"Is the surface of a planet really the right place for expanding technological civilization?"

A Stewart Brand's interview with Gerard O'Neill – July 1975

Gerry O'Neill, his wife Tasha, Mike Phllips and I in a July ghetto apartment in San Francisco til 2:a.m. Figuring that Space Colony details would be covered elsewhere, we concentrated on the life of the idea itself, then six years of age (1975)
- Stewart Brand

Stewart Brand:

What is the point of origin for you on space colonies?

Gerard O'Neill:

My interest in space as something for people to be in, rather than simply to look at, goes back a long way. But the particular thing that started the space colonies concept, really, was a course that I taught at Princeton in 1969. It was the big, standard Freshman physics course, with about 320 students in it. "Physics 103."

I chose to do double-load teaching that whole year - my idea was that I would be the lecturer in that course, and I would also take a class section so I'd see the course from the top and the bottom at the same time. There were quite a few things that I wanted to do to improve the course. One of the things I felt most concerned about was that this was the peak time of disenchantment with anything in science and engineering. The students who were good at science, and particularly the students who were good at engineering, felt very defensive about it, because all of their friends and their roommates were saying that they weren't doing anything relevant. And I felt that, despite the bad times, improvements in the human condition could be reached by using science and engineering in the right ways, as opposed to the wrong ways.

So I thought it would be worthwhile, particularly for those few students who were so far ahead of everyone else that the ordinary coursework couldn't challenge them, to invite them to come to an extra seminar where I would try to find examples of problems to look at which could be of interest in their lifetimes, and which would be challenging on a large scale, and potentially very beneficial to the rest of humanity. And now having given you a non-answer to your question, I'll give you a complete non-answer, because I have to say that out of somewhere, and I don't know where, it occurred to me that the first reasonable question to ask was: "Is the surface of a planet really the right place for an expanding technological civilization?" And, of

course, once you ask the right question, the right answer follows almost automatically. That's simply a question of working out the numbers.

SB:

Now, this is how many students in the seminar?

O'Neill:

Oh, not more than 6 or 8, I suppose. We met once a week for several weeks.

SB:

You asked that question and what happened then?

O'Neill:

Well, the students were able mainly to do library research, going and looking up in Encyclopedia Britannica how big the land area of the world was and things of that kind. I had to supply a good fraction of the calculations although they were able to do some of them, but within the time of the seminar I did encourage them to do calculations of how big could a rotating pressure vessel in space, to hold an atmosphere and provide a gravity, be made. That answer came back pretty quickly. It already started being interesting because it was several miles in diameter.

The reason is that if you're using the electromagnetic interaction - that is the ordinary interaction that holds solid matter together, instead of the very weak gravitational interaction (which is holding on to an atmosphere the difficult way, the way a planet does) - then you've got an enormous factor in your favor. What does that mean in terms of how much land area you can build with a rather small amount of material? The first answers that we came out with indicated that we were talking about more than a thousand times the land area of the Earth as the potential room for expansion. So those two numbers, the question of the largest structure size using ordinary materials and the question of what the limits to growth were, were enough to get me interested in the problem.

Another item that came in was energy, because it seemed pretty clear that solar energy was the obvious way to go And also that if you were building large things, in the long run it would be better to do it in zero-gravity than in a planetary gravity.

SB:

So, as I understand it, the question was asked, and the implied answer was, "No, the planet's surface is not the right place." And the implied next question is, "Where, then?" And then the answer was inside-out planets.

O'Neill:

Well, the classical science fiction idea of colonization is always you go off and you find another planetary surface, like the moon or Mars. . . That misadventure we sidetracked very quickly because first of all there just isn't that much area involved, and second, most of those other planetary surfaces are fairly unpleasant in terms of where they're located. They're the wrong distance from the sun, and they've got the wrong rotation times, and the wrong gravities usually. Besides all that, there was the fact that it didn't make sense once you could get out into the space beyond a planet to give up the fulltime solar energy that you could get if you just stayed there.

The sort of analogy that I like to use nowadays is to say that, "Here we are at the bottom of a hole which is 4,000 miles deep. We're a little bit like an animal who lives down at the bottom of a hole. And one day he climbs up to the top of the hole, and he gets out, and here's all the green grass and the flowers and the sunshine coming down. And he goes around and it's all very lovely, and then he finds another hole, and he crawls down to the bottom of that hole. And if we go off and try to get serious about colonizing other planetary surfaces, we're really doing just that. It's kind of atavistic but there really isn't any other excuse for it.

SB:

I want to track a little more on the sequence of events for you and for the students discovering all this. You asked the question… Were you already being electrified by all of this as it got started or did that come later?

O'Neill:

I was already. I started getting interested quite quickly. There was the question of how to make it as earth-like as possible, because certainly right from the beginning, my feeling certainly was, that I had no desire to go the route of just inventing a big spaceship or something that would be a space station. That had no interest for me at all. This was to be something that was to be potentially beneficial for a lot of people. It had to look an awful lot like the Earth. So, one of the questions I worried about quite a bit was how to provide earth-normal gravity, and a normal atmosphere, and a normal appearance of the sun as well. It was during that first few weeks I think that I came up with this simple geometry of the 3-fold symmetry of the mirrors and the alternating land and window areas, which so far still looks fairly reasonable in terms of the constraints that you put on it. The fundamental thing, but one that didn't occur to me until quite a long time later - because of course my work on this was very occasional, a few minutes every few weeks kind of thing - was the question of how you cope with the angular momentum. The spinning cylinders are there, and it's sort of not very elegant to go throwing away reaction mass to try to process that angular momentum. But it wasn't until sometime later, I have to admit, that it occurred to me that the easy way was to make two of these things and to hitch them together.

SB:

And they rotate in opposite directions?

O'Neill:

Right. It should have occurred pretty quickly, because it's an awful simple-minded idea, but it didn't.

Mike Phillips:

Does it occur in any natural form?

O'Neill:

Well, again, if you ask the question in the right way, it should occur to you very well. I mean the wrong way to ask the question, and the way that I asked it first, was "How do you apply forces to a gyroscope to make it process?" The right way to ask the question is "How can you have a rotating object that doesn't have any angular momentum?" and then you get the answer immediately. That's easy to say after the fact.

SB:

Was there a point or a series of points where the practicality started to overwhelm you?

O'Neill:

I think I began to realize, really, within the first month or two that this was, in my opinion at least, something very important. And that I somehow had to get it out into the open and get it discussed. But then, as you probably know, it was a long and very frustrating period before anything really came out on it. I talked about it a little bit to some of my friends. I used to talk about it to my children. I'd take them on walks in the woods, and speculate about what life in a space colony would be like. In fact Tasha came to one or two of the seminars at that time, because we had met only within weeks of that same time.

SB:

Were you electrified, Tasha? Or was this just something he was doing?

Tasha O'Neill:

Well, at first it was beyond me, anyway. I had just come from Europe and I didn't understand anything anyway. And I didn't understand anything about physics. And then, you know, time went on, and it took hold of me too. I understand far more by just listening over and over and over . . .

O'Neill:

You'd be surprised to hear her explain angular momentum now.

SB:

Let me pursue this, because I am always interested in how ideas take root in a person and then in society. So here you are now with what must be a gradually increasing obsession and not many listeners. Did you take a strategic approach in any way? Or just keep talking and let things find you?

O'Neill:

It was awfully irregular and unplanned. I spoke about these things with a few friends and at one party, in the home of some friends. There happened to be someone who was associated in an indirect way with one of the magazines and that lady got very interested and excited about this and suggested that I write up an article for the magazine. And that seemed to me to be a worthwhile idea so through her, the magazine editor and I got in touch, and at his suggestion I went ahead and wrote an article.

SB:

What magazine? What editor? What lady?

O'Neill:

I think that was **Atlantic.**

SB:

That's the East coast phenomenon, Michael.

O'Neill:

What's the East coast phenomenon?

SB:

That publishing occurs on the East coast. If you were in Nebraska, you'd still be there.

O'Neill:

Well, the reaction was - the editor was quite interested and he wrote back and asked an enormous number of questions, and then I expanded on the article, answered the questions, and sent it back again. Again, long months went by and finally he rejected it and said, "It's not that I'm not interested, it's just that I have this feeling that I've asked ten questions and you've given me ten answers and now that suggests a hundred more questions, and it's not going to converge somehow. Better that I not do anything about it."

SB:

That's the difference between our magazines. **Atlantic** converges; we don't.

O'Neill:

So then it went through a period of-let's see, that was 1970, and it was not until four more years that I was able to get an article published.

SB:

All this time you're just muttering to friends?

O'Neill:

No, I kept on. I rewrote the article again and . . .

Tasha: Collected rejection slips.

O'Neill:

Yes, collected rejection slips. I wrote a letter to **Scientific American.** I didn't send in the manuscript, but they had published two articles of mine previous to that, so . . .

SB:

On what?

O'Neill:

Subjects of physics. There was an article on spark chambers, which was a technique of high-energy physics which was in vogue in the 1960's, and an article on particle storage rings, which happened to be something that I'd started. So I wrote an historical article about that in the 60's. And since I had written for that magazine before, why I felt that it might make sense to try them again. So I wrote them a letter suggesting an article on this topic, and just in a couple of paragraphs outlined what had been done. And I got a very stuffy letter of rejection back. I think it was two lines, and sort of immediately dismissed the whole thing. They didn't even want to look at a manuscript.

So then I rewrote it again and that time I tried **Science.** And that rejection was curious and more complicated. In all of these cases, of course, the time to accumulate rejection slips was very long. You know, many months would go by, in each case. In the case of **Science**, they sent me the reviewers' comments Both of the reviewers had recommended rejecting the article. One of them had gone into shock, really, there's no other way to say it. He had just said, "No one is thinking in this direction, and therefore it's got to be wrong." And the other one started to think about 2 or 3 possible objections but he didn't let his own mind carry him far enough logically to see the answers to the objections. Now that was a curious case, one of the reviewers,

I'd never met. I don't even know to this day who it was. The other one, oddly enough, was my host at the first lecture that I ever gave on this subject. It was an odd coincidence, at Hampshire College in late 1972. A friend of mine said, "Look you're having all this trouble getting this idea out and under discussion, take it to the people. Give some talks at universities. And if you can't get the ideas out to the public any other way, take it to the students, they're a very good test of whether something is worthwhile or not."

SB:

This is what Buckminster Fuller did a while back when no one was buying. He went to students, and students bought, and then everybody else bought.

O'Neill:

Well this fellow said, "Look, come and give the talk at our college" - this was Hampshire. And so I went up there in late 1972, and the man who was the dean of the engineering college, the college of science, was the host. The talk itself was a lot of help to me because it was an 8 o'clock in the evening lecture, and I talked for less than an hour, and then questions went on for more than an hour after that, and the students were very excited about it. Finally after something like 2 or 2 1/2 hours had gone by, the host got up and said two things. "First," he said, "l want to say that when I first heard this idea I thought it was complete nonsense, and now I want to tell you that I've changed my mind. The second thing is that the speaker has an 8:30 class tomorrow and a 4-hour drive to get to it and we really have got to give him a chance to get to sleep. So let's just let those few people who want to ask questions, continue asking questions." And what happened was that about half the audience left, and the rest proceeded to take chairs closer to the front, and the whole discussion went on for about another hour.

When I left with my host to go back to his place to sleep the few hours that remained, he started asking me some very elliptical questions that I couldn't understand at first. He said, "You had all of these rejection slips now for all of these years. Does this personally get to you? Is this something that is personally threatening to you in some way?" And I laughed and said, "No, it doesn't. First, I really think that what I'm doing is worthwhile and, second, this is something completely beside my normal work, and I don't have any trouble getting my ordinary work accepted. I don't have to worry about my job and so on. So that I don't feel personally threatened by it at all. I'm sorry that people are so slow to catch on, but that's my only reaction." "Well, it was important to me to ask that," he said, "because I want to tell you that I was one of the reviewers who turned down your article for **Science**." And he said at that time that he would write to the editors of **Science** and tell that he had changed his mind.

SB:

Very nice. Did that then have some effect on **Science**?

O'Neill:

I never got any direct reply from them on that. There was another man later on who got quite interested in that work who wrote them and I got a very stuffy short note from the editor, saying that in view of this suggestion that they would reconsider if I wished to resubmit the manuscript. By that time, **Physics Today** had already agreed to publish the article, and I wanted to be loyal to the first people who had gone out on a limb and said that they would be willing to publish this work.

SB:

That was the first major publication . . .

O'Neill:

That was the ONLY publication. The article was accepted about the beginning of 1974 and published in September of 1974. So there was a period of approximately four years during which I was trying to get it published and couldn't.

SB:

As this was going along, and before you talked with students at Hampshire, were there friends of the idea that were sort of helping you stay afloat about it? Or were you pretty much all alone in your enthusiasm?

O'Neill:

Well, there were personal friends whom I talked to, and who got quite interested and enthusiastic about it, but it was a sort of word of mouth thing among comparatively few people. And then I did start giving other lectures in colleges - The second lecture was at Princeton. And I gave talks at quite a few colleges on the West coast in 1973. But that already represented a passage of about 3 years of time.

SB:

Is this with graphics and slides and things like that? Or straight. . .

O'Neill:

I had some fairly primitive graphics.

SB:

During this time, how much were you actually working on the idea itself, refining it?

O'Neill:

Very little. It would be a question of if I were in the course of a working trip someplace and had to spend a day or a night in some city where I didn't know anybody, I might work in my hotel room or I might spend a Saturday on it, or the middle of the night, or something like that. That was all the time I had.

SB:

So the **Physics Today** article, which was basically the same original article, slanted for . . .

O'Neill:

I think it was about the 6th or 7th draft by then, but the ideas were basically the same. It had been improved and a whole lot of detail had been added, arid of course as you say it was for a different audience. The original article had been written for a popular audience.

SB:

Then what was the response to the magazine article?

O'Neill:

It was very strong. But already between the time that the article was accepted and when it actually appeared, you see, there was the May 1974 Princeton Conference, and that really was when the concept got known to a fair number of people.

SB:

Because of Sullivan in **The New York Times**?

O'Neill:

Yes. And then the articles that followed from that.

SB:

Michael where did you come into the picture? And how?

Mike Phillips: Gerry, you wanted to talk to somebody at POINT Foundation.

O'Neill:

Yes. I wanted to have a little conference, and try to get some people in to talk about this and see whether there was anything fundamentally wrong in the ideas. And I thought, well, look, we could probably put on the conference with no budget at all, in some kind of way. But darn it all, it ought to be possible to get a little bit of money to do a few things that would make it better. So why not waste the few hours to become educated in the question of how you go about getting money to do something which has not been done before in our society. And so I started calling foundations. And I

very rapidly found that no matter what it says in the title of any foundation, and no matter what people may say about a foundation - that it's always looking for new ideas and things like that - it's really not true. The only kind of new ideas that foundations are looking for are those that follow directly along the lines of things which are already in the mainstream. And I got personal interest from a number of foundation executives, and so on, but not a penny of money from any of them.

SB:

This is how many foundations you're talking about?

O'Neill:

Oh, I must have tried 8 or 10, something like that.

And then someone suggested the POINT Foundation.

Phillips:

Probably David Hunter.

O'Neill:

I don't know who it was, Mike, it could have been. Stern Foundation sounds familiar. Then I got in touch with Richard Austin, which was not easy, by the way, because it came by way of the Portola Institute. He had moved and now he was in San Francisco, and there was a sequence of following telephone numbers, and so on. Finally I talked to him, and he was his own absolutely unchangeable self and, you know, very genuine and very open right from the start. So that was how we set up that appointment with you and Richard and me.

SB:

You were out here anyway or flew out for that?

O'Neill:

No, I was out here anyway in connection with my high-energy physics work. There was no budget, so I couldn't go any other way. So, Mike instantly understood what I was talking about, and I gather you were almost out of money.

Phillips:

It was getting down there, it was almost near the end [mumbled]. .

O'Neill:

So you came up with the famous $600 dollars and that was what funded the first conference.

Phillips:

I just got that figure out of the air.

SB:

So the **Whole Earth Catalog** is responsible for the colonization of space.

Phillips:

I didn't give it to him without restrictions though. You see, I thought they ought to go through Princeton. That Princeton had to accept it. The grant to him wouldn't be nearly as . . .

O'Neill:

I think it had an excellent effect. In fact let's trace that effect. You see, it had never occurred to me to even talk to reporters about this. Our idea was, we'll invite a few friends, and we'll have a little conference. And because that was handled as an official university grant, a certain amount of boiler-plate went along with it. Part of that boiler-plate was that a statement of that grant came across the desk of the University Publicity office. They automatically sent out a university publicity release on it, and that was the reason why reporters came down to the May conference, and articles started getting written.

SB:

What reporters did you get?

O'Neill:

Local ones, and Walter Sullivan came down from the **Times.**

SB:

Do you happen to know what drew him down?

O'Neill:

I think he's a good conscientious reporter and science writer, and there must have been something in it that interested him, but beyond that I don't know. Incidentally, I think he may be opposed to this idea now. The latest that I've heard is that he is personally somewhat negative on it, though he continues to report the work accurately and fairly.

SB:

So, this was May 1974. The conference included who?

O'Neill:

We had, let's see, Gary Feinberg, from Columbia, and Eric Hannah, who was a graduate student at Princeton at that time, and Eric Drexler, who was an undergraduate from MIT, who had found me rather than the other way around, incidentally. He's a very interesting guy. And we had Joe Allen, a young NASA astronaut, who presumably will fly some of the shuttle missions. Joe had learned about my work quite indirectly. He had talked to someone who had been to a lecture that I'd given on the West coast. I think Cal-Tech, or something like that. So Joe was interested and he came up to the conference. And then there were two people from NASA headquarters, and one of them was in the advanced launch vehicle division of NASA, Manned Space Flight office. He was very helpful because he gave us some initial estimates of launch costs. Those are still within a factor of 1 1/2 the same numbers that are being kicked around now, so we had already the basic answers from him at that time.

SB:

It was just one day? Was it papers, or people chit-chatting, or what?

O'Neill:

Well, it was really two days because we had people come in on a half-day on Thursday. Perhaps 10 -15 of us, just sat quietly around some tables and tried to review some of these ideas and get in hand how these papers would mesh, how these informal talks would mesh on the following day. Freeman Dyson came on that day, and Freeman got very interested and he stayed for the whole conference in fact. Dave Anderson, a student from Columbia; George Hazelrigg from Princeton in the Aerospace Engineering Dept. So the first day was just a few people sitting informally around a table, and then the second day was open.

SB:

So there were a reporter or two there, and Sullivan did what with it in the **Times**?

O'Neill:

He wrote, I think, a very good article, which the editors of the **Times** chose to put on the front page. He called a few days later. He said his first reaction was to be surprised, Gosh, that they had put it on the front page, and then his second reaction was, Well, why not? So, then, everybody sort of picked up on it from there, and there was an article on it in **Time**, and lots of interview requests. The BBC was on the phone within a day or two, and CBC and various New York stations and so on, and stations out on the West coast.

SB:

And you were doing the interviews?

O'Neill:

I was doing the interviews. That was still in a time which I had the time to be able to do the interviews that got asked for.

SB:

So there was a media flash for how long?

O'Neill:

Well, it really never stopped. The Associated Press did an article in the summer of '74, quite a good article. Howard Benedict was the reporter, and he took care to check his facts very carefully. It was quite a good job. The **Los Angeles Times** asked me to do an op-ed piece, which I did for them, and they had it illustrated reasonably well. And since they're part of the **L.A. Times - Washington Post** syndicate, that got picked up by papers in many different places in the country. And then the **Physics Today** article came out in September. That prompted a large amount of response which was more from technically educated people. And also that prompted some of the counter-blasts. There were two that I would call carefully worked out, in the sense of someone at least sitting down and trying to work out some numbers. And it took me a lot of time, because I then had to sit down and answer these things in detail.

Phillips:

Were they creative? Did they result in new forms for . . .

O'Neill:

It's a very good question. There was nothing that came out of them that was creative in the sense of suggesting a new possibility that had not been floating around earlier, or a new solution to a problem that hadn't been floating around earlier. But I think they were very helpful in forcing me to go into detail and justify on a numerical basis things which I hadn't taken the time to calculate, because I just had had a sort of hunch that the numbers would work out all right. I think that I certainly learned a lot in terms of additional insights into, say, how the economics of the whole thing might go than I would have without those criticisms. So it was probably quite worthwhile. Then, let's see, there was the **New Scientist** article - that was in late 1974.

SB:

You said then there was a second Princeton conference. When, this May?

O'Neill:

That's right. We've been trying to measure in some way the exponentiation time for the whole thing, and at the second Princeton conference I just made a hasty

calculation that during the last year the exponentiation time was something like 3 - 4 months.

SB:

"Exponentiation time" being what?

O'Neill:

Time in which some level of interest, activity and so on is growing by a factor of *e*.

SB:

"Factor of *e*" being what?

O'Neill:

2.71 . . . Pocket calculators would automatically think in those terms too. Physicists are just used to it. So just for fun at that time, off the cuff, I tried to think of the ratio of the funding level of the 1975 Princeton conference which as far as I'm concerned will be the last one it will be necessary to hold of this general introductory types, to the funding level of the first one, which you paid for, or YOU [readers] paid for, depending on how you want to measure it. And the ratio was something like 14 or 15, and so working out the exponentiation time, it was just about four months. I'll admit that's a silly way to try to measure something.

Phillips:

The NASA-Ames study is a hundred thousand dollars. May at Princeton was $12,000.

O'Neill:

The big crunch will come now, because we're at the point where you have to sit down and do some serious studies. Bunches of people getting together and waving and shouting is not going to push the thing along. At this point you really have to do your homework and have serious, specific research which runs for a year or more, and on a much more fine-scaled set of topics. To do that right would take something between $500,000 and $800,000, I would say, spent over the next year. And I cannot imagine any way within the present set up of the government that that money could come out. Because the 2-year funding cycles that you normally have just don't permit that.

SB:

Summarize briefly what came out of the second Princeton conference, and what you expect to come out of the summer at NASA-Ames.

O'Neill:

Well, the NASA-Ames study, I'm not sure what will come out of that, because that really is not a directed project study in the same way that the previous work has been. First of all it's funded out of the American Society of Engineering Education through a NASA grant, a continuing thing. It's really intended to be an educational process for young faculty members, not for aerospace professionals by any means. They came in for the summer with the intention of going through an exercise in systems design, and many of them arrived on the scene knowing next to nothing about the whole subject. So it's mainly an educational process. The challenge is to obtain a serious design study from a formal setup which is nondirective and quite different in outline. So far the Ames study is doing quite well, given its limitations.

SB:

In a sense this is like your original seminar.

O'Neill:

Maybe so. The Princeton conference got us quite a bit farther, because that was a directed kind of thing where we had about 25 or 30 invited speakers, each of whom prepared a paper on a given topic. I think we can now make some fairly definite statements: one is that as far as the quantity of material that does have to be brought up from the earth - that is, what you need to give you the stepping - stone, to establish this sort of first beachhead in space - the costs, numbers and sizes of the vehicles involved are well within what people can do in the 1980's timeframe. They don't require anything more advanced than the space shuttle and the sort of vehicles that you could easily develop from it. There's nothing super advanced involved, no nuclear-powered rockets or anything like that.

The second solid thing that we could say is a consequence, not just of the Princeton conference but also of a lot of very thoughtful letters and calculations I've had from various people whom I would never have known about had it not been for all the publicity that's come to this business. The agricultural numbers that I used in **Physics Today** now seem to be very much on the conservative side. You could probably do quite a lot better than that in terms of yields per square meter to support people. But that's okay. We are farther along on the question of design of the massdriver, which is really crucial to the whole thing. It's the electromagnetic machine for bringing lunar surface material from the surface of the moon up to the colony site. That's extremely important because practically all the material for the first colony, and everything for the products that it produces has got to come from the moon. There I would say we're somewhat further along now than we were a year ago, we seem to be qualitatively okay, and even quantitatively in terms of the basic details, but a lot of calculations still have to be done. And we are somewhat further along in terms of guidance methods and things of that kind. That's the sort of thing where nothing less

than a serious, quiet study where four or five people sit down full-time on this subject for several months or a year would do the job.

And we had an interesting paper on Space Law. Apparently the building of the first space community would fit within all of the international treaties if you stick to, as I recall, three conditions. First thing, it's got to be non-military. The second, that if anything interesting, new research, comes out of it, like information about the surface composition of the moon or something of that kind, that it does have to be made available through the United Nations to anybody who wants the information. And the last is that, at least in some nominal form, the community has got to be under the jurisdiction of the nation or group of nations which establishes it. You cannot, at least deliberately, send people out to be absolutely on their own.

SB:

So there's a funny point now between the Princeton conference level and the next serious study level. What's your expectation as to how it will actually proceed over the next couple of years?

O'Neill:

Well, we know that our support from NASA (which is small, but enormous by the standards of what we had just a year ago) is going to be continued and increased somewhat for this next year.

SB:

Will you be administrator of that?

O'Neill:

It's such a tiny thing, there isn't really much administration involved. Yes I'm the, whatever it is, the - I forget the title I'm supposed to have. It's the usual thing; you have to be responsible for these things.

SB:

Are you getting any kind of on going cadre of people tending to track along with the project?

O'Neill:

Oh, very much so.

SB:

There's how many people now?

O'Neill:

Again it's a question of the level of involvement. There are now at least 15 or 20 people who are spending some significant fraction of their time on a volunteer basis, working on this, unpaid entirely. Some of them are spending quite a substantial amount of time that way. There are a very much larger number of people who have written offering to help if there's some way that they can within their limitations; they've got full-time jobs to hold down. So far I've felt that I ought to put out the newsletter myself.

SB:

The newsletter, what's that?

O'Neill:

It doesn't cost anything, you just have to write to my address in Princeton, and the secretary should send the newsletter. There's one coming out now I just finished writing it. Prof. Gerard K. O'Neill, Physics Dept., Box 708, Princeton, NJ 08540.

SB:

You're still being basically a high energy physicist?

O'Neill:

Oh, yes. There's no real government commitment, for example, to push this program hard at this point. I've spent many years building up my little group in experimental high-energy physics and I'm certainly not about to tear it apart in an unstable moment like this.

SB:

What would it take for you to become a fulltime space colonizer?

O'Neill:

Well, if the president came to me and said, "Here is X-billion dollars, we're going to go ahead with the thing and we want you to be involved with it." That would sure fetch me.

SB:

Suppose NASA said "Here's 5 years of personal salary to administer the growth of this program?"

O'Neill:

That's not enough. I have a deep suspicion of governments, and really - although I'm not politically active-I know enough about politics to be very suspicious of it; I think I would have to see a really substantial committed kind of program going. I don't

mean at the spending level of billions of dollars, but I'd like to see something where there's a very solid commitment to continue in the same sense as there was in the Apollo program.

SB:

Of the level of Kennedy saying, "We're going to be on the Moon in this decade" For some politician to make this go, he's going to have to say "by the year so-and so." What year is that?

O'Neill:

Arthur Kantrowitz, the president of AFCO-Everett was out visiting us a few days ago. He happens to be quite enthusiastic about this work, and he says that his answer for things of that kind is to say, "You'll have the result ten years after you've stopped laughing," which is I think, a pretty good answer. The most responsible answer I could give is to say that if I really had the responsibility for getting it done by a certain time and the authority to do it in what I would consider the right way, then I would be willing to make a very strong commitment that it could be done in 15 years from time-zero. Whatever that time-zero is.

SB:

This is Model One with an extra-territorial population of what?

O'Neill:

Yes, Model One. Roughly 10,000 people. If you look at the growth rates that you could get from that first one, then you'd probably be talking about a quarter of a million people by the year 2,000. Because you'll be going up very fast after you get the first beachhead.

SB:

And your graph I saw in Washington suggested a net population decrease on the planet's surface by . .

O'Neill:

I think the turn-over there is about 2018. Now that was based - first of all, I don't make it as a prediction - it was indicated as a technical possibility, and it was based on a time-zero of essentially now, which is certainly unrealistic politically, and a completion date of 13 years, so that would put Model One in place by 1988. Maybe you could even do it from now, technically, but it's probably more reasonable to say 13-20 years from a time of decision.

SB:

Do you think there's no way to get the toothpaste back in the tube at this point.... that the idea is inevitable?

O'Neill:

There are other possibilities. Civilization could tear itself apart with energy shortages, population pressures, and running out of materials. Everything could become much more militaristic, and the whole world might get to be more of an armed camp. Things of this kind might just not be done because no nation would dare to divert that much money away from military efforts. or without war, it could be that the world will become poor, to the point where it can't afford to try things like this.

Of course, if neither of those possibilities occurs, then I do think there is some sort of inevitability about it. With that, of course, you can't associate a time-scale. It could be a long time.

SB:

Who resists the idea in any large way? If anyone.

O'Neill:

Well there was a while when I thought that elderly and famous professors of physics were the greatest opponents. . . In fact of all the mail I've gotten only about 1% has been in opposition to it.

SB:

And what's your short roster of planetary problems that will be solved by this particular technique? Energy, population. . .

O'Neill:

Well, yes, but by phrasing the question in that way it's difficult for me to answer except with a prediction or promise, and that's something that no decent scientist likes to make. I think it's very wrong to assume that something like this is going to promise happiness to all people, because people manage to make themselves unhappy in almost any circumstances.

SB:

Well, now I'm going back to '69 when you and your students were on the defensive about relevance.

O'Neill:

"What's the relevance?" That's a fairer way to ask the question. From the economic viewpoint, which is perhaps the narrowest, there are starting to be products which are

needed, and whose end use is in very high orbits above the earth, like geo-synchronous orbit or even father out, escape distance or beyond. And for that class of products, a space community has a very strong advantage. We tried to run the numbers for several different kinds of products of that kind: processing lunar materials, satellites, solar power stations, very large radio telescopes, things like Project Cyclops, something that would listen for extraterrestrial civilizations. We concluded that you could do Project Cyclops for 1/10 the price if you built it at a space colony, rather than on the earth. And things like large space research vessels for going out to the outer parts of the solar system with a large research team, hundreds of people - very much in the spirit of Darwin's voyages. Exploring the planets in detail is something where you'd go out with a ship of several hundred people, that would be a self-contained community. It would be able to run for several years, and would go into orbit around one of the outer planets and send down small vessels to take samples and do surface explorations. You'd be doing your data analysis in real time, and any startlingly important results you would be beaming back to the vicinity of the Earth immediately. The detailed tapes you'd carry back at the end of the voyage.

One of the ideal industries for the community at L-5 is ship-building, because if you're going to build a big ship that's going to be in space, it's pretty absurd to build it at the bottom of the hole that's 4,000 miles deep and then try to haul the pieces up. As far as the satellite power stations are concerned, again we're going through the numbers, but it looks as if it can be done that way more cheaply than it could from the surface of the earth, again, because you're using lunar materials which can be obtained at low cost. Having cheap energy may do more toward feeding the population of Asia than almost anything else we can provide.

One product that can be built, once you have a first colony there, is more colonies. You can construct a community which is self-contained in terms of all of its basics, of relatively small size. You're not depending on a food distribution system that's a thousand miles long, for example, as we do here on the Earth. Or an energy distribution system that's 7,000 miles long, as we do here on the Earth. Suppose that all of those essentials were obtainable over a distance of only ten miles, and by a population which was as small as ten thousand or a hundred thousand. I would think that in the long run, the tendency toward community diversity, the diversity of governments, diversity of the ways people choose to live, the kinds of architecture that they choose to have, and so on, would be enormous. Which is, I think, in exact contrast to the way that things are going on the surface of the Earth at the present time. And I believe that if someone were to look back on this whole business from the vantage point of say a hundred years further in time, probably the economic factors, which loom so large to us, will seem then to be relatively unimportant, because they won't be able to appreciate from their presumably much wealthier vantage point, what our problems were like. But the question of diversity and of the opening up of new possibilities and new frontiers, both of the body and of the mind, I

suspect will come to be regarded as the most important contribution that these ideas have made.

Phillips:

I wanted to ask about the conference. What papers, or what people were the most exciting, or the most interesting?

O'Neill:

That depends an awful lot on your point of view, of course. Naturally, I was most concerned over those speeches which bore directly on the question of the validity of the calculations that we'd been making up to the present time. So from my point of view, two of the most important papers of the conference were those by Hugh Davis of Johnson Space Center, and Del Tishler who was formerly at NASA headquarters. And those were very straight-forward launch vehicle papers, which might not be so exciting to someone who is interested in sociological questions for example.

Phillips:

What about the materials talks?

O'Neill:

Materials? There was a good talk by David Criswell, from the Lunar Science Institute in Houston, and it looks as if from the Apollo samples of lunar rock and the additional information that Dave was able to give us, we're in quite good shape for metals, glass, oxygen. We already knew a year ago that we don't have good sources of carbon, nitrogen, and hydrogen on the surface of the Moon. Dave went through an exercise which seems to indicate that we could, if we want to, get enough hydrogen out of the lunar surface by preselecting fine-grain material before we send it heating and processing a greater quantity of material than the amount out to L-5.

SB:

It is my understanding that the lunar material is not what anyone would call ore in any Earth sense.

O'Neill:

It's not so bad. There are lots of places on the earth where 1% ore is regarded as relatively good these days. And there are large areas of the lunar surface where just the ordinary dirt that you pick up out of the ground is as much as 10% aluminum, and around 30% in total metals.

SB:

How does that compare to bauxite?

O'Neill:

Not as good. Bauxite's a richer ore than that. But that's becoming a scarce resource. The Bureau of Mines is already conducting studies, some of which are up to the pilot plant stage, for the processing of some ores which turn out to be identical to the ones we would have to work with on the moon.

SB:

Does working in vacuum in 1/6th gravity give you any advantages in working the ore?

O'Neill:

Well the vacuum environment of the moon is vital for the question of low shipping costs. The mass-driver, the electromagnetic machine, can only work efficiently in vacuum. So that point is critical. The low gravity of the moon is also necessary for low transport costs.

Phillips:

Vacuum processing might have some influence on ore.

O'Neill:

Well, you have your choice, you see. You can do your processing either in vacuum or in an oxygen atmosphere. If you want to, because the soils that you have on the moon are 40% oxygen by weight. In the long run you can get everything from the asteroid belt.

Phillips:

Just because people haven't become emotionally attached to asteroids yet, and because they have become emotionally attached to the Moon?

O'Neill:

Well if you look at the economics, it's certainly going to be much better to build new colonies by going out with the construction equipment to the vicinity of an asteroid, taking the material right there, for which you don't have to pay anything in terms of a velocity interval to get it away, build the colony, and then move in the people, because their mass is very small, so the cost of bringing them is very small. And you've got the colony already working and productive and beginning to pay back its construction costs, and then you can do whatever you like after that. Incidentally, the asteroid belt can very easily give the colonists Earth-normal sunlight. That's not a problem at that distance.

They have their choice. They can roughly over a period of one generation at a relatively low energy cost, work their way back into the vicinity of the Earth. Or,

they could go the other way if they feel like it. You can imagine that during one generation, within 30 years or so, it would be technically quite possible for a big colony to move itself into even a polar orbit relative to the ecliptic. They could move themselves into an orbit so far removed from the rest of the human race that there'd be no interaction at all, except for communication of course,-if they chose to communicate. There might just be some totally absorbing colonies that would be listening to what was going on from the outside but not saying anything at all.

Phillips:

What are the things that you want worked on right now? If you were to pick the 10 subjects.

O'Neill:

That's an awful good question, Mike. I would love to see some really good work on chemical processing of the ore coming out from the moon. How to get the good quality glass, good quality metals, and any non-organic fibers you want, anything of that kind.

Phillips:

OK that's one. If there were 10 people you could set to work in teams . . .

O'Neill:

Yes. I'd like to see some really good work on small-scale, closed-cycle agriculture. Some of that sort of stuff is already going on in some places. The question is to vary some things like oxygen concentrations, CO_2 concentrations, and so on. There are ways in which you could model this environment more thoroughly than it has been done up to now. I think that somebody should be doing something which is really hard - it hasn't been done before and yet it's very accessible - and that is to analyze a number of the existing industries on the surface of the Earth in terms of their productivity, but measured in ways that we've not measured them before. Productivity in the sense of what is the total mass of the products that the industry turns out in the course of a year, divided by the total mass of the installed construction equipment of the factory itself. You can see why this is extremely important for us. It's never mattered to anybody before.

There's the question also of taking an industry, and saying what is the productivity of that industry measured in terms of the output products per person in the industry. But now possibly dividing the people into two classes, in a way that hasn't been done before. In an electronic age there need not be a distance of 50 feet between a design loft where someone is designing the next generation of products and the construction area where people are building this generation. There is no reason why, in this day and age, those things couldn't be a quarter of a million miles apart. And therefore you

want to analyze an industry, seeing not just what is the total productivity in tons per man-year, but in tons per man of a kind that has to be associated with the production machinery, as opposed to all of the people who are selling, designing, administrating, and so on. You can imagine an industry which has one foot in each camp. You can imagine it with many of those activities carried on on the surface of the Earth, and a very good wide-band computer link-up between that area and the space community and the actual construction going on in the space community.

SB:

Let's see, as you get into lunar distances, you're getting what kind of lag in communications?

O'Neill:

Enough to be annoying for voice. It's like a second or two. In fact it's more than that. For a round trip time it would be almost 3 seconds.

Phillips:

You got a lot of things you could get started right now. In fact, by simply listing and describing them, you can get people to do them.

SB:

That's the kind of list I would be particularly interested in, because presumably some of our readers will go "Aha, that's me," and take off on it.

O'Neill:

That would be very good. We need to have a more thorough and careful job done of looking at albedos and questions of thermal radiation from a space community, making sure there's no problem about holding the temperatures about right. We've been assured by the people down at JPL, who've sent all the spacecraft out, close to the sun and all the rest, that our particular problem is well within the range that they know how to handle. But it would be nice to look at that more thoroughly.

Let's see what other basic ones we've got. There's another class of problems which may take a while to get answered. It's the sort of thing that NASA would logically do, but I don't think they're prepared to go in this direction yet. The curious fact is that if you start designing one of these large communities, in terms of just the economics of how much in the way of materials you have to put in per person, it costs you very little to make earth-normal gravity. It turns out to be very easy. But to make earth-normal atmospheric pressure, costs you very badly, for two reasons. One is that 80% of our atmosphere is nitrogen, which we don't use at all. People can breathe pure oxygen atmospheres perfectly well. The Apollo astronauts were breathing pure oxygen atmospheres for days at a time. I've done it for hours at a time.

SB:

What about plants? Are they happy with that?

O'Neill:

They couldn't care less. They take their nitrogen from the roots; they don't take it from the air. The main reason for going to anything but a pure oxygen atmosphere is just fire protection, apparently. And the situation that NASA has never had any reason to investigate, is one in which you have a pure oxygen atmosphere but have only 2 or 3 pounds per square inch pressure. That's about the same as the partial pressure of oxygen on the Earth, within our range of altitudes. In large volumes, as opposed to the confined volumes of the existing spacecraft, and with an abundant water source present. Now if you'll look at fire protection problems in that particular environment, I'm reasonably confident that you're going to find that fire protection is not that difficult, but that situation has not existed up to the present time, and no research has been done on it. All it would take really is a large vacuum tank, - where you can get rid of the nitrogen and have 3 psi of oxygen. To try to light some matches and see what happens when you've got a reasonable size space and that pressure and lots of water on hand to put out a fire.

Phillips:

What is the coriolus effect on a small colony? What are the interesting things that would occur?

O'Neill:

Well, we've been told that somewhere between two rotations per minute and three rpm, the range for Model One, that only a very small fraction of the population would have any problems with initial seasickness. Pop-flies in baseball on Model One would be curious affairs. In your rotating coordinate system, you would see them assume a curve which they didn't really have.

SB:

Someone I talked to yesterday, said you wouldn't feel it walking around along a cylindrical axis, or along a cylindrical circumference, but if you changed elevation, you would feel it. If you jump.

O'Neill:

I don't know if that's true. Maybe. Not at the lower rotation rates. Apparently the people who have been put in centrifuges on the earth have been able to acclimatize to spin rates as high as 10 per minute. Going around once every 6 seconds. But that's something which you're going to get with practice say over a 10-day period.

SB:

If "in wildness is the preservation of the world," then in what is the preservation of the space colony?

O'Neill:

Making it wild, I think. The long-term plan, really dream, that I would have is a situation in which, in 50, 100, 150 years, it would be so cheap to replicate large communities that you would be building quite large ones, many, many square miles in land area for each one, and they would be very thinly populated. And so the natural development it seems to me, is toward a situation where you have a great many wild species involved, and as wild an environment as you choose to make. I would imagine one on which there is a lot of forest and park area and wild areas, and a relatively small amount which is manicured and put into the form that people like to have for their dwellings.

SB:

Now you're restating your question, whether a planet's surface is the best place for a wilderness?

O'Neill:

Maybe so. But this situation that I was just describing, this possibility if pursued, is one that could occur both on the Earth and in the communities of course. Because the existence of the space communities as a place to which many people might choose to move would also be perhaps the only realistic non-violent way in which the Earth's population might really decrease.

SB:

I'm trying to imagine the trapped feeling that one might have. Travel between communities would be relatively easy. Travel to the Earth's surface and back would be relatively hard. Is that correct?

O'Neill:

It would be interesting to compare it in terms of real income. Passage between the colonies and the Earth probably corresponds to passenger travel back and forth between Europe and the United States in, say, the 1700's. It's the kind of thing that Benjamin Franklin did to go and negotiate treaties in France. It was not the sort of thing that the ordinary guy was able to accomplish.

The cost of going back and forth to the Earth - I made some rough estimates on what that might be with the technology of let's say 20 - 30 years from now, still nothing far out like nuclear power or anything like that - and came out to about $3,000 per person for a round trip. Among the colonies it should be very easy, very cheap. From

one community to another, even 5,000 miles away would probably be as little as $100 or something like that. A few dollars in energy costs is enough to launch a vehicle over that kind of distance.

SB:

Another question on the life of the idea. Who are your predecessors?

O'Neill:

I think the one that is really the most relevant is Konstantin Tsiolkowsky - the Russian who did the early work on liquid rockets. I had been looking for his works, and I had made various attempts in libraries without ever connecting with the right ones. Finally just this spring, a friend gave me a couple of Tsiolkowsky's books. I'm still trying to get copies of my own and haven't been able to yet. But the book which is most relevent is called Beyond the Planet Earth. It was written more than 50 years ago, almost 75 years ago. It's a novel, and so of course he was able to duck lots of issues, but he had the essential ideas, I think, very much better than most people who came after him. In particular, he imagined his first voyagers out from earth, soon after liftoff got out of the eclipse area and started building greenhouses. That was the whole point. They had been out there for weeks when it occurred to one of them to say, "Maybe it would be nice to go over and have a look at the moon." So as an afterthought, an aside, they went over and visited the moon. In the course of the visit they found gold and diamonds, easy enough in a novel, and then they did the next sensible, logical thing, they went out and started exploring the asteroids as material sources. There were some people much, much later, like at least 25, more like 50 years later, that talked a little bit in those terms, but not even they, I think, saw the whole as clearly as Tsiolkowsky.

Some more references

3-D Universe

. . . astronomy has shown us that the stars are very far away, and they surround the earth in 3 dimensions, except I continue to experience them as "points of light in the sky." They might as well be glued to an acrylic sphere 20 miles away.

One evening, I looked at the zodiacal light, and rather than being "a cone of light in the sky," it became a mass of dust and gas encircling the sun. Its size frightened me so much that a circuit breaker in my mind blew, and the zodiacal light returned to normal within a second. Even so, I was so shook up that I had to go back inside the house, to the comfort of a human-sized space.

Have any of your readers experienced the Milky Way in 3-d? Did they survive? Did it affect them permanently?

My wife says she can have 3-d flashes at will, when the mood is right. However, in asking around, I gather that such experiences are rare. This points out a dilemma which is common to all science, not just astronomy: little emphasis has been placed on how scientific knowledge can affect our experience of the universe. Instead, the knowledge is packed away in some abstract corner, isn't systematically integrated into our lives, and we remain, in many important respects, medieval peasants, only now we're smart.

The integration process completes a cycle: observe the universe, abstract knowledge from the observations, integrate the knowledge into our experience, observe the universe again . . . only now it's a WHOLE NEW UNIVERSE. This is an exciting point they never told me at the university, since they concentrated exclusively on the first half of the cycle.

But I imagine you Californians have been transforming the universe for some time now. When are you going to do an article on it? Do any of your readers have 3-d flashes? Do they have any ideas about how to have them at will? And how about experiencing fire as an oxidation process?

Gordon Solberg. Rimfire Ranch

Radium Springs, New Mexico

The High Frontier

The one book you must have if you're interested in Space Colonies is this one by Gerard O'Neill. His scheme has aroused so much rabid support and rabid opposition that O'Neill's gentle voice and responsible perspective has a critical balancing influence. I have seen environmentalists who at first blush loathed the idea of Space Colonies come away from O'Neill's book impressed and interested.

Having one individual most strongly identified with a grand vision such as Space Colonies is the healthiest way to proceed, I'm convinced. And I'm glad Gerry has the job on this one.

-SB

The High Frontier

Human Colonies in Space
Gerard O'Neill 1976;
288 pp.Bantam Books, Inc.
414 E. Golf Road
Des Plaines, IL 60016
or Whole Earth

When I have considered the effect of our discovering, one day, signals from a more advanced civilization (note that it would be, with almost 100 percent certainty, millennia more advanced than we are because of our own position at the threshold of communication) it has seemed to me overwhelmingly probable that the first effect of the discovery, as soon as the excitement and the novelty have worn off a little, would be to kill our science and our art. What purpose to study the natural sciences? We already know that they are universal, so if a civilization now radioing to us is 50,000 years ahead in its knowledge, why continue to study and search for scientific truth on our own? Gone then the possibility of new discovery, or surprise, and above all of pride and accomplishment; it seems to me horribly likely that as scientists we would become simply television addicts, contributing nothing of our own pain and work and effort to new discovery.

In the arts, music and literature, the case may be somewhat more unclear; yet on earth the almost invariable consequence of contact between a primitive civilization and one more advanced is the stagnation of the arts in the former. Only in the form of a "tourist trade" does art survive, in most cases.

If this sequence of effects is of more than local significance, as I think it is, it will be quite obvious to any civilization more advanced than our own. I would then add one more

assumption: that the same characteristics which render a civilization immune to intellectual decay and stagnation, if there be such characteristics, are accompanied by a repugnance to inflict harm on others, in particular to other "emerging" civilizations more primitive than its own. In that case, "They may be out there, but they're kind enough to keep quiet."

Large tugboat driven by reaction engine seen in background has decelerated an asteroid sent in from the main belt and is about to process it from materials to be used in construction of new space habitats and Earth-orbital solar powered stations.

I confess to a humanitarian bias in the design that I suggest. Technological revolution is a powerful force for social change, and in choosing among several technical possibilities I have been biased strongly toward those which seem to offer the greatest possibilities for enlarging human options, and for breaking through repressions which might otherwise be unbreakable. Yet I offer no Utopia; man changes only on a time scale of millenia, and he has always within him the capacity for evil as well as for good. Material well-being and freedom of choice do not guarantee happiness, and for some people choice can be threatening, even frightening. Though I acknowledge that my study will be of the physical environment, and only indirectly with the psychological, I will still try to describe an environment which combines with its efficiencies and its practicality opportunities for increasing the options, the pleasures, and the freedoms of individual human beings.

I have argued that there is only one way in which we can develop truly high-growth-rate industry, able to continue the course of its development for a very long time without environmental damage: to combine unlimited solar power, the virtually unlimited resources of the Moon and the asteroid belt, and locations near Earth but not on a planetary surface.

L-5 News

Much the best source of news on Space Colony matters, the L-5 News is an enthusiastic publication of admirable vigor, and it's no fanzine. The editors and contributors are in the thick of Space Colony design and speculation. They plan to live in Space.

L-5 News
L-5 Society
1620 N.Park Ave
Tucson, AZ 85719

-SB

WHAT ARE LIBRATION POINTS?

T. A. Heppenheimer

Our organization name is the L-5 Society, and our newsletter has stated that L-5 is one of the libration points in the Earth-Moon system. But what are libration points? The answer is that libration points are locations where a spacecraft may be placed so as always to remain in the same Position with respect to the Earth and the Moon.

Suppose the Earth and Moon were fixed in space and did not move. Then a single libration point would exist at the point where the gravity fields of Earth and Moon cancel out. A body placed there would feel equal and opposite attractions from Earth and Moon, and so would stay fixed in place. But if the body were moved slightly, it would feel a slightly greater attraction from either Earth or Moon, and so would fall down, moving rapidly away from the libration point. That point, therefore, is unstable.

In reality, the Earth and Moon are in motion about their center of mass. (It is the Moon, of course, which does most of the moving.) This means that, in addition to the gravity of Earth and Moon, we must take account of the centrifugal force acting on a body in orbit. Libration points are then the points where these *three effects* cancel out: the two gravity fields, and the centrifugal force.

The French mathematician, Lagrange, in 1772, showed that there are five such points. Three of them lie on a line connecting the Earth and Moon. These are L-1, L-2, and L-3. They are unstable; a body placed there and moved slightly will tend to move away, though it will not usually crash directly onto the Earth or Moon. The other two are L-4 and L-5. They lie at equal distance from Earth and Moon, in the Moon's orbit, thus forming equilateral triangles with Earth and Moon. These Points are stable. It is a curious fact that they are stable because the Moon is only 0.01215 times the total mass of Earth and Moon together. If the Moon were greater than 0.03852 times the total mass, L-4 and L-5 would be unstable.

The situation, however, is even more complex than this. The Sun is in the picture, and it disturbs the orbits of spacecraft and colonies. It turns out (from an extremely messy calculation done only in 1968) that with the Sun in the picture, a colony should be placed not directly at L-4 or L-5, but rather in an orbit around one of these points. The orbit keeps the colony about 90,000 miles from its central libration point. The orbit is roughly bean- or kidney-shaped. It may seem curious to speak of an orbit about a point. Actually, the colony is in orbit about the Earth, but the simplest way to describe the orbit is from the point of view of an observer sitting always at the libration point.

In the colonization project, the colonies are to be located in the vicinity of L-4 or L-5. L-2, located behind the Moon, is the site of a catcher vehicle, which collects mass shot up from the Moon by the mass-driver. L-1, between the Earth and Moon, is the location of a satellite power station, to provide power for the moon base. No use has yet been found for L-3. However, at L-3 the Moon is permanently eclipsed by the Earth, so it could serve as an asylum for people suffering from lycanthropy (werewolf tendencies).

VAPOR DEPOSITION OF MASSIVE STRUCTURES

Work done this summer suggests the possibility of fabricating space structures directly from vaporized metals. If proven out by further design work and by vacuum chamber experiments, it promises to provide a textbook example of the use of space conditions in processing, and may cut the cost of a colonization program by some tens of billions of dollars.

Fabrication of seamless hulls or hull segments would be a simple and useful application. The solar energy flux, vacuum, and lack of gravity in space make it easy to vaporize metal and direct it as a conical beam: metal plate of the desired strength and thickness can then be built up on a balloonlike form made of plastic film.

This technology seems applicable to both aluminum and steel alloys, to structures many kilometers in diameter, and to structures more complex than smooth balls. Because it requires little equipment and negligible labor, it promises to reduce the cost of some space structures to little more than the cost of raw material. It seems a fruitful area for further research.

Eric Drexler

A recent study at the Hudson Institute entitled The Next 200 Years in Space (NASA Bicentennial Planning) by Herman Kahn and William M. Brown, predicts the building of space communities and manufacturing facilities.

Those interested in the complete report should write to:

Hudson Institute
Quaker Ridge Road, Croton-on-Hudson
New York 10520
1 Rue du Bac, Paris 75007, France
1-11-46 Akasaka Minato-ku, Tokyo, Japan

National Space Institute

National Space Institute Newsletter
1911 N. Fort Meyer Dr.
Suite No. 408
Arlington, VA. 22209

This is a public lobby set up by Werner von Braun shortly before he died to help build a broad Space constituency and help keep Washington informed of what that constituency wants. Apparently it's pretty effective and is riding adroitly the burgeoning new public interest in Space. Good newsletter!

-SB