

The following ISQ questions are used to measure Proposing:

9. When others are uncertain what to do, he will come up with a good idea.
19. She puts forward lots of good ideas and proposals.
29. He puts forth ideas that are both incisive and highly relevant to the problem at hand.
39. Her proposals and suggestions have a strong impact on others.
49. He will make a proposal or suggestion that he feels has merit, no matter how unpopular it may be.
59. She asserts herself in putting forth her ideas and suggestions; she doesn't hold back.
69. He expresses his ideas clearly and logically.

REASONING FOR AND AGAINST (RFA)

The other aspect of Assertive Persuasion is **Reasoning For and Against**, where people enjoy the cut and thrust of verbal battles. They emphasize logical argument rather than emotional appeal. They ingeniously marshal evidence in their own behalf and against their "opponent's." They listen to others only to find weaknesses in their arguments. Even when they are defending an inferior position, they battle away with determination and elan. Examples of Reasoning For and Against:

- "You've left the following data out of your calculations:"
- "That won't work, because the other side will misinterpret our message."
- "This proposal gives a clear cost advantage over the other one."
- "Whether or not those facts are true, my opinion still is that we should proceed with the original plan, because we've invested so much in it already."

The following ISQ questions are used to measure Reasoning For and Against:

10. He puts together a good logical argument.
20. When opposed, she is quick to come forward with a counter-argument.
30. He defends his own ideas energetically.
40. She anticipates objections to her point of view and is ready with a good counter-argument.
50. He is ingenious in producing evidence in support of proposals he favors.
60. She draws attention to inconsistencies in others' ideas or logic.

SPECIAL ARTICLE

ANATOMY OF AN ILLNESS (AS PERCEIVED BY THE PATIENT)

NORMAN COUSINS

EVER since the publication of Adam Smith's much-talked-about *Powers of the Mind* some months ago, people have written to ask whether his account of my recovery from a supposedly incurable illness¹ was accurately reported. In particular, readers have been eager to verify Mr. Smith's statement that I "laughed" my way out of a crippling disease that doctors believed to be irreversible.

I have not written until now about my illness, which occurred in 1964, largely because I was fearful of creating false hopes in other persons similarly afflicted. Moreover, I knew that a single case has small standing in the annals of medical research. I had thought that my own episode might have anecdotal value — nothing more. However, since my case has surfaced in the public press, I feel justified in providing a fuller picture than was contained in Mr. Smith's account.

In August, 1964, I flew home from a trip abroad with a slight fever. The malaise, which took the form of a general feeling of achiness, rapidly deepened. Within a week it became difficult to move my neck, arms, hands, fingers and legs. I was hospitalized when my sedimentation rate hit 80 mm per hour. The sedimentation rate continued to rise until it reached 115.

There were other tests, some of which seemed to me to be more an assertion of the clinical capability of the hospital than of concern for the well-being of the patient. I was astounded when four technicians from four different departments took four separate and substantial blood samples on the same day. That the hospital didn't take the trouble to co-ordinate the tests, using one blood specimen, seemed to me inexplicable and irresponsible. When the technicians came the second day to fill their containers with blood for processing in separate laboratories, I turned them away and had a sign posted on my door saying that I would give just one specimen every three days and that I expected the different departments to draw from it for their individual needs.

I had a fast-growing conviction that a hospital was no place for a person who was seriously ill. The surprising lack of respect for basic sanitation, the rapidity with which staphylococci and other pathogenic organisms can run through an entire hospital, the extensive and sometimes promiscuous use of x-ray equipment, the seemingly indiscriminate administration of tranquilizers and powerful painkillers, more for the convenience of hospital staff in managing patients than for therapeutic needs, and the regularity with which hospital routine takes precedence over the

rest requirements of the patient (slumber, when it comes for an ill person, is an uncommon blessing and is not to be wantonly interrupted) — all these and other practices seemed to me to be critical shortcomings of the modern hospital.

Perhaps the hospital's most serious failure was in the area of nutrition. It was not just that the meals were poorly balanced; what seemed inexcusable to me was the profusion of processed foods, some of which contained preservatives or harmful dyes. White bread, with its chemical softeners and bleached flour, was offered with every meal. Vegetables were often overcooked and thus deprived of much of their nutritional value. No wonder the 1969 White House Conference on Food, Nutrition, and Health² made the melancholy observation that the great failure of medical schools is that they pay so little attention to the science of nutrition.

My doctor did not quarrel with my reservations about hospital procedures. I was fortunate to have as a physician a man who was able to put himself in the position of the patient. Dr. William Hitzig supported me in the measures I took to fend off the random sanguinary assaults of the hospital laboratory attendants.

We had been close friends for more than 20 years, and he knew of my own deep interest in medical matters. We had often discussed articles in the medical press, including the *New England Journal of Medicine* and *Lancet*. He felt comfortable about being candid with me about my case. He reviewed the reports of the various specialists he had called in as consultants. He said there was no agreement on a precise diagnosis. There was, however, a general consensus that I was suffering from a serious collagen illness. I had considerable difficulty in moving my limbs and even in turning over in bed. Nodules appeared on my body, gravel-like substances under the skin, indicating the systemic nature of the disease. At the low point of my illness, my jaws were almost locked.

Dr. Hitzig called in experts from Dr. Howard Rusk's rehabilitation clinic in New York. They confirmed the general opinion, adding the more particularized diagnosis of ankylosing spondylitis.

I asked Dr. Hitzig about my chances for full recovery. He leveled with me, admitting that one of the specialists had told him I had one chance in 500. The specialist had also stated that he had not personally witnessed a recovery from this comprehensive condition.

All this gave me a great deal to think about. Up to that time, I had been more or less disposed to let the doctors worry about my condition. But now I felt a compulsion to get into the act. It seemed clear to me

Address reprint requests to Mr. Cousins at the *Saturday Review*, 488 Madison Ave., New York, NY 10022.

that if I was to be that "one case in 500" I had better be something more than a passive observer.

I asked Dr. Hitzig about the possible cause of my condition. He said that it could have come from any one of a number of causes. It could have come, for example, from heavy-metal poisoning, or it could have been manifested by the aftereffects of a streptococcal infection.

I thought as hard as I could about the sequence of events immediately preceding the illness. I had gone to the Soviet Union in July, 1964, as chairman of an American delegation to consider the problems of cultural exchange. The conference had been held in Leningrad, after which we went to Moscow for supplementary meetings. Our hotel was in a residential area. My room was on the second floor. Each night a procession of diesel trucks plied back and forth to a nearby housing project in the process of round-the-clock construction. It was summer, and our windows were wide open. I slept uneasily each night and felt somewhat nauseated on arising. On our last day in Moscow, at the airport, I caught the exhaust spew of a large jet at point-blank range as it swung around on the tarmac.

As I thought back on that Moscow experience, I wondered whether the exposure to the hydrocarbons from the diesel exhaust at the hotel and at the airport had anything to do with the underlying cause of the illness. If so, that might account for the speculations of the doctors concerning heavy-metal poisoning. The trouble with this theory, however, was that my wife, who had been with me on the trip, had no ill effects from the same exposure. How likely was it that only one of us would have reacted adversely?

There were two possible reasons, it seemed to me, for the different responses. One had to do with individual allergy. The second was that I was probably in a condition of adrenal exhaustion and I was less apt to tolerate a toxic experience than someone whose immunologic system was fully functional.

Was adrenal exhaustion a factor in my own illness?

Again, I thought carefully. The meetings in Leningrad and Moscow had not been casual. Paper work had kept me up late nights. I had ceremonial responsibilities. Our last evening in Moscow had been, at least for me, an exercise in almost total frustration. A reception had been arranged by the chairman of the Soviet delegation at his *dacha*, located 50 to 65 km outside the city. I had been asked if I could arrive an hour early so that I might tell the Soviet delegates something about the individual Americans who were coming to dinner. The Russians were eager to make the Americans feel at home, and they had thought such information would help them with the social amenities.

I was told that a car and driver from the government automobile pool in Moscow would pick me up at the hotel at 3:30 p.m. This would allow ample time for me to drive to the *dacha* by 5:00 p.m., when all our Russian conference colleagues would be gathered for

the social briefing. The rest of the American delegation would arrive at the *dacha* at 6:00.

At 6:00, however, I found myself in open country on the wrong side of Moscow. There had been a misunderstanding in the transmission of directions to the driver, the result being that we were some 130 km off course.

We didn't arrive at the *dacha* until 9:00 p.m. My host's wife looked desolate. The soup had been heated and re-heated. The veal was dried out. I felt pretty wrung out myself. It was a long flight back to the States the next day. The plane was overcrowded. By the time we arrived in New York, cleared through the packed customs counters, and got rolling back to Connecticut, I could feel an uneasiness deep in my bones. A week later I was hospitalized.

As I thought back on my experience abroad, I knew that I was probably on the right track in my search for a cause of the illness. I found myself increasingly convinced, as I said a moment ago, that the reason I was hit hard by the diesel and jet pollutants, whereas my wife was not, was that I had had a case of adrenal exhaustion, lowering my resistance.

Assuming this hypothesis was true, I had to get my adrenal glands functioning properly again and to restore what Walter Cannon, in his famous book *The Wisdom of the Body*,³ called homeostasis.

I knew that the full functioning of my endocrine system — in particular, the adrenal glands — was essential for combating severe arthritis or, for that matter, any other illness. A study I had read in the medical press reported that pregnant women frequently have remissions of arthritic or other rheumatic symptoms. The reason is that the endocrine system is fully activated during pregnancy.

How was I to get my adrenal glands and my endocrine system, in general, working well again — both physically and emotionally?

I remembered having read, 10 years or so earlier, Hans Selye's classic book, *The Stress of Life*.⁴ With great clarity, Selye showed that adrenal exhaustion could be caused by emotional tension, such as frustration or suppressed rage. He detailed the negative effects of the negative emotions on body chemistry. He wrote, for example, about the increase of hydrochloric acid in the stomach. He also traced changes in corticoids and anticorticoids under conditions of emotional stress.

The inevitable question arose in my mind: What about the positive emotions? If negative emotions produce negative chemical changes in the body, wouldn't the positive emotions produce positive chemical changes? Is it possible that love, hope, faith, laughter, confidence and the will to live have therapeutic value? Do chemical changes occur only on the downside?

Obviously, putting the positive emotions to work is nothing so simple as turning on a garden hose. But even a reasonable degree of control over my emotions might have a salutary physiologic effect. Just replac-

ing anxiety with a fair degree of confidence would be helpful.

A plan began to form in my mind for systematic pursuit of the salutary emotions, and I knew that I would want to discuss it with my doctor. Two preconditions, however, seemed obvious for the experiment. The first concerned my medication. If that medication were toxic to any degree, it was doubtful whether the plan would work. The second precondition concerned the hospital. I knew I would have to find a place somewhat more conducive to a positive outlook on life.

Let's consider these preconditions separately.

First, the medication. The emphasis had been on painkilling drugs — aspirin, phenylbutazone (Butazolidin), codeine, colchicine, sleeping pills. The aspirin and phenylbutazone were anti-inflammatory and thus were therapeutically justifiable. But I wasn't sure they weren't also toxic. With Dr. Hitzig's support, we took allergy tests and discovered that I was hypersensitive to virtually all the medication I was receiving. The hospital had been giving me maximum dosages: 26 aspirin tablets a day; and 3 phenylbutazone tablets four times a day. No wonder I had hives all over my body and felt as though my skin was being chewed up by millions of red ants.

It was unreasonable to expect positive chemical changes to take place so long as my body was being saturated with, and toxified by, painkilling medications. I had one of my research assistants at the *Saturday Review* look up the pertinent references in the medical journals and found that drugs like phenylbutazone and even aspirin levy a heavy tax on the adrenal glands. I also learned that phenylbutazone is one of the most powerful drugs being manufactured. It can produce bloody stools, the result of its antagonism to fibrinogen. It can cause intolerable itching and sleeplessness. It can depress bone marrow.

The hazards of phenylbutazone are explicit. Aspirin enjoys a far more auspicious reputation, at least with the general public. The prevailing impression of aspirin is that it is not only the most harmless drug available but also one of the most effective. When I looked into research in the medical journals, however, I found that aspirin is quite powerful in its own right and that it warrants considerable care in its use. The fact that it can be bought in unlimited quantities without prescription or doctor's guidance seemed indefensible. Even in small amounts, it can cause internal bleeding. Articles in the medical press reported that the chemical composition of aspirin, like that of phenylbutazone, impairs platelet function. Did the relation between platelets and collagen mean that both drugs do more harm than good for some sufferers from arthritis?*

It was a mind-boggling train of thought. Could it

be, I asked myself, that aspirin, so universally accepted for so many years, was actually harmful in the treatment of collagen illnesses?[†]

The history of medicine is replete with instances involving drugs and modes of treatment that were in use for many years before it was recognized that they did more harm than good. For centuries, for example, people believed that drawing blood from patients was essential for rapid recovery from virtually every illness. Then, midway through the nineteenth century, it was discovered that bleeding serves only to weaken the patient. King Charles II's death is believed to have been caused in large part from administered bleedings. George Washington's death was also hastened by the severe loss of blood resulting from this treatment.

Living in the second half of the twentieth century, I realized, confers no automatic protection against unwise or even dangerous drugs and methods. Each age has had to undergo its own special nostrums. Fortunately, the human body is a remarkably durable instrument and has been able to withstand all sorts of prescribed assaults over the centuries, from freezing to animal dung.

Suppose I stopped taking aspirin and phenylbutazone? What about the pain? The bones in my spine and practically every joint in my body felt as though I had been run over by a truck.

I knew that pain could be affected by attitudes. Most people become panicky about almost any pain. On all sides they have been so bombarded by advertisements about pain that they take this or that analgesic at the slightest sign of an ache. They are largely illiterate about pain and so are seldom able to deal with it rationally. Pain is part of the body's magic. It is the way the body transmits a sign to the brain that something is wrong. Leprous patients pray for the sensation of pain. What makes leprosy such a terrible disease is that the victim usually feels no pain when his extremities are being injured. He loses his fingers or toes because he receives no warning signal that he is being injured.

I could stand pain so long as I knew that progress was being made in meeting the basic need. That need, I felt, was to restore the body's capacity to halt the continuing breakdown of connective tissue.

There was also the problem of the severe inflammation. If we dispensed with the aspirin, how would we combat the inflammation? I recalled having read in the medical journals about the usefulness of ascorbic acid in combating a wide number of illnesses — all the way from bronchitis to some types of heart disease. Couldn't it also combat inflammation? Did vitamin C act directly, or did it serve as a starter for the body's endocrine system — in particular, the adrenal glands? Was it possible, I asked myself, that ascorbic acid had a vital role to play in "feeding" the adrenal glands?

*I realize, of course, that the implications here are not entirely negative in view of the fact that the same properties of aspirin that prolong bleeding also prevent clotting. Aspirin is therefore useful to some patients with cardiac disease and those for whom clotting is a danger.

†The scientific verification that aspirin can be harmful in the treatment of collagen diseases came in 1971 and is discussed later in this article.⁵

I had read in the medical press that vitamin C helps to oxygenate the blood.⁶ If inadequate or impaired oxygenation was a factor in collagen breakdown, couldn't this circumstance be another argument for ascorbic acid? Also, according to some medical reports, people suffering from collagen diseases are deficient in vitamin C.⁵ Did this lack mean that the body uses up large amounts of vitamin C in the process of combating collagen breakdown?

I wanted to discuss some of these ruminations with Dr. Hitzig. He listened carefully as I told him of my speculations concerning the cause of the illness, as well as my layman's ideas for a course of action that might give me a chance to reduce the odds against my recovery.

Dr. Hitzig said it was clear to him that there was nothing undersized about my will to live. He said that what was most important was that I continue to believe in everything I had said. He shared my sense of excitement about the possibilities of my recovery and liked the idea of a partnership.

Even before we had completed arrangements for moving out of the hospital, we began the part of the program calling for the full exercise of the affirmative emotions as a factor in enhancing body chemistry. It was easy enough to hope and love and have faith, but what about laughter? Nothing is less funny than being flat on your back with all the bones in your spine and joints hurting. A systematic program was indicated. A good place to begin, I thought, was with amusing movies. Allen Funt, producer of the spoofing television program "Candid Camera," sent films of some of his "CC" classics, along with a motion-picture projector. The nurse was instructed in its use.

It worked. I made the joyous discovery that 10 minutes of genuine belly laughter had an anesthetic effect and would give me at least two hours of pain-free sleep. When the painkilling effect of the laughter wore off, we would switch on the motion-picture projector again, and, not infrequently, it would lead to another pain-free sleep interval. Sometimes, the nurse read to me out of a trove of humor books. Especially useful were E.B. and Katherine White's *Subtreasury of American Humor*⁷ and Max Eastman's *The Enjoyment of Laughter*.⁸

How scientific was it to believe that laughter — as well as the positive emotions in general — was affecting my body chemistry for the better? If laughter did in fact have a salutary effect on the body's chemistry, it seemed at least theoretically likely that it would enhance the system's ability to fight the inflammation. So we took sedimentation-rate readings just before as well as several hours after the laughter episodes. Each time, there was a drop of at least five points. The drop by itself was not substantial, but it held and was cumulative.

I was greatly elated by the discovery that there is a physiologic basis for the ancient theory that laughter is good medicine.

There was, however, one negative side effect of the laughter from the standpoint of the hospital. I was dis-

turbing other patients. But that objection didn't last very long, for the arrangements were now complete for me to move my act to a hotel room.

One of the incidental advantages of the hotel room, I was delighted to find, was that it cost only about one-third as much as the hospital. The other benefits were incalculable. I would not be awakened for a bed bath or for meals or for medication or for a change in the bed sheets or for tests or for examinations by hospital interns. The sense of serenity was delicious and would, I felt certain, contribute to a general improvement.

What about ascorbic acid and its place in the general program for recovery? In discussing my speculations about vitamin C with Dr. Hitzig, I found him completely open-minded on the subject, although he told me of serious questions that had been raised by scientific studies. He also cautioned me that heavy doses of ascorbic acid carried some risk of renal damage. The main problem right then, however, was not my kidneys: it seemed to me that, on balance, the risk was worth taking. I asked Dr. Hitzig about previous recorded experience with massive doses of vitamin C. He ascertained that at the hospital there had been cases in which patients had received up to 3 g by intramuscular injection.

As I thought about the injection procedure, some questions came to mind. Introducing the ascorbic acid directly into the bloodstream might make more efficient use of the vitamin, but I wondered about the body's ability to utilize a sudden massive infusion. I knew that one of the great advantages of vitamin C is that the body takes only the amount necessary for its purposes and excretes the rest. Again, there came to mind Cannon's phrase — the wisdom of the body.³

Was there a coefficient of time in the utilization of ascorbic acid? The more I thought about it, the more likely it seemed to me that the body would excrete a large quantity of the vitamin because it couldn't metabolize it that fast. I wondered whether a better procedure than injection would be to administer the ascorbic acid through slow intravenous drip over a period of three or four hours. In this way we could go far beyond the 3 g. My hope was to start at 10 g and then increase the dose daily until we reached 25 g.

Dr. Hitzig's eyes widened when I mentioned 25 g. This amount was far beyond any recorded dose. He said he had to caution me about the possible effect not just on the kidneys but on the veins in the arms. Moreover, he said he knew of no data to support the assumption that the body could handle 25 g over a four-hour period, other than by excreting it rapidly through the urine.

As before, however, it seemed to me we were playing for bigger stakes: losing some veins was not of major importance alongside the need to combat whatever was eating at my connective tissue.

To know whether we were on the right track, we took a sedimentation test before the first intravenous administration of 10 g of ascorbic acid. Four hours lat-

er, we took another sedimentation test. There was a drop of nine full points.

Seldom had I known such elation. The ascorbic acid was working. So was laughter. The combination was cutting heavily into whatever poison was attacking the connective tissue. The fever was receding, and the pulse was no longer racing.

We stepped up the dosage. On the second day we went up to 12.5 g of ascorbic acid, on the third day, 15 g, and so on until the end of the week, when we reached 25 g. Meanwhile, the laughter routine was in full force. I was completely off drugs and sleeping pills. Sleep — blessed, natural sleep without pain — was becoming increasingly prolonged.

At the end of the eighth day I was able to move my thumbs without pain. By this time, the sedimentation rate was somewhere in the 80's and dropping fast. I couldn't be sure, but it seemed to me that the gravel-like nodules on my neck and the backs of my hands were beginning to shrink. There was no doubt in my mind that I was going to make it back all the way.

Two weeks later, my wife took me to Puerto Rico for some sustained sunshine. On the first day, friends helped support me in the breaking surf. Within a few days I was standing up by myself. As first the soles of my feet were so sensitive that I felt as though I were standing on my eyeballs. But walking in the sand was the best possible therapy, and within a week I was able to jog — at least for a minute or two.

The connective tissue in my spine and joints was regenerating. I could function, and the feeling was indescribably beautiful.

I must not make it appear that all my infirmities disappeared overnight. For many months I couldn't get my arms up far enough to reach for a book on a high shelf. My fingers weren't agile enough to do what I wanted them to do on the organ keyboard. My neck had a limited turning radius. My knees were somewhat wobbly, and, off and on, I had to wear a metal brace.

But I was back at my job at *Saturday Review* full time again, and this was miracle enough for me.

Is the recovery a total one? Year by year the mobility has improved. During the past year I have become fully pain free, except for my knees, for the first time since I left the hospital. I no longer feel a sharp twinge in my wrists or shoulders when I hit a tennis ball or golf ball, as I did for such a long time. I can ride a horse flat out and hold a camera with a steady hand. And I have recaptured my ambition to play the *Tocata and Fugue in D Minor*, though I find the going slower and tougher than I had hoped. My neck has a full turning radius again, despite the statement of specialists as recently as 1971 that the condition was degenerative and that I would have to adjust to a quarter turn.

It was seven years after the onset of the illness before I had scientific confirmation about the dangers of using aspirin in the treatment of collagen diseases, which embrace the various forms of arthritis. In its May 8, 1971 issue, *Lancet* published a study by Drs.

M.A. Sahud and R.J. Cohen⁵ showing that aspirin could be antagonistic to the retention of vitamin C in the body. The authors said that patients with rheumatoid arthritis should take vitamin C supplements since it has often been noted that they have low levels of the vitamin in their blood. It was no surprise, then, that I had been able to absorb such massive amounts of ascorbic acid without kidney or other complications.

What conclusions do I draw from the entire experience?

The first is that the will to live is not a theoretical abstraction, but a physiologic reality with therapeutic characteristics. The second is that I was incredibly fortunate to have as my doctor a man who knew that his biggest job was to encourage to the fullest the patient's will to live and to mobilize all the natural resources of body and mind to combat disease. Dr. Hitzig was willing to set aside the large and often hazardous armamentarium of powerful drugs available to the modern physician when he became convinced that his patient might have something better to offer. He was also wise enough to know that the art of healing is still a frontier profession. And, though I can't be sure of this point, I have a hunch he believed that my own total involvement was a major factor in any recovery.

People have asked what I thought when I was told by the specialists that my disease was progressive and incurable.

The answer is simple. Since I didn't accept the verdict, I wasn't trapped in the cycle of fear, depression and panic that frequently accompanies a supposedly incurable illness. I must not make it seem, however, that I was unmindful of the seriousness of the problem or that I was in a festive mood throughout. Being unable to move my body was all the evidence I needed that the specialists were dealing with real concerns. But deep down I knew I had a good chance and relished the idea of bucking the odds.

Adam Smith, in *Powers of the Mind*,¹ says he discussed my recovery with some of his doctor friends, asking them to explain why the combination of laughter and ascorbic acid worked so well. The answer he got was that neither laughter nor ascorbic acid had anything to do with it and that I probably would have recovered if nothing had been done.

Maybe so, but that was not the opinion of the specialists at the time.

Two or three doctors, reflecting on the Adam Smith account, have commented that I was probably the beneficiary of a mammoth venture in self-administered placebos.

Such a hypothesis bothers me not at all. Respectable names in the history of medicine like Paracelsus, Holmes and Osler have suggested that the history of medication is far more the history of the placebo effect than of intrinsically valuable and relevant drugs. Physicians in the past who favored such modalities as bleeding (in a single year, 1827, France imported 33 million leeches after its domestic supplies had been depleted); purging through emetics; physical contact

with unicorn horns, bezoar stones, mandrakes or powdered mummies — the physicians prescribing such treatments no doubt regarded them at the time as specifics with empirical sanction. But today's medical science recognizes that whatever efficacy these treatments may have had — and the records indicate that the results were often surprisingly in line with expectations — was probably related to the power of the placebo.

I have wondered, in fact, about the relative absence of attention given the placebo in contemporary medicine. The literature on the subject is remarkably sparse considering the primacy of the placebo in the history of medicine. The late Henry K. Beecher⁹ and Arthur K. Shapiro¹⁰ are among the small number of contemporary medical researchers and observers who have done any noteworthy thinking and writing about this phenomenon. In connection with my own experience, I was fascinated by a report citing Dr. Thomas C. Chalmers,¹¹ of the Mount Sinai Medical Center in New York, which compared two groups that were being used to test the theory that ascorbic acid is a cold preventive. "The group on placebo," says Dr. Chalmers, "who thought they were on ascorbic acid had fewer colds than the group on ascorbic acid who thought they were on placebo."

I was absolutely convinced, at the time I was deep in my illness, that intravenous doses of ascorbic acid could be beneficial — and they were. It is quite possible that this treatment — like everything else I did — was a demonstration of the placebo effect. If so, it would be just as important to probe into the nature of this psychosomatic phenomenon as to find out if ascorbic acid is useful in combating a high sedimentation rate.

At this point, of course, we are opening a very wide door, perhaps even a Pandora's box. The vaunted "miracle cures" that abound in the literature of all the great religions, or the speculations of Charcot and Freud about conversion hysteria, or the Lourdes phenomena — all say something about the ability of the patient, properly motivated or stimulated, to participate actively in extraordinary reversals of disease and disability. It is all too easy, of course, to raise these possibilities and speculations to a monopoly status — in which case the entire edifice of modern medicine would be reduced to little more than the hut of an African witch doctor. But we can at least reflect on William Halse Rivers's statement, as quoted by Shapiro, that "the salient feature of the medicine of today is that these psychical factors are no longer allowed to play their part unwittingly, but are themselves becoming the subject of study, so that the present age is serving the growth of a rational system of psychotherapeutics."¹⁰

What we are talking about essentially, I suppose, is the chemistry of the will to live. In Bucharest in 1972, I visited the clinic of Ana Aslan, described to me as one of Rumania's leading endocrinologists. She spoke of her belief that there is a direct connection between a

robust will to live and the chemical balances in the brain. She is convinced that creativity — one aspect of the will to live — produces the vital brain impulses that stimulate the pituitary glands, triggering effects on the pineal glands and the whole of the endocrine system. Is it possible that placebos have a key role in this process? Shouldn't this entire area be worth serious and sustained attention?

If I had to guess, I would say that the principal contribution made by my doctor to the taming, and possibly the conquest, of my illness was that he encouraged me to believe I was a respected partner with him in the total undertaking. He fully engaged my subjective energies. He may not have been able to define or diagnose the process through which self-confidence (wild hunches securely believed) was somehow picked up by the body's immunologic mechanisms and translated into anti-morbid effects. But he was acting, I believe, in the best tradition of medicine in recognizing that he had to reach out in my case beyond the usual verifiable modalities. In so doing, he was faithful to the first dictum in his medical education: *primum non nocere*. He knew that what I wanted to do might not help, but it probably would do little harm. Certainly, the threatened harm being risked was less, if anything, than the heroic medication so routinely administered in extreme cases of this kind.

Something else I have learned. I have learned never to underestimate the capacity of the human mind and body to regenerate — even when the prospects seem most wretched. The life-force may be the least understood force on earth. William James¹² said that human beings tend to live too far within self-imposed limits. It is possible that those limits will recede when we respect more fully the natural drive of the human mind and body toward perfectibility and regeneration. Protecting and cherishing that natural drive may well represent the finest exercise of human freedom.

REFERENCES

1. Smith A: Powers of the Mind. New York, Random House, 1975, pp 11-14
2. White House Conference on Food, Nutrition and Health: Final report. Washington, DC, Government Printing Office, 1969
3. Cannon WB: The Wisdom of the Body. New York, WW Norton and Company, 1963
4. Selye H: The Stress of Life. New York, McGraw-Hill, 1956
5. Sahud MA, Cohen RJ: Effect of aspirin ingestion on ascorbic-acid levels in rheumatoid arthritis. *Lancet* 1:937-938, 1971
6. Hamburger E: A two-stage study of plasma ascorbic acid and its relation to wound healing. *Milit Med* 127:723-725, 1962
- 6a. Kinderlehrer J: Vitamin C: The best thing that ever happened to antibiotics. *Prevention* 26:71-75, 1974
- 6b. Klenner FR: Observations on the dose and administration of ascorbic acid when employed beyond the range of a vitamin in human pathology. *J Appl Nutr* 23:61-87, 1971
7. White EB, White KS: A Subtreasury of American Humor. New York, Capricorn Books, 1962
8. Eastman M: The Enjoyment of Laughter. Johnson Reprint of 1937 edition, 1971
9. Beecher HK: The powerful placebo. *JAMA* 159:1602-1606, 1955
10. Shapiro AK: Factors contributing to the placebo effect: their implications for psychotherapy. *Am J Psychother* 18: Suppl 1:73-88, 1964
11. Blake K: Vitamin C: the case looks stronger, but.... *Pastimes* [Air-shuttle edition] (Eastern Airlines) March, 1976
12. James W: Psychology. New York, World Publishing Company, 1948

BLACK HOLES

THE biggest thing in science now is black holes. Everyone is talking about them. Professor Sigmund Schmeltzer, of Göttingen, has just conducted a symposium on black holes in Aspen, Colorado. Dr. T. Wycliffe Meazley, of Utah A. & M., is working on black holes in Heidelberg. The junior class of the Massachusetts Institute of Technology is testing black holes in the basement of Beaumont Laboratory. Observers from Lockheed and I.B.M. are snooping around Göttingen. Dr. Meazley had lunch with a vice-president of Westinghouse. Professor Pierson Flintleach, of M.I.T., is preparing a black-hole bibliography for the Pentagon. What is a black hole? Why all the interest?

A black hole is a hole that is really black. It has no color at all. It actually sucks in any light that happens to be hanging around it, including its own, which means that it can only be seen when it is in front of something else, like a grapefruit.

Figure 1



Rectangular black hole Grapefruit Rectangular black hole passing in front of grapefruit

Black holes can be dangerous. If you were to run into a black hole in Central Park at 10 P.M. you probably wouldn't know what had happened to you. If you ran into a black hole in Central Park *no one would ever see you again*. That's why the Pentagon is interested. There are a lot of people the Pentagon never wants to see again, like Paul Warnke.

Black holes, once so rare, are becoming almost common. Under development is a rectangular black hole that can be attached to a television set to take care of commercials. (You should make certain, however, that it is properly installed.) When the pretty waitress in the commercial slides a McDonald's hamburger toward you, your rectangular black hole can be tuned to make the hamburger disappear. The great thing is, the hamburger disappears not only from your set but from every other set in the country—even sets that are not switched on. Also, the

was filmed six months before, in order to make the commercial, disappears, too, together with Ronald McDonald and the composer of the McDonald's jingle and the McDonald's account executive at Forbush, Scrimshaw & Nash.

There is also a toroidal, or doughnut-shaped, black hole (Figure 2) that can absorb a market-research interviewer through a keyhole or a literary agent through a Martini glass, and

Figure 2



Bagel

Toroidal black hole passing in front of bagel

Professor Schmeltzer is reported to be working on a lozenge-size black hole that, taken internally, will perform an appendectomy in less time than it takes to read this sentence. Remember, though: if your black hole is not properly installed you are in trouble. A man in Roslyn, Long Island, who acquired a trapezoidal black hole in order to eliminate a small stand of poison sumac failed to notice one loose screw, and his garden and driveway disappeared, together with his living room, the bottom half of the staircase, and the first five volumes of the *Micropædia* section of his new *Encyclopædia Britannica*.

IT is difficult to believe that just a few years ago it took an eight-man team from Cornell most of a summer to produce one inverted black hole. An inverted black hole is a black hole that pierces the fabric of time. Suppose, for example, you are a suburban matron who has just written two letters, one reminding your in-laws that they are expected for Memorial Day weekend, and the other to your son's college roommate to change the site of your forthcoming assignation from the Copley Plaza to the Sheraton Boston. Suppose further that, having dropped the letters in the mailbox at 3 P.M., you suddenly realize that you have put them in the wrong envelopes. With an inverted black hole, you can slip back to 2:30 P.M., when you were just signing the letter to your son's roommate, and put it in the *right* envelope, or even write two *white* letters cancelling both

Not everyone is equipped to handle an inverted black hole successfully. Mr. Sidney Platelet, a retired closed-end-fund consultant, of Red Wing, Minnesota, recently purchased an inverted black hole in order to obtain newspapers one day in advance—a scheme he thought would help him in making personal investment decisions. Unfortunately, when he eagerly opened the front door of his split-level ranch at seven-fifty the following morning, it turned out to be seven-fifty-one the *previous* morning, and he ran into himself entering the house with the previous day's Minneapolis *Tribune* (which he had already read) and the milk. This was upsetting to Mr. Platelet, who was in the habit of breakfasting alone. Finding himself admitting an additional duplicate of himself with each passing day, Mr. Platelet soon ran out of beds and, unable to stand the squabbling over coffee and oatmeal and who would get first crack at the paper, had to resettle himself in Phoenix, Arizona.

Black holes never wear out or become obsolete. A black hole has no moving parts and keeps itself clean. A black hole is extremely useful in dealing with contemporary crises like the power crunch and environmental pollution. Sam Epping, the owner of Pete's Diner in Summit, New Jersey, has recently been using an oval black hole for waste disposal and to light up his neon sign, thus saving on electric bills as well as on garbage service. Of course, after five months of silently disposing of potato peelings, coffee dregs, eggshells, cans, jars, and old copies of the Sunday New York *Times*, Epping's black hole has somewhat increased in size. At the time of delivery, it fitted in a shoebox. Now it is bigger than four trailer trucks, and Epping's customers can no longer park in the lot behind the diner. All deliveries have to be made at the front door, and Fred, the night short-order cook, is getting nervous about the way chicken bones are being snatched out of his hand.

Once a black hole is installed, it is probably there for good, and home repairs are inadvisable. If, for example, that householder in Roslyn now tried to adjust his faulty black hole, his screwdriver wouldn't be the only thing affected. Before he knew it, he might be two miles long and thin as a needle, or one hundred and forty-six acres in area and flat as a coat of paint, or part of a clump of poison sumac—depending on whether one follows the Schmeltzer hypothesis or the most re-

**THE CASE FOR AN
INTERNATIONAL LUNAR BASE**

INTERNATIONAL ACADEMY OF ASTRONAUTICS

1st COSMIC STUDY OF THE IAA:

THE CASE FOR AN INTERNATIONAL LUNAR BASE

Compiled by the
Lunar Development Subcommittee
of the
Committee on International Space Plans and Policies

INTERNATIONAL ACADEMY OF ASTRONAUTICS

BP 1268-16
75766 Paris Cedex 16
France

Table of Contents

Preface	ii
1. Introduction	page 1
2. The WHY	4
2.1 Objectives	
2.2 Pros and Cons	
2.3 Valuation Criteria	
3. The WHAT	10
3.1 Lunar surface activities	10
3.2 Lunar logistics	29
4. The HOW	38
4.1 Economic Aspects	
4.2 Political aspects	
4.3 Organizational aspects	
5. Summary Plan	48
5.1 Program scope and structure	
5.2 Program organization	
5.3 Program budgeting	
5.4 Program initiation	
6. Concluding statement	57
7. Literature	58
8. Appendix 1	60
Appendix 2	63

PREFACE

Lunar Base

The International Academy of Astronautics is pleased to present the first of a series of "Cosmic Studies", designed to fully explore the many major aspects and implications of the implementation, the impact, and the rewards of cooperative and coordinated international programs for the exploration and habitation of the solar system and beyond. In this and subsequent studies we are attempting to provide the decision makers of the space faring countries of the world an unbiased scientific and technological basis for their commitment to multinational space programs.

This cosmic study, "The Case for an International Lunar Base", examines the possibilities and implications of an international base on the Moon. This and subsequent studies are designed to provide a knowledgeable unbiased technical perspective and assessment of proposed programs as a basis for governmental decisions.

Since 1959, when the USSR launched Luna 2, the first man-made object to reach the Moon, the nations of the world have been keenly aware of the technical possibility for fulfilling the centuries old ambition of Man's first hand exploration and study of the Universe.

The ensuing 30+ years have witnessed one of the most astounding periods in the history of mankind. Few of us envisaged in 1960 that the frontier of mankind would have reached the Moon before 1970.

In 1968, when Frank Borman, Jim Lovell and Bill Anders carried out their circumlunar flight, celebrating Christmas in their encounter with the Moon, spaceflight captured the imagination of the world. Communications satellites carried television pictures of the flight all over the world.

On July 16, 1969, **Apollo 11**, was launched on its epic voyage, sent off by the largest group of media people and equipment ever assembled. The world watched as Mike Collins circled the Moon and Neil Armstrong and Buzz Aldrin landed on the Moon on July 20, 1969. This moment, shared by more of the people on Earth than had ever witnessed a single event before, brought space and space travel to every nation on Earth.

No earthbound citizen of the world, watching this exciting technological achievements on TV, could have foreseen, having reached the frontier the Moon and begun its exploration, that for the next twenty-five years would retreat to the confines of Earth's gravity.

The next major step in lunar exploration, that of establishing a scientific base that might be enlarged into permanent Moon colonies where 50 100 people could live and work for months or years, has yet to be taken. It is this next step, an international cooperative effort to establish permanent human presence on the Moon, that the IAA explores in this comprehensive study.

The International Academy of Astronautics was established in 1960 for the dual purpose of recognizing individuals of great achievement and promoting the peaceful uses of outer space and cooperation between nations in the advancement of aerospace science.

It was based on the precept of the classical academies who, with essentially modest means, made their vast contributions simply by bringing together individuals to exchange ideas and experiences, to make studies and recommendations, and to bring the results of their work to the attention of their communities. (A brief description of the Academy is included in Appendix 1).

Today, the IAA is a symbol of international cooperation in space science, just as the Moon is a symbol of the peaceful exploration of space. The "Moon" treaty, signed in 1967, declares that outer space, including the Moon, cannot be claimed by any country or be used for military purposes.

Tomorrow, I would hope the **Moon** would become the launching port for Mankind's journey to **MARS** and beyond. The most important challenge facing the world today is to define and then implement that vision which will lead all Mankind to its destiny, to colonize the Solar System and ultimately to spread humanity to the stars.

George E. Mueller
President
International Academy of Astronautics

October, 1990

1. Introduction

Barring world catastrophe, permanent human presence on the Moon and inventions throughout the century. It is vital to seed the future for the International Space Station. How permanent human presence on the Moon, what return, what push for a return?

The space age began only four years ago. In 1959 the first manned flight followed ten years later. In 1969 was the year of the Apollo 11 mission, which was a major step toward permanent human presence on the Moon.

During 1969 through 1970, 30 research hours were spent on the Moon. The first lunar surface traverses were accomplished by the Apollo 11 mission and almost 400 samples were returned to Earth between 1970 and 1972.

The relatively high cost of space exploration is changing political attitudes toward space exploration. The leading space powers are the United States, the Soviet Union, and Japan. Improved international cooperation is needed to improve the space economy.

The last decade of the 20th century will see the development of a permanent space station for purposes of scientific, commercial, and information exchange. There are many space projects.

Continuing exploration of the Moon, annually, in pursuit of a permanent human presence on the Moon. There is tremendous potential for making life on the Moon a reality.

Large, peaceful space stations, world's high-technology, weapons. It is a peaceful use of these resources.

1. Introduction

Barring world catastrophe humans will soon permanently inhabit the Moon. Permanent human habitation of the Moon will spark the human discoveries and inventions that will establish the two-planet culture of the twenty first century. It is vital that the permanent human settlement and industries seed the future for cooperative, healthy growth of mankind beyond Earth. The International Academy of Astronautics offers its thoughts and hopes for how permanent habitation will occur, how international cooperation can be nurtured, what rewards can now be glimpsed, and why it is vital to strongly push for a return to the Moon:

The space age began in 1957 with the first launch of an artificial satellite. Only four years later the first human being circled our home planet. In 1959 the first man-made object reached the surface of the Moon to be followed ten years later by the first manned lunar landing. Thus, the year 1969 was the year where humankind set foot onto a celestial body other than our own planet. In 12 short years, the human race had taken its first major steps toward becoming an interplanetary civilization.

During 1969 through 1972 six exploratory lunar landings produced nearly 30 research hours for astronauts outside their spacecraft. Over 90 km of traverses were accomplished on the lunar surface at six different locations, and almost 400 kg of rock and soil samples were returned to Earth. Between 1970 and 1976, several automated missions to the Moon, some with sample return, were carried out in addition to the manned exploration.

The relatively high cost of the exploration ($25 \cdot 10^9$ \$ at that time) and changing political priorities did not allow the proposed immediate buildup of a permanent lunar base. Orbital laboratories were developed instead by the leading space faring nations and space transportation systems were improved in terms of performance, mission flexibility, reliability and economy.

The last decade of this century will see the construction and operation of permanent space stations in near Earth orbits in an altitude of about 400 km for purposes of scientific research, hoping to make progress towards commercial applications of space technology in addition to communication and information processing. But the evolution of humankind will not stop here and we can safely assume that the space stations will not be last large space projects.

Continuing expenditures, equivalent to hundreds of billions of dollars annually, in pursuit of national security are an attempt to make our life safer. There is tremendous progress but no guarantee of success. Other ways of making life on this planet more secure and attractive are preferred.

Large, peaceful space programs could be a constructive employment of the world's high-technology industry, much of which is now devoted to weapons. It is a political challenge to find better ways and means to convert these resources to more constructive endeavours. In the current

geopolitical environment it is thus possible to think of long range programs again, a subject not very fashionable after the APOLLO program had come to an end. In the United States a "National Commission on Space" was created by the US Congress and the President with the task to develop a blueprint for the next 50 years in space. This Commission published a report in 1986. One of the primary recommendations was the return to the Moon in the first decade of the next century, to be followed by a Mars expedition in the third decade of the 21st century. Although there is no approved project for building a permanent lunar base on the Moon, the President of the United States endorsed these goals in July 1989. Professional planners of the space community are now challenged to develop feasible plans to do so.

The "International Academy of Astronautics" (IAA), comprising nearly thousand scientists and engineers from more than 50 countries, is the professional international body which can undertake a technical planning effort from a global viewpoint leading to an international or multinational program. The IAA is doing so in the conviction that developing a lunar program with the goal of exploring the use of extraterrestrial resources to the benefit of humankind is an excellent trust-building measure leading to increase peace on Earth and in line with global political developments.

This report is intended to support this planning process on an international scale. It concentrates on strategies and policies, not on technical details. These can be looked up in a great number of technical reports and publications produced since the first (1958) system analysis of a permanent lunar base conducted in the USA. This effort is also a continuation of the former IAA Lunar International Laboratory (LIL) which held a number of symposia during the late sixties.

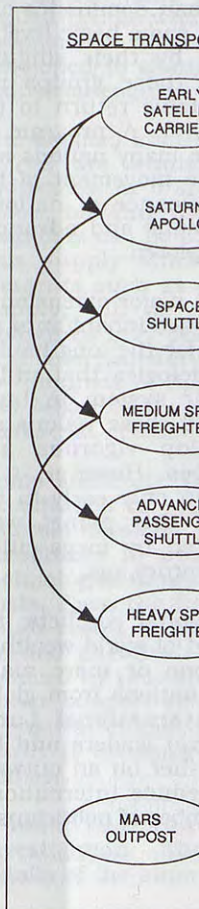
With this intent, the objectives of a lunar program will be discussed first to establish a frame-of-reference that can be used to compare different architectures and approaches and to derive essential attributes of a lunar program (see chapter 2).

Next, the available knowledge on activities which would be part of the lunar program is summarized: A lunar science program, a manufacturing program, a lunar infrastructure development program and finally a research program to develop the know-how and technology not yet available to carry out an international enterprise. To complete the WHAT of the lunar program a typical transportation system as envisaged today is then described to provide the logistics support of a permanent lunar base (see chapter 3).

This is followed by a discussion of the non-technical aspects. As a prelude to the future, the economic, political, social, legal and organizational aspects of the lunar program proposed are summarized. In this sequence chapter 4 tries to answer the HOW of the undertaking.

The last chapter (5.) illustrates a typical plan for an international lunar program in a simple and clear manner, giving the essential information to those who are interested in the subject. This should enhance the discussion in the

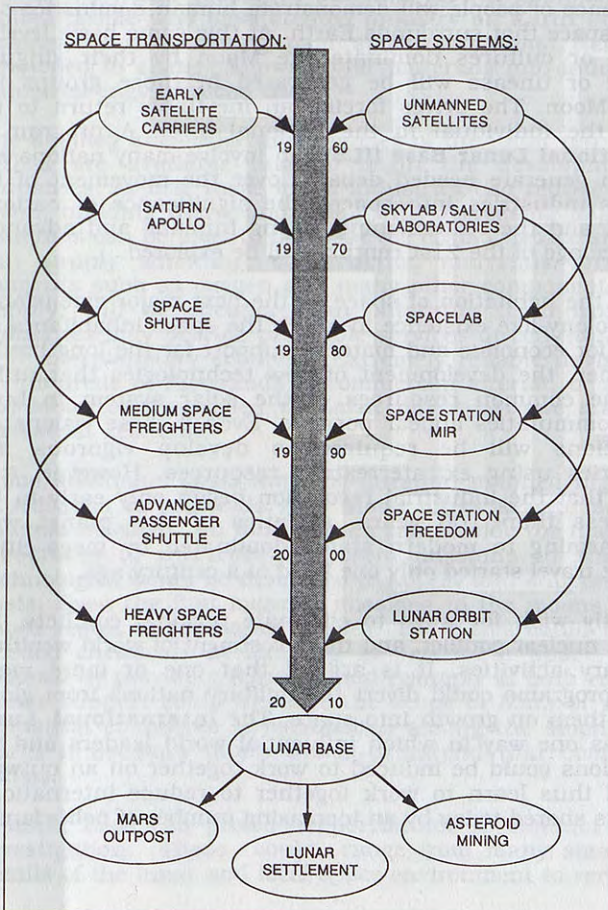
Fig. 1: The evolution of space transportation



of long range circles influencing decisions of global proportions. For the Academy it is a foregone conclusion that humankind will return to the Moon and make use of its resources. Being an international space organization, the Academy can influence only the WHEN and HOW, but this we would like to do!

It is obvious, that most of the arguments made in this report for a lunar base can also be made for an expedition to Mars and its satellites. Figure 1 tries to illustrate that all these individual stepping stones are part of a scenario to develop the resources of space in due course of the evolution of our civilization.

Fig. 1: The evolutionary process towards a lunar base



2 The WHY

2.1 Objectives

The Moon is humanity's first stepping stone on a limitless path into space. It is the first place where people can live with the aid of local resources. The Moon is the planet that is obviously visible from Earth. It is different from Earth and accessible by humans and machines demonstrated. A major drive by many people to support the establishment of a lunar base comes directly from mankind's desire for people to be in the permanent presence of people will demonstrate human dominance in a small portion of the space that surrounds Earth. At this same basic level, only a few nations or cultures dominate the Moon by their simple presence, then fear or unease will be generated in those groups represented on the Moon. The drives forcing an inevitable return to the Moon extend from the individual to the national level. A program to establish an **International Lunar Base (ILB)** can involve many nations and their citizens. It can generate needed debates over the movement of human race and its industries into space. The significance of national boundaries, and the relationships among humans and advanced machines in the space age of the 21st century will be explored.

Many people foresee the habitation of space as the next major extension of the human race. A colony-like existence in which the space inhabitants are dependent on Earth for economic and material support for the long term is not envisioned. Rather, the development of new technologies that harness solar power and the common resources of the solar system to support productive human communities appear possible. Even if these visions are attainable, generations will be required to develop vigorous independent industries using extraterrestrial resources. However, it is useful to remember that the industrial revolution began only early in the 18th century. In less than 100 years, societies of this planet have been transformed from farming to modern states dominated by mega-structures. Computers and space travel started only one third of a century ago.

Many people fervently wish for ways to eliminate regional conflicts, the possibilities of global nuclear conflict, and the investment of world resources in weapons and military activities. It is argued that one or more large international space programs could divert the military nations from their struggles and focus them on growth into space. The **International Lunar Base (ILB)** is seen as one way in which influential world leaders and citizens of many nations could be induced to work together on an ambitious directed project and thus learn to work together to reduce international tensions. This belief is shared today by an increasing number of political

2.2 Pros and cons

Humans have been able to represent approximately 1% of the population of the Earth. It is not too farfetched to go back to the context for an ILB. There is no doubt that we can develop the technologies of space. During the 1970s, geosynchronous satellites have traveled to orbit beyond. During the 1970s, from Earth to orbit. The known lunar base is a skilled people who have been extensively in space. The industrial engine developed to change the detailed knowledge of the 1970s are available. At first, building a lunar base, building materials can be obtained from the supply of elements such as oxygen, hydrogen, and helium. Industries may be developed on the Moon and hundreds of thousands of people may live there. Some additional expeditions to the Moon and asteroid missions are planned. Technologies would be developed. Even the cost of space travel could result in a new era of space exploration. The lunar base could be a stepping stone to the investigation of the universe. The lunar base could be a stepping stone to the investigation of the universe.

2.2 Pros and cons

Humans have been to the Moon. The American and Soviet lunar programs represent approximately 30 % of all world space expenditures to date. Why bother to go back? One reason is that the economic, technical and operational context for an ILB will be different from that of the 1960s. There is now no doubt that we can travel to the Moon more efficiently than in the past. The technologies of space flight and automation have evolved since the 1960s. During the 1970s flights of people to low Earth orbit (LEO) and of machines to geosynchronous orbit (GEO) have become commonplace. Over 100 people traveled to orbit during 1985. Many nations launch satellites to orbit and beyond. During the next decades new and less expensive methods of flying from Earth to orbit will be established.

The known lunar resources permit a growth approach that can draw on the skilled people who have created industry on Earth but have not participated extensively in planning past space programs. New technologies can be developed to change known lunar materials into industrial commodities that industrial engineers can use.

The detailed knowledge and samples of the lunar resources gained during the 1970s are available now to begin the development of extraterrestrial industries. At first these micro industries can reduce the cost of going to the Moon, building there, and living with decreasing imports from Earth. Lunar materials can be used to decrease the costs of space stations. Lunar industries can supply shielding, construction materials, propellants, life support elements such as oxygen and many other components that, at some scale of supply, will be cheaper than obtaining them from Earth. Later, lunar industries may provide profitable services directly to Earth and establish the first interplanetary economy. Extremely reliable navigation services provided to hundreds of thousands of commercial aircraft, or solar power collected on the Moon and supplied to Earth might become major components of the extraterrestrial economy.

However, some additional goals are long-duration manned flights to Mars, or mining expeditions to asteroids. The Moon offers several advantages to Mars and asteroid missions. An ILB program can provide the management and industrial structures to underpin long-term missions to Mars or asteroids. Basic technologies were developed to supply and support such missions at lower costs. Even the first manned missions to the moons of Mars or to asteroids could result in permanent bases. The bases could be expanded to provide needed chemicals at facilities in cis-lunar space. Travel costs could be reduced by providing refueling and resupply at both ends of long space flights. Lunar support could increase the scope of Mars or asteroid missions. Once industrial commerce is established among the Moon, low Earth orbits, and Earth it becomes much easier to extend that commerce to more distant bodies.

International lunar base can provide opportunities to conduct new types of scientific investigation. These could range from many small projects focused on details of the lunar and local space environment to very large programs. The

Moon is a gigantic stable platform with resources. Experiments are being developed that are so delicate that they must be duplicated in widely separated laboratories. Eventually duplicate laboratories will have to be developed on Earth to confirm important experiments or to add higher resolution observations of the universe. The Moon can support the first of these two world experiments.

By the turn of the century research and development will have an annual world cash flow exceeding one trillion dollars. Advanced research will likely be a noticable share of this total and will require an increasing amount of space experimentation because of the greater control that can be provided over fundamental variables such as acceleration, isolation, contamination, localized heating, and others. At some point money will be saved by using lunar resources to build the necessary facilities and support their operation. At that time spin-off industries will appear and net economic growth will be assured. There will always be competition for resources among research communities. However, new economic growth can be directly seeded by the space research community with access to growing lunar resources. The growth can underpin a permanent expansion of scientific research off Earth.

In some ways the environment of the Moon is extremely delicate and can be changed by very small levels of activity. The entire exosphere has a mass of only tens of kilograms. Rocket or industrial operations can coat the lunar surface with thin layers of effluents. Some, such as water vapor or carbon-based chemicals, will boil off in low latitude regions during the lunar day and will be trapped in the permanently dark craters at the poles. High levels of contamination could destroy or degrade electronic devices such as solar cells emplaced on the lunar surface. Effluents containing radioactive elements can destroy the utility of radioisotope methods for the age-dating of lunar samples and make the use of lunar sample data to study the evolution of the solar system difficult. Small industrial activities can generate dust that propagates throughout the Moon and can make seismic research more difficult. An ILB can be a source of pollutants that could degrade research activities. Much planning will be required to prevent or minimize such degradation.

Military space facilities and expenditures are still a major factor of national space programs. Military space systems are critical to surveillance, command, control, communications, intelligence, and could even have a role in the defense against possible bombardment. Some discussions to the basic aspect of space arose by the public during the last years. American and Soviet studies of strategic defense against ballistic missiles have instigated broad debates over space and defense but are now declining in intensity. Much of that discussion may be closed to public participation and understanding. In contrast, many aspects of the exploration of the international lunar base can be public and can at the very least involve many policy makers. Such involvement will lend deeper understanding to the debates concerning the expansion of national interests and facilities in deeper space. Attempts to establish cooperative efforts can thus be conducted in a more knowledgeable manner.

international uncertainty and tensions over lunar occupancy can grow rapidly if uses are found for the Moon which imply significant military or commercial advantages. Competing nations might spend enormous sums on parallel commercial or defensive facilities in space and on the Moon that would not result in new scientific advances or economic gain. At the other extreme, an international commitment to a lunar base could reduce world uncertainties. Those resources could go into building shared infrastructure and development of systems that could pay back the investments. An ILB program could provide an economy in transportation and construction. It could promote openness for the sake of safety and national image. It could advance research by reducing duplication of facilities and speed the development of new wealth from that research. If major new methods of wealth production are realized then the cooperation engendered under ILB could expedite development of those resources.

their operation technology development is the life blood of modern economies. An ILB could be used to stimulate this development worldwide much as the Apollo program did in the United States during the 1960s. Various national programs could be organized that emphasize the development of particular elements of the ILB program as a means to enhance the development of those technologies relevant to their own growth. For example, an arid nation might concentrate on tapping solar energy in space and returning it to Earth. These would be difficult tasks to allocate and coordinate. Sufficient openness would be required to deliver components and systems. However, there would be strong forces to retain proprietary knowledge for benefit in international trade. This might be balanced by the favorable publicity and knowledge associated with participating in the ILB.

such as solving radioactivity problems for an ILB will include giving many nations and their citizens opportunities to participate in formulating a return to the Moon, understanding clearly what is taking place there, and allowing some of their people to be spacefarers.

3 Valuation Criteria

The central objectives have been stated above but it appears useful to derive a more detailed list of individual objectives which will allow the comparison of various strategies and lunar base architectures in a more systematic manner. This detailed list can also be subjected to a judgement of decision makers on the relative importance of these objectives at a given time to assist in a difficult choice among many alternatives.

Table 1 is such a detailed list of humanistic, political, scientific and utilitarian objectives. This list of objectives is based on the assumption that such an undertaking is of global nature and not one of competition between nations or groups of nations.

The lunar program as envisaged in this report will take place throughout the latter 21st century, but should be developed and agreed upon before the present century is over. Thus, the political aspects have a great impact in the launching of the advocated program.

Tab. 1: Objectives of a program leading to a Permanent Lunar Base

(a) HUMANISTIC OBJECTIVES

- a-1: assist in reducing tensions and conflicts on Earth, thus contributing to peace on Earth
- a-2: provide opportunity for involvement of a broad spectrum of people in exciting frontier activities
- a-3: enhance the evolution of the human culture
- a-4: establish the first extraterrestrial human settlement as an initial step for expanding human activities in the solar system
- a-5: provide a survival shelter for elements of the human race in case of a global catastrophe.

(b) POLITICAL OBJECTIVES

- b-1: demonstrate the potential growth beyond the limits on Earth
- b-2: provide opportunity for international co-operation
- b-3: provide the infrastructure and experience for global enterprises
- b-4: provide a peaceful outlet for national, competitive high technology and a useful employment of existing industrial-military capabilities
- b-5: enhance the national prestige of participating nations.

(c) SCIENTIFIC OBJECTIVES

- c-1: improve the understanding and control of our own planet
- c-2: improve our knowledge of the Moon and its resources
- c-3: improve our understanding of the solar system beyond the Earth system
- c-4: improve our understanding of the universe beyond our own solar system
- c-5: provide a science laboratory in a unique environment for experiments in physics, chemistry, biology, geology, physiology, and sociology which cannot be conducted on Earth.

(d) UTILITARIAN OBJECTIVES

- d-1: provide rewarding job opportunities and thus, stimulate the economy on Earth in general
- d-2: stimulate the development of advanced industrial technology on Earth
- d-3: produce marketable space products other than in the aerospace industry for extraterrestrial as well as for terrestrial use
- d-4: contribute to the supply on Earth with renewable solar energy
- d-5: provide an isolated depository to store high-level, long-lived and other wastes on the far side of the Moon (if legally possible)
- d-6: provide safe and economical space transportation systems including lunar spaceport and production facilities (mandatory for the exploration of other celestial bodies of the solar system)
- d-7: provide thrust and focus for continued development of space technology other than space transportation systems.

ie relative impo
valuations in th
articipating spec
governments of t
object. 142 judg
ranked list of ob
be above averag

b. 2: Ranked

1. Provide
environ
chemist
sociolog

2. Establis
settleme
human a

3. Improve
resourc

4. Provide opp

5. Provide saf
lunar space

6. Provide thr
other than

7. Provide a p
and a usefu

8. Demonstra

9. Improve th

10. Improve ou
system.

Lunar Base

The relative importance of these objectives was determined by three rounds of valuations in the years of 1988/89 among the members of the Academy and participating specialists. The viewpoint to be taken was that of the national governments of those countries expected to participate in the lunar base project. 142 judgements from participants of 15 nations were integrated into a ranked list of objectives. The ten objectives judged to be most important and be above average are as follows:

b. 2: Ranked list of priority objectives

- 1. Provide a science laboratory in a unique environment for experiments in physics, chemistry, biology, geology, physiology and sociology which cannot be conducted on Earth**
- 2. Establish the first extraterrestrial human settlement as an initial step for expanding human activities in the solar system**
- 3. Improve our knowledge of the Moon and its resources**
- 4. Provide opportunity for international co-operation**
- 5. Provide safe and economical space transportation systems including a lunar spaceport and production facilities**
6. Provide thrust and focus for continued development of space technology other than space transportation systems
7. Provide a peaceful outlet for national, competitive high technology urges and a useful employment of existing industrial-military capabilities
8. Demonstrate the potential growth beyond the limits on Earth
9. Improve the understanding and control of our own planet
10. Improve our understanding of the solar system beyond the Earth - Moon system.

3 The WHAT

3.1 Lunar Surface Activities

3.1.1 Science at the lunar base

A lunar base should incorporate a strong program of investigations in lunar and planetary science, scientific applications of the lunar environment, and science that supports long term capabilities for living on and utilizing the Moon. A science-oriented base can be a straightforward extension of Space Station architecture, as it must provide habitation, power, environmental control, EVA capability, and laboratories. It would be different from orbiting space station in the need to provide surface mobility systems to allow extensive surface traverses, and in the design of specialized scientific experiments. Modifications to space station technology could be required to adapt to the 1/6 g surface gravity, the constant lunar polar environment, and the day/night cycle elsewhere on the Moon. A program for science must be included at a lunar base (Tab. 3) for any kind of a lunar project:

Tab. 3: Typical lunar science program

Lunar global survey	1992-2005	polar orbiter	maps chemistry, topography, for selection of lunar base site
Lunar basecamp	2006-2009	habitation, 100 km mobility daytime visits, limited infrastructure	lunar and planetary science, small astronomical observatory, life science research
Lunar science outpost	2010-2015	expanded habitation long range mobility extensive power communications	extensive labs, advanced astronomical facilities, physics, chemistry, environment studies

Lunar and planetary science:

A lunar base will provide the logistical capability from which the next major step can be taken in understanding the origin and history of the Moon, and, in general, the process of planet formation. Results of the Apollo investigations, particularly the analysis of the lunar samples, have provided general concepts of lunar origin and development that are believed to have much broader applicability. Among these major concepts are:

4. The Moon's volcanism is associated with the formation of the maria basins with

4. Volcanic activity was probably arrested by asteroidal strikes, but I was arrested thinking about it.

1. The Moon originated in a giant collision between a Mars-sized planet and the Earth, very early in solar system history, but after the Earth's differentiation and separation of a core had occurred (Hartmann, 1986).
2. The Moon was endowed with sufficient thermal sources that it melted sufficiently to differentiate a crust and might have included a "magma ocean" stage where the entire lunar exterior was melted. This crust was rich in the mineral plagioclase which was of lower density than the molten Moon and floated upward in the magma ocean.
3. Rather late in the developmental process, about 4 billion years ago, about 500 million years after its formation, the Moon experienced major collisions in which several very large (10^{20} - 10^{21} g) objects excavated the major mare basins (Wetherill, 1976).
4. The Moon's physical properties were such that a period of intensive volcanism subsequently occurred which led to the filling of the mare basins with basaltic lavas, rich in iron-magnesium silicates.

This general model for the Moon is currently accepted, but may not be correct. Particularly, the hypothesis for impact origin and the existence of the magma ocean are widely debated. Clear resolution of these issues will have deep implications for the origin and history of the Earth and other planets of the inner solar systems:

1. If the Moon originated by collision, the time of the collision may be determinable, and important information about chemical and physical state of the Earth as it was just beginning its geological development may be obtained. This information cannot be obtained from Earth, as later geological processes have erased this earliest record.
2. If the Moon had a magma ocean, the Earth could also be assumed to have developed wide-spread melting leading to formation of its crust. However, the earliest observable crust of the Earth is unlike the lunar crust in chemical composition. Why? Similar magma oceans could have dominated the early history of Mars, and without further information, this concept will form the baseline against which Mars' geological history will be assessed when exploration of Mars resumes.
3. A late stage bombardment of the Moon almost certainly was shared by the Earth. Occurring at a formative stage of Earth's crustal evolution, it could have been a particularly important influence in Earth's later development. It is possible that we will be able to find confirming evidence on Earth; however, little evidence of the period before 4 billion years ago remains and details will have to come from the Moon.
4. Volcanic activity has been important in the development of Earth, Mars, probably Venus, and most likely on any planet or satellite of large asteroidal size or larger. The study of lunar volcanism, which probably was arrested about 2.5 billion years ago, should continue to influence our thinking about this important process.

Table 5: Ty

The Apollo Program allowed the collection of rock and soil samples at various locations, the different automated Soviet Lunar Program sampled others. In order to progress substantially in understanding the lunar environment, samples which can be related to mappable rock units will have to be obtained and three-dimensional studies will need to be undertaken. Instruments such as the ALSEP (Apollo Lunar Surface Experiment Package) will be more sensitive and longer-lasting, will be required. The collection of samples, preliminary analysis, and identification of the best samples for return to Earth for intensive study, and the emplacement and monitoring of long-lived geophysical instruments will be principal functions of a lunar base. To enable intensive three-dimensional studies, the lunar base will require substantial surface mobility to reach important geological features and will require capabilities to obtain subsurface samples using deep trenches.

Table 4 defines the necessary elements of a lunar base at an early stage. Siting of an initial base will depend on the specific objectives of the mission. However, an optimum location would probably be near a mare-highland boundary, where both early crust and later volcanic processes can be studied.

Table 4: Requirements for an early lunar science laboratory

- Habitation module(s) for support of crew of 7
- Regenerative life support system
- 100 kW power
- Moon-Earth communication system
- Unpressurized roving vehicle, range of 25 - 50 km
- Solar flare storm shelter
- Materials laboratory
- Surface experiments and small observatories
- 20 meter drill

Astronomy:

A lunar base can be the site of the next order of magnitude increase in astronomical capability beyond the Hubble Space Telescope and the space observatories planned for the next 15 years. The lunar environment for astronomy is characterized by extremely high vacuum, no atmospheric contamination, low radiation background, extraordinary stability, freedom from significant seismic activity, 1/6 gravity, slow rotation, and continuous cryogenic temperatures at the poles. These features offer new wavelengths to be explored, larger antennas to be constructed, increased sensitivity for many classes of observations. Among the facilities for a lunar observatory, the instruments listed in Table 5 will significantly expand observing capability in the years beyond 2000 (1986). Although the age of spaceborne observatories is just dawning, it will be anticipated that the new generation of space observatories, as it develops, will raise as many new questions as it answers old ones.

Large cryogenic
Long baseline in
Large single dis
Very low frequen

A lunar observ
maintenance,
operation; most
communication
instruments, ho
from these imp
required on the

the location of a
the lunar limb,
suggested (Burk
Pyrogenically co
ites.

Physics and chemistry:

the lunar base
fundamental ph
properties of th
include high vac
direct sunlight a
and low vibrati
larged particle
degrees absolute
om cosmic inte

among the re
accelerators; str
rays; hypervel
chemistry analys

Life sciences:

life science lab
ability of tes
development of
widerations. In a
structurally free o
the paraclean condi
organic synt
ilation facility
restrial enviro

Table 5: Typical instruments of a lunar astronomical laboratory

Large cryogenically cooled IR telescope
Long baseline interferometers and arrays (Moon - Moon; Moon - Earth)
Large single dish radio telescope
Very low frequency far side array

A lunar observatory will require the capability inherent in a lunar base (maintenance, development, operation) for emplacement and continued operation; most scientists would remain on Earth utilizing modern electronic communications to direct the observing schedules and changeout of instruments, however, with the large volumes of data that would be expected from these improved instruments, significant data handling power would be required on the Moon also, in order to provide "quick look" information.

The location of a lunar astronomical observatory would benefit from a site near the lunar limb, where shielding from Earth is attainable. It has also been suggested (Burke, 1985) that polar sites may be favorable for emplacement of cryogenically cooled telescopes, due to the access to permanently shadowed sites.

Physics and chemistry:

The lunar base should also provide a general developmental capability for fundamental physics and chemistry. Such a facility would utilize special properties of the Moon's environment for basic research. These properties include high vacuum (10^6 smaller than vacuum of low-Earth orbit), access to direct sunlight and shadow, absence of a significant planetary magnetic field, and low vibration (highly stable). Capabilities such as very long paths for charged particle beams, ease of access to very low temperatures of a few degrees absolute or very high temperatures, and paucity of secondary radiation from cosmic interactions may allow new investigations to be performed.

Among the research areas that could benefit are: charged particle accelerators; studies of very long half-life isotopic or fundamental particle decays; hypervelocity acceleration/impact studies; nuclear fusion, and surface chemistry analysis.

Life sciences:

The lunar environment as a life science laboratory at a lunar base would probably devote its attention to the extraordinary stability of terrestrial life forms to subsist in 1/6 g environment; applied gravity, slow rotational development of a life support system that includes plants; and medical research. These features would be constructed naturally free of organic materials, which should allow experiments where sterile conditions must pertain, such as the analysis of trace constituents listed in Table 5 organic synthesis. Additionally, the Moon could be used as a natural isolation facility for the study of organisms potentially dangerous to the terrestrial environment. Finally, it may be possible to learn more about the origins of life in the universe.

nature of the organic constituents in the early solar system and through time by investigating the endogenic and exogenic carbon cycles of the Moon. Although very low in concentration, the Moon apparently contains indigenous carbon. Carbon is also delivered by the solar wind that perpetually bombards the lunar surface.

Advanced science facility:

The creation of a robust lunar facility can change the nature of science in space. Many experiments now are limited by the high cost of development, very long-lived and highly reliable instruments to merit the expense of transportation to space. As the capability of utilizing lunar materials develops and the range of materials that can be fabricated at the base grows, additional opportunities will appear. For example, large simple antennas for space astronomy may be developed, even though they might not be feasible if they had to be brought from Earth. Neutrino telescopes that would take advantage of a much-reduced radiation background on the Moon to make fundamental new observations seem to be infeasible if material for detectors need to be brought from Earth in the massive amount needed, however, they could be practical if lunar materials can be utilized. At an advanced facility, the capability of instrument repair may provide an alternative to returning instruments to Earth for servicing. All these research activities can be broken down into research tasks. A more detailed compilation and analysis of identified so far some sixty research tasks in the following research fields

Table 6: List of representative lunar research fields

1. Global photographic, geochemical and geophysical mapping of the Moon by a polar orbiter
2. Geological traverses across the Imbrium basin region, the younger basins, investigations of lunar highlands and the poles
3. Search for ore mineral occurrences
4. Passive data collection, search for selenologic/geologic activity
5. Astronomical interferometry
6. Radio astronomy
7. Neutrino astronomy
8. Plasma and field observatory
9. Optical astronomy
10. High-energy astrophysical observation
11. Particle physics
12. Sociology/psychology studies and experiments
13. Health and medicine, human functions and performance
14. Exobiology experiments
15. Biological experiments
16. Material science
17. Applied technology
18. Pilot production facilities and processes.

This tentative scientific activity requires equipment and even less personnel. It is necessary to plan for research tasks.

If we take only the literature, we estimate that from about 30 years ago, it has been estimated that from Earth can do lunar science projects.

3.1.2 A Lunar Facility

Overview:

A sizable number of people on local production growth toward manufacturing on the lunar surface:

The first two goals are to production of a cost/benefit ratio. The nature but could develop its resources. One of the capabilities of the process will take laboratories, space is a major difficulty. materials, on propellants, and raw materials!

Considering lunar that we have to

The objective in feedstocks obtained suitable processes also clear that adequate job.

This tentative list is representative but not complete. It illustrates that these scientific activities require manpower, electrical and thermal power, equipment and facilities. Not all of them can be carried out at the same time, and even less at the very beginning of the lunar science program. Therefore, it is necessary to develop a strategy that assigns priorities and resources to these research tasks as a function of time.

If we take only those research tasks which have been proposed so far in the literature, we can easily stay busy for 30 years with a sizable research staff from about 30 to 100 scientists. The total effort in terms of man-years has been estimated to be between 50 and 1000! The equipment to be flown in from Earth can reach several 100 metric tons. Detailed planning efforts of a lunar science program has to include the support for these activities on Earth!

3.1.2 A Lunar Manufacturing Program

Overview:

A sizable number of studies have shown that a lunar base will strongly depend on local production to become cost effective and offer reasonable prospects of growth towards a lunar settlement. There are at least three classes of manufacturing or materials processing activities which can take place on the lunar surface:

1. Activities to support the lunar base and its growth
2. Activities to support other space operations
3. Activities to support the terrestrial economy.

The first two groups are of the type which can be decided upon with respect to production volume as a function of time purely on the basis of the cost/benefit ratios of each product. Class 3 activities are certainly of long range nature but could ultimately be the real justification to return to the Moon and develop its resources. HELIUM-3 as a fuel for nuclear fusion power plants is one of the candidate lunar products for use on Earth. This evolutionary process will take a long time and begin with material processing in space laboratories, space stations and space factories in near Earth orbits. But there is a major difference: In low Earth orbit lies the emphasis of refinement of materials, on the lunar surface the emphasis is the production of food, propellants, construction materials and many other useful things from local raw materials!

Considering lunar manufacturing from the systems viewpoint, it becomes clear that we have to take into account at least the following factors:

- o mass of equipment
- o man-hours per year
- o personnel safety
- o probability of success or risk
- o lunar environmental impact
- o scientific or utilitarian value.

The objective in general is to produce the broadest possible range of industrial feedstocks obtainable from lunar sources. However, it will take time to develop suitable processes and install the equipment required. On the other hand it is also clear that a "stone age" or "iron age" culture will not be sufficient to do an adequate job.

Markets:

Materials availability and processing technology:

The natural resources of the Moon include major elements that can be extracted from common rocks (oxygen, iron, titanium, aluminum, calcium, silicon and magnesium) and the trace elements that may be extractable from the lunar soil (hydrogen, helium, carbon, nitrogen and sulfur). It is clear that with abundant energy, the basic materials to support life, provide structural materials, produce propellants, and form the basis of a varied manufacturing capability, are available.

Silicates and oxides in the lunar rock and soil can provide the raw materials for non-metallics, such as glasses and ceramics. Sintering a lunar soil or the lunar cement as a basis for making solid construction materials has been proposed.

Some elements can be separated from lunar soil by simple heating. These include hydrogen, helium, carbon, and nitrogen. These are elements that are from the solar wind and are ubiquitous, but present only in the 100 parts per million (by weight) range. Metallic iron also exists in the soil in small amounts and could be concentrated by magnetic separation followed by heating.

Considerable thought and some experimentation have gone into the development of processes to extract oxygen and metals from lunar materials. The principal approaches include chemical extraction and electrolysis, although plasma processes have also been proposed. Among the chemical processing techniques, procedures that can separate virtually all elements from lunar rocks, such as carbo-chlorination or fluorine oxidation have been studied theoretically. These procedures utilize a flux or reactant that must be recovered or reconstituted. A special case, hydrogen reduction of the mineral ilmenite (iron-titanium oxide) has been developed to a bench scale. In this process, the water produced by the reaction is electrolyzed and the hydrogen is recycled. Systems to contain and recycle reactants are a fundamental requirement. Energies needed are similar to those needed to produce materials in terrestrial processes.

Alternative means of extracting metals by direct electrolysis of molten silicates have been studied. It appears feasible to extract iron, titanium, silicon, and oxygen in this manner. The process could use solar thermal energy to heat the raw material, and electrical energy for the separation. Total electrical energy requirements might be smaller than that required for reconstitution of reactants in chemical processing. Lunar exploration to date has not discovered high concentrations (mineral deposits) of otherwise rare lunar elements. It is not surprising, as the number of sites sampled has been small and not detailed. Among the elements that might be discovered by future exploration that could be useful to lunar development, water is the most outstanding. Lunar water is probably surface-related, coming from long-term outgassing reactions of solar wind species, and impacts of comets. Water may be trapped in cold polar regions or in the vicinity of comet impact craters. The U.S. Observer Mission and the Soviet Lunar Polar Orbiter planned for the near future could discover concentrations of water, should they be present.

At the current state of materials development, the extraction of materials from the Moon is a major task. Helium-3, which is recovered from the lunar soil, can be used to regain the energy used in its extraction, and is a valuable resource for a variety of uses.

Lunar materials development has a wide range of applications, including shielding, and speciality uses. The developed materials can be used in a variety of ways, including as a base for construction materials, and as a source of raw materials for manufacturing.

Manufacture of materials from lunar resources is a major task. The principal approaches include chemical extraction and electrolysis, although plasma processes have also been proposed. Among the chemical processing techniques, procedures that can separate virtually all elements from lunar rocks, such as carbo-chlorination or fluorine oxidation have been studied theoretically. These procedures utilize a flux or reactant that must be recovered or reconstituted. A special case, hydrogen reduction of the mineral ilmenite (iron-titanium oxide) has been developed to a bench scale. In this process, the water produced by the reaction is electrolyzed and the hydrogen is recycled. Systems to contain and recycle reactants are a fundamental requirement. Energies needed are similar to those needed to produce materials in terrestrial processes.

While it appears that the extraction of materials from the Moon is a major task, the development of materials from lunar resources is a major task. The principal approaches include chemical extraction and electrolysis, although plasma processes have also been proposed. Among the chemical processing techniques, procedures that can separate virtually all elements from lunar rocks, such as carbo-chlorination or fluorine oxidation have been studied theoretically. These procedures utilize a flux or reactant that must be recovered or reconstituted. A special case, hydrogen reduction of the mineral ilmenite (iron-titanium oxide) has been developed to a bench scale. In this process, the water produced by the reaction is electrolyzed and the hydrogen is recycled. Systems to contain and recycle reactants are a fundamental requirement. Energies needed are similar to those needed to produce materials in terrestrial processes.

Markets:

At the current development stage of space industry, and considering the range of materials available on the Moon, most lunar materials will not merit development for use on Earth. A possible exception is Helium-3, an isotope of helium that is present in small quantities on the Moon, but is absent on Earth, and can find application in terrestrial nuclear fusion reactors. The energy recovered from Helium-3 in a fusion reactor is so great that it is possible to regain the energy of extracting and transporting it to Earth by a factor of more than 200. However, fusion reactor technology has not developed to the stage where Helium-3 can be confidently called a lunar resource.

Lunar materials have been proposed for use in space, where they compete with materials brought from Earth. Among the materials that may merit development are lunar oxygen for propellant, metals for structures and shielding, and unprocessed soil, glasses and ceramics for shielding and speciality uses. Their extraction has been described above. Whether they will be developed for export to other space destinations, depends on economic competition with materials from Earth, but the prospects look very good. There is little doubt that lunar materials should be utilized in support of lunar base operations. Losses of expendable materials (oxygen, water, nitrogen) could be replaced with relatively small extraction units. Utilization of metals, sintered products, glasses, ceramics, and concrete for base extensions of habitable facilities would allow for more rapid expansion of facilities. Manufacture of photovoltaic devices from silicon extracted from lunar rocks or from lunar ilmenite appears possible, and could form the basis of expanding lunar power facilities. Many of these capabilities could later develop into exports for lunar industry.

Processing and manufacture of lunar materials will have to take into consideration the characteristics of the lunar environment, but may also benefit from that environment. Little is known at this time of the effect of 1/6 gravity and high vacuum on the basic industrial processes that would be carried out. At first, to help build and expand the lunar base, the range of basic materials will be small, the range of uses wide, and the quantities required small. This suggests that development of a very flexible machine tool manufacturing capability will be a crucial step, consisting of a small foundry and sufficient basic tools to create the needed specialized tools. This could also function as a shop for repair of existing systems.

While it appears likely to begin with simple physical beneficiation of lunar soil to accumulate glass and iron powder, this will have to be supplemented by refined ways to produce raw materials, building materials and liquid oxygen at the earliest practicable time. True growth in capacity will require growth in power and capital equipment, including plenty of automation and robotics, but slower growth in human population. To accomplish this the lunar factory must make solar or other power converters, building products including pressure vessels, tools, radiators, construction equipment and even vehicles. But it should not be overlooked that there will always be a demand for specialized equipment of high value to be imported from Earth. Thus, logistic cost will be the decisive factor and requires continuous attention. Lunar resources can greatly contribute to keeping down the logistics support costs for the lunar base.

While the logistics of the lunar base will be a priority task, also of importance is the availability of energy for lunar manufacturing activities. Of all the capabilities which could be developed on the Moon, certainly one of the most important is the in-situ conversion of solar energy into electricity. Photovoltaics will play a major role in this technology because they are suitable for large scale application. The raw materials for solar mats are locally available and are suitable for fully automatic production. A lunar base with multi-megawatt capacity could chemically process lunar materials at rates in excess of 1 metric ton per hour, could deploy material to the Moon at velocities at several tons per hour and could beam power to cis-lunar plants with microwave arrays. Although there are great potentials for human-tended production, a detailed, integrated plan consistent with available resources has yet to be developed.

Program structure and elements:

A first architecture of lunar production has the following basic structure:

Tab. 7: Architecture of lunar production

- I. Primary organizational dimensions:
 1. Product groups and markets
 2. Functions to be performed
 3. Subsystems and elements required
 4. Locations of activities, facilities and equipment
- II. Locations:
 - a. Lunar base camp
 - b. Outposts at some distance from the base camp
 - c. Lunar orbit
 - d. Neutral gravity point between Earth and Moon (L-1)
- III. Product groups:
 - (1) Air, nutrition, food, water
 - (2) Propellants
 - (3) Building materials
 - (4) Metal products
 - (5) Non-metal products
 - (6) Electrical and thermal power
 - (7) Information
 - (8) Services

A first list of detailed functions to be carried out at a fairly advanced lunar base with considerable production capacity is presented in Table 8. To carry out these functions a lunar factory would require the subsystems identified in Table 9.

Figure 2 is an attempt to correlate these functions and subsystems which can be extended to the element and component level as the planning process for the lunar factory evolves.

Tab. 8: Typical lunar production

Product	Production rate
Aluminum	100 tons per hour
Steel	100 tons per hour
Plastic	100 tons per hour
Chemicals	100 tons per hour
Food	100 tons per hour
Water	100 tons per hour
Propellants	100 tons per hour
Building materials	100 tons per hour
Metal products	100 tons per hour
Non-metal products	100 tons per hour
Electrical and thermal power	100 tons per hour
Information	100 tons per hour
Services	100 tons per hour

Production plants

Tab. 9: List of detailed functions

Function	Production rate
1-1: Mining	100 tons per hour
1-2: Beneficiation	100 tons per hour
1-3: Primary processing	100 tons per hour
1-4: Secondary processing	100 tons per hour
1-5: Tertiary processing	100 tons per hour
1-6: Distribution	100 tons per hour
2-1: Production of primary products	100 tons per hour
2-2: Production of secondary products	100 tons per hour
2-3: Production of tertiary products	100 tons per hour
2-4: Production of quaternary products	100 tons per hour
2-5: Production of quinary products	100 tons per hour
2-6: Production of quaternary products	100 tons per hour
3-1: Support functions	100 tons per hour
3-2: Maintenance	100 tons per hour
3-3: Extension	100 tons per hour
3-4: Collection	100 tons per hour
3-5: Storage	100 tons per hour

also of import
activities. Of all gr
certainly one of

Tab. 8: Typical lunar manufacturing program

Adapt available technology	1980's-1990's	Earth laboratories	Evaluate available technologies
Lunar global survey	1990's	Lunar orbiter	Establish resource potential, select base location
Automated pilot plants	2000-2005	Automated, self-contained landers	Site inspections, 2-3 processes
Human-tended small plants	2006-2015	Small package plants; habitation; power	Sortie missions for maintenance
Production plants	beyond 2015	Full production plants, hab. extensive power	Delivery of product full time maintenance crew

basic structure:

Tab. 9: List of detailed functions of extraterrestrial production

- Production of raw materials:
- 1-1: Mining of minerals
 - 1-2: Beneficiation of minerals
 - 1-3: Production of raw materials /feedstock
 - 1-4: Production of propellants
 - 1-5: Production of metal products (ingots, sheets, plates, wires, cables ...)
 - 1-6: Production of non-metallic raw products (fibers, crystals, solar cells...)
- Production/manufacturing of end-products:
- 2-1: Production of structural components and elements (bricks, pipes, panels, mats, brackets, beams, radiators...)
 - 2-2: Production of foodstuff (vegetables, meats, water, air...)
 - 2-3: Production of other products for own use (solar panels, filters, tools...)
 - 2-4: Production of other products of export (energy, Helium-3, pharmaceuticals...)
 - 2-5: Assembly operations using produced and imported parts and components
 - 2-6: Services produced for export (maintenance and repair of space vehicles, rent of laboratories, support of external research activities, tourism...)
- Direct production support operations:
- 3-1: Supervision and control (of manufacturing processes, facilities and equipment including infrastructure)
 - 3-2: Maintenance and repair of facilities and equipment
 - 3-3: Extension of facilities
 - 3-4: Collecting and recycling (of trash and scrap)
 - 3-5: Storage operations

SUBSYSTEMS (● Prime X Secondary)	SYSTEM FUNCTIONS									
	A Mining Fac. & Equipment	B Mechanical Shops	C Chemical Prosc. Fac. & Equip.	D Electrical/Electronic Shops	E Biological Prod. Fac.	F Assembly Fac. & Equip.	G Transportation Fac. & Equip.	H Power Infrastructure	I Maintenance & Repair Fac.	J Research Labs. & Fac.
1-1 Mining of Minerals	●						X			
1-2 Beneficiation of Minerals	●	X					X			
1-3 Prod. of Raw Material & Feedstock		X	●	X	X					
1-4 Production of Propellants			●							
1-5 Production of Metal Products		●	X							
1-6 Prod. of Non-Metal Raw Products		X	●	X	X					
2-1 Prod. of Structural Comp. & Elem.		●				X				
2-2 Prod. of Foodstuff					●					X
2-3 Prod. of other Products for own use		●	●	●	●					
2-4 Prod. of other Products for Export		X	X	X	X					
2-5 Assembly Operations					X	●		X	●	X
2-6 Services Produced for Export						●				
3-1 Supervision and Control	X	X	X	X	X		X	X		
3-2 Maintenance & Repair of Fac. & Equip.									●	
3-3 Extension of Facilities		X	X	X		X			●	
3-4 Collecting and Recycling		X	X	X	X	X	X	X	X	X
3-5 Storage Operations			®							
4-1 Local Transportation	X	X	X	X	X	X	●	X	X	X
4-2 Power Conversion, Storage & Distrib.	X	X	X	X	X	X	X	●	X	X
4-3 Habitation										●
4-4 On Site Training of Personnel										●
4-5 On Site Research Activities										●
4-6 On Site Administrative Services										●
4-7 Logistics & Space Transportation					X		●			

Fig. 2: Correlation of functions with subsystems

4. Indirect p
4-1: I
4-2: P
4-3: P
4-4: C
4-5: C
4-6: C
4-7: I

We can already
products and f

Tab. 10: Tenta

PRODUCTION

- A. Mining f
- earth
B. Mechan
- furna
C. Chemica
- for g
D. Electrica
- circu
E. Biologica
- food,
F. Assembl
- tools,
G. Transpor
- space
H. Power in
- conve

INFRASTRUCT

- I. Mainten
- fixed
J. Research
- contr
selfsu
K. Habitats
- living
facili
L. Storage
- prop
M. Control
- comm
equip

4. Indirect production support activities:

- 4-1: Local transportation (within extraterrestrial complex)
- 4-2: Power conversion, storage and distribution
- 4-3: Habitation (life support, housing, recreation, health services...)
- 4-4: On site training of personnel
- 4-5: On site research activities in support of own needs (exploration, observation, experimentation)
- 4-6: On site administrative services (personnel management, financing, planning, legal aspects, public relations...)
- 4-7: Logistics and space transportation.

We can already identify the equipment and facilities which go along with the products and functions required. A tentative list is as follows:

Tab. 10: Tentative list of lunar base subsystems

PRODUCTION FACILITIES & EQUIPMENT

- A. Mining facilities and equipment
 - earth movers, beneficiation equipment, drills
- B. Mechanical processing shops
 - furnaces, mills, presses, numerically controlled machine tools
- C. Chemical processing facilities and equipment
 - for gases, liquids and solids
- D. Electrical/electronic shops
 - circuitry, solar cells
- E. Biological production facilities
 - food, flowers, animal farms
- F. Assembly facilities and equipment
 - tools, jigs, shops
- G. Transportation facilities
 - space and ground transportation systems and facilities
- H. Power infrastructure
 - conversion, storage and distribution facilities

INFRASTRUCTURE FACILITIES & EQUIPMENT

- I. Maintenance and repair facilities
 - fixed and movable workshops, tools and equipment
- J. Research laboratories and facilities
 - contract facilities, product development, research supporting selfsufficiency
- K. Habitats
 - living quarters, recreation facilities, space suits, hospital, training facilities
- L. Storage facilities
 - propellants, import products, export products, spares, trash
- M. Control facilities
 - communication, data storage, data processing, operational control equipment, software, administrative facilities.

3.1.3 Developing the Lunar Infrastructure

If humans are to reside continuously and productively on the Moon, they must be supported there by an infrastructure having some attributes of the support systems that have made advanced civilization possible on Earth. Building this lunar infrastructure will - in a sense - be an investment. Creating it will require large resources from Earth, but once it exists it can do much to limit the further demands of a lunar base for Earthside support. The term "infrastructure" as used here means a complex of hardware, software, and operating procedures that makes it possible for organized human activities to be carried forward. While a material life support system may be considered fundamental, an energy conversion system is even more so because life support depends on it. And both depend on information: human knowledge for their original design, and data flows for their operation. Thus, an operating lunar infrastructure may be thought of as a machine handling information, energy and matter. This machine will have to go through an evolutionary development, starting with limited capability and expanding over time. At first, the machine will merely sustain humans, enabling them to use energy to transform matter, and generate information for the next steps. But soon, properly planned and executed, infrastructure development should pass beyond these early functions as civilization has done on Earth, to enable "bootstrapping" or "breakout" behavior resulting in the appearance of new and unanticipated information: scientific discoveries and other intellectual achievements, arts, entertainments, perhaps new social structures.

Thus, the lunar infrastructure will grow by accretion. At the outset it will probably comprise a powerplant, a habitat, experiment modules and a limited complement of teleoperators for construction and transport on the lunar surface. Initially, one would need an electrical power supply in the 500 kW to 1 MW range and would make maximum use of sunlight and power plant waste heat for thermal processing and environmental control. Information processing in the gigabit/sec. range within the station and in the megabit/sec. range between the station and Earth appears practical. Processing of matter in this early phase would be limited to recycling for essential life support and agricultural research experiments.

Assuming successful, stable operation of the first encampment, with several crew replacements and a continuing flow of earthside supplies, the infrastructure should grow to the point where large increases in energy, matter and information processing rates could occur: multi-megawatt electrical power, multi-ton daily matter handling, robotics supplementing teleoperation, and gigabit/sec. data rates to and from Earth. Large and powerful robots, transporters, roadways, a power grid, and small settlements and outposts would spread over the lunar surface at an increasing rate. It is quite likely that, in this sense, the self-reproductive organism might be the key concept for the industrialization of the Moon. This will be a very long process and we cannot predict the rate of progress in this direction because we do not have the knowledge today to understand such an evolutionary process. In spite of this, even incomplete or partial self-reproductivity should be pursued on the Moon within the available state-of-the-art.

One part of development. In this sense, development length of the network would be time, however

The decision on many infrastructure boundary conditions created to develop models are chemical reactions, simple tracking seats for surface, thus will likely be will prepare possible to in

3.1.4 Development

The primary very high cost people who possible to and barren providing for

Any consideration approach with other and will determine the continuing h

Events occurring and actions, future. Thus will be formed occurring no

The impact There are very narrowed a

One part of the lunar infrastructure will require early efforts. It is the development of a road structure to explore the lunar surface and its resources. In this sense, the lunar surface transportation system is a key element in lunar development. The construction of this sub-system will take time since the length of the equator is close to 10 000 km, thus, a criss-crossing road network would require about 100 000 km of roadways. It is not clear at this time, however, whether or not an extensive road system is desirable.

The decision as to which means of conveyance should be preferred depends on many influencing factors such as transportation requirements, physical boundary conditions and economics. The first system models have been created to define its elements and the relations among these elements. Such models are required to compare alternative transportation systems such as chemical rockets, electric cars, maglev-trains, cableways, mass drivers and simple tracked vehicles. During the Apollo missions the "Moon-cars" with two seats for suited astronauts travelled already almost 100 km over the lunar surface, thus we are not starting from scratch. Wheeled and tracked vehicles will likely be the initial means of transportation for small distances. But one will prepare soft and hard roads in the vicinity of the base as quickly as possible to increase the travel speed and thus conserve precious man-hours.

3.1.4 Developing the Social Infrastructure

The primary ingredient in a lunar settlement program is the people. At the very high cost that will be required to transport, maintain and supply the people who will staff the lunar operations, it is important to do everything possible to ensure their continued effectiveness in such an isolated, confined, and barren environment. This section identifies some of the issues involved in providing for effective human performance in lunar settlements.

Any consideration of the development of a lunar settlement requires an approach which links the social, economic, and technical factors with each other and with their context. The combination of all of these elements will determine the degree of success of not only the lunar settlement, but also the continuing human presence in space.

Events occur within the flow of time, and are the culmination of past decisions and actions, as well as being the foundation for events that will occur in the future. Thus, the character and success of any lunar settlements that are built will be formed by decisions and actions that have already occurred, are occurring now, and will take place in the near future.

The impact of decisions and actions over time has an element of timeliness. There are windows of opportunity and vulnerability that are continuously narrowed as decisions limit the range of available alternatives. Options and

opportunities for a successful lunar settlement are still ample, and in fact, are probably enhanced because of the early consideration being given to design and use relationships. However, these windows close rapidly and the Lunar Settlement windows for success may be enabled or constricted by decisions made regarding the space stations which will be precursor facilities.

In designing space facilities, also those on the lunar surface, we have to realize that the way facilities are designed will drive the character and success of the operations to be carried out in and with them. Furthermore, long duration missions in isolated and confined environments are qualitatively different from short missions and require a different approach for mission operations, crew selection and training and ground involvement. These factors are synergistic with the design features of the facility, and hence need nearly delineation in order to be accommodated in the design and development process. Because the actual missions are so many years away, however, these requirements need to permit a high degree of flexibility to accommodate the unexpected and unanticipated features of the future.

A great deal of work has been done on understanding the technical and physical relationship of settings to performance, so that "Human Factors" has become a systematic discipline which is now able to identify patterns and their relationship to outcomes according to rigorous criteria. The findings of this discipline are being adapted to the unique situations of space environments in terms of isolation and confinement, and also in terms of variable gravity. Human factors "standards" are currently being developed for application to space facilities, and will be available for use in lunar settlement design.

The organic environment in totally closed, "built environments" is critical in determining crew health, and also impacts housekeeping and monitoring activities that are related to crew performance rates and expenditures of precious time. The role of plants and other life forms in the formation of totally closed life support systems is very important from the perspectives of resupply from Earth, health, and psychological support. However, much is yet to be understood about the interactive consequence of various organic substances in totally closed environments of limited volume.

We do know that the physical and technical setting in which a group lives and works has a significant impact on the tone and capabilities of group members to function successfully and productively. Setting deprivation can result in extremes of grotesque accommodations, can amplify error, or can increase stress and fatigue, and hence result in an increase in the general rate and nature of mistake and errors team members make in their work. Studies that have been done on settings as a causal variable have shown that the setting has a major impact on the ability of people to act effectively, and changes in the setting result in changes in performance.

Group dynamics are the most important factor in the success of lunar missions and settlements. Confined environments are dynamic of common experience. Submarines, Soviet long duration qualitative missions considered missions extended over longer

It is possible for them to perform factors including members, different skill mix as activities, communication are not present and access

In lunar settlements, ineffective construction of human settlements

Both building use and application of information treatment of resources

Since known lunar settlements, thinking, a generate the of the quality decade - and Working resources"

Group dynamics is probably the newest area for the aerospace community, and the most unfamiliar. However, with the advent of very long space station missions and lunar settlements, which will need a high degree of autonomy, success will be significantly impacted by the ability of groups in the lunar settlements and on Earth to interact together synergistically. In isolated and confined environments, individual performance is highly related to the dynamic of the group's composition, organization, training, skill base, and common experience. From past analog studies of the Antarctic, nuclear submarines, oceanographic research vessels etc. as well as reports of the Soviet long duration space station flights, it has been found that there is a qualitative difference between short and long duration missions. Short missions could be considered about 28-30 days. Beyond that missions are considered long. Thus, it is not possible to extrapolate from current short missions experience by assuming that the experiences are simply "additive" over longer missions.

It is possible to identify numerous factors in the context of a group, and tie them to performance success rates of individuals as members. Some of these factors include types of decision-making systems, compatibility factors of members, degree of autonomy and control of both the group and its members, skill mix as a factor in workload and job variety, opportunities for creative activities, physical volume and layout as it affects privacy, personal communications, and group activities, relationships to family and friends who are not present in the group, role variety, clarity of mission goals and limits, and access to conflict management skills.

In lunar settlements, the cost of retrofitting the environment and replacing ineffective crews would be exorbitant. For real success in lunar activities, then, it will be as important to build strength in sociotechnology as it will be in building hardware. The goal is to become highly effective in the construction of the institutions and systems needed to support and operate human settlements.

Both building and operating the lunar settlement will be an exercise in the use and application of information, that is, it will require the effective use of information, networks, long range planning, international participation, and a treatment of the investment as one tied more to the success of human resources than to financial or technological resources.

Since knowledge is a human phenomenon, the character and nature of the lunar settlement will need to foster the observations, experimentation, thinking, and creativity of the people living and working there in order to generate that new knowledge. Scientific and practical interest in this aspect of the quality of the work environment has grown enormously over the last decade - another manifestation of the emerging importance of information. Working smarter, enhancing productivity, and focusing on the "human resources" has been found to be good business.

In a lunar settlement, far away from Earth, surrounded by electronic and mechanical systems that protect them, support them, with which they work and which connect them to the Earth, the people will be the critical link - the crux of the total system. No person, machine, or situation is entirely predictable. Thus, it will be the settlement team who coordinate all of the real time variables into action. The settlement team is the final line of control.

This small cross-disciplinary group of people will be the ultimate decisionmakers in the management and direction of all the hardware and software. To do that effectively, they will need to be resourceful, flexible, accurate, timely, agile, adaptable, reliable, and correct more often than not. Their ability to think, access, interpret, invent, react, strategize, coordinate resources, initiate changes, and interact will be the key to the amount of focused and congruent action they will take, and will determine the degree of their success.

Studies on productivity have shown that there is a direct connection between the conditions within which people live and work, and the quality of their actions. The environment influences fatigue, stress, mobility, perception, and general emotional tone. The organization and group dynamics influence communication, motivation, evaluation, as well as stress and tone. Added to general health, these factors are critical in the perception, interaction, and decision-making processes of the individual, and subsequently the group and its capacity to perform successfully.

To enhance the performance of the team, then, it is necessary to do as much as possible to enhance the conditions within which they live and work. A lunar settlement is a facility - a permanent "place in space" to be staffed by interdisciplinary teams of people who come from many countries, cultures and communities and will be living together, building things, and pursuing knowledge and information as teams. In this situation, the industrial/technical approach is incomplete. The focus will be on the quality and amount of information the facility can provide. Enhancing the conditions within which the flight and ground teams live and work is part of the emphasis on human resources as the major variable in influencing the quality of the information and product outputs and hence the ultimate value to be achieved.

We will build a lunar habitat - that is more than likely. Since this is to be a completely built life space, we need to realize that the quality of the context to create for the humans who go out to live on the Moon will have a major effect on the type and quality of life of all of the humans who live off the Earth, as well as on it. Since, we will be starting new communities, we have an option that has not been available to many before us as we can set the pace and the tone for designing human/technical synergy to a degree that has not been done before.

3.1.5 Devel

Thanks to th
fairly good u
from the Moo
surface. Neve
work before v

Table 11 list
identifying th
general, clas
Station Prog
includes hal
systems; ph
communicati

The following
be taken up:

- New plan
- long term
- contamin
- mobile sr
- automate
- closed lif
- long term
- long life
- space ma
- electro-m
- photovolt
- simulated
- lunar soi
- productio
- productio
- energy st
- hypervelo
- productio

A more syste

3.1.5 Developing the Technology

Thanks to the Apollo program and its supporting research activities we have a fairly good understanding of what is involved to provide transportation to and from the Moon, and also what we have to do to establish a base on the lunar surface. Nevertheless, there many research tasks awaiting attentions and hard work before we have all the technology at hand to realize such a plan.

Table 11 lists some possible design choices for initial and later lunar bases, identifying the types of technologies that would be needed. It appears that, in general, classes of space technology being developed for the U.S. Space Station Program can be easily modified for use on the lunar surface. This includes habitation modules and interconnects; regenerative life support systems; photovoltaic or solar dynamic and nuclear power systems; and communication and data systems.

The following are some technologies to be developed and research subjects to be taken up:

- New plant varieties for lunar farms,
- long term response of people, animals and plants to 1/6 g and toxic contamination,
- mobile smart robots,
- automated mining and manufacturing processes and equipment,
- closed life support systems,
- long term effects of off-Earth living,
- long life rocket engines,
- space maintainable rocket engines,
- electro-magnetic accelerators,
- photovoltaic collectors on compressed simulated lunar soil,
- simulated deposition of amorphous thin films,
- lunar soil refinement methods and equipment,
- production of rocket propellants on the Moon,
- production of liquid oxygen on the Moon,
- energy storage systems for lunar night application,
- hypervelocity fine particle impact phenomena,
- production of optical and microwave mirrors using lunar feedstock.

A more systematic list is offered in Tab. 11.

Tab. 11: Technologies for the Moon - from initial bases to selfsufficiency

System/Technology	Early Base	Mature
SPACE TRANSPORTATION		
Earth to orbit - heavy lift vehicles	X	X
Orbital transfer vehicles	X	X
Spaceports		
- Earth orbit	X	X
- Lunar orbit	-	X
Low thrust propulsion	-	X
Lunar landers (cargo and human-rated)	X	X
Lunar launch facility	X	X
LUNAR SURFACE INFRASTRUCTURE		
Nuclear power plant	X	X
Solar energy conversion		
- Terrestrially fabricated	X	-
- Lunar fabricated	-	X
Habitation modules		
- Modified space station modules	X	-
- Utilizing lunar materials	-	X
Lunar Mobility		
- Short range, electric rovers	X	X
- Long range, fixed bed	-	X
Construction, mining equipment		
- Simple (loaders, cranes, trucks)	X	-
- Complex	-	X
SPECIAL PURPOSE EQUIPMENT/FACILITIES		
Scientific experiments/laboratories		
- Apollo and space station derivatives	X	-
- Special purpose, utilizing indigenous materials	-	X
Materials processing plants		
- chemical extraction	X	X
- solar thermal processing	-	X
Manufacturing/fabrication		
- simple	X	-
- complex	-	X

3.2 Lunar Lo

3.2.1 The Stat

The past space produced a va activities have develop detaile the members o make a judge discussed. The relative consen

Tab. 12: Ranke

- Refueling sta
- Chemical pr
- space transp
- The present
- lunar space
- Eventually n
- early lunar c
- Mission stag
- Space station
- for the initia

Using these ju be grouped into

- A. Firm kn
- B. Conclus
- C. Prelimin

The following s present state- development:

Tab. 13: Space

- A. Firm know
- A-1 The Apoll
- space tran
- transport
- and back.

efficiency

Mature

3.2 Lunar Logistics

3.2.1 The State-of-the-Art

The past space program, including the manned lunar landing project, has produced a vast body of knowledge. Numerous studies and experimental activities have contributed greatly to our present insight and enable us to develop detailed plans for a permanent lunar base. In 1987 through 1989 the members of the Academy and some external specialists were asked to make a judgement on some of the issues of lunar logistics presently discussed. The results of this questioning is best summarized by listing the relative consensus achieved on the issues queried:

Tab. 12: Ranked list of relative consensus on lunar base logistic issues

- | | | |
|---|---|------|
| - | Refueling station in lunar orbit is mandatory or desirable | 94 % |
| - | Chemical propellants are a clear choice for first generation lunar space transportation systems | 85 % |
| - | The present SPACE SHUTTLE is not a suitable backbone of a lunar space transportation system | 80 % |
| - | Eventually non-chemical propulsion systems will complement the early lunar cargo space transportation system | 78 % |
| - | Mission staging in lunar orbit is the preferable mission mode | 76 % |
| - | Space stations in low Earth orbit should be used as a staging area for the initial passenger flights to the lunar base. | 73 % |

Using these judgements and other information, the available knowledge can be grouped into the following three categories:

- A. Firm knowledge from past experience
- B. Conclusions with a high degree of confidence
- C. Preliminary conclusions to be verified.

The following statements, listed in a logical manner, are summaries of the present state-of-the-art available or to be expected for a lunar base development:

Tab. 13: Space transportation system "state-of-the-art"

A Firm knowledge:

- A-1 The Apollo program has demonstrated in a convincing manner that space transportation systems using chemical propellants can safely transport people and cargo from the Earth surface to the lunar surface and back.

- A-2 The Soviet Union has demonstrated convincingly that logistic flights to supply space laboratories can be fully automated and provide reliable access to space facilities. It has also shown that launch rates of more than 100 p.a. are feasible.
- A-3 Hydrogen/oxygen propulsion systems are the primary candidates for cislunar space transportation systems providing the logistics support of a permanent lunar base.
- A-4 Staging of lunar missions in lunar orbit has proven to be feasible and efficient, it should be part of the logistics concept.
- A-5 The annual payload capacity of the Earth launch vehicle and its cost effectiveness will determine the overall cost and growth rate of a lunar base more than any other factor.
- A-6 Production of liquid oxygen on the lunar surface offers to improve the efficiency of lunar transportation systems and should therefore receive a high priority. Its priority is higher than that for developing other propulsion systems.

B. Conclusions with a high degree of confidence

- B-1 Launch vehicles presently in the inventory of the USA and other Western countries will not suffice to provide efficient logistics support in cislunar space. The ENERGIA launch vehicle of the USSR could possibly be modified to be used in such an operation.
- B-2 The present US Space Shuttle (STS) will have served its purpose by the time the lunar base program will reach an operational stage and should not be considered as an element of a permanent lunar space transportation system.
- B-3 In conceptualizing lunar space transportation systems the most simple flight profiles and technical solutions should be chosen because they will turn out to be the most attractive ones considering cost, risk and availability. Conservative approaches are preferred over sophisticated solutions.
- B-4 Transportation of passengers and cargo should use a high degree of technical commonality, but be decoupled for reasons of flexibility and efficiency, also to avoid a choking point in the growth of the lunar base.
- B-5 The space station in low Earth orbit can be used initially as a staging point for personnel transportation to and from the Moon, but it would be overburdened by servicing activities for cargo flights. These should go directly to the lunar orbit station.

C. Preliminary conclusions to be verified

- C-1 A medium-sized automated cargo vehicle may become available within the next 15 years in the USA. Its payload capability to LEO is estimated to be in the order of 50 metric tons (Cargo Shuttle or Advanced Launch Vehicle).
- C-2 A second generation space shuttle will likely be available in about 15 to 20 years having a smaller payload capability than the present version, but it will be fully reusable and more cost effective. An air-breathing first stage appears attractive from the operational viewpoint. It should be used for the transport of passengers and small cargo between the Earth surface and the space station in the low Earth orbit.

- C-3 By the Earth's Moon. operati
- C-4 The tec this ce vehicle might l
- C-5 It appe chemi transp transpo chemi

These facts design and the next cen

3.2.2 The S

The mission problems to APOLLO prop cargo and pa serve as a tr serve as a r Earth surface. simplicity, the stage of the from lunar o mode (Fig. 5)

The passeng Earth surface crews to the multi-engine. The same fer in the Earth the crew bo surface in a lunar orbit a very similar shield is excl propulsion s Eventually a employed.

Maximum u produced on Earth orbit a

- C-3 By the turn of the century there will probably be two space stations in Earth orbit that can provide services to space ferries going onto the Moon. Considerable experience will be at hand in all facets of orbital operations including orbital launch operations.
- C-4 The technique of aerobraking is expected to be available by the end of this century and should be the adopted design principle for all space vehicles returning to Earth orbit. Similar techniques (dust braking) might be applied at a later stage during some lunar landing operations.
- C-5 It appears unlikely that propulsion systems other than high energy chemical propulsion systems will do a better job in cislunar transportation missions for the foreseeable future. Passenger transportation will probably always depend on propulsion systems with chemical propellants.

These facts and insights will allow us, with a high degree of confidence, to design and develop lunar space transportation systems for the early part of the next century which will satisfy the requirements in an efficient way.

3.2.2 The Standard Mission Modes

The mission mode selected as a flight profile to illustrate the logistics problems to be solved is very close to the mission mode used during the APOLLO program (see Fig. 3). It uses mission staging in lunar orbit for both cargo and passenger transportation tasks. A manned lunar orbit station will serve as a traffic node, e.g. a refueling and maintenance facility. It will also serve as a rescue station. All lunar cargo flights will go directly from the Earth surface to the lunar orbit station and from there onto the lunar surface. They will bypass the Earth space station for reasons of operational simplicity, flexibility and minimizing cost. The empty tanker stages (3rd stage of the launch vehicle) will return directly to the Earth launch site from lunar orbit by aerobraking and execute a dry landing in an automated mode (Fig. 5).

The passenger standard flight mission is different. It will originate on the Earth surface with a winged Shuttle type vehicle (Fig. 4) and bring the crews to the LEO space station. There, they board a space ferry vehicle, multi-engined for safety reasons, and fly to the lunar orbit station (Fig. 6). The same ferry is used for the return flight which makes use of aerobraking in the Earth atmosphere and ends up at the LEO space station. From there the crew boards an improved Shuttle vehicle and return to the Earth surface in a gliding mode. The passenger traffic at the lunar side, between lunar orbit and lunar surface, is taken care of by a lunar bus which is of a very similar design compared to the orbital ferry vehicle, only the heat shield is exchanged for landing legs. An important feature is a multi-engine propulsion system with engine out capability for crew safety reasons. Eventually a direct flight to lunar orbit with ballistic spacecraft might be employed.

Maximum use will be made of refueling, preferably with propellants produced on the Moon to reduce transportation costs. Both stations in low Earth orbit and in lunar orbit will have provisions for refueling.

Fig. 3: Standard mission modes

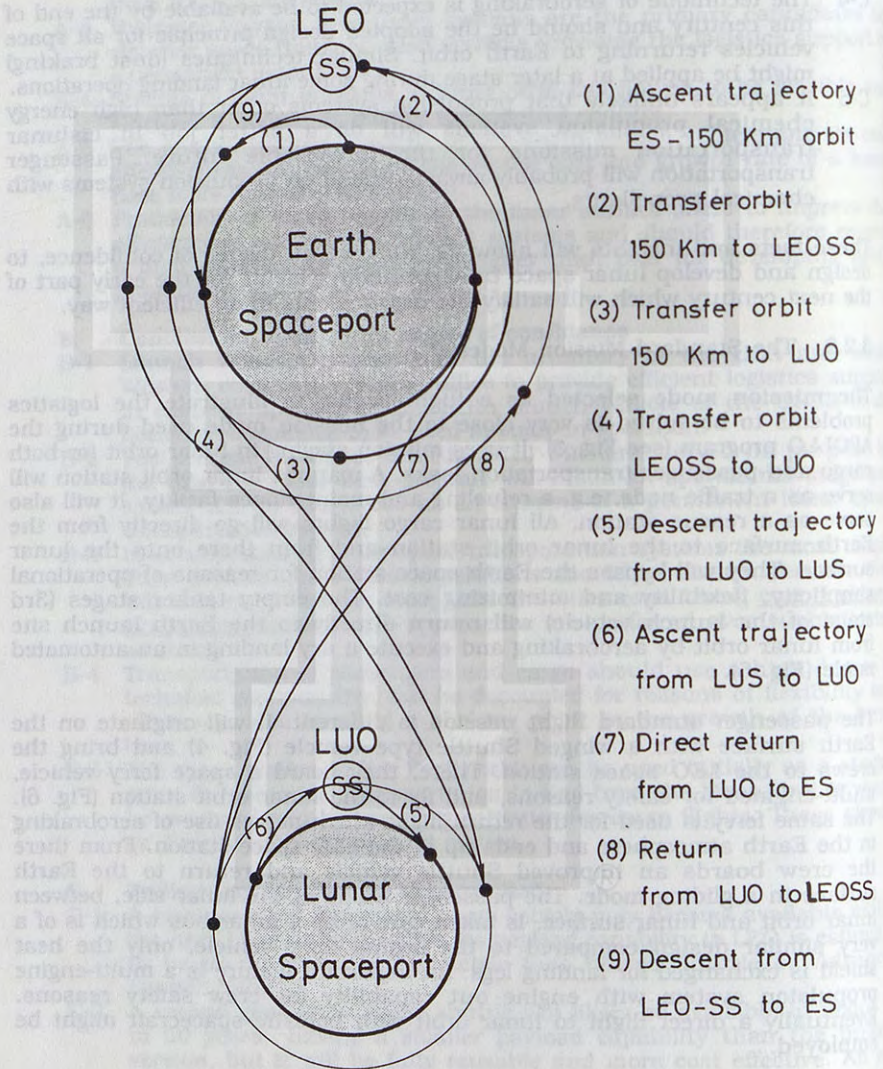


Fig. 4: Typical passenger

Fig. 4: Typical concepts for a second generation Space Shuttle for passenger transport to LEO

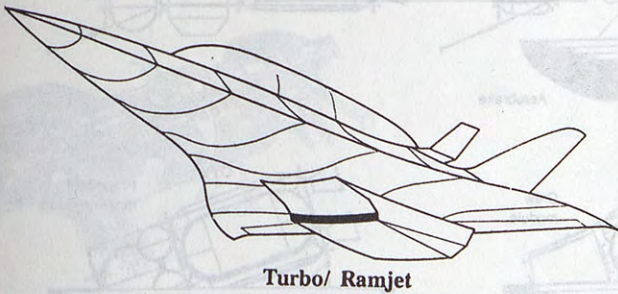
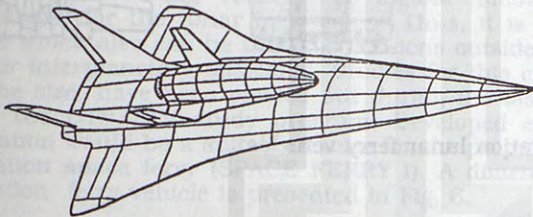
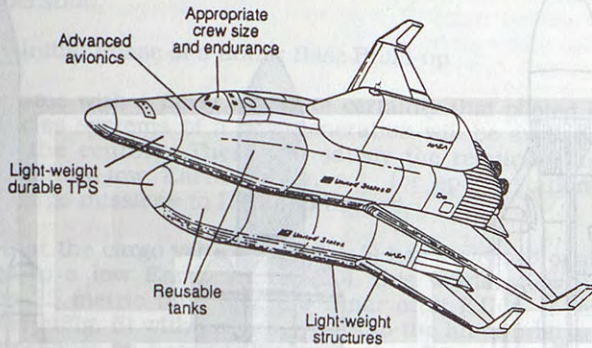


Fig. 5: Typical space freighters for initial lunar logistics operations (50 to 100 tons LEO payload capability)

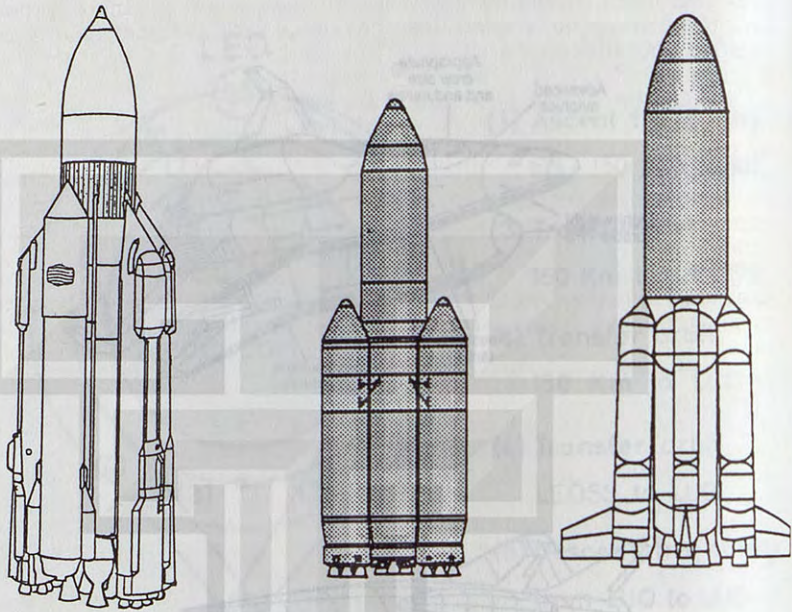
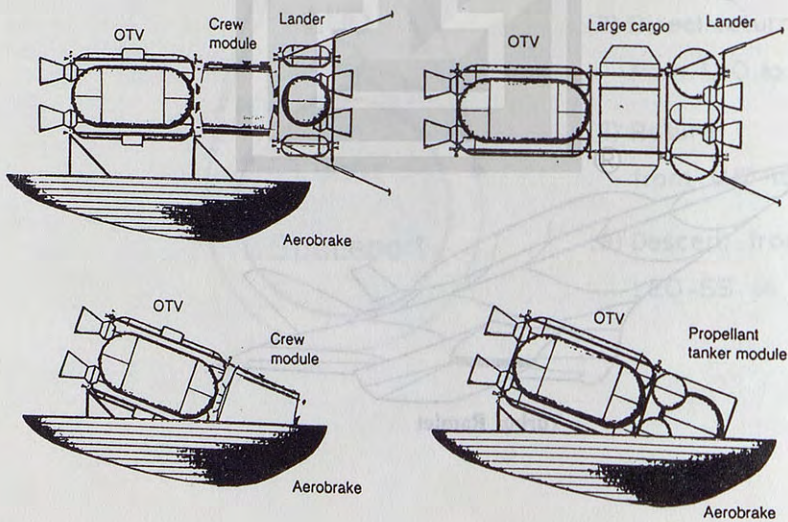


Fig. 6: First generation lunar ferry vehicles



The flight launch window allow minimum have to be logistics operations

3.2.3 The

We can assume launch vehicle the turn of transportation automated operations

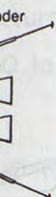
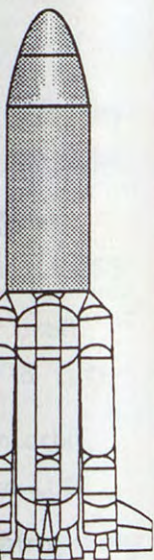
Assuming the metric tons about 20 to passenger ferry enough propellant an aerobrake

If the recent without refueling mode, unless components vehicle which GEO or into half the size under the application generation generation

The development of 2 billion 10 years, since



erations (50 to



llant
module

obrake

The flight times between Earth and Moon will be 60 to 80 hours. The launch window for passenger flights starting from the LEO space station will allow minimum energy flights every nine days. Launch window problems will have to be observed, but are not considered serious handicaps for the entire logistics operation.

3.2.3 The Initial Phase of a Lunar Base Build-up

We can assume with a fairly degree of certainty that piloted and automated launch vehicles systems of a new generation will be available shortly after the turn of the century. These will satisfy the requirements of passenger transportation to low Earth orbits, e.g. for space station logistics and automated cargo missions to LEO and beyond.

Assuming that the cargo vehicle (see Fig. 5) has a payload of about 80 to 100 metric tons to a low Earth orbit (LEO), this would allow us to transport about 20 to 25 metric tons to a low lunar orbit (LUO). It can also bring a passenger ferry (Fig. 6) without passengers to the lunar orbit station, and has enough propellants on board to return to the LEO space station by means of an aerobraking flight profile as described above.

If the reentry heat shield is replaced by legs, the same vehicle - with or without refueling - can land on the surface of the Moon in an automated mode, unload roving vehicles or logistic modules or even the first components for the lunar base camp. Thus, it is a universal space ferry vehicle which also can be used for missions outside the lunar program (e.g. GEO or interplanetary missions). Studies for this class of vehicle, but only half the size, have been carried out during the last decade in great detail under the OTV/STV study program. Developed engines adapted to this application would be a suitable choice for the propulsion systems of this 1st generation space ferry (SPACE FERRY I). A dimensional sketch of a first generation ferry vehicle is presented in Fig. 6.

The development cost of such a first generation ferry should be in the order of 2 billion dollars (1990) and the development period should be less than 10 years, since most of the required technology is at hand.

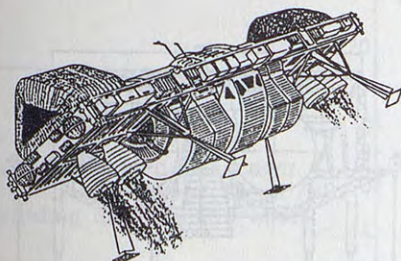


Fig. 7: Second Generation Lunar Passenger Bus

3.2.4 The Advanced Phase of of a Lunar Base Build-up

The capability of landing payloads in the 20 metric ton class will not suffice for more than setting up a lunar orbiting station and an initial base camp on the lunar surface. Thus, new cislunar transportation capabilities will have to be developed to achieve reasonable growth rates and operational efficiencies of the lunar base. Since the early sixties, heavy lift launch vehicles (e.g. the NOVA concept) have been studied in great detail to provide payload capabilities to low Earth orbit of 300 metric tons and more which translate into 50 tons that could be delivered to the lunar surface. A great amount of design information for this type of vehicle is available. The vehicle resulting from a recent study is shown in Fig. 8. A two-stage ballistic space freighter using clustered SSME's or derivations thereof will be able to lift about 330 tons into a low Earth orbit or as a three-stage vehicle nearly 100 tons into a lunar orbit. The 3rd stage could be a space ferry alternatively serving as a lunar bus (using a single Space Shuttle Main Engine) providing automated transportation between the lunar orbit station and the lunar surface. It would refuel in lunar orbit station and on the lunar surface as soon as lunar oxygen becomes available. Initially, the liquid hydrogen will have to come from Earth in an automated mode by a tanker vehicle, to be replaced by hydrogen produced on the Moon at a later development stage.

The heavy space freighter described above and shown in Fig. 8 (or a similar design concept with equal payload capacity) will be used for passenger transportation during the later base operation only. The passenger ferry of the initial phase (Fig. 6) will be replaced by an improved version for 36 passengers to be transported between the lunar base and lunar orbit. (Fig. 7) It is a much smaller vehicle than the freighter version of the lunar bus. It appears unwise to integrate the passenger and cargo transportation mission modes because this would reduce flexibility, safety and efficiency.

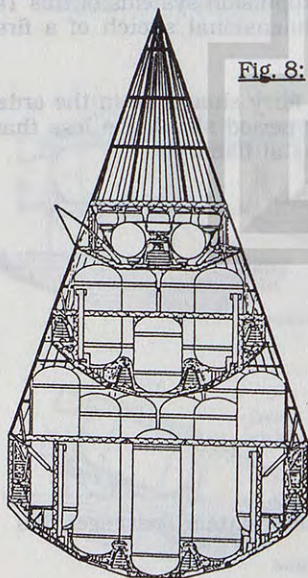
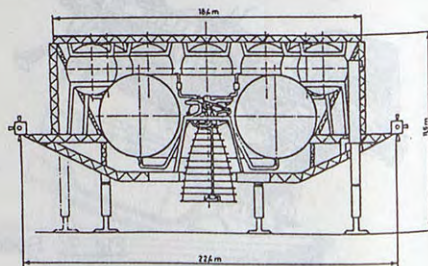


Fig. 8: Heavy lift launch vehicle and lunar cargo shuttle



It is generally is the space passengers a originates from Consequently The specific estimated on development latest availab is shown in R space freight base versus c less than 1 transportation depend also from about 5 3 million \$/p used in a di from low Ear lunar orbit s lunar passen (as shown in there to the

Fig. 9: Proj cargo deliver - Moon (exc development

Fig. 10: Pro roundtrip co (excluding c

It is generally agreed that the key to an economical and affordable lunar base is the space transportation system which has to provide safe flights for passengers and reliable cargo delivery to the lunar base. Most of the cost originates from the first leg from the Earth surface to a low Earth orbit. Consequently, the space freighter is the key to the lunar base development. The specific cost for cargo and passenger transportation have to be estimated on the basis of available vehicles and an individual lunar base development scenario, which is a function of size and growth ratio. The latest available estimate (Ref. 20) for a base with a 100 to 200 person crew is shown in Figs. 9 and 10. Fig. 9 depicts the specific cargo delivery cost for space freighters in terms of \$ (1990)/kg payload from Earth to the lunar base versus operational year, indicating a drop from about 10 000 \$/kg to less than 1 000 \$/kg after 20 years of operation depending on the transportation volume. The passenger roundtrip cost shown in Fig. 10 depend also strongly on the vehicles and mission modes used. They range from about 50 million \$(1990) per person during the first year to less than 3 million \$/person after 10 years if a heavy lift launch vehicle (see Fig. 8) is

used in a direct flight mode from low Earth orbit to the lunar orbit station and a lunar passenger bus (as shown in Fig. 7) from there to the lunar surface.

Fig. 9: Projected specific cargo delivery cost Earth - Moon (excluding development /20/)

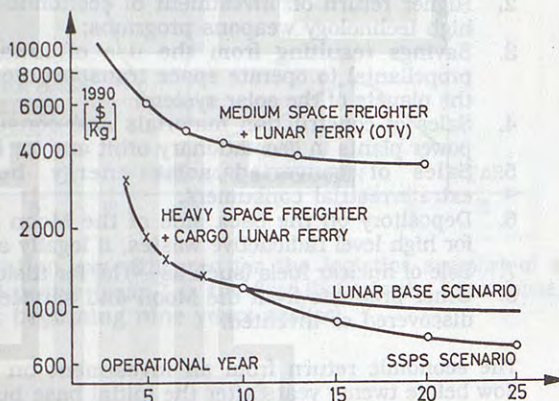
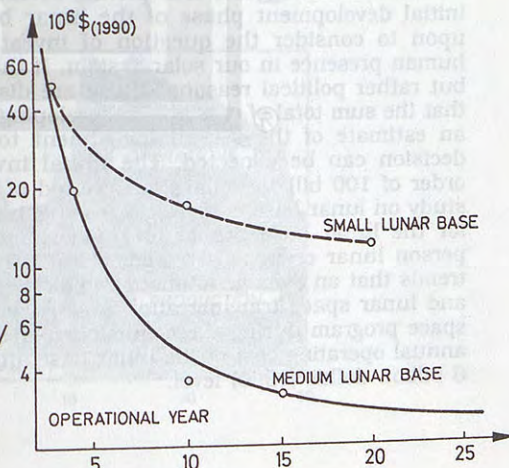


Fig. 10: Projected passenger roundtrip cost Earth - Moon /20/ (excluding development cost)



4 The HOW

4.1 Economic Aspects

Economically minded people will ask the question of whether such a project is economically viable? The answer is: Yes, on the long run it will, but we cannot prove it at this time. When Columbus sailed the ocean to discover new routes and lands, nobody could answer whether his trip would pay off. It will certainly take a fairly large investment of resources to install an infrastructure on the lunar surface but they are small if compared with other expenses from a global perspective. Within a century we expect that the economic return of the lunar base and later a lunar settlement will be derived from several of the following sources:

1. New knowledge derived from research activities of lunar laboratories and installations;
2. Higher return on investment of economic resources now consumed in high technology weapons programs;
3. Savings resulting from the use of lunar resources (hardware and propellants) to operate space transportation systems travelling between the planets of the solar system;
4. Sales of construction materials and consumables to commercial solar power plants in geostationary orbit and/or lunar power stations;
5. Sales of converted solar energy beamed to terrestrial and extraterrestrial consumers;
6. Depository on the back side of the Moon (in a 10 000 m deep crater) for high level radioactive wastes, if legally and politically accepted;
7. Sale of nuclear fuels (such as ^3He) for fusion power plants on Earth;
8. Other products from the Moon and services in space which are not yet discovered or invented.

The economic return from an investment on the Moon will probably not flow before twenty years after the initial base build-up. We should not expect wonders! This suggests that private investments will not be a factor in the initial development phase of the lunar base. Governments will be called upon to consider the question of investing public funds to expand the human presence in our solar system. If they do, it will not be for economic, but rather political reasons. These are discussed in chapter 4.2. Assuming that the sum total of reasons for developing a lunar base appears favourable, an estimate of the size of investment to be made is required before a decision can be expected. The initial investment will have to be on the order of 100 billion dollars in a period of about 15 years. The most recent study on lunar base cost (Ref. 21) indicates a cost trend as shown in Fig. 11 for the lunar base proper and associated transportation costs for a 200 person lunar crew as depicted in Fig. 12. It can be concluded from these trends that an average of about 5 billion each per annum for the lunar base and lunar space transportation system will have to be expected for such a space program during the acquisition phase starting in the late nineties. The annual operating cost of the lunar base after acquisition will be closer to the 6 billion dollar (1990) level.

Fig. 11: Typical cost trend for six of

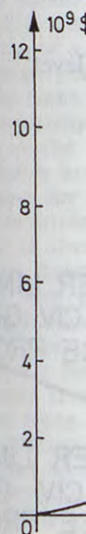


Fig. 12: Annual lunar costs with

Fig. 11: Typical lunar base acquisition cost through development and initial six operational years (excluding transportation cost)

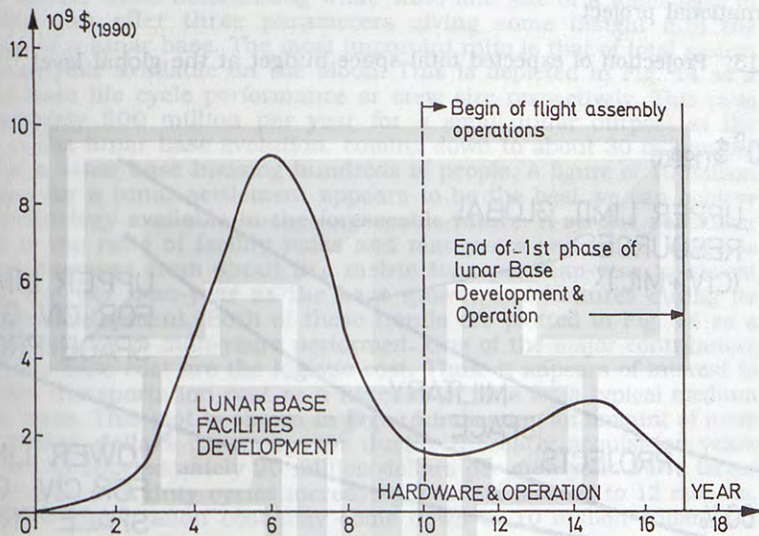
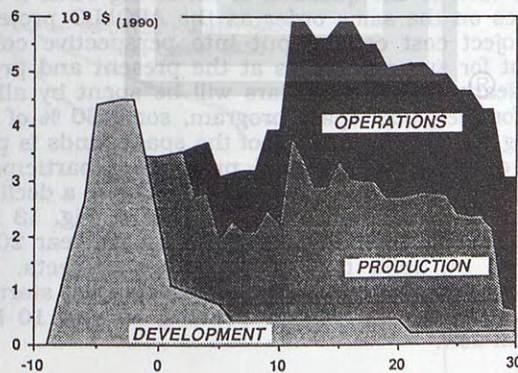
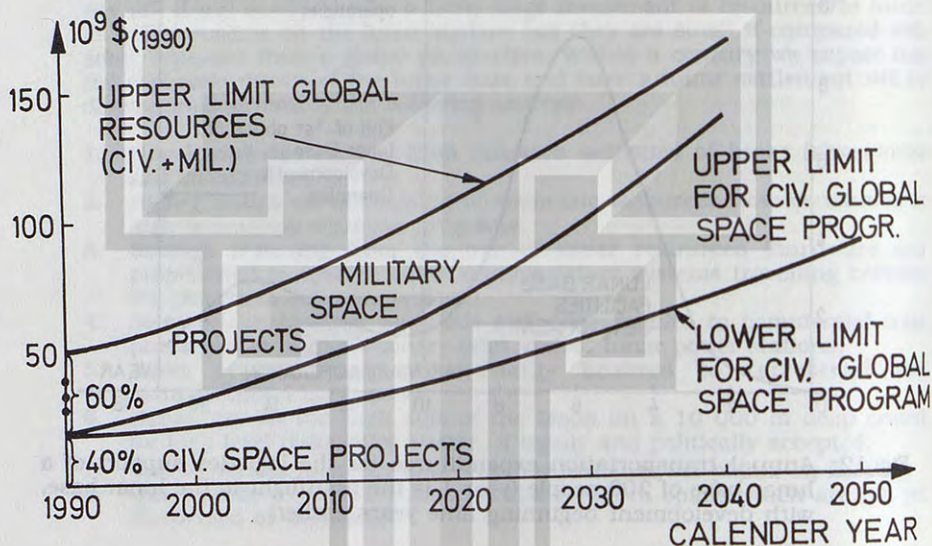


Fig. 12: Annual transportation expenditures for the logistics support of a lunar base of 200 people (year 1 is the first flight to the lunar base, with development beginning nine years earlier)



This figure should not scare us at all comparing it with the 1 000 billion dollars spent globally per annum now for defense purposes, or with 100 billion dollars per year for development of new energy resources and facilities. Consequently, it appears feasible to finance a lunar base as an international project.

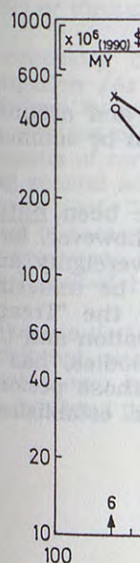
Fig. 13: Projection of expected total space budget at the global level



Thus, we have to turn to the question of financing such a space project, requiring resources on the same order as the APOLLO project during the sixties. These project cost can be put into perspective considering the global funds spent for space activities at the present and projecting these into the future. Nearly 50 billion dollars will be spent by all participating nations in 1990 for the global space program, some 60 % of it for military projects. Assuming that the growth rate of the space funds is proportional to the growth rate of the gross national product of participating nations (assumed to be 2.5 % p.a.) and furthermore assuming a declining share for military space projects, we obtain a trend shown in Fig. 13 indicating the availability of approx. 50 billion dollars (1990) by the year 2010 and up to 100 billion dollars by 2030 for civilian space projects. If this trend materializes then a global lunar base program could get started in the late nineties reaching annual expenditures peaking around 10 billion dollars some 15 years from now.

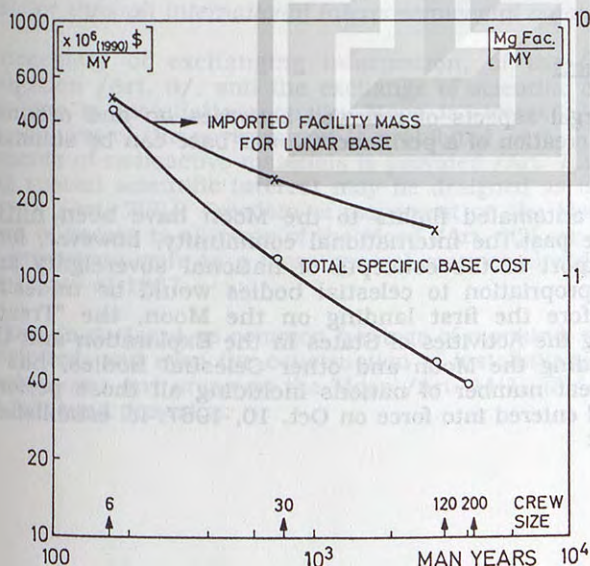
While we have for play a major role requires a health is a major factor develop. We can effectiveness of a cost per man-year function of base is approximately beginning of the manyyear for a lunar per manyyear for with the technolo of interest is the expected to decre one metric ton p evolutionary deve function of cumu to these lunar ba plot the total tran sized lunar base. than one billion coming down to a lunar settlement this specific tran manyyear.

Fig. 14: General man-pow



While we have found that the economical objectives of a lunar base do not play a major role (see Tab. 2) and in spite of the fact that a lunar base requires a healthy investment, the cost-effectiveness of such an enterprise is a major factor, when determining what kind and size of a lunar base to develop. We can offer three parameters giving some insight into the effectiveness of a lunar base. The most important ratio is that of total system cost per man-year available on the Moon. This is depicted in Fig. 14 as a function of base life cycle performance or crew size respectively. This ratio is approximately 500 million per year for a small lunar outpost at the beginning of the lunar base evolution, coming down to about 30 million per manyear for a lunar base housing hundreds of people. A figure of 10 million per manyear for a lunar settlement appears to be the best we can achieve with the technology available in the foreseeable future. A second parameter of interest is the ratio of facility mass and man-years performed, which is expected to decrease from about five metric tons per man-year to almost one metric ton per man-year as the base grows and matures during its evolutionary development. Both of these trends are plotted in Fig. 14 as a function of cumulative man-years performed. One of the major contributors to these lunar base cost are the logistic cost. Thus, it appears of interest to plot the total transportation cost as a function of time for a typical medium sized lunar base. This plot is shown in Fig. 15 indicating an amount of more than one billion dollars per man-year during the early acquisition years coming down to approximately 20 million dollars per man-year. For a larger lunar settlement with duty cycles increasing from six months to 12 months, this specific transportation cost may come down to 10 million dollars per manyear.

Fig. 14: General lunar base effectiveness trend as a function of life cycle man-power volume /22/



The exploration and use shall be carried out in the interests of and be free for all countries /Art. I (1)/. Free access to all areas of Celestial Bodies is declared /Art. I (2)/. National appropriation is prohibited /Art. II/. The activities shall be peaceful /Art. III/, weapons of mass destruction are not to be stationed on the Moon, and military activities of any type are forbidden /Art. IV/. States of registry shall retain jurisdiction over installations on a Celestial Body /Art. VIII/. And free access to stations is guaranteed /Art. XII/.

These provisions were never disputed during the time of the flights to the Moon, and their applicability was recognized by all nations.

However, the international community foresaw that further flights to the Moon and activities on this and other celestial bodies would continue. Therefore, in the framework of the United Nations, the Committee on the Peaceful Uses of Outer Space, especially the legal subcommittee, proceeded towards a more detailed regulation, and finally proposed the "Agreement Governing the Activities of States on the Moon and Other Celestial Bodies" which finally was adopted by the United Nations General Assembly on Dec. 5, 1979, and which came into force in 1984, although neither the USA or the USSR has yet signed this agreement.

The Moon-Agreement made further provisions strengthening international cooperation and mutual responsibility of Nations relating to the Moon as follows:

The Moon shall be used exclusively for peaceful purposes and weapons of mass destruction, military bases etc. are prohibited /Art. 3/. Especially important seems the following provision which is quoted verbatim:

States Parties shall be guided by the principle of cooperation and mutual assistance in all their activities concerning the exploration and use of the Moon. International cooperation in pursuance of this Agreement should be as wide as possible and may take place on a multilateral basis, on a bilateral basis or through international intergovernmental organisation /Art. 4/.

The necessity of exchanging information, of the freedom of scientific investigation /Art. 5/, and the exchange of scientific or other personnel on expeditions to installations on the Moon is stressed /Art. 6/. The harmful contamination of the environment is prohibited /Art. 7(1)/, notification of all placements of radioactive materials is provided /Art. 7(2)/. Areas of the Moon having special scientific interest may be designed as international scientific preserves /Art. 7(3)/. Freedom of movement on the Moon /Art. 8(2) and the freedom of access to all parts of the Moon /Art. 9(2) are agreed upon. Many of these provisions were in a more general manner already agreed upon in the Space Treaty of 1967.

The Moon is declared as common heritage of mankind, national appropriation is prohibited, and even the construction of installations gives no right of the ownership over any areas on the Moon /Art. 11(1), (3)/. Especially important is the following provision:

States Parties to this Agreement hereby undertake to establish an international regime, including appropriate procedures, to govern the exploitation of the natural resources of the Moon as such exploitation is about to become feasible. This provision shall be implemented in accordance with Art. 18 of this Agreement /Art. 15(2)/.

States retain jurisdiction and control over their stations and personnel /Art. 12(1)/ they bear international responsibility and liability /Art. 14/ and a system for settling disputes is agreed upon /Art. 15(3)/. Particular lunar resources of limited extent, such as the polar environments, will need to be protected by international agreement.

This short investigation of the Moon-Agreement shows clearly the interests of the signatories in fostering international cooperation, and especially in establishing an international regime regarding the exploitation of the natural lunar resources and of the benefits derived therefrom.

It is in the light of this international legal development, that the political aspects of the proposed "Return-to-the-Moon" should be seen.

One problem to be solved soon is the clarification of how can the Moon treaty be revised to be acceptable to the USA and USSR before a truly international lunar base program can proceed.

The above summary of the legal bases of global space flight activities proves that space programs have strong political aspects. The history of the space program shows clearly that prestige was the strongest motivation in shaping goals and projects. The first SPUTNIK launch in 1957 and the first manned lunar landing in 1969 are typical cases of politically motivated space projects. We must expect and hope that competition will give way to complementation and finally to cooperation. Large space projects such as a global system of space power stations, a lunar research and industrial settlement, or even a manned Mars project with the goal of establishing there a permanent outpost as a spearhead to utilize the resources of the solar system, are excellent vehicles to improve international cooperation. This cooperation probably will lead to more mutual trust and interdependence. That is why we should continue to reduce the worldwide burden of weapons and thus, achieving more security on our home planet. Step by step we should be able to turn armour, submarines and fighters into spaceships in due course of the development. As we reach out beyond the limits of the gravity field of planet Earth, we will gradually become citizens of this planet and may learn to solve our problems here without resorting to military force.

Aside from the country can have to realize

Thus, we can that it allows national contr

4.3 Organiz

The rapid growth of the world over the presence can base program and provide oxygen, power base represent nature of the and peaceful

Three mechanisms a lunar base among a country which takes participate, and supply the high

An example of Nuclear Research resources in the with the high difficulties have been resolved might be adapted

The International national enter Sea Drilling National Science auspices of the (JOIDES), and world. The international the United States Japan, United Nations participation membership in Glomar Challenger Along similar initiated by other nations toward

Aside from this political motivation there is an economic motivation. Not each country can afford its own national lunar base program or carry out manned exploration of the outer planets of the solar system. Sooner or later we will have to realize that the nations of this planet can do this only together.

Thus, we conclude that a lunar program has to be laid out in such a fashion that it allows phases with increasing cooperation, starting, however, with national contributions toward the goal of a joint coordinated program.

4.3 Organizational Aspects

The rapid growth and number of achievements in space activities throughout the world over the past three decades indicate that a permanent human presence can be established on the Moon during the next few decades. A lunar base program will advance scientific knowledge, broaden technological skills, and provide access to additional resources. The possibilities of producing oxygen, power, fuel, and structural materials on the Moon suggest that a lunar base represents an investment in other space programs as well. The scale and nature of the undertaking will provide opportunities for global cooperation and peaceful competition.

Three mechanisms for nurturing global cooperation in building and managing a lunar base can be categorized: internationalism, requiring total cooperation among a consortium of nations, national enterprise, involving one nation which takes the major role but invites other nations to contribute and participate, and private venture, calling for a consortium of private interests to supply the high-technology management system.

An example of an international undertaking is the European Center for Nuclear Research (CERN) in Geneva. Eleven member nations combined resources in the 1950s to build an accelerator laboratory that competes well with the high energy physics programs of other larger nations. Although many difficulties have arisen that are indigenous to this type of operation, they have been resolved successfully for over two decades. CERN serves as a model that might be adapted to conduct international science on the Moon.

The International Program of Ocean Drilling (IPOD) provides a model of national enterprise fostering international participation. Since 1968, the Deep Sea Drilling Project has been supported by the United States through the National Science Foundation. Scientific planning was conducted under the auspices of the Joint Oceanographic Institution for Deep Earth Sampling (JOIDES), an advisory group of distinguished scientists from all over the world. The international phase of Ocean Drilling (IPOD) began in 1975 when the United States extended membership to the Federal Republic of Germany, Japan, United Kingdom, France, and the Soviet Union. The IPOD member nations participate in the scientific planning of the project through membership in JOIDES, they take part in the field work aboard the D/V Glomar Challenger, and they collaborate in the post-cruise scientific studies. Along similar lines, a lunar base conducting scientific research could be initiated by one lead nation which in turn solicits contributions from other nations toward building facilities and planning activities.

If the economic potential for a lunar base is to be stressed, the International Telecommunications Satellite Consortium (INTELSAT) yields a successful model. INTELSAT is a user-based management system made up of participants from many countries. The participants work to coordinate the operations of international communication satellites. The INTELSAT concept could be modified appropriately to form "INTERLUNE", an organization that would bring into the management of a lunar base those states and other interests which manifest the greatest motivations for ensuring the successful implementation of that managerial system.

Until a specific lunar base program begins to materialize, it is neither appropriate nor possible to determine which scheme will be best for promoting international cooperation. Certainly, a fourth model consisting of several lunar bases operated independently by competing nations could evolve if for example launch costs are reduced by orders-of-magnitude. As an alternative to choosing a particular scheme for global participations, we suggest three models that have worked successfully on Earth under particular circumstances.

Of the three models for global cooperation on a lunar base program that have been presented here, it is clear that the first three decades of international space activities have been dominated by the national enterprise model. This model works best when a large project can be broken down into a number of discrete and relatively independent projects, such as the Canadian-built manipulator arm on the US Space Shuttle. The "Canadarm" has performed well on the Space Shuttle - in part because designers knew that Canada's national prestige was going to be affected by the outcome of that program. National pride, expressed through the fulfillment of scientific and technical achievements, is a strongly motivating force in our world. This force can be harnessed to develop and build an international base on the Moon.

The private venture model would seem to work best if commercial interests in a lunar base are displayed, or if the base has been operational for a number of years and an acceptable contractor can be found to manage it. Internationalism in space is a worthy goal that could improve the quality of life on Earth. It would be particularly appropriate if no one nation alone could afford to fund the entire lunar base program. However, the ease with which the concept of internationalism can be politicized indicates that this concept must be approached with caution.

The exact form of considerable expansion of space agency comes with rigidity in design the creation of the concerned with t example, the in staging facilities nations could for small region or the same time fr programs. Such

An ILB should r space facilities o resources are operating faciliti to travel between a device for exp important as the

Establishing an tortuous process of a lunar bas development of l efficient internat agency. Adequat institutions, and will be more diff be larger but th most of the r international co evenly spread to

The exact form of international cooperation to establish an ILB will require considerable exploration. The creation of a multinational development agency comes quickly to mind. However, such an approach might lead to rigidity in design and operation. One danger of a global ILB program will be the creation of support organizations on Earth that become primarily concerned with their own survival. Many options should be considered. For example, the international cooperation might focus on construction of staging facilities in low Earth orbit and large fleets of space ferries. Then nations could form subteams to build their own facilities on the Moon, in a small region or at several sites. Very likely an ILB program will occur in the same time frame as one or more national or perhaps even small private programs. Such possibilities should be encouraged.

An ILB should nest inside a large program whereby flight from Earth to space facilities can be made progressively less expensive, whereby lunar resources are used to progressively reduce the costs of building and operating facilities in space, and whereby it becomes progressively easier to travel between the Moon and Earth. These goals will enhance the ILB as a device for expediting the habitation of space by mankind and are as important as the base itself.

Establishing an international program for an ILB will likely be a long and tortuous process compared to the ability of one nation to set itself the goal of a lunar base. The rewards will likely be less clear than in the development of INTELSAT OR INMARSAT, which is also an example of an efficient international intergovernmental organization and an operational agency. Adequate commitments must be obtained by individuals, institutions, and governments. One can anticipate that the commitments will be more difficult to break and that the base of potential resources will be larger but that revision of goals will be difficult. If one nation commits most of the resources then the collective leverage of the other international commitments will be reduced. The investments should be evenly spread to ensure the widest international advantages.

5. Summary Plan

5.1 Program Scope and Structure

Members of the Academy and a few other well informed people were asked some questions concerning the programmatics of a lunar base development scenario during the 1987/89 period of planning activities of the Academy. The following two tables show the result of judging the major questions concerning the program structure and timing of such an undertaking.

Tab. 14: Relative consensus on major programmatic issues

- The lunar base is considered to be a precursor to a manned Mars Mission	91 % agreed
- The lunar base should be an international project	82 %
- The lunar base should void of military activities	76 %
- The lunar base should grow into a lunar settlement	69 %

Tab. 15: Expectations on the time frame of lunar base acquisition

The year in the middle is the expected year for the milestone (median), the other two years give the bounds of the range where 50 percent of the votes were placed.

First formal steps towards realization of a lunar base	1991	<1992>	1995
Initiation of the development of a heavy space freighter for lunar base logistics	1991	<1993>	1995
Replacement of the present Space Shuttle by an improved passenger transport vehicle for the traffic between Earth surface and low Earth orbit	1996	<1999>	2005
Initial beneficial occupancy (IOC)	2001	<2006>	2010

On the basis of these judgements and other relevant information a preliminary plan can be drafted. This may assist to develop a well-coordinated, detailed plan for exploring the Moon and developing the lunar resources. The following list may be useful to develop the scope and structure of a typical plan to provide a focus for further discussion and detailed planning. We envision a phased development which would allow the participants to alter the program from time to time at distinct milestones. The program will thus be subdivided into phases and these into individual steps.

FIRST PHASE:

1. Step:

2. Step:

3. Step:

This phase will
to 100 tons of a
Some 30 space
flights should be
A heavy space f
accomplish this

SECOND PHASE

1. Step:

FIRST PHASE: Goal is the establishment of a manned lunar orbiting station by no later than the year 2004.

1. Step: 1992/98
Accelerated exploration of the lunar environment, resources and possible base locations by automated lunar satellites within national space programs.
2. Step: 1999/2002
Continued lunar exploration with automated roving vehicles, landing of automated long lived lunar stations, and establishment of a communication system to provide safe communication for future lunar activities.
3. Step: 2003/04
Construction and operation of a manned lunar orbit station with refueling, maintenance and repair capabilities. The six crew members will also carry out scientific tasks as time permits. The emphasis is on initial operational capability as a transportation node and site preparation for lunar base erection.

This phase will require approximately 200 metric tons in lunar orbit and up to 100 tons of automated spacecraft and roving vehicles on the lunar surface. Some 30 space freighters of the first generation and some 10 Space Shuttle flights should be able to satisfy the transportation requirements of this phase. A heavy space freighter, if available at this time, would be in the position to accomplish this goal quicker and cheaper.

SECOND PHASE: Goal is the establishment of a lunar research laboratory by no later than 2010.

1. Step: 2005/7
Landing of a construction crew of six at the selected and prepared landing site to assemble a base camp for initial operational occupancy by a first science team of six. This crew will take up priority science tasks of particular relevance for the further growth of the lunar base. The construction crew returns to Earth and is replaced by a maintenance and repair crew which is also charged with the task of preparing the extension of the lunar base facilities. This step requires cargo deliveries to the lunar base site in the order of 150 metric tons. Base capacity: 12 crew members. The average stay time of each crew contingent should be approximately six months.

2. Step: 2008/10
Landing of additional modules and equipment on the lunar surface to increase base capacity gradually to 100 persons. Additional teams of six to twelve persons will arrive with specific task assignments, such as the development of the lunar power and transportation infrastructure, the development of a pilot production capability for building materials and propellants, and enlarging base facilities. This step will require the delivery of some 600 metric tons of facilities and equipment to the lunar surface, a demand which can best be handled by a space freighter of the second generation, otherwise launch rates and cost would be too high. It is further anticipated that the passenger transport will, for reasons of operational flexibility, have to carry out bi-monthly flights during this build-up period.

THIRD PHASE: Goal is the development of a major production facility.
2011-2025

1. Step: Construction of facilities to satisfy the requirements of lunar oxygen and most of the raw material requirements of the lunar base by 2015.
The construction and assembly of a lunar factory complex with all the power and transportation infrastructure would be the primary objective to get ready for the export of raw materials and propellants. A secondary objective would be the set-up of major research facilities, such as astrophysical observatories. The lunar crew would have to haul cargo to the lunar base at a rate of about 1 000 metric tons p.a. and monthly passenger flights with 12 to 24 people will become necessary.
2. Step: Extension of facilities to provide growth of the export production capability to about 100 000 metric tons p.a. for export to GEO and other locations by 2025.
The emphases will be to develop new export markets and to satisfy their demands including the propellant requirements for transporting the lunar products from the Moon to their destination.

This phase will lead to a heavy traffic from and to the Moon with several hundred launches per year of automated space freighters and passenger flights twice a week. The lunar crew will grow to about 500 people.

FOURTH PHASE: Lunar settlement with a high degree of self-sufficiency by the end of the 21st century (2026-2100)

This appears to be a logical long range goal for an extensive use of lunar resources and the establishment of the first extraterrestrial civilization of several thousand people, most with permanent residence on the Moon. New technologies might be available for this phase of development, also for the space transportation systems required in the second half of the next century. It is too early to speculate how they may look.

5.2 Program

A multinational process to plan. The space pro organizations w and the Europe this experience development pr

First organization One or several should invite conference in presented and schedule and should be a b sufficient detail not they want t The Internation such an agree

Second operati A second confe agreement to e has the charter within no late agreed upon.T duration. It ha to establish a l are listed in th participating n the office ope technical orga payrolls of the participating co many clerical a of the detailed participating Development P

Tab. 15: Priori

- draft of a p
- draft of a ch
- draft of a p
- Agency into
- draft of a p
- draft of a li
- identificatio
- preliminary
- developmen
- draft of a
- preparation

5.2 Program Organization

A multinational, complex, and long-duration program requires a stepwise process to plan, to acquire and to operate the product of the joint venture.

The space program of the last decades has seen several multinational organizations which have grown as a function of time. INTELSAT, INMARSAT and the European Space Agency are examples of such organizations. Using this experience the following organizational model is proposed to start a lunar development program and carry it through to fruition:

First organizational step: Lunar Development Conference.-

One or several national governments participating in the space program should invite interested national governments to participate in a special conference in which the project of a multinational Lunar Base (ILB) is presented and discussed with respect to objectives, structure, scope, schedule and organizational alternatives. The result of such a conference should be a basic frame of reference for a lunar development program in sufficient detail to enable national governments to make a decision whether or not they want to participate in the next step.

The International Space Year (1992) would offer a fitting opportunity to sign such an agreement.

Second operational step: Lunar Development Planning Office.-

A second conference (preferred timing: 1993) should draft a memorandum of agreement to establish a "Lunar Development Planning Office" (LUDPO) which has the charter to draw on all sources of the participating nations to develop within no later than three years alternative plans to meet the objectives agreed upon. This initial planning effort has a limited scope and limited duration. It has to compile all relevant information required to take a decision to establish a lunar development organization. Some of the tasks for this office are listed in the following table. This office should be hosted by one of the participating nations which will provide the office infrastructure and pay for the office operation. The participating nations will delegate from their technical organizations specialists on the subject who will be kept on the payrolls of these institutions. Thus, the personnel costs will be paid by the participating countries. A professional staff of about 20 people supported by as many clerical assistants should be sufficient to carry out this assignment. Most of the detailed work should be accomplished in existing institutions of the participating countries. The draft of a memorandum leading to a Lunar Development Planning Office is enclosed as an appendix.

Tab. 15: Priority task assignments to a lunar development planning office

- draft of a preliminary lunar development plan
- draft of a charter for a Lunar Development Agency
- draft of a program schedule and procedures to put the Lunar Development Agency into operation
- draft of a preliminary budget for the first phase of the development
- draft of a list for priority lunar science projects
- identification of precursor activities
- preliminary definition of the initial lunar base logistic system
- development of organizational options
- draft of a treaty establishing the Lunar Development Agency and preparation of all legal documents.

Third organizational step: Institutional Conference

The alternative program plans resulting from the efforts under step 2 will be presented and discussed in detail in this conference. These plans must include all political and legal considerations, stipulations and treaty drafts to be submitted to the representatives of the potential member nations at the ministerial level. (Preferred timing: 1995). The outcome of this conference should be a basic multi-national agreement for a "Lunar Development Agency"(LDA) and pledges of the national government with respect to their financial support. It is envisioned that - similar to the ESA convention - about 90 % of the contributions of the member nations will be spent in the country of origin.

The Academy members were also queried on the type of organization they would prefer to develop and operate the lunar base. Seven organizational options from national institutions up to an organization of the United Nations were offered for a ranking to these judges. Only the three following organizational options received a noticeable number of votes. The ranking produced the following preferences:

Tab. 16: Relative priorities of organizational options for an International Lunar Base

1. Lunar Development Agency of a consortium of nation states similar to ESA and INTELSAT.
2. Joint lunar development program by those nations possessing a manned space capability with other nations as junior partners contributing 1/3 to 1/4 of the resources.
3. Lunar development program as a multi-national effort, but with a leading nation contributing more than 50 percent of the resources similar to the international space station FREEDOM program.

Fourth organizational step: Buildup of the LDA (1996 or later)

The LDA will probably be primarily a management organization using the development capacities of the member nations to the largest possible extent. Staff appointments and facility selection will get underway. The development organization will be charged with the acquisition of the initial lunar base.

Fifth organizational step: User Organization of the Lunar Base

At the time the initial operational occupancy of the lunar base is within reach, a user organization should be set up which will deal with the utilization of the lunar facilities by the member nations and will also have a decisive influence on the extension of the lunar facilities and infrastructure. At this time commercial interests may play a major role including the financing of the further development of the lunar base into a lunar factory and possibly into a lunar settlement. The development as such in technical and organizational terms might be delegated to the then existing LDA.

The basic structure for a lunar development program and its progressive evolution is illustrated in Fig. 16. Some selected milestones as described above are presented in an overview chart in Fig. 17.

Major Program Phase
Development of a C Transportation Sys
Development of Lun Modules and Subse
1st Lunar Base Acq Phase
Buildup of Lunar Fac
Activation of Major L Research Facilities
Growth of Lunar Bas Lunar Settlement

FIG. 16: Typical

Milestones:
International Lunar Development Con
Lunar Base Develop Organization activ
Development Contr Space Freighter
Lunar Base Element under Contract
Lunar Orbit Station activated
Lunar Base Constr Crew on Lunar S
Initial Operational C of Lunar Base
Pilot Production Pl installed
Lunar Observatory completed

FIG. 17: Major M

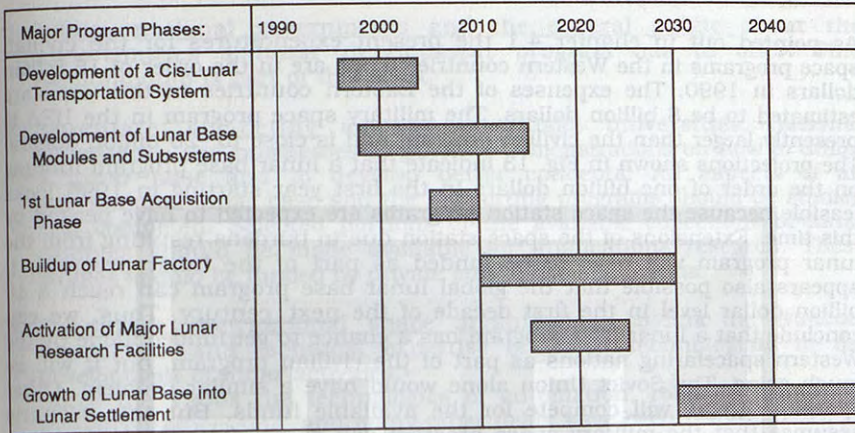


FIG. 16: Typical Lunar Base Evolution

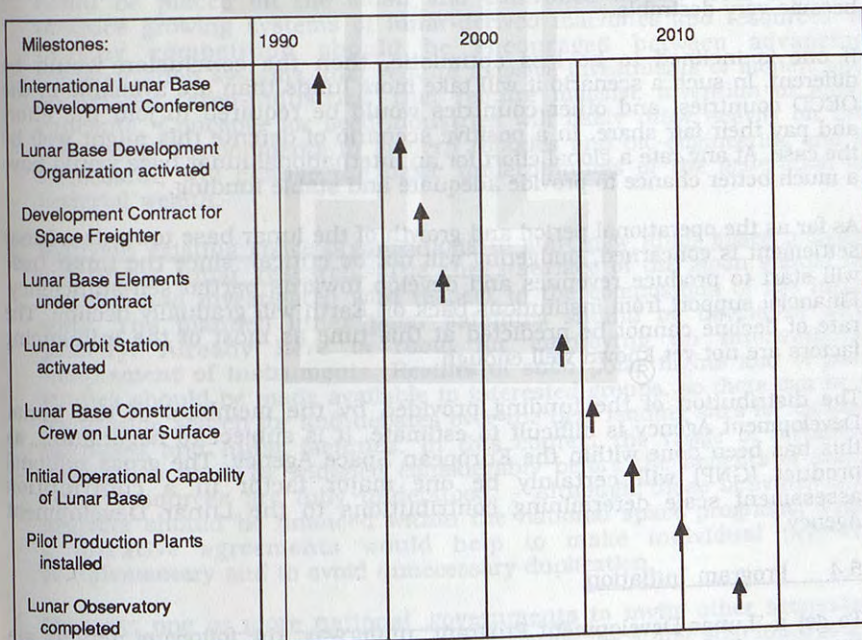


FIG. 17: Major Milestones of typical Lunar Base Development Program

5.3 Program Budgeting

As pointed out in chapter 4.1 the present expenditures for the civilian space programs in the Western countries alone are in the order of 15 billion dollars in 1990. The expenses of the Eastern countries in this area are estimated to be 8 billion dollars. The military space program in the USA is presently larger than the civilian program and is close to 20 billion dollars. The projections shown in Fig. 13 indicate that a lunar base program funding on the order of one billion dollars in the first year starting in 1996 looks feasible because the space station programs are expected to have peaked by this time. Extensions of the space station due to burdens resulting from the lunar program will have to be funded as part of the lunar program. It appears also possible that the global lunar base program can reach a 10 billion dollar level in the first decade of the next century. Thus, we can conclude that a lunar base program has a chance to get funded alone by the Western spacefaring nations as part of the civilian program, but it will be tough going. The Soviet Union alone would have a similar problem. Other space programs will compete for the available funds. But this scenario assumes that the military space program will go on strongly in this time period. However, it appears unlikely that this will be the case, but rather that the military space expenditures will go through a slow decline around the turn of the century. Should this happen, then the lunar program will be out of a squeeze and will take up the slack in terms of available manpower, institutions, facilities and funds (see Fig. 13) which may politically even become very desirable.

If one is inclined to be less optimistic, then the conclusion would be different. In such a scenario it will take more funds than are available in the OECD countries, and other countries would be required to join the effort and pay their fair share. In a positive scenario of detente this might well be the case. At any rate a global effort for an international lunar base would have a much better chance to provide adequate and stable funding.

As far as the operational period and growth of the lunar base towards a lunar settlement is concerned, budgeting will not be critical, since the lunar base will start to produce revenues and develop towards partial self-sufficiency. Financial support from institutions back on Earth will gradually decline. The rate of decline cannot be predicted at this time as most of the influencing factors are not yet known well enough.

The distribution of the funding provided by the members of the Lunar Development Agency is difficult to estimate. It is subject to negotiation, as this has been done within the European Space Agency. The gross national product (GNP) will certainly be one major factor in a contribution assessment scale determining contributions to the Lunar Development Agency.

5.4 Program Initiation

To get a "Lunar Development Program" underway, the following actions are recommended:

1. Inform nations of opportunities and opportunities memorandum
2. Stimulate laboratories and a lunar base international and compete samples should studies should
3. Encourage intellectual development. Since the 19 industrial pro the invention photonics are to work at di being develop should be di could be pla produce grow healthy con transportation automated " concepts. Co theoretical d successful, v material weal
4. Motivate exist identifying l mapped and soils. The p priority. Al complement studies shou world-wide s purposes an disciplines n lunar resour projects sho cooperative complementa
5. Motivate one nations for a organized lun

1. Inform national governments and the general public about the opportunities a lunar development program has to offer. This memorandum is part of this effort.
2. Stimulate competing among individuals, universities, national laboratories and businesses to generate demonstrations on how to utilize a lunar base and to develop better concepts. All aspects of an international lunar base and the supporting programs should be studied and competed. Selected portions of the available collections of lunar samples should be made available for applications research. These studies should be funded by private and public institutions.
3. Encourage the national space organizations to link the available intellectual and technical expertise of Earth technologists to the development of lunar activities.
Since the 1960s the technologies of automation, robotics, materials, industrial processing, and many other fields have been revolutionized by the invention of microprocessors. Even newer technologies such as photonics are bringing additional capabilities to engineers and scientists to work at distant locations via remote control. Autonomous systems are being developed that greatly leverage manpower. Considerable effort should be directed toward developing seed-like industrial systems that could be placed on the Moon and controlled largely from Earth to produce growing systems of lunar-derived machines and resources. A healthy competition should be encouraged between advancing transportation systems, that require massive investments of money, and automated "seed-industries" that require massive invention of novel concepts. Concepts for seed-industries will likely draw heavily on the theoretical developments in modern robotics and bio-engineering and if successful, will change the basic underpinnings of the generation of material wealth.
4. Motivate existing space organizations to start new lunar space projects identifying lunar research. - The entire surface of the Moon should be mapped and investigated with respect to the composition of the lunar soils. The planned lunar polar satellites should be developed with priority. Already here is room for employing an international complement of instruments. Results of such polar flights and of past studies should be made available to interested groups, so there can be a world-wide search for and debates over the best landing sites for various purposes and lunar facilities. In this context the range of technical disciplines must be widened considerably before the benefits of using lunar resources are fully understood. - Although these activities and projects should be financed within the national space programs, some cooperative agreements would help to make individual projects complementary and to avoid unnecessary duplication.
5. Motivate one or more national governments to invite other interested nations for an "Lunar Development Conference" as a first step towards an organized lunar program as described in chapter 5.2.

6. Encourage the national space organizations to take steps leading to an increase in payload capabilities of launchers, their launch rates and their operational effectiveness including reliability and crew safety.
7. Support study activities and conferences leading to clarifications of the desirable specifications of a lunar base development, complementing the efforts of the "Lunar Development Planning Office" as proposed as the second formal step in chapter 5.2.-
These activities should help to make the choices of attributes a lunar base may have. Some of the choices to be made are:
 1. Polar or equatorial site for a first base camp,
 2. initial lunar crew size and build-up rate,
 3. size, number and location of outposts on lunar surface,
 4. separate or combined space transportation systems for cargo and passengers,
 5. size and functions of a lunar orbit space operations center,
 6. degree of ecological closure in the first lunar habitats,
 7. type and size of lunar power systems,
 8. priorities of lunar science,
 9. rate of build-up of lunar oxygen production,
 10. priorities for manufacturing of lunar products.

6. Concluding

Almost twenty times more than their homelands are used by others. The space. This implies use extraterrestrial asteroids in the accessible and

For the past two decades, the major space program has been on Earth's home planet. The relationship between Earth and space have been major issues. The machines deployed in space have a connection between the industrial and the space programs of the future. The acceptance of the space program more permanent. The machines will support industrial

[illegible]

We feel encouraged
time, because
returning to the
benefit human

We recommend
invite the other
international s
new continent
neighbouring p

6. Concluding Statement

Almost twenty years ago, humans set their feet on a celestial body other than their home planet. This evolutionary step of humanity will be followed by others. The next century will see a true expansion of humankind into space. This implies the development of a technical and social capability to use extraterrestrial resources. Although there are many planets, moons and asteroids in the solar system offering such resources, our Moon is the most accessible and therefore the logical place to start.

For the past twenty years, since the landings on the Moon, the priorities of the major spacefaring nations have been on the conflicts and fears of our home planet. Conversely space activities have focused on piloted flights between Earth and orbit and automated flights beyond the Moon. There have been major advances in mapping our solar system and universe with machines deployed over short periods of time from Earth. The Moon is the connection between Earth and the solar system. The Moon can connect the industrial and economic engines of terrestrial activities to the space programs of the 1960s planted the seeds of technology growth and public acceptance of having people on another celestial body. Humans can move more permanently into space with the help of machines. Some of those machines will protect us and let us grow. Others will conduct research and support industry for us just as happens on Earth.

A primary challenge to the technical leadership for a return to the Moon and an International Lunar Base is to lead people to realize that they and their children need no longer be confined to one planet. They can live and grow within the two-planet system of Earth and Moon. Technical leadership must develop the many connections which could be constructed between Moon and Earth. Those leaders must explore and present how those connections can bring new richness of intellect, freedom of movement, and possibly wealth and safety to the people of the world. An International Lunar Base program can serve as a focus for the development and exercise of that leadership and a central image for the people of all nations. If the effort is successful then any person on Earth will be able to see the lights of the lunar base glowing on the dark face of the Moon early in the next century. Those lights and the people near them will be the leaders of the twenty-first century.

We feel encouraged to draft a plan for a lunar development program at this time, because the political environment appears to be favourable for returning to the Moon and also because funds spent on space programs benefit human society more than almost any other public expenditure.

We recommend that one or more of the spacefaring nations of this planet invite the others for an international development conference in the international space year, 500 years after COLUMBUS set sail to discover a new continent. The time has come to initiate steps to develop our neighbouring planet: the MOON!

Selected Literature and References

- / 1/ Project Horizon Report - A U.S. Study for the Establishment of a Lunar Outpost, Vol. I: Summary and Supporting Considerations, Washington D.C., based on a full report compiled by ABMA 1958 (1959)
- / 2/ Cole, D.M.: Lunar Colonization. Paper M-M-P59-18, ARS Meeting, Martin Co., Denver (1959)
- / 3/ U.S. House of Representatives, House Report No. 1931 (1960): Army lunar construction and mapping program. Report of the Committee on Science and Astronautics. 86th Congress, 2nd Session,
- / 4/ Ruzic, N.P.: The Case for Going to the Moon. Putnam, New York (1965)
- / 5/ Malina, F.J. (Ed.): Proceedings of the First Lunar International Laboratory (LIL). Symposium, Springer, New York (1966)
- / 6/ Malina, F.J. (Ed.): Proceedings of the Fourth Lunar International Laboratory (LIL). Symposium: Applied Sciences Research and Utilization of Lunar Resources, Pergamon Press, Oxford (1968)
- / 7/ Clarke, A.C.: The Promise of Space. Harper & Row, New York (1968)
- / 8/ NASA CP-2255 : Advanced Automation and Robotics for Space Missions. (1982)
- / 9/ Duke, M.B.; Mendell, W.W.; Keaton, P.W.: Report of the Lunar Base Working Group. Rept LALP 84-43, Los Alamos National Laboratory (1984)
- / 10/ California Space Institute of the University of California, A-016: Automation and Robotics for the National Space Program. A Report to NASA and the U.S. Congress by the Automation and Robotics Panel, University of California at San Diego, La Jolla, Calif. (1985)
- / 11/ Joyner, J.J.; Schmitt, H.H.: Extraterrestrial Law and Lunar Bases: General Legal Principles and a Particular Regime Proposal (Interlune). In Lunar Bases and Space Activities of the 21st Century (Edited by W.W. Mendell), p. 741, Lunar and Planetary Science Institute, Houston, Tex. (1985)
- / 12/ Mendell, W.W. (Ed.): Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Science Institute, Houston, Tex. (1985)
- / 13/ Smith, P.M.: Lunar Stations - Prospects for International Cooperation. In Lunar Bases and Space Activities of the 21st Century (Edited by W.W. Mendell), p. 707, Lunar and Planetary Science Institute, Houston, Tex. (1985)
- / 14/ Apel, U.; Jochenning, B.; Koelle, H.H.: Comparison of Alternative Strategies of Return-to-the-Moon. Aerospace Institute, Technical University of Berlin, TN 154 (1985)
- / 15/ Report of the U.S. National Commission on Space: Pioneering the Space Frontier. Bantam Books, New York (1986)
- / 16/ Woodcock, G.R.: Economic Potentials for Extraterrestrial Resources Utilization. 37th International Astronautical Congress, Paper IAA-86-451 (1986)

- / 17/ Woodcock, G.R.: Economic Potentials for Extraterrestrial Resources Utilization. 37th International Astronautical Congress, Paper IAA-86-451 (1986)
- / 18/ Finney, J.: Astronautics and the Future of Space. (1987)
- / 19/ Ride, S.: Astronautics and the Future of Space. (1987)
- / 20/ Griffin, J.: Astronautics and the Future of Space. (1987)
- / 21/ Matijevic, J.: Astronautics and the Future of Space. (1987)
- / 22/ IAA Ad Hoc Committee on the Future of Space. (1987)
- / 23/ Aron, J.: Astronautics and the Future of Space. (1987)
- / 24/ Aldred, J.: Astronautics and the Future of Space. (1987)
- / 25/ Koelle, H.H.: Astronautics and the Future of Space. (1987)
- / 26/ Cammer, J.: Astronautics and the Future of Space. (1987)
- / 27/ Koelle, H.H.: Astronautics and the Future of Space. (1987)
- / 28/ Mielke, J.: Astronautics and the Future of Space. (1987)
- / 29/ Koelle, H.H.: Astronautics and the Future of Space. (1987)
- / 30/ Stanley, J.: Astronautics and the Future of Space. (1987)
- / 31/ NASA - Johnson Space Center: Astronautics and the Future of Space. (1987)
- / 32/ Miller, J.: Astronautics and the Future of Space. (1987)

Acknowledgements

This position is a result of the development of Plans and Policies of Transport and contributions of countries.

- / 17/ Woodcock, G.R.: Logistics Support of Lunar Bases. 37th International Astronautical Congress, Paper IAA-86-511 (1986)
- / 18/ Finney, B.R.: Anthropology and the Humanization of Space. Acta Astronautica 15, 183-194 (1987)
- / 19/ Ride, S.K.: Leadership and America's Future in Space. NASA, August 1987, 63 pp.
- / 20/ Griffin, B.N.; Hudson, P.: Lunar Landing Vehicle (LLV). Space Manufacturing 6, AIAA, Oct. 1987, Title Page
- / 21/ Matijevic, Z.: Analysis and Preliminary Design of a Universal Space Ferry for Heavy Space Freighters. Aerospace Institute, Techn. Univ. of Berlin, TN 199/1988, 165 pp.
- / 22/ IAA Ad Hoc Committee Return-to-the-Moon: The Case for an International Lunar Base. Acta Astronautica, Vol. 17, No. 5, pp. 463-489 (1988)
- / 23/ Aron, J. et al.: Beyond Earth Boundaries. Office of Exploration, NASA, 51 pp. (1988)
- / 24/ Aldred, J. et al.: Lunar Outpost. Johnson Space Center, NASA, 60 pp. (1989)
- / 25/ Koelle, H.H.: The First 1000 Days of a Future Lunar Base. Aerospace Institute, Techn. University Berlin, ILR-Mitt. 224(1989), May 1st, 1989, 51 pp.
- / 26/ Campbell-Seltzer, J.: A Lunar Base Bibliography, NASA/JSC 22 873 (Rev.A), November 1989
- / 27/ Koelle, H.H.; Altmann, Th.; Kerinnis, O.: NEPTUNE - 2000 PLUS, Concept of a Heavy Space Freighter for the 21st Century, Aerospace Institute, Techn. Univ. Berlin, ILR-Mitt. 229(1989), December 1989, 61 pp.
- / 28/ Mielke, M.: Draft of a Cost Model for the Acquisition of a Permanent Lunar Base. Diploma Thesis, Techn. Univ. Berlin, May 1990, Technical Note ILR-Mitt. 245 (1990), 45 pp.
- / 29/ Koelle, H.H.; Johanning, B.: A Multi-Vehicle Space Carrier Fleet Cost Model for a Multi-Mission Scenario. Aerospace Institute, Techn. Univ. Berlin, ILR-Mitt. 240(1990), May 1, 1990, 99 p.
- / 30/ Stanley, D.O.; Talay, T.A.: Propulsion System Optimization for Advanced Manned Launch Vehicle Systems. J. Spacecraft and Rockets, Vol. 27, No. 3, May-June 1990, pp. 246-252
- / 31/ NASA -The Office of Exploration: FY 1989 Annual Report, Vol. 0 through VI, NASA TM 4170, 1990
- / 32/ Miller, K. L.: Concepts for an Export Oriented Lunar Colony, Acta Astronautica, Vol. 21, No. 11/12, pp. 795-818, 1990.

Acknowledgements:

This position paper was compiled during the years 1985-89 by the Lunar Development Subcommittee of the IAA Committee for International Space Plans and Policies, chaired by Prof. Dr. H.H. Koelle, Dean of the Department of Transportation, Technical University of Berlin/Germany with contributions of more than one hundred Members of the Academy from 12 countries.

APPENDIX 1

DRAFT, Nov. 1989

TO WHOM IT MAY CONCERN:

**MEMORANDUM OF UNDERSTANDING
on the Establishment of an
INTERNATIONAL LUNAR PLANNING OFFICE (ILPO)**

PREAMBLE

In recognition of exceptional faculties, status and special needs of humankind in the solar system and perhaps in the universe as a whole and with awareness of the responsibilities this implies, in order to preserve life, and improve its quality on its home planet, humankind is destined to explore the frontiers of this solar system as specified already in the Outer Space Treaty of 1967 opening the neighbouring celestial bodies for their exploration development, use and settlement, it is resolved to start the development of the lunar resources in the spirit of the Moon Treaty of 1979 by agreeing to establish an **International Lunar Planning Office (ILPO)**.

Article 1: Objectives

An **International Lunar Planning Office (ILPO)** shall be established to compile essential planning information concerning the ways and means to explore and utilize the resources of the Moon for the benefit of humankind. This office shall provide within a period of 24 months:

- a draft of the preliminary lunar development plan in sufficient detail to (1) enable a decision on the establishment of a **Lunar Development Agency (LDA)**, and (2) prepare a detailed program which may be adopted by the interested governments;
- a draft of a charter for the Lunar Development Agency (LDA) which shall be responsible for preparation and execution of plans for the development of lunar resources; and
- a draft of a schedule and procedures to put the Lunar Development Agency in operation, if such an organization is agreed upon.

Article 2: Parties

Parties of this Memorandum of Understanding shall be the National and Regional Space Organizations (.....) authorized by their respective governments and/or international institutions willing and capable to initiate steps towards a return of men to the Moon.

Article 3: Organization

1. The ILPO shall be comprised of the national and regional **Task Teams**, which shall remain attached to their parent institutions.

2. The head of the Board of the Board of time prof
3. A host co the Execu
4. The head hosting th of the ILP
5. In case s this office provision concurre
6. The host countries
7. The Chair by the UN
8. Internati entitled t Executive their choi Directors
1. Internatio not antich
2. All perso Executive country.
3. The adm by the ho
4. Studies c the ILPO, interferen
1. The Boa participat the date o

2. The heads of those national or regional task teams shall constitute the Board of Directors providing ten per cent or more of the full-time professional staff members contributing to the overall effort.
3. A host country shall provide offices and administrative support for the Executive Office of the ILPO.
4. The head of the national or regional task team of that country hosting the Executive Office shall also act as the Executive Director of the ILPO unless the Board decides otherwise with a 3/4 majority.
5. In case several countries make an offer to host the Executive Office, this office shall rotate between them in alphabetical order with the provision that the period of rotation shall be no less than one year if concurred in by the majority of the Board of Directors.
6. The hosting of meetings shall rotate among the participating countries.
7. The Chairman of the UN Committee on Outer Space, if so mandated by the UN, shall be an ex-officio member of the Board of Directors.
8. International organizations involved in space matters shall be entitled to nominate liaison officers in an observer status at the Executive Office of the ILPO or at any regional task team office of their choice at their own cost, subject to approval by the Board of Directors.

Article 4: Funding

1. International transfer of funds during this two year planning effort is not anticipated.
2. All personnel assigned to the task teams or delegated to the Executive Office shall be paid by the respective participating country.
3. The administrative support of the Executive Office shall be paid for by the hosting country.
4. Studies contracted to third parties may be paid by sponsors outside the ILPO, subject to approval by the Board of Directors, preventing interference and/or possible profiteering.

Article 5: Working Operations

1. The Board of Directors shall assign workpackages to the participating task teams indicating the level of effort desired and the date of completion. Decisions shall be taken by majority vote.

2. The Executive Director is responsible for coordinating and issuing a semi-annual report on the progress made and the final report.
3. The workpackages shall include, but not be limited to, the following tasks:
 - Preliminary definition and assessment of a lunar base.
 - Identification of preferable locations for an initial base.
 - Draft of regulations to protect the lunar environment.
 - Draft of a list for priority lunar science projects.
 - Identification of precursor activities for a lunar base acquisition.
 - Identification of potential goods and services which may be exported by a lunar base during its operational life.
 - Preliminary definition of an initial lunar logistics system.
 - Draft of a guideline for commercial utilization of lunar resources.
 - Draft of the most likely scenario and schedule for the acquisition and operation of a lunar base.
 - Draft of a funding plan for the lunar base.
 - Compilation of national capabilities and potential contributions to the development of a lunar base.
 - Identification of technical long-lead time items.
 - Identifications of possibilities for non-governmental organizations to contribute to a lunar development program.
 - Development of organizational plans for the structure of the proposed Lunar Development Agency.
 - Proposal for a public relations policy and a distribution list for the communications and reports of the ILPO.
 - Proposal for a personnel selection procedure and policy in an international scenario.
 - Definition of interfaces to other international organizations and institutions.

Article 6: Effective Date

1. The International Lunar Planning Office shall begin its operations on January 1, 1993.
2. The Executive Office shall be located at

Signatures of Participants

Note: This draft was compiled by the members of the LUNAR DEVELOPMENT SUBCOMMITTEE of the INTERNATIONAL ACADEMY OF ASTRONAUTICS with Dr. H.H. Koelle, Berlin, as the chairperson, to initiate the discussion on this priority item.

APPENDIX 2

The International Academy of Astronautics fosters the development of international scientific achievement in astronautics and space science.

Just as the century has entered the seventeenth in the development of astronautics, the International Academy of Astronautics, in the thirtieth year of its advancement, is possible by its foreground of development.

Organization of the Academy of Astronautics and its contributions to the experiences, results of the committee of the structure of the Academy, such as, The Academy of Sciences in Astronautics.

The Founding of its very nature of mankind, inhabitants of the world of such common materials that both time and space.

The history of the Academy, its membership, their respect, Academy to be in the field of astronautics.

The total Academy of Astronautics, 70, is now approaching the century.

APPENDIX 2

The International Academy of Astronautics

An Overview

The International Academy of Astronautics (IAA) was established in 1960 to foster the development of astronautics for peaceful purposes through international scientific co-operation, and to recognize individuals of scientific achievement who are committed to the advancement of aerospace science.

Just as the classical academies were created at the birth of modern science in the seventeenth century, the formation of the International Academy of Astronautics in 1960 coincided with the beginning of manned space flight. In the thirty years since its establishment, there have been great advancements in the development of rockets and of travel into space made possible by them. Astronautics is now firmly and permanently in the foreground of scientific and technological progress, influencing the development of individual branches of science and technology.

Organization of the Academy was based on the precept of the classical academies that with essentially modest means, made their vast contributions simply by bringing together individuals to exchange ideas and experiences, to make studies and recommendations, and to bring the results of their work to the attention of their communities. The founding committee of the Academy, led by Dr. Theodore Van Karman, patterned the structure of the organization after the great classical scientific academies such as, The Royal Society in London (1662), and the Academie des Sciences in Paris (1663) with the difference that the Academy of Astronautics is international in character.

The Founding Committee of the Academy recognized that astronautics is by its very nature international. The study of the Universe is a deep aspiration of mankind, and the use of the space environment will affect all the inhabitants of our planet Earth. Any exploration of extra-terrestrial space is of such complexity and involves so much expense in manpower and materials that the pooling of ideas inevitably produces incalculable savings in both time and resources.

The history of the Academy is really a history of the accomplishments of its members, an elite international body of individuals, elected by its own membership, who are the leaders of space and aeronautical activities in their respective countries. These distinguished members enable the Academy to be a working institution dedicated to producing effective results in the field of international co-operation in space science.

The total Academy membership, limited to 1000 members under the age of 70, is now approaching full capacity.

The Academy membership is divided into of four sections: Basic Sciences, Engineering Sciences, Life Sciences and Social Sciences. Academy work is performed by the members of committees covering all aspects of aerospace sciences and its effects on society. Currently, these committees and subcommittees are:

The Space Sciences Committee

The International Space Plans and Policies Committee

- Subcommittee on Lunar Development
- Subcommittee on Mars Exploration
- Subcommittee on Small Satellite Programs

The Life Sciences Committee

- Subcommittee on Space Physiology and Medicine
- Subcommittee on Space Planetary Biology and Biophysics
- Subcommittee on Human Factors
- Subcommittee on Biotechnology and Life Support

The Space Activities and Society Committee

- Subcommittee on Art and Literature
- Subcommittee on Education

The Economics of Space Operations Committee

The Interstellar Space Exploration Committee

The Search for Extraterrestrial Intelligence Committee

The Safety and Rescue Studies Committee

The Space and Environmental Changes Committee

The History of Astronautics Committee

The Scientific Legal Liaison Committee

The Multilingual Terminology Data Base Committee.

The emphasis of the Sections is to ensure and reward the highest standards of quality in membership; whereas the emphasis in the scientific committees is to organize symposia and specialist meetings that are interactive debates on areas of international importance, often in affiliation with other international societies and academies. The transactions of these proceedings are generally published for use by the world space community.

The work of the Academy, as well as the proceedings of the International Astronautical Congresses, are documented and published in periodic and special issues of **Acta Astronautica**, a world-class scientific-technical journal published by Pergamon Press in London.

The Academy's plan for the decade of the nineties is full of opportunities, challenges and international endeavors that provide a program through which prominent space scientists from different nations can work in concert to maintain peace and foster scientific co-operation in outer space.