NASA/TM-2014-217396

Autonomous Mission Operations Test Report
Johnson Space Center Exploration Medical Capability

Victor Hurst IV, PhD
Kathleen Garcia
David Ham

National Aeronautics and
Space Administration

Johnson Space Center
Houston, Texas 77058

August 2014

NASA STI Program ... in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA scientific and technical information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NASA Aeronautics and Space Database and its public interface, the NASA Technical Report Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA Programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include creating custom thesauri, building customized databases, and organizing and publishing research results.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at *http://www.sti.nasa.gov*

- E-mail your question via the Internet to help@sti.nasa.gov

- Fax your question to the NASA STI Help Desk at 443-757-5803

- Phone the NASA STI Help Desk at 443-757-5802

- Write to:
  NASA Center for AeroSpace Information
  7115 Standard Drive
  Hanover, MD 21076-1320

NASA/TM-2014-217396

Autonomous Mission Operations Test Report
Johnson Space Center Exploration Medical Capability

Victor Hurst IV, PhD
Kathleen Garcia
David Ham

National Aeronautics and
Space Administration

Johnson Space Center
Houston, Texas 77058

August 2014

Available from:

NASA Center for AeroSpace Information
7115 Standard Drive
Hanover, MD 21076-1320

National Technical Information Service
5301 Shawnee Road
Alexandria, VA 22312

Available in electric form at http://ston.jsc.nasa.gov/collections/TRS

I. Executive Summary

The Exploration Medical Capability (ExMC) Element of the NASA Human Research Program was requested by the NASA Autonomous Mission Operations (AMO) team in December 2011 to provide medical scenarios as part of the AMO Test to evaluate autonomous operations for exploration class spaceflight missions. The ExMC then coordinated the development, integration, and execution of medical scenarios for the AMO team's two-phased test with Phase 1 being a baseline data collection and Phase 2 being a data collection using tools to mitigate deficiencies captured during Phase 1. This report details the development, integration, execution, results, and conclusions from the ExMC's preliminary evaluation of the autonomous management of medical events during an exploration class mission.

II. Introduction

The primary objective of the AMO Test was to discern how astronauts will autonomously execute their mission tasks in the very limited presence of ground-based resources as part of an exploration class mission. This included the execution of medical procedures by minimally-trained caregivers with very limited remote guidance from a ground-based flight surgeon. With that, the ExMC's specific aims for the AMO test were as follows:

A. To discern the level of ground assistance (remote guidance) necessary, if any, when using minimally-trained caregivers to assess and treat a patient during an extensive communication time delay.
B. To determine whether non-physicians can autonomously assess and treat a patient with minimal training.
C. To determine whether non-sonographers can efficiently collect useful ultrasound imagery with minimal training and remote guidance.
D. To determine whether the available similar-to-current International Space Station (ISS) resources are sufficient for assessing and treating these exploration-relevant medical conditions.
E. To determine whether written procedures with imagery are sufficient to guide autonomous non-physicians to efficiently and effectively assess and treat a patient.

III. Methods

A. Test Subjects

The protocols described in this report were reviewed and approved by the NASA Johnson Space Center's (JSC) Institutional Review Board.

B. Scenarios

The AMO Test team required that the scenarios 1) included medical conditions that presented similar symptoms but led to different diagnoses, and 2) lasted 1.5 to 1.75 hours. The ExMC selected urinary retention and renal stone formation as the two scenarios they would use as medical conditions for Phase 1 (Baseline) data collection and Phase 2 (Mitigation) data collection, respectively. Both medical conditions presented similar symptoms with the primary symptom being abdominal pain.

C. Protocol

The data were collected during a 2-hour simulation exercise with a crew of 4 within the Habitation Development Unit (HDU). The crew consisted of 3 astronaut analogs and 1 experienced astronaut. One of the three astronaut analogs was assigned as the Crew Medical

Officer (CMO). The CMO participated in a very brief medical training session approximately 10 to 14 days before their scenario was conducted.

Each crew participated in a 2-hour simulation exercise with a specific communication delay of either 50 seconds or 300 seconds (5 minutes). The communication delay was the same for each crew during each phase of the test. For example, if Crew A had a 50-second communication delay during Phase 1 of the AMO Test, then that crew would have the same time delay during Phase 2 of the AMO Test.

Data collection started at a designated point in the simulation timeline. The ExMC's scenario moderator (moderator) identified a crewmember to act as the ill astronaut and subsequently had that person act out the symptoms of the medical condition to the CMO. The CMO then would use their procedure display system (iPad), communication capability (voice or text), and any other resources at their disposal to mitigate the medical issue. During the initial sequence of the scenario, the moderator provided the ill crewmember with the information needed for any questions asked by the CMO (e.g., answers to examination questions and vital sign data). At a certain point, the moderator took over the role of the ill astronaut with that crewmember no longer participating in the scenario. This was done to keep the scenario relatively consistent between crews and help with comparisons between sessions.

The communication profile for the experiment limited real-time remote guidance in regards to effective medical care and proper ultrasound image collection from ground-based subject matter experts for the CMOs. As a result, communication between the CMO and the flight surgeon analog (surgeon) in the Mission Control Center (MCC) was limited to voice messages and text messages. Video data were transmitted to the MCC and observed by the surgeon with support provided by a JSC certified biomedical engineer flight controller (BME).

The CMO continued the scenario until the moderator stopped the session. Once the session was complete, the CMO completed a questionnaire compiled by the ExMC team.

D. Equipment

The scenarios were conducted at the Medical Operations Work Station (MOWS) within the HDU at JSC. The MOWS consisted of 1) a table top for conducting experiments and other life science activities, 2) a drawer system (located above the table top) for storage of resources, and 3) an examination table (located under the table top) that could be deployed when needed (Figure 1). The examination table consisted of a rotating utility shelf that could be deployed on either side of the table and be used as placement for items and equipment.

Figure 1: The MOWS with the examination table deployed.

A Philips CX-50 Ultrasound device was used as the anatomical image collection tool for the scenarios conducted at the MOWS (Figure 2).

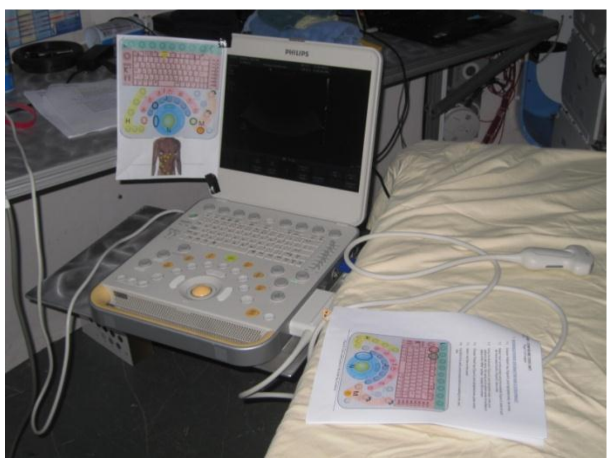

Figure 2: Deployment of the MOWS examination table and utility shelf. The CX-50 ultrasound device can be seen on the utility shelf.

The mitigation tool that was used to help the crew during Phase 2 (Mitigation Phase) of the AMO Study was the Advanced Diagnostic Ultrasound System (ADUS). The ADUS is a just-in-time training tool that can rapidly show the user how to position the ultrasound probe over the body to achieve the correct ultrasound view. The ADUS acts as a guide for ultrasound users that lack expertise in ultrasound image collection and have limited or no real-time support from an expert. The ADUS format is a digital information resource of “how to perform” hand positioning and patient positioning. In addition, image examples are provided in a layout that is convenient for both novice and experienced sonographers. The intuitive nature of the guide is an evolution and enhancement in remote guidance and aids in autonomous performance of the standardized examinations.

E. Procedures

The medical procedures used for the AMO Test were based upon the certified procedures used aboard the ISS. Adjustments were made to accommodate the resources available and the environment in which they were being used. All procedures were accessed using iPads; however, the format for how the procedures were displayed differed between each phase of the study. For Phase 1, procedures were electronic images of paper procedure while Phase 2 displayed procedures in "Web PD" format, which has a feature where the CMO can indicate when each task of a procedure is started and completed. These indications are automatically sent to ground controllers without any assistance from the CMO and remaining crew. Lastly, procedure selection was executed by the CMO. If needed, ground controllers confirmed to the CMO that the proper procedure was selected for that medical condition.

Ten procedures were generated for the study; however, the following procedures were the only ones that could be executed by the CMO during either phase of the AMO Test.

1. Examination-Abdominal Pain
2. Vital Signs
3. Ultrasound Configuration
4. Ultrasound-Bladder Images
5. Ultrasound-Kidney Images
6. Ultrasound-Gallbladder Images

F. Questionnaires

The CMOs were given questionnaires to assess whether they liked the content and preciseness of the procedures for all scenarios conducted. In addition, levels of frustration for understanding the procedures, their ease of use, and whether their formats were intuitive were also assessed. The CMOs provided answers to statements based on the following sliding scale: 1-Completely Disagree, 2-Disagree, 3-Neutral, 4-Agree, 5-Completely Agree, and 6-Not Applicable. All answers were averaged (n=6 to 8, depending on the number of responses collected for each procedure).

G. Audio/Video Configuration

The HDU was configured so audio and video data could be collected for retrospective analysis. The audio data consisted of verbal communication among the following two groups:

1. CMO and the ill crewmember
2. CMO and the remote guider (surgeon/sonographer) in the MCC

The video recorders were configured to capture images of the CMO working at the MOWS, especially during the CMO's capture of ultrasound images from the ill crewmember (Figure 3).

Figure 3: A video image view within the HDU. The CMO captures ultrasound images from the ill crewmember.

H. Training

1. *Biomedical Engineer Flight Controllers*

   Approximately one week before the start of Phase 1, the BMEs received a brief familiarization session of the ultrasound system. The familiarization followed the written "Ultrasound Configuration" procedure and was conducted in the HDU. By following the procedure, each BME demonstrated their knowledge of ultrasound system deployment, powering-up the system, initial configuration of the system with the imaging probe, powering-down the system and re-stowage. The BMEs were not given organ-specific scanning instruction; however, they did receive examples of how the ultrasound system displays cross-sectional areas of body organs and how moving the probe (pan, tilt, rotate, and translate) changes the cross-section displayed. Great feedback from the BMEs during this session enabled the investigators to fine tune the procedure in preparation for CMO training.

2. *Crew Medical Officers*

   The CMOs received two training sessions with each one being approximately 10 to 14 days before their actual AMO Test session.

   The objective of the first CMO training session was to provide the CMOs with the experience of holding an ultrasound probe and comprehending the result of moving the probe over the body to obtain a correct cross-sectional ultrasound image of the anatomy. The session began with all CMOs receiving an ultrasound configuration-familiarization session similar to that received by the BMEs. This group was then introduced to the concepts of scanning with ultrasound, how to use the ultrasound unit (record, save images and video), and move the probe (pan, tilt, rotate, and translate/slide) over the body to see the cross-sections of several body organs. This was followed by each CMO operating the ultrasound system as they practiced image scanning and collection on a human volunteer. This included each CMO being briefed on the anatomic locations for the bladder, right and left kidneys, and gallbladder.

   The objective of the second training session before the start of Phase 2 was to introduce the CMO team to all the applicable components of the ADUS. No changes were made to the medical procedures from the previous phase and no additional hands-on practice or familiarization with ultrasound was given; however, it was emphasized that the CMOs could access ADUS on the MOWS laptop computer and use it as a supplemental tool to help with ultrasound image collection. They were shown the subsections within the ADUS that contained video instruction and reference images pertaining to the bladder, kidneys, and gallbladder. The crew was given a CD copy of ADUS after the session for review before their test.

I. Evaluation of the Ultrasound Image

The measure of a successful ultrasound image must consider whether the areas of interest or the intended organ are identifiable. A novel yet measurable scale was used to evaluate the quality of the images collected by the CMOs during the AMO Test. An Ultrasound Organ Scale (UOS) of 0 to 3 was assigned to represent the quality of the ultrasound images collected. The scale was established based on the percentage of organ seen as determined by a certified sonographer. The scale was assigned based strictly on the images that were stored to the hard drive of the ultrasound unit and not based on any experiment notes or anecdotal recollection from the experiment.

The UOS scoring system worked as follows:

0 = ultrasound of the organ was not stored
1 = < 50% of the organ can be identified from the stored images
2 = 50% to 75% of the organ can be identified from the stored images
3 = 100% of the organ can be identified from the stored images

UOS score maximums

Bladder:	The maximum score for the two required views is 6.
Right and left Kidney:	The maximum score for all four required views is 12.
Gallbladder:	The maximum score for the two required views is 6.

Total maximum individual score per CMO = 24

Normalized UOS across all of the data for the entire group (24 x 4) yields a
UOS maximum=98

J. Additional Crew Medical Officer Scoring as Assigned by the Certified Sonographer

1. *Use/acquisition of color imaging*

   The CMOs were given verbal instructions outside of the written protocols. For example, CMOs were given remote guidance instruction to identify urine jets in the bladder and blood-flow targets in the kidneys with color-flow Doppler. Using color-flow Doppler to monitor flow and direction wherever appropriate points to the CMO's ability to document renal hemodynamics. In the case of the bladder scan, the CMO documents the presence of unobstructed urine flow. If the CMO attempted color at each possible location for each organ, then the maximum score would be six (6). The score for this section is reported as a number in relation to the maximum score of 6 (e.g., 4 out of 6, 5 out of 6, etc.)

2. *Characteristics of the specific type of stored images*

   The ability to document the image by using the multiple frame or cinema-loop (cine-loop) feature followed by scroll selecting the appropriate frame versus storing a still or frozen image without review was evaluated. This was assessed by a certified sonographer to capture the CMO's understanding of correctly documenting the organs using ultrasound. The score in this area was reported as a percentage of the total protocol.

3. *Organ dimensions*
   Caliper measurements of the bladder and kidneys were requested by the remote guider during Phase 1. Additionally, these measurements were described in each procedure. For Phase 2, the investigator team omitted the measurement step, regardless of protocol, to increase the likelihood of the CMO scanning more body organs. The score in this area is reported as a percentage of the total protocol.

IV. Results

A. Crew

The crew portion of the results provided information relating to each scenario and how the CMO addressed (mitigated) the concern. The information consisted of an overview of how the CMOs executed the scenario and, where needed, indicated:

- How a CMO used a different strategy or information for diagnosing the medical issue.
- How communication with ground support and/or the other crew effected the CMO's execution of the tasks.
- Where the CMO used different configurations for the equipment and/or the MOWS.

Each CMO began his/her mitigation of the crewmember's medical issue by using a similar approach. They first asked about the primary complaint of the ill crewmember followed by asking whether they were able to execute their tasks in spite of the illness. Once the questions were answered, the CMOs then differed on what was done next. They did either of the following:

- Began searching for an appropriate medical procedure that would address the issue followed by informing the Crew Commander (CDR) and discussing the impacts.

OR

- Informed the CDR about the issue and discussed the impacts followed by searching for the appropriate medical procedure.

Once these steps were complete, the CMO then executed the tasks within the selected procedure followed by any other tasks in supplemental procedures. The CMOs finished at different end points of the scenario timeline regardless of communication time delay (50 seconds vs. 300 seconds (5 minutes)). The number of tasks completed by the CMO as well as the time to complete the tasks differed between CMOs. Several factors contributed greatly to this difference. They were:

1. The time for a CMO to pull up a procedure on their iPad differed from session to session.
2. In 7 of 8 sessions, the MOWS examination table was configured as shown in training. The times to configure the table for these 7 sessions were similar. For the one session that differed, the already-deployed table of the HDU's General Maintenance Station prevented the CMO from deploying the MOWS examination table per their training. For that session, it took the CMO an additional amount of time (approximately 20 minutes) to find a new location, determine its impact on the execution of tasks by other crewmembers, and subsequently set up the table and supporting equipment.
3. The timeliness of the CMO to complete their tasks depended on their personal approach to executing procedures. For example, two of the four CMOs expressed that they were very

conservative with executing tasks because they were not formally medically trained and, thus, did not want to make a mistake. The remaining CMOs used an approach where they would expeditiously read the task and then execute it; however, the latter approach led those CMOs to have to go back to the procedure to make sure they properly executed that task.

4. In 3 of 8 sessions, the CMO, either on their own or with help from the crew, attempted to diagnose or treat the patient before data collection was complete. In one session, the CMO believed the cause of the abdominal pain to be food poisoning and, subsequently, began to ask questions not in the procedure to rule out that diagnosis. In another session where the ill crewmember was experiencing urinary retention, one crewmember diagnosed the crewmember with a urinary tract infection and directed the CMO to treat the patient as such. This confused the CMO in regards to whose direction they should follow (i.e., crew vs. ground-based flight surgeon). Another session had the CMO questioning the direction and instructions from the flight surgeon based on what the CMO believed to be the problem ("Why am I still looking at the bladder when the problem appears to be in the kidney?").

The overall communication between the CMO and crew was constructive and helpful. In some cases, where it appeared that the CMO was very busy, the CDR offered to relay information about the medical event to the ground by either voice or text to ground support to save the CMO time. The CDR and other crewmember not involved with the medical event worked to make sure the tasks of the CMO and ill crewmember were either being addressed or tabled for later completion. There was only one instance where it appeared the pressure of multitasking overwhelmed the CMO. This was demonstrated by the CMO being "short" with another crewmember as the CMO was trying to listen to instructions from ground support.

The questionnaire data revealed that the CMOs liked the content and preciseness of the procedures, regardless of the scenario conducted (Table 1). The levels of frustration for understanding and navigating the procedures were indicated by the CMOs as not being applicable; however, upon discussion with this cohort, it was learned that the procedures did not induce any level of frustration. The ease of which the CMOs navigated the procedures was rated high. The intuitive format of the procedures may have played a role in that ease of navigation (Table 1).

Table 1: Questionnaire Data

	Procedure Content Precise	Procedure Content Understandable	Frustration understanding instructions	Useful information from pictures	Cue Card Usefulness	Ease of Navigation	Frustration of Navigation	Format Intuitive	Overall Rating
Examination of Abdominal Pain	4.7	4.7	N/A	N/A	N/A	4.3	N/A	4.3	5
Vital Signs	4.4	4.4	N/A	N/A	N/A	4.7	N/A	4.5	4.9
Ultrasound Configure CX50	4.9	4.6	N/A	4.8	5	4.7	N/A	4.7	5
Ultrasound-Bladder	4.6	4.3	N/A	5	N/A	4.2	N/A	3.8	5
ADUS	4.5	4.5	N/A	5	N/A	4.5	N/A	4.5	5

The CMOs provided answers to the statements in the questionnaire based on the following sliding scale:
1-Completely Disagree, 2-Disagree, 3-Neutral, 4-Agree, 5-Completely Agree, 6-Not Applicable

B. Remote Guidance

1. *Communication dynamics with crew*

a. Verbal

Historically during medical events aboard the ISS, crew communicates with medical support through a privatized communication loop that is engineered to be isolated from all other communication channels. The flight surgeon and other medical support such as instructions from remote guidance operators (e.g., certified sonographer) are isolated and controlled by those individuals in the secure communication. Similar to the ISS, communication between ground medical support (*"Psyche" as it was called during this test*) and the CMO during the AMO Test was also achieved over a "privatized" loop. The privatized loop was achieved by the flight director asking the other flight controllers in the room to omit one of the space-to-ground channels. Once this channel was assigned to the personnel involved with AMO medical event, other flight controllers in the scenario could neither communicate nor listen to that channel.

Discrete control of the communication software interface had some unconventional behavior during the AMO Test. The communication software allowed for a single headset to speak or listen at one time regardless of the loop. To speak or listen required switching back and forth between remote guidance communication needs and those of the BME. One did not know if the other flight controller could hear or not hear the crew. Without careful attention, the interface would mute the secondary head set, thus injecting a level of difficulty not common to real-life medical events during spaceflight.

b. Text Message

Text messaging tools allowed Ground Medical Support to quickly summarize instructions to the crew. This tool had positive impact in scenarios where the round-trip delay extended to 5 minutes. The use of text tool to package or summarize instructions was a useful follow-up method. The tool was used for the majority of the medical scenario communication during Phase 2 of the AMO Test.

2. *Communication dynamics with flight controllers*
   a. Psyche/BME
   Verbal and text communication features at the console are a shared resource. One small delay was caused by the inadvertent muting of remote guidance voice on the communication channel. BME support unintentionally muted the flight surgeon's communication during the CMO's initial report back on the ill crewmember's vital signs. The error was discovered and quickly resolved.

   b. Flight Director
   Professional ground control support was provided by the flight director, CMO, and BME. Requests by the flight director consisted of calls for crew condition updates and calls to forecast crew availability.

   c. Other Flight Control Disciplines
   The AMO research coordinators quickly responded to the transient and occasional communication and video issues throughout the AMO Test. All of the AMO flight controllers were professional, courteous, and respectful to the medical event, as if it were an actual medical situation aboard the vehicle.

3. *Image Quality Results*
   a. UOS scores for image quality
   The UOS scores for each CMO increased during Phase 2 of the AMO Test as compared with Phase 1 (Table 2). The increased UOS was observed across all communication delay configurations. The overall UOS score for Phase 2 was a higher value as compared with Phase 1 (32.5% increase between phases).

Table 2: UOS Scores for the AMO Test

Individual UOS (max=24)	Phase 1 (Baseline)	Phase 2 (Mitigation)
CMO1 5-minute com delay	7	11
CMO2 50-second com delay	12	15
CMO3 5-minute com delay	14	15
CMO4 50-second com delay	7	12
Normalized UOS (max=98)	40	53

Each CMO's individual UOS score is provided for each AMO Test phase (max=24). The data are then normalized to provide an overall score for each AMO Test phase (max=98).

   b. Remote guidance comprehension
   Successful use of the color-flow Doppler increased during Phase 2 of the AMO Test (Table 3) while use of the frozen image and cine-loop storage capability was increased during Phase 1. Measurements were attempted 50% of the time by the CMOs during Phase 1.

Table 3: Remote Guidance Comprehension Assessment

Remote Guidance Comprehension Components	Phase 1 (Baseline)	Phase 2 (Mitigation)
Color-Flow Doppler	3 out of 6	5 out of 6
Frozen Image or Cine-Loop Storage	100% both used	50% one or the other was used
Measurements Attempted	50%	0%

V. Conclusion

The study indicates that written medical procedures can be effectively executed by minimally-trained caregivers (e.g., CMOs) to provide useful clinical data to ground-based medical support with minimal remote guidance from subject matter experts. The study also shows that use of mitigation tools, such as the ADUS, enable minimally-trained caregivers to autonomously execute clinical tasks in a manner that increases the quality of clinical deliverables, in this case, ultrasound imagery.

In addition to these findings, data from the AMO Test addressed each of ExMC's specific aims for this study.

A. To discern the level of ground-assistance (remote guidance) necessary, if any, when using minimally-trained caregivers to assess and treat a patient during an extensive communication time delay.

   Feedback from CMO questionnaires along with observational data collected by the investigation team during this study indicated that the use of remote guidance can be minimized and possibly be removed when a minimally-trained caregiver is assessing a patient that is experiencing a medical issue. Use of mitigation tools, such as the ADUS, enabled minimally-trained caregivers to autonomously yet effectively execute clinical tasks despite an extensive communication time delay. The CMOs were able to deliver useful ultrasound images of both the bladder and kidney to the ground-based medical support team. It is understood that the time constraints of the simulation prevented the investigators from discerning whether these tools would have led the CMOs to successfully diagnose and treat the illness in either phase of the AMO Test; however, this study demonstrates the level of effective autonomous medical operations by non-physician crewmembers has been augmented and can possibly be expanded for exploration class missions.

B. To determine whether non-physicians can autonomously assess and treat a patient with minimal training.

   It is understood that the data did not demonstrate that CMOs could successfully diagnose and treat the illness in either phase of the AMO Test; however, the study did demonstrate a higher level of effective autonomous medical operations by non-physician crewmembers with minimal medical training (< 1.5 hours training per CMO). It remains to be seen what can be accomplished by non-physician CMOs with increased clinical training hours.

C. To determine whether non-sonographers can efficiently collect useful ultrasound imagery with minimal training and remote guidance.

Refer to paragraphs in Section V, Part A and B of this document.

D. To determine whether the available similar-to-current ISS resources are sufficient for assessing and treating these exploration-relevant medical conditions.

The study showed that similar-to-current ISS resources can be used effectively to help assess space exploration-relevant medical conditions. This was demonstrated in every session by each CMO when they successfully and effectively used similar-to-current ISS equipment to collect vital sign data from their ill crewmember as well as using an ISS-similar ultrasound system to collect anatomical imagery of several body organs. It remains to be determined whether this equipment can be used to successfully diagnose and effectively treat an ill crewmember suffering from the medical conditions specific to this study (urinary retention and renal stone formation).

E. To determine whether written procedures with imagery are sufficient to guide autonomous non-physicians to efficiently and effectively assess and treat a patient.

The study showed that written procedures with imagery can be used effectively by autonomous non-physicians to assess a patient. The CMOs demonstrated their ability to follow written procedures during Phase 1 of the study in the absence of the ADUS to effectively execute tasks to successfully collect useful medical data in the form of vital sign data and ultrasound imagery of anatomical organs (Per the protocol stated in Section J-3 of the Methods, no caliper measurements were made during Phase 2 as they were neither indicated by ADUS nor requested by the ground). It remains to be seen whether these written procedures could have been used to successfully diagnose and effectively treat an ill crewmember suffering from the medical conditions specific to this study (urinary retention and renal stone formation).

The usefulness of the texting option between ground support medical team and the CMO requires further analysis. Access to texting tools while acting as a primary caregiver to an ill crewmember may be problematic for the effective management of a medical event. Also, additional support or expanded text features may be required for the CMO to effectively monitor the text messaging while caring for that crewmember. For example, there may be a situation where a medical event requires additional crew support. Such a scenario would be a reasonable consideration for future study.

During extensive communication delays (e.g., 5 minutes), medical support via text messaging with crew would appear to be a necessary step for managing a medical event. Whether this technology could be expanded towards the use of “smart” tools/applications remains to be determined. Taken together, these technologies could expand autonomous yet effective use of clinical procedures and equipment by non-physician crewmembers in the absence of ground-based clinical personnel.

The increase in the UOS and use of color-flow Doppler by the CMOs during the two phases of the study may be an indirect assessment of CMO confidence in ultrasound. It is unknown whether a learning effect also contributed towards this increase in ultrasound image quality and color-flow Doppler use. Combining this more complex use of the ultrasound tool with the higher overall UOS score does lend itself to the improved clinical usefulness of the data obtained during Phase 2 as compared with Phase 1. If the learning effect is removed from consideration, it can be said that the ADUS and texting communication tool combined to improve the clinical usefulness of the ultrasound images by one third going from Phase 1 to Phase 2. This is a remarkable finding considering the CMO team had received 1 hour of formal ultrasound training by a subject matter expert and a 20-minute briefing on the ADUS tool.

ADUS is a just-in-time tool that focuses on simple concepts such as probe placement and ultrasound pattern recognition. The ADUS can be used to augment the limited formal ultrasound training a CMO receives but it cannot replace the clinical decision needed along with next steps and ground support; however, tools like texting and ADUS could be developed, expanded, and personalized to minimize the gap needed for a crew to autonomously yet effectively diagnose and treat an ill crewmember. The texting tool could also act as a reference for the CMO, thus acting to reinforce instructions from ground support.

VI. Next Steps

ExMC will conduct an evaluation of the current ISS medical capability within the HDU as part of the JSC Mission Operations Test in September. This evaluation will act as a baseline test for ExMC's Exploration Medical System Demonstration project.

Ultrasound

The ExMC team will continue their expansion of remote guidance techniques and just-in-time training tools during the baseline and in-flight data collections of the cervical and lumbar vertebrae of ISS crew volunteers. A just-in-time training tool recently developed by the ExMC team will be implemented with ISS crewmembers to help them prepare for their remote guidance session later in their mission. This will also include the use of a new ultrasound probe recently manifested aboard the just-launched H-II Transfer Vehicle by the Japan Aerospace Exploration Agency.

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.			
1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE August 2014	3. REPORT TYPE AND DATES COVERED NASA Technical Memorandum	
4. TITLE AND SUBTITLE Autonomous Mission Operations Test Report Johnson Space Center Exploration Medical Capability			5. FUNDING NUMBERS
6. AUTHOR(S) Victor Hurst IV, PhD; Kathleen Garcia; David Ham			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Lyndon B. Johnson Space Center Houston, Texas 77058			8. PERFORMING ORGANIZATION REPORT NUMBERS S-1162
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001			10. SPONSORING/MONITORING AGENCY REPORT NUMBER TM-2014-217396
11. SUPPLEMENTARY NOTES			
12a. DISTRIBUTION/AVAILABILITY STATEMENT Available from the NASA Center for AeroSpace Information (CASI) 7121 Standard Hanover, MD 21076-1320 Category: 52			12b. DISTRIBUTION CODE
13. ABSTRACT *(Maximum 200 words)* The Exploration Medical Capability (ExMC) Element of the NASA Human Research Program was requested by the NASA Autonomous Mission Operations (AMO) team in December 2011 to provide medical scenarios as part of the AMO Test to evaluate autonomous operations for exploration class spaceflight missions. The primary objective of the AMO Test was to discern how astronauts will autonomously execute their mission tasks in the very limited presence of ground-based resources as part of an exploration class mission. This included the execution of medical procedures by minimally-trained caregivers with very limited remote guidance from a ground-based flight surgeon. The ExMC coordinated the development, integration, and execution of medical scenarios for the AMO team's two-phased test with Phase 1 being a baseline data collection and Phase 2 being a data collection using tools to mitigate deficiencies captured during Phase 1. This report details the development, integration, execution, results, and conclusions from the ExMC's preliminary evaluation of the autonomous management of medical events during an exploration class mission.			
14. SUBJECT TERMS medical science;simulation; crew procedures; training; medical personnel; diagnosis; long duration space flight		15. NUMBER OF PAGES 20	16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT Unlimited