Extended Duration Orbiter Medical Project

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Biomedical research in the Space Shuttle Program began in 1983 through efforts managed by the Space Biomedical Research Institute at the NASA Johnson Space Center. The operational nature of these early missions meant that in-flight research data, although critical for establishing the course of reactions to weightlessness and adaptations to it, had to be gathered without interfering with the primary mission objectives. The mechanism for obtaining such data was the Detailed Supplementary Objective (DSO). Investigations initially focused on identifying detrimental physiological effects and their impact on spaceflight operations. DSOs had to be conducted in a manner that minimized demands on crew time, stowage volume, weight, and power requirements. Typical DSOs involved collecting baseline data before and after flight, although a few required in-flight data collection. Onboard DSO investigations were carried out in parallel with procedures involving either testing or refining the performance of the orbital vehicles and their subsystems, or evaluating new hardware and procedures; these studies were called Detailed Technical Objectives (DTOs). DSO data typically involved small numbers of crewmember subjects, which limited valid statistical analyses. Bungo et al.[1] documented results from activities completed before the Challenger accident in 1986. A 3-yr flight hiatus followed the loss of Challenger and its crew.

In February 1989, biomedical DSOs were given a new focus and increased priority with the initiation of the 5-yr, $40M Extended Duration Orbiter Medical Project (EDOMP). Prior to the EDOMP, all Shuttle flights were under 10 d. A Shuttle Program Directive authorized modifications to Columbia, enabling missions of up to 16 d, and to Endeavor for missions of up to 28 d.[2] This was accomplished by the installation of a 7000-lb pallet in the aft payload bay (**Fig. 1**), which provided additional liquid hydrogen and liquid oxygen for the fuel cells. These extended duration missions were anticipated to be operationally challenging, particularly with regard to requirements for the crew to actively pilot and land the spacecraft on a runway. Early missions typically landed at NASA Dryden Flight Research Center, where the wide and lengthy desert runways provided a large margin of safety. The EDOMP ended in 1995, although the EDO flights continued until 2003. There were 14 EDO flights beginning with STS-50 (all but 1 used Columbia); 9 were longer than 15 d and STS-80 was the longest at 18 d.

NASA established a unique management approach for EDOMP. Travis Brown managed all financial and personnel issues and maintained project schedules. Chuck Sawin, Chief Scientist for the Medical Sciences Division, together with Ellen Baker, a physician astronaut, and Richard Jennings, Chief of Flight Medicine, formed an integrated science management team that developed and approved research manifests for each mission. This unique collaborative management approach was also very important for establishing project credibility within the Astronaut Office. Another key ingredient for the success of EDOMP was the support contractor group led by Genie Bopp and Keith Kreutzberg of the organization then known as Wyle Life Sciences. Their excellent management contributed immensely to the ultimate success of EDOMP.

Relations between the Astronaut Office and the Medical Sciences Division had become very strained during the period preceding the initiation of the EDOMP. Astronauts as a group had lost their trust in Medical Sciences Division management due to concerns regarding events that might have impacted individual astronaut flight status. This was a complex environment since all research personnel as well as Flight Surgeons were located within the Medical Sciences Division. If the EDOMP was to be successful, this credibility issue had to be resolved. An important step was to initiate direct presentations of the proposed DSO manifest for a given mission to the crew itself in their office building. I started these one-on-one briefings initially between just myself and the crew. I believe a key point was our ability to convince the prospective astronaut subjects that the studies being proposed were indeed highly relevant to understanding critical issues associated with spaceflight. I presented an overview of each DSO and the requested number of subjects. An open discussion would follow. The crew commander would then take the presentation under consideration and provide us feedback in a few days. This direct approach began to work and the initial resistance to participation was gradually overcome. We then broadened participation to include direct briefings by each investigator responsible for DSOs planned for that mission. We ultimately would have more volunteer subjects than we could accommodate for a specific mission.

Procedures sometimes required some unpleasant interventions. Peggy Whitson at that time was a researcher studying changes in endocrine regulation of orthostatic

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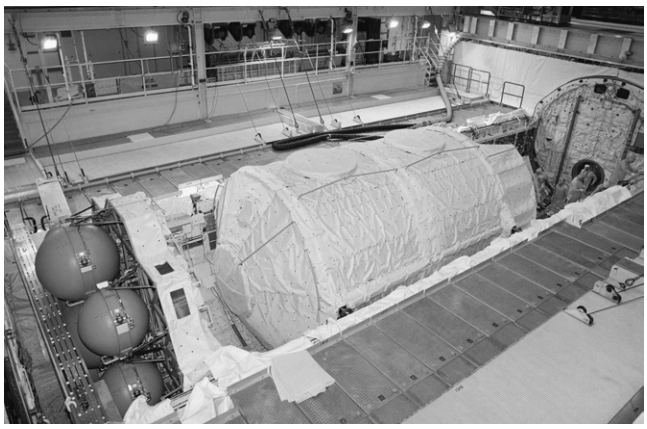

Fig. 1. EDO pallet in the aft cargo bay of the Shuttle. The tanks held additional oxygen and hydrogen for the fuel cells.

function. Her protocol required insertion of a venous catheter in the forearm of the subject, to permit drawing blood samples at appropriate times. Peggy won the crews over by having a catheter placed in her own forearm prior to the crew briefing. She would then roll up her sleeve during her pitch to the crew, displaying the "innocuous" catheter. This approach was very effective and she obtained her subjects. Bioethics issues came to the forefront at the onset of the Space Shuttle Program, in large part because of the Privacy Act of 1974, coupled with an increasing awareness that space crewmembers were essentially a "captive" subject population and theoretically subject to coercion and invasion of privacy.[2] The foremost concern for potential subjects was that voluntary participation in a research protocol might result in detection of some previously undocumented physiological abnormality that could result in loss of flight status. For example, significant concern was expressed regarding the potential for detecting abnormalities in heart rhythm in the course of electrocardiographic monitoring by Holter monitors. These concerns were alleviated when the Johnson Space Center Director issued a management policy that precluded the use of findings associated with biomedical research data in determination of flight status unless a "life-threatening condition" had been documented. In that case, the crewmember's flight surgeon would be contacted and the crewmember would obtain appropriate medical follow-up. Fortunately, this situation did not occur during research activities associated with the EDOMP.[4]

Prior to EDOMP, medical data collection could be initiated 1.25 h to 2.5 h after Orbiter wheels stop. This delay permitted partial physiological recovery and prevented investigators from determining physiological status of the crew closer to landing. Dr. Sam Pool, Chief of the Medical Sciences Division, suggested a novel approach to improve crewmember privacy and immediate medical care at landing. He suggested purchasing and modifying airport passenger transports to become Crew Transport Vehicles (CTVs). Two airport passenger transports were acquired; one was shipped to NASA Dryden Flight Research Center and the other to NASA Kennedy Space Center, where they were reconditioned and outfitted with an emergency medical care room, a rest room, a refrigerator, and recumbent lounge chairs for each crewmember. The CTVs could be raised as much as 11 ft to enable them to dock with the Shuttle on the runway following post-landing checks for potential propellant leakage. Flight surgeons were then able to board the Shuttle and evaluate crewmembers' status in total privacy. A few select researchers were permitted onboard occasionally to begin their evaluations within the CTVs. The addition of the CTVs to the landing day complement contributed significantly to enhanced emergency medical care, improved crew comfort and privacy, and a reduction in the time required to initiate biomedical data acquisition (**Fig. 2**).

A large number of DSOs and DTOs were conducted during the EDOMP. Significant biomedical hardware devices were developed and evaluated during the EDOMP, including a collapsible lower body negative pressure (LBNP) device, reentry blood pressure and electrocardiograph monitors, an improved anti-g suit, a rower, a barcode reader used to document food consumption by package codes, a microbial air sampler, and a combustion product analyzer. Flight cycle ergometer and treadmill prototypes eventually were refined into flight units for use on the International Space Station (ISS).

An inertial vibration isolation system (IVIS) was developed for the cycle ergometer (**Fig. 3**). IVIS was conceived to provide the roll stabilization lacking in the earlier attempts to isolate exercise equipment vibration from impacting payloads requiring a microgravity environment. The IVIS consisted of two aluminum boxes that mechanically interfaced with the cycle ergometer. Each box contained a throw mass, mounted on linear bearings, and a system of linkages to drive the throw mass. As the astronaut pedaled the ergometer, the throw masses moved inside the IVIS boxes to create a counter torque that was applied to the ergometer. This counter torque acted to nullify the major torque created by the motion of the cyclist's legs and upper body. The torque created when riding the ergometer was dependent on cycling speed and workload. Weight and cycling style were major factors in

Fig. 2. Crew transport vehicle docked to the Shuttle after landing.

Fig. 3. Cycle ergometer with IVIS.

gravitational disturbance, so the ability to allow for gross adjustments was included. When the gain was properly set, the torque produced by the IVIS boxes was equal and opposite to the torque produced by the cyclist. Performance was verified by using the microgravity measuring device, which was mounted in a middeck locker.

Two rower ergometers were developed and evaluated through DTOs 653 and 673 to provide Shuttle crews with an exercise alternative to the treadmill or cycle ergometer. They were designed to be quiet and effective, while requiring minimal stowage space and electrical power. The first generation rower (MK-1) was flown on STS-42, STS-53, STS-54, and STS-56. The combination of workload setting, flywheel speed, and rowing cadence could be used to compare relative workloads preflight and in flight; however, such comparisons were highly subjective and not quantitative. For launch and landing, the rower was stored in a middeck locker. During use, it was attached to the seat studs on the Orbiter middeck floor. The second generation rower, the MK-2, was designed with features to compensate for the shortcomings of the MK-1 unit. Among other modifications, it had the ability to quantify workload. The first flight of MK-2 was on STS-64 in 1994.

Cardiovascular studies received a high priority during this program because of concerns regarding decreased orthostatic tolerance and egress capability.[3,4] Microgravity exposure up to 16 d was found to be a relatively benign environment as shown by the fact that resting blood pressures and heart rates were below ground-based control levels.

One of the hardware items developed during this project was a collapsible LBNP (**Fig. 4**). It supported multiple in-flight cardiovascular investigations. DSO 623 specifically evaluated the use of the LBNP as a countermeasure the day prior to landing. The protocol required what was termed the "soak." This began as a stepwise decompression to −50 mmHg, followed by approximately 3.5 h of decompression at −30 mmHg below ambient pressure. During the first hour at −30 mmHg decompression, 1 L of water or artificially flavored fruit drink and 8 g of sodium chloride were ingested. The objective was to determine whether the soak protocol performed 24 h before landing would preserve "normal" orthostatic tolerance. Five in-flight subjects participated in the soak treatment approximately 24 h before landing. Their average heart rates, systolic blood pressures, mean arterial

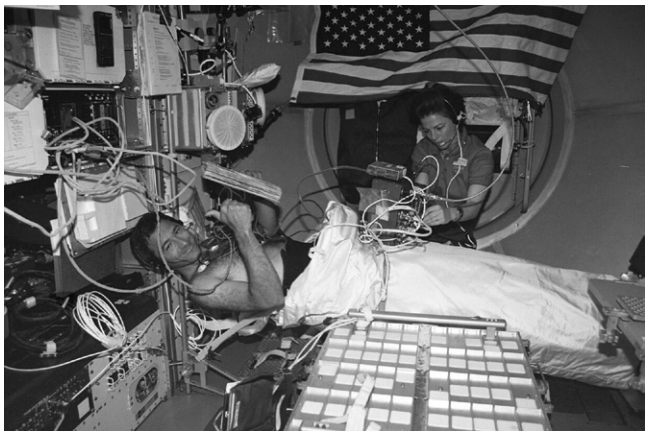

Fig. 4. Cardiovascular studies performed using the collapsible LBNP in Spacelab.

pressures, and pulse pressures were determined at each stage of decompression. Results from subjects who had performed the soak (active subjects) were compared with a group who did not perform the soak (inactive subjects). The active subjects clearly demonstrated lower heart rates and improved blood pressure parameters relative to the inactive subjects. Unfortunately, this promising cardiovascular countermeasure faced some difficult practical issues that ultimately prevented it becoming operational. First, the fact that each crewman required a 4-h soak treatment made it impractical for larger crew sizes. Second, if a 24-h wave-off for landing occurred, it would have been impossible to repeat the soak treatments because all hardware items would have been stowed for landing.

Electrocardiographic abnormalities were low for the group evaluated before flight and were even less during flight for these subjects.[3] Multiple factors associated with orthostatic tolerance were evaluated in integrated cardiovascular investigations. Lower epinephrine responses in a group of astronauts who were relatively more susceptible to presyncope showed a high correlation with their lower total peripheral vascular resistance. Further, it was shown that plasma volume replenishment per se did not prevent presyncopal episodes during laboratory stand tests. These data were consistent with multiple observations of altered autonomic control during spaceflight.

Centrifuge studies conducted at the U.S. Air Force Armstrong Laboratory led to guidelines for use of standard CSU-13 anti-g suits. Maintaining orthostatic tolerance and exercise capacity was a primary consideration, since all post-Challenger crewmembers wore a 34-kg launch and entry suit, and many crewmembers had previously demonstrated 10–20% decrements in the strength of major muscle groups. Results of the centrifuge studies led to a mandatory pre-inflation schedule to optimize orthostatic protection during reentry.[3] A second portion of these studies developed an improved anti-g suit designated as the reentry anti-G suit (REAGS). REAGS provided more comfortable protection at lower pressures. The standard CSU-13 garment consisted of five inflatable bladders, including an abdominal bladder. The abdominal bladder caused great discomfort for fluid-loaded crewmen. It did not provide any significant anti-g protection with the Shuttle reentry profile of less than 2 g. The REAGS was designed to complement the advanced crew escape suit. The first Shuttle flight to evaluate REAGS was STS-71. REAGS was further modified to decrease bulkiness by using Gortex fabric and a lightweight zipper for use in combination with the liquid cooling garment. Resulting flight rules required use of the liquid cooling garment and pre-inflation of the anti-g suit before reentry, together with revised fluid loading. This complement greatly reduced the incidence of orthostatic intolerance.

Alternative isotonic fluid loads were verified and optimized by determining total volume in relation to the subject's preflight weight. Florinef treatment was studied as a method to restore plasma volume using certain protocols late in the mission. Interestingly, when it became difficult to obtain a subject for this DSO, the Commander of STS-45 (Charlie Bolden) volunteered. This caused great consternation among the flight directors. First of all, Charlie had never experienced orthostatic intolerance. Second, he stated that if the effects of Florinef bothered him, he would stop taking the medication before reentry. He ended up stopping the protocol because of discomfort due to perceived head congestion. This event ended the Florinef trials.

Nutritional assessments showed that ground-based and flight energy expenditures were comparable. Energy intake during flight was typically decreased relative to preflight levels. Additionally, a preference was noted for carbohydrates vs. fat in choice of foods by the astronauts. Renal stone risk profiles were established and a potential countermeasure was tested.

No correlation could be established between maintenance of exercise capacity and orthostatic tolerance. Minimal losses in aerobic capacity were noted in subjects who exercised at least three times weekly, reaching 60–80% of preflight maximum workloads.[3] Treadmill exercise appeared to be important for maintenance of neuromuscular patterns required for walking or running.

Extensive neuroscience investigations dealt with the complex integrated systems where it was difficult to factor out underlying mechanisms associated with changes known to occur in the vestibular system. Studies were conducted to evaluate changes in visual target acquisition, postural stability and locomotion, assessment of perceived self-orientation or motion, and eye-head-trunk coordination during locomotion. Preflight laboratory sessions that simulated flight spatial environments reduced the occurrence of space motion sickness during actual spaceflight. Interestingly, the time required to foveate images increased by as much as 100% following spaceflight. This finding led to some Shuttle commanders altering their pattern of instrument monitoring during final approach and landing to minimize potential hazards.[4]

The EDOMP continued the long duration spaceflight physiology research and hardware development which significantly began during the Skylab Program and transitioned into the ISS Human Research Program. The importance of this effort cannot be understated as the frequent Shuttle flights allowed for dynamic procedural and hardware development. No decrements were found in Shuttle pilot performance during the EDO flights, which lasted as long as 18 d. The unanswered question (as the EDOMP was curtailed) is what aspects of pilot performance will be affected on flights longer than 18 d.

REFERENCES

1. Bungo MW, Bagian TM, Bowman MA, Levitan BM, editors. Results of life sciences DSOs conducted aboard the Space Shuttle 1981–1986. Houston (TX): Space Biomedical Research Institute and NASA Johnson Space Center; 1987. Report No.: NASA TM-58280.
2. Risin D, Stepaniak PC, editors. Biomedical results of the Space Shuttle Program. Houston (TX): NASA; 2013. Report No.: NASA/SP-2013-607.
3. Sawin CF. Biomedical investigations conducted in support of the Extended Duration Orbiter Medical Project. Tex Med. 1998; 94(2):56–68.
4. Sawin CF, Taylor GR, Smith WL, editors. Extended Duration Orbiter Medical Project final report (1989–1995). Washington (DC): National Aeronautics and Space Administration; 1999. Report No.: NASA/SP-1999-534.