Focus on: ORBIS International Flying Eye Hospital, Department of Technical Services

MARK R. PRAUSNITZ, Ph.D.
Department of Technical Services, ORBIS International, New York, New York
School of Chemical Engineering, Georgia Institute of Technology, Atlanta, Georgia

ISMAEL CORDERO, CBET
ALAN LEVENSON
Department of Technical Services, ORBIS International, New York, New York

The ORBIS International Flying Eye Hospital is dedicated to restoring sight to the blind through medical education programs in developing countries. The modification of a DC-10 aircraft to house a teaching hospital for ophthalmic surgery involved a variety of engineering challenges to satisfy standards for both hospital and aircraft safety. The Technical Services Department maintains all medical equipment on the aircraft, encountering situations not found in traditional clinical engineering departments. Technical education is also an important part of the ORBIS biomedical engineering program. Future plans include expansion of existing technical training efforts, as well as using technology to improve the medical education program as a whole.

Index Under: Department, Technical Services, Description of; Airplane Hospital; Education, Biomedical Engineering; International Education, Biomedical Engineering; Management, Equipment; Equipment Management.

INTRODUCTION

The **ORBIS International Flying Eye Hospital** is a nonprofit, teaching hospital with approximately 2,000 square feet of hospital space, including one operating room and a four-bed recovery room. ORBIS's size is limited because the hospital is contained within a fully-operational DC-10 aircraft (see Figures 1 and 2), which flies to developing countries around the world to teach ophthalmology. The on-plane crew of 25 consists of ophthalmologists, anesthesiologists, nurses, audio-visual specialists, aircraft engineers, pilots, administrators, and biomedical engineers from 12 different countries. An off-plane support and fundraising team of 50 operates out of offices in New York, Houston, London, and Hong Kong.

ORBIS is dedicated to restoring sight to the blind and to promoting peaceful cooperation among nations. Since the first flight in 1982, ORBIS has held 230 medical programs in 70 countries, training almost 30,000 medical personnel and treating 18,000 patients. Most ORBIS medical programs take place during three-week missions to countries with the ORBIS aircraft. During each visit, volunteer ORBIS doctors, assisted by doctors from the host countries, perform eye surgery in the operating room on board the airplane. As nurses from the host country work side-by-side with ORBIS nurses throughout each surgery, local doctors seated in the plane's classroom watch live surgery and discuss surgical techniques via a two-way audio-visual system.

While the ORBIS aircraft is operating in a country, other training and educational activities are conducted in local hospitals, universities, and community centers. ORBIS also carries out similar training courses in countries without the plane, including surgical, nursing, and technical programs. ORBIS visits a country at the invitation of its Ministry of Health and National Ophthalmological Society. Once an invitation is accepted, ORBIS sends advance teams to meet the country's host doctors and plan an appropriate curriculum based on that country's needs.

The first ORBIS Flying Eye Hospital was aboard a DC-8 aircraft, now displayed as a museum exhibit in Beijing, China. After a $15 million, 18-month modification, the new ORBIS DC-10 flew its first mission in July, 1994. The modification provided a 52-seat classroom (see Figure 3), laser and diagnostic room (see Figure 4), operating room (see Figure 5), instrument preparation room, patient recovery room (see Figure 6), audio-visual control center, adminis-

Journal of Clinical Engineering • Vol. 20, No. 5, September/October, 1995 •

Figure 1
The ORBIS Flying Eye Hospital is a fully operational DC-10 aircraft that contains a state-of-the-art teaching hospital for ophthalmic surgery.

trative office, conference room, technical services area in the aircraft belly (see Figure 7), and a modular electrical and air-handling system outside the plane (see Figure 8).

MODIFICATION OF A DC-10 AIRCRAFT INTO A TEACHING EYE HOSPITAL

Modification of a commercial passenger DC-10 aircraft into the world's only flying eye hospital involved many challenges. Special engineering considerations went into designing a fully operational and self-sufficient eye hospital that allows for flight safety, patient safety, and teaching facilities.

Electrical Power

Although the DC-10 has its own aircraft *auxiliary power unit* (APU), it is noisy and costly to operate. To solve this problem, a 400-Hz, 90-kW generator was built and housed in a standard LD-3 cargo container (see Figure 8). This module is stored in the aircraft belly during flight and set up outside the aircraft to provide power during medical programs. The generator runs on diesel fuel from the aircraft fuel supply, which is automatically fed to the generator on a demand basis. If the external generator were to fail, then power would be obtained from the aircraft's APU or a standard airport generator

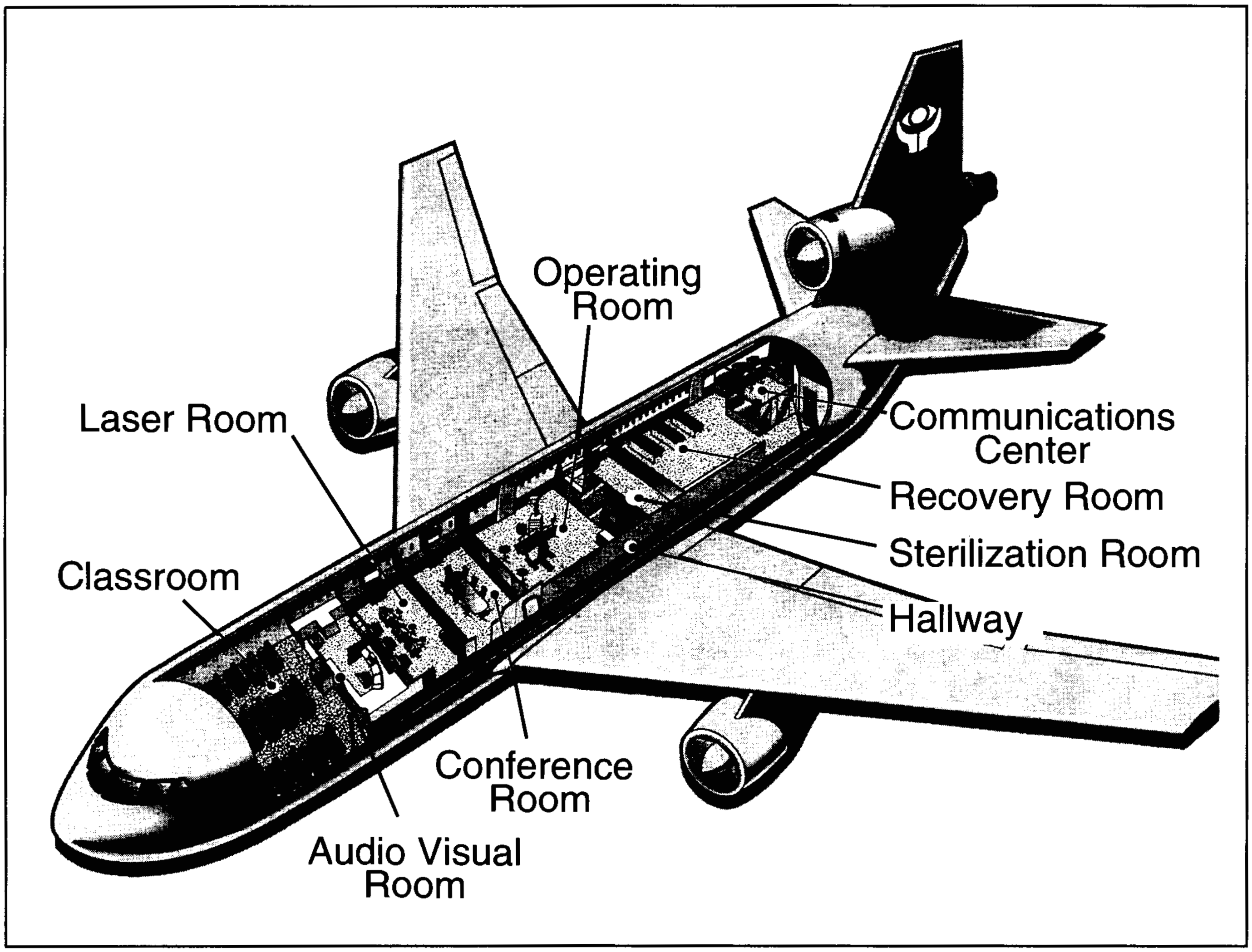

Figure 2
A schematic of the ORBIS aircraft layout. The technical services area is not shown but is in the aircraft belly, located below the classroom.

Figure 3
The classroom seats up to 52 doctors who watch and actively participate in live surgeries via a two-way, audio-visual system.

truck. Moreover, two *uninterruptable power supplies* (UPS) continuously power essential equipment (such as the operating microscope, anesthesia machine and ventilator, patient monitors, telephone system, and computer network server).

Airplanes use 400-Hz power because the wiring is thinner and lighter than that required for 60 Hz. Therefore, 400-Hz (115 V) power is provided for aircraft systems such as lights and lavatories, and converted to 50 Hz (240 V) and 60 Hz (115 V and 220 V) for the plane's medical, video, computer, and office equipment. Two additional 60-Hz generators power external air conditioning units, all housed in LD-3 containers. If these units fail, conditioned air is provided by the aircraft's APU-powered system or from a standard airport air conditioning truck.

Hospital Gases

Compressed air, oxygen, medical vacuum, and waste-gas evacuation outlets are located throughout the plane. Two compressors, housed in an LD-3 container, provide compressed air at 100 psi for anesthesia, surgical, and sterilization equipment. Because only one compressor is used at a time, the active compressor can be switched if one fails. Housed in the same container is a vacuum pump that provides up to 660 mmHg suction in the operating and recovery rooms.

Because oxygen in developing countries is sometimes difficult to obtain and of questionable quality, the DC-10 is equipped with an oxygen concentrator. Using compressed air as its source, the concentrator provides up to 25 L/min of oxygen having at least 93% purity. Two H-size cylinders automatically provide back-up oxygen if the concentrator outlet pressure drops below 45 psi. An evacuation system allows ethylene oxide from the sterilizer and scavenged anesthetic gases to be vented to atmosphere.

Water and Air Treatment

To provide safe water for drinking and scrubbing, a 300-gallon tank feeds water through a bromine treatment system, which includes micron and charcoal filtering, and bacteriacidal ultraviolet light. Water pressure is maintained by pressurizing the water tank with compressed air.

Airflow in the plane was designed to produce a positive pressure in the operating room, thereby reducing the entrance of dust, dirt, and microorganisms from outside. Moreover, all air is filtered with hospital-grade *high-efficiency particulate air* (HEPA) filters. Adequate air exchange is provided to remove residual anesthetic gases from the operating room and to supply fresh air throughout the plane.

Structural Considerations

As mandated by the **Federal Aviation Administration**, a structural analysis of every wall, cabinet and piece of mounted equipment on the plane was made to assure safety in flight and during medical programs. In addition to numerous small modifications, the floor in the operating room is reinforced to prevent vibration and to support all of the OR equipment, including a 150-kg anesthesia machine and a 200-kg surgical microscope. The low weight and high strength requirements led to a design unique to the hospital and aircraft industries. Because the floor could not support it, another unprecedented approach was used to suspend the extensive wiring in the audio-visual room from the ceiling. Finally, before flight, all unmounted equipment is packed into cases and placed under special nets and harnesses that are secured to the aircraft floor.

Audio-Visual System and Communications

The audio-visual system was designed to enhance teaching by capturing all aspects of on-board surgeries and procedures. Fifteen cameras supply views of the clinical rooms and, to provide the same image viewed by the surgeon, relay video output from the surgical microscope, indirect ophthalmoscopes, A/B scans, and

Figure 4
The laser and diagnostic room allows for patient examination using optical and ultrasonic diagnostic instruments and treatment with Argon and Nd:YAG lasers.

slit lamp used for argon laser procedures. All video can be viewed by ophthalmologists in the classroom or on any of the 54 video monitors located throughout the plane. Microphone outlets and speakers also found throughout the plane allow for continuous exchange between teachers and audience.

Between surgeries, lectures on current ophthalmic topics are presented using single- or dual-slide projection, a white-board, or video projection from VHS tapes with any of several standard video formats. When the 52-seat capacity of the on-board classroom is exceeded, a supplemental classroom can be set up inside the airport using an infrared transmitter/receiver system for two-way audio and video communication. All surgical procedures are recorded on videocassettes, copies of which are given to the host doctors as a teaching resource.

For communications from the aircraft, worldwide telephone and fax capabilities are achieved using a satellite dish or a cable linked to the local phone system. Telephones located throughout the airplane facilitate internal communication and allow global paging for urgent or emergency situations. Four walkie-talkies can be used for contacting staff in the supplemental classroom, lunch room, or elsewhere outside the plane.

DEPARTMENT OF TECHNICAL SERVICES

Departmental Structure and Overview

The ORBIS *Technical Services Department* has three members: Director of Technical Services, Senior Biomedical Engineer, and Biomedical Engineer. The department director is a permanent employee based in ORBIS's New York office and visits the plane a few times each year. His responsibilities include providing technical advice, information, and parts for medical equipment; planning and implementing off-plane technical training workshops; hiring and supervising plane-based engineers; and providing overall direction for the deparment.

Figure 5
The operating room contains equipment for ophthalmic surgical procedures performed by ORBIS doctors and nurses along with their local counterparts.

Figure 6
Patients remain in the recovery room before and after surgery, tended to by ORBIS and local nurses with the help of standard patient monitoring equipment.

The plane-based biomedical engineers have one-year appointments on board the ORBIS aircraft. They are responsible for maintaining ORBIS medical, office and computer equipment; preparing and implementing technical education programs for local technicians; repairing broken equipment in host-country hospitals; and providing technical advice to the ORBIS crew, as needed.

On-Plane Clinical Engineering Responsibilities

As a self-sufficient, fully functioning eye surgery facility, the ORBIS airplane has equipment for a range of uses in ophthalmic procedures: diagnosis by optical and ultrasonic techniques; cleaning and sterilization of surgical instruments; and surgical operations including vitrectomy, phacoemulsification, irrigation/aspiration, cryogenic and laser procedures, and standard patient anesthesia and monitoring. In addition to a few pieces of standard electronic office equipment, the plane also contains a networked computer system, including seven computers and a number of peripherals. To ensure patient safety, the aircraft is equipped with an alarm system for oxygen, air and vacuum levels. A computer-based preventive maintenance schedule and repair system, along with an inventory of spare parts, basic electronic test equipment, and an equipment manual and catalog library contribute to an up-to-date clinical engineering program. Although not required, ORBIS strives to conform to the standards of the **Joint Commission on Accreditation of Healthcare Organizations**.

In addition to the responsibilities found in traditional clinical engineering departments, ORBIS engineers encounter additional challenges. For example, medical and other equipment must be secured during flight. All instruments are either placed in a secure housing built into the plane or put in padded boxes and secured to the aircraft floor with specially designed nets and harnesses. Every three weeks, when it flies to a new country, the plane's interior is completely dismantled, secured and

Figure 7
The technical services area contains workbenches, along with test equipment, spare parts, and a technical library, where Biomedical Engineer Mark Prausnitz (left) and Senior Biomedical Engineer Ismael Cordero (right) work.

set up again on arrival. Three times each year, the plane stocks up on medical supplies for both ORBIS use and donation abroad. The belly of the plane is filled with boxes that are inventoried and arranged so that supplies can be easily retrieved when needed.

To facilitate fax and phone transmission, the plane is equipped with satellite communication capabilities. This requires erecting and aiming a satellite dish on the airplane wing in each country visited. Although some countries have readily available, reasonably priced telephone service, others do not, making self-sufficiency in communications a great advantage.

Because the quality and availability of distilled water in developing countries is variable, the Technical Services Department operates a small distillation unit to provide water for autoclaves and instrument cleaning. Moreover, airplane water used for drinking and surgical scrubbing is routinely checked for microbiological purity.

Instrument repair can be a lengthy and difficult process because only a small inventory of spare parts can be maintained on the aircraft. Service manuals and schematics are sometimes difficult to obtain, because most equipment is donated, and some donors will not provide technical literature. Occasionally, the Director of Technical Services in New York is contacted for assistance. Because visiting doctors and others come to the plane almost every week, small spare parts can generally be carried out by hand. Most spare parts and labor are donated or provided at a reduced price by manufacturers.

Off-Plane Clinical Engineering Activities

Whenever possible, ORBIS engineers repair broken ophthalmic equipment at the hospitals they visit, usually fixing 10-20 instruments during each three-week stay. In the countries ORBIS visits, a donation is made consisting of medical supplies valued between $50,000 - $100,000 in addition to pieces of medical equipment, when available. These materials have been previously donated to ORBIS for use in countries in need. Donations are usually given to the Ministry of Health for use in public hospitals serving patients who could otherwise not afford treatment.

In addition to planned activities, there are often unexpected opportunities for engineers to improve medical practice. For example, on a recent mission to Myanmar (formerly Burma), the Deputy Minister of Health asked ORBIS to prepare a report on improving biomedical engineering in his country. In Jamaica, a clinic for the poor asked ORBIS engineers to help design a new operating room for ophthalmic surgery. And in Sudan, ORBIS engineers were asked to meet with the Vice Chancellor of Sudan University to discuss the creation of a clinical engineering certificate program and to serve as long-term advisors.

Biomedical Engineering Education

ORBIS's primary mission is educational. Although the Technical Services Department supports the medical teaching program, it also offers technical education to the local clinicians and engineers. Informal exchange of skills occurs when engineers visit hospitals to repair their equipment and when local engineers visit the plane.

Lectures are also provided for audiences of 5-50 people on a wide variety of topics including management (for example, medical equipment, administration) and technical issues (for example, theory and applications of lasers and ultrasound). Material is presented in forms useful to engineers and technicians of different educational and skill levels, as well as physicians, nurses, administrators, and researchers. Supplemental handouts include copies of the slides presented, engineering articles, and booklets (for example, on the safe use of lasers). Lectures on videotape are also shown and given to local engineers for their future use.

Figure 8
The modular electrical and air-handling system is housed in standard LD-3 cargo containers that are stored in the aircraft belly during flight and set up on the ground during medical programs.

While the immediate goal of ORBIS technical education programs is to share specific knowledge, the long-term goal is to stimulate interest in further education. The Technical Services Department is therefore compiling and making available a database of biomedical/clinical engineering programs in developing countries all over the world.

Technical Training Workshops

Since ORBIS's first program in 1982, host country engineers and technicians expressed interest in training programs geared toward their needs. As the organization's reputation grew within the ophthalmic community, so did the number of requests both from countries in which ORBIS was working and from other countries throughout the developing world. For many years, ORBIS had been organizing surgical and nursing programs without the plane that were taught by distinguished visiting faculty. In 1992, off-plane technical training courses also become part of the ORBIS educational program.

Patterned after its medical and nursing counterparts, ORBIS technical training programs utilize professionals who volunteer their time to teach theory and supervise hands-on sessions in the repair and maintenance of a diverse array of ophthalmic instrumentation ranging from the simple Schiötz tonometer to the complex argon laser. These five-day courses are, depending upon available training equipment, usually limited to 30 participants so that each member of the small subgroups of five or six will have an adequate opportunity to "play" with the device under study. Written materials and ORBIS-produced training videotapes are given to participants with permission to copy and distribute them.

A typical five-day course includes: lectures on basic theory of light and optics; lectures on anatomy and diseases of the eye; introductions to ophthalmic instruments and their applications; and theoretical analysis of each ophthalmic device prior to its hands-on training component. In addition, a roundtable discussion focusing on management and logistics is conducted toward the latter part of the week. These sessions have proved to be both lively and useful as participants discuss common regional problems and seek viable solutions. Major contributions are made by the visiting faculty who often provide workable solutions based on their own professional experience.

To date, technical training programs have been held in Colombia, India (2), Nigeria, Romania, El Salvador, Costa Rica and Guatemala. Programs are currently being planned for India, Guatemala, Romania, China (2) and Ecuador.

Future Plans

The Technical Services Department plans to continue growing primarily in two directions. The first is to provide more technical workshops that further emphasize hands-on training and involvement of visiting experts from industry and academia. The second focus involves using technology to improve the medical education program as a whole. For example, a prototype has already been developed at ORBIS for an interactive video system for surgical training, which operates on a Macintosh® computer with video stored on CD-ROM. With this, a surgeon can "perform," for example, phacoemulsification surgery, and decide how each step should be carried out (for example, incision site and size, type of intraocular lens to use). The results of these decisions are displayed in the form of real-time video footage from surgeries performed on the plane. This allows a surgeon to simulate a surgery and thereby learn the techniques involved.

Telemedicine is another area for future expansion. ORBIS is developing an Internet-based forum for ophthalmologists around the world to discuss clinical topics. Designed primarily for developing countries, where access to current information is often limited, doctors could send questions and receive responses and advice from leaders in their field by e-mail. Moreover, the possibility of making live surgeries from the plane available to clinicians in other countries by broadcast over the Internet or using satellite communications could dramatically expand the number of eye doctors worldwide who may benefit from ORBIS's interactive medical education program.

ACKNOWLEDGEMENTS

We thank B. Childers, K. J. Gupta, R. W. Orvis, H. Peppe, and D. Samuel for helpful discussions.

BIOGRAPHIES

MARK R. PRAUSNITZ

Mark R. Prausnitz is an Assistant Professor of Chemical Engineering in the Bioengineering Center at the Georgia Institute of Technology. During 1994/95, he was on leave, serving as a Biomedical Engineer with ORBIS International. He received a B.S. in Chemical Engineering from Stanford University in 1988 and a Ph.D. in Chemical Engineering from the Massachusetts Institute of Technology in 1994.

ISMAEL CORDERO

Ismael Cordero is the Senior Biomedical Engineer on the ORBIS DC-10 airplane. Prior to ORBIS, he was a Biomedical Engineer at Albert Einstein Medical Center in Philadelphia. He is accredited by the International Certification Commission as a Certified Biomedical Equipment Technician. He received a B.S. in Biomedical Engineering Technology at Temple University in 1989.

ALAN LEVENSON

Alan Levenson is the Director of Technical Services at ORBIS International. He previously served as Director of Biomedical Engineering at Bellevue Hospital Center in New York City and as Supervisor of Clinical Engineering at Morristown Memorial Hospital in Morristown, NJ. He is also a member of the American College of Clinical Engineering. He received a B.S. in Healthcare Administration at Montclair State University in 1980.

Address all correspondence and reprint requests to Alan Levenson, ORBIS International, 330 West 42nd Street, Suite 1900, New York, NY 10036.