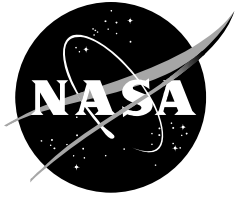


NASA/CP—2006–214202



**NASA Space Exploration Logistics Workshop  
Proceedings  
January 17-18, 2006  
Washington, DC**

---

**April 2006**

## NASA STI Program ... in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA scientific and technical information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NASA Aeronautics and Space Database and its public interface, the NASA Technical Report Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- **TECHNICAL PUBLICATION.** Reports of completed research or a major significant phase of research that present the results of NASA Programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.
- **TECHNICAL MEMORANDUM.** Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- **CONTRACTOR REPORT.** Scientific and technical findings by NASA-sponsored contractors and grantees.

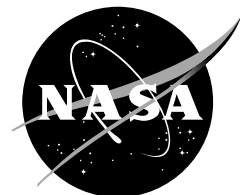
- **CONFERENCE PUBLICATION.** Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.
- **SPECIAL PUBLICATION.** Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.
- **TECHNICAL TRANSLATION.** English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include creating custom thesauri, building customized databases, and organizing and publishing research results.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at <http://www.sti.nasa.gov>
- E-mail your question via the Internet to [help@sti.nasa.gov](mailto:help@sti.nasa.gov)
- Fax your question to the NASA STI Help Desk at (301) 621-0134
- Phone the NASA STI Help Desk at (301) 621-0390
- Write to:  
NASA STI Help Desk  
NASA Center for AeroSpace Information  
7121 Standard Drive  
Hanover, MD 21076-1320

NASA/CP—2006–214202



# **NASA Space Exploration Logistics Workshop**

## **Proceedings**

**January 17-18, 2006**  
**Washington, DC**

The first Space Exploration Logistics Workshop, hosted by [MIT](#) and [SOLE](#) - The International Society of Logistics, was held in January 2006 at the Omni Shoreham in Washington, DC. Fifty-four participants from government, industry, academia, small business and trade/professional organizations participated in the workshop designed around targeted space logistics issues in support of NASA's Vision for Space Exploration.



Jet Propulsion Laboratory  
California Institute of Technology

**JPL**



Massachusetts  
Institute of  
Technology

Payload Systems Inc.



National Aeronautics and  
Space Administration

*Kennedy Space Center*  
*Kennedy Space Center, FL 32899-0001*

---

**April 2006**

Available from:

NASA Center for AeroSpace Information  
7121 Standard Drive  
Hanover, MD 21076-1320  
(301) 621-0390

This report is also available in electronic form at

<http://spacelogistics.mit.edu/workshops.htm>



The diagram illustrates a space exploration logistics network. It features a central yellow line representing a supply chain, connecting various nodes. On the left, a large Earth globe is shown with a network of red nodes and lines. A satellite is depicted in orbit around Earth. On the right, a smaller Earth globe is shown with a network of blue nodes and lines. A rocket is shown launching from the bottom left, following a curved path towards the top right. The background is black.

# NASA Space Exploration Logistics Workshop Proceedings

January 17-18, 2006  
Omni Shoreham Hotel  
Washington, DC



NASA Interplanetary  
Supply Chain Management  
and Logistics Architectures  
Project



SOLE-  
The International  
Society of Logistics



Massachusetts  
Institute of  
Technology



American Institute  
of Aeronautics and  
Astronautics

NASA Space Exploration Logistics Workshop  
January 17-18, 2006  
Omni Shoreham Hotel  
Washington, DC

## Executive Summary

As NASA has embarked on a new Vision for Space Exploration, there is new energy and focus around the area of manned space exploration. These activities encompass the design of new vehicles such as the Crew Exploration Vehicle (CEV) and Crew Launch Vehicle (CLV) and the identification of commercial opportunities for space transportation services, as well as continued operations of the Space Shuttle and the International Space Station. Reaching the Moon and eventually Mars with a mix of both robotic and human explorers for short term missions is a formidable challenge in itself. How to achieve this in a safe, efficient and long-term sustainable way is yet another question. The challenge is not only one of vehicle design, launch, and operations but also one of space logistics. Oftentimes, logistical issues are not given enough consideration upfront, in relation to the large share of operating budgets they consume. In this context, a group of 54 experts in space logistics met for a two-day workshop to discuss the following key questions:

1. What is the current state-of the art in space logistics, in terms of architectures, concepts, technologies as well as enabling processes?
2. What are the main challenges for space logistics for future human exploration of the Moon and Mars, at the intersection of engineering and space operations?
3. What lessons can be drawn from past successes and failures in human space flight logistics?
4. What lessons and connections do we see from terrestrial analogies as well as activities in other areas, such as U.S. military logistics?
5. What key advances are required to enable long-term success in the context of a future interplanetary supply chain?

These proceedings summarize the outcomes of the workshop, reference particular presentations, panels and breakout sessions, and record specific observations that should help guide future efforts.

### The Organizing Committee:

Olivier L. de Weck  
Assistant Professor of Aeronautics &  
Astronautics and Engineering Systems  
Massachusetts Institute of Technology  
[deweck@mit.edu](mailto:deweck@mit.edu)

William A. Evans  
Project Lead, Space Logistics  
United Space Alliance LLC  
[William.A.Evans@usa-spaceops.com](mailto:William.A.Evans@usa-spaceops.com)

Joe Parrish  
President, Payload Systems Inc.  
[parrish@payload.com](mailto:parrish@payload.com)

Sarah R. James  
Executive Director  
SOLE – The International Society of Logistics  
[solehq@erols.com](mailto:solehq@erols.com)

## Table of Contents

Executive Summary .....	5
Table of Contents .....	6
Acknowledgements .....	7
Plenary Presentations .....	8
Panel Sessions .....	9
Breakout Session Summary .....	10
Future Actions – Conclusions .....	20
Key Takeaways .....	20
Appendix A: List of Attendees .....	23
Appendix B: Agenda .....	26
Appendix C: Events/Conferences on Space Logistics .....	28
Appendix D: Space Logistics Resources .....	30
Appendix E: Additional Information .....	32

Electronic versions of all presentations and breakout summaries are available online at:

<http://spacelogistics.mit.edu/workshops.htm>

## **Acknowledgements**

NASA and the organizing committee wish to gratefully acknowledge the following individuals and groups for their outstanding support in organizing and conducting the workshop:

### ***Keynote and panel speakers*** (in order of appearance)

Prof. Olivier L. de Weck of the Massachusetts Institute of Technology  
Ms. Sarah R. James of SOLE – The International Society of Logistics  
Mr. William A. Evans of United Space Alliance LLC  
Dr. Martin Steele of the NASA Kennedy Space Center  
Dr. Robert Shishko of the Jet Propulsion Laboratory  
Dr. Douglas Stanley of the National Institute of Aerospace  
Mr. Brant Sponberg of NASA Headquarters  
Mr. Joe Parrish of Payload Systems Inc.  
Mr. Frank Cepollina of NASA Goddard Space Flight Center  
Mr. Tony Butina of NASA Johnson Space Center  
Dr. Kevin Watson of NASA Johnson Space Center  
Prof. David Simchi-Levi of the Massachusetts Institute of Technology

### ***MIT faculty, staff, and students***

Prof. Olivier de Weck  
Prof. David Simchi-Levi  
Prof. Diego Klabjan  
Mr. Mike Li  
Ms. Sarah Shull  
Mr. Matt Silver  
Ms. Christine Taylor  
Ms. Deanna Laufer

### ***Breakout session and presentation leads and facilitators***

Prof. Olivier de Weck, Massachusetts Institute of Technology  
Mr. William A. Evans of United Space Alliance LLC  
Dr. Robert Shishko of the Jet Propulsion Laboratory  
Ms. Sarah R. James of SOLE – The International Society of Logistics  
Mr. Joe Parrish of Payload Systems Inc.  
Mr. Tony Trovato of Raytheon Technical Services Company  
Dr. Martin Steele of NASA Kennedy Space Center  
Visiting Professor Diego Klabjan, MIT and University of Illinois, Urbana-Champaign

The staff of SOLE – The International Society of Logistics  
The staff of the Omni Shoreham Hotel, Washington, DC.



## **Plenary Presentations**

### ***Summary of Interplanetary Supply Chain Management and Logistics Architectures Project***

*Dr. Olivier de Weck, Massachusetts Institute of Technology, Cambridge, MA*

Dr. de Weck described the NASA-funded Interplanetary Supply Chain Management and Logistics Architectures (ISCM&LA) project, which is a collaborative effort between the Massachusetts Institute of Technology (MIT), the Jet Propulsion Laboratory (JPL), United Space Alliance (USA), and Payload Systems Inc. (PSI) to merge the fields of aerospace systems analysis and supply chain management to address the significant challenges for logistics support of our emerging space exploration goals.

### ***Overview and Objectives of Space Logistics Workshop***

*Dr. Martin Steele, NASA Kennedy Space Center, FL*

*Dr. Robert Shishko, Jet Propulsion Laboratory, Pasadena, CA*

*Mr. William A. Evans, United Space Alliance, Houston, TX*

Drs. Steele and Shishko and Mr. Evans described the overall agenda of the workshop, identified key objectives and expectations, and introduced the structure and processes to be utilized during the breakout sessions. See also Appendix B for a complete agenda.

### ***Reflections from the NASA Exploration Systems Architecture Study***

*Dr. Douglas Stanley, National Institute for Aerospace, Hampton, VA*

Dr. Stanley's presentation focused on key results and lessons learned during his leadership of the NASA Exploration Systems Architecture Study (ESAS). A number of aspects of the ESAS effort are relevant to space logistics—including design for commonality to support near-term missions to International Space Station (ISS), as well as longer-term logistics analysis and support of Lunar and eventual Mars bases.

### ***Logistics Lessons Learned from Space Telescope Servicing***

*Mr. Frank Cepollina, NASA Goddard Space Flight Center, Greenbelt, MD*

Mr. Cepollina reflected on key lessons learned during his tenure with NASA, going back to the Apollo era. Mr. Cepollina is presently the Deputy Associate Director, Hubble Space Telescope Development Project, and has played a leadership role in many of the spacecraft servicing missions conducted by NASA using the Space Shuttle. Mr. Cepollina's presentation addressed logistical aspects of on-orbit servicing, and showed that on-orbit servicing has been a cost-effective and successful approach for maintaining and extending the life of high-cost and scientifically productive space assets.

### ***Logistics Lessons Learned from International Space Station***

*Mr. Anthony Butina, NASA Johnson Space Center, Houston, TX*

Mr. Butina reflected on key lessons learned during his tenure as the Logistics Manager for the International Space Station Program. Mr. Butina discussed the simultaneous assembly and maintenance of the ISS as major challenges, along with the coordination of multi-national, multi-agency participants. Standardization and consistent logistics approaches across the entire program are major challenges for ISS. Mr. Butina felt that the ISS would be an excellent platform to prove and mature key logistics approaches for subsequent exploration missions.

## **Panel Sessions**

### ***NASA Reference Missions and Commercial Opportunities for Space Logistics***

*Dr. Douglas Stanley, National Institute for Aerospace, Hampton, VA*

*Mr. Brant Sponberg, Program Executive, NASA Exploration Mission Systems Directorate*

*Mr. Joseph Parrish, President, Payload Systems Inc.*

This panel session discussed both the NASA reference missions as well as potential commercial opportunities for space transportation and logistics.

Dr. Doug Stanley gave a summary of the NASA design reference missions (DRMs) for the future as recommended by the ESAS study. This includes a capability to send three astronauts to and from the ISS at regular intervals using a Block I CEV that has the ability to rendezvous and dock with ISS and remain attached to it for at least six months in a quiescent mode. The second DRM are lunar sortie missions - Apollo-style - but with a crew of four, a maximum of seven days of lunar surface stay and larger payload-to-the-surface capacity. This would be accomplished by a Block II lunar CEV. The third set of DRMs build up a lunar outpost—most likely at the lunar South Pole near the Shackleton Crater—which would comprise a combination of manned lunar flights and robotic pre-positioning and resupply flights. Open issues are the exact choice of propellant for the Service Module (SM) and Lunar Surface Access Module (LSAM) (LOX/LH2, hypergols, LOX/methane) as well as design details of the LSAM.

Brant Sponberg discussed the NASA Centennial Challenges and, in particular, the one dealing with demonstration of cryogenic refueling capability. Also, NASA has dedicated \$500 million over the next five years to build up a commercial capability to supply the ISS. The Commercial Orbital Transportation Services (COTS) proposals (<http://procurement.jsc.nasa.gov/cots/>) were received by NASA on March 3, 2006 and are currently under review. This will potentially have a fundamental impact on NASA's supply chain in space.

Finally, Joe Parrish gave a longer-term perspective in terms of future Mars Design Reference Missions. He showed timelines for a Mars campaign design reference mission (DRM) that had been developed by the Draper/MIT CE&R team in 2004/2005. The key point was that while the 27-month Mars launch windows pose challenges, they also offer opportunities if one extra element is consistently pre-positioned during the campaign. Specifically, by always sending ahead one extra Mars Ascent Vehicle and Habitat, a failure can be tolerated without disrupting the entire campaign. Thus, with a relatively modest increase in the number of elements that are pre-deployed, the mission risks at the campaign level can be dramatically reduced. Such benefits are missed if one only considers exploration on a mission-by-mission basis.

### ***Panel Discussion - Logistic Strategies for Space Exploration***

*Mr. Anthony Butina, NASA Johnson Space Center, Houston, TX*

*Dr. Kevin Watson, NASA Johnson Space Center, Houston, TX*

*Dr. Robert Shishko, Jet Propulsion Laboratory, Pasadena, CA*

*Dr. David Simchi-Levi, Massachusetts Institute of Technology, Cambridge, MA*

This panel discussion focused both on relevant lessons learned as well as on future strategies for logistics and supportability in NASA's Vision for Space Exploration.

Tony Butina discussed lessons from ISS logistics and ways in which to structure future space exploration supportability, logistics and maintenance functions. One of the key conclusions is that there needs to be close ties between Systems Engineering and Logistics & Maintenance functions, especially early during development. Specifically, the Systems Engineering and Logistics & Maintenance functions need to be co-located in the Program Office to ensure that the design of both "in-space" and "surface destination" hardware is done in a way that promotes mission safety, supportability and low lifecycle costs.

Kevin Watson, who is leading the Supportability Integration Group (SIG) within Project Constellation, explained the key concepts involved in Integrated Logistics Support (ILS). These include a balanced use of resources in terms of mass, volume, crew time and money, the minimization of mass and volume of spares, a multi-level maintenance capability, the imposition of commonality at all levels across elements, and the introduction of capabilities for in-situ fabrication of structural and mechanical replacement parts as-needed. Some of these ideas are not new, but have already been proven and tested in recent Department of Defense (DOD) campaigns. The challenge now is to infuse them into early program requirements and to make sure they are adhered to both within NASA, but also the contractor community.

Bob Shishko described a federation of models that already exist or are in development in support of space exploration logistics. Each of these capabilities model one aspect of the system and can talk to each other. At the center of this stand three tools: (i) SpaceNet, a discrete event interplanetary logistics simulation and optimization tool, and (ii) a tool for future lunar outpost trade space analysis developed at JPL, that relies on PRA (probabilistic risk assessment) models, vehicle design/performance models, logistics models, cost models and mission rates models to compute measures of effectiveness (MOEs) and project requirements on CEV and CLV design. The third model (iii) is an Exploration Architecture Operations Cost Model (ExAOCM) that quantifies the budgetary impact of operational scenarios. The major inputs affecting the MOEs of future exploration campaigns and the lunar outpost in particular are the rate and capacity of Cargo Launch Vehicle (CaLV) cargo flights, the use of in-situ resources (ISRU), surface mobility assets, and the rate of Environmental Control and Life Support System (ECLSS) closure.

David Simchi-Levi demonstrated that the concept of Push-Pull boundaries has transformed terrestrial supply chains, particularly those that are subject to uncertainty. Elements in the push-part of the supply chain are produced and shipped based on forecasts; while elements in the pull-part of the supply chain are only assembled and shipped when actual orders have been received. This is a major strategy by which both service levels can be maximized and inventory holding costs can be minimized at the same time. NASA should consider how the push-pull boundary concept applies to future exploration logistics on the ground and in space.

## **Breakout Session Summary**

This section provides a brief summary of the 9 breakout sessions that occurred at the workshop. The subsequent paragraphs focus primarily on the issues that were raised in each breakout session. While some of the issues are particularly relevant to ISS, or Moon and Mars reference missions, it was found that most space logistics issues discussed were pervasive and applicable across the spectrum of NASA's current and future operations. For each breakout session there is a set of debriefing charts available online in pdf format at: <http://spacelogistics.mit.edu/workshops.htm> . The charts also lists the predicted impact, potential mitigation, testing methods, impact on other systems as well as potential solutions for each of the issues that were raised.

*Note:* Breakout session groups B and H did not take place based on participant assignments.

## **Group A – Radio Frequency Identification (RFID) and Information Architecture for Remote Logistics**

Leader: Olivier de Weck; Facilitator: Andy Evans; Scribe: Mike Li

The group discussed the latest technologies and trends in Radio Frequency Identification (RFID) and the development of interfaces to open systems architecture to provide asset visibility, accountability and other utility in remote logistics operations. The following issues were raised as requiring attention in order to transition from the current manual bar-code based asset tracking system for ISS (Inventory Management System- IMS) to a more automated, less-labor intensive and reliable system:

1. *Criteria* need to be established for tagging/tracking supply items and equipment with RFID (what? when? why? where?).
2. *Design of middleware*: While RFID hardware such as tags and readers is now relatively mature, the middleware that transforms raw read/trigger signals to useful enterprise level applications, including rule-based analytics, is not. An international standard layered architecture (EPCglobal) is evolving and NASA should be aware of this and potentially participate in definition of the standards.
3. *Durability*: Current RFID technology is not space qualified and mission reliability, maintainability and tag/reader survivability in harsh environments will first have to be assessed.
4. *Package vs. Cost vs. Reliability*: There is also an impact on the design of future bags (e.g. Cargo Transfer Bags - CTB), containers, racks and vehicles to ensure that they are RFID compatible. This needs to be coordinated with space logistics vendors.
5. *Reliability/Robustness*: Current RFID read rates vary significantly between 70-99%, built-in redundancy must be considered to allow the system to be reliable despite missed transactions, e.g. by supporting both bar codes and RFID tags and/or building in robust analytics to resolve conflicts.
6. *Human Systems Integration*: Improving business processes to reduce human factors errors by taking a long view of a 10-15 year time horizon to incorporate passive tags, active tags, and automated solutions with well-organized groupings/procedures. Some pilot projects would help before committing to full implementation.
7. *Smart Tags*: These are tags that not only store a unique item ID number but also their own maintenance, temperature history, etc. This could lead to increased information accuracy and availability but raises other issues such as centralization versus decentralization of data storage.
8. *Integrated Database/Open Architecture*: There is a need for consolidation of currently fragmented inventory databases, making sure the software environment is user friendly, including development of a standard data dictionary.
9. *Standards*: Make information exchangeable, reduce implementation costs.
10. *Criticality Analysis*: Identify the most critical space supply items for tracking (similar to 1).

## **Group C - Database Management**

Leader: Robert Shishko; Facilitator: Sarah James; Scribe: Deanna Laufer

This was a facilitated discussion of logistics databases, their design, accessibility to information, and configuration management, taking into account exploration missions. Recommendations for further investigation were derived from the discussion. The key discussion focused on (i) the required functionality of logistics databases, (ii) how to maintain data integrity, (iii) database security and (iv) configuration management. The following two issues raised impact primarily longer duration missions and campaigns on the Moon and Mars rather than the short (“sortie”-style) missions:

1. *Capture and Use of actual performance data/RMS data to feed into the design of future systems and components:* How will operational experience with operations and failures/repairs be captured to improve the reliability of future hardware and software?
2. *Provide Crew with needed logistics information:* As future missions will be longer-duration and farther from Earth (communications time delays), the local crew will have to have access to logistics/maintenance information locally. How will this be accomplished?

The following issues are common to all missions:

3. *Increase data connectivity and integration:* Eliminate redundancies, data validation, create better visibility.
4. *Defining Critical Functional System Requirements and Interfaces germane to the new missions:* Need Key Performance Indicators (KPIs)/MOEs, apply lessons learned from existing programs.
5. *Need Top-Down Direction:* Need to develop program wide standards for logistics database management and include a Chief Logistics Officer (CLO).

#### **Group D - Logistics Implications of Space Vehicle Design & Manifesting**

Leader: Joe Parrish; Facilitator: Tony Trovato; Scribe: Christine Taylor

This group discussed a variety of “design for supportability” implications in space vehicle design, including the development of support systems that optimize vehicle capabilities. The main issues raised that affect all missions were as follows:

1. *Integrate logistics considerations into vehicle design upfront:* This is particularly important as mission duration increases and supply lines get thinner: need integration between operations and engineering, management of crew risk, avoidance of catastrophic failures, quantification of the benefits of including lifecycle considerations upfront.
2. *Past systems have had different components perform similar functionality unnecessarily:* Reduces supportability, creates duplication of effort, inefficiency, design for supportability and careful systems architecting (with commonality) is critical. Identified primarily as an organizational, not a technical challenge.
3. *Examples of accommodating commonality and better logistics efficiency in vehicle design:* Space vehicle design implications (stowage areas, hatch sizes, crew resources for inventory tracking and management, see also Group A). Carrier design implications (pressurized cargo, unpressurized cargo, heritage from Shuttle, ISS, etc.). Manifesting implications (consumables/spares estimating, manifesting approaches to accommodate logistics).

Specific Issues for long duration Lunar and Mars Missions:

1. *Crew Autonomy:* Reduce lifecycle cost by reducing reliance on ground resources. This would have high impact by potentially reducing the large amount of current mission controller support (currently about \$800million/year for ISS), but this must be traded off against larger requirements for crew training and a potential increase in near-term vehicle design costs. Potential conflict of interest between engineering organization, crew agendas and mission operations.
2. *Reusable Infrastructure:* Partial reusability of ground and planetary infrastructure and some vehicles is probably important but where/how? Reusable infrastructure can cause increase in cost

across multiple expendable missions but can also create cost benefits in the long term. Utilize simulation and analysis methods to identify where reusability is most beneficial. Accumulate and maintain infrastructure at an accessible node in the network to minimize access cost; amortize infrastructure across decades, with multiple users.

3. *System/Component Lifetime*: If lifetime is too short major replacements are required, if lifetime is too long, it might be expensive to achieve, overly conservative, and subject to danger of technology obsolescence. Plan for maintenance and upgrades, cost of minor repair is much less than major replacement; modular system design for effective maintenance/upgrade.
4. *Crew Survivability (especially for Mars)*: Reliability, consumables, and spares management are all intertwined. Avoid catastrophic failures, loss of crew. Design with redundancy/reliability; provide spares and training for maintenance, technical and medical diagnosis and treatment. Ensuring critical spares/consumables to ensure crew survivability can potentially dominate Mars mission design.

The group felt that there were also a lot of non-technical issues that greatly affect vehicle design (e.g. policy, sponsor risk tolerance, technical obsolescence, etc.).

### **Group E - Technology Impacts on Logistics Requirements**

Leader: Martin Steele; Facilitator: Tony Trovato; Scribe: Sarah Shull

The group identified and defined the impacts of technology on the three different types of exploration missions (short lunar, long lunar, Mars) and their logistics support. A partial list of technologies that will likely impact the logistics requirements of future space exploration is as follows:

- Radio Frequency Identification (RFID)
- UID (Unique Identifier) is a new globally unique "part identifier" containing data elements used to track DoD parts through their life cycle.
- Advanced Propulsion Systems (high ISP chemical, electrical propulsion)
- In-Situ Resource Utilization (ISRU): local manufacturing of propellants and consumables
- Low to Zero-Boiloff (ZBO) storage of cryogenic liquids
- In-Space Fuel Depots
- Autonomous Space Tugs

Generally the impact of these technologies can be grouped in terms of:

1. *Effect on quantity (mass, volume) of supply mass*
  - a. Need to optimize launch cargo mix as a function of technologies, try to maximize allocation to science and exploration equipment, increase operational efficiency
  - b. Development of ISRU, Commonality, Repair-in-Space, lower level repair technologies
  - c. Will impact crew processes/time, hardware design/redesign, software complexity, quality control during manufacturing, ground handling, launch integration
2. *Inventory Management and Logistics Situational Awareness*
  - a. Help optimize inventory effectiveness, increase knowledge of operational status without burdening the crew
3. *System Robustness and Operability*
  - a. Improve system performance and reliability to reduce logistics impact and footprint in the first place

- b. Strategies: wireless networks, reduction of thermal and vibration constraints, Failure modes and effects analysis (FMEA) and failure reporting corrective action system (FRCAS), design for shipping, certification for multiple configurations at once, standard rack/bag sizes, plug-and-play technologies and modules
- c. Consider low reliability (but cheaper) launchers for consumables only. Separate out logistics into different streams depending on criticality, value, bulk density...
- d. Ability to return failed parts (not just rock samples) back to Earth for detailed dissection and post-mortem; FMEA and FRCAS.

## **Group F - Spares Management**

Leader: Robert Shishko; Facilitator: Sarah James; Scribe: Matt Silver

This discussion of the current and future state of spares selection and management, in view of the evolving complexity of missions and infrastructure, provided strategic recommendations. The topics of discussion that were introduced in this breakout session were: sparing-to-availability (single echelon) using concepts such as functional availability and PRA (probabilistic risk assessment), optimal multi-echelon distribution of spares inventory in an interplanetary supply chain, optimal procurement strategies (lifetime buy, hedging against demand/supply uncertainty and Economic Order Quantity - EOQ), managing condemnations (optimal triage, cannibalization, cost of repairs vs. new buys) as well as inventory management and tracking of spares.

The top three spares issues that were identified in the session are common to all missions:

1. *Logistics Engineering is (often) ignored in the Design Phase*: leading to inability to spare and maintain, support costs and risks will soar later in the program (see Shuttle and ISS). How can this be mitigated? Do Logistics Engineering in the design phase and/or buy more spares upfront, use simulation and modeling for sparing to availability. Program authority must impose logistics considerations in the design phase “top-down” emphasis.
2. *Loss of Supplier and Product Line Viability*: long program life leads to suppliers disappearing, being merged or deciding not to further carry or support obsolete parts unless contractually obligated (and paid) to do so: leads to reduced parts availability and increased cost due to increased demand uncertainty and long lead times. Possible mitigation: A. Consolidation of the organic supply base, B. Standardized interfaces and functions to allow for parts substitution and easy upgrade/technology insertion.
3. *Lack of integrated hardware/software design and maintenance strategies and policies*: Overly rigid designs and constraints drive costs up; people look for operational “workarounds” which increase mission risk and labor costs. Potential mitigations include: A. Implementation of a condition-based maintenance policy, B. Identify optimal levels of repair in space, C. Increased use of embedded diagnostics (self-test) or external testers.

Other points discussed, but not fully developed included:

- procurement of spares
- demand forecasting
- focus shift to new concepts such as sparing-to-availability, level of repair analysis (LORA)

## **Group G - Space Logistics Network Design**

Leader: Diego Klabjan; Facilitator: Andy Evans; Scribe: Christine Taylor

The Space Logistics Network was first defined and discussed, and impacts of the design on mission planning and execution followed. The space logistics network will be the set of nodes, trajectory arcs, facilities, vehicles, supplies and crews working together to achieve mission and campaign objectives. Recommendations and observations were provided as products. The main discussion points of the breakout session included:

- Fuel considerations (pre-positioning of fuel and propulsive elements), in-space refueling
- The use of on-orbit and surface depots for all classes of supply
- Non-expendable vehicle strategies (cyclers, have design requirements impact and different operational models and logistics impact)
- Impact of time horizon and time steps considered for logistics modeling and optimization
- Connection between surface/Earth logistics and in-space logistics

The key impacts on the space logistics network design are:

1. *ISRU/Fuel Strategies*: 93% of mass launched from Earth is propellant. The propellant/fuel cycle drives the system to a large extent. Traditional architecture is to launch expendable, fully fueled vehicles from Earth. New strategies such as (i) “cheap” consumables launchers, (ii) in-space refueling and (iii) ISRU could have a large impact on the long term launch strategy, robustness and efficiency of the space logistics system.
2. *Reusability*: Whether or not vehicles will be designed to be throw-away (expendable), completely reusable or partially reusable will impact the space logistics network. E.g. an LSAM cycler between a lunar outpost and lunar orbit would be very different from a non-reusable LSAM that would have to be brought every time. Need to find the optimum degree of reusability among vehicles and within vehicles. Utilize what-if analysis to determine how extensively to employ reusability in the architecture
3. *Inherent Reliability*: Reliability and complexity of vehicles will drive the robustness of the system and the degree to which sparing requirements drive the system. If reliability is very high, then spares management is less of a driver, if on the other hand complexity is high and reliability low, then spares need to be potentially pre-positioned (depot), carried along or re-supplied. Will learning curves occur and impact the space logistics network design?

## **Group I - Spaceport and Earth-to-Orbit (ETO) Logistics**

Leader: Martin Steele; Facilitator: Tony Trovato; Scribe: Sarah Shull

This group discussed the issues/topics related to Spaceports, ground processing, and Earth-to-Orbit (ETO) Logistics for the three different exploration mission types. By definition spaceport and ETO logistics affect all missions, including those to ISS. The three key issues that were identified were:

1. *Lack of robustness in getting supplies from Earth-to-orbit*: this leads to a loss of mission effectiveness. Apart from meteorological uncertainties and current launch scrub probabilities on the order of 40%, robust access to low Earth orbit is hampered by the complexity of launch vehicles and payloads and the difficulty of getting and keeping them in a “clean” state for launch.



Potential mitigations include: Integrated Vehicle Health Management (IVHM), flexibility to accommodate unknown-unknowns, the ability to “move” payloads quickly between vehicles (U.S. and others), commonality, universal (=flexible) test equipment, and responsive manifesting and lead-times (just in-time manufacturing JIT).

2. *Inadequate operations considerations in design*: lack of sustainability, need early operations cost/modeling also for the ground segment and spaceport operations. Impact of vehicle and ground infrastructure design decisions on operations using metrics (e.g. fastest launch response times, spaceport throughput/year); requires partnering of design personnel with operations personnel. Establishing the hardware flow, adapt Generic Environment for Modeling Future Launch Operations (GEM-FLO, a ground operations discrete event simulation) for future use. Optimize launch turn-around logistics (spaceport processing): CEV refurbishment location at launch site vs. manufacturer, minimize refurbishment at remote locations like the landing site.
3. *Lack of lean design in the current processes*: Implement lean design (commonality, modularity, optimization, etc.) as a top-down process. Education about the importance of global optimization vs. local optimization, clearly document and define processes. Integration of logistics needs and requirements, lean design/supply chain optimization, including business processes. Concept of “cost-to-orbit” (launch site to Low Earth Orbit – LEO).

## **Group J - Space Depot Maintenance**

Leader: Robert Shishko; Facilitator: Sarah James; Scribe: Deanna Laufer

This discussion was about the development of infrastructure, with and without technology advances, to provide logistics capability at remote nodes that develop during exploration, but also covered general issues of space maintenance beyond remove-and-replace. Specific discussion points were:

- Identification of appropriate tasks and locations for in-space intermediate and depot-level maintenance
- Level of repair analysis (LORA analysis techniques, data sources, ISS experience)
- Robotic versus human repair agents (feasibility, cost, safety/risk issues)
- Design for maintainability/serviceability
- Infrastructure and technology requirements for intermediate and depot-level maintenance
- Return on Investment (ROI) for in-space intermediate and depot-level maintenance

The issues raised in this breakout session were found to be common to all missions:

1. *Maintenance Policy must be integrated into the design process*
  - a. Reduces logistics footprint, which reduces lifecycle costs, but potentially requires greater costs upfront
  - b. Optimize supportability and maintainability
  - c. Requires discipline in requirements articulation and acquisition processes
2. *The need for highly common spares*
  - a. Configuration Management is critical
  - b. Common interfaces with equivalent or upgradeable functionality
  - c. Impacts of common spares:
    - i. Reduces overall cost requirements which allows for higher probability of funding

- ii. Increase of “box” level acquisition cost
  - iii. Design to a common tool set
  - iv. Example: Reprogrammable *Field-Programmable Gate Arrays* (FPGAs) for multiple functions
- 3. *Determination and Requirements for Levels of Repair*
  - a. Requires assessment of supporting infrastructure
  - b. Human factors impact (training, culture change, crew mix, on-flight maintainers, environmental adjustments)
  - c. Carry-along materials and manufacturing and repair facility. Similar to “postponement” in manufacturing industry, this means only make a spare once one knows what spare is actually needed. Applicable for some parts (structures, pipes, electrical cables ...) but probably not all parts (e.g. some integrated circuit boards, integrated control units, etc.)
- 4. *Reuse of “un-needed” Modules:* e.g. empty LSAM descent stages could be dismantled and reused for other purposes, or cannibalized for spares, etc.
  - a. Increase value for cannibalization
  - b. Fuel storage/backup
  - c. Land vs. crash of CEV ascent stages allows for raw materials use for parts and storage

List of logistics activities that *could* be done at a Space Depot:

- Wire repair
- Fire recovery/restoration
- Circuit card replacement
- Cannibalization
- Seal Repair
- Plumbing and hydraulic
- Programming of FPGAs
- Technology insertion and upgrades
- Modification applications
- Reconditioning (filters, batteries)
- Calibration
- Recertification/inspections (e.g., Non-Destructive Inspection – NDI)
- Nuclear Refueling (assuming a nuclear surface reactor is used)
- Intervention Servicing
- Refueling
- Structural Repair (welding, sheet metal, polymer bonding)
- Warehousing and distribution of spares, consumables

How should these activities be prioritized? How are they driven by vehicle architecture and design choices? How much crew time will these activities consume relative to exploration/EVAs and crew rest times?

### **Group K - Space Logistics Regulations, Policy, Guidance**

Leader: Olivier de Weck; Facilitator: Andy Evans; Scribe: Matt Silver

This group discussed the development of meaningful policy over time as infrastructure, commerce, and international involvement increase in space, their impacts on logistics capability, and provided a set of

recommendations. The questions that the panel discussed regarding space logistics regulations, policy and guidance were:

- Are there any in existence today?
  - o If so, are they adequate?
- What should be implemented and/or changed for missions to the Moon and Mars?
- Who should initiate/mandate these regulations and policies?
- Best practices?

The breakout session felt that all the following issues applied across NASA's human spaceflight missions:

1. *NASA Acquisition Policy and Regulations* need to be very carefully reexamined, crafted and executed:
  - a. This affects contracts, PBL (performance based logistics), Interfaces, NPDs and NPRs (see details below)
  - b. Need for effective requirements and specifications
  - c. What can be put into a design specification?
  - d. PBL and how do you flow this into contracts?
  - e. Metrics based performance arrangements
  - f. Need for consistency in supportability regulations requirements
  - g. Impact of design and procurement approach on logistics and supportability
  - h. Contractual decisions/actions should be based on purely technical and economic grounds rather than political
  - i. NPDs (NASA Policy Directives)
    - i. Set forth principles to strategically manage the agency
  - j. NPRs (NASA Policy Requirements)
    - i. Often confusing/open-ended directives and requirements
    - ii. Not always clear who is responsible -- programs versus projects
    - iii. Stove pipes hinder collaborative demand planning and commonality
  - k. Policies often encourage "push" – based logistics
    - i. Increases stockpile and waste
  - l. Need to *discuss and potentially revise* the following NPDs and NPRs
    - i. NPD 7500.1A Program and Project Logistics Policy
    - ii. NPD 7120.5C Program and Project Management Processes and Requirements
    - iii. NPD 4100.1A Supply Support and Materials Management
    - iv. NPR 5900.1 NASA Spare Parts Acquisition
    - v. NPD 8720.1B NASA Reliability and Maintainability (R&M) Program Policy
    - vi. NPD 9501.2D NASA Contractor Financial Management Reporting
  - m. Contracts should include options / flexibility
  - n. Performance-based contracting versus need for commonality, and yet how to achieve commonality across projects and flight and ground hardware and software elements?
  - o. Treat space-system appropriations as infrastructure rather than high-tech investments
    - i. Change expectations in Congress
    - ii. Select parts of missions
2. *International Regulations, Policies and Protocols*: the Vision for Space Exploration will be an international endeavor. Our current international collaboration and experience comes primarily from ISS:

- a. Cultural issues with respect to Space Station
    - i. Example: different ways of doing things in different nations, Russians pay much less attention to logistics than U.S., tend to improvise more, different risk tolerance, but also have a tradition of designing simpler, more passively robust systems
    - ii. Barter system: flow of money across international boundaries for operations and supportability services is difficult and tends to be bureaucratic and slow things down. Can we conceive a bartering system between nations that has agreed upon exchange rates for goods (e.g. spares), services and crew time?
    - iii. Astronaut Training: logistics and maintenance knowledge and skill of the crew is critical. Have found that crew can do much more difficult maintenance on ISS than originally thought, but requires training, skills, tools, parts and a change in attitude
  - b. Standards and protocols for foreign participation needed
3. *Lack of Integration of Policies:* (follow-up from item 1)
- a. MIL-PRF-49506 Logistics Management Information and the DOD 5000 series regulations are not being consistently applied across systems (within DOD)
    - i. Wiggle room remains even within standards
    - ii. High personnel turnover – 2 to 4 years
  - b. Need for early recognition of integration and supportability
  - c. Need for Standardized interfaces early in the design process
    - i. Difficulty standardizing in multi-national settings from design to end-use
    - ii. Need for interface control documents (ICDs) and configuration control board early in the exploration program
  - d. Need for strong leadership
    - i. Disconnect between perception of program and state of technology
    - ii. Stove pipes and insulation of NASA enterprise
    - iii. Avoid sacrificing potential technical advances due to cultural and budget issues
    - iv. Hardware, practices, processes, etc
  - e. Industrial base issues
    - i. Other nations often ahead in hardware, practices, processes
    - ii. Tension between using proving Technology Readiness Level (TRL) 6-9 tech and processes versus developing wholly new technologies that are potentially more efficient in the future
  - f. Need to develop supplier/industrial base policy for long-term logistics approach
    - i. Need for modular open system architecture and commonality
    - ii. Flexible rather than proprietary
    - iii. Need to sustain supplier interest through long-term program
  - g. Need for broader understanding of logistics
    - i. Who do the policies apply to?
  - h. Lack of visibility and real-time information
    - i. Web-based system may help
    - ii. Problem of fractured databases
    - iii. Need to identify and have visibility for commonality

## Future Actions – Conclusions

During the course of the workshop, it became apparent that there were several major “common themes” upon which there was high level of agreement within the space logistics community. These common themes include: (1) the need for logistics considerations to be incorporated into space system engineering and operations from the outset; (2) the need to reduce the launched mass of consumable items such as propellant, food, and spares; (3) the need to increase standardization, commonality, and modularity. It is a good sign that these tenets are held consistently within the logistics community, because the community can rally around these themes and use them to influence decision-makers and to build grassroots advocacy at all levels throughout the program. However, it is not good enough for us (as space logisticians) to agree amongst ourselves and thereby foster an “us vs. them” mentality.

Everyone (including “them”) knows that life cycle costs, operational efficiency, etc. are improved by incorporating the “common themes.” Due to a variety of offsetting factors, this philosophical agreement does not consistently translate into application in a real-world environment dominated by budget and schedule pressures. In particular, we ask for too much up front (increased design cost, reduced mass/volumetric efficiency, need to consider more things – more constraints) in exchange for benefits that may not be realized until the latter phases of a program. To be successful, we must: (1) be robust to survive program budget and schedule crises, (2) enable even the short-sighted to see the utility/ROI of incorporating an emphasis on logistics, and (3) provide tangible benefits early in the program.

## Key Takeaways

### **1. Need to integrate logistics considerations into space system engineering (and operations) from the outset**

Many of the current problems in space logistics on the Space Shuttle and ISS can be traced to a lack of logistics considerations in vehicle design and process architecture. Specifically this captures how supplies are stowed and transferred between modules and vehicles, how space vehicles are re-supplied, maintained, repaired and so forth. There was philosophical agreement by all participants at the workshop that while lip-service is being paid to spending extra time and effort upfront; this does often not translate into real application in a real-world environment of budget and schedule pressures. Rather than pointing fingers, the space logistics community needs to focus on producing hard data to convince decision-makers that investing early in logistics and lifecycle considerations is worthwhile and pinpoint particular areas of concern. One of the challenges is to identify the obvious wins (a.k.a. “low-hanging fruit”), where improvements and benefits can be achieved very early, rather than much later in some distant uncertain future. The key “low hanging fruit” were identified as follows in terms of their applicability to NASA’s Project Constellation:

- Automated inventory management and tracking
- Common interfaces and spares
- Reusable and flexible maintenance infrastructure

The solution is largely one of organizational dynamics, i.e. conducting trade studies that demonstrate the effect of various upfront design and process decisions on subsequent lifecycle and in particular on

operations costs, followed by managerial discipline to implement these requirements and levy them into specific design and contractual actions.

**2. Need to reduce launched mass of consumable items (propellant, food, ECLSS, spares) to either allow the vehicles to be smaller, have fewer resupply flights, or to make room for more exploration equipment and mobility assets**

There are countless studies showing the ultimate benefits of reducing launch up-mass. The further from Earth we go, the larger the  $\Delta V$ 's and the mass multipliers will be. Large required masses for resupply translate into a large number of resupply flights, higher costs, and mission risk if launch failures occur—especially for pre-positioning and even more so for critical re-supply flights. Approaches to reducing launch mass were discussed, and these are listed here. There was less consensus among participants as far as the priority with which these launch mass reduction measures should be pursued:

- High(er) closure rates for environmental control and life support systems (ECLSS)
- A reconfigurable/common spares strategy across system elements
- The ability to refuel vehicles in space, potentially with propellant launched by lower cost commercial providers
- In-Situ Resource Utilization (ISRU) for Moon and Mars missions

There was also general agreement that technology development gains would go unrealized unless human aspects are considered (RFID, inventory management, human-systems integration) Nevertheless, the solution to launch mass reduction is largely one of technology development (e.g., for ISRU) and system engineering/integration (for spares).

**3. Need for standardization, commonality, and modularity throughout the system of systems**

These issues of infusing the “illities” in exploration and operations systems architectures were very significant at the workshop, in part because the space logistics community can rally around these themes, and in part because they truly have a large impact on operations costs. The key challenges are how to persuade decision-makers and make sure these considerations are taken seriously:

- Standardization, modularity, commonality are the keys to reliability, maintainability, and reusability
- Reconfigurability will ensure that systems both on-orbit and on planetary surfaces can be used not just for a single function, but that they can be redirected to either provide higher levels of mass efficiency or to allow for graceful degradation given various failures

This thinking needs to become pervasive and reflected in contracts. This is a major challenge, since it is unclear how commonality can be mandated across contractors and suppliers of different systems, when contractual requirements are typically expressed in terms of functional requirements. The Government Furnished Equipment (GFE) approach is one possibility and there was significant debate around the desirability and effectiveness of NASA pursuing such an approach.

Beyond the contractual and design issues around commonality and the other “illities”, there was agreement that it must be ensured that appropriate requirements and guidelines appear in program documentation and that the chosen and implemented system architectures must reflect these objectives.

One of the “illities” that also came up was the requirement for flexibility in launch vehicle choice. Rather than designing equipment, supplies and carriers to only be compatible with one particular launch vehicle, it was felt that flexibility in launch vehicle choice from an interface, loads and general compatibility standpoint would be highly desirable.

Finally, in order to be proactive in achieving higher levels of logistics integration in future space programs, a number of topical suggestions were made:

- Educate decision-makers – raise the appreciation of key logistics considerations among those who have strong influence in the up-front development and operational phases. One possible avenue is to conduct an executive short course in space logistics, open by invitation to a select group of highly influential persons.
- Change the perspective of skeptics by showing near-term benefits – particularly via solid, compelling examples and by articulating the benefits of integrated logistics strategy to others outside the field – putting the benefits in terms relevant to those persons, not just to the logistics community.
- Raise the visibility of logistics considerations – throughout the program through a targeted marketing strategy, with due consideration of the key political and architectural factors.
- Briefing of the key messages from this workshop to decision makers at various levels at NASA with particular emphasis on Project Constellation.
- Consider the use of interfaces – as a natural place to enforce commonality. Interfaces can be regulated via Interface Control Documents (ICDs). A companion suggestion was to use Government Furnished Equipment (GFE) to ensure interface commonality.

The participants agreed that a follow-up workshop on Space Exploration Logistics would be desirable in late 2006 or early 2007 to continue the discussion of these critical issues.

## Appendix A: List of Attendees

<b><u>Name / e-mail</u></b>	<b><u>Title</u></b>	<b><u>Company</u></b>
Austin, Mr. Bryan P. bryan.p.austin@boeing.com	Director, Flight Operations	The Boeing Company
Bachman, Dr. Tovey C. tbachman@lmi.org	Research Fellow	Logistics Management Institute
Barber, Mr. Andrew andrew.barber@aia-aerospace.org	Manager, Space Operations	Aerospace Industries Association
Blick, Mr. Donald (Don) donald_blick@raytheon.com	Manager, Civil Space Development	Raytheon
Blanchard, Professor Benjamin (Ben) S., CPL, bsblanch@vt.edu	Professor of Engineering-Emeritus	Virginia Tech
Brady, Dr. Stephan (Steve) P. stephan.brady@wright.edu	Assistant Professor, ISOM	Raj Soin College of Business Wright State University
Bruckner, Ms. Yue yue.bruckner@boeing.com	Product Support Engineer	Mainthia Technology, Inc.
Bull, Mr. John E. john.e.bull@lmco.com	Logistics Engineer	Lockheed Martin Space Systems
Butina, Mr. Anthony (Tony) J., Sr. anthony.j.butina@nasa.gov	Manager, Logistics & Maintenance Office	NASA/JSC - ISS Logistics and Maintenance
Ceppollina, Mr. Frank J. frank.j.ceppollina@nasa.gov	Deputy Associate Director	Hubble Space Telescope Development Project
Davidson, Mr. Donald (Don) don.davidson@osd.mil	Program Analyst, Logistics Plans & Programs	Office of the Deputy Under Secretary of Defense
de Weck, Dr. Olivier (Oli) L. deweck@mit.edu	Professor	Massachusetts Institute of Technology
Evans, Mr. William A. (Andy) william.a.evans@usa-spaceops.com	Space Logistics	United Space Alliance, LLC
Farkas, Michael (Mike) A. michael.a.farkas@boeing.com	Systems Engineer, Cargo Systems Group	The Boeing Company
Galuzzi, Mr. Michael (Mike) michael.c.galluzzi@nasa.gov	Shuttle Supply Chain Manager	NASA/KSC - Shuttle Program
Garten, Mr. David (Dave) B. dave.garten@honeywell.com	Product Support Manager	Honeywell - DSES Glendale
Gaseor, Mr. Thomas (Tom) J. gaseort@blackhawkmgmt.com	Vice President, Space Systems	Blackhawk Management Corporation
Hicks, Mr. Richard (Dick) J. rhicks@hst.nasa.gov	Vice President, Technical Services Division	Orbital Sciences Corporation
James, Ms. Sarah R. solehq@erols.com	Executive Director	SOLE - The International Society of Logistics
Johnson, Mr. Terrence (Terry) B. terrence.b.johnson@mdnt.com	BMDS Logistics Architect	Missile Defense Agency
Klabjan, Dr. Diego klabjan@mit.edu	Associate Professor	Massachusetts Institute of Technology, UIUC
Kline, Mr. Robert (Rob) Kline	Research Fellow	Logistics Management Institute



rkline@lmi.org		
Korkemaz, Mr. Paul (Korky) N. paul.korkemaz@honeywell.com	Director, Space Programs	Honeywell
Laufer, Ms. Deanna deanna@mit.edu	Graduate Research Assistant	Massachusetts Institute of Technology
Li, Mr. Xin (Mike) mikeli@mit.edu	Research Scientist	Massachusetts Institute of Technology
McClain, Mr. Michael L., CPL mcclainl@usa-spaceops.com	Logistics Manager	United Space Alliance
Moe, Mr. Rud V. rud.v.moe@nasa.gov	Servicing Mission Manager	Hubble Space Telescope Development Project
Murphy, Mr. Charles (Charlie) W. charles.w.murphy@usa-spaceops.com	Logistics Process Director	United Space Alliance
Parrish, Mr. Joseph (Joe) C. parrish@payload.com	President	Payload Systems, Inc.
Patterson, Ms. Linda P. linda.p.patterson@nasa.gov	DF53/ISS Mechanisms and Maintenance Group Lead	NASA Mission Operations
Pavlatos, Ms. Marina E. marinaep@arkcove.com	Founder/CEO	Arkcove Industries
Pierotti, Ms. Elizabeth (Liz) A. elizabeth.pierotti@honeywell.com	Logistics Principal Engineer	Honeywell - DSES Glendale
Ross, Mr. Michael (Mike) michael.ross@lasangeles.af.mil	Program Manager Integrated Logistics Support	Space Tracking and Surveillance System Program Office
Schwaab, Dr. Douglas (Doug) G. douglas.g.schwaab@boeing.com	Lead, ISS Supportability Engineering	The Boeing Company
Shishko, Dr. Robert robert.shishko@jpl.nasa.gov	Principal System Engineer/Economist	Jet Propulsion Laboratory, Caltech
Shull, Ms. Sarah sshull@mit.edu	Graduate Research Assistant former Inventory Stowage Officer (ISO) for ISS	Massachusetts Institute of Technology, NASA JSC
Silver, Mr. Matthew (Matt) mrsilver@mit.edu	Research Scientist	Massachusetts Institute of Technology
Simchi-Levi, Dr. David dslevi@mit.edu	Professor of Engineering Systems	Massachusetts Institute of Technology
Sponberg, Mr. Brant brant.sponberg-1@nasa.gov	Program Executive	NASA Exploration Mission Systems Directorate
Snead, Mr. Michael (Mike), PE james.snead@wpafb.af.mil	Agile Combat Support Lead, AFRL, head AIAA Space Logistics Technical Committee	4236 Straight Arrow Road Wright Patterson Air Force Base
Stanley, Dr. Douglas (Doug) stanley@nianet.org	Faculty Member in Residence	National Institute of Aerospace
Steele, Dr. Martin J. martin.j.steele@nasa.gov	Simulation Analyst	NASA / DX-C Kennedy Space Center
Stockdale, Ms. Ursula E. ursula.e.stockdale1@jsc.nasa.gov	Inventory Support Officer	NASA - Johnson Space Center
Taylor, Ms. Christine c_taylor@mit.edu	Doctoral Candidate	Massachusetts Institute of Technology
Tellado, Mr. Joseph (Joe)	ISS Logistics Engineering Lead	Kennedy Space Center

joseph.tellado-1@nasa.gov		
Thronson, Dr. Harley A. harley.a.thronson@nasa.gov	Chief Scientist	Hubble Space Telescope Development Project
Tomczykowski, Mr. Walter (Walt) wtomczyk@arinc.com	Director	ARINC Engineering Services
Trovato, Mr. Anthony (Tony) E., CPL aetrovato@raytheon.com	Senior ILS Manager	Raytheon Technical Services Company
VanAndel, Mr. Sean M. sean.m.vanandel@boeing.com	Product Data Management Engineer	The Boeing Company
Watson, Dr. J. Kevin j.k.watson@nasa.gov	Lead, Supportability Integration Group (SIG), Constellation Program Office	NASA - Johnson Space Center
Williams, Ms. Marianella marianella.williams1@jsc.nasa.gov	Maintenance Planner	United Space Alliance
Wyman, Dr. Joanne Stone jswyman1@earthlink.net	Vice President	EnDyna, Inc.
Zapata, Mr. Edgar edgar.zapata-1@nasa.gov	Operations Engineer	NASA/KSC - Systems Engineering Office

## Appendix B: Agenda

### Space Exploration Logistics Workshop 17-18 January 2006

*Omni Shoreham Hotel*

Washington, DC

#### Pre-Workshop (Monday, 16 January 2006)

Meeting Set-Up  
Guests Arrive in Hotel  
1900-2100 No-Host Social in Hotel

#### Day 1 (Tuesday, 17 January 2006)

0730-0830	Continental Breakfast	Hampton Room
0830-0900	Plenary Session	Hampton Room
	Welcome and Introductory Remarks	
	<ul style="list-style-type: none"><li>• Project Overview – Olivier de Weck</li><li>• Workshop Overview – Andy Evans, Sarah James</li><li>• Discussion Area Introduction – Robert Shishko, Martin Steele</li></ul>	
0900-0930	Introductions	Hampton Room
0930-1015	Keynote Speaker – Doug Stanley	Hampton Room
1015-1030	Break	Hampton Room
1030-1230	Day 1 Breakout Sessions - Session I	Breakout Rooms
	Group A - RFID and Information Architecture for Remote Logistics	
	Group C - Database Management	
	Group D – Logistics Implications of Space Vehicle Design & Manifesting	
1230-1330	Lunch	Hampton Room
1330-1415	Panel Discussion – NASA Reference Missions and Commercial Opportunities for Space Logistics (Doug Stanley, Brant Sponberg, Joe Parrish)	Hampton Room
1415-1430	Break	Breakout Rooms
1430-1600	Day 1 Breakout Sessions - Session II	Breakout Rooms
	Group E - Technology Impacts on Logistics Requirements	
	Group F - Spares Management	
	Group G - Space Logistics Network Design	
1600-1630	Report-out Preparation	Breakout Rooms
1630-1830	Day 1 Reports Out	Hampton Room

1900-2100	Dinner & Decompression	Hampton Room
	Keynote Speaker – Frank J. Cepollina, Deputy Associate Director, Hubble Space Telescope Development Project	

## **Day 2 (Wednesday, 18 January 2006)**

0730-0830	Continental Breakfast	Hampton Room
0830-0915	Keynote Speaker – Tony Butina, NASA JSC	Hampton Room
0915-1015	Panel Discussion - Logistic Strategies for Space Exploration (Tony Butina, Kevin Watson, Robert Shishko, David Simchi-Levi)	Hampton Room
1015-1030	Break	Hampton Room
1030-1230	Day 2 Breakout Sessions - Session III Group I - Spaceport and Earth-to-Orbit Logistics Group J - Space Depot Maintenance Group K - Space Logistics Regulations, Policy, Guidance	Breakout Rooms
1230-1330	Lunch	Hampton Room
1330-1400	Report-out Preparation	Breakout Rooms
1400-1530	Day 2 Reports Out	Hampton Room
1530-1630	Closing Plenary Session <ul style="list-style-type: none"> <li>• Review of Open/Parking Lot Items</li> <li>• Identification of Action Items</li> <li>• Overview of Future Workshops</li> <li>• Closing Remarks</li> </ul>	Hampton Room

## **Appendix C: Events/Conferences on Space Logistics**

For more information on these events, visit: <http://spacelogistics.mit.edu/conferences.htm>

### **Space Exploration Logistics Workshop**

**January 17-18, 2006**

**Washington, D.C**

The first Space Exploration Logistics Workshop, hosted by MIT and SOLE - The International Society of Logistics), was held this past January at the Omni Shoreham in Washington, DC. Fifty-four participants from government, industry, academia, small business and trade/professional organizations participated in nine breakout sessions designed around targeted space logistics issues.

### **SPIE Defense and Security Symposium**

**April 17-21, 2006**

**Orlando, FL**

Major elements of space transportation, on-orbit operations, and the technology that goes into individual missions are at crossroads today or will be in the near future. Never has space played a more operational role in the defense and security of our country. In many areas, such as launch vehicle development and on-orbit satellite servicing, the decisions made today will impact the course of space utilization and operations for many years to come. For example, the ability to refuel, repair, and upgrade satellites on orbit is becoming increasingly important for extending the lifetime and utility of space assets. It has also become readily apparent that real-time monitoring of space assets, or space situational awareness, is no longer a nicety, but a necessity. On-orbit demonstrations and technology development programs that are taking place or being planned today will have a significant impact on the satellite architectures of the not-so-distant future.

### **Improving Space Operations Workshop**

**April 27-28, 2006**

The 12th Annual Improving Space Operations Workshop, hosted by the AIAA Space Operations and Support Technical Committee (SOSTC), immediately follows the 2006 Responsive Space Conference. The SOSTC are professionals engaged in space operations development, integration, and management in the aerospace industry. Visit: <http://www.responsivespace.com> for more details.

### **SpaceOps 2006**

**June 19-23, 2006**

**Rome, Italy**

SpaceOps 2006 will bring together space operators from around the world to discuss the current status and future direction of space operations. Focusing on the theme of “Earth, Moon, Mars, and Beyond”, **SpaceOps 2006** will allow for the investigation of topics including but not limited to future programs for earth observations, solar system exploration, planetary surface exploration, deep space communications architectures, integration of human and robotic missions, in-situ resource utilization, and the operability of all of these elements.

### **SOLE 2006, The Next Generation of Logistics**

**August 15 – 17, 2006**

**Dallas, TX**

The 41st annual conference and international exhibition of SOLE- The International Society of Logistics, will be held in August 2006. August 16, 2006 will be devoted to Space Logistics. For more details visit: <http://www.sole.org>.

### **Space Exploration Logistics Workshop II (tentatively planned)**

**August 18, 2006**

**Dallas, TX**

The second Space Exploration Logistics Workshop is tentatively planned to be held in Dallas, TX in conjunction with **SOLE 2006**.

### **Space 2006**

**September 19 – 21, 2006**

**San Jose, CA**

The AIAA Space 2006 conference theme seeks to convey the importance of space for civil, commercial, security, and scientific purposes, and to identify the investments in security, logistics infrastructure, horizontal integration and scientific investigation that will maximize space's value to ensuring prosperity for humanity in the future. The conference will address a wide array of topics, including technical, economic, and policy themes, to provide a forum to discuss "the value proposition for space."

### **57<sup>th</sup> International Astronautical Congress**

**October 2-6, 2006**

**Valencia, Spain**

The 57th International Astronautical Congress, technical program includes 26 symposia with 160 sessions (*including posters sessions*). Each symposium falls under one of the 5 following categories: Science and Exploration, Applications and Operations, Technology, Infrastructures, Space & Society.

### **4th International Logistics and Supply Chain Congress**

**November 29 – December 1, 2006**

**Izmir, Turkey**

**Main Theme:** The Era of Collaboration through Supply Chain Networks

**Sub-topics:** Transportation and Logistics, Regional Logistics, Supply Chain Management, Security in Logistics, Global Social Responsibility in Logistics, Logistics in Agriculture, Logistics in Service Sector, Logistics and Regional Development, Global Sourcing, Innovative Technological Solutions for Supply Chain Management (SCM), SME Integration into Supply Chain (SC) Networks, Lean Management, Virtual Corporations and Logistics, Logistics Training and Education

## Appendix D: Space Logistics Resources

### Websites

MIT Space Logistics site  
<http://spacelogistics.mit.edu>

Haughton-Mars Project (HMP) site  
<http://www.marsonearth.org>

AIAA Space Logistics Technical Committee  
Homepage: <http://www.aiaa.org/tc/sl/>  
SLTC Reference Material: [http://www.aiaa.org/tc/sl/index\\_files/SLTC\\_page0017.htm](http://www.aiaa.org/tc/sl/index_files/SLTC_page0017.htm)

KSC International Space Station/Payloads Processing Directorate, Logistics Division  
<http://www-ss.ksc.nasa.gov/Logistics/default.htm>

Defense Logistics Agency  
<http://www.dla.mil/>

Naval Supply Systems Command (NAVSUP)  
[http://www.navsup.navy.mil/portal/page?\\_pageid=477,1&\\_dad=p5star&\\_schema=P5STAR](http://www.navsup.navy.mil/portal/page?_pageid=477,1&_dad=p5star&_schema=P5STAR)

Naval Logistics Library, NAVSUP  
<http://nll1.ahf.nmci.navy.mil/com.cfm>

SOLE—The International Society of Logistics  
<http://www.sole.org>

### Books

Blanchard, B.S.. *Logistics Engineering and Management*. Englewood Cliffs, NJ: Prentice Hall, Inc., 1992.

DoD Supply Chain Management Implementation Guide. Logistics Management Institute, McLean, VA, 2000.

Langford, J.W.. *Logistics: Principles and Applications*. McGraw-Hill Inc., 1995.

Larson, W.J. and L.K. Pranke. *Human Spaceflight Mission Analysis and Design (HSMAD)*, McGraw-Hill, Inc.

Shishko, R. *NASA Systems Engineering Handbook*. SP-6105. Washington, D.C.: National Aeronautics and Space Administration, 1995. (Note: this handbook is currently in revision)

Simchi-Levi, D., X. Chen, and J. Bramel. *The Logic of Logistics: Theory, Algorithms, and Applications for Logistics and Supply Chain Management*. Springer Science and Business Media, Inc., 2005.

## Technical Papers

NASA's Exploration Systems Architecture Study Final Report, Dec. 27, 2005.  
<http://www.spaceref.com/news/viewsr.html?pid=19094>

Bachman, T.C. and R.C. Kline. "Model for Estimating Spare Parts Requirements for Future Missions." AIAA 2004-5978. Space 2004 Conference, 28-30 Sept. 2004, San Diego, CA.

Butina, A.J. "Managing NASA's International Space Station Logistics and Maintenance program." Space Technology and Applications International Forum-2001.

Evans, W.A. "Space Logistics: The Ultimate Logistics Enterprise Challenge." Logistics Spectrum, Jan.-Mar. 2005.  
[http://www.findarticles.com/p/articles/mi\\_qa3766/is\\_200501/ai\\_n15869342](http://www.findarticles.com/p/articles/mi_qa3766/is_200501/ai_n15869342)

Joosten, B.K and L.A. Guerra. "Enabling Lunar Exploration through Early Resource Utilization." NASA Johnson Space Center, 1993,  
<http://ares.jsc.nasa.gov/HumanExplore/Exploration/EXLibrary/DOCS/EIC033.HTML>

Siddiqi A. and de Weck O., "Spare Parts Requirements for Space Missions with Reconfigurability and Commonality", *Journal of Spacecraft and Rockets*, 2006, (accepted for publication)

Snead, J.M. "Architecting Rapid Growth in Space Logistics Capabilities," 2004-4068. Presented at the 40th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, 11-14 July 2004, Ft. Lauderdale, FL.  
[http://www.aiaa.org/tc/sl/Reference\\_materials/Architecting\\_Rapid\\_Growth\\_in\\_Space\\_Logistics\\_Capabilities\\_updated.pdf](http://www.aiaa.org/tc/sl/Reference_materials/Architecting_Rapid_Growth_in_Space_Logistics_Capabilities_updated.pdf)

Snead, J.M. "Near-Term Manned Space Logistics Operations." Air and Space Power Chronicles, 31 August, 2005. <http://www.airpower.maxwell.af.mil/airchronicles/cc/snead.html>

"Space Logistics Symposium, 6<sup>th</sup>", Houston, TX, Feb. 22-24, 1995, Collection of Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1995.

Walz, C., J. Uri, and D. Baumann, "Far From Home-Human Presence on ISS as Preparation for a Lunar Base and Beyond." NASA Johnson Space Center, Houston, TX AIAA-2005-2549. 1st Space Exploration Conference: Continuing the Voyage of Discovery, Orlando, Florida, Jan. 30-1, 2005

Watson, J.K. et al. "Supportability Concepts for Long-Duration Human Exploration Missions." AIAA 2003-6240. Space 2003, 23-25 Sept. 2003, Long Beach, California.

Watson, J.K., Constellation Systems Supportability Strategy (SS), NASA, Constellation Systems Document 0000028493, , Baseline, Effective Date: February 23, 2005, Exploration Systems Mission Directorate, NASA Headquarters, Washington, DC 20546-0001



## Appendix E: Additional Information

Additional information about this workshop and the Interplanetary Supply Chain Management and Logistics Architecture project can be obtained from the following website:

<http://spacelogistics.mit.edu/index.htm>

This document can be viewed in html form at: <http://spacelogistics.mit.edu/workshops>

The html version of this document has links to downloadable files of the presentations, keynote addresses, panel discussions, and breakout session reports of the workshop. A listing of those documents is as follows:

1. Project Overview (O. L. de Weck and D. Simchi-Levi)
2. Discussion Area Introduction (R. Shishko and M. Steele)
3. Keynote address (D. Stanley)
4. Panel Discussion – NASA Reference Missions and Commercial Opportunities for Space Logistics (B. Sponberg)
5. Session Reports
  - a. Group A – RFID and Information Architecture for Remote Logistics
  - b. Group C – Database Management
  - c. Group D – Logistics Implications of Space Vehicle Design & Manifesting
  - d. Group E – Technology Impact on Logistics Requirements
  - e. Group F - Spares Management
  - f. Group G – Space Logistics Network Design
  - g. Group I – Spaceport and Earth-to-Orbit Logistics
  - h. Group J – Space Depot Maintenance
  - i. Group K – Space Logistics Regulations, Policy, Guidance
6. Keynote address (F.J. Ceppollina)
7. Keynote address (A. Butina) ISS Logistics
8. Panel Discussion- Logistics Strategies for Space Exploration (A. Butina, K.J. Watson, R. Shishko)