APPENDIX G: Opportunities to Improve ISS Productivity with AHST

Provided in Response to the ReMAP Request to OBPR for Strategies to Improve Productivity on ISS
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The Advanced Human Support Technology (AHST) program through its individual project elements can make a substantial contribution toward improving ISS productivity by increasing: 1) available crew time; 2) crew efficiency; and 3) crew safety. Estimates contained in this document for technology development lead-times reflect Code U efforts in the advancement of these technologies up to technology readiness level (TRL) 6. Developing these technologies to TRL 9 (operational implementation) will be the responsibility of the ISS Program. Each of the AHST projects identifies current problems on ISS, possible remedies, and benefits associated with pursuing these remedies.

The Space Human Factors Engineering (SHFE) Project can help realize increases in crew time up to 30 hours per week (for a crew of three) through improvements in procedure design, stowage design, communications effectiveness, systematic labeling, and revised computer interfaces. Table 1 provides the summary for each of the aforementioned areas to improve ISS productivity. More details about each of these problems and possible solutions can be found throughout. Table 1A provides some other areas where the SHFE project could effectively increase crew time with modest research efforts. Over a two year time period the SHFE project can develop these tools to TRL 6 for an eventual ISS application. Implementing these improvements will involve a joint effort between OBPR and the ISS Program.

The Advanced Environmental Monitoring and Controls (AEMC) Project can help in developing sensors that are portable and consume low power. Current station monitoring equipment (Major Constituent Analyzer, Volatile Organics Analyzer) has not performed reliably over extended time periods. The advantage of using AEMC generated sensors would be their low mass and power requirements. Other, indirect benefits associated with AEMC monitoring technologies include reduction in storage volume and providing for a safe environment. Table 2 outlines the areas of improvement that could be achieved through R&TD in the AEMC project. By developing these miniaturized monitoring technologies, it is estimated that there would be mass savings of more than 100 lbs for the instruments alone. Developing real-time monitoring devices (e.g. microbial monitors) can save up to 125 hours of annual crew time for microbiological monitoring and also would reduce expendables.

The Advanced Life Support (ALS) Project has engaged in research and technology development activities with the goal of validating ALS technologies in an integrated test environment. The focus of the ALS Project on the development of next generation technologies includes development of technology upgrades for ISS. Table 3 outlines the mass and crew-time savings that would be achieved through the activities in the ALS Project. It is estimated that developing resource recovery technologies can save upmass to station by 3000-4000 lbs annually. Some other proposed upgrades can improve the power efficiency of currently baselined ISS technologies. Most of these savings can be achieved by developing unit processors for recovering resources through the air, water and solid waste streams. These processes achieve their greatest economy at crew size of seven.

The Advanced Extravehicular Activity (AEVA) Project can also provide improvement in efficiencies toward the current ISS baseline. Some of these improvements would be contingent upon cooperation with our international partners and the ISS Program. Table 4 outlines the AEVA project contributions that can be adapted to improve EVA technologies and crew time efficiency. It is estimated that by making upgrades to current EVA equipment up to 28 crew hours can be saved per EVA (assuming one EVA every other week).

As requested by the ReMAP committee, the AHST Program has made conservative estimates with regard to the crew time savings (these numbers are within a factor of two).

Table 1. Top Space Human Factors Opportunities to Improve ISS Productivity

Item	**Problem**	Remedy	**Benefit**	**Mechanism**	**Yrs to TRL 6**	**Total crew hours per week saved**
Procedure design	Procedures are too long and complex, time wasted, errors.	Guidelines and tools for procedure writers.	Reduced crew time and errors from better procedures.	Guidelines, prototypes, training material.	2	6
Stowage design	Ineffective, blocks access, crew time spent rearranging for access and searching for items.	Novel designs for stowage design and use of space.	Reduced time repeatedly rearranging stowed inventory.	Design concepts developed and tested.	1.5	3
Communications Effectiveness	Audio Terminal Units (ATU) located at far ends of US modules, noisy environment, time spent translating to ATUs and other crew members to communicate.	Provide portable communications units; untethered (wireless) comm.	Improve communications effectiveness, reduce time spent translating to comm hardware and other crew members.	Modify off the shelf portable communications options.	2	9
Systematic Labeling	Inconsistent or not meaningful, not user centered.	Systematize labeling.	Reduced time and errors.	Develop standard requirements and processes for labeling.	1	3
Revised Computer Interfaces: - navigation - log in & passwords - C&W	Lack of commonality; Cumbersome too many IDs, passwords too many pages to resolve warnings	Revise interfaces for greater commonality among systems, payloads, Caution and Warning (C&W).	Reduced time and errors; reduced time to access / control systems.	standardize navigation 1 ID & password per crew member reorganize displays for consistency	3	9

Notes:

1. The details of crew hours saved per week are explained in the pages following Table 1A.
2. For sanity checks on the time savings estimate, the following ISS Operations experts were consulted:
   - ISS Mission Integration and Operations Office representative to crew time tiger team.
   - Biomedical Engineer (from mission control center back room; supports flight surgeons).
   - Crew trainer from Mission Operations Directorate.
   - Astronaut who was heavily involved in Expedition 3 ground support.
   - Representative from ISS independent assessment group.

Table 1A. Additional Space Human Factors Opportunities to Improve ISS Productivity

Issue	Problem	Remedy
Inventory Management System (IMS)	Excessive crew time to locate items.	Redesign IMS.
Automation	Many crew tasks do not require human judgment.	Identify tasks with highest benefit to cost ratio.
Flight Crew Equipment	Many crew equipment items were not designed with serious attention to usability because they were not critical items.	Redesign items such as vacuum cleaner (does not retain debris when opened), fasteners (used many, many times per week), etc. to save crew time.
Communication with Various Systems	Inefficient and inconsistent communications with systems.	Standardize interfaces to e.g. IMS, other devices, by using PDAs.
Scheduling Tools	Crew time inefficiencies may occur because scheduling tools may not address resource requirements and conflicts (e.g., some tool or location needed by two different activities; assistance from 2nd crew member needed briefly during procedure).	Implement analysis/simulation tools with necessary sophistication to anticipate conflicting requirements of various tasks being scheduled for different crewmembers.

OPPORTUNITY: Procedure Design Improvements

CURRENT TIME COST:
8 hours/week PER CREWMEMBER

- Procedures are long and are not clear; reading them takes time, especially if they are unclear.
- Assume procedures are used primarily during work hours (6.5 hours/day).
- Assume procedures are used primarily during the work week (5 days).
- Assume 1/2 of work performed during work hours (6.5) is new, complicated, or infrequent, and therefore procedures are used 3.25 hours/day.
- Assume procedures are cumulatively 1/2 of the total task time (1.63 hours/day, 8.13 hours/week).
- Since all crew members use procedures, assume this time is per crewmember.

POSSIBLE TIME SAVINGS

2 hours/week PER CREWMEMBER

- Procedure approach, content, and technologies are all candidates for human factors review and improvements. Changes in accordance with human perceptual or cognitive capabilities and established Human Factors (HF) guidelines and methodologies will result in instructions that are more readily and quickly comprehended.
- Assume that HF improvements in procedures could reduce time costs associated with them by 25%. This would save 0.4 hours/day and 2 hours/week.

NOTE:

- Crew may be inclined to skip procedures entirely because they are long and not clear; skipping procedures results in increased possibility of errors. HF improvements to procedures will improve accuracy of performing tasks because: (1) information will be clearer, and (2) procedures will not be skipped.
- Impact from reading procedures is a larger issue for Russians reading US procedures written in English.
- Procedures are more of an impact for first-time, difficult, or infrequent operations.
- There may be a learning curve associated with procedures.

OPPORTUNITY: Stowage Design Improvements

CURRENT TIME COST:
5 hours/week PER CREWMEMBER

- Lack of enough dedicated stowage volume/lockers requires crew to stow cargo in open volume, in front of workstations, equipment, maintenance panels, or stowage panels; crew repeatedly rearranges stowage to perform daily activities.
- Assume this impact occurs on workdays, as well as on non-work days when crew does housekeeping and recreation (7 days/week).
- To gain access to other equipment, assume crew spends 0.75 hours/day, 5.25 hours/week.
- Since all crewmembers interact with stowage, assume this time is per crewmember.

POSSIBLE TIME SAVINGS

1 hours/week PER CREWMEMBER

- Additional and more organized stowage accommodations facilitated by innovative design solutions would reduce need to move things out of the way for access.
- Time spent looking for items can be reduced if stowage facilities provide means of quickly identifying contents.
- Assume reduce time demand by 25% and save 0.2 hours/day, 1.4 hours/week.

NOTES:

- Crew repeatedly rearranges stowage to consolidate; even with stowage system improvements, the crew will still have to stage for transfers and would occasionally rearrange inventory for efficiency.

OPPORTUNITY: Communications Effectiveness Improvements

CURRENT TIME COST:
6 hours/week PER CREWMEMBER

- Communications with each other is impacted due to acoustics. It takes time to translate to each other or to Audio Terminal Units (ATUs), which are located the ends of modules. Assume 0.5 hour/day spent translating to each other and to ATU to communicate, primarily on work days (5 days/week). This costs 2.5 hrs/week.
- Communication with ground – takes time to translate to ATU to talk – takes time away from other tasks (ref. robotics on exp 4 interrupted several times to talk to ground). Assume 0.5 hour/day translating to ATU to address ground calls. This is primarily on work days, and costs another 2.5 hours/week.
- Assume 4% increase in communications time due to interruptions and acoustic noise interference. With 6.5 work hours/day, this costs 0.26 hour/day or 1.3 hours/week.
- Summing the three sources of time costs from communications problems results in 1.26 hours/day, or 6.3 hours/week.
- Since all crew members must communicate with each other and the ground, assume this time is per crewmember.

POSSIBLE TIME SAVINGS:

3 hours/week PER CREWMEMBER

- Portable communication could reduce costs associated with communication issues by 50% and save approximately 0.63 hours/day, 3.15 hours/week

OPPORTUNITY: Systematic Labeling Improvements

CURRENT TIME COST:
3 hours/week PER CREWMEMBER

- Some hardware is not labeled, is labeled unclearly, or does not match procedures or other documentation. Time costs are associated with delays from trying to identify equipment. The crew sometimes re-labels items themselves on-orbit, which also takes time.
- Assume time impact from labeling problems is 7 days/week.
- Assume labels are the largest impact during daily ops, work hours, and meal prep (activities which total 12.5 hours per day).
- Assume 3% increase in task time due to labeling issues. Applied to 12.5 hours per day, the labeling impact is 0.4 hours/day, or 2.6 hours/week.
- Since all crew members interact with labels, assume this time is per crewmember.

POSSIBLE TIME SAVINGS:

1 hours/week PER CREWMEMBER

- More complete labeling and better commonality with procedures might result in 50% saving: 0.2 hours/day and 1.3 hours/week.

OPPORTUNITY: Revised Computer Interfaces Improvements

CURRENT TIME COST:
13 hours/week PER CREWMEMBER

- Software displays on computers have been reported to have basic human factors flaws (appearing like a familiar Windows application but not behaving like that application).
- Displays have been reported to be difficult and time-consuming to navigate across screens.
- Crews report too many usernames and passwords to remember.
- Displays are reportedly dissimilar enough from other displays on-board to cause confusion and transfer-of-training issues.
- Assume the largest impact from displays is on work days (5 days/week).
- Assume the largest impact is during work hours (6.5), planning & coordination (0.5), and daily systems ops (1.5) totaling to 8.5 hours of work involving displays per day.
- Assume 30% of task time due to Human Computer Interface (HCI) issues. With 8.5 hours of task time involving displays, the impact is 2.5 hours/day, or 12.8 hours/week.
- Since all crew members interact with computer interfaces, assume this time is per crewmember.

POSSIBLE TIME SAVINGS:

3 hours/week PER CREWMEMBER

- Focused human factors and usability evaluations of interfaces as well as development of more useful and generalized standards should improve the usability of the displays and reduce the time spent interacting with them by 25%: 0.6 hours/day, or 3.2 hours/week.

Table 2. Top Advanced Environmental Monitoring and Control Opportunities to Improve ISS Productivity

Item	Problem	Remedy	Benefit	Mechanism	Time frame	Savings	Safety
Enose	Air quality on ISS must be monitored for trace contaminants. Existing space-qualified analytical instruments, MCA, VOA, TGA, are larger, costlier, and complex. MCA, VOA, and TGA have all had problems (though some success as well).	Develop simpler, yet highly capable Enose technology. Less sensitive than analytical device like VOA, but more robust, virtually no maintenance. NASA Enose is designed to be quantitative and future units will have improved classification capability.	More air quality checks through use of numerous small deployable, possibly handheld units. These units serve as a first alert to chemical hazard, and as some backup function to the primary analytical air analysis instruments. The unit will be crew-upgradeable by changeout of the polymer chip and software upgrades.	AEMC works with ISS operations, ALS, and MSFC on prototype testing and implementation plan.	2 yrs to build and test 2nd generation prototype.		Enhanced safety through better understanding of chemical environment.
Tunable Diode Laser (TDL) Gas Sensor	(1) VOA or any other highly capable analytical instrument can nevertheless not detect every species of interest. (2) Miniature, sensitive, specific devices will be useful throughout the life support system, to indicate system health.	TDL gas sensor is very sensitive and specific. In the near term, Difference Frequency Generation (DFG) has been successfully used to detect formaldehyde levels. In the longer term, non DFG TDL development for smaller, more rugged, and efficient units.	Monitoring of chemicals that are beyond the capability of current analytical instrument. Small size and power make monitoring of many sites feasible.	AEMC works with ISS operations, ALS, and MSFC on prototype testing and implementation plan.	2 yrs for DFG version or 5 years for direct TDL.		Enhanced safety through better understanding of chemical environment.

Item	Problem	Remedy	Benefit	Mechanism	Time frame	Savings	Safety
UV/Raman Bacterial Sensor	Rapid microbial testing can reduce the water storage requirement (currently two days).	Develop rapid test for microbial analysis. Leverage related efforts in astrobiology, planetary protection, and counter-terrorism using UV/Raman spectroscopy	Saves required storage mass of water and associated tankage.	AEMC works with ISS operations, ALS, and MSFC on prototype testing and implementation plan.		23 kg water/person/day plus associated tankage no longer need be kept on board. Savings of crew time since UV/Raman will be less labor-intensive than plate culturing.	Will be as effective as plate cultures, but take less time.
Microgravity Reagentless Organic Acid and Alcohol Detection in Water	Total organic carbon analysis of water does not discriminate between toxic and non-toxic organics, thus the TOC limit is very strict.	Organic carbon analysis that will discriminate for alcohols or acids thus allowing for a safer determination of potable water quality.	Assessment of water quality while being much less demanding of the TOC requirement resulting in better assessment of water safety.	AEMC works with ISS operations, ALS, and MSFC on prototype testing and implementation plan.	Ready for ground test in months.		Improved safety through improved water quality analysis.
Colorimetric Solid Phase Extraction for Biocide Determination	Trace biocide in potable water has been identified as a potential problem in ground testbeds. Iodine can potentially impair thyroid function; algyria of the skin can occur due to excessive silver.	These are a set of rapid, simple, specific tests for biocides which to date have been tested in KC135 flights.	Improved safety through identification of safe biocide levels in potable water.	AEMC PI has been coordinating with ISS operations since the start of the NRA grant.	<2 years		Improved safety through verification of safe biocide levels.

Item	Problem	Remedy	Benefit	Mechanism	Time frame	Savings	Safety
DNA Microchip-based Microbial Monitoring	Level of pathogenic organisms in the spacecraft environment and growth of biofilms in water supply lines.	DNA microchip approaches can be used to identify the microorganisms.	Improved safety through the identification of safe levels of microorganisms.	AEMC works with ISS operations, ALS, and MSFC on prototype testing and implementation plan.	4-6 years		Improved safety through verification of safe microbial levels.
Miniaturized Gas Chromatograph Mass Spectrometer (GCMS)	Monitoring of air and water to assure safe levels of trace chemicals and microbials as well as proper operation of life support equipment through monitoring of process gases. If all these can be monitored effectively with a single instrument, mass savings of multiple instruments is obtained.	This approach employs GCMS, which is the "gold standard" for ground-based analysis, in a small, low power, highly capable instrument.	Improved safety through speedy identification of safe levels of trace chemicals, analysis of major constituents and unknowns, and microbial analysis for either air or water samples.	AEMC works with ISS operations, ALS, and MSFC on prototype testing and implementation plan.	3-5 years	Mass savings over multiple instruments, roughly 40 kg.	Improved safety through verification of safe chemical and microbial levels; and proper operation of life support equipment.

Item	**Problem**	**Remedy**	**Benefit**	**Mechanism**	**Time frame**	**Savings**	**Safety**
Lack of Near Real-time Microbial Monitoring	Present methods are minimal at best and in addition are crew time intensive, do not identify genus/species at any level, and require 2 to 5 days to obtain results.	Automated microbial monitor that can provide near real-time assessment of harmful microorganisms in the environment.	Sample analysis within 2-5 hours, reduction in crew time, does not rely upon culturing microorganisms in flight (eliminates potential biohazard). Provides identification.	Resources to develop an automated microbial monitor.	2-3 years	Estimated net annual crew time savings as follows: air = 8 h vs. present 18 h; surface = 10 h vs present 25 h; water = 8 h vs present 108 h; total = 26 h vs present 151 h; total net annual savings = 125 h. Time to obtain results reduced from 5 days to < 5 h/sample. Logistics savings cannot yet be quantified.	Improved capabilities for portable water quality monitoring

Table 3. Top Advanced Life Support Opportunities to Improve ISS Productivity

Item	**Problem**	**Remedy**	**Benefit**	**Mechanism**	**Time-frame**	Savings
Sabatier reactor	CO_2 currently vented from ISS; O_2 lost must be replaced by splitting H_2O resulting in net H_2O loss from ISS systems.	Utilize CO_2 via Sabatier reactor to produce water for splitting to O_2.	Saves upmass of resupplied water ~ 2000 lbs/year (w/ 7person crew).	ALS works with MSFC to develop upgrade for ISS ECLS System	<2yrs	2000 lbs upmass/year
Advanced catalyst substrate, reactor/heater design for retrofit into the ISS TCCS catalytic oxidizer.	Trace Contaminant Control System (TCCS) on ISS is a catalytic oxidizer - charcoal combination. The current Oxygen Regeneration Unit (ORU) weighs 35 lbs.	This advancement combines the heater and catalyst into a single package which is more energy efficient and would be a separate ORU weighing 5-10 lbs instead of the current ORU of 35 lbs.	Mass savings & reduced energy consumption.	MSFC SBIR and NRA efforts - the initial design that runs on 27 VDC power is at TRL 6. Now being tested under MSFC CDDF funding - will be at TRL 6 by the end of this FY.	2-3 yrs	Upmass savings is modest at 30 lbs with ORU replacement every 5 years. Reduced energy consumption of 20% (122 watts vs 98 watts).
Advanced food packaging.	Conventional packaging is higher mass.	Nanomaterials for food packaging.	Could result in up to 50% less weight in packaging with the same or better water & oxygen barrier properties.	Triton Systems is in the first year of the SBIR.	3-5 yrs	750 lbs/year
Solid waste de-watering.	Currently all wet trash is thrown away; wet trash is bagged, then crew wraps bags with tape to reduce smell and then trash is stored on-orbit until burned up in Progress or returned on Shuttle.	Extract and recycle water from trash.	Saves on water transfer requirements; save crew time spent on packing wastes/trash; saves on storage volume.	Current low TRL lyophilization NRA at ARC near completion; no other on-going work in this area.	3-5 yrs	280 - 675 lbs/year

Item	Problem	Remedy	Benefit	Mechanism	Time-frame	Savings
Bacteria Filter Pressure Drop Sensing	Bacteria Filter Element (BFE) service life presently set at 1 year based on ground evaluation and analysis. Replacement is based on time on stream rather than actual filter loading to the upper pressure drop threshold of 0.5 inches of water.	Develop flow measurement technique correlated to BFE pressure drop to determine replacement need rather than time on stream.	Saves crew time, up/down mass, stowage volume, and may eliminate the potential need to purchase additional spare elements. Note that there are a total of 88 BFE spares as of October 2000. At least 10 of those spares have been replaced. Using the 1-year replacement interval, new spare elements will need to be purchased within 7 years. Extending the service life by only 6 months extends that to 10 years.	Develop flow measurement technique correlated to filter loading and pressure drop or a more direct pressure drop measurement technique.	2-3 years	0.09 m^3/year (3.1 ft^3/year) by doubling present service life. Doubling service life avoids future spares purchase of at least 48 BFE units at a ROM of $5,000 each for ground use only. Flight qualification may double the unit price. Annual mass savings is 17 kg by doubling service life (based on 2.62 kg BFE weight and 13 presently on orbit).
Lack of a Portable Emergency Response Air Scrubber.	The present approach (LiOH and charcoal canisters) provides a maximum 9 cfm flow making scrubbing duration and recovery time very long in emergency situations. Scrubbing system requires significant stowage volume.	Develop a high flow, dedicated emergency scrubber that can be used to recover from fire, particulate matter, and chemical release events. Such a scrubber will help to preserve expendable ECLSS resources.	Reduced recovery time from an emergency event.	Leverage ALS and SBIR technologies on ultrafiltration and trace contaminant control into the development of a portable emergency response-scrubbing unit.	2-3 years.	51.7 kg upmass/event. Assumes complete contamination control system overhaul. Stowage volume is most likely an even trade.

Item	**Problem**	**Remedy**	**Benefit**	**Mechanism**	**Time-frame**	Savings
Polar Volatile Organic Compound (VOC) Impacts on Water Processing System Performance and Logistics	Water processing systems on ISS are more sensitive to polar VOC concentrations in the cabin than the crew by an order of magnitude. Impact is increased water processor logistics and crew time to maintain proper function.	Evaluate alternate cleaning agents for use onboard-crewed spacecraft that are compatible with equipment, water processor function, and provide adequate cleaning function. Further investigate the cabin atmosphere/humidity condensate trace contaminant partitioning to better assess the problem.	Reduced water processor logistics mass and crew time.	Fund evaluation of alternate cleaning solvents. Fund experimental testing to expand the knowledge base on contaminant loading of humidity condensate.	1-2 years.	Estimated 45 kg/year savings on expendable beds.

* These are the costs associated with developing these technologies to a TRL 6.

Table 4. Top Advanced Extravehicular Activity Opportunities to Improve ISS Productivity

Item	**Problem**	**Remedy**	**Benefit**	**Mechanism**	**Yrs to TRL 6**	**Total crew hours per week/EVA saved***
External Science Automation	US and Russian external science experiments are consuming valuable crew time for installation and removal support.	Design all external materials exposure experiments for robotic installation and removal. Discontinue all totally manual experiments. Rely on automated external pallets. Reserve EVA support for off-nominal failure response to science success.	EVA time reduced and made available for other IVA science. Using Mir history as an example, total EVA demand would be reduced by 26% or 100hrs thru assembly complete	International management decision	0	2
Single EVA Suit	Maintaining and using both Orlan and EMU suits adds to crew overhead demands. Orlan does not have regenerable CO_2 removal or rechargeable battery, as does the EMU. Higher Orlan pressure minimizes prebreathe demand for crew time and O_2 waste/resupply (no overnight campout, no mask prebreathe, short in-suit prebreathe).	Select a single suit type. Discontinue production and maintenance of the other suit type. For the widest range of crew size accommodation, most mobility/dexterity and least burden upon resupply consumables, the EMU would be the preferred choice. The single size minimal prebreathe Orlan could be selected if improved gloves and task lighting were implemented and a smaller range of crew sizes could be used.	Reduced logistics mass and stowage volume. Less crew time demanded pre-flight and onboard to obtain and maintain dual suit proficiency.	International management decision required. Common interface for EMU gloves on Orlan suit required. Better helmet mounted lighting needed to allow work to continue during orbital darkness.	1	3

Item	**Problem**	**Remedy**	**Benefit**	**Mechanism**	**Yrs to TRL 6**	**Total crew hours per week/EVA saved***
Single EVA Airlock	The joint airlock can accommodate both Orlan and EMU suits. Its central location and pump, which recycles depressurization gas, make it ideal for common use. Continued use of the Russian airlocks wastes limited O_2/N_2 gases.	Discontinue use of the Russian airlocks, which have no atmosphere-recycling pump.	Reduced resupply of ISS O_2 and N_2 gases. No crew time needed for gas tank changeout or other EVA preps. Progress, Shuttle and DC1 stowage mass/volume freed for other needs.	International management decision required. Access to Russian segment from joint airlock would be improved by Strela crane mounted on joint airlock by new interface adapter.	1	1.5
Water Tanks	Water must be manually transferred from the Orbiter to ISS during docked operations. The transfer time and ISS stowage volume detract from other users. Time to refill EMU water tanks is also a burden.	Replace the current suit cooling system sublimator with a radiator.	No crew time or stowage wasted on EVA cooling water management.	Replace the life support sublimator with a freezable radiator. Finish development of existing radiator design.	2	1
CO_2 Removal Canister	Both LiOH and Metox CO_2 removal canisters place demands upon crew time and stowage. Removal, installation, and regeneration activities detract from higher priority scientific tasks. Shuttle and ISS logistics are burdened unnecessarily.	Replace the existing CO_2 removal system (canisters and regenerator oven) with long life, self regenerable system. Consider swing bed or membrane systems.	No crew time or STS/ISS stowage wasted on CO_2 system logistics.	Replace existing CO_2 removal system. Develop 2-3 candidate solutions to ensure effective solution.	3	2

Item	**Problem**	**Remedy**	**Benefit**	**Mechanism**	**Yrs to TRL 6**	**Total crew hours per week/EVA saved***
Communications Cap	Donning, doffing, and manifesting of the EVA "Snoopy" comm cap wastes crew time and stowage mass/volume.	Replace the comm cap with a microphones and speakers permanently installed in the suit's helmet or upper torso.	No crew time or stowage wasted on comm cap operations.	Modify existing suit electronics. Include noise canceling features to offset audible airflow interference.	2	1
Helmet Antifog	Helmet insulation and airflow is not sufficient to preclude visor fogging from breath moisture. Manual application of soap solution wastes crew time and has caused eye irritation when excess inadequately removed.	Devise permanent antifog coating and/or modify existing helmet so inner and outer visor sealed for improved insulation.	No crew time wasted on manual application and removal of antifog solution.	Modify existing helmet coatings and insulation.	3	1
EVA Bioinstrumentation	Crew time wasted on installation, removal, and cleanup of EVA bioinstrumentation wire harness and sensors.	Devise wireless sensors permanently integrated into the suit upper torso or undergarments.	No pre or post EVA time wasted on biomedical instrumentation.	Replace current biomedical sensor system.	2	1
Drink Bag	Resupply of reusable or disposable drink bags occupies limited manifest mass/volume. Filling and degassing procedures waste crew time.	Eliminate the drink bag. Replace with increased capacity life support water tanks. Tap into cooling water supply for drinkable water.	No pre or post EVA time wasted on drink bag operations. No manifest.	Modify existing suit water system.	2	1

Item	**Problem**	**Remedy**	**Benefit**	**Mechanism**	**Yrs to TRL 6**	**Total crew hours per week/EVA saved***
EVA Information Display	EVA crew must rely on preflight and on-orbit training to memorize external task procedures. Paper cuff checklist is too full to accommodate any ISS task data. IVA crew burdened by serving as procedures support service. Extended increment duration negates utility of pre-flight training.	Develop arm or helmet mounted display.	On-board and pre-flight crew training time can be reduced.	Prove cutting edge commercially produced displays are compatible with suit external or internal environments. For arm mounted display, provide power via existing external battery/harness. Consider both pre-EVA memory loading and radio linked interactive data.	2.5	2
Onboard Virtual Reality Training Computer	EVA crew must rely on preflight and on-orbit training to memorize external task procedures/techniques. Ground based VR simulation is not available on-orbit. In cabin suited and unsuited practice of external tasks detracts from IVA science time. IVA crew burdened by serving as procedures support service. Extended increment duration negates utility of pre-flight training.	Develop small, lightweight, low power and portable virtual reality capability. Use for crew self paced on-orbit instruction and refresh training. Devise means to link and display software during EVA as in-situ task procedures aid.	On-board and pre-flight crew training time can be reduced.	Condense ground based hardware and software to be on-orbit compatible. Devise radio link using existing ISS transceivers and antennas to access software/simulation during EVA. If radio link is impractical, consider sufficient memory on suit for expected tasks.	3	2
Robotics Control Location	IVA crew time for science is reduced by time spent operating external robotics.	Demonstrate capability for ground team to safely and productively conduct all SSRMS and SPDM operations.	No IVA crew time needed to support EVA tasks.	Develop and demonstrate automated safety functions and compensation for time delay issues.	3	5

Item	**Problem**	**Remedy**	**Benefit**	**Mechanism**	**Yrs to TRL 6**	**Total crew hours per week/EVA saved***
Robotic Assistant	Productive EVA time is unnecessarily expended on low complexity overhead tasks. $^{1}/_{3}$ of external crew time is spent relocating and reconfiguring body restraints and tools. More time is wasted on hardware inspections and post task closeout photography.	Provide dexterous robotics that can perform simple EVA tasks such as worksite inspection/photography and manipulation and transport of EVA crew tools/restraints. Maximize usage and capabilities of planned dexterous robotics (SPDM).	$^{1}/_{3}$ of total EVA for ISS assembly, maintenance, and science would be eliminated. This could equate to over 100 hours thru assembly complete.	Complete development of Robonaut. Enhance capabilities and usage of SPDM robotics.	3	3
Voice-activated EVA Crew Control of Robotic Manipulator	The EVA crew has no capability to command robotic manipulator motions directly. IVA and EVA crew time is wasted on this interface deficiency.	Create the ability for direct voice command control of external robotics.	Crew transported on the end of the manipulator or guiding manipulator attached cargo can keep hands free for work and rapidly maneuver into needed work positions.	Integrate voice recognition/command software into suit and robotic systems. Use existing radios for communication transmissions. Develop automated manipulator joint trajectory and contact analysis.	2	0.5
IVA Monitor	Using the IVA crewmember to read procedures, operate cameras and track EVA crew tasks detracts from IVA science ops.	Use Russian proven technique which relies upon MCC based EVA expert to provide procedural advice and track external crew tasks.	One crewmember freed for over 6 hours during each EVA.	Management decision.	0	2

* Average of one EVA every other week assumed.