Operational & Functional Problems Faced by Space Stations and the Biological Effects of Zero Gravity Conditions

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Abstract

In 1903, When the Wright brother flew the first airplane, they demonstrated that human intelligence and hard work could make any dream a reality. But little did they know that future experimenters would set sight on something far more ambitious than flight in the atmosphere. And that one day it would be possible to travel to other worlds and design human living quarters or operational stations in space. The Russians were the first to launch such a space station named '*Salyut-1*' and put it in orbit in 19th April 1971, but ironically the first space station crew under *Nikolai Rukavishnikov* was unable to get in as something was wrong with the hatch. Since then a number of attempts have been made, some succeeded while many failed but the enthusiasm of the scientific community has not dimmed. The failures are a majority because of the numerous operational and functional problems faced in designing, lauching and living inside a space station and also primarily due to the unpredictability of various systems working satifatorily in weightless conditions. But these challenges, be they structural, biological or technological have helped in bringing about a ameliorated process of evolution resulting in every successive design being better than the previous one. This paper aims at externalising some of these problems faced, chiefly due to effects of weightlessness and highlighting their existing as well as the hypothesized solutions.

Introduction

Jules Verne in his science fiction novel *From the Earth to the Moon*(1885) described humans living in 'floating habitats for living organisms' orbiting around the earth and the perils these humans had to go through to even carry out the normal processes that people living on Earth have taken for granted. To a layman a Space Station may be a similar orbiting structure which can house a certain number of humans for requisite period of time. This structure can be used as a observatory with telescopes to view different celestrial bodies which are otherwise impossible or difficult to view from the Earth or as a laboratory to carry out experiments in weightless conditions. But every process, from conceptualizing a design to implementing it would encounter numerous problems. To understand these problems the evolutionary history of Space Stations and a knowledge of their working is essential.

History of Space Stations

1. The Soviet Union launched the world's first space station, Salyut 1, on April 19, 1971. Since then, we have learned a lot about living in space. Many of the procedures and systems on the current space station reflect this history. The first space station crew, Nikolai Rukavishnikov, Vladimir Shatalov, and Alexei Yelisyev, arrived at the Salyut 1 three days after its launch. But they couldn't get in. Something was wrong with the hatch. Running low on supplies, they had to leave after 6 hours.

   The second crew, Georgi Dobrovolsky, Vladislav Volkov, and Viktor Patsayev, got in okay and stayed for 24 days. They were the first people to spend that long in space. But on June 30, 1971, tragedy struck.

The ground team sent to greet the returning heroes opened the hatch of their spaceship to a terrible sight. The three men were dead. A valve had opened by mistake in space and let all the air out of the ship. With no space suits to provide air, the cosmonauts died before reaching the ground.

2. The world's second space station, Salyut 2, launched in April of 1973. It had been in space less than two weeks when the engine exploded. The space station tumbled out of control and crashed to Earth in May. Luckily, there were no cosmonauts onboard.

3. The next space station was a secret one called Cosmos 557. Its main job was to provide spy photos of the ground as it flew overhead. But before a crew got there, it too went out of control. It burned up in May of 1973. The Soviets then designed more reliable engines.

4. The United States launched its first space station. This was Skylab, an orbital workshop for three people. To save money, the Americans used leftover Apollo boosters, called Saturn V's, for their space station. The Saturn V's were gigantic, so Skylab ended up three and a half times bigger than a Salyut. Skylab's first crew, Charles Conrad, Joseph Kerwin, and Paul Weitz, showed the value of having human problem-solvers in orbit. The next crew (July - August 1973) set a record of 58 days in space -- the first time the United States had a crew in space longer than the Soviets. One of the astronauts was Alan Bean, the first person to both walk on the Moon and live on a space station. The other crew members were Owen Garriott and Jack Lousma. The third crew of Skylab (Carr, Gibson, Pogue) were in orbit and away from their families for 84 days. Also, astronauts returning from these long missions were too weak to stand, let alone escape if there had been a landing emergency. As a result, exercise equipment became a requirement of all long space missions.The United States abandoned Skylab in February 1974.

5. The Soviets launched Salyut 3 in June of 1974, Salyut 4 in December 1974, and Salyut 5 in June of 1976. Because of the new rule to wear space suits, crews were limited to two men each until a new design in 1979. A limiting factor on time in orbit was how much supplies the crew could bring with them. The Soviets solved this problem by designing Salyut 6 with two docking ports. One was always occupied by their return/escape ship. The other was used for visiting ships. Supplies were unloaded from unmanned cargo ships. Then the rocket was used to 'take out the trash,' solving another problem of long missions. Sometimes the extra port was used for manned ships.

6. Salyut 7, launched in 1982, had lots of problems. The radios broke, the power failed, and the water pipes leaked. The Soviets added new solar panels and chemical batteries and fixed the water pipes. However, there was one problem they could not solve. The sun was in a cycle of increased activity. This caused the Earth's atmosphere to get hotter and expand. Like steam lifting the lid off of a pan on the stove, the expanding atmosphere ran into Salyut 7. The Soviets boosted it to a higher orbit. But like an old car, it used a lot of fuel. After operating far longer than any previous station, it was abandoned in 1986. It fell to Earth over Argentina in 1991.

7. The next space station was called Mir which means 'peace' in Russian. This space station was launched in February 1986. Unlike the Salyuts, it was designed for expansion. New modules were docked and moved to ports using a robot arm. Two modules were added to the Mir core before 1990, and four more by 1996. Improved engines were able to keep this biggest-ever station from being dragged down like the Salyuts. This capability plus continued use of supply ships allowed Mir cosmonauts to become the first humans ever to spend more than a year in orbit.

8. After the break up of the Soviet Union in 1991, Russia decided not to replace the aging Mir. Instead they joined the United States, Canada, Japan, and ten European countries as partners in the International Space Station program. Mir became a place to test new station procedures and equipment.

The International Space Station (ISS)

In 1984, President Ronald Reagan proposed that the United States, in cooperation with other countries, build a permanently inhabited space station. Reagan envisioned a station that would have government and industry support. The U.S. forged a cooperative effort with 14 other countries (Canada, Japan, Brazil, and the European Space Agency -- United Kingdom, France, Germany, Belgium, Italy, The Netherlands, Denmark, Norway, Spain, Switzerland, Sweden). During the planning of the ISS and after the fall of the Soviet Union, the United States invited Russia to cooperate in the ISS in 1993; this brought the number of participating countries to 16. NASA is taking the lead in coordinating the ISS's construction.

ISS Facts
Length: 290 ft (88m)
Width: 356 ft (109 m)
Height: 143 ft (44 m)
Volume: 46,000 ft3 (1300 m3); living space will be about the cabin size of two 747 jets
Mass: 1,000,000 lb (454 metric tons)
Orbit: 217 to 285 miles (362 to 476 km), inclined 51.6 degrees relative to the equator

The assembly of the ISS in orbit began in 1998. The ISS has more than 100 components and will require 44 space flights by at least three space vehicles (space shuttle, Soyuz and Russian Proton rocket) to deliver the components into orbit. One-hundred sixty space walks, totaling 1,920 man-hours, will be required to assemble and maintain the ISS, which is scheduled for completion in 2006 and will have an anticipated life of 10 years at a projected total cost of $35 to $37 billion. When completed, the ISS will be able to house up to seven astronauts. It will have the following major components:

Control Module (Zarya) or Functional Cargo Block - contains propulsion (two rocket engines), command and control systems
Nodes - connect major portions of the ISS
Service Module (Zvezda) - contains living quarters and life support for early parts of the ISS, docking ports for Progress re-supply ships and rocket engines for attitude control and re-boost.
Scientific Laboratories - contain scientific equipment and a robotic arm to move payload on an outside platform.
Laboratory Module - shirt-sleeve environment facility for research on micro-gravity, life sciences, Earth sciences and space sciences
Truss - long, tower-like spine for attaching modules, payloads and systems equipment
Mobile Servicing System - robotic system that will move along the truss; equipped with remote arm for assembly and maintenance activities
Transfer Vehicles - a Soyuz capsule and a Crew Return Vehicle (X-38) for emergency evacuation
Electrical Power System - solar panels and equipment for generating, storing, managing, and distributing electrical power

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Working Of Space Stations

Primary Conditions

To sustain a permanent environment in outer space where people can live and work, the Space Station must be able to provide the following things:

- Life support
- Atmosphere control, supply and recycling
- Temperature control
- Food supply & Waste removal
- Fire protection
- Propulsion (move the station in orbit)
- Communications, Tracking (talk with ground-based flight controllers) and Navigation
- Generation of Electrical power
- Computers (To coordinate and handle information)

General Problems in Operation

We take for granted all of the things that the Earth and our society provides to keep us alive. We have a constant supply of fresh air. The carbon dioxide that we exhale gets recycled by plants. We have a large supply of fresh water from rivers, lakes and streams that we use for drinking, showers, cooking and laundry. We are warmed by heaters or the sun, and cooled by air conditioning. We have fire protection from local fire stations. All of these things must be designed into the Space Station.

Astronauts on board the Space Station need to have the following:

1. Atmosphere similar to Earth's

Our atmosphere is a mixture of gases -- 78 percent nitrogen, 21 percent oxygen, 1 percent other gases -- at a pressure of 14 lbs/in2 (1 atm). The Space Station astronauts will need a similar atmosphere. To achieve this, oxygen and nitrogen will have to be supplied. The Russian Elektron generator will make oxygen by splitting water into hydrogen and oxygen (electrolysis). Solid fuel oxygen generators or oxygen candles will be burned to make additional oxygen, if required. The space shuttle or Progress supply ships will bring nitrogen from Earth, and store it in external tanks on the station.

In later phases of construction, external tanks will supply oxygen; these tanks can be refilled by the space shuttle. In the final stage, an additional electrolysis oxygen generator will be added to the station. The pressure control assembly (a system of pumps and valves) will mix the nitrogen and oxygen in the right percentages, monitor the atmospheric pressure, and de-pressurize the station when necessary to prevent overpressure or to extinguish a fire during an emergency.

2. Carbon dioxide that they exhale removed alongwith contaminating or trace gases removed.

A carbon dioxide removal assembly (a series of beds of special material) will absorb carbon dioxide and release it into outer space. In addition, back-up chemical carbon dioxide canisters can remove carbon dioxide by reacting it with lithium hydroxide. The trace contaminant control system will filter cabin air to remove trace odors and volatile chemicals from leaks, spills and outgassing. As a back-up, the harmful impurities filter will also be used.

3. Normal humid environment

The major constituent analyzer will constantly monitor the amount and type of gases in the cabin air, and control the atmosphere supply and recycling systems.

4. Water Recycling

Besides air, water is the most important element aboard the Space Station. Initially, the space shuttle and Progress supply vehicles will bring water from Earth. On the Space Station, water will be highly conserved. There will be no long, luxurious showers. In fact, most astronauts get by with sponge baths. The water recovery and management subsystem will collect, recycle and distribute water from various sources including:

- Sink
- Shower
- Urine (from the astronauts and from laboratory animals onboard)
- Heating and cooling systems

The water recovery and management subsystem consists of various condensers, filters and water purifiers. The water will be used for drinking and cooling electrical systems. This system is not 100 percent efficient, and water will be lost through the Elektron oxygen generator, airlocks and carbon dioxide removal systems. Water will be periodically replenished from Earth. However, this system will greatly reduce the amount of water needed from Earth.

5. Temperature Control

Outer space is an extremely cold environment, and temperatures will vary drastically in different parts of the Space Station. You might think that heating the Space Station would be a problem. However, the electronic equipment generates more than enough heat for the station. The problem is getting rid of the excess heat. So the temperature control system has to carry out two major functions, distributing heat where it is needed on the station and getting rid of the excess. To do this, the Space Station has two methods to handle temperature control:

- Passive methods - generally simple; handle small heat loads and require little maintenance
- Insulating materials, surface coatings, paints - reduce heat loss through the walls of the various modules, just like your home insulation
- Electrical heaters - use electrically heated wires like a toaster to heat various areas
- Heat pipes - use liquid ammonia in a pipe to transfer heat from a warm area to a cold area over short distances. The ammonia evaporates at the warm end of the pipe, travels to the cold end and condenses, giving up heat; then the liquid travels back to the warm end along the walls of the pipe (capillary action).
- Active methods - more complex; use fluid to handle large heat loads; require maintenance
- Cold plates - metal plates that collect heat by direct contact with equipment or conduction
- Heat exchangers - collect heat from equipment using fluid. The equipment radiates heat to a fluid (ammonia), which in turn passes heat on to water. Both fluids are pumped and recirculated to remove heat.
- Pumps, lines, valves - transport the collected heat from one area to another
- Heat rejection units - large, winged structures, similar to solar panels, that radiate the collected heat to outer space.

6. Food Supply

The space shuttle and Progress supply ships will bring food to the Space Station. Food comes in several forms (dehydrated, low moisture, heat-stabilized, irradiated, natural, fresh). The Space Station has a galley (kitchen) equipped with the following:

- Food storage compartments

- Food warmers
- Food preparation area

7. **Waste Removal**

Like any home, the Space Station must be kept clean. This is especially important in space, where floating dirt and debris could present a hazard. Wastes are made from cleaning, eating, work and personal hygiene. For general housecleaning, astronauts will use various wipes (wet, dry, fabric, detergent, disinfectant), detergents and wet/dry vacuum cleaners to clean surfaces, filters and themselves. Trash will be collected in bags, stowed in a Progress supply ship and returned to Earth for disposal. Solid waste from the toilet is compacted, dried and stored in bags, where it is returned to Earth for disposal (burning). Water reclaimed from solid waste is processed and purified for drinking purposes.

8. **Fire Protection**

Fire is one of the most dangerous hazards in space. During astronaut Jerry Linenger's stay on Mir, a fire broke out. The Mir crew extinguished the fire, but not before the station was damaged. The Space Station has a fire detection and suppression subsystem that consists of the following:

- Area smoke detectors in each module
- Smoke detectors in each rack of electrical equipment
- Alarms and warning lights in each module
- Nontoxic portable fire extinguishers - foam or liquid extinguishers that are either

9. **Navigation**

The Space Station must be able to know precisely where it is in space, where other objects are and how to go from one point in space to another, especially during reboosting. To know where it is and how fast it is moving, the Space Station uses both U.S. and Russian global positioning systems (GPS). To know which way it is pointing, its attitude, the Space Station has several gyroscopes. The combination of all this information will help the Space Station move from one point to another in space. In addition, the Russian navigation system uses sighting on the stars, sun and Earth's horizon for navigation.

10. **Escape**

If a crew member has a serious injury or illness, he or she will need to get back to Earth as soon as possible. The whole crew of the space station might have to evacuate in the case of a serious fire, or some other life-threatening damage to the station. So there has to be a way to escape the station quickly. A Soyuz capsule will always be docked at the Space Station, capable of carrying two people in a medical emergency, or three people in other emergencies. A crew will take a fresh Soyuz capsule to the station every six months. NASA is designing and building a crew-return vehicle (CRV), called the X-38, for emergency use. The X-38 will be capable of transporting 7 people to the surface.

Biological Problems faced by the Human Body Due to Weightless Conditions

From bones to balance to tiny cells, scarcely any system in the body remains unaffected by weightlessness. Yet astronauts adjust quickly and come to enjoy the freedom of zero gravity, save for the threat of solar and galactic radiations that can devastate human tissues and genes. When astronauts return to Earth, their space adapted systems must learn to cope again with gravity.

Different Problems encountered:

1. **Disorientation**

   Spacefarers usually become disorientsd. Without gravity there is no 'up' or 'downs'. The inner ear sends confusing data to the brain, while eyes play tricks with visual illutions. For many astronauts the sensory mix-up brings temporary nausea.

   Deprived of gravity information, a confised brain engenders visual illutions. Body fluids surge to the chest and head. Neck veins bulge. The head enlarges a bit,as do other organs. Sensing too much fluid the body begins to excrete it, including calcium,electrolytes and blood plasma.The production of red blood cells decreases, rendering the astronauts slightly anemic. With the loss of fluids legs shrink. Spinal discs expand and so do the astronaut.

2. **Cardiovascular Problems**

   Cardiovascular adaptation to space flight investigations have documented an initial increase in astronaut cardiac function followed by a progressive reduction in both left ventricular volume index and stroke volume index with a compensatory increase in heart rate to maintain cardiac output. The reduced cardiac size and stroke volume have been presumed to result from a reduction in circulating fluid volume within a few days after orbital insertion, but no specific mechanism for the reduced stroke volume has been identified. Factors which influence the filling of the heart during diastole include: (1) the atrial pressure, (2) the inertia of the blood as it enters the ventricle, (3) the transmural pressure difference, (4) the myocardial compliance including myofibril passive, elastic recoil, and (5) the gravitational acceleration-dependent hydrostatic pressure that exists in the ventricle due to its size and anatomic orientation.

3. **Bone Loss**

   Healthy astronauts have strong bones until they go into space, where weightlessness triggers bone loss. Density in weight- bearing bones declines at the rate of 1 to 2 % a month. During stay in a Space Station a astronaut could reach the weakened state of severe osteoporosis.

4. **Radiation Damage**

   Radiation exposure for Space Station astronauts is far greater than on Earth's surface or in orbit because a Space Station will no longer be shielded from Earth's magnetic field and atmosphere. This could translate to a cancer risk. Supernova forge heavy ions – atoms heavier than Helium and shorn of electrons – that bombard cells in a branching pattern, causing breaks in the DNA sequence, These can cause gene mutations.

5. **Developments of Infections**

   In a Space Station even development of minor infections can snowball into large crisis situations. Even cases of poisoning may take place due to the varied diet patterns.

Treatments and Research Developments

- To face the challenges of disorientation due to weightlessness, virtual rooms can be used, i.e a room which mimics weighless conditions where a few symbols would be placed to serve as orienting clues as the person moves(ref. 5). Researchers hope to adapt this technique to help astronauts maneuver in large spacecrafts.

- Underwater Labs and low pressure chambers can also serve as preparatory areas.

- Radiation damage leading to cancer can be detected and removed by the use of an optical imaging system wherein an astronaut not necessary a doctor will use optical imaging to locate the cancer or clot and destroy it with a laser beam.

- Development of body parts in-vitro artificially can help to a large extent eg. To deal with the ear, an astronaut may consult a three dimentioned computer model of the injured person's body. The computer then teaches him how to build a polymer model of the ear and then grow new cartilage using the injured astronaut's DNA. Then the computer would guide him in seating the new ear part and a ultrasound pulse would heat and seal the wound. This same technique can be used to treat a ruptured artery.

- Even now the most effective method to treat bone loss is an advise to the astronauts to do regular excise in the Space Station. Quoting Inessa Kozlovska a physiologist working with cosmonauts, "A regular detailed exercise can help in reducing bone loss." She highlights the exanple of astronaut Shanon Lucid who being 53 still remained in good shape due to regular exercise in Space.

- To cope with infections scientists envisage the need of new drugs, miniature optical and ultrasound devices that will pinpoint the exact location of concern. Also a complete record of each astronaut's DNA sequence needs to be kept for development of artificial body parts.

Conclusion

"We have certainly learned a lot since the days of Salyut 1. Some of the lessons have been costly and painful. But we continue to explore because history has taught us we can only achieve if we keep trying." - Valery Polyakov(1995)

The development of Space Stations would result in a new beginning of space explorations when man would be able to colonise space as well. It would truly mark the arrival of the Space age when space would cease to become the final frontier and we will be able to unravel the mysteries it holds and answer the numerous questions which still haunt us.

References

1. *National Geographic Magazine – January 2001 issue*
2. *Jules Verne – From The Earth to the Moon*
3. *Sir Arthur C. Clarke – Beyond Gravity*
4. *Michael E. Long – Surviving In*
5. *Cary Wolinsky & Brian Strauss, NSG Staff – Computer Enhancements*
6. *How Space Stations Work by Craig Freudenrich, Ph.D.*
7. *Hearts in Space - University of Utah's Dr. George Pantalos'*
8. *Space Stations - Marcia S. Smith of Science Policy Research Division*