Training and Operations Engineering

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Outline

- European Human Exploration Architecture
- Global experience in Human Exploration Operations
- Crew Operations Challenges
- Mission Operations Challenges
- Conclusions Q&A
The International Space Exploration Coordination Group (ISECG) - the Global Exploration Roadmap (GER)

The two main paths are “Moon Next” and “Asteroid Next”
# ISECG Mission Scenario

**To Mars with an Asteroid as the Next Step**

## Missions and Destinations

### Low Earth Orbit
- ISS Operations
- ISS Operations
- ISS Operations
- Exploration Test Module
- Crewed visits to Exploration Test Module

### Cislunar
- Crewed visits to Cislunar
- Opportunities for Commercial or International Cislunar Missions

### Near-Earth Asteroids
- Precursor to First NEA
- Precursor to Second NEA
- First Human Mission to a NEA
- Second Human Mission to a NEA

### Moon
- Robotic Exploration
- Future Human Mission

### Mars System
- Robotic Exploration
- Next Gen Spacecraft
- MSL Opportunity
- Advanced In-Space Propulsion

## Key Enabling Capabilities
- Commercial Crew
- Commercial Cargo
- Service & Support Systems
- NGSLS
- SLS/Heavy Launch Vehicle
- Cryogenic Propulsion Stage
- Deep Space Habitat
- Space Exploration Vehicle

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**European Space Agency**
• The Apollo missions are the only true experience humankind has with human exploration of other heavenly bodies
• The last Apollo mission was December 7 1972 - 41 years ago...

Great for in-flight experiments, but these missions all have in common that they could/can be commanded in real-time from Earth.
When it comes to Human Exploration to other Heavenly bodies, ESA is looking at the deltas between such missions and LEO Human Exploration missions.

This presentation will address the following main operations-related areas:

- The Crew in flight
- The End-To-End System (including robotic operations)
What are the challenges for a crew (ops) perspective?

- Distance reduces communications => higher autonomy of crew
- Long mission duration => loss of knowledge & skills
- Need for on-board evaluation for critical operations with high skill level / perishable skills (robotics, EVA, descent)
- Potential increase # of unforeseen events (operational and flight systems maintenance)
- Duration of ground training limited to approx. 3 years
- Crew needs to be “occupied” during long travel periods
How to cope with these challenges from a training & ops perspective? (I)

- **Crew autonomy**
  - definition of training objectives to identify tasks for autonomous operation – higher proficiency level required / to be maintained
  - Some real-time control centre functions need to be performed by the on-board crew
  - Crew needs to be supported by adequate on-board ops tools

- **Loss of knowledge & skills**
  - administer on-board refreshers at regular intervals
    - various types / scenarios for each operation to prevent boredom
    - Limited H/W => use 3D animations or augmented / virtual reality for realism
How to cope with these challenges from a training & ops perspective? (II)

- **Evaluation of perishable skills**
  - tests without immediate ground involvement (other than ISS)
  - simulators with direct crew feedback and performance file downlink for checks
- **Unforeseen events**
  - design novel training tools for unplanned activities (high fidelity on-board sim)
  - training development on ground e.g. using CAD drawings – uplink of training
How to cope with these challenges from a training & ops perspective? (III)

• **Training duration on ground**
  - efficiency of training decreases if over 3 years due to increased time spent on skill maintenance / refreshers
  - time between assignment and mission should not be too long
  - train uncritical / late mission tasks on board only

• **Crew “occupation” during mission**
  - limited scope of crew activities expected for the “travel time”
  - training can provide a meaningful task for crew members
  - acceptance will depend upon novel, interactive, and varied training design
What are the current European Astronaut Centre activities?

- Development of on-board training tools / platforms
  - ATV Rndz/Docking simulator - file downlink for evaluation by instructors
  - ATV On-board training for attached phase – 3D visualisation of tasks
  - Use of mobile devices for training (iPad, iPhone)
- Analysis of increased use of video / animation for on-board training
- Development / improvement of training for critical astronaut tasks relevant to ISS and for exploration
  - Rndz/Dock – ATV, Soyuz
  - Robotics – GRT, SSRMS
  - EVA – EVA Pre-Familiarisation
  - Human Behaviour & Performance
  - Mechanical Skills / Maintenance
On-board ops tools developments

- CRUISE - crew user interface system enhancements
- mobiPV - mobile procedure viewer
- MECA - mission execution crew assistant
CRUISE was executed end of increment 34

1. Voice activated procedure viewer, providing an alternative interaction mode

2. Procedure display

Both experiments were enhancements of current Columbus laptop software application
We believe that increased autonomy requires that crew tasks must be supported by a procedure viewer that mixes traditional ops content (manual instructions) with C&DH display elements.
mobiPV provides versatile HW configurations
Collaboration options afforded by ISS operations
As ISS space-to-ground links provides more capable end-user services (e.g. full bi-directional broadband with web-services), mobiPV promises not only to improve ISS real-time distributed team collaboration, but also to serve as a key element in investigations of required team support for human exploration missions to come
- Objective: support mission goals by empowering the cognitive capacities of human-machine teams during planetary exploration missions in order to cope autonomously with unexpected, complex and potentially hazardous situations.

- Vision: crew support that acts in a ubiquitous computing environment as “electronic partner”, helping the crew
  - to assess the situation,
  - to determine a suitable course of actions to solve a problem,
  - to refresh skills and knowledge,
  - to improve resilience.
Analogue environments (e.g., Eifel volcanic area): ePartner helps to cope with (social, cognitive and affective) demanding situations.

MARS500: gaming as diagnostic and training tool for resilience

Concordia: maintaining physical and mental fitness
Control centre aspects

- Real-time monitoring functions need to be transferred to on-board systems and crew
- Control centre needs to be able to react on unforeseen events (= exploration)
- The classical control centre concept may be neither affordable nor needed (at least for some mission phases)

=> Decentralised control centre with changing team composition
Payload Data Centre concept

- Virtualize the system
- Centralize maintenance and configuration management
- Separate physical infrastructure from operational implementation
- Platform independence on operations entity side
- Support the Operations form “anywhere authorized” concept
Mission Operations-related areas requiring investigation / demonstration

- What do we (still) know how to do, and do regularly?
  - Operate crewed missions in Low-Earth Orbit
  - Operate un-crewed missions to other heavenly bodies (including rovers)
  - Operate crewed “missions” to analog sites on Earth (D-RATS etc.)

- From an operations point of view – what are some key areas of investigation for crewed missions to other heavenly bodies?
  - **Communications** - disruption tolerance, delays caused by distance, hard real-time communications (video, haptic data, etc.) and multiple asset communications.
  - **Robotics** - supervisory control, haptic tele-operation, need for force feedback and stereovision, where to put the robot operator, operations of multiple rovers / robots (at different locations or at the same site), and human/robot collaboration
A typical Operations Team for a Human Exploration Mission

- 3 Astronauts on the surface
- 3 Astronauts in orbit
- GS Network 1 team
- GS Network 2 team
- GS Network 3 team
- Main Mission Ops Centre
- Mission Ops Centre 1
- Mission Ops Centre 2
- Mission Ops Centre 3
- Surface Ops Team
- Orbiter OPS team
- Robotic Ops team
- Flight Dynamics
- Boards/Committees etc.
- Public Relations
- Communications
- +many, many more
A typical Operations Team for a Human Exploration Mission – a simplified view

- 3 Astronauts on the surface
- 3 Astronauts in orbit
- GS Network 1 team
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- Surface Ops Team
- Orbiter CPS team
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- Boards/Committees etc.
- Public Relations
- Communications
- +many, many more
The Multi Purpose End-To-End Robot Operations Network (METERON) project will help to prepare Europe for future Human Exploration Missions in the areas of Communications, Operations and Robotics.

Objectives for each of the three pillars of METERON:

**Communications**
Demonstrate communications concepts and technologies that are being considered for use in future human exploration missions. Issues such as disruption tolerance, delays caused by distance, hard real-time communications (video, haptic data, etc.) and multiple asset communications will be demonstrated.

**Operations**
Demonstrate operations concepts and technologies that will be required for future human exploration missions. Issues such as human-in-the-loop rover/robot operations, multi-rover operations, multi-operator interaction, and monitoring and control of systems-of-systems will be demonstrated.

**Robotics**
Demonstrate robotics technologies and operations that are being considered for use in future human exploration missions. Issues such as supervisory control, haptic tele-operation, need for force feedback and stereovision, where to put the robot operator, operations of multiple rovers / robots (at different locations or at the same site), and human/robot collaboration will be demonstrated.

- METERON takes its requirements from exploration initiatives in ISECG and similar forums.
- METERON is a framework that is adaptable to changing human exploration goals and priorities.
Why use the ISS?

- Highly Demanding Workload
- Realistic Communications Constraints
- Microgravity Environment

Human-centered Telerobotics

Haptics space validation

Communications:
- Delay
- Jitter
- Loss Of Signal
- Bandwidth/data-rate

[N. Y. Lii et al, 2010]
- Reference architecture

- ISS as test bed
METERON is a combination of:

- **Ground Simulation Testing (GST)**
- **In-Orbit Demonstration (IOD)**
- Only experiments requiring the flight segment will use it
- Flight experiments will be validated first on the ground
- All other experiments will be conducted using the ground segment only (including the Mission Operations Environment – MOE)
• First communications test using ISS successfully completed (OPSCOM-1 Oct 2012) - control of a simple rover from ISS

• Preparation for Second communications test using ISS mid 2014 (OPSCOM-2 with Eurobot)

• Project then implemented step by step through 2017

• On-going mission scenarios analysis will continue – simulations using the METERON Mission Operations Environment

• Development of the METERON Operations Environment (MOE) under development - and E2E M&C environment for human exploration operations sc
OPSCOM-1 Delay Tolerant Network experiment - Key Features

- Protocol designed for space scenarios
- Higher throughput over extreme distances (interplanetary scale), long latency, interference, resources overburdened
- Protocol Layer on top of existing protocols (TCP/IP, UDP, space protocols...)
- Store and forward mechanism
- Already deployed between CU and ISS (CGBAs)

With IP: User must wait for a continuous end-to-end path.

With DTN: Data are held at DTN routers and continue to destination when next hop is available.
E2E scenario execution – how does it help?

- **Training**
  - Scientists
  - Ground Operations Team
  - Rover Operations/Support Team
  - Orbiting Crew

- **Ops preparation**
  - Procedure generation (all stations)
  - Software Development
  - H/W Development
  - Coordination between sites/agencies
  - Legal/Political considerations
# METERON Operations Scenario – OPSCOM-2

## Preparations

<table>
<thead>
<tr>
<th>Issues</th>
<th>Plan-based driving</th>
<th>LOS</th>
<th>Waypoint-based driving</th>
<th>LOS</th>
<th>Waypoint-based &amp; free driving</th>
<th>LOS margin</th>
<th>Test closeout</th>
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</thead>
<tbody>
<tr>
<td>- Connectivity check to ESOC</td>
<td>rover monitoring via local control system</td>
<td>rover &amp; MOPS/laptop monitoring in MOE</td>
<td>rover &amp; MOPS/laptop monitoring in MOE</td>
<td>rover TM via ground route</td>
<td>rover TM via ground route</td>
<td>rover &amp; MOPS/laptop monitoring in MOE</td>
<td>- ESP shutdown</td>
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<td>- MDR startup and configuration</td>
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<td>Collect experiment data and logfiles and provide to ESOC</td>
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<td>- EGIP preparations</td>
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<tr>
<td>- ESOC/ESTEC voice system setup</td>
<td>Monitoring of MOE system and ITN network</td>
<td>rover &amp; MOPS/laptop monitoring in MOE</td>
<td>rover &amp; MOPS/laptop monitoring in MOE</td>
<td>rover TM via ground route</td>
<td>rover TM via ground route</td>
<td>rover &amp; MOPS/laptop monitoring in MOE</td>
<td>Collect experiment data and logfiles (also from other sites)</td>
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<td>- Time synchronization</td>
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<td>- MOE system startup and configuration</td>
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<td>- Adapt timeline to latest coverage data</td>
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<td>- Check connectivity to ISS laptop</td>
<td>Contingency recovery management</td>
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<td>- mOPC input</td>
<td>Monitoring of GSE and ERIS linker</td>
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<td>- Test day system check</td>
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<td>- Provide latest coverage data</td>
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<td>- Coordination with Col-CCB</td>
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<td>- ISS OCC</td>
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<td>- MOPS</td>
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<td>- ISS crew</td>
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## ISS crew

- Preparations and plan-based driving
  - Local MOPS map
  - Load plan file
  - Send plan to rover and confirm plan received
  - Execute plan
  - Wait for successful plan execution

## Waypoint-based driving

- Drive rover sequentially to several predefined waypoints/pictures

## "Free driving"

- Drive rover to a point based on map data and images

## Crew time margin

- More LOS, or more free driving
The METERON Operations and Communications Architecture – OPSCOM-2
### E2E Scenario operations using the ISS

#### Current METERON experiment horizon

<table>
<thead>
<tr>
<th>ISS Activity/Experiment Name</th>
<th>Rationale &amp; Benefits</th>
<th>Category</th>
<th>Earliest possible execution date TO BE COMPLETED</th>
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<tbody>
<tr>
<td>OPSCOM</td>
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<td>OPSCOM-1</td>
<td>First DTN in-flight demonstration</td>
<td>Communications</td>
<td>Complete 2012</td>
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<td>OPSCOM-2</td>
<td>Validation of DTN, Basic Sequential Operations of Eurobot</td>
<td>Communications, Operations</td>
<td>1st Quarter 2014</td>
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<td>OPSCOM-3</td>
<td>European DTN, Basic Sequential Operations of Eurobot</td>
<td>Communications, Operations</td>
<td>TBD 2015</td>
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<td>HAPTICS</td>
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<tr>
<td>HAPTICS-1</td>
<td>In-orbit calibration Exo joints, body-grounded haptics tests of Direct Teleoperation</td>
<td>Robotics</td>
<td>4th Qtr 2013</td>
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<td>HAPTICS-2</td>
<td>Demonstrate Kontur commss with first bilateral control over low latency link 1def</td>
<td>Robotics, communications</td>
<td>Mid 2014</td>
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<td>HAPCOM</td>
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<tr>
<td>COM4HAP-1</td>
<td>Demonstrate 2 ESTRACK + Weihlem KONTUR Commss link(s) (QS-b)</td>
<td>Communications</td>
<td>TBD 2015</td>
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<tr>
<td>COM4HAP-2</td>
<td>Demonstrate Complete chain (QS-c)</td>
<td>Communications</td>
<td>TBD 2015-2016</td>
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<td>SUPVIS</td>
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<tr>
<td>SUPVIS-1</td>
<td>Eurobot Supervisory Operations on Lander Mockup (with additional rover for vision)</td>
<td>Operations, Communications, Robotics</td>
<td>4th Qtr 2014</td>
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<td>EXO</td>
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<td>EXO-1</td>
<td>Exo control of LWR in TRH Lab.</td>
<td>Robotics</td>
<td>Mid 2015</td>
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<tr>
<td>EXO-2</td>
<td>Exo control of EUROBOT</td>
<td>Robotics</td>
<td>Mid 2016</td>
</tr>
<tr>
<td>EXO-3</td>
<td>Exo control of JUSTIN (DLR) incl supervisory tasks</td>
<td>Robotics</td>
<td>Late 2016</td>
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#### Planned additional METERON experiments

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<th>ISS Activity/Experiment Name</th>
<th>Rationale &amp; Benefits</th>
<th>Category</th>
<th>Earliest possible execution date</th>
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<tbody>
<tr>
<td>ANALOG</td>
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<tr>
<td>ANALOG-1</td>
<td>E2E Mars Exploration Scenario with Rover (EUROBOT)</td>
<td>Operations</td>
<td>2018?</td>
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<tr>
<td>EXO</td>
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<tr>
<td>EXO-4</td>
<td>Full Exo control dual arm of JUSTIN</td>
<td>Robotics</td>
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<tr>
<td>EXO-E2E</td>
<td>Full Exo control of EUROBOT/DEXARM + 3D+ Misson Ops process</td>
<td>Robotics, Operations</td>
<td>2018 (?)</td>
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<tr>
<td>EXO-5</td>
<td>Exo dual arm control of ISS’ Robonaut</td>
<td>Robotics</td>
<td>2019 (?)</td>
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Thanks for your attention!

Any Questions?