EVOLUTION OF SPACE STATION EMU PLSS TECHNOLOGY RECOMMENDATIONS

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EMU PLSS TECHNOLOGY RECOMMENDATIONS

Human physiology drives the EMU PLSS hardware functions. Two major considerations constrain the implementation of these functions:

- Provide unobtrusive support for crewmembers performing EVA, i.e., make EVA easier and safer.
- Support EVA from a vehicle with well-defined but linked resources, i.e., reduce logistical and support overheads.

Improving the EMU in the PLSS technology areas recommended supports these considerations.

O_2 SUPPLY STORAGE

For small systems like EMU PLSS gaseous O_2 (GOX) remains the storage medium of choice. Supercritical and liquid O_2 systems are larger owing to insulation requirements, require on-board power to maintain conditions or convert to gas, are not amenable to long term charged storage due to boil-off requirements and require an on-orbit cryoplant or storage which is not currently baselined for station.

The central issues for GOX storage are storage pressure and how to recharge the tanks after use.

Recharge technology is a driver. Both mechanical compressor and electrolytic decomposition of water concepts are being developed, but it is not yet clear which technology will be more compatible with Space Station operations. These efforts should be continued.

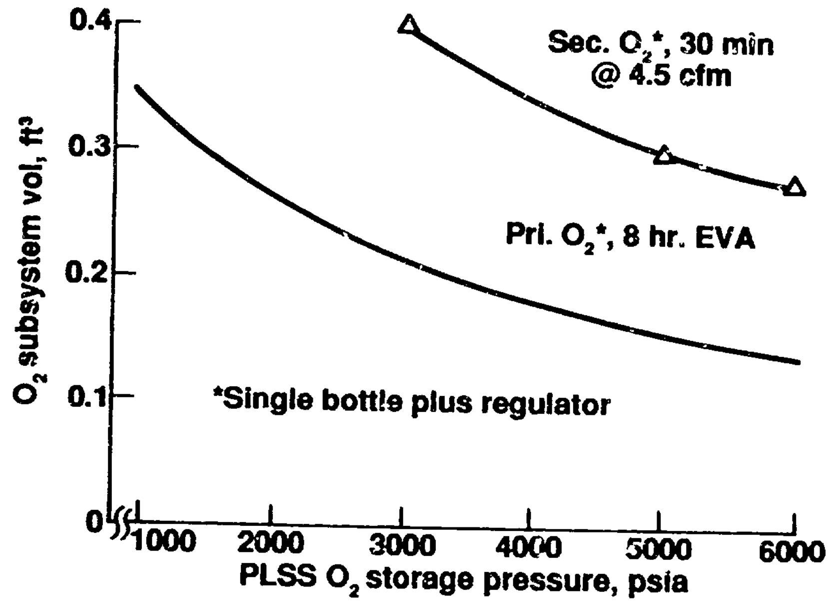
O_2 SUPPLY STORAGE

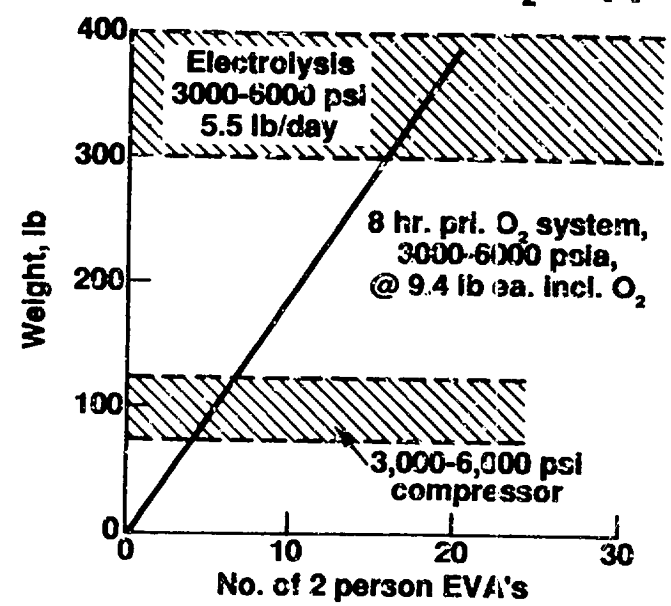
Recommended Future Approaches

- Continue gaseous O_2 recharge development
  - — Compressor
  - — Electrolysis

Principal Advantages

- Provides smallest volume PLSS O_2 supply consistent with recharge safety
- Provides on-orbit recharge of both primary and secondary PLSS O_2 supplies





O_2 SUPPLY STORAGE
(Continued)

Other desired attributes

- Minimum volume on the back
- Safe - fire & contamination
- Quick recharge for EVA contingencies
- Minimal crew reservice effort
- Safe, reliable, compact, low power recharge facility

Current status

- NSTS, EMU: Operational
  - Primary: 950 psi GOX
    On-orbit rechargeable
  - Secondary: 6,000 psi GOX
    Ground rechargeable
    On-orbit replaceable
- SSF EMU: Pre PDR design/may be cancelled
  - Primary: 3,000 - 5,000 psi GOX
    On-Orbit rechargeable
  - Secondary: Individually replaceable
    On-orbit
- NASA A/D programs
  - 3,000 - 6,000 psi electrolysis
  - 6,000 psi compressor

O2 Supply Regulators

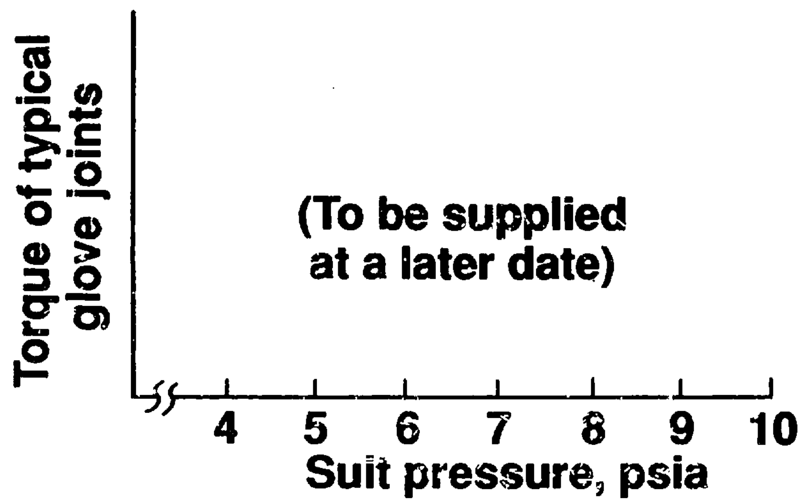
Mechanical O2 regulators have been satisfactory to date. They are operational for NSTS EMU and are baselined in the Space Station AEMU. They are designed for fire safety and system design accommodates their droop characteristics. Mechanical O2 regulators are autonomous. They would operate even if all other PLSS subsystems had failed.

The electronic O2 regulator second stage presents an opportunity to eliminate all droop characteristics, and more importantly, to change suit pressure at will. This feature is potentially useful for softening a suit or gloves to perform particularly demanding EVA tasks. An electronic regulator would be used at the primary O2 loop. If that loop or its power supply went down, a mechanical regulator in the secondary loop would handle the safety functions.

O_2 SUPPLY REGULATORS

Recommended Future Approach
- Continue use of mechanical regulators
- Develop electronic primary regulator second stage as back-up for dexterous glove

Principal Advantage
- Reducing suit pressure during a manually demanding EVA may enhance productivity



O_2 SUPPLY REGULATORS
(Continued)

Other desired attributes

- Stable operation
- Minimum droop with flow and supply pressure
- Operation independent of other subsystems
- Reliable operation after long periods of disuse

Current status

- STS, EMU:
  - Primary: Mechanical 950 psi, Single stage
  - Secondary: Mechanical 6,000 psi, Dual stage
- SSF EMU: Mechanical 3,000 - 6,000 psi, Dual stage
- NASA A/D programs: Electronically controlled, Variable pressure second stage

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CO_2 CONTROL

LiOH has been the CO_2 removal mechanism for all short manned space flights, including Apollo's two week missions. Regenerable CO_2 removal makes sense for Space Station EMU when EVA sortie rates drive the weight of expendable LiOH above the power and weight penalties for regenerable CO_2 removal.

Metal oxide is the most mature concept for EVA use, having been developed mostly under the NASA A/D programs and is currently baseline for the station AEMU.

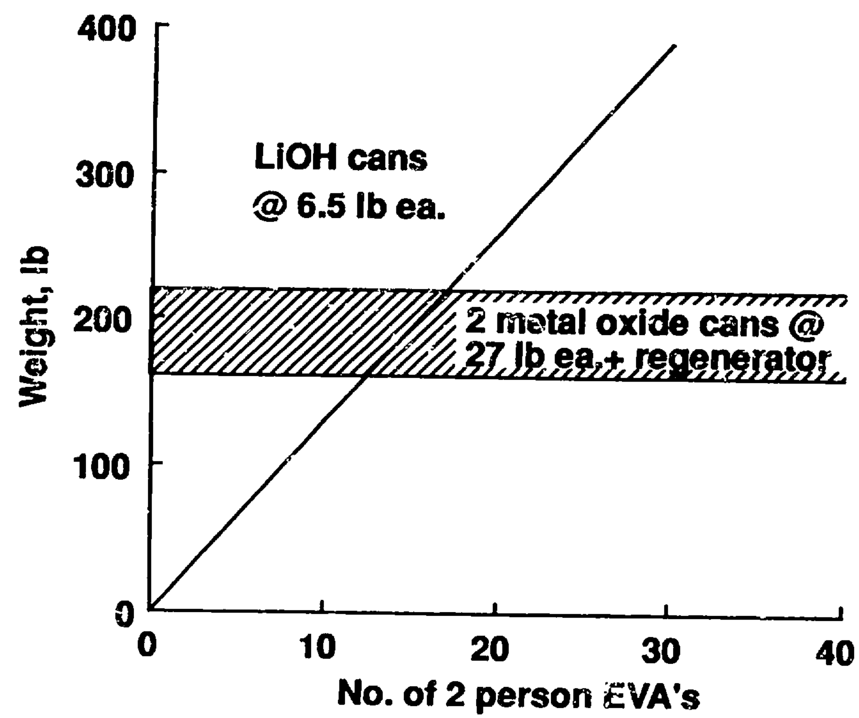
CO_2 CONTROL

Recommended Future Approach

- Continue metal oxide development

Principal Advantage

- On-orbit regenerable — saves resupply weight



CO_2 CONTROL (CONT'D)

Other Desired Attributes

- Low volume
- Regenerable on-orbit with low power at low temperature
- Long shelf life
- High cycle life
- Insensitive to relative humidity
- Static system — no moving parts
- Non-venting capability
- Quick regeneration/changeout for contingency EVA's

Current Status

- STS EMU: LiOH, ~0.13 ft^3 and 6.5 lb for 7 hrs.
  On-orbit replaceable, non-regenerable
- SSF AEMU: Metal oxide, ~0.13 ft^3 and 27 lb for 8 hrs.
  On-orbit replaceable and regenerable
- NASA A/D programs
  - — Metal oxide
  - — Metal oxide + desiccant
  - — ERCA liquid hydroxide/membrane electrochemically regenerated

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PRIME MOVERS

High speed fans, operating at above 100,000 RPM, offer significant volume reductions in the fan and motor mechanical elements. The fundamental acoustic frequencies are also well above the voice frequencies that carry speed information, so speed interference is reduced. The main development concern is bearings for operation in pure O2. Magnetic bearings may be a good starting point.

The present fan-pump-separator for Shuttle EMU was optimized for small volume by mounting these centrifugal wheels on a single 19,000 RPM motor shaft. Due to the very small size of the water pump, it is potentially contamination sensitive and does not pump if started in a gas-bound condition.

Scroll pumps act more like positive displacement pumps, thus offering increased tolerance to contamination and gas inclusion. The chief development concern todate is the eccentric coupling/drive mechanism which must also keep the orbiting scroll "pointing North".

PRIME MOVERS

Recommended Future Approaches

- Evaluate scroll machines (pump and fan/pump) — include couplings and drives
- Evaluate high speed fan — include bearings
- Update electric, electronic and electro-magnetic (EEE) parts availability for use in motors. Shrink motor electronics volume to 1/[illegible] and improve efficiency ~15%.

Principal Advantages

- Scroll machines: Quiet operation, long life, insensitivity to gas inclusion and contamination (pump)
- High speed fan: Small volume, reduced speech interference
- EEE parts: Reduced volume, reduced power consumption

	Wt, lb	Vol, in^3	Power, watts
Scroll pump*	~2	~80	~5-6
120K rpm fan*	~3	~60-80	~20 @ 8.3 psi
SSF EMU pump	2	70-80	8
SSF EMU fan	4.5	150	45 @ 8.3 psi
STS EMU fan/pump/separator	5	150	38 @ 4.3 psi

*With updated EEE parts

PRIME MOVERS (CONTINUED)

Motor electronics volume could be reduced to approximately 1/3 of present volume if the MIL-approved EEE parts list were to include the following types of parts now available commercially:

- Monolithic devices for motor control circuits. Motor control functions are presently implemented using discreet components. Commercial monolithic devices are available that perform the following function in single devices:
  - Filtering
  - Speed signal
  - Digital drive signal
  - Position/speed feedback and Hall sensor interface
  - "Soft" start: reduces EMI by starting motor slowly

- Surface Mount Technology for motor electronic devices.

- Low resistance MOSFET devices for power switching - will increase motor efficiency also.

Current estimates of motor efficiency improvement are on the order of 15% in the baseline SS AEMU. This would yield a power savings of 9 watts, and permit ~ 7% reduction in battery size.

PRIME MOVERS (Cont'd)

Other Desired Attributes

- Long life
- High reliability
- Low EMI signature

Current Status

- STS EMU
  - — Integral fan, pump and water separator, canned motor
  - — 3 centrifugal wheels on one 19,000 rpm shaft
  - — Pump magnetically driven
  - — Fan flow 6 cfm @ 1.0 in. H_2O
  - — Pump flow 240 lb/hr at 2 psi
  - — Separator flow ~11 lb/hr @ 16.6 psid
- SSF AEMU
  - — Separate fan/separator and pump
  - — Fan: 19,000 rpm, 6.5 cfm @ ~5 in. H_2O, centrifugal
  - — Pump: Vane or scroll, canned motor, 240 lb/hr @ 9.7 psi

COMFORT

Some subtleties of EV crew comfort are not fully understood at this time. In theory, the liquid cooling garment suppresses sweating over the torso so that the latent metabolic heat load is mostly from respiration, with a relatively small portion coming from the head. Cooling garment temperature is controllable by the crewmember as a function of work load and personal preference. There should be no cold spots in the suit and the cooling garment should be dry after EVA.

There is evidence that the comfort control system does not work like this all the time. Sometimes, the cooling garments are wet after EVA, indicating either condensation or sweating. Occasionally, the crew has reported cold hands. It is not understood if cold hands result from low local temperature at the hands or are a symptom of a cold body resulting from re-evaporation of moisture from a wet cooling garment.

The NASA/JSC A/D program which developed the automatic cooling control algorithm did not address these issues to the point where this problem could be solved for the STS EMU. This problem should be understood and solved for EVA operation from evolved SSF.

COMFORT

Recommended future approaches

- Understand "Cold Astronaut" problem
- Evaluate no vent flow over torso
- Evaluate heating hands and/or feet

Principle advantages

- Improved crew acceptance
- Improved EVA productivity

COMFORT (Cont'd)

Other Desired Attributes
- Adjustable comfort control
- Accommodates full range of metabolic loads and external environments
- No local hot, cold or wet areas
- Minimize sweating

Current Status
- STS EMU
  - — Liquid cooling over torso, arms and legs
  - — Gas cooling over head, hands and feet
  - — Manual cooling control, no heating
- SSF AEMU
  - — Liquid cooling over torso, arms and legs
  - — Gas cooling for head and hands, no cooling for feet
  - — Automatic cooling control, no heating
- NASA A/D program
  - — Automatic cooling control algorithm

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HEAT REJECTION

Both Apollo and Shuttle EMU use sublimators and stored water for heat rejection. This is a good choice for the following reasons:

- Adequate water availability with acceptable penalties. The Shuttle Orbiter is fuel-cell powered and makes excess water as a by-product. Apollo LM was battery powered, but carried sufficient water for EVA.

- Small volume/weight system on the back does not encumber the EVA crew.

Space Station originally mandated non-venting because closed ECLSS loops did not produce excess water for EVA use. Non-venting EMU hjelped make SSF attractive to the scientific user community by removing issues of contamination deposition and obscuration from consideration. However, the large weight and volume of the EMU non-venting heat concepts made the baseline SS AEMU unacceptably large and heavy.

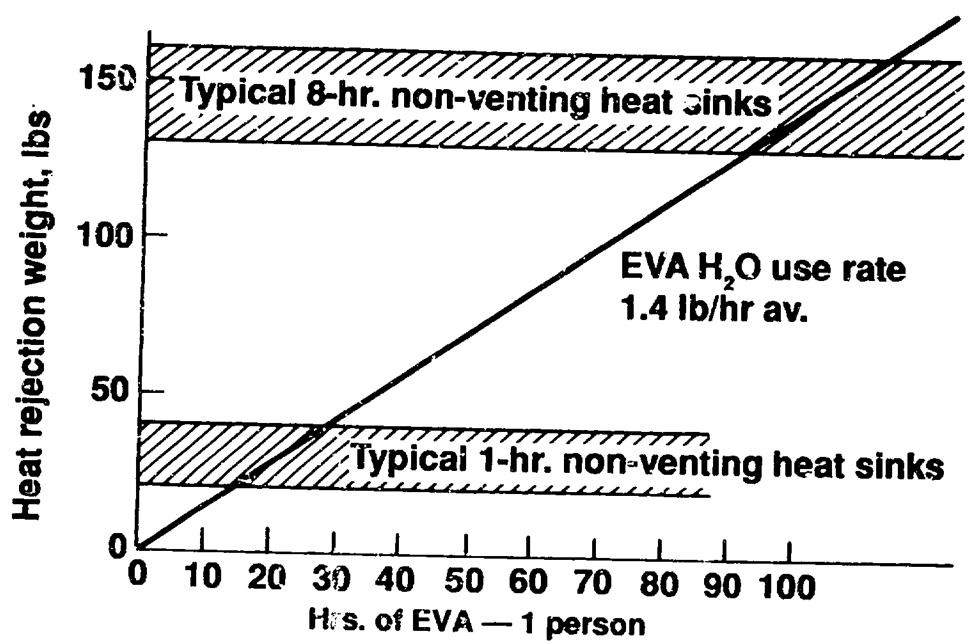
"Scrub '89" opened some of the ECLSS loops and eliminated the EVA non-venting requirement. However, a requirement for one hour of non-venting operation may still exist, and some future scenarios for evolved SSF may require non-venting EVA. Future logistical restrictions may also favor part or full time non-venting capability to save weight of water to orbit.

For these reasons the development of promising, non-venting heat sinks should continue.

HEAT REJECTION

Recommended Future Developments
- Continue ice chest development
- Continue metal hydride development
- Continue wax-radiator development

Principal Advantages
- Provide non-venting capability
- Reduce resupply penalty



HEAT REJECTION (Cont'd)

Desired Attributes

- Small volume
- Regenerable on-orbit
- Low power
- Insensitive to external environment extremes
- Quick recharge/changeout for contingency EVA's
- Minimal crew reservice effect
- Reliable, compact, low power recharge/ regeneration facility

Current Status

- STS EMU
  - Sublimator, stored water, 100% venting for 7 hrs., ~12 lbs and 0.2 ft^3
- SSF AEMU
  - Baseline: TE-wax-radiator, 100% non-venting for 8 hrs, 150 lbs, 2.0 ft^3, 20 watts av.
  - 3 ft^3 version: Metal hydride, 7-hr venting, 1-hr non-venting, (TBD) lbs, TBD ft^3
- NASA A/D programs
  - Ice chests: Direct and indirect contact
  - Vapor cycle heat pump w/radiator
  - TE-wax-radiator w/65°F wax
  - 50°F wax radiator
  - Metal hydride heat sinks, venting and non-venting

POWER SOURCES

The Shuttle EMU uses a silver-zinc battery which remains the highest energy density rechargeable battery in production today: 42 watt-hr/lb. Its late 1970's design is optimized for low volume, which results in a rated cycle life of 10 cycles and a wet shelf life of 120 days. Work is underway to extend wet shelf life and 180 days has been achieved todate.

Meanwhile, the quest for advanced secondary (rechargeable) batteries continues in industry. Driven by common needs of military equipment and electric vehicles for high energy density, and by opposing needs for long shelf life and high cycle life, battery development has taken two tracks. Long life, high density, but non-rechargeable lithium primary batteries are now becoming commonplace in the marketplace. On a slower track, secondary lithium and silver-iron batteries are only now beginning to emerge from the laboratory.

It is time to review current developments in secondary batteries to evaluate their potential use in supporting EVA from evolved SSF.

Fuel cell development for EVA applications has progressed to the demonstration hardware stage. The application is potentially interesting because of its small size relative to the extended duration silver-zinc battery baselined for the SS AEMU. The fuel cell would share the primary O_2 supply with the EMU pressurization subsystem, and could share its nickel hydride hydrogen storage subsystem with a hydride heat sink. This EMU concept would require presence of a hydrogen recharge facility in the air lock, which is not presently in the baseline.

POWER SOURCES

Recommended future developments

- Continue fuel cell development
- Evaluate advanced secondary batteries, eg. lithium, silver-iron

Principle advantages

- Batteries:
  - High energy density, 45-55 w-hr/lb
  - Long shelf life, years
  - High cycle life, hundreds
- Fuel cell
  - Low volume
  - Integrates well with metal hydride heat sink

POWER SOURCES (Cont'd)

Desired Attributes

- High power density
- Low volume
- Flat voltage/time characteristic
- High peak power capability
- Long shelf life
- Safety
- High cycle life
- 16 hr. max. recharge
- Quick, easy replacement
- Minimal crew reservice effect
- Safe, reliable, compact, low power recharge facility

Current Status

- **STS EMU**
  Silver zinc battery, 42 W-hr/lb
  16.8V, 404 W-hr, 10 cycle
  9.6 lb, 142 in³, 120 day wet life
- **SSF AEMU**
  Silver zinc battery, 26 W-hr/lb
  28V, 1355 W-hr, 40 cycle
  53 lb, 925 in³, 180+ day wet life
- **NASA A/D program**
  H_2/O_2 fuel cell, 25 W-hr/lb
  Hydride alloy: Cerium-free mischmetal
  Penta nickel
  28+4/-2V, 930 W-hr
  38 lb, 415 in³

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CONTROLS

Apollo and Shuttle EMU's use manual control of communication, display, comfort, crew safety and backup functions. Most of these controls are located on the chest in a Display and Control Module (DCM). Only a purge valve is located elsewhere, on the helmet.

Voice control for comm. display and comfort functions is baseline in the SS AEMU to help overcome some of the drawbacks to chest-mounted controls, which are:

- Some controls are not visible. Some crewmembers wear a forearm mirror to see these controls.
- Mechanical linkages from a DCM have to cross the entry closure in the AEMU rear-entry suit.
- The DCM intrudes on the work space in front of the EMU for some of the EV crew, especially those with shorter arms.

Voice control in the AEMU has helped reduce the number of comm and display controls from 8 to 2 which simplifies finding a suitable location for the remaining comfort, crew safety and backup controls. Continuing to develop such non-manual controls will ultimately improve the EMU's convenience and will enhance EV productivity.

CONTROLS

Recommended Future Developments
- Continue voice actuation development
- Identify and evaluate other promising control technologies, eg, eye motion control

Principal Advantages
- Hands-free operation more convenient than manual operation
- Reduces number of manual controls on EMU — inconvenient location
- Simplifies packaging — eliminates manual/mechanical leakages to remote actuators

Voice control supports reduction of 8 EMU control switch functions to 2

STS EMU	SSF AEMU
Power mode	Mode
* CWS	Ack/Select
* Fan	
Feedwater	
* Volume control (2)	
* Display intensity	
* Push-to-talk	

*Functions under voice control in SSF AEMU

CONTROLS (Cont'd)

Desired Attributes

- Convenient, accessible location
- No inadvertant actuation
- Positive, unambiguous actuation
- Two-step actuation where feasible, e.g., command/execute or enable/actuate
- Easy detection of control state where feasible, e.g., valve position indicator

Current Status

- STS EMU
  - — Manual controls located on chest and helmet (no automatic controls)
- SSF AEMU
  - — Voice actuation of comm, display and comfort functions
  - — Manual control of backups and crew safety functions, located on helmet and either over-the-shoulder or chest
- NASA A/D programs
  - — Voice control of helmet mounted display

DISPLAYS

The current STS EMU uses a 12 character, alphanumeric display for EMU status information. EV task promps use cuff cards to pre-identified procedures. This is adequate for Shuttle where EV tasks have been well defined and the crews well trained on Earth before their one-to-two week flights. Crews are expected to remain aboard station from three to six months and the potential number of EV tasks, contingency and planned, will be greater owing to the long duration use of Station. Hence, the need is foreseen to perform EV tasks for which crewmembers have not been specifically trained. Such tasks will proceed more quickly and with more confidence with the ability to display text and graphics to the crewmember in real-time.

NASA A/D program work to date in helmet-mounted displays is promising. Other display locations that reduce EMU volume include the body (chest or wrist), hand-held, or structure mounted. Halographic properties makes it possible to project 3-D images. EV task aids such as these will improve EVA productivity and reduce ground training requirements.

DISPLAYS

Recommended Future Developments

- Continue HMD development
- Evaluate holographic projections
- Evaluate direct view displays, e.g.
  - — Body mounted
  - — Hand held
  - — Structure mounted

Principal Advantages

- Future displays can display more information (text and graphics) than present EMU
- Text and graphics can convey task procedure information. Present EMU displays EMU status only. Cuff cards are used as prompts to EVA tasks.
- Task training can be reduced if real-time instructions can be displayed
- Unanticipated EV tasks can be performed, i.e, tasks <u>not</u> specifically trained for on the ground

DISPLAYS (Cont'd)

Desired Attributes

- Viewable in bright sunlight and darkness
- Low power requirement
- Low cooling requirements
- Freeze-frame TV image initially, ultimately moving TV images
- Where applicable
  - — Video compatible input
  - — Voice actuation of image control
- For helmet-mounted displays:
  - — Virtual see-thru image
  - — High information density
  - — Binocular image
  - — Wide field of view
  - — Non pupil forming

Current Status

- STS EMU
  - — Back-lit 12 character LCD display (formerly LED) on chart — EMU status alpha-numerics only
  - — Cuff cards for pre-identified EV tasks
- SSF AEMU
  - — Helmet mounted display with requirements for 640x480 pixel display in 1.25x1.0 in. LCD (best industry responses are for 557x346 pixel 1.25x1.0 LCD and 640x200 in. 1.4x1.1 in LCD)
- NASA A/D program
  - — Helmet mounted display concepts using CRT and 320x220 pixels in 1.0x1.0 in. LCD

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SENSORS

The STS EMU uses sensor technology from the late 1970's. The electrochemical CO_2 sensor is no longer available and is being replaced. Sensor technology is changing very rapidly now with the advent of digital signal processing, fiber optic data transmittal and "smart sensors" that contain integral error correction and signal conditioning. In addition, "mono-machines", mechanical and electromechanical devices fabricated by integrated circuit methods on a mono-meter scale are beginning to receive serious research attention.

These advances in sensor technology warrant evaluation for application in EVA equipment for evolved SSF. This equipment could make good use of the miniature, error-correcting and rugged sensors now being developed for industrial and military applications.

SENSORS

Recommended future developments

- Evaluate current technologies for miniature pressure temperature and proximity sensors
- Evaluate/develop sensors with
  - Integral signal conditioning
  - Integral data formatting
  - Fiber optic data output
  - Miniature connectors

Principle advantages

- Small size
- Compatible with all-digital signal processing

SENSORS (Cont'd)

Desired Attributes

- Small size
- Low power consumption
- Mechanically rugged
- Useable signal output level
- Simple mechanical interface
- Small error band
- No hysteresis
- Long calibration interval
- Highly repeatable
- High EMI tolerance

Current Status

- STS EMU
  - Electrochemical CO_2 sensor no longer available — being replaced
  - Other sensors use thermister and strain gages of late 1970's technology
- SSF AEMU
  - Uses new STS CO_2 sensor with relative humidity capability added
  - Uses current technology for pressure and temperature sensors
- NASA A/D program
  - N/A