Objectives and Overview

• Define Extravehicular Activity (EVA), identify the reasons for conducting an EVA, and review the role that EVA has played in the space program
• Identify the types of EVAs that may be performed
• Describe some of the U.S. Space Station equipment and tools that are used during an EVA
  • Extravehicular Mobility Unit (EMU)
  • Simplified Aid For EVA Rescue (SAFER)
  • International Space Station (ISS) Joint Airlock and Russian Docking Compartment 1 (DC-1)
• EVA Tools & Equipment
• Outline the methods and procedures of EVA Preparation, EVA, and Post-EVA operations
• Describe the Russian spacesuit used to perform an EVA
• Provide a comparison between U.S. and Russian spacesuit hardware and EVA support
• Define the roles that different training facilities play in EVA training
• Extravehicular Activity (EVA)
  – Definition: Crewmember leaves the protective environment of a pressurized spacecraft cabin and ventures out into vacuum of space wearing an extravehicular spacesuit.

  – Purpose
  • Contingency or Mission Success Repairs
  • Experiments or Testing
  • Spacecraft Servicing
  • Space Structure Construction [e.g., International Space Station (ISS)]
Definition of Spacesuits

• Spacesuits
  • Typically, 2 types of pressurized ‘spacesuits’ have been constructed to support our space programs

  • Launch, entry, and abort (LEA) spacesuit
    – Used to protect crewmembers from launch, ascent, abort, landing and other dynamic loading
    – Capable of providing protection from loss of cabin pressure and crew rescue following landing.

  • Extravehicular Activity (EVA) spacesuit
    – Used to allow crewmembers to work effectively in the harsh external space environment (provides protection from vacuum, thermal, micrometeoroids, radiation, etc.).
Historical Overview

• First EVA was conducted by USSR/Alexi Leonov on March 18, 1965.
  – Many EVAs have since been accomplished by the Soviet Union & Russia continuing into the International Space Station era.

U.S. EVA Experience

• Gemini EVA Experience -
  – Start of EVA program was excursion to perform a special set of procedures in a new and hostile environment.
  – Proved EVA to be a viable technique for operations outside the spacecraft crew compartment.
  – Problems encountered: helmet fogging, overheating due to high metabolic activity (primarily due to suit constraints and lack of training).

  – Gemini Extravehicular Spacesuit and Life Support
    • 5-layer Gemini spacesuit was intended primarily for Intravehicular Activity (IVA).
    • 2 additional layers were added for EVA (making 7 layers total).
    • An umbilical was used to tether the EVA crewmember to the spacecraft and to supply breathing oxygen.
  – 5 Gemini missions involved nine EVAs for a total of 12 hours and 22 minutes of EVA.
Historical Overview

• Apollo EVA Experience
  – Spacesuit was redesigned to allow greater mobility.
  – Suit used for lunar and in-space EVAs.
  – Suit was configured with its own portable life support system providing:
    • Pressurization & Atmosphere
    • Communication
    • Ventilation
    • Cooling
    • Waste management system
  – 7 EVA missions totaling 170 hours of EVA (15 on lunar surface, 5 outside Crew Module).
  – Last 3 Apollo missions (15, 16, & 17) utilized the lunar rover vehicle for greater range in lunar exploration.
Historical Overview

• Skylab EVA Experience
  – Apollo-style suit used.
  – Umbilical replaced portable life support system and provided breathing oxygen, cooling, and served as a tethering device.
  – 10 EVAs were performed during the 3 Skylab missions totaling 82.5 hours.

• Space Shuttle EVA Experience
  – New space suit design for additional mobility and modularity.
  – Portable life support system designed for microgravity operation.
  – Increased operational capability from orbiter.
  – Accumulated 1000s of hours of EVA experience over 200+ EVAs.

• Space Station EVA Experience
  – EMU certified for extended duration on-orbit operations (25 EVAs).
  – Orbital Replacement Unit (ORU) capability added.
  – Accumulated 1000s of hours of EVA experience over 150+ EVAs.
• Three basic categories of EVA:

1. **Scheduled EVA:**
   
   EVA planned and trained prior to launch and included in the mission timeline.

   - Both ‘skills-’ and ‘task-based’ training used

2. **Unscheduled EVA:**

   EVA, although trained, not included in the scheduled mission activities, but which may be required to achieve mission or operational success.

   - Both ‘skills-’ and ‘task-based’ training used

3. **Contingency EVA:**

   EVA required to effect the safety of the crew and vehicle.

   - ‘Skills-based’ training used
EVA Systems

- Extravehicular Mobility Unit (EMU)
- ISS Joint Airlock
- Equipment & Tools (including Simplified Aid For EVA Rescue (SAFER))
• The EMU is an independent system that provides the crewmember with environmental protection, mobility, life support, and communications during EVA.

• EMU provides consumables to support an EVA of 7 hours maximum duration.
  • 15 minutes for egress
  • 6 hours for useful work
  • 15 minutes for ingress
  • 30 minutes for reserve

• EMU is an integrated system consisting of two subassemblies:
  • Space Suit Assembly (SSA)
  • Portable Life Support System (PLSS)
Space Suit Assembly Components:

- Hard Upper Torso (HUT)/arms
- Lower Torso Assembly (LTA)
- Extravehicular (EV) gloves
- Helmet/Extravehicular Visor Assembly (EVVA)
- Communications Carrier Assembly (CCA; Comm Cap)
- Liquid Cooling and Ventilation Garment (LCVG) / Thermal Cooling Under-Garment (TCU)
- Operational Bioinstrumentation System (EKG)
- Disposable In-Suit Drink Bag (DIDB)
- Maximum Absorption Garment (MAGs)
EVA Systems – Space Suit Assembly

- Extravehicular (EV) gloves
- Extravehicular (EV) boots (and insert)
EVA Systems – Life Support

• Life Support System Components:
  • Display and Control Module (DCM)
    - Provides Caution & Warning System (CWS) messages, EMU parameters, and EMU controls to crewmember
• Life Support System Components:
  • Portable Life Support Subsystem (PLSS)
    - Provides breathing O₂, electrical power, communications, cooling
    - Responsible for suit pressure control
    - Circulates O₂ and removes CO₂, humidity and trace contaminants
    - Controls thermal environment
  • Secondary Oxygen Package (SOP)
    - Provides a minimum of 30 minutes of emergency O₂ in open-loop purge mode
    - Activated automatically during EVA, if necessary
• Life Support System Components (Cont’d):
  • Space-to-Space EMU Radio (SSER)
  • Caution and Warning System (CWS)
  • Early Caution and Warning System (ECWS)
    - Provides EMU status parameters and biomedical data for transmission to Mission Control
  • Battery
    – Primary
    – Rechargeable EVA Battery Assembly (REBA)
  • Contaminant Control Cartridge (CCC; LiOH Cartridge or Metal Oxide (METOX) Cartridge)
    - Removes CO₂ and trace contaminants
• Space Shuttle
  • Two (2) EMUs are baselined on each Shuttle flight with enough consumables to support three (3),
    two-crewmember EVAs. Of these 3 EVAs,
    – One 7-hour EVA may be supported.
    – Two EVAs of 3-hours and 4-hours respectively may be supported for Orbiter contingency EVA
      operations.
  • Consumables provided include:
    • CO2 cartridge (non-regenerable LiOH)
    • Oxygen
    • Potable water (for drink bags)
    • Feedwater (or sublimator water)
    • Power
    • Battery chargers

• International Space Station (ISS)
  • 4 - EMUs are, typically, kept on board to support EVAs
  • Sufficient consumables allow a large number of EVAs to be performed
  • Consumables provided include:
    • CO2 cartridge (metal oxide) and regenerator
    • Oxygen
    • Potable water (for drink bags)
    • Feedwater (or sublimator water)
    • Power
    • Battery chargers
• ISS Joint Airlock:
  • Primary for U.S. ISS EVAs (both Orbiter and Station-based)
  • Compatible for use with Russian Orlans
  • Made up of two parts: Crew Lock and Equipment Lock
    – Equipment Lock is used for stowage, recharge and servicing of EMUs and to don/doff the EMUs
    – Crewlock is the volume nominally depressed to vacuum for crew to go EVA
EVA Systems - ISS Joint Airlock

STS-104 / Flight 7A
(Summer 2001)
EVA Systems - ISS Joint Airlock
EVA Equipment & Tools

- EMU-mounted tools & equipment
  - TV Camera
  - Lights
  - Mini-workstation
  - Waist tethers
  - EVA Cuff Checklist
  - Wrist mirror
  - Body Restraint Tether
  - Pistol Grip Tool (PGT)
  - ISS Small Trash Bag
Mini Work Station (MWS)
- Attaches to front of the EMU
- Used to carry small tools
- Tools are secured via tether rings or via bayonet receptacles
- MWS end-effector with retractable tether provides restraint to EVA Crewmember at worksite

Note: “Drop-proof tether” PIP pins are used to secure certain items such as a socket onto a tool caddy.
• Commonly Used Tethers
  - Safety Tether (55’ and 85’)
    - Used to secure the EVA crewmember to the vehicle
  - Suit tethers (Waist, Wrist)
    - Used to secure small items to the suit, usually for transfer
  - Retractable EVA Tether (RET)
    - Used to secure small items, usually while item is in use
  - Body Restraint Tether (BRT)
    - Attaches to the Mini-Work Station (MWS)
    - End-effector provides semi-rigid restraint to EVA crewmember at worksite via handrail (also used for translating small objects)
    - Requires less time than setting up a Portable Foot Restraint and is more stable than a MWS end effector
  - Note: EVA tether protocol is that crewmembers and equipment must be tethered at all times
    - Always make a connection before you break a connection.
SAFER is a self-contained, propulsive backpack self-rescue system that provides the EV crewmember with self-rescue capability when the orbiter is not present or cannot immediately perform EVA rescue.

- Propellant: Pressurized nitrogen gas
- Controlled by a single hand controller
- Stowed in ISS Airlock, used on ISS EVAs
- Sufficient propellant and power for one self-rescue (~13 min)
- Test flight on mission STS-64; self-rescue capability on STS-76
- Power up of production model SAFER on STS-86
- Tethered test flight of production model SAFER on Flights 2A and 3A
EVA Systems -
SAFER (Simplified Aid for EVA Rescue)

SAFER Deployment
EVA Equipment & Tools

• Pistol Grip Tool (PGT)

• EVA torque wrench (i.e., a bolt turner)
  • Has a programmable torque limiter and turn limiter
  • Crewmember needs to be secured depending on amount of torque required
  • 2ft-lbs to 25ft-lbs of torque available
  • Generally used for ISS assembly missions and maintenance EVAs

↔ 1-G Testing of the PGT
EVA Equipment & Tools

• Foot Restraints
  • Attach to structure via a socket
  • Provides EVA crewmember rigid restraint at a worksite (Newton’s 3rd Law)
• Different types:
  • Portable foot restraint (PFR) *(Shuttle)*
  • Articulating PFR (APFR) *(U.S. ISS)*
  • Interoperable APFR (IAPFR) *(U.S. & Russian ISS)*
EVA Equipment & Tools

- Crew and Equipment Translation Aid (CETA) Cart
  - Essentially an EVA equipment cart
  - Translates by CM manually pulling it along truss
  - Use brakes to stop and stay parked
  - Typical use: small ORU replacement on front truss face
EVA Operations Overview

EVA operations can be divided into three phases:
Pre-EVA: Preparation & Checkouts

• Equipment Prep
  – Prepares the airlock and the EMUs to be checked out before EVA.
    • This is normally performed a few days before the EVA or before the Orbiter docks to the Station.

• EMU Checkout
  – Checks all EMU systems.
    • Performed a few days before the EVA or before the Orbiter docks to the Station.

• EVA Prep
  – All steps performed the day of the EVA prior to going EVA, including:
    • EMU Donning
    • Prebreathe with 100% oxygen
### Pre-EVA: Prebreathe

O₂ Prebreathe reduces the risk of Decompression Sickness (DCS)

<table>
<thead>
<tr>
<th>Protocol</th>
<th>In-Suit</th>
<th>In Suit Light Exercise (ISLE)</th>
<th>Campout</th>
<th>Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mask prebreathe time</strong></td>
<td>None</td>
<td>1 hour</td>
<td>1 hour (1st day)</td>
<td>80 minutes</td>
</tr>
<tr>
<td><strong>In-suit prebreathe time</strong></td>
<td>4 hours</td>
<td>100 min</td>
<td>50 min (2nd day)</td>
<td>1 hour</td>
</tr>
<tr>
<td><strong>Ops Overview</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>(Details of EVA Prebreathe protocols are in the Aeromed Flight Rule #B13-107)</em></td>
<td>Breathe 100% O₂ in-suit for 4 hours while cabin is at 14.7, go out the door.</td>
<td>In Suit prebreathe light exercise totals 90 min; 50 min light exercise, 40 min Metox change out</td>
<td>Breathe 100% O₂ on mask while depressing cabin to 10.2, wait approx. 9 hours before in-suit prebreathe, go out the door.</td>
<td>Exercise on ergometer (i.e., bike) for 10 minutes at beginning of mask prebreathe (100% O₂), depress airlock to 10.2, breathe in-suit for 1 hour, go out the door.</td>
</tr>
<tr>
<td><strong>Total EVA prep &amp; P/B time:</strong></td>
<td>5:42 hrs</td>
<td>3:12 hrs</td>
<td>13:12 hrs</td>
<td>4:02 hrs</td>
</tr>
</tbody>
</table>

*Note: Long-duration exploration vehicles plan to utilize 8 psia / 32% O₂ atmosphere.*
20-Foot Chamber
### Night Before EVA

- **PRE SLEEP 3 hours**
  - 60 min mask PB
  - 10.2 Dep
  - 45 min before 11.8

### EVA Day

- **HYGIENE BRK 70 min**
- **EVA PREP 90 min**
- **Purge**
- **C/L Dep (30 min)**
- **EMU Prebreathe (50 min)**
- **EMU Donning 55 min**
- **Ck**
- **Rep**
- **POST SLEEP 35 min**
- **POST SLEEP 40 min**

### Night Before EVA Summary
- Pre Sleep (3 hours total)
- Mask Prebreathe (1 hour)
  - 10.2 psi Airlock Depress (20 mins)
- 10.2 psi Overnight Campout (8 hours 40 mins minimum)

### EVA Day Summary
- **EVA DAY SUMMARY (continued)**
  - EVA Prep (~1 hour 30 mins)
    - EVA Prep for Donning (30 mins)
    - Suit Donning at 10.2 (1 hour)
  - Suit Purge (12 mins)
    - Airlock Repress to 14.7
  - In-suit Prebreathe (50 mins)
  - Crewlock Depress to vacuum (30 mins)
  - EVA tasks (6 hours 30 mins)
  - Airlock Repress (20 mins)
  - Post EVA without EMU H2O Recharge or METOX Regeneration (1 hour)
  - Pre Sleep (2 hours)
### EVA Operations: Overview of EVA Tasks

<table>
<thead>
<tr>
<th>Time</th>
<th>Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 min</td>
<td>Airlock depress</td>
</tr>
<tr>
<td>15 min</td>
<td>Airlock egress</td>
</tr>
<tr>
<td>15 min</td>
<td>Airlock ingress</td>
</tr>
<tr>
<td>30 min</td>
<td>Airlock repress</td>
</tr>
</tbody>
</table>
| 6 hours| **Worksite operations: Shuttle and ISS-based**

- All Shuttle EVA crewmembers are trained to perform the following Orbiter contingency tasks (if necessary) for each flight:
  - Failed airlock hatch latches or actuator tasks
  - Failed Remote Manipulator System (RMS) tasks
  - Manual stowage of radiators or Ku-band antenna
  - Manual closure of payload bay doors
  - Installation of payload bay door latch tools
  - Manual separation of Shuttle from ISS (96 bolt task)

- EVA crewmembers assigned to a flight are also trained for scheduled, unscheduled, or contingency tasks.
Post-EVA Operations

• EMU Doffing

• EMU Maintenance and Recharge
  – \( \text{O}_2 \) tank recharge
  – Battery recharge
  – \( \text{H}_2\text{O} \) tank refill
  – METOX regeneration/ LiOH swap
  – Suit cleaning
  – Suit resize (if required)
Comparison of Russian & U.S. EVAs

- Russian Orlan-M Spacesuit
- U.S. Extravehicular Mobility Unit (EMU)
• Orlan-M Spacesuit

- Visors
- Electrical Control Panel (ПО-4МТ)
- Fluid Umbilical Connector (ОРК-19)
- Orlan Safety Tether
- Helmet Lights
- Suit Pressure Gauge (УДСК)
- Backpack Closure Strap
- Backpack
- Emergency O₂ Hose
- Pneumo-Hydraulic Control Panel (ПГПУ-1М)
- Electrical Umbilical

Back-Entry Orlan-M
• Arm Assembly
(Thermal Micrometeoroid Garment “TMG” Removed)
• Leg Assembly
(TMG Removed)
Electrical Control Panel (ΠΟ-4ΜΤ)

- Primary Pump Switch
- Primary Fan Switch
- Reserve Fan Switch
- Power Switch
- Volts/Tone Mute Button
- Reserve Pump Switch
- Battery Voltage/Oxygen Tank Pressure Display
- Liquid Crystal Display

Orlan-M Electrical Control Panel (ΠΟ-4ΜΤ)
Electrical Control Panel (ΠΟ-4МТ)

• Orlan-M Electrical Control Panel (ΠΟ-4МТ) (side view)

- Helmet Light Switch
- Reserve Radio Switch
- Primary Radio Switch
- Push-to-Talk Switch
Radio Telemetry Apparatus Unit (БРТА-1М)

- Contains the following electrical assemblies:
  - Korona-M Communications Radio
  - Tranzit-A Telemetry Radio (2 parts)
    - Data Gathering Unit (TA-237)
    - Transmitter (ИША-347)
  - Battery (autonomous power supply)
  - Current and Power Measurement Unit (БКНТЗ)
  - High-Frequency Filter (ФР (ТК))
  - Annunciation Unit (БС-1М)
  - Relay Module (МР)

- БРТА-1М attaches to bottom of backpack enclosure (not pressurized)

- Easily attached to and removed from suit
Radio Telemetry Apparatus Unit (БРТА-1М) (Shown without Primary Oxygen Tank installed)
Safety Tethers

- Two Safety Tethers attached on the right HUT/Leg Assembly flange
  - Not designed for EVA removal
  - One Tether is fixed length
  - One Tether is variable length
  - Both tethers share an attaching strap
  - Tether hooks
    - One fault tolerant
    - Titanium construction
    - Certified for 600 kg (1320 lbs)

- Variable Length Safety Tether
EVA Tools and Crew Aids

- Orlan Tether Adapter (OTA)
  - Provides interface points for U.S. tools
  - Provides various equipment tether loops

- OTA Interface Block
  - Permanently mounted to the waist flange of the Orlan suit
  - Provides load support to the OTA
  - Provides one crew safety tether loop

- Standard U.S. Tool Configuration
  - OTA
  - Right Swing Arm
  - Retractable Equipment Tethers (RET)
  - EVA Camera (Digital or F5)
Comparison with Russian EVAs
EMU vs. Orlan - Manufacturers

• EMU
  United Technologies, Hamilton-Sundstrand, Windsor Locks, CT

• Orlan
  Zvezda Research, Development, and Production Enterprise,
  Tomilino (Moscow Region), Russia
• EMU – Space Shuttle and International Space Station (ISS)
  – In operation since 1981 to present
    • Several upgrades have been made

• Orlan-M – Mir Space Station and ISS
  – In operation since 1997 (replaced Orlan-DMA)
    • Upgraded Orlan-MK to be delivered to the ISS in 2008
Comparison with Russian EVAs

EMU vs. Orlan – General Characteristics

- **EMU**
  - Suit operating pressure: 4.3 psi
  - Mission duration: 6.5 hours + 30-minute contingency
  - Weight: ~280 lbs
  - On-Orbit Service life: 25 uses/2 years (with maintenance)
    - Returned for refurbishment

- **Orlan-M**
  - Suit operating pressure: 5.8 psi
  - Mission duration: 6.5 hours + 30-minute contingency
  - Weight: ~230 lbs
  - On-orbit Service life: 12 uses/4 years (with maintenance)
    - Not returned for refurbishment
Comparison with Russian EVAs
EMU vs. Orlan – Spacesuit Assembly

- **EMU Construction**
  - Semi-rigid construction; aluminum hard upper torso
  - Urethane-coated nylon pressure bladder
  - Orthofabric and aluminized mylar thermal/meteoroid garment
  - Ball-bearing joints
  - Liquid-cooling and ventilation undergarment
  - Display & Controls Module (DCM)
  - Polycarbonate helmet and polysulfone visors; helmet lights
  - Location for attachment of mini-work station, etc.

- **Orlan-M Construction**
  - Semi-rigid construction; aluminum hard upper torso
  - Urethane-coated nylon pressure bladder
  - Orthofabric and aluminized mylar thermal/meteoroid garment
  - Liquid-cooling undergarment
  - Electrical Control Panel / Pneumo-Hydraulic Control Panel
  - Polycarbonate helmet and visors; helmet lights
  - Probe provided for attachment of mini-work station, etc.
Comparison with Russian EVAs
EMU vs. Orlan – Spacesuit Assembly Differences

• EMU
  – Sizing: Medium, large, and extra large size modular components and the use of sizing inserts (legs and arms) allow a fairly large population range to be accommodated
    – Multiple glove sizes including some custom-sized gloves
  – Gloves are heated to provide protection from cold environment; wrist disconnect is on suit side
  – Suit Donning: Bottom entry
  – Helmet is removable
  – Waist tether(s) removable
  – Includes provisions for TV camera

• Orlan-M
  – Sizing: One size with adjustable sizing axial restraint cable in arms/legs
    – 2 glove sizes
  – Glove wrist disconnect is on glove side
  – Suit Donning: Back entry
  – Helmet integrated into suit
  – 2 Waist tethers (fixed and variable length); not removable
  – Orlan-MK includes provisions for U.S. TV camera
Comparison with Russian EVAs
EMU vs. Orlan – Portable Life Support Assembly

- **EMU**
  - Closed-loop, 100% oxygen
  - Expendables replaced or recharged on-orbit
  - Primary & secondary oxygen tanks
  - Liquid cooling via garment and use of sublimator
  - Carbon Dioxide and trace gas scrubber
  - Average/Max metabolic rates: 1000 BTUs (290 W) / 2000 BTUs (580 W)
  - Primary battery Li-ion
  - Radio for voice, data, and medical information; use of headset

- **Orlan-M**
  - Closed-loop, 100% oxygen
  - Expendables replaced or recharged on-orbit
  - Primary & secondary oxygen tanks
  - Liquid cooling via garment and use of sublimator
  - Carbon Dioxide and trace gas scrubber
  - Average/Max metabolic rates: 1025 BTUs (300 W) / 2050 BTUs (600 W)
  - Primary battery is zinc-silver-oxide (rechargeable)
  - Radio for voice, data, and medical information; use of headset
Comparison with Russian EVAs
EMU vs. Orlan – Portable Life Support Assembly Differences

• EMU
  – Primary O2 pressure: 2 tanks @ 900 psi (rechargeable); Secondary O2 pressure: 2 tanks @ 6000 psi (non-rechargeable)
  – Most electronics located in life support backpack @ vacuum
  – Crewmembers communicate between each other
  – Single fan-pump-water separator
  – Liquid cooling and ventilation garment; biocide: iodine
  – CO2 scrubber: silver oxide or lithium hydroxide
  – Additional rechargeable battery used for glove heating (nickel-metal-oxide)
  – Prebreathe: 4-hour in-suit, 10.2 psi, and 14.7/10.2 psi & ergometer protocols available

• Orlan-M
  – Primary and Secondary O2 pressure: 6000 psi; both removable and non-rechargeable
  – Electronics (except for БРТА) located in life support backpack @ 100% O2
  – Crewmembers communicate via the vehicle (signal is relayed)
  – Redundant fans and pumps
  – Liquid cooling garment; biocide: silver ions
  – CO2 scrubber: lithium hydroxide
  – Prebreathe: 1-hour @ 550 torr
Comparison with Russian EVAs
EMU vs. Orlan – Work Aids

• EMU
  – Compatible with:
    • Mini-work station
    • Numerous EVA tools including foots restraints, etc.
    • Simplified Aid For EVA Rescue (SAFER)
    • Donning stations

• Orlan-M
  – Compatible with:
    • Mini-work station
    • EVA tools including foots restraints, etc.
    • REBA – helmet lights
    • Donning stations (however, rarely used on orbit)
Comparison with Russian EVAs
EMU vs. Orlan – Crew Preference Items

- **EMU**
  - Comfort gloves
  - Eyeglass holder
  - Fresnel lens (various strengths)
  - In-suit drink bag
  - Maximum absorbent garment (MAG)
  - Socks
  - Valsalva device
  - Wristlets
  - Miscellaneous: Lint free wipes, Anti-fog wipes, Comfort pads, Moleskin tape, Stericide sanitizer

- **Orlan-M**
  - Comfort gloves
  - Dosimeter (passive)
  - Socks
Comparison with Russian EVAs
EMU vs. Orlan – Operations Differences

- Russian EVA crewmembers talk directly to engineers on ground
- U.S. EVA crewmembers talk through Capcom

- Russian EVA training is more skills based
- U.S. EVA training is more task based

- Russian EVA crewmembers have little or no Intravehicular (IV) interaction
- U.S. EVA crewmembers work with an IV crewmembers before, during, and after an EVA

- Russian EVA crewmembers use a hand-over-hand tether protocol
- U.S. EVA crewmembers use a safety tether (ISS & shuttle) and a slidewire (Shuttle)
EVA Training Facilities

- Shuttle Full-size Mockup Trainers (historical)
  - Crew Cabin Trainer (CCT) and CCTII
  - Full Fuselage Trainer (FFT)
EVA Training Facilities

- Space Station Mockup Training Facility (SSMTF) Airlock Mockup
EVA Training Facilities

- EMU Caution and Warning System (ECWS) Trainer
EVA Training Facilities

- Vacuum chambers
  - 11-foot chamber
  - Environmental Test Article (ETA) chamber
  - Space Environment Simulation Lab (SESL) chamber
  - Space Station Airlock Test Article (SSATA)
EVA Training Facilities

- Virtual Reality Lab
EVA Training Facilities
Charlotte for Low Gravity Mass Ops

Source: Osterlund, J. & Lawrence, B. 2012
EVA Training Facilities

- Precision Air-Bearing Floor (PABF)
EVA Training Facilities

- Neutral Buoyancy Laboratory (NBL)
EVA Training Facilities

- Micro-gravity via DC-9 (KC-135 below retired)
EVA Training Facilities
The Active Response Gravity Offload System (ARGOS)

• ARGOS uses an inline load cell to continuously offload a portion of a human or robotic subject’s weight during all dynamic motions
WEB Links

• EVA History/Advanced suit program –
  http://www.jsc.nasa.gov/xa/advanced.html

• Hamilton Sunstrand (designers of the EMU) -
  http://www.hsssi.com/Applications/SpaceSuits/

• DX32/35 Home page –
  http://mod.jsc.nasa.gov/dx/dx32/evahp.htm

• EC5 Homepage –
  http://ctsd.jsc.nasa.gov/ESS/index.html

  http://dx.doi.org/10.1016/j.actasp.2011.03.031
Backup Material
Extravehicular Activity Suits For ISS

EMU General Reference Data
Port Number – SEG12/12/22
Life – 2 year limit post delivery
Wet Mass – 310 lbs
Wet Mass, Crew – 180 kg
Max Mass, Crew – 110 kg
Max Mass, Leak Repair – 651 cm³ or 0.7 ammeters
Port opening from Nasa to 0.4 meters

Oxygen Supply
EMU Primary Oxygen Supply
Pressure – 840 psig
Volume – 454 liters
Quantity of O2 – 1.97 kg
Burst Pressure – 2100 psi
Secondary Oxygen Supply
2200 Cubic Feet 300 Bariters
Pressure – 85.6 psi
Volume – 460 liters
Quantity of O2 – 1.3 kg
Burst Pressure – 1400 psi

Regulator maintains pressure in nominal mode to compensate oxygen consumption and leaks.

Gas Recovery System
CO2 Removal – Life Support or EMU
LIFE Limit – 10 hours
Sensitivity – 100 ppm
Gas Recovery System
2000 Liter Life Support
300 days (33 cycles)
Battery Capacity of 12 Silver Zine Cells
Nominal Voltage – 18.5 V
1200 Lumen Life Support
1225 days (62.5 cycles)
Battery Capacity of 5 Lithium Polypropylene Cells
Nominal Voltage – 10.5 V

Cooling Supply
Feedwater – 1 liter
Tank Capacity – Wet Mass
Tank Water (US) – 14.5 lbs
Tank Water (EU) – 14.5 lbs
Water Temp at Output – 105°F
Gas Temp at Output – 55°F
Cooling Water Flow – 380 liters/hour
310 liters/hour

Outlet water for cooling the EMU and feedwater cycle water through the LCP and provides water for sanitation.

Orlan-M General Reference Data
Port Number – SNA-1/06-0771
Life – 1 year post delivery
Wet Mass, Crew – 120 kg
Max Mass, Crew – 65 kg
Max Mass, Leak Repair – 651 cm³ or 0.7 ammeters

Oxygen Supply
EMU Primary Oxygen Supply
Pressure – 840 psig
Volume – 454 liters
Quantity of O2 – 1.97 kg
Burst Pressure – 2100 psi
Secondary Oxygen Supply
2200 Cubic Feet 300 Bariters
Pressure – 85.6 psi
Volume – 460 liters
Quantity of O2 – 1.3 kg
Burst Pressure – 1400 psi

Regulator maintains pressure in nominal mode to compensate oxygen consumption and leaks.

Gas Recovery System
CO2 Removal – LIFE (13 cycle)
LIFE Limit – 30 hours
Sensitivity – 100 ppm
Gas Recovery System
2000 Liter Life Support
300 days (33 cycles)
Battery Capacity of 12 Silver Zine Cells
Nominal Voltage – 18.5 V
1200 Lumen Life Support
1225 days (62.5 cycles)
Battery Capacity of 5 Lithium Polypropylene Cells
Nominal Voltage – 10.5 V

Cooling Supply
Feedwater – 1 liter
Tank Capacity – Wet Mass
Tank Water (US) – 14.5 lbs
Tank Water (EU) – 14.5 lbs
Water Temp at Output – 105°F
Gas Temp at Output – 55°F
Cooling Water Flow – 380 liters/hour
310 liters/hour

Outlet water for cooling the EMU and feedwater cycle water through the LCP and provides water for sanitation.

Extravehicular Mobility Unit

Orlan-M

Extravehicular Activity Suits For ISS

EMU General Reference Data
Port Number – SEG12/12/22
Life – 2 year limit post delivery
Wet Mass – 310 lbs
Wet Mass, Crew – 180 kg
Max Mass, Crew – 110 kg
Max Mass, Leak Repair – 651 cm³ or 0.7 ammeters
Port opening from Nasa to 0.4 meters

Oxygen Supply
EMU Primary Oxygen Supply
Pressure – 840 psig
Volume – 454 liters
Quantity of O2 – 1.97 kg
Burst Pressure – 2100 psi
Secondary Oxygen Supply
2200 Cubic Feet 300 Bariters
Pressure – 85.6 psi
Volume – 460 liters
Quantity of O2 – 1.3 kg
Burst Pressure – 1400 psi

Regulator maintains pressure in nominal mode to compensate oxygen consumption and leaks.

Gas Recovery System
CO2 Removal – LIFE (13 cycle)
LIFE Limit – 30 hours
Sensitivity – 100 ppm
Gas Recovery System
2000 Liter Life Support
300 days (33 cycles)
Battery Capacity of 12 Silver Zine Cells
Nominal Voltage – 18.5 V
1200 Lumen Life Support
1225 days (62.5 cycles)
Battery Capacity of 5 Lithium Polypropylene Cells
Nominal Voltage – 10.5 V

Cooling Supply
Feedwater – 1 liter
Tank Capacity – Wet Mass
Tank Water (US) – 14.5 lbs
Tank Water (EU) – 14.5 lbs
Water Temp at Output – 105°F
Gas Temp at Output – 55°F
Cooling Water Flow – 380 liters/hour
310 liters/hour

Outlet water for cooling the EMU and feedwater cycle water through the LCP and provides water for sanitation.

Extravehicular Activity Suits For ISS

EMU General Reference Data
Port Number – SEG12/12/22
Life – 2 year limit post delivery
Wet Mass – 310 lbs
Wet Mass, Crew – 180 kg
Max Mass, Crew – 110 kg
Max Mass, Leak Repair – 651 cm³ or 0.7 ammeters
Port opening from Nasa to 0.4 meters

Oxygen Supply
EMU Primary Oxygen Supply
Pressure – 840 psig
Volume – 454 liters
Quantity of O2 – 1.97 kg
Burst Pressure – 2100 psi
Secondary Oxygen Supply
2200 Cubic Feet 300 Bariters
Pressure – 85.6 psi
Volume – 460 liters
Quantity of O2 – 1.3 kg
Burst Pressure – 1400 psi

Regulator maintains pressure in nominal mode to compensate oxygen consumption and leaks.

Gas Recovery System
CO2 Removal – LIFE (13 cycle)
LIFE Limit – 30 hours
Sensitivity – 100 ppm
Gas Recovery System
2000 Liter Life Support
300 days (33 cycles)
Battery Capacity of 12 Silver Zine Cells
Nominal Voltage – 18.5 V
1200 Lumen Life Support
1225 days (62.5 cycles)
Battery Capacity of 5 Lithium Polypropylene Cells
Nominal Voltage – 10.5 V

Cooling Supply
Feedwater – 1 liter
Tank Capacity – Wet Mass
Tank Water (US) – 14.5 lbs
Tank Water (EU) – 14.5 lbs
Water Temp at Output – 105°F
Gas Temp at Output – 55°F
Cooling Water Flow – 380 liters/hour
310 liters/hour

Outlet water for cooling the EMU and feedwater cycle water through the LCP and provides water for sanitation.

Extravehicular Activity Suits For ISS

EMU General Reference Data
Port Number – SEG12/12/22
Life – 2 year limit post delivery
Wet Mass – 310 lbs
Wet Mass, Crew – 180 kg
Max Mass, Crew – 110 kg
Max Mass, Leak Repair – 651 cm³ or 0.7 ammeters
Port opening from Nasa to 0.4 meters

Oxygen Supply
EMU Primary Oxygen Supply
Pressure – 840 psig
Volume – 454 liters
Quantity of O2 – 1.97 kg
Burst Pressure – 2100 psi
Secondary Oxygen Supply
2200 Cubic Feet 300 Bariters
Pressure – 85.6 psi
Volume – 460 liters
Quantity of O2 – 1.3 kg
Burst Pressure – 1400 psi

Regulator maintains pressure in nominal mode to compensate oxygen consumption and leaks.

Gas Recovery System
CO2 Removal – LIFE (13 cycle)
LIFE Limit – 30 hours
Sensitivity – 100 ppm
Gas Recovery System
2000 Liter Life Support
300 days (33 cycles)
Battery Capacity of 12 Silver Zine Cells
Nominal Voltage – 18.5 V
1200 Lumen Life Support
1225 days (62.5 cycles)
Battery Capacity of 5 Lithium Polypropylene Cells
Nominal Voltage – 10.5 V

Cooling Supply
Feedwater – 1 liter
Tank Capacity – Wet Mass
Tank Water (US) – 14.5 lbs
Tank Water (EU) – 14.5 lbs
Water Temp at Output – 105°F
Gas Temp at Output – 55°F
Cooling Water Flow – 380 liters/hour
310 liters/hour

Outlet water for cooling the EMU and feedwater cycle water through the LCP and provides water for sanitation.
# Pressures

<table>
<thead>
<tr>
<th>Altitude (ft)</th>
<th>Atmospheric Pressure (psi)</th>
<th>Oxygen Concentration (%)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea Level</td>
<td>14.7</td>
<td>20</td>
<td>Nitrogen Concentration is 80%. 1 atmosphere (1 atm). 101.325 kPa.</td>
</tr>
<tr>
<td>10,000</td>
<td>10.11</td>
<td>70% of Sea Level</td>
<td>Early signs of hypoxia (shortage of oxygen in the body)</td>
</tr>
<tr>
<td>15,672</td>
<td>8.3</td>
<td>56% of Sea Level</td>
<td>Exploration Atmosphere recommended pressure</td>
</tr>
<tr>
<td>18,000</td>
<td>7.34 or (14.7 / 2)</td>
<td>51% of Sea Level</td>
<td>½ atm</td>
</tr>
<tr>
<td>23,500</td>
<td>5.8</td>
<td>40% of Sea Level</td>
<td>Russian Orlan operating pressure</td>
</tr>
<tr>
<td>30,250</td>
<td>4.3</td>
<td>30% of Sea Level</td>
<td>U.S. EMU operating pressure</td>
</tr>
<tr>
<td>34,000</td>
<td>3.62 or (7.34 / 2)</td>
<td>25% of Sea Level</td>
<td>¼ atm</td>
</tr>
<tr>
<td>101,381 (19.2 miles)</td>
<td>0.147 or (14.7 / 100)</td>
<td>≈1% of Sea Level</td>
<td>1/100 atm</td>
</tr>
<tr>
<td>283,076</td>
<td>0.000147 or (14.7 / 100,000)</td>
<td>0% of Sea Level</td>
<td>ISS (220 miles or 1,161,600 ft)</td>
</tr>
</tbody>
</table>
Life Support Schematics
## Comparison with Russian EVAs
### EMU vs. Orlans

<table>
<thead>
<tr>
<th>Suit Feature</th>
<th>Orlan - M</th>
<th>EMU</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Entry Method</strong></td>
<td>Rear Entry: Self-donning typical Easy suit ingress/egress</td>
<td>Waist Entry: Self-donning possible More difficult in/egress</td>
</tr>
<tr>
<td><strong>Pressure</strong></td>
<td>5.7 psid nominal</td>
<td>4.3 psid nominal</td>
</tr>
<tr>
<td><strong>Pre-breathe</strong></td>
<td>30-minute nominal</td>
<td>40 min. nominal from 10.2 psi cabin 4 hour nom from 14.7 psi</td>
</tr>
<tr>
<td><strong>Sizing</strong></td>
<td>One size Adjust lengths of arms and legs</td>
<td>Modular 137 measurements made</td>
</tr>
<tr>
<td><strong>Useful Life</strong></td>
<td>4 years or 12 EVAs Burns on re-entry in Progress vehicle</td>
<td>2 years or 25 EVAs Refurbished and recertified on ground</td>
</tr>
<tr>
<td><strong>Displays</strong></td>
<td>C&amp;W lights on front of suit and in helmet; can send suit data to ground</td>
<td>CWS, DCM display: msg and status; can send suit data to ground</td>
</tr>
</tbody>
</table>
Comparison with Russian EVAs
EMU vs. Orlans

- Resupplying/Recharging
  - Orlan H2O tank refilled and O2 tanks replaced after each EVA
  - EMU H2O and O2 tanks resupplied via umbilical
- Orlan and EMU coolant operation similar
  - Both Orlans and EMUs use sublimators
  - Liquid Cooling (and Ventilation) Garments [LC(V)Gs] are similar
- Umbilicals
  - Orlan umbilical provides power, comm, and pre-breathe O2
  - EMU umbilical provides power, comm, O2, recharge H2O and cooling H2O
- Gloves
  - Orlan gloves used for two EVAs
  - EMU gloves used multiple times, electrically powered glove heaters
- Emergency procedures
  - Orlan: Few simple messages, gloves have reference tables on them
  - EMUs have Caution and Warning System, combined with a cuff checklist
- Both Orlans and EMUs have duplex comm
Thermal Micrometeoroid Garment