Enhanced hydrogen fire detection • Visualization techniques for fire detection (e.g. IR, acoustic)	• Wireless sensors • Clean pad and clean runway • Transport under own power to departure point (horizontal) • See Atlas V model • Transport erector/ launcher – mobile launch pad (Russian model)	• Minimize to zero – eliminate by design • Automated umbilicals with self-verifying interfaces • Artificial vision for umbilical mate • Self-healing seals on umbilicals • Leak-free mechanical interfaces (quick disconnects) • Eliminate confined spaces • Eliminate potential leak sources • Wireless or laser communications – decouple from the umbilical method • Liftoff umbilical system rather than swing arms • Expand bandwidth in the ground infrastructure • Decouple payloads from other systems	• Remote sensing of hazardous gases • Remove need for closeout photos • Artificial vision and intelligence for ice and debris inspection • Integrated health monitoring • Onboard sensing • Perform checks earlier in the countdown • Automated configuration control • Self-fault isolation and repair systems • High-accuracy optical techniques for gas imaging	• Automatic hardware recognition and configuration • Reusable and reconfigurable hardware/ software checkout modules • Self generating software • Self-validating software • High-capacity data handling • High-accuracy models and simulations • Data visualization • Adaptive reasoning advisors • Software fusion • Automated sensing techniques – remote sensing of hazardous gases • Multiparameter temporal/ spatial and quantitative monitoring system • Remote optical imaging for fire detection and leak detection • Distributed launch control and knowledge networks • Automated decision-making process, criteria • Risk management approach • Automated hand-off between launch and flight management • Transfer responsibility to crew or autonomous	• Paperless automated systems • Real-time data reduction, configuration control analysis • File a flight plan – see the FAA's AST con-ops • Risk management vs. risk adverse	• Automated, intelligent processing • Automated trend analysis – control center-oriented • Data warehousing and archive • Semantic networks and AI tools • Knowledge-based decision tools • Generic crew training • High-fidelity training models • Continuous download • Automated decision-making process, criteria • Automated integration of weather data

	Servicing	Handling & Transportation	Assembly & Interfaces	Inspection & Checkout	Command, Control, and Monitor	Planning / Documentation	Analysis / Learning
Monitor, Control, and Manage the Flight **(F)** (The transition from E to F is the commit to depart. The commit to depart is based on the vehicle – manage the ascent, not the traverse between spaceports – that is the mission ops.)	• n/a	• Established infrastructure – see ARTWG	• Comprehensive communication architecture • See ARTWG for communication architecture	• More robust onboard sensors and health management • Wider abort envelope • Self-checkout and analysis • Alert crew and spaceport of changes	• Integrated with NAS	• Real-time replanning • Transfer to crew or intelligent autonomous system • Automated flight plan generation and analysis • Automated risk management • Standardized systems • Robust communication network to directly transfer data to user (link to the communications subgroup)	• Automatic real-time data reduction • Self-finding or by-exception data reduction • Normalized data • Reduce need for ground communication • State-of-the-art computing systems • Data compression techniques • Integrated health monitoring with logistics (planned pit stops, just-in-time logistics with integrated health monitoring) – throughout all phases/ operations communicates maintenance needs to all appropriate stakeholders
Land / Recover Flight Element(s) and Payload (G)	• Self-safing vehicle systems • Self-inerting vehicle systems • Mobile purging/safing/ environmental systems or automated purging • Allow hot tanking operations for turnaround operations (eliminate the need to purge lines prior to reservicing) • Provide an environmentally safe area to do safing • Standard interfaces for support services (e.g., power, purge) • Minimize hazardous commodities used • Use robotics for remote sensing for toxics • Facility: vacuum system, scrubbers, etc.	• Pull to a gate – no handling necessary • Robotic towing • Autocleaning runways/auto-FOD detection • Robotic handling of sensitive equipment • Decontamination facility with robotic capability • Docking station to remove payload easily and readily • Instrumented tarmac	• Self-contained payload – external payload attachment (e.g., payload is not within the mold line) • Wireless connections for data transfer – laser communication systems • Minimized and standardized (simplified) interfaces • Nonpyro separation systems	• Robotic inspections • Advanced imaging systems – wireframe images – electronic imaging • Universal cameras • Holograms • Laser imaging (MRI) for vehicle • Remote hazards detection (gas, temperatures)	• Remote, automated command and control • Automated sequencing • Wireless connections for data transfer – laser communication systems	• Automated checklist • Heads-up displays • Responsive planning	• Fault identification data transfer from vehicle • Integrated health monitoring to begin maintenance actions • Autonomous data/archival warehousing • Automated data and trend analysis • Automated debrief systems

	Servicing	Handling & Transportation	Assembly & Interfaces	Inspection & Checkout	Command, Control, and Monitor	Planning / Documentation	Analysis / Learning
Restore/ Reservice Ground Systems for Reuse **(J)** (Pads, runways, GSE, MLP)	• Onsite commodity production and distribution • Horizontal launch vehicles • Materials that minimize periodic maintenance (materials science) • Low-maintenance fluid transfer lines • Low-loss or zero-loss propellant storage tanks/spheres • Advanced payload equipment storage facilities: vary the cleanliness and performance as needed	• Standardized cranes • Flexible platforms, transporters • Flexible transporters • Less expensive rail vs. crawler tracks • Simplify launch platforms • Universal and flexible stands • Standardized fixtures	• Modular, standardized containerized system • Connector covers • Configuration control • Sacrificial interfaces • Horizontal launch vehicles • No T-0 umbilicals • Wireless interfaces • Retracting umbilicals to blastproof compartments • Modular, standardized containerized system • Connector covers	• Self-fault isolation and repair systems • Condition-based maintenance – maintenance on demand	• Condition-based maintenance • Standardized information systems – distributed information systems	• Automated planning tools • "Turbo Tax" • Predictive maintenance approach • Configuration control systems	• Learning databases/tools • Configuration management tools • Knowledge capture-based systems • Expert systems • Learning databases/tools • Configuration management tools

Appendix H
Enabling Functions Capabilities Roadmap, Challenges, and Technical Approaches

B4 – Spaceport Enabling Operations Capabilities Roadmap

Spaceport Logistics (L) Capabilities Roadmap

		Baseline	Near (2003–2009)	Mid (2010–2016)	Far (2017–2028)
Function	**Subfunction**		Logistics Delays < 1/100 Reduce government-required assets by 25%	Logistics Delays < 1/1000 Reduce government-required assets by 50%	Logistics Delays < 1/10K Eliminate all government-required assets
Support Maintenance Operations	• What: vehicle, payload, spaceport • Spares management (sustaining/replen/repair turnaround) • Operation support area (facility-based vs. contact team) • Material service center (MSC)/tool crib/ garment/bench stock • Kitting • In-place calibration • Limited-operating-life-item (LOLI) management • Flight/facility systems and equipment/GSE repair • Materials and processes/NDE/failure analysis/ quality control • Calibration • Fabrication/manufacturing (mech/electr/cable/ structural) • Offline repair management (depot/original equipment manufacturer [OEM]/third party/etc.)	• Tool tracking uses shadow boxes/ outlines • Manual kitting from paper lists • Too many unique tools • Test sets for each LRU type • Hands-on, manual calibration • Availability of TD&D - Expensive to obtain - Not available - Incomplete - Reverse-engineer to fix component - Proprietary information/data • Fabricate/manufacture - Time-consuming - No data (TD&D) • No materials on hand	• Enhanced bench check capability based on fault detection • IVHM, minimum unique test equipment • Minimize unique tools through promotion of design guidelines and adaptable tools • Enhanced tracking of tools • Complete set of standardized, formatted TD&D	• Single integrated, portable test equipment • Automated tracking of tools • Universal tool • Integrated electronic TD&D, maintenance plans/ procedures, manuals, etc., (heads-up display) with paperless instructions • Automatic sign-off on completed steps	• Nearly all fault isolation and retest accomplished via IVHM • Universal test equipment for testing multiple LRUs (reconfigurable) • Minimize need for tools • Virtual reality TD&D, maintenance plans/ procedures, manuals, etc. • Takes 1 person 1 minute to do any repair with 1 tool • Predictive maintenance • Integrated with vehicle health monitoring
Manage Supply	• Shipping/receiving (acceptance) • Packaging, handling, storage, and transportation (PHS&T) (includes warehousing and MSC) • Customs/export implementation	• Time-consuming • Manually input into inventory system • Conditioned storage space required • Various sources of item data are not integrated • Bar codes are not consistent • Need to install bar code and populate inventory system manually • Manually scan item and manually download data into inventory system at a later time	• Manually scan with real-time automatic update into inventory system	• Automatic scanning through portal with real-time update into inventory system • Rapid prototype manufacturing of parts for demonstration purposes only	• "Hands-off" dock-to-stock-to-issue system • Parts arrive before need is identified • Have all parts when and where needed – have any resource, anytime, anywhere needed • Just-in-time logistics – no inventory, never run out of parts • Lossless commodity transfer (no boiloff, no spills, no vents) • Automated procurement, receiving/ inspection, storage, and retrieval system • Continuous asset tracking • Automatic rapid prototyping from raw materials • Disposable parts
Perform Logistics Engineering Analysis and Planning	• Design support (maintainability/reliability/ supportability/etc.) • Maintenance and logistics plans • Spares analysis (initial) • Logistics sustaining support • Technical data and documentation (TD&D)	• OEM TD&D in bits and pieces • Need to manually generate ops maintenance plans (operations and maintenance instructions [OMIs]) • Up-front planning/engineering analysis	• Automated TD&D system • Development of detailed design documentation • Use of components and equipment with known long-term availability for spares and reprocurements • Design for existing crew skill levels and training	• Minimize requirements for special repair capabilities, tools, and equipment	• Online, centralized TD&D repository
Track Logistics Information IT/Logistics Information Systems	• Inventory management (logistics parts tracking) • Equipment management (logistics parts tracking) • Asset tracking (customer items) • Fleet resource management – heavy equipment/GSE/ payload racks (location/ quantity/condition/availability) • Work scheduling • Logistics parts tracking/maintenance planning • Training/skills certifications	• Manually input into inventory system • Bar codes are not consistent • Manually scan item and manually download data into inventory system at a later time	• Develop logistics IT systems that easily share data • Standardized operations and repair manuals	• Integrated all logistics systems (share data, single source for a given data element, entire logistics process electronically integrated) • Automated collection and analysis of metric data • Automated data feedback to operations • Automated identification of potential problems and scheduling of maintenance before the failure – predictive maintenance – understanding system degradation	• Integrated LPS for entire spaceport, includes all functional areas: ops, facilities, logistics, etc. • Online, real-time, centralized documentation – universally available • Integrated supply chain management • Adaptable inventory management system integrated with vendors

Management of the Spaceport and Flight Operations (M) Capabilities Roadmap

Function	Subfunction	Baseline	Near (2003–2009)	Mid (2010–2016)	Far (2017–2028)
Customer Services	• Single point for program planning/support (program introductions/customer requirements) • Customer relations • Sales/marketing seeking new vehicle operators to the spaceport • Sales/marketing seeking payloads to the spaceport (operator)	• Government-focused customer (spaceport) • International launch services organizations conduct marketing • Manufacturer is the vehicle operator and in some cases spaceport operator • Small number of customer types (vehicles and payloads) • Evolving from government-dominated market • Business cyclic market (high peaks and valleys) • Diverse types of customer interfaces – a customer goes to many different interfaces for support • Lack of standard, documented process for a customer to follow	• Enhance the one-stop champion or customer support organization for the spaceport services • Develop spaceport interface standards for flight and payload systems design	• Automated cafeteria plan for flight and spaceport services supporting the one-stop champion • Integrate customer/spaceport services into vehicle and payload design tools	• Self-service cafeteria plan for spaceport services
Strategic Management	• Master planning • Strategic planning • Capacity planning (fleet size issues and allocations) • New business/marketing (get new operators to base at the spaceport)	• Support the design, rather than design for support • Accommodate whatever vehicle and payload come along through customization and specialized temporary equipment • Limited planning for the future – dynamic target in a cyclical, suddenly changing market – reaction to a stable market • Spaceport evolved over time vs. master-planned • Operator facilities converted to support new programs • Licensing is an involved, fragmented process • Limited or evolving cost tracking • Custom, mission-unique orientation • Programmatic	• Enhanced, customer-friendly service • Continue master planning on a local level • Each provider develops a strategic plan and business case for operations across many spaceports • Keep better performance metrics • Unified licensing approach • Lead and champion development of business case and standards for vehicles and payloads	• Continue master planning on a regional level • Create investment incentives and mechanisms for spaceports • Each provider evolves strategic plan and business case for operations across many spaceports	• Continue master planning on a national/global level • Unified planning for the spaceport • Each provider evolves strategic plan and business case for operations across many spaceports • Unified planning for the operations and the infrastructure • Market-driven planning • Flexible to meet different customer (e.g., passenger, cargo, experiments) needs
Business Management	• Procurement • Financial • Human resources • Legal • Insurance	• Limited cost tracking • Budget databases not connected, tracking budget not tracking specific costs for specific tasks • Not an integrated effort • Government program management approach	• Develop spaceport actual cost model and consistent pricing structure for spaceport operations • Determine commercial best business practices to run an operational spaceport • Develop innovative concepts for insurance of spaceport operations • Create incentives and processes to track actual data at a task level	• Adapt and refine cost model and pricing structure • Provide commercial best business practices to run an operational spaceport • Design facilities and operations to align with insurance requirements	• Adapt and refine cost model and pricing structure • Provide commercial best business practices to run an operational spaceport
Engineering	• Facility design and upgrades • Ground system design and upgrades • Reliability/maintenance • Flight system design and upgrade	• Limited number of programs that provide this service • Vehicle-unique • Focus on break-fix vs. preventative maintenance and upgrades • Focus on O&M budget for the next year	• Develop master plan for spaceport facilities • At the national level, adopt commercial (e.g., IEEE or SAE) standards where applicable and define simplified standards for spaceport-unique facilities and equipment • Capture and communicate heritage spaceport engineering knowledge that is retiring and leaving the space programs • Develop curriculum for spaceport operations engineering • Develop reliability database for spaceport facilities and equipment (e.g., Government-Industry Data Exchange Program [GIDEP]) • Vehicle, payload, range, and spaceport operators develop standards together	• Develop standardized models for design of facilities and equipment • Academic infrastructure provides spaceport operations engineering curriculum • Avoid custom-designed equipment	• Universal facilities, equipment, and standard interfaces to support (e.g., universal launch pads) • Custom-designed equipment is the exception to the rule, not the rule • Designed for upgradeability and scalability

Management of the Spaceport and Flight Operations (M) Capabilities Roadmap

Function	Subfunction	Baseline	Near (2003–2009)	Mid (2010–2016)	Far (2017–2028)
Operations Safety, Health, and Mission Assurance	• Safety risk management • Occupational health • Incident management	• OSHA-based regulations for personnel primarily • Internal policies for equipment safety • Duplicate safety reporting entities within the spaceport	• Define nonoverlapping responsibilities among spaceport, vehicle operator, and regulatory organizations for safety management	• Reduce the significant redundancy in and streamline responsibilities across spaceport, vehicle operator, and regulatory organizations for safety management • Develop common safety metrics across the organizations	• One layer of integrated safety across the spaceport
Operations Management of the Spaceport	• Requirements management – manage spaceport support service requirements • Requirements management – manage inline (flight, payload, and integrated) operations requirements	• Contractual • Custom for each mission • Low level • Evolve as deploy the system	• Standardize means to document requirements • Streamline the requirements process • Segregate development and operational requirements • Standardize means to document operations (e.g., processing, testing) requirements • Streamline the requirements process • Segregate development and operational requirements • Electronic management of requirements – real-time requirements sign-off during operations	• Separate development/test from operational requirements • Exit criteria for moving beyond development into true O&M requirements • Identify integrated work management system • Begin to integrate systems	• Operational requirements are stable and mature • Seamlessly integrated with other data and work process systems
	• Operations risk management	• Accommodate the risk, don't retire it • Procedure around it • Difficult to identify • Focus is on safety risk only	• Build the development infrastructure (e.g., testbed) to identify, understand, and quantify risk and develop strategies to overcome them	• Implement mitigation techniques – infuse into operational spaceports • Develop predictive risk management techniques	• Embrace risk from a business perspective • Implement process in place to retire the risk
	• Configuration and state management	• Manual • Labor-intensive • Paper-driven • Distributed responsibility, accountability, and information • Poorly defined requirements • Weight-and-balance-based calculations (relate to the flight side)	• Unify requirements and discipline for configuration management • Establish centralized responsibility, accountability, and data	• Automate the configuration management function – data collection and distribution of configuration documents • Automated configuration and state verification	• Seamlessly integrated with data management and floor procedures – linked to logistics • Self-configuration and state verification
	• Work control and scheduling	• Labor-intensive • Manual • Paper-driven • Based on meetings • Too many layers	• Capture as-run data in real time (i.e., actual historical data) for strategic management • Develop resource loading • Adopt best practices and tools	• Develop standard procedures and work controls • Provide automated performance support • Seamlessly integrated with all other spaceport data management tools	• Transparent to the customer
	• Work authorization	• Signatures • Manual • Paper-based • Meetings • Engineering-intensive	• Limit approval cycles • Tie procedures and documents to scheduling	• Certified, standardized procedures • Precertified procedures • Automated routing, approval, and feedback	• Seamlessly integrated with all other spaceport data management tools
	• Analysis, learning, and process improvement • Data capture, trend analysis, lessons learned	• Ad hoc • Expensive lessons • Limited infrastructure to do	• Collect the data • Look for opportunities to document and improve the process • Develop incentives for improvement	• Fully integrated as an operational philosophy	• Seamlessly integrated with all other spaceport data management tools
	• Operations data management	• Filing cabinets • Microfilm • Limited online • Don't have all the relevant data needed • Lack of consistent strategy • Lack of centralized data source	• Define data management strategy for learning, analysis, and process improvement • Begin data collection and analysis	• Ubiquitous data collection and analysis	• Seamlessly integrated with all other spaceport data management tools
	• Documentation (procedures, ops manual, requirements, meeting minutes, schematics, checklists, etc.)	• Inconsistent • Paper-based		• Standardized format • Shared • Online • Seamlessly integrated with other systems	• Seamlessly integrated with all other spaceport data management tools

Management of the Spaceport and Flight Operations (M) Capabilities Roadmap

Function	Subfunction	Baseline	Near (2003–2009)	Mid (2010–2016)	Far (2017–2028)
	• Maintain interface and compliance with licensing, export/ITAR, and safety regulations/regulators (e.g., customs, import/export control, and FAA)	• Organizations complete on own, not a spaceport-centralized-level function • Fragmented across the spaceport • Takes 5 years to license a new vehicle	• Define and implement a consistent, integrated, standard services approach provided by the spaceport for existing programs • Understand and define approaches for new programs and vehicles • Develop "space worthiness" regulations – regulations that apply to spaceports and commercial spacelines • Develop concepts for a single responsible entity for spaceport regulations • Establish space free trade zone	• Adapt and implement for new programs as they come online • Provide input to new regulations • Develop "space worthiness" regulations – regulations that apply to spaceports and commercial spacelines • Establish a single responsible entity for spaceport regulations	• Adapt and implement for new programs as they come online • Provide input to new regulations

Spaceport Provided Support Services (N) Capabilities Roadmap

	System/Function	Baseline/Today	Near (2009)	Mid (2015)	Far (2028)
Support Services	• Training/certification (e.g., common safety training, or hazardous comm., or OSHA) to ensure meet needs to be on the spaceport	• Completed onsite • Tracked by different organizations • Certifications expire within days of getting warning • Different requirements for different badges/ environments • Focused on certification for a single spaceport	• Develop unified common practices for procedures • Establish "accreditation" criteria • Developing standard courses • Develop standards for training records • Develop standards for curriculum	• Move technician from one spaceport to the next with certifications and skills transferring – certify to work on any spaceport • "Spaceport Operations Training Center/ Institute" - Common, standardized training for all spaceports - Standardized core training with augmentation for facility- and equipment-unique applications - Distributed learning environment - Automated tracking of certification	• Just-in-time training and performance support with heads-up display to provide unique training aids
	• Environmental management (e.g., monitoring, sensing, testing – hazardous gas) • Sense, mitigate, contain • Issues: run-off, acoustic, venting, RF	• Use of legacy systems • Reactive in monitoring • Focused on restoration from past • Focused on compliance within a segment • Deal with issues from an "impact" perspective • Warnings • Deal with acoustic problems by brute force • Manage RF via line of sight and paper process	• Integrated compliance approach across segments • Integrated data across systems via algorithms • Integrated with the local community • Coordinated, real-time, environment management system with the local community	• Instrumented "sensing/tracking web" across the spaceport for proactive management - Dynamic - Provide temporal and spatial data and prediction - Integrated with weather systems	• Real-time, proactive mitigation • Coordinated with other spaceports for rerouting • Advanced acoustic techniques • Advanced containment methodologies • Automated frequency control across devices
	• Imagery/graphics (e.g., surveillance of operations) • Monitoring of vehicles as they flow through spaceport • Closeout photos • Photographic services • Documentation of operations and problem areas • Capture, distribute, archive, and analyze	• Manual capture • Capture is optical • Every group has digital cameras • Image propagation is ad hoc and unofficial • Inconsistent, slow archival and analysis	• Enhanced surveillance of operations • Fully automatic tracking cameras • Nonintrusive, automated operations monitoring • Balancing very high resolution where needed • Efficient archival and distribution system	• Semiautonomous surveillance of operations (online and offline)	• Autonomous surveillance of operations • Autonomous tracking system for departure and arrival • Balance online and offline activities • Complete spectrum of capturing means (e.g., optical, x-ray, infrared) – use complete electromagnetic spectrum
	• Custodial • Hazardous and biological waste handling	• One-time-use garments for clean rooms • Unique disposal requirements	• Use less paper in day-to-day operations • Establish standards for hazardous items processing	• Reuse/recycle waste streams	• No-waste spaceport
	• Information technology architecture (e.g., communication architecture/network at the spaceport, IT security)	• Varying levels of copper and fiber • Segmented • Data, video, and audio on different plugs • Inaccessible onsite • Combination of off-the-shelf and property systems • Layers of administration	• Enhance architecture at a spaceport • Establish standards for information networks at spaceports • Standardize media (e.g., fiber) • Increased use of COTS • Consolidate media across the spaceport	• Integrated flight and ground operations network • Link national spaceports and customers	• Seamlessly integrated with global spaceport and customer network • Plug & Play • Highly secure to appropriate users • Communications nodes throughout the facility wherever they are needed • Remote access to spaceport network for operations • Integrated media (voice, data, video)
	• Utilities (e.g., power, water, fuel/ commodity lines)	• Different flavors of electrical power (e.g., high-voltage) • Every commodity has its own vendor • Limited master planning	• Enhance propellant and utility capabilities • Streamline propellant and utilities acquisition • Develop the systems approach to production, storage, and distribution	• Develop business case and technology for integrating spaceport with the community • Implement the systems approach to production, storage, and distribution • Use state-of-the-art technology for water and sewer utilities	• Integrated utility and propellant self-sustaining capability on the spaceport (e.g., cogeneration) • Use state-of-the-art technology for water and sewer utilities

Spaceport Provided Support Services (N) Capabilities Roadmap

	System/Function	Baseline/Today	Near (2009)	Mid (2015)	Far (2028)
Consumer Services	• Shops, food services, entertainment, postal, money exchange, hotels, etc.	• Focused on onsite workforce and contracts • Public is focused on offsite	• Develop master plan for the microeconomy	• Develop the business • Create incentives • Establish a "military base" model	• Microeconomy within the spaceport – spaceport enterprise
Maintenance of Spaceport Infrastructure	• GSE ops and maintenance • Facility O&M • Don't change availability to do the maintenance	• Complete on a window basis • Preventive maintenance inspection and semischeduled basis • Completed on noninterference • Work driven by reaction to breakdown – emergency repair • Resource-constrained	• Develop trends for maintenance approach • Health monitoring of facilities and redundancy where needed	• Implement appropriate maintenance based on trend analysis • Remote monitoring for maintenance concerns and remote repair as appropriate • Automated maintenance reports	• All facilities and equipment fully available at all times – no operational impact due to maintenance • Manage based on degradation rather than failure
Security	• Spaceport grounds security • Information security/ITAR • Personnel security screening (e.g., badging/access) • Operations/area security (e.g., protecting the vehicles, public screening) • Customs	• Manual security • Integrating human and automation in limited locations • Highly procedural • Focus is on access control vs. security • Limited threat detection	• Develop uniform standards and processes for access • One-stop shopping for access • Two-dimensional perimeter detection across the spaceport	• Automated security • Less intrusive	• Ubiquitous security • Integrated access control and security • Freedom to operate – nonhindering security • Three-dimensional perimeter detection and autonomous response across the spaceport
Emergency Services	• Fire • Medical • Haz mat • Emergency management response	• Partially integrated • Mostly manual • Distributed across the spaceport and functions	• Totally integrated – all necessary functions to be at the emergency when needed	• Autonomous emergency detection and response system	• Preventive emergency service is the focus • Uninterrupted service during an emergency operation
Occupational Health	• Health checks and certifications (public and employees) • Quarantine • Personnel protective equipment • Incident management	• "Sick" buildings • Manual response • Ad hoc • After-the-fact, reactive • Mechanical • Not integrated with emergency services • Numerous work-related occupational hazards • Hazardous areas are inefficiently isolated • OSHA-based regulations	• Complete task analysis to identify potential hazards	• Proactive analysis of operational safety concerns – risk and task analysis to predict	• Eliminate the hazardous operations and workplace • Spaceport architecture accommodates the public going through the spaceport • Embedded sensors

Offline Maintenance, Repair, and Overhaul (O) Capabilities Roadmap

System/Function	Baseline/Today	Near (2009)	Mid (2015)	Far (2028)
Inspect (came to here from scheduled maintenance or something went wrong)	• Intrusive • Manually intensive • Time-consuming • Diverse formats and documentation • Layered systems requiring teardown or disassembly • Removes asset from the fleet	• Develop standards for inspection and documentation • Greater emphasis on nonintrusive • Nondestructive evaluation • Self-healing computer systems	• "Smart" structures and fluids systems	• Nonintrusive • Self-inspect with automated systems • Longer intervals between required inspections • Easy access • Linked to health monitoring
Modify/repair/rebuild	• Schedule modification intervals (mod windows for facilities) • Accumulate mods and take out of the loop for some time • Mods creep into the online operation • Configuration and documentation control is manual and lags	• Extend intervals for existing items • Automated configuration and document control • Prioritize mods based on overall space transportation system (e.g., flight performance and ground operations performance) • Focus mods on operational improvement	• Easily upgradeable • Real-time configuration updates and status • High use of modular components • Using operationally certified equipment • Fully integrated schedules	• Self-healing structures and systems
Reassemble	• High-maintenance parts that are buried below other parts • Fragile parts are impacted through reassembly process • Requires extensive interface retest	• Establish design criteria for support • Common durable fastening systems • Access doors for frequently accessed components • Fewer higher-temp. mold line penetrations (e.g., landing doors on vehicle)	• Higher-level LRUs (boxes vs. individual pieces) • Use modular components to swap out in lieu of individual	• Little or no reassembly • Self-verification of interfaces • Durable interfaces • Minimize interfaces
Test	• Manual • Procedurally intensive • Incremental (components→subsystems→system) • Build-test-build-test… • Manual paperwork system • Multilevel signature requirements • Operator retests from offline repair • Extensive flight recertification	• Semiautomated testing at the component level	• Automated testing only at the system level	• Self-test • Self-healing

C4CHTA – Challenges and Technical Approaches: Spaceport Enabling Functions
Spaceport Logistics

Predict and Restore/Replenish/Change/Fix – Know when it's going to fail, order it, and get it to the operations (schedule maintenance) before it fails.

Subfunction	Ideal	Challenge	Technical Approach
Support Maintenance Operations	• Nearly all fault isolation and retest accomplished via IVHM • Universal test equipment for testing multiple LRUs (reconfigurable) • Minimize need for tools • Virtual reality TD&D, maintenance plans/procedures, manuals, etc. • Takes 1 person 1 minute to do any repair with 1 tool • Predictive maintenance • Integrated with vehicle health monitoring	• Vehicles don't have the design margin – no system for predictive maintenance systems – limited capability for predictive maintenance systems • Manual trending • Small fleet size – small buys • Lack of consistently following vehicle design guidelines • Tracking of tools, unique tools • Paradigm that logistics is least important, low priority – not enough $ to buy all the parts needed • Undependable systems • Limited design corrective action/design taken • Cost of downtime is high • Availability drives the requirement for spares • Large number of unique parts for each vehicle	• Integrated with vehicle health monitoring • Rapid onsite prototyping/manufacturing of space-qualified items • Seamless ordering on the floor for pickup on the floor • Management control of design process to minimize the tools
Manage Supply • Shipping/receiving (acceptance) • Packaging, handling, storage and transportation (PHS&T) (includes warehousing and material service centers [MSC]) • Customs/export implementation	• "Hands-off" dock-to-stock-to-issue system • Parts arrive before need is identified • Have all parts when and where needed – have any resource, anytime, anywhere needed • Just-in-time logistics – no inventory, never run out of parts • Lossless commodity transfer (no boiloff, no spills, no vents) • Automated procurement, receiving/inspection, storage, and retrieval system • Continuous asset tracking • Automatic rapid prototyping from raw materials • Disposable parts	• Transportation • Maintainability and reliability data collection and analysis are lacking for predictive maintenance • Technology limitations for cryogenic material storage and transfer • Integrating the various information systems • Intelligent storage facilities • Hazardous materials – volume limited by transportation and storage	• Integrated with vehicle health monitoring • Standardized shipping containers • Computerized storage facilities • Onsite production of commodities
Perform Logistics Engineering Analysis and Planning • Design support (maintainability/reliability/supportability/etc.) • Maintenance and logistics plans • Spares analysis (initial) • Logistics sustaining support - Trend analysis/reliability-centered maintenance - Modification assessments • TD&D		• Limited number of qualified vendors • Low demonstrated reliability • Inadequate testing of new systems • Ability to influence the design • Lack of integrated metric data capture • Lack of design for maintainability, design using metrics • Custom processes • Flight certification of components • Incomplete documentation and multiple formats/dialects	• Design guidelines • Integrated design environments that include logistic functions • Automated data capture and analysis • Simulating techniques to assess reliability/maintainability vs. testing to failure • Online, real-time, centralized documentation – universally available
Track Logistics Information **IT/Logistics Information Systems** • Inventory management (logistics parts tracking) • Equipment management (logistics parts tracking) • Asset tracking (customer items) • Fleet resource management – heavy equipment/GSE/payload racks (location/quantity/condition/availability) • Work scheduling • Logistics parts tracking/maintenance planning • Training/skills certifications	• Integrated LPS for entire spaceport, includes all functional areas ops, facilities, logistics, etc. • Online, real-time, centralized documentation – universally available • Integrated supply chain management • Adaptable inventory management system integrated with vendors	• Not using off-the-shelf inventory management systems • Distributed systems • Manual • Diverse data formats • Lack of compatibility • Proprietary information • Time-consuming to collect data • Workforce doesn't see the need for the data • Lack of recording of data for contractual advantages • No "ACME" spaceport provider • RF-unfriendly environments • Export control	• Integrated health monitoring systems • Smart systems – sensing and instrumentation built into the structure • Automated data collection • More wireless technologies

Management of the Spaceport and Flight Operations (M)

	System/Function	Far (2028)	Challenges	Technical Approach
	Customer Services • Single point for program planning/support (program introductions/customer requirements) • Customer relations • Sales/marketing seeking new vehicle operators to the spaceport	• Self-service cafeteria plan for flight and spaceport services	• Growing the paying customer/payload market – increase the demand for flights • Lack of integrated design approaches and tools that incorporate spaceport operations • Too many organizations required to communicate requirements • Changing environments for vehicle • Lack of historical data • Change in mind-set to design for operations	• "Turbo Tax" • Design guidelines for operations vs. performance • "Vision spaceport"-type tools • Integrated engineering environment tools
	Strategic Management • Master planning • Capacity planning (fleet size issues and allocations) • Strategic planning • New business/marketing (get new operators to base at the spaceport) • Command and control of the organization	• Continue master planning on a national/global level • Unified planning for the spaceport • Each provider evolves strategic plan and business case for operations across many spaceports • Unified planning for the operations and the infrastructure • Market-driven planning • Flexible to meet different customer (e.g., passenger, cargo, experiments) needs	• Strategic thinking • Supporting next-generation vehicles • Being vehicle-centric • Political and regulatory environment • Funding • Prematurely deploying immature technology • Getting away from being vehicle-centric • Political and regulatory environment (e.g., ITAR, EPA, noise, range safety, orbital space) • Limited investment capital	• Virtual prototyping and simulation • Business case – criteria for viability • Metrics tracking and analysis • Development and communication of standards for vehicles and payloads • Testbeds to mature the technology development for operational use • Establish industry association board for operators (e.g., AIA)
	Business Management • Procurement • Financial • Human Resources • Legal • Insurance	• Adapt and refine cost model and pricing structure • Provide commercial best business practices to run an operational spaceport	• Adapting business models and processes for a spaceport • Gaining buy-in and funding to develop the models • Getting the data/tracking the data	• Spaceport operations management discipline • Data acquisition/tracking systems • Useful metrics to help drive improvement • Cost models for spaceport operations
	Engineering • Facility design and upgrades • Ground system design and upgrades • Reliability/maintenance • Flight system design and upgrade	• Universal facilities, equipment, and standard interfaces to support (e.g., universal launch pads) • Custom-designed equipment is exception to the rule, not the rule • Designed for upgradeability and scalability	• Lack of standards • Increasing reliability without increased cost • Large amount of engineering skills devoted to sustaining operations vs. improving product/process • Majority of spaceport engineers trained on how to maintain a specific system vs. understanding the larger system and why the function is performed • Changing the culture to support innovation • University to develop spaceport operations degree	• Develop spaceport engineering, operations standards • Develop spaceport operations curriculum • Developing modeling and simulation capability to test design with real-world concerns
	Spaceport Safety & Health Assurance Management • Safety risk management • Occupational health • Incident management	• One layer of integrated safety across the spaceport	• Lack of incentives to simplify approaches • Changing paradigm from risk aversion to risk management • Changing job from "why we can't do it" to "how we can help" • Lack of ability to demonstrate safety	• Ground system testbed • Dedicated test flight facility to certify new systems

Management of the Spaceport and Flight Operations (M)

	System/Function	Far (2028)	Challenges	Technical Approach
Operations Management of the Spaceport	• Requirements management – manage spaceport support service requirements • Requirements management – manage inline (flight, payload, and integrated) operations requirements	• Seamlessly integrated with other data and work processes systems • Operational requirements are stable and mature	• Not documented • Not well understood • High level of changes to requirements for every flight • Large volume of requirements within inconsistent definition of levels and flowdown • Lack of management and control • We don't start at top level requirements – we start at the smallest component • Still determining requirements • Need to make money	• Automated closed-loop requirements management tools • Systems approach to operations • Requirements tied to verifiable measures
	• Operations risk management	• Embrace risk from a business perspective • Implement process in place to retire the risk	• Proper identification of risk • Don't understand what risk is • Don't use best tools	• Risk management tools for spaceports • Automated analysis of procedures for risk
	• Configuration and state management	• Seamlessly integrated with data management and floor procedures – linked to logistics • Self-configuration and state verification	• Many parts to keep track of • Keeping track of process configuration and state of the spaceport • Reconfiguring for different operations	• Smart-chip tracking of parts • Bar codes • Enhanced weight-and-balance algorithms (vehicle) • Preflight checklist
	• Work control and scheduling	• Transparent to the customer	• Current and diverse operational philosophies • Implementation costs • Lack of good, consistent, relevant data • Scheduling is an art, not a science • Cost to convert from legacy to new • Lack of situational awareness • Immense number of tasks to produce a flight • High level of skill required	• Standard processes and philosophies • Data management • Decision support tools • Scheduling algorithms • System integration across all disciplines • Wireless "PDAs"
	• Work authorization	• Seamlessly integrated with all other spaceport data management tools	• Current philosophies • Blurring of operational and development systems • Spreading of responsibility – everyone must sign the paper • Unique procedures	• Groupware • "Turbo Tax" • Standardized procedures
	• Analysis, learning, and process improvement • Data capture, trend analysis, lessons learned	• Seamlessly integrated with all other spaceport data management tools	• Hard to improve nonstandard processes • Limited incentives • Lack of data	• Commitment to formal operations improvement program • Automated feedback to procedures • Task analysis tools
	• Operations data management	• Seamlessly integrated with all other spaceport data management tools	• Data not in format that can be easily captured • Not a customer-oriented data access system for trending • Not having the right amount of data • Different terms for different items	• Drop menus for data capture • Consistent terminology, taxonomy
	• Documentation (procedures, ops manual, requirements, meeting minutes, schematics, checklists, etc.)	• Seamlessly integrated with all other spaceport data management tools	• Current philosophies • "Pay by the pound" • Duplicative information • Updating information	• Standard formats
	• Maintain interface and compliance with licensing, export/ITAR, and safety regulations/ regulators (e.g., customs, import/export control, and FAA)	• Adapt and implement for new programs as they come online • Provide input to new regulations	• Getting everyone on the same page • Gaining political advocacy and participation to scope new regulations • "My job" syndrome	• Technical group and analysis for space worthiness criteria • Standards development for space worthiness criteria

	System/Function	Far (2028)	Challenges	Technical Approach
Support Services	• Training/certification (e.g., common safety training or haz comm. or OSHA) to ensure meet needs to be on the spaceport	• Just-in-time training and performance support with heads-up display provide unique training aids	• Getting consistent procedures • Eliminating the uniqueness in procedures • Accuracy of instructions • Overcoming local customs • Inconsistent training content and methods across spaceports/ programs	• Spilt-screen virtual reality helmet performance support • Voice recognition/synthesis to support procedures execution
	• Environmental management (e.g., monitoring, sensing, testing – hazardous gas) • Sense, mitigate, contain • Issues: run-off, acoustic, venting, RF	• Real-time, proactive mitigation • Coordinated with other spaceports for rerouting • Advanced acoustic techniques • Advanced containment methodologies • Automated frequency control across devices	• Tightening regulations • Sensing • Efficient protocols to connect the sensors within the webs • Streamlining the environmental licensing requirements • No common thread for sensors • No standard technical approach to sensing • Federal, state, and local regulatory agencies are not coordinated – overlapping and inconsistent regulations	• Plug & Pplay sensors • Protocols • Integrated environmental monitoring system • Integrated sensing web • Sound wave cancellation and suppression techniques • Simulation of RF • Advanced receiver and antenna design • Lower-power amplification • Spread spectrum or frequency allocation
	• Imagery/graphics (e.g., surveillance of operations) • Monitoring of vehicles as they flow through spaceport • Closeout photos • Photographic services • Documentation of operations and problem areas • Capture, distribute, archive, and analyze	• Autonomous surveillance of operations • Autonomous tracking system for departure and arrival • Balance online and offline activities • Complete spectrum of capturing means (e.g., optical, x-ray, infrared) – use complete electromagnetic spectrum	• Volume of imagery receiving • Time-consuming to find image needed • Getting clear images of ascent phase • Cost risk • Archival of large volume	• “MRI scan”-type, roll-through, full electromagnetic monitoring • Fly-around sensors • Advanced receptors and filters • Integrated sensors combining multiple sensing • Fully automatic tracking cameras • Advanced data search engines for retrieval
	• Custodial • Hazardous and biological waste handling	• No-waste spaceport	• Diverse set of hazardous items that don’t have a mechanism to reuse, make useful, or neutralize	• Advanced composting • Scrubbers • See medical industry for examples
	• Information technology architecture (e.g., communication architecture/ network at the spaceport, IT security)	• Seamlessly integrated with global spaceport and customer network • Plug & Play • Highly secure to appropriate users • Communications nodes throughout the facility wherever they are needed • Remote access to spaceport network for operations • Integrated media (voice, data, video)	• Cost to convert • Limited bandwidth • Security of wireless	• Easily switching of wiring throughout a building • Encryption/wireless • Secure, open networks • Office-hours cooperating information grid
	• Utilities (e.g., power, water, fuel/ commodity lines)	• Integrated utility and propellant self-sustaining capability on the spaceport (e.g., cogeneration) • Use state-of-the-art technology for water and sewer utilities	• Expensive to move cryogenic items over a distance (e.g., piping) • Efficient pumping • Integrating utility and commodity production • Risk management and perception of hydrogen	• Advanced cryogenic distribution handling techniques

Spaceport Provided Support Services (N)

	System/Function	Far (2028)	Challenges	Technical Approach
Consumer Services	• Shops, food services, entertainment, postal, money exchange, hotels, etc.	• Microeconomy within the spaceport – spaceport enterprise	• Developing an integrated business and legal/municipality concept	• Strategic community planning • Business incentives
Maintenance of Spaceport Infrastructure	• GSE ops and maintenance • Facility O&M • Don't change availability to do the maintenance	• All facilities and equipment fully available at all times – no operational impact due to maintenance • Manage based on degradation rather than failure	• Determining the appropriate maintenance intervals • Inadequate budget	• Maintenance scheduling algorithms • Self-diagnosing, testing, healing facilities and GSE • Ground health monitoring
Security	• Spaceport grounds security • Information security/ITAR • Personnel security screening (e.g., badging/access) • Operations/area security (e.g., protecting the vehicles, public screening) • Customs	• Ubiquitous security • Integrated access control and security • Freedom to operate – nonhindering security • Three-dimensional perimeter detection and autonomous response across the spaceport	• Balancing passenger screening and spaceport personnel screening • Identifying/tracking people	• Physical characteristic/biometric scanning is the central source for identifying people throughout the complete process • "Personal signatures" recognition • Passive surveillance systems
Emergency Services	• Fire • Medical • Haz mat • Emergency management response	• Preventive emergency service is the focus • Uninterrupted service during an emergency operation	• Dealing with untrained, public passengers through the spaceport • A wide range of scenarios and hazardous materials • Response to the different materials are many • Different skills for the response team members • Keeping emergency personnel proficient	• Enhanced sensor technology • Decision support systems for response level determination • Simulation-based practice/training and procedures
Industrial Safety/ Occupational Health	• Health checks and certifications (public and employees) • Quarantine • Personnel protective equipment • Incident management	• Eliminate the hazardous operations and workplace • Spaceport architecture accommodates the public going through the spaceport • Embedded sensors	• Protecting humans from hazardous operations • Understanding potential impacts from operations	• Virtual prototyping of operations and workplace, operations environment • "Virtual klutz" • Personnel health monitoring • Secure areas (storm cellars) – safe zones • Individual shields • Advanced SCAPE suits • Electronic canary

Offline Maintenance, Repair, and Overhaul (O)

System/Function	Far (2028)	Challenges	Technical Approach
Inspect (came to here from scheduled maintenance or something went wrong)	• Nonintrusive • Self-inspect with automated systems • Longer intervals between required inspections • Easy access • Linked to health monitoring	• Strength and durability of structures • Fluid leak detection • Connections • Decontamination to begin the inspection process • Accessibility	• Strength of materials • Health monitoring for prognosis (move beyond monitor, diagnostics) • Sensors for detection • Predictive algorithms • Artificial intelligence
Modify/Repair/Rebuild	• Self-healing structures and systems	• Nonoperational elements worked • Reliability achieved through redundancy rather than long life	• Design for reliability • Build to last • Fewer and less expensive parts • Move space qualification standard toward the commercial-grade standard • Integrated requirements management tool to support individual users/ technicians
Reassemble	• Little or no reassembly • Self-verification of interfaces • Durable interfaces • Minimize interfaces	• Fragile components • Expensive • Confined spaces • Lack of intelligent layout of parts for maintenance	• Virtual prototyping for maintainability analysis
Test	• Self-test • Self-healing	• Don't design for long life • Don't design for maintainability or testability • Lack of demonstrated reliability	• Virtual prototyping for maintainability analysis • Artificial intelligence • Intrinsic IHM should provide retest capability • Self-verifying interface

Appendix I
Plug & Play Challenges and Technical Approaches

		Receive and Accept Flight Elements (A1)	Assemble Flight Elements (B1)	Service and Checkout Flight Elements (C1)
Advanced Servicing	Challenge	• Purge and maintain environmental controls for active systems • Deservicing after receipt • Remove protective covers	• Safety concerns • Lack of blowout capabilities	• Multiple fuels, propellants, fluids • Hazardous operations • Waste stream generation • Many grades of same fluids • Commodities are kept onsite • Need to certify hoses • Use manifolds, isolation valves, drainbacks
	Technical Approach	• Environmentally sealed elements • New designs to balance zero- and 1-g environments • Reduce the need for conditioning of lines and purging	• Modular line units • Standardized servicing approaches	• Minimize breaking the systems • New techniques for fluid handling and transfer • Materials for handling hazardous fluids • Keep lines hot to the vehicle
Transportation, Handling, and Assembly	Challenge	• Special fixtures and equipment • Receive from all modes • Vertical and horizontal repositioning/ reorientation • Different transportation along the flow • Incrementally receive • Multiple and unique interfaces	• Requires multiple, special facilities • Moving of hazardous or radioactive elements • Major structural assembly • Movement to multiple facilities • Interfaces/connections are inconsistent and numerous • Unique access • Maintaining single orientation throughout processing • Safety concerns • Weather-dependent	• Toxic/hazardous commodities • Waste stream generation • Numerous grades of same fluids • Commodities are kept onsite • Use manifolds, isolation valves, drainbacks • Many storage tanks • Cryogenic operations • Closeout of servicing ports • Leaks • Multiple, nonstandard connections/interfaces • Preuse certifications • Gaining access to connections
	Technical Approach	• Standardized interfaces • Horizontal processing capabilities • Robust, standardized, safe class of all-weather transporters and containers • Optimized attached points	• Minimize amount of handling • Elements that do not require unique attitudes • Minimize need for clean room • Smart and multifunction buildings • Standardized transports • Modular LRUs • Minimized and automated assembly • Weather-independent ops • Clamshell • Standardized interfaces	• Minimize breaking the systems • New techniques for fluid handling and transfer • Materials for handling hazardous fluids • Self-verifying systems • Smart standardized interfaces • Self-sealing quick disconnects • Self-clearing interfaces • Automatic seals • Standardized access points • Better-insulated fuel tanks
Inspection & System Verification	Challenge	• Unique acceptance/inspection criteria • Unique equipment • Damages in shipping • Mostly visual and manual • Recomplete factory test	• Serially intertwined testing • Unique equipment • Very intrusive • Hands-on • Paper trail is heavy • Specialized labor skills	• Redundant, intrusive, and incremental checkout and test • Unique HW and SW • Limited access during and after fuel • Hazardous environment
	Technical Approach	• Minimize need to validate and verify SW • Automated testing and inspecting	• Minimize need to validate and verify SW • Automated testing and inspection • Intelligent analysis • Self-verifying, modular, interfaces • Integrated health monitoring • MEMS	• Telepresence heads-up displays • Nondestructive sensors • Integrated health management • Remote sensing
Command, Control, and Monitoring	Challenge	• Environmental controls • Element-unique monitoring equipment	• Environmental controls • Element-unique monitoring equipment • Maintain quality assurance and documentation	• Using launch consoles for checkout and control • Labor-intensive • Non-real-time data reductions
	Technical Approach	• Automated environmental monitoring and tracking • Self-contained test units • Smart shipping containers (pods)	• Automated environmental monitoring and tracking • Self-contained test units	• Automated, remote sensing techniques • Integrated monitoring systems • Advanced hazardous detection systems • Integrated checkout and maintenance system
Planning/Documentation/ Analysis/Learning	Challenge	• Nonstandard, slow, paper, labor-intensive documentation methods • Limited cross checks • Analyzing records of shipment for off-nominal conditions • Capturing lessons learned	• Nonstandard, slow, paper, labor-intensive documentation methods • Conflicting checklists • Numerous approvals • Difficult real-time changes • Diverse configuration control systems • Analyzing records for off-nominal conditions • Capturing lessons learned • Processes that depend on craftsmanship	• Labor-intensive • Subsystem-unique/-centric • Do not capture configuration change information • Procedures have too many optional steps
	Technical Approach	• Common standard for documentation • “Turbo Tax” • “FedEx” tracking • Monitoring in transporter • Automated, intelligent, real-time analysis • Data warehousing	• Automated work instructions • Automated check-offs • Standardized format • Voice interfaces • Heads-up displays • Automated, real-time, intelligent analysis • Data warehousing	• Standard procedures • Automated configuration management systems • “Turbo Tax” for procedures

		Payload Element Receipt and Acceptance (A2)	Assemble Payload Elements (B2)	Service and Checkout Payload Elements (C2)
Advanced Servicing	Challenge	• Standard services • Tying different sources together (e.g., 50 vs. 60 Hz)		• Keep cryos cold • Loading hazardous commodities/ ordnances • Contamination control • Incremental servicing
	Technical Approach	• Environmentally sealed payloads • Minimal purging required • Reduce the need for conditioning of lines	• Move servicing to Gas & Go • Standardized servicing approaches	• New techniques for fluid handling and transfer • Materials for handling hazardous fluids • Keep lines hot to the vehicle – no conditioning • Remote sensing of contaminants
Transportation, Handling, and Assembly	Challenge	• Lack of standard approaches • Clean payload transporter before moving into controlled facility • Facilities for environmental/contamination control/monitoring • Securing facilities • Lack of a national ICD for payload-to-spaceport interfaces	• Unique/customized handling • Nonstandard container/interfaces and connectors • Clear under lifts • Building subassemblies • Unique GSE installation/checkout • Aligning components	• Hazardous commodities and ordnances • Difficult to set up and move access stands • Suspended loads • Multiple, unique subsystem interfaces
	Technical Approach	• Standardized interfaces • Standard all-weather container • Same transport and lifting interfaces • A payload-to-spaceport ICD	• Minimize amount of handling • Smart, multifunction buildings • Standardized transport, payload-to-spaceport, and assembly interfaces • Weather-independent ops • Modular, easy-access, wireless, and self-verifying interfaces	• Standardize movement within spaceport • Robotic handling • Self-verifying systems • Smart, standardized interfaces • Self-sealing quick disconnects • Self-clearing interfaces • Automatic seals • Standardized access points
Inspection & System Verification	Challenge	• Complex and lengthy • Each payload is unique • Lack of standards/unified approach	• Iterative verification at launch site • Buried or layered components result in retesting	• Incremental checkout
	Technical Approach	• Automated • Self-contained test units • Smart shipping	• Automated • Intelligent analysis • Integrated health monitoring • Self-contained test units	• Stereoscopic vision helmets • Heads-up displays • Wireless sensors • Remote sensing
Command, Control, and Monitoring	Challenge	• No “shipping” state-of-health data	• Monitoring state of health while assembling • Monitoring industrial safety	• Unique monitoring and commanding
	Technical Approach	• Automated environmental monitoring	• Automated tracking • Automated environmental monitoring • Integrated health monitoring • Autonomous command/control	• Automated/remote sensing techniques • Integrated monitoring systems • Advanced hazardous detection systems
Planning/Documentation/ Analysis/Learning	Challenge	• Preparing ITAR is ill defined • Tracking free trade zones usage • No real-time tracking of costs • Lack of integrated resource scheduling • Lengthy safety review process • Lack of central repository of initial inspection data	• Inventory tracking and control • Takes time to learn • One-shot deals leave no room for lessons learned	• Managing many checklists • Lengthy review/approval process • Configuration management and tracking • Everything is treated as a unique operation • Catching and using lessons learned
	Technical Approach	• Cafeteria plan for spaceport services • Standardized/minimal safety review • Common standard for documentation • Central repository • “FedEx” tracking • Intelligent analysis • Auto archive with easy access/retrieval • Integrated with trend analysis tools	• “FedEx” tracking of payload elements location and status • Automated work instructions and associated signoff • Data warehousing/archiving in real time • Ongoing intelligent analysis of data	• Automated/autonomous configuration management

		Integrate Flight System and Payload (D)	
Advanced Servicing	Challenge	• Contamination control • Maintain blanket purges	
	Technical Approach	• Advanced filtering • Eliminate need while mating elements • Self-contained flight elements – only mating is structural	
Transportation, Handling, and Assembly	Challenge	• Transporting hazardous materials • Integrating large, fragile, and delicate pieces across facilities • Complex positioning, rotating, and lowering of elements • Lifting, moving, and mating are done in different orientations • Manual alignment • Controlled and monitored moves • Specialized lifting fixtures and handling equipment (e.g., breakover fixtures) • 1-g limitations • Customized equipment and carrier panels • Gaining access to payload once inside vehicle	• Unique vehicle interface • Hookup and closeout interfaces • Too many and elevated umbilicals • Interfaces involve bridging pieces • Closeouts and cover plates • Too many nonstandard, complex, dangerous interfaces (e.g., ordnances) • Mechanically connect and then electrically test • Pyrotechnic separation • Weather impacts
	Technical Approach	• Minimize handling • Fewer connection points • Standardized transport modes • Self-contained hardware (e.g., factory-packaged for shipping, handling, assembly) • Self-contained payload • "Sensed" alignment (wireless technology) • Design for horizontal assembly and delivery • Transporter doubles as breakover fixture • Minimized and standardized interfaces (e.g., ICDs) • Alignment and positioning sensors (e.g., laser)	• Robotic and artificial intelligence/visual element mating • Provide utilities to need point • Nonpyrotechnic, debrisless separation techniques • Eliminate T-0 umbilicals – wireless • Self-verifying connections • Self-latching mechanisms • Clocked electrical connectors • Design guidelines for spaceport infrastructure • Simulation models for ground traffic management • Virtual reality planning and testing
Inspection & System Verification	Challenge	• Continuous checks – multiple subsystem and interface tests • Manual operations completed within the critical path • Many ground and range interfaces – need approval from range to perform certain tests • Weather-dependent • Multiple manual and electrical interface verification tests • Gaining physical access	
	Technical Approach	• Self-verifying interfaces • Self-fault isolation and repair systems • Integrated health management • Risk management approach • Noninvasive NDE techniques • Automated defect and material characterization systems • Standardized tests	
Command, Control, and Monitoring	Challenge	• Unique HW/SW • Using launch consoles for checkout and control • Non-real-time data reductions • Mission/vehicle unique control system	
	Technical Approach	• Automated, remote sensing techniques • Integrated monitoring systems • Advanced hazardous detection systems • Data fusion • Knowledge-based systems • Automated configuration control • Autonomous command and control	
Planning/Documentation/ Analysis/Learning	Challenge	• Multiple sources of database • Paper-based • Diversity of approvals for procedures and paperwork • Conducting trend analysis (e.g., determining out-of-family/out-of-spec issues – risk aversion) • Integrating requirements • Lack of standardized documentation formats • Difficult methods to make changes to documents • Integrating requirements with other systems • Verification data reduced after the fact • Who is in charge?	
	Technical Approach	• Standard, paperless system for document generation and approval • Standardized processes • Automated plan generation, deconflicting, scheduling, and approval • Heads-up display of procedures • Automated go/no-go criteria • Integrated health management • Automated, integrated trend analysis • Automated responsive, dynamic requirements management • Simulation models for preplanning • Automated decision models • Data warehouse • Electronic approvals • Comprehensive health management • Risk management intelligence	

		Execute Departure Operations (E)	
Advanced Servicing	Challenge	• Weather-dependent • Last-minute power requirements for last possible moment for vehicle • Final commodity fueling and topping is hazardous operation and requires contamination control • Need to condition lines for cryogenics before pump-through	
	Technical Approach	• Minimize servicing required • Nonvolatile fuels • Advanced fluid system filtering, storage, and transfer • Robust fluid systems for weather mitigation • Service station approach • Nonintrusive instrumentation for cryogenic system	• Autonomous umbilical • Self-cleaning, leak-free mechanical interfaces (quick disconnects) • Automatic deicing • High-accuracy, multiparameter leak detection capability • Visualization techniques for fire detection and enhanced hydrogen fire detection
Transportation, Handling, and Assembly	Challenge	• Large amount of structure around vehicle to be retracted and stowed • Last-minute handling • Runway orientation • Vertically stacked element movement • Final component installation • Flight crew systems • Battery activation	• Range safety system activation • Number of interface and umbilical connections • Potential move to final departure point • A lot of T-0 umbilicals • Last-minute connection of pyrotechnic devices • Control hazards through brute-force methods
	Technical Approach	• Wireless sensors • Clean pad and clean runway • Transport under own power to departure point (horizontal) • Eliminate by design • Artificial vision • Rechargeable batteries • Self-healing seals • Sealing technology • Leak detection	• Eliminate confined spaces • Eliminate potential leak sources • Integrate and fuel at or as close to departure point as possible • Use rechargeable batteries • Wireless sensing and commanding • Minimize and automate umbilicals with self-verifying interfaces • Leak-free mechanical interfaces (quick disconnects) • Wireless or laser communications • Decouple payloads from other systems
Inspection & System Verification	Challenge	• Final FTS checks • Countdown procedure = final checkout • Restriction on available data – bandwidth-limited • Loading range safety code is manual • People in danger for final inspection	
	Technical Approach	• Artificial vision and intelligence • Integrated health monitoring • Onboard sensing • Fault-tolerant systems • Remote sensing of hazardous gases and high-accuracy optical techniques for gas imaging • Self-fault isolation and repair systems	
Command, Control, and Monitoring	Challenge	• Loading range safety code is manual • Pseudoautomated process – direct touch • Many people in the decision loop • Limited by weather • Final FTS checks • Countdown procedure = final checkout	
	Technical Approach	• Centralized launch management • Automated hand-off between launch and flight management • Automated go/no-go criteria • Risk management approach • Automated decision-making process: knowledge-based decision tools and adaptive reasoning advisors • Automatic hardware recognition and configuration • Data visualization • Software fusion • Automated and remote sensing techniques • Remote optical imaging for fire detection and leak detection	
Planning/Documentation/ Analysis/Learning	Challenge	• Lots of interaction for approval to launch • Massive critical requirements documentation process • Manually recording and processing thousands of measurements and comparing to family and trends • Limited lessons learned • Limited operational learning opportunities • Integration of requirements between vehicle owner/operator and payload developer	• Modifications for flight data files – hard to get in last-minute changes • Who is in charge? Who notifies NORAD and other countries? • Lengthy planning process • Flight plan development (e.g., trajectory) • Large quantity of data needs to be recorded and processed • Information shared verbally over comm nets
	Technical Approach	• Automated systems • Real-time data reduction, configuration control analysis • Automated, intelligent processing • Data warehousing and archive • High-fidelity training models	• File COMBO analysis and orbit insertion data similar to flight plan • Risk management • Automated trend analysis • Semantic networks and AI tools • Knowledge-based decision tools

		Monitor, Control, and Manage the Flight (F)
Advanced Servicing	Challenge	• Airborne servicing in some concepts
	Technical Approach	
Transportation, Handling, and Assembly	Challenge	• Some flights require mobile comm assets – expensive • Multiple communication architecture paths • Network of spaceports communicating with each other • Need mobile range information equipment • Distributed spaceport communications
	Technical Approach	• Comprehensive communication architecture
Inspection & System Verification	Challenge	• Limited ability for onboard abort situation • Limited onboard inspection (Shuttle) • Making the deploy/no-deploy decision and communicating the decision are manual and distributed across a variety of “nets”
	Technical Approach	• More robust onboard sensors and health management • Wider abort envelope • Self-checkout and analysis
Command, Control, and Monitoring	Challenge	• Limited ability for onboard abort situation • Limited onboard inspection (Shuttle)
	Technical Approach	• Integrated with NAS • Reduce need for ground communication
Planning/Documentation/ Analysis/Learning	Challenge	• Little real-time analysis and planning • Unique to each mission • Limited onboard data monitoring • Determining the data the payload operator wants/needs • Data reduction is completed postmission • Multiple agency approval • Cumbersome alternative trajectory analysis • Limited bandwidth
	Technical Approach	• Real-time replanning • Intelligent autonomous system • Automated flight plan generation and analysis • Automated risk management • Automatic data reduction • Data compression • Integrated health monitoring with logistics • Transfer to crew or intelligent autonomous system • Automated monitoring • Exception data reduction

		Land/Recover Flight Element and Payload Elements (G)	
Advanced Servicing	Challenge	• Need for active safing systems while on the ground • Hazardous operation • Nonroutine • Removing hazardous commodities/materials • Long delay for clearance to approach vehicle • Protective equipment required for approaching vehicle after landing	
	Technical Approach	• Self-safing and self-inerting vehicle systems • Mobile purging/safing/environmental systems or automated purging • Hot tanking operations for turnaround operations • Area for environmental safing • Standard interfaces • Minimize hazardous commodities used • Robotics for remote sensing	
Transportation, Handling, and Assembly	Challenge	• Dedicated and special support equipment • Vehicle is toxic and dangerous to handle • Crew cannot egress • Sensitivity to FOD, weather, and wildlife • Destowing time-critical items • Unique portable access equipment • Mobile interfaces to get to hangar • Transporting hazardous payload • Storing payload • Handling contaminated/hazardous elements • Payload may be inaccessible	• Gaining access for safing may be difficult • Complex interfaces • Too many different and dangerous connections • Closeouts and cover plates • Connecting to ground support systems • Long time to get ready from recovery • Crew cannot egress without assistance from ground operations • Distance for vehicle to travel to its servicing point • Contaminated situations • Special equipment required to gain access to various areas on the vehicle • Mechanical or physical safing of active systems
	Technical Approach	• Get to staging area under own power • Automated purging • Autocleaning runways/auto-FOD detection • Instrumented tarmac • Standardized interfaces • Mobile purging/safing/environmental systems (e.g. clamshell operations) • Automated/autonomous hazard monitoring, assessment, and purging	• Robotic towing and handling • Decontamination facility • Docking station to remove payload easily and readily • Self-contained payload • Wireless connections for data transfer • Laser communication systems • Nonpyro separation systems
Inspection & System Verification	Challenge	• Runway inspections • Hazardous operations • Landing systems deposit debris on landing area • Visual inspection techniques	
	Technical Approach	• Robotic inspections • Advanced imaging systems • Wireless communication • Standardized interfaces to any transporter • Laser imaging (“MRI”) for vehicle • Remote hazards detection	
Command, Control, and Monitoring	Challenge	• Hazardous gas detection • Hand-off from mission control to firing room • Single mission capability • Mechanical or physical safing systems • Weather-dependent • Monitoring contamination levels	
	Technical Approach	• Remote hazards detection • Remote, automated command and control • Automated sequencing • Robotic inspections • Advanced imagery systems • Wireless connections for data transfer • Laser communication systems	
Planning/Documentation/ Analysis/Learning	Challenge	• Big checklist • Can’t change plan easily • Manual crew debrief • Limited flexibility to adapt to real-time changes • Learn as you go	
	Technical Approach	• Heads-up displays • Integrated health monitoring • Data warehousing • Automated debrief systems • Wireless sensor network assessment of state • Autonomous command and control • Automated checklist generation based on the reported “state” • Responsive planning • Fault identification data transfer from vehicle integrated health monitoring	

		Prepare Flight Elements for Turnaround or Disposal (H1)	Prepare Payload Elements for Turnaround or Disposal (H2)	Restore / Remanufacture Flight Element (I1)	Refurbish / Remanufacture Payload Element (I2)
Advanced Servicing	Challenge	• Processing hazardous materials • Decontaminating • Completed in special and separate facilities • Special equipment	• Hazardous operation • Nonroutine • Hazardous material disposal • Environmental monitoring and control • Weather-dependent	• Completed in special and separate facilities • Hazardous operations • Labor-intensive • Special equipment • Corrosion control	• Specialized tooling • Mechanical system lubrication • Determining what to repair • Component repair and replacement
	Technical Approach	• In-place deservicing • Modular deservicing		• In-place deservicing • Modular deservicing	
Transportation, Handling, and Assembly	Challenge	• Jack and level • Position access • Environmental and ground support • Access the access • Time-consuming to open access points • Lots of systems to be removed and documented	• Sensitive and live cargo • Hazardous operations • Residual fluids – toxics • Attitude requirements • Unique transport methods • Many interfaces/connections • Contaminated and hazardous environment • Unique orientation, methods, and tools for disassembly • Breaking connections without breaking the connectors • Hard to gain access	• Specialized handling equipment • Position access • Environmental support • Access the access points • Multiple facilities • Time-consuming to open/close access points • Labor-intensive • Many systems to document • By taking apart, may break things that weren't broken • Lots of interfaces and connections	• Specialized handling tools • Unique storage and packaging • Retaining operators' certification • Ensuring connectors don't get damaged • Restoring to a configuration
	Technical Approach	• Use standard facilities • Standard access points • Movable access platforms	• Standardized containers • Clamshell • Self-sustained, contained payload • Common, automated offloading equipment • Phased inspections, periodic phased maintenance • In situ deservicing	• Standard facilities • Standard access points • Movable access platforms • Common handling and shipping containers/fixtures • Phased inspections, periodic phased maintenance	• Standard, self-contained shipping container • Standard hangar/facilities • Standard access points
Inspection & System Verification	Challenge	• Labor-intensive • Documenting state of the systems	• Hazardous • Time-consuming	• Labor-intensive • Determining what needs to be serviced • Documenting systems' state • Determining electrical system integrity	• Functional verification, recertification, and calibrations
	Technical Approach	• Integrated health monitoring • Phased inspection • Integrated logistics and maintenance systems	• Standard interface to support equipment	• Integrated health monitoring • Robotic inspection • Integrated logistics and maintenance systems • Nondestructive testing • Wire inspection methods	• Standard interface
Command, Control, and Monitoring	Challenge	• Recalibrating elements • Power up entire flight system to check out a single system • Complex scheduling system	• Monitoring of environmental and confined spaces • Hazard control and monitoring	• Recalibrating elements • Power up entire flight system to check out a single system • Complex scheduling system	• Maintaining environmental conditions
	Technical Approach	• Automated scheduling • Automated subsystem test • Integrated health monitoring	• Self-test/self-reporting of status	• Automated scheduling • Automated subsystem test • Integrated health monitoring	• Integrated health/self-inspection/self-reporting
Planning/Documentation/ Analysis/Learning	Challenge	• A lot of documentation • Big checklist • Can't change plan easily • Diverse providers/formats • Diverse system requirements • Extensive postflight analysis – recording quantities of residuals to feed back to systems owners • Manual process	• Determining and documenting the condition of the payload elements is manual and nonstandardized • If contaminated, can't gain access	• Big checklist • Can't change plan easily • Diverse providers/formats • Diverse system requirements • Manual process	• Configuration control • Documenting any discrepancies • Updating configuration data • Updating performance metrics • Initiating corrective actions • "Tribal" knowledge not captured
	Technical Approach	• Paperless systems • Standardized documentation • Integrated health monitoring • Data warehousing • Self-diagnosing and self-healing • Automated scheduling of necessary support • Automated checklist generation based on state-of-health data • Heads-up displays		• Heads-up displays • Paperless systems • Standardized documentation • Integrated health monitoring • Data warehousing • Automated scheduling of any calibration • Self-monitoring/self-healing • Automated checklist generation based on self-diagnosis	

		Restore / Reservice Ground Systems for Reuse (J)
Advanced Servicing	Challenge	• Specialized tooling • Lubrication of mechanical systems • Determining what to repair (unplanned) • Repair/replacement of components • Contamination control • Safety and environmental • Commodity replenishment • Drainback
	Technical Approach	• Onsite commodity production and distribution • Materials that minimize periodic maintenance • Low-maintenance fluid transfer lines • Low-loss or zero-loss propellant storage • Advanced payload equipment storage facilities
Transportation, Handling, and Assembly	Challenge	• Unique/customized handling, tooling, equipment • Retaining operators' certification • Infrastructure interfaces are destroyed during launch • Massive refurbishment efforts required
	Technical Approach	• Standardized cranes • Universal and flexible stands, platforms, and transporters • Standardized fixtures • Advanced storage facilities • Flexible platforms and transporters • Modular, standardized, containerized system • Connector covers • Configuration control • Sacrificial interfaces • No T-0 umbilicals • Wireless interfaces • Blastproof umbilical compartments
Inspection & System Verification	Challenge	• Functional verification, recertification, and calibrations
	Technical Approach	• Self-fault isolation and repair systems • Condition-based maintenance • Self-checking systems • Maintenance on demand
Command, Control, and Monitoring	Challenge	• Maintaining environmental conditions
	Technical Approach	• Condition-based maintenance • Standardized information systems
Planning/Documentation/ Analysis/Learning	Challenge	• Configuration control • Determining future needs to stage and configure equipment • Time-consuming to collect and manage detailed maintenance records • Cumbersome to identify and track discrepancies • Updating configuration • Updating performance metrics • Initiating corrective actions • "Tribal" knowledge
	Technical Approach	• Configuration control systems • Automated planning tools • Learning databases/tool • Configuration management tools • Knowledge-based systems • Predictive maintenance

Spaceport Logistics

Sub-function	Challenge	Technical Approach
Support Maintenance Operations	• Vehicles don't have the design margin – no system for predictive maintenance systems – limited capability for predictive maintenance systems • Manual trending • Small fleet size – small buys • Lack of consistently following vehicle design guidelines • Tracking of tools, unique tools • Paradigm that logistics is least important, low priority – not enough $ to buy all the parts needed • Undependable systems • Limited design corrective action/design taken • Cost of downtime is high • Availability drives the requirement for spares • Large number of unique parts for each vehicle	• Integrated with vehicle health monitoring • Rapid onsite prototyping/manufacturing of space-qualified items • Seamless ordering on the floor for pickup on the floor • Management control of design process to minimize the tools
Manage Supply	• Transportation • Maintainability and reliability data collection and analysis are lacking for predictive maintenance • Technology limitations for cryogenic material storage and transfer • Integrating the various information systems • Intelligent storage facilities • Hazardous materials – volume limited by transportation and storage	• Integrated with vehicle health monitoring • Standardized shipping containers • Computerized storage facilities • Onsite production of commodities
Perform Logistics Engineering Analysis and Planning	• Limited number of qualified vendors • Low demonstrated reliability • Inadequate testing of new systems • Ability to influence the design • Lack of integrated metric data capture • Lack of design for maintainability, design using metrics • Custom processes • Flight certification of components • Incomplete documentation and multiple formats/dialects	• Design guidelines • Integrated design environments that include logistic functions • Automated data capture and analysis • Simulating techniques to assess reliability/maintainability vs. testing to failure • Online, real-time, centralized documentation – universally available
Track Logistics Information IT/Logistics Information Systems	• Not using off-the-shelf inventory management systems • Distributed systems • Manual • Diverse data formats • Lack of compatibility • Proprietary information • Time-consuming to collect data • Workforce doesn't see the need for the data • Lack of recording of data for contractual advantages • No "ACME" spaceport provider • RF-unfriendly environments • Export control	• Integrated health monitoring systems • Smart systems – sensing and instrumentation built into the structure • Automated data collection • More wireless technologies

Management of the Spaceport and Flight Operations (M)

Function	Challenge	Technical Approach
Customer Services	• Growing the paying customer/payload market – increase the demand for flights • Lack of integrated design approaches and tools that incorporate spaceport operations • Too many organizations required to communicate requirements • Changing environments for vehicle • Lack of historical data • Change in mind-set to design for operations	• "Turbo Tax" • Design guidelines for operations vs. performance • "Vision spaceport"-type tools • Integrated engineering environment tools
Strategic Management	• Strategic thinking • Supporting next-generation vehicles • Being vehicle-centric • Political and regulatory environment • Funding • Prematurely deploying immature technology • Getting away from being vehicle-centric • Political and regulatory environment (e.g., ITAR, EPA and noise, range safety, orbital space) • Limited investment capital	• Virtual prototyping and simulation • Business case – criteria for viability • Metrics tracking and analysis • Development and communication of standards for vehicles and payloads • Testbeds to mature the technology development for operational use • Establish industry association board for operators (e.g., AIA)
Business Management	• Adapting business models and processes for a spaceport • Gaining buy-in and funding to develop the models • Getting the data/tracking the data	• Spaceport operations management discipline • Data acquisition/tracking systems • Useful metrics to help drive improvement • Cost models for spaceport operations
Engineering	• Lack of standards • Increasing reliability without increased cost • Large amount of engineering skills devoted to sustaining operations vs. improving product/process • Majority of spaceport engineers trained on to how maintain a specific system vs. understanding the larger system and why the function is performed • Changing the culture to support innovation • University to develop spaceport operations degree	• Develop spaceport engineering, operations standards • Develop spaceport operations curriculum • Developing modeling and simulation capability to test design with real-world concerns
Operations Safety, Health, and Mission Assurance	• Lack of incentives to simplify approaches • Changing paradigm from risk aversion to risk management • Changing job from "why we can't do it" to "how we can help" • Lack of ability to demonstrate safety	• Ground system testbed • Dedicated test flight facility to certify new systems

Management of the Spaceport and Flight Operations (M)

Function		Challenge	Technical Approach
Operation Management	**Requirements Management**	• Don't start at top-level requirements • Not documented • Not well understood • High level of changes to requirements for every flight • Large volume of requirements within inconsistent definition of levels and flowdown • Lack of management and control • Still determining requirements • Need to make money	• Automated closed-loop requirements management tools • Systems approach to operations • Requirements tied to verifiable measures
	Operations Risk Management	• Proper identification of risk • Don't understand what risk is • Don't use best tools	• Risk management tools for spaceports • Automated analysis for of procedures for risk
	Configuration and State Management	• Many parts to keep track of • Keeping track of process configuration and state of the spaceport • Reconfiguring for different operations	• Smart-chip tracking of parts • Bar codes • Enhanced weight-and-balance algorithms (vehicle) • "Preflight" checklist
	Work Control & Scheduling	• Current and diverse operational philosophies • Implementation costs • Lack of good, consistent, relevant data • Scheduling is an art, not a science • Cost to convert from legacy to new • Lack of situational awareness • Immense number of tasks to produce a flight • High level of skill required	• Standard processes and philosophies • Data management • Decision support tools • Scheduling algorithms • System integration across all disciplines • Wireless "PDAs"
	Work Authorization	• Current philosophies • Blurring of operational and development systems • Spreading of responsibility – everyone must sign the paper • Unique procedures	• Groupware • "Turbo Tax" • Standardized procedures
	Analysis, Learning, and Process Improvement	• Hard to improve nonstandard processes • Limited incentives • Lack of data	• Commitment to formal operations improvement program • Automated feedback to procedures • Task analysis tools
	Operations Data Management	• Data not in format that can be easily captured • Not a customer-oriented data access system for trending • Not having the right amount of data • Different terms for different items	• Drop menus for data capture • Consistent terminology, taxonomy
	Documentation	• Current philosophies • "Pay by the pound" • Duplicate information • Updating information	• Standard formats
	Maintain Interface and Compliance With Licensing, Export/ITAR, and Safety Regulations/ Regulators	• Getting everyone on the same page • Gaining political advocacy and participation to scope new regulations • "My job" syndrome	• Technical group and analysis for space worthiness criteria • Standards development for space worthiness criteria

Spaceport-Provided Support Services (N)

Function		Challenge	Technical Approach
Consumer Services	**Shops, food services, entertainment, postal, money exchange, hotels, etc.**	• Developing an integrated business and legal/municipality concept	• Strategic community planning • Business incentives
Maintenance of Spaceport Infrastructure	**GSE/facility ops & maintenance**	• Determining the appropriate maintenance intervals • Inadequate budget	• Maintenance scheduling algorithms • Self-diagnosing, -testing, -healing facilities and GSE • Ground health monitoring
Security	**Spaceport grounds, information, personnel, operations, security, and customs**	• Balancing passenger screening and spaceport personnel screening • Identifying/tracking people	• Physical characteristic/biometric scanning is the central source for identifying people throughout the complete process • "Personal signatures" recognition • Passive surveillance systems
Emergency Services	**Fire, medical, haz mat, emergency management response**	• Dealing with untrained, public passengers through the spaceport • A wide range of scenarios and hazardous materials • Response to the different materials are many • Different skills for the response team members • Keeping emergency personnel proficient	• Enhanced sensor technology • Decision support systems for response level determination • Simulation-based practice/training and procedures
Industrial Safety/ Occupational Health	**Health checks and certifications; incident management**	• Protecting humans from hazardous operations • Understanding potential impacts from operations	• Virtual prototyping of operations and workplace, operations environment • "Virtual klutz" • Personnel health monitoring • Secure areas (storm cellars) – safe zones • Individual shields • Advanced SCAPE suits • Electronic canary
Support Services	**Training/ certification**	• Getting consistent procedures • Eliminating the uniqueness in procedures • Accuracy of instructions • Overcoming local customs • Inconsistent training content and methods across spaceports/programs	• Split-screen virtual reality helmet performance support • Voice recognition/synthesis to support procedures execution
	Environmental management	• Tightening regulations • Sensing • Efficient protocols to connect the sensors within the webs • Streamlining the environmental licensing requirements • No common thread for sensors • No standard technical approach to sensing • Federal, state, and local regulatory agencies are not coordinated – overlapping and inconsistent regulations	• Plug & Play sensors • Protocols • Integrated environmental monitoring system • Integrated sensing web • Sound wave cancellation and suppression techniques • Simulation of RF • Advanced receiver and antenna design • Lower-power amplification • Spread spectrum or frequency allocation
	Documentation of operations or/and problem areas	• Volume of imagery receiving • Time-consuming to find image needed • Getting clear images of ascent phase • Cost risk • Archival of large volume	• "MRI scan"-type, roll-through, full electromagnetic monitoring • Fly-around sensors • Advanced receptors and filters • Integrated sensors combining multiple sensing • Fully automatic tracking cameras • Advanced data search engines for retrieval
	Custodial and hazardous/ biological waste handling	• Diverse set of hazardous items that don't have a mechanism to reuse, make useful, or neutralize	• Advanced composting • Scrubbers • See medical industry for examples
	IT architecture	• Cost to convert • Limited bandwidth • Security of wireless	• Easy switching of wiring throughout a building • Encryption/wireless • Secure, open networks • Office-hours cooperating information grid
	Utilities	• Expensive to move cryogenic items over a distance (e.g., piping) • Efficient pumping • Integrating utility and commodity production • Risk management and perception of hydrogen	• Advanced cryogenic distribution handling techniques

Offline Maintenance, Repair, and Overhaul (O)

Function	Challenge	Technical Approach
Inspect	• Strength and durability of structures • Fluid leak detection • Connections • Decontamination to begin the inspection process • Accessibility	• Strength of materials • Health monitoring for prognosis (move beyond monitor, diagnostics) • Sensors for detection • Predictive algorithms • Artificial intelligence
Modify/repair/ rebuild	• Nonoperational elements worked • Reliability achieved through redundancy rather than long life	• Design for reliability • Build to last • Fewer and less expensive parts • Move space qualification standard toward the commercial-grade standard • Integrated requirements management tool to support individual users/technicians
Reassemble	• Fragile components • Expensive • Confined spaces • Lack of intelligent layout of parts for maintenance	• Virtual prototyping for maintainability analysis
Test	• Don’t design for long life • Don’t design for maintainability or testability • Lack of demonstrated reliability	• Virtual prototyping for maintainability analysis • Artificial intelligence • Intrinsic IHM should provide retest capability • Self-verifying interface

Appendix J
Abbreviations and Acronyms

ARTWG	Advanced Range Technologies Working Group
ASTWG	Advanced Spaceport Technologies Working Group
COLA	collision avoidance
COMSTAC	Commercial Space Transportation Advisory Committee
COTS	commercial off-the-shelf
DoC	Department of Commerce
DoD	Department of Defense
Ec	expected casualties
ELV	Expendable Launch Vehicle
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FOD	foreign object debris
FTS	Flight Termination System
GIDEP	Government-Industry Data Exchange Program
GPS	Global Positioning System
GSE	ground support equipment
HRST	Highly Reusable Space Transportation
HW	hardware
ICD	Interface Control Document/Drawing
IPT	Integrated Product Team
ITAR	International Traffic in Arms Regulations
IGHM	integrated ground health management
IPHM	integrated payload health management
IVHM	integrated vehicle health management
KSC	Kennedy Space Center

LOLI	limited-operating-life item
LPS	Launch Processing System
MEMS	Micro-Electromechanical Systems
MLI	multilayer insulation
MRI	magnetic resonance imaging
MSC	material service centers
NAS	National Airspace System
OEM	original equipment manufacturer
OMI	operations and maintenance instruction
ORM	operational risk management
OSHA	Occupational Safety and Health Administration
OSIDA	Oklahoma Space Industry Development Association
OSTP	Office of Science and Technology Policy
PHST	packaging, handling, storage, and transportation
RCA	root cause analysis
RF	radio frequency
RPC	remote power controller
RLV	Reusable Launch Vehicle
SCAPE	self-contained atmospheric-protective ensemble
SLI	Space Launch Initiative
SRB	Solid Rocket Booster
STC	Spaceport Technology Center
SW	software
TD&D	technical data and documentation
TDRSS	Tracking and Data Relay Satellite System
TFA	technology focus area

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