ISS Imagery Requirements for MPCV Optical Navigation
The MPCV Loss of Comm Problem

• The Problem
  – With a loss of communication with the ground or the DSN, MPCV loses its transponder based navigation capability and with it the capability to accurately target Return Trajectory Correction (RTC) burns.

• The Solution
  – MPCV is implementing an onboard Optical Navigation Solution to target RTC burns to make sure the crew meets their entry flight path angle requirement under contingency loss of comm conditions.
• **CA0416 – Orion Return Crew to Earth Independent of Communications with Mission Systems**
  – Orion shall return the crew to the Earth surface independent of communications with the Mission Systems during all mission phases.
  – **EM2:** This requirement applies at any point along the trajectory. Crew can be utilized.

• **CA0416-D - Orion Return CM to Earth Independent of Communications with Mission Systems - EM1**
  – Orion shall return the CM to the Earth surface independent of communications with the Mission Systems once the CM has been placed on the return to Earth trajectory.
  – **EM1:** This requirement applies once on a trajectory towards Earth (after Lunar Gravity Assist maneuver).
• **MPCV Program Need**
  – An automated Optical Navigation solution is still developmental and requires truth data in the form of imagery from the field in order to validate its performance.

• **ISS Imagery Experiment Purpose**
  – Collect Moon Images from known Low Earth Orbit positions for Orion Optical Navigation Algorithm Refinement
    • Collect images over a span of at least one lunar cycle (29 days)
    • Eliminates atmosphere image distortion present in Earth based images

• **Supporting Organizations**
  – OZ:  Dave Hornyak, Submit experiment requirements
  – GA:  Debbie Korth, Orion MPCV Affordability Manager
  – DX:  Steven Berenzweig, ISS Video and Photography
  – KX:  David Bretz, Senior Imaging Scientist
  – KA:  Gary Kilgo, Imagery Hardware
  – EG:  Tim Straube, Orion GN&C
Example Image Analysis

Find the well defined limb from black and white threshold image

Determine moon radius and mass center from limb edge measurements
ISS Imagery Requirements

• Requirements needed to validate optical navigation algorithms
  – Need to know location of camera. Knowing the relative state between the moon and the image provides truth to compare the algorithms against.
  – The camera’s clock needs to be calibrated to an accurate time source to accurately determine camera’s true position when the image is taken.
  – Need a consistent fixed focus and focal length for all images taken. If the focus or zoom ring changes between the images, that changes the magnification of the image.
  – Need imagery that is consistent with the expected optical navigation camera, 28 arcsec between pixels. (approximately 5 mp)
  – Subpixel measurement precision: Moon limb location to 1/3 pixel (1σ)
Imagery Already Looked At

- **Moon imagery captured from ground cameras**
  - Earth’s atmosphere proved to add too much distortion to the images

- **Lunar Atmosphere and Dust Environment Explorer (LADEE)**
  - the vast majority of the images were close up’s of the moons surface
  - See examples here:
  - Did not have capability to image sunlit side of moon.

- **Lunar Reconnaissance Orbiter (LRO)**
  - the vast majority of the images were close up’s of the moons surface
  - Two cameras:
    - Narrow FOV 2.85 deg
    - Wide FOV 92 deg
• Reviewed high resolution Moon photos from Imagery Online (IO)
  – reviewed high resolution Moon photos from Imagery Online (IO) and other sources.
  – In the photos we reviewed, we did not have confidence the time tag in the photo’s meta-data could be correlated to GMT within a known tolerance.
  – The camera’s clock had not necessarily been routinely synchronized to an accurate time source for the existing photos
  – Focus setting not known to high precision.
  – Effect of scratch pane on images not characterized
Experiment Requirements

• Timing
  – Sample moon imagery on at least three days spanning the lunar cycle (29 days)
    • Can be days from different lunar cycles
    • Two image collecting sessions, half day apart, on each designated sampling day
  – Photo opportunity pass ~10 minutes (assumes viewing through oblique Cupola window)
  – 3.3 hours (for minimum set) + 1.1 hour for scratch pane characterization

• Camera
  – Camera and lens must be dedicated for the span of the experiment
  – Lens focus must not change during the experiment.
  – Camera clock must be correlated to accurate time source
    • Used to determine ISS position when image is captured
  – Camera to be mounted
    • Reduces camera shake

• Schedule
  – Need imagery in time to incorporate into MPCV EM1/2 CDR (October 2015)
  – Need ISS imagery by April to incorporate into review
Candidate Optical Navigation Cameras
## Candidate Equipment Characteristics

<table>
<thead>
<tr>
<th>Camera Vendor</th>
<th>IDS</th>
<th>PixeLink</th>
<th>Nikon D3*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor Manufacturer</td>
<td>Aptina Sensor</td>
<td>ON Semiconductor</td>
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<tr>
<td>Shutter type</td>
<td>Electronic rolling</td>
<td>Electronic Global</td>
<td>Mechanical focal plane</td>
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<tr>
<td>Sensor size (mm)</td>
<td>5.7 x 4.28</td>
<td>12.44 x 9.83</td>
<td>35.9 x 24</td>
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<tr>
<td>Lens focal length</td>
<td>16mm</td>
<td>35mm</td>
<td>60mm</td>
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<tr>
<td>Pixels</td>
<td>2592 x 1944 (5mp)</td>
<td>2592 x 2048 (5mp)</td>
<td>4256 x 2832 (12mp)</td>
</tr>
<tr>
<td>Field of View (FOV) deg</td>
<td>20.2 x 15.2</td>
<td>20.2 x 16</td>
<td>33.4 x 22.5</td>
</tr>
<tr>
<td>Instantaneous FOV (arc-sec)</td>
<td>28</td>
<td>28</td>
<td>28.25**</td>
</tr>
</tbody>
</table>

*ISS camera. Used as alternative if our own cameras can’t be placed on board
**Matching iFOV of proposed optical navigation camera is the driver
Constraints or Issues

- **Shooting through cupola windows**
  - Unknown optical quality
    - Different windows or section of same window may have their own aberrations
    - Moon will appear through different sections, portions and angles of glass
      - Vacuum-glass-air transitions
- **Shooting through scratch panes**
  - Image quality will be reduced
  - Possibility of piggy-backing on the IMAX work
- **Moon visible for 8-10 minutes per pass**
  - Plan to use Cupola oblique windows
  - Are other windows on board available with good views of the Moon?
- **Limited range of distance between LEO and Moon**
- **If MPCV supplied camera(s) can’t be qualified and flown:**
  - ISS lens and camera calibration data not available
  - Difficult dedicating an ISS camera for experiment duration
Crew Time Required for Experiment – Desired Approach

• Minimum estimated time to complete one day (two sessions per day) of moon imagery capture
  – 67 mins (shooting through scratch panes and setting up/taking down camera hardware after each shooting day)

• Minimum estimated time to complete all imagery capture every four days over entire lunar cycle (a total of 16 sessions)*
  – 9 hours (shooting through scratch panes; setting up/taking down camera hardware after each shooting day)

• Crew member typically gets faster at performing tasks after executing procedures after first time

• Request one crew member to be dedicated for the duration of the experiment

* Detailed breakdown of Crew activity times available
Crew Time Required for Experiment – Minimum Acceptable Set of Images

• Minimum estimated time to complete one day (two sessions per sampling day) of moon imagery capture
  – 1.1 hr (67 mins) per sampling day
    • assumes scratch panes are left in place
    • setting up/taking down camera hardware after each shooting day
    • estimate will increase if camera must be stowed between sessions on the same sampling day

• Minimum estimated time to complete all imagery capture on at least three days spanning the lunar cycle (29 days)
  – 3.3 hours (assuming shooting through scratch panes; setting up/taking down camera hardware after each sampling day)

• Scratch Pane Characterization photos
  – Take photos of Moon through different areas of a window
  – Trying to detect any change in apparent Moon diameter or distortion due to local scratch pane irregularities
  – 1.1 hours per window (One window minimum)
Summary

• MPCV has a requirement to be able to reliably return home in the event of loss of communications
• The MPCV Program needs a space based platform to collect Moon images from a known position to help validate its optical navigation approach
• The MPCV Program endorses the need for these ISS-based moon images, and sponsors the proposed activity.
• Camera resolution should be equivalent to the type to be used on board MPCV
• ISS is an excellent platform from which low Earth orbit Moon imagery can be collected using a suitable camera
• Total crew time estimate for minimum set:
  – 4.4 hrs = 1.1 hr (SP test) + 3 sampling days * 1.1 hr/sampling day)