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# Paper Session III-A - Closed Loop Systems

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DIVIDENDS ON EARTH FROM SPACE

# CLOSED LOOP SYSTEMS

by Charles D. Quincy and Susan A. McBrearty

## Summary

National Aeronautics and Space Administration (NASA) is unique in its search for man made, closed loop life support systems and in its total engineering methods. Short term space travel has given NASA tremendous knowledge in closed loop systems and the vision of extended space travel will require the expansion of this knowledge base.

Earth and its surrounding atmosphere has been operating as a closed loop life support system for billions of years. It has gone through many changes to best suit an equilibrium state. In recent years, man has developed to a level where we can effect that state. With this in mind, the task of protecting our life support system on earth and designing the systems for long duration space travel have great communality.

"Mission to Planet Earth" should not be just an observation system but should include an interactive participation with all environmental activities. Spacecraft limitations, on space, energy and other life support systems have required maximum use of available resources. This learned experience, along with our spacecraft design and operation philosophies, opens great potential for expanding our support base.

The American public wants a strong space program and a clean environment. They are being asked to continue funding our space program, so we must continue to prove that our budget payback is greater then zero. One area where tremendous potential exists is support for environmental improvement projects. Working environmental improvement projects alongside spacecraft design projects will provide a double dividend.

The goal of any business is to satisfy the customer. Profits are the measure of our success. NASA needs to tap into the economic benefit of what it is producing in the field of closed loop life support systems.

## Introduction

Like Earth, long-duration spacecraft must have closed-loop support systems. When operating perfectly, both require an energy input and both give up heat to their surrounding environment. To support its propulsion requirements, a spacecraft accelerates mass away from itself. This is the major difference between a long-duration spacecraft and the Earth system.

Indoor environmental conditions are the same for a spacecraft and a typical office with the possible exception of gravity. The outside conditions, even on Earth, must increasingly be kept outside because the environment is becoming more and more hostile. In our large cities, just opening the doors, or bringing in makeup air floods the building with unhealthy contamination. Completely closing our building to the outside environment creates new problems and makes it more like a spacecraft. The working volume for the normal office area roughly equates to the volumes being identified for Space Station and subsequent programs. NASA is finding the answers to one of the questions being asked by the Environmental Protection Agency (EPA): How do we maintain a healthy environment for the people?

Solutions to space travel problems can be used to correct Earth based conditions. Our customer, the American public, loves our space program, but our funding base is eroding in favor of more immediate problems, like the environment. Now that the Cold War has ended, we need to evaluate what our customer requirements are. People are interested in cleaning up the aftermath of 40 years of high technology weapons development and years of losing materials to the environment. Research in this area will pay high dividends when funding is requested and will allow continued focus on our deep space adventure. Many projects are currently underway across the agency to move us away from regulated materials. This should be expanded to a wholesale maximization of all our Earth-based activities. Once this expansion has occurred, techniques and support data need to be supplied to organizations that have the widest distribution. The time is now for getting the message out that we are solving the problems of spaceship Earth.

An example of Earth based commercial activity that must be addressed is that one third of all solid waste is packaging material. This would not be an acceptable condition on an orbiting spacecraft and it cannot continue on Earth.

## Laws of Science

The laws of science govern the most ardent environmental activity, just as it does spacecraft design. $E=mc^2$ expresses an equivalence between mass and energy. The First Law of Thermodynamics states that energy can be converted from one form to another. The Second Law of Thermodynamics states entropy is always increasing (energy no longer available for work). The Third Law of Thermodynamics states that the change in total energy is equal to the change in useful energy plus the change in entropy.

On the basis of these laws, waste materials do not exist. They are just materials we do not know how to use. Energy, with the exception of entropy considerations, is available for use. Our job is to figure out how to use these materials and continue to use energy until entropy takes over. Spacecraft designers have been very successful at optimizing both material and energy usage.

## Health Science

In any closed-loop system, such as the Space Station, chemicals released to the atmosphere will circulate freely until trapped. Their removal is very difficult under any conditions but is particularly difficult under conditions of weightlessness. Release sources include: (1) leaks or spills from storage tanks; (2) volatile metabolic waste products of the crew; (3) volatile components of spilled food; (4) leaks from environmental or flight control systems; (5) thermal reaction products produced by small electrical fires or contaminated removal systems, and (6) outgassing of cabin construction materials. These chemicals can have a variety of effects on the people exposed to them. The health effects are not specific to spacecraft environments and studies to support space travel are useful in Earth bound environments. Some factors that are of concern in space as well as on Earth include bioaccumulation, air quality, and stress.

Bioaccumulation is something that any closed loop system will have to take into account, understand, and potentially eliminate. Chemicals that are immiscible in water accumulate in the lipids of plants and animals, particularly if the chemical is persistent and stable. Some examples of lipophilic compounds are halogenated hydrocarbons, DDT, and PCB's. In many cases, these compounds do not adversely affect the organism that ingested them unless that organism goes through a starvation phase when fats are mobilized for energy production. However, they do accumulate in the food chain. They can reach a point of saturation in the food chain such that higher organisms are very adversely effected. Heavy metals also bioaccumulate. Some compounds are stored in specific body tissues and are not harmful until the storage capacity is reached. Once the storage capacity is reached, the toxin will stay in circulation in the body and cause illness or death.

Air quality interests everyone. The make-up of the air we breath is directly effected by the environment. Most of the carbon monoxide (CO) in the environment originates from natural sources, such as the decomposition of organic matter. CO is highly toxic because hemoglobin has a higher affinity for it than for oxygen. Carbon dioxide ($CO_2$) is a product of human respiration. The effects of increased $CO_2$ in the human body are increases in heart rate, and respiration rate. Chronic exposure to $CO_2$ upsets the acid-base balance of the body. Respiratory acidosis (blood pH $<7.4$) causes depression of the central nervous system and can lead to coma and death should the blood pH fall below 7.0. Respiratory alkalosis (blood pH $>7.4$) causes overexcitement of the nervous system and leads to muscle tetany, extreme nervousness, and convulsions. Death often results from respiratory arrest.

One natural source of sulfur dioxide ($SO_2$) is decaying organic matter. The physiological effects of $SO_2$ are manifested by a thickening of the mucous layer in the trachea and a slowing of the action of the mucociliary escalator. The mucociliary escalator is located in the trachea and contains special glands that produce a thick mucus secretion. The many cilia that line the trachea continuously propel the mucus, loaded with dust particles and other debris, to the throat, where it can be swallowed or expelled. It is also an irritant of the upper respiratory system and causes bronchial constriction and increases air-flow resistance. Nitrogen oxide (NO) is formed by microbial digestion of organic matter. Microbial digestion first produces nitrous oxide that is then oxidized to $NO_2$. Symptoms of exposure to Nitrogen dioxide are a cough, mucoid or frothy sputum production, chest pain, eye irritation, and tachycardia.

Hydrocarbons originate from vegetation, microbial decomposition, paints and lubricants. Some hydrocarbons are carcinogenic.

The Controlled Environment and Life Support System (CELSS) research is developing an understanding of how gases move through the environment. This research will have direct application on Earth bound systems.

A restricted living environment often leads to dramatic changes in attitude and temperament, marked changes in motivation, extensive emotional reactions, and deterioration in ability to remember, think and reason. People need both physical privacy and mental privacy. Techniques must be learned for keeping the innermost thoughts and feelings private. Constant noise is also a source of stress. Monotonous and unvarying environments, long work hours, and stress can lead to boredom, fatigue, and irritability and will have a negative impact on life. These conditions are critical for long-duration space travel, but effect all living environments.

## Money

For many years the US space program was strongly supported by the Department of Defense (DOD) but, with the downsizing of their activities we can expect a cutback in that support. We must look for other organizations that can use our expertise. The American public is being asked to continue funding our programs so we must prove to them that our budget pay-back is greater then zero. One area where tremendous possibility exists is the support of environmental improvement projects. For years we have been optimizing our usage of on-orbit materials to maximize our on-orbit potential. It is now time to bring those many lessons back to Earth.

The American taxpayer must view space industry as a business that makes money. Our national budget problems are largely due to the fact that not enough money is spent on businesses that generate taxes. As a business we must continue to look for new areas to market our product and increase our profit making potential. Product and process refinements must be quickly made available in order to remain competitive in our changing world. The space environment and the Earth environment both have the potential for generating tremendous income sources.

## Executive Mandates

Cooperative efforts between government agencies have long been a part of the way NASA does business. NASA has been partners with DOD, Department of Energy (DOE), National Oceanographic and Atmospheric Administration (NOAA), Federal Communications Commission (FCC) and many others. With our capabilities, a strong connection to the EPA is logical. The avenues and the needs exist to bring our spacecraft successes down to Earth. Both political sides are on record and calling for aggressive pollution prevention technology infusion in the way America does business. President Clinton has signed two Executive Orders that mandate pollution prevention throughout the federal government. Carol Browner, head of the EPA, has said that "Pollution Prevention will be the central ethic in everything we do at EPA." Former President Bush was on record with "Environmental programs that focus on end of the pipe or top of the stack, and cleaning up after the damage is done are no longer adequate. We need new policies, technologies and processes that prevent or minimize pollution -- that stop it from being created in the first place." Mission to Planet Earth has largely been considered an observation program, it should be expanded to use NASA developed solutions to correct the situations we observe.

Pollution Prevention has been a part of our spacecraft design since the beginning of the space program. Many items initially developed for space flight can be seen everyday on Earth. As we move toward longer and longer space flights, our control of the environment will become ever tighter. EPA will certainly be interested in what we are doing and we may find solutions to our problems from what they are doing.

Most of the statutes mandate that "Best Management Practices" be the minimum acceptable level of compliance. Many are using "Maximum Achievable Control Technology" to define the level of compliance. We at NASA, can help define that technology level.

## Design for the Environment

The "Design for the Environment" idea is a response to a fundamental change in the scale of human activity and how these activities relate to Earth's supporting biological, physical and chemical systems. This change has made it necessary for us to perform complete life-cycle assessments of our activities and understand our total impact. We can begin by incorporating our spacecraft design philosophies into how we design our Earth based facilities and equipment. "Beginning with the end in mind" and with a final objective of zero waste production, the design process needs to cover the entire life of the product. Earth based projects have for years used a "Command and Control of the environment" philosophy. This must change to a "Design Out All Waste" frame of mind. Spacecraft designers have been doing this for years to control spacecraft size and function. Earth based systems need the same comprehensive design process.

"Total Engineering" or "Design for the Environment" is a new initiative in ground based systems. Systems that do not produce waste during fabrication, use or disposal are the goals. This will require the development of new design methods, considerations, and analyses. Some of these techniques are already well developed for spacecraft design. The use of energy efficient lighting and computers, smart systems and power management will become common place in all activities. Optimizing the impact of cooling and heating loads on other activities, will be a major consideration. Attention to the total life cycle cost during the design phase will reduce the cost of a system and better support the program.

Environmentally conscious engineering requires a more comprehensive investigation initially but the life time savings will result in a competitive advantage and sustainable performance. Recycling needs to become a closed loop method of business. Companies should use only recycled materials as raw materials and send all of their unusable materials to a recycler for reprocessing. Processes will need continuous modification until their only waste is entropy heat loss. If an input material will not support this zero waste goal, then a substitute must be found that will. Waste generated by defects must be eliminated; why build it if you can not use it? Suppliers need to understand what their products produce in waste and support elimination activities.

As process management practices are developed, wide distribution to potential users is needed. This will drive down the processing costs for all users and in an environment of continual improvement, the innovator will always be ahead in process optimization. Many of these new design philosophies have been used successfully on spacecraft design and provide a very useful road map.

## New Technology

NASA has a history of spinning off products it has developed for commercialization and in many cases they have had a direct impact on the environment. A system to transfer halon and freon from one piece of equipment to another without any loss was developed at Kennedy Space Center. This will permit usage of these environmentally harmful materials long after they have been removed from the market. A hazardous material in a closed loop does not cause environmental damage.

Aqueous cleaning techniques now being developed will eliminate the need for freon in precision tube cleaning. When you cannot control the waste product, the system or material must be changed.

By systematically addressing each waste, we will be moving closer and closer to our goal. At each stage of development we must make the extra effort to make sure that our development is placed into maximum utilization. Expanding spacecraft closed-loop systems to Earth-bound activities will require intensive technology transfer activities and working with EPA can ensure our success.

## Closing

The goal of any business is to satisfy the customer. Profits are the measure of our success. NASA needs to tap into the economic benefit of what it is producing in the field of closed loop life support systems.

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