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Use of Telescience for Biomedical Research During Space Flight

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When the U.S. first embarked on a manned space flight program, NASA's use of medical telescience was focused on crew health monitoring. In recent years, medical telescience use has been expanded to include support of basic research in space medicine. It enables ground support personnel to assist on-board crews in the performance of experiments and improves the quality and quantity of data return. NASA is continuing to develop its telescience capabilities. Future plans include telemedicine that will enable physicians on Earth to support crewmembers during flight and telescience that will enable investigators at their home institutions to support and conduct in-flight medical research. This paper describes NASA's use of telescience for crew safety and biomedical research from Project Mercury to the present and presents NASA's plans for the future.

For the Mercury, Gemini, Apollo, and Skylab programs, air to ground and ground to air transmissions were relayed by the Manned Space Flight Network, a world-wide network of ground tracking stations. Modifications and augmentations were made to the Network for each successive program to provide increased data handling. For the Mercury and Gemini Programs, two-way audio and data transmission were possible. The capability to downlink video images was added for the Apollo and Skylab Programs. Transmissions from or to a spacecraft were possible only when the spacecraft was over one of the tracking stations. At these times both real-time data and data previously recorded on-board were downlinked.

All four programs conducted in-flight medical monitoring. Physicians and support-personnel provided continuous monitoring from the ground. During Mercury and Gemini they relied on voice communications and biotelemetry. Electrocardiogram (ECG), blood pressure, respiration rate and body temperature data were continuously monitored. For Apollo, video monitoring and metabolic expenditure monitoring during extravehicular activity (EVA) were added. (An approximate measure of metabolic expenditure was calculated by monitoring oxygen usage and the inlet and the outlet temperatures of the liquid-cooled garment.) During Skylab, physiological measurements were made during launch, docking, EVA, landing, medical experiment performance and medical emergencies as needed.

The use of telescience for medical investigations also increased from the Mercury to Skylab Program. Prior to Skylab, audio communications between the ground and crews were used as required but data collected from in-flight medical investigations were not downlinked. During Mercury and Apollo, no extensive in-flight medical investigations were conducted. On Apollo 16 and 17, urine samples were collected for endocrine, metabolic, and clinical biochemistry studies, and deviations from programmed menus were reported for nutritional studies. Several in-flight medical investigations were performed during Gemini 4, 5, and 7, including studies to evaluate depth of sleep, human otolith function, and duration of the cardiac cycle and its phases. Data from these investigations were recorded, and investigators obtained their data postflight. During the Skylab Program numerous in-flight medical investigations were performed and experiment data were downlinked. The Lower Body Negative Pressure device was used to test orthostatic tolerance. Other studies included venous compliance measurements and testing of vestibular function. The majority of experiment data were recorded on-board and downlinked later, with investigators receiving complete experiment data within 12 to 24 hours after completion of an experiment. Experiments were discussed by the crew and investigators on a weekly basis, providing the investigators an opportunity to modify protocols based on the data gathered and downlinked.

Presently, the Tracking and Data Relay Satellite System (TDRSS) is used to relay transmissions from the Space Shuttle to the ground and the ground to the shuttle. Telecommunications consist of two-way audio and data transmission, and video downlink. Both dedicated-experiment video and general video of crew activities can be downlinked. Real-time communication can be accomplished during periods when the Orbiter's Ku-band or one of the four S-band antennas has a direct line of sight to one of the TDRSS satellites. (Ku-band is used for high data rate, voice and video transmissions, and S-band is used for voice and low data rate transmissions.) These periods vary depending on the Orbiter's attitude. During periods when real-time communication is lost, data is recorded on-board and later downlinked.

To support crew health and safety, continuous indirect monitoring and periodic direct monitoring of every flight crew is conducted by a Flight Surgeon who is located either at the Mission Control Center or the Science Monitoring Area (SMA). Indirect monitoring involves monitoring video and voice transmissions. Direct monitoring involves conducting Private Medical Conferences (PMCs) and monitoring downlinked biomedical data. During PMCs medical concerns or treatments are discussed with the crew and, if required, ECG data can be downlinked for the Flight Surgeon to monitor. These conferences are scheduled each day and additional conferences can be conducted if requested. During EVA and medical investigations biomedical data is downlinked for the Flight Surgeon to monitor. Data downlinked during EVA include EVA suit pressure, the partial pressure of carbon dioxide, the amount of oxygen remaining, and the EVA crewmembers' ECG data. During medical investigations, physiological data is monitored to verify the health of the crewmembers performing the investigation. If a crewmember's health is in jeopardy, the investigation may be interrupted by the Flight Surgeon. For example, throughout the performance of the Lower Body Negative Pressure investigation on STS-32, the Flight Surgeon monitored the subject's ECG and blood pressure. No complications arose during the performance of the experiment.

Telescience is used to involve ground-based researchers and support personnel in biomedical research being conducted on the Space Shuttle, thereby providing maximum scientific return. During a mission, investigators located at an investigator monitoring area monitor and review processed downlinked data and can communicate with the crew when necessary to assure proper conduct of their experiments. The SMA at the Johnson Space Center is primarily used by investigators to monitor experiments involving human subjects while the Test Monitoring Area (TMA) at the Ames Research Center is used to monitor experiments involving animal subjects.

Investigators are responsible for observing in-flight activities, monitoring experiment data, and adjusting experiment protocols. By observing televised activities of crewmembers performing experiments, investigators can verify that procedures are performed correctly, record any factors affecting their data, and verify the time of experiment performance. Monitoring experiment data in real time or close to real time, allows investigators to verify the quality of the data and hardware performance. Observing experiment performance, discussing it with the crew, and monitoring downlinked data, allows investigators to adjust experiment protocols or develop alternate procedures if necessary.

For Spacelab missions, additional monitoring is performed from the Payload Operations Control Center (POCC) at the Marshall Space Flight Center. From the POCC the performance of the entire payload is overseen. Ground-support personnel provide 24-hour support to insure overall mission success. Their responsibilities include recording data and playing it back, monitoring experiment hardware, and revising the daily timeline when necessary. Data are acquired and recorded during Acquisition of Signal and can be played back for review. Experiment hardware is monitored to verify performance and identify hardware malfunctions to minimize science loss. In the event of a malfunction, ground-support personnel will instruct the crew to initiate malfunction procedures or use backup hardware, or they will develop alternate protocols for the crew. They also provide re-plan capability if the daily timeline needs to be revised based on experiment performance.

To illustrate NASA's use of telescience, examples of its use during the recent Spacelab Life Sciences 1 (SLS-1) mission, during which extensive biomedical research was conducted, are presented. SLS-1, launched on June 5, 1991, was the first life sciences dedicated Spacelab mission. Its payload was composed of investigations of the mechanisms, magnitudes, and time course of physiological changes due to space flight and investigations of the consequences of the body's adaptation to weightlessness and readjustment to 1-g. SLS-1 was a nine-day mission and had a crew of seven, four payload crewmembers and three Orbiter crewmembers. In addition, the experiment investigators and ground-support personnel were also involved in the collection of in-flight medical experiment data.

Remote hardware monitoring was one area on SLS-1 in which telescience support was provided by ground-based personnel. For example, rising refrigerator and freezer temperatures were detected and closely monitored by ground-support personnel during the mission. When temperatures rose above specification, ground-support personnel developed several solutions to avoid the loss of experiment samples. Ground-support personnel also monitored the Research Animal Holding Facility's environmental parameters, conserving crew time during the day and allowing monitoring while the crew slept. If required, the ground also had the capability to remotely control alarm sensor limits.

Video monitoring was another use of telescience during SLS-1. It allowed, in combination with crew comments, ground-support personnel to verify the operation of the General Purpose Work Station, thereby permitting animal handling by crewmembers. It also allowed investigators to view echocardiography data and verify its quality.

Also utilized on SLS-1 was the investigators' capability to monitor downlinked data. For example, investigators detected noise in the data being downlinked from the Gas Analyzer Mass Spectrometer during an investigation and alerted ground-support personnel to the problem. The ground-support personnel were able to develop and uplink a solution for crew implementation. The result of implementing the procedures developed on the ground was improved data quality.

For upcoming Spacelab missions NASA will expand its telescience capability by providing investigators the same data-monitoring capability they now have at the SMA and TMA at other locations. Remote Data Acquisition and Analyses Equipment, developed as a derivative of telescience research for Space Station Freedom, will be used by investigators for data acquisition. (The system consists of a workstation linked through a computer network to a data-monitoring area.) During the Spacelab Japanese mission, the Remote Data Acquisition and Analyses Equipment will be used as the backup monitoring system for investigators at the Marshall Space Flight Center. During the Spacelab Deutsche 2 mission, it will be the primary monitoring system for investigators in Germany. There is also a potential for its use during preflight and postflight data collection.

In the future, NASA plans to expand its use of both telemedicine and telescience. For the Space Station Freedom, NASA's primary goal for telemedicine is to give physicians the ability to provide remote health care support to the on-board Crew Medical Officer (CMO). Ground-based physicians will provide telemedicine support from the Space Station Control Center.

Aboard the station, the Health Maintenance Facility (HMF) will provide the medical equipment for the CMO.

When the space station is completed, telemedicine capabilities will include two-way audio communication between the physician and crew, downlink and on-board display of radiographic and non-radiographic images, and transmission of data from on-board medical hardware. Radiography of the face and mandible, skull, neck, spine, chest, abdomen, gall bladder, extremities, peripheral soft tissues, pelvis and urinary tract will be possible. Non-Radiographic imaging will include both macroscopic and microscopic imaging. Fixed and portable video cameras will acquire and transmit full color, full motion video images of physical examinations in space of various medical, surgical, and dental procedures. A microscope video camera will transmit a microscopic image to the ground for diagnosis by an expert observer. It will capture a color video image of the microscope's visual field for downlink. Physiological data such as ECG, blood pressure, and pulse oximetry will also be downlinked.

An example of HMF hardware that will provide telemedicine support is the Electronic Stethoscope System. It will be used to downlink the audio auscultation portion of physical examinations. The Stethoscope acquires, stores, replays, and transmits auscultated sounds of the heart, lungs, and bowels. The system has already been tested with positive results. A signal was transmitted from a mock-up of the HMF to physicians at a remote workstation, where they gave a positive clinical evaluation of the system.

NASA's primary goals for telescience for the space station are to permit investigators access to payload data, in real-time, from any network location and to allow investigators control of on-orbit experiments. Requirements for meeting these goals include a communications network for real-time audio, video, and data transmission. Data to be transmitted will include experiment hardware parameters, station environmental parameters, experiment data, science data, and experiment execution commands. The benefits of the use of telescience for Space Station Freedom research include reduced crew time requirements, the ability for investigators to access supporting data through the network, the provision of data distribution services through the network, and an overall increase in science productivity.

In summary, telescience and telemedicine technology has evolved as NASA's space program has evolved. From the Mercury to the Apollo Program, communications and medical telemetry was used for in-flight crew health monitoring. For the Skylab Program, the addition of near real-time downlink of science investigation data was added for additional crew health monitoring and for support of medical investigations. Presently in the Space Shuttle Program, science investigation data can be downlinked in real-time. For the future, NASA is continuing research and development of telemedicine and telescience technology for Space Station Freedom. Telemedicine has been an important tool for safeguarding the health of astronauts and ensuring the success of in-flight experiments, and it will be indispensable for the long-term sojourns in space that will come in the future.