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"Space Settlements"

John Billingham

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June 25, 1978
Portland State University

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JOHN BILLINGHAM: We are not tied in to this very specific objective, okay, but there may be a journalist group which wants to explore the interaction between environmental education and journalism. There may be, as Dave mentioned, some of the other groups that he has in mind, and at some point, I guess you have to put up a list…

DAVE [last name unidentified]: Tomorrow.

BILLINGHAM: Tomorrow on the blackboard somewhere, and let you begin to sign up for whatever you… whatever you require. Okay?

The groups will be a little bit different. Each, of course, can feed across to the other. In other words, these groups will surely go to the journalists and ask for ideas about ways in which material might be written up or prepared in the packages, okay? So there will be this sort of thing going on, but it's easier if we think of it in this way; it's sort of, I think, easier to get this picture from the start.

You may think that this is, perhaps, an awful lot of work involved in all this, and for those of you who want to get into it, there could be... When we first started this, we wondered, in fact, if people really would enjoy this type of thing and really get involved, and it turned out that they did. It turned out that after contemplating it for a little bit and trying to find out what was involved and so on, they got involved, they got into discussion groups, and really got very interested in the idea, not just of absorbing stuff in a summer course, but at the end of that summer course, being the authors of something which was very useful not only for themselves, but also for other people.

Just to show you that I have proof here, okay, that it works. We are not going to ask you to produce fifteen hundred pages of a document, anyway... huge volumes or anything this summer that's impossible in a period of twenty days.

But I want to tell you what happened in 1974. We ran a series of workshops, teacher-training institutes; something like this, but longer. Each one was eight weeks instead of four weeks, and each one had a smaller number of participants, about twenty-five to thirty people. And we ran three only. We used exactly the same system, and some people were a little bit unhappy with it at first because they weren't used to it, but they rapidly got into it, and produced, at the end of that time... at eight weeks, now, they produced all the raw material which was turned, in the following year, into this very sophisticated workbook, a faculty institute workbook on their resources.

The idea, at that time, was for people to develop materials for their own use to take back with them—and this was all teachers at that time—to take back to their classroom and use, so this has various types of exercises in it. It has the talks given by the visiting speakers and it has the material actually developed by the workshop itself. Okay? It's a very sophisticated and quite a formidable product.

It is being used more and more as the years go by. We have been back to the original participants, about, oh, sixty or seventy participants, to find out what happened to this. And it is being used more and more and more, but of course, it is not available as a published document. This was simply the result of their own endeavors, for their own purposes. And what's happened is that their colleagues have borrowed it and borrowed it and borrowed it, and so its use has spread. This encouraged us, and encouraged us to be more ambitious this time and say, "Well, why don't we take one step beyond that?" And rather than have a workbook for your own use or for your friends or for your own college or school, why not… at least let's try to think of a workbook or something else, maybe? Maybe this isn't quite appropriate. Or maybe this should be combined with more materials or slide collections, whatever, on a much wider basis.

So, if you'd like to browse through this at the end, or, alternatively, I can pass it around. It's a bit heavy to pass around.

DAVE: And it might fall apart.

BILLINGHAM: Yep.

DAVE: But they'll only get about three hundred pages of that, I think, again in about four days?

BILLINGHAM: Yes. What we do… When you start into this sort of discussing, what you might generate, we've pulled out of this some of the very best material developed by the groups in 1974. For reference purposes for you. We've also got lots more reference materials for you, which Dave will talk about. But, for example, here is a list of readings. These are actual Xerox copies of the key references, okay, in the various areas of resources, and each of you will get one of these shortly. So that was just about all I had to say, and whether Dave wants to say any more about schedules.

DAVE: Just a few things, John.

BILLINGHAM: Yeah?

DAVE: About, uh…

BILLINGHAM: Questions, maybe?

DAVE: Yeah. Do you have questions you would like to ask Dr. Billingham?

[unintelligible voice in background]

DAVE: Something. Hold the questions until tomorrow if you would like. We will… even though we start right off tomorrow with a lecture, it will be more of a formal beginning. Then we sort of become more casual and relaxed, starting afterwards over in the cafeteria. Then it will be just as any classroom in the university, you know. Not the formality of the lecture which we'll have at the beginning of nine and one o'clock.

We'll have name tags, so that you can put your favorite name down that you like to be called by and help us all get acquainted tomorrow, because there will be… we are trying to plan some social events like volleyball or swimming for four o'clock. After we work hard, we can go relax or drown other people if you feel that way after the first day. [laughter]

We will have, for those who registered and paid, the booklet tomorrow, and some of you haven't registered possibly, and we have some forms that we will have in the back lobby that you could sign up and finish up that registration. I know of some have brought theirs in already. We assume that you would and hadn't counted you, so we may end up with about seventy in this program, which is fine.

We'll be adjusting schedules, posting them, and all of this as it comes in, but the only other technical aspect or detail is to sign up on a piece of paper on a clipboard in the lobby out there if you're registered so we know you came today. The only reason for this is that we want to be sure that we talked to all the others who didn't come today and do the same thing. We hoped we'd have that recorded so you can listen to that tomorrow, but that didn't work quite the way we hoped.

Any other questions? It'll happen, it'll be something very exciting. Yes?

STUDENT 1: Is the cafeteria in the same building, or where is it?

DAVE: It's in Science 2, which is over at 10th and Harrison. It's in Science Building 2, the new one. How else can I describe it? There's a big stairway that goes up to it, cross on the other side of the Park Blocks. And we'll have our brochure signs up on all of the doors so you can see which it is. Incidentally, if there are any people in art, we'd like to encourage people to develop ideas like posters, collections of cartoons, and ways of informing people about environment. But it takes some analysis of that. You can't just go collect a bunch of clippings. It would say, "This explains something," and the intention is to learn a great deal using media and other things along the way.

And other questions or… Michael, do you have any comments that you'd like to make?

MICHAEL [last name unidentified]: Well, I have a couple of questions that I'd like to make. I'd like to… My concern was the [speaking in background, indistinct] nothing to do with the [...]. You heard that… I'm a teacher of education […] science teacher in education, as some of you might know, for many years. And what I would like to say is that we're offering an opportunity here to rework school curriculum in such a way to make it really speak with issues... the crucial issues that we are facing today. As I view what's happening in the school… and I go there fairly often and I look at what's being taught, what's being studied. I look at problems that have been identified here by Dr. Billingham: in part, the problems with energy, the problems that deal with food and other resources, urban planning, policy… […] policy, political policy. These are all intertwined, and some of them are rather… the schools really have not gotten the point. The problems that are important are interconnected and they're not even spoken to individually in the school, much less in the interdisciplinary fashion that has got to be done. And so I'm looking forward to a new opportunity working with you to do what has not been done in public education in the past. And […] moving forward. Thank you.

DAVE: Thanks a lot. It is an opportunity; we are going to loosen up a lot of faculty as well as students to these ideas of… those university people that are on campus, we hope, are ready to become a part of this in an individual way from time to time, and we hope they'll become a little more realistic. Some of our classrooms get pretty stiff and stilted, so we want to get the originality coming. Any other comments and questions that anybody would like to come up with? We'd like to just move on into the lecture by Dr. Billingham on extraterrestrial settlements. It'll cheer up some of the people that are really anxious to see that part of…

He needs another introduction. Dr. Billingham is a physician. He was trained in England; he had a variety of scholarships moving into research endeavors, as well as training in English and European systems. The research that he pursued following receiving the M.D. was directed mostly toward physiology, which led into—during the post-World War II years, when space flight became a different kind from the old aviation medicine—into outer space exploration. And Dr. Billingham moved from the Royal Air Force to NASA in 1965 as a deputy, but he soon moved to chief of extraterrestrial biology, and has been directing research programs in all aspects of biology in outer space, and related phenomena of psychological factors, performance, human factors, and so on. And at lunch, we were talking about some others involving whales that they're involved in, and his tie has three species of whales on it. [laughter] But, at any rate: Dr. Billingham on extraterrestrial settlements.

BILLINGHAM: Okay. At this point, I put aside the last hat and put on a new hat. A different hat. The two things aren't really terribly connected, because Earth Resources is dealing very much with what goes on here and the way in which we've got to, as Mike was explaining, come to grips with probably the major problems, which are places here. But there is a sort of relationship between the two.

They've asked me if I will tell you about our work on space settlements, okay? When we think about Earth Resources and our own environment here, and the way in which we should behave to keep it intact, we don't think very much about space. We don't think beyond the confines of the Earth. And that's a great problem. But there is this possibility that in the future, our own civilization will expand out into the solar system in a way not too dissimilar to the great expansions of the past. For example, the settlement of this campus.

We've been working on this for four or five years now. We did not put very much effort into it because it does not have much priority in the lasting concern, mostly in things very much closer to the present. And this is looking way into the future. However, it is important that, occasionally, we do look into the future and see what might await us if, indeed, one wishes to continue the whole business of outer space exploration and the movement, physical movement of people out to the space environment.

I always hesitated to talk about this in approximation to a question of Earth resources because it's not yet clear that we can be completely successful with moving out into space, even if we wanted to be. Although it's looking more and more as though we can as time goes by. It's simply that the one thing not to do is, I think, to assume that a movement out into space, as it were, conquering a new frontier, is any replacement for making sure that we do the right things here on Earth, with our environment here on Earth. So, it conceivably could be included in a discussion of Earth's resources, but that's something, I think, I must leave to you.

I want to show you some pictures, perhaps, about the space settlement business. When we began four or five years ago, it was very unclear as to whether or not we would, in fact, be able to move into space and take up residence there, as it were. But there is a sort of sequence of ideas which is developing now as to how this might be done, to a degree due to the stimulus provided by Dr. Gerard O'Neill, Gerry O'Neill at Princeton University, and we have been working with him these last four years to try and see what the next fifty or a hundred years might look like if, indeed, there are sufficient pressures or if there is interest for people to want to go out into space.

As you know, the space shuttle will be launched shortly. The shuttle is what it says, it is a transportation system. It's a shuttle bus, which takes things and people backwards and forwards between the surface of the Earth and orbit in space.

Here it is. It'll be going up fairly soon now. It'll land like an airplane instead of landing in the sea like existing vehicles have done. Next, please, Dave. And here it is reentering the Earth's atmosphere from orbit. The heating, as the vehicle comes into contact with the atmosphere, of course, makes it glow red underneath like this, and ultimately, it lands like a rather unconventional type of airplane. I'm not quite sure what that strange organization is listed on the tail there.

DAVE: Reverse NASA. [laughter] ASAN.

BILLINGHAM: This is the very first true step into space, and I guess we have to ask ourselves what would come next, if anything. And the results of our studies show that it is feasible to go on and begin to settle space with larger numbers of people, if you do certain things. And the two most important things are not to rely on mass or material or matter from the surface of the Earth, and the second thing is not to rely on energy from the Earth. In other words, if we started building huge space stations or space settlements out in space, and to do that, had to take all the material to build them from the surface of the Earth, and attain the energy from the Earth, they would rapidly become intolerable. The number of launches needed would pollute the atmosphere, we would deplete our energy resources, and we would deplete our precious mineral and other material resources. Okay, so that's out. We don't really consider that very much. What is the alternative?

The alternative is very straightforward, and that is to obtain the matter, the materials, the metals, the stuff you need to build space settlements out of material that already exists in space. So that is principle number one. Principle number two is to obtain the energy you need to convert those materials into habitats or settlements from space itself. And you get the energy from the sun. Okay?

So, over these last few years, these ideas have developed. They are now pretty concrete, and the story I'm going to tell you is how one would get those materials from space, and then what sort of settlements or habitats you might think of putting together. I would emphasize that the next series of pictures are liberally laced with artistic… "license" is too strong, but these are mostly going to be artists' concepts. [slide projector clicks] No, go back please.

Here we are on the moon, an obvious source of materials out of which to build space habitats. It turns out that it is probably not very economical to build your settlement or your habitat on the surface of the moon itself, or on Mars, or on Mercury, or on the moons of Jupiter and Saturn, because it takes you a tremendous amount of energy to get down onto the surface and to get off the surface because they all have gravitational fields.

Therefore, if you want to build space settlements, the best place to build them is in space. And the source of the material to build them: there are two major possible sources; one source is the moon, and the other source is the asteroids. The asteroids are bodies which go around the Sun, goes like the Earth does, for those of you who are not familiar with them. There is a main asteroid belt out between Mars and Jupiter, but there are asteroids which are much nearer here to the Earth. Okay, so those asteroids are huge chunks of rock. They may be a hundred million tons of rock, already with metal there. Iron. Aluminum. Silicon. Platinum. All of the metals you could want for construction purposes. There is oxygen, plenty. There is carbon in some of the asteroids, or organic matter. There is nitrogen and there is hydrogen. They are, in fact, the best source of materials for building things out of, like settlements, than is the moon. The moon has no nitrogen, no hydrogen, and no power to speak of.

Nevertheless, the moon is an obvious easy source of material; and how do you get material from the moon into space where you'd want to use it to construct your settlements? You'd build a mass driver, and on the left here, you see a mass driver powered with solar cells all the way down there. You'd load up lunar materials into buckets. You'd accelerate the buckets electro-magnetically down a track, levitate it magnetically for a mile or so until it reaches a very high velocity, and then you suddenly slow the bucket down and the payload, which is lunar material, goes sailing out into space, okay, and you have reached a stable velocity. So this material simply leaves the moon. This is sort of like a catapult, as it were.

And then let me show you a little bit more of the mass driver. Next, please. This is the principle: there's the mass driver, and there's the payload, and it goes off towards the lunar horizon and escapes. Next, please. And that might focus a bit… The power comes into the magnetic accelerator, payload goes off like this all the way down. At this point, you break, start breaking. The payload itself is released, and the bucket returns. Here and here is checked, reloaded, and goes back again. It's like a draping machine, okay, on a very different scale. Next please. And we put the mass driver at the lunar equator. This is the moon, and it fires off the material like this out to a point beyond the moon, which we'd pull down to, which is the second lunar libration point, which is a good place to catch things, and there we have a big catcher which catches the rocks. And I must say that we have not designed a catcher yet… [laughter] and we do anticipate a little trouble with the catcher, but you'd so arrange things that by the time the masses arrived for the catcher, in fact its velocity has been lowered to something which is very reasonable. So that's the idea. Next, please.

On the lunar surface itself, here is the crew. We'd envisioned a… oh, possibly a hundred, as many as a hundred people. Maybe fifty on the lunar surface, running the mass driver. And this is inside the control room, and here is the mass driver over here. Here are vehicles, collecting lunar rock. I don't think the Sierra Club would be too upset about this, because the actual amount of rock you need to remove is incredibly small. To build a full-scale space settlement for millions of people, you'd need to excavate a football field worth of lunar material down to a depth of about, oh, fifty feet, I think. Anyway, it's not really… Next, please.

This is the business end of the mass driver, and here is one of the people in the lunar colony, one of the engineers. At this point, the payload has left its bucket, all right, and is now receiving its final adjustments for its trajectory. This is a lump of lunar rock, about twenty kilograms, about forty pounds of lunar rock sort of glued together, and it has a charge, okay? And you can adjust the exact final trajectory or pathway of a chunk of rock by passing it through these structures here, which give a little… have a little charge on themselves, and they will side shift to one direction or another. So you can guarantee that when the payload arrives at the other end, the catcher will be there to meet it, okay? And you can get accuracies of something like one meter at the other end, and I've forgotten how many, tens of thousands of miles.

So here it is. Here is the stream of mass from the moon now arriving at this catcher, which goes around in a little orbit of its own. So that's one method, and that gets the material out into space. Here is another method, and this is rather different. We are now going to capture an asteroid, okay? An asteroid, which begins its life in orbit around the sun, just like we are in orbit around the sun, and the asteroid's orbit is very close to ours, and the idea is if you can go and capture it and give it a nudge, you can nudge it into an orbit which is identical with our own orbit around the sun, and then you give it another nudge, and you bring it into orbit around the Earth. And there, lo and behold, you have a hundred million tons of immediately available construction material.

To get the asteroid into the right orbit, you build a mass driver in space, and this is the first stage of building a mass driver in space. This is being carried out in Earth orbit, say a hundred and fifty-two miles up. The moon is up on the right. You can see the space shuttle bringing up bits and pieces. The panels are solar panels for providing power for the magnets, and these things here… This and this are shuttle tanks. They're tanks which originally took the space shuttle up and which were full of fuel and are now empty of fuel. What you do is convert them into living quarters. Okay, next, please. Here's… the artists, of course, love these things. And here are the living quarters in an empty shuttle tank after… at least the artists have been at work on it. Next, please.

And so you make your journey, two or three-year journey, to an asteroid. When you get to the asteroid, then you attach the mass driver to it by three legs, okay? And you can see the legs here, and what you start to do is to mine it. And at these points here, the asteroid is being mined; material comes up here at the end of the mass driver. It is then put in the mass driver, accelerated down for I think ten miles we have here, in just the same way as the lunar mass driver I have described.

STUDENT 2: Well, is this car in motion or…

BILLINGHAM: Yes.

STUDENT 2: In orbit?

BILLINGHAM: And that gives you a proportion course. Okay?

DAVE: That's why it's orbiting with the Earth in the same…

BILLINGHAM: This is… No.

DAVE: No?

BILLINGHAM: No. This is to get it from its original orbit, which is *not* the same as the Earth's, into an orbit which is the same as the Earth's. You have to nudge it. You have to push it, and you push it with the mass driver, and the mass you obtain from the asteroid itself and the energy you obtain from the Sun. Okay? Please ask questions about… This is sometimes not terribly clear.

The stuff on the outside of here is a bag. All right? It's just a big bag. That asteroid might be a mile across, for example. And this is just a bag, and the idea of the bag is to make sure you don't keep losing material as you mine it out in space and keep the asteroid in a nice, tight package. Next, please.

STUDENT 3: Is there a parachute there?

BILLINGHAM: Here it is. Here's the bag. Now here is the bagged asteroid. [chuckling from a couple of audience members] Now you see the complete mass driver with three components here. One, two, three, here. And here it is, returning to the vicinity of the Earth, which is here, going past the moon I think there. And that's simply for convenience. Somebody had a question about the bag?

STUDENT 3: The bag looks like a parachute.

BILLINGHAM: Yeah, just like a large parachute. It's just to keep it all together, yes.

STUDENT 4: When you move the asteroids, if you move enough of them, wouldn't you affect the orbit of the Earth itself?

BILLINGHAM: Yes. Everytime you move something in space, you affect the orbits of everything else. But the thing is that the mass of this is so incredibly small compared to the mass of the other things that it doesn't matter. Unless you start moving, you know, some very large objects, and I don't think people would stand for that. Yes?

STUDENT 5: So I was wondering [in background, indistinct] …mass projector to [...] asteroid of another.

BILLINGHAM: Yes. Right. You lose some of the mass of the asteroid doing this, of course, but it doesn't really matter, because there is an awful lot left.

So, here we have two methods. One is to use lunar material, one is use asteroidal material, okay? You bring them to some suitable point in orbit, going around the Earth, and then out of these materials, you build a space habitat. Next, please.

Now the orbit around the Earth doesn't have to be a perfect circle, a essentially the lunar orbit is, all right? Or it can be a very complex orbit, and there are reasons for doing this, which I won't bother you with. But here's one orbit that one might finish up with. And there, you see, at the very top, you see the L-2 point, which is the point, if you remember, where the catcher was to catch lunar material. What you do once you've collected that lunar material, you send it off from that point along a trajectory given by the white line, and ultimately it will finish up at the location of your construction base with very little in the way of energy requirements. One could be very clever with these orbits and sail from one part of the solar system to another using very little energy. It's very extraordinary. Yes?

STUDENT 6: Using this method, what would be the cost of, say, a ton of copper?

BILLINGHAM: What would be the cost of a ton of copper? I don't… We have not gone into it in quite that detail yet, but let me… So, I can't answer your question directly. Later on, I'll give some very rough costs for the whole thing, okay, to give you a feel for all this. It does turn out to be, of course, incredibly expensive to do all this, hence the question, you know, is it a reasonable thing to think about, is it worth it? Is it worthwhile, and why? Next, please.

So, with all your building material, you can design space habitats and they can be… they come in various shapes and sizes. Here are some of the shapes: the top one is a sphere, the second one is a cylinder, and the third one is a torus, and the fourth one is a torus made of small toruses, which we call "crystal palaces" for some reason.

Now, these vehicles all spin with artificial gravity, because we know that people can live very well, thank you, very nicely with a gravitational field, and our biomedical knowledge is such that we still don't know whether people can survive weightlessness indefinitely because of loss of bone strength. So, to be conservative, we designed our space settlements or habitats with artificial gravity, okay? Next, please.

And for those of you who are interested in some of the sorts of calculations we get into, some of the costs, this shows you the effect of different gravity levels: .1, .2, .3, across to .7 of Earth's normal gravity down to zero here; that's against the cost per person to establish a space settlement with thousands of people. Okay? You can see these costs are pretty high, but notice that they are at a minimum of $20,000 per person, which I guess is not really too bad. For a zero-G space station. It's much cheapest at zero G, at weightlessness, because you don't have to contend with complex rotating mechanisms and additional strength in the rotating environment. And these are all the different types of vehicles I showed you in the last slide, and you see some are much more expensive than others. Next, please, Dave.

And, once again, for those interested in the effects of atmospheric pressure here, this shows a scale of pascals along this axis as against, again, the cost per person, and you can see that this atmosphere here results in, at this pressure here, results in a cast which is one-hundredth of the top of Earth's atmosphere. So, there are obviously different types of atmospheres that you can design to make this whole thing much more economical, and in turn, that presents some very important physiological and medical questions. Next, please.

So, you would build perhaps something like this. This would be a preliminary construction base, housing perhaps, oh, three thousand or five thousand people. And next, Dave, please. And here is the chemical processing plant, which would receive material from the moon or the asteroid. Goes in the top left here and, using various fairly novel—at least some of them—chemical processing procedures here, […] thermic reduction in particular, we wind up with aluminum, silicon, iron, magnesium, carbon, oxygen. All the things that you want. Calcium. All the things you want for... to build, to make things out of, that can then be used for construction. Next, please.

And here is the device itself. Here is the processing plant with all the furnaces and crushers, and pacifiers and separators which produces your construction materials. Next, please. And this is the same one I showed you before. This is a manufacturing facility here, and the little factory from the last slide is right there at the top. And people live here in this "crystal palace" structure, which rotates. And here you have an agricultural section. Here, you have mirrors for bringing sunlight into the habitat. Next, please. Just to show you a portion of this… this is a "crystal palace" structure. Windows on the inside here… and light comes in this way, and you can have agriculture in the top there. And then you have an animal husbandry underneath. Sheep, goats, and cows go here. This is just an idea, but it can probably be made to work. Have to be sure to get the right mass balance and right energy balance. So, this is the construction shack, or manufacturing habitat. Then, you've got to build your settlement, okay? Next, please.

And I've shown you three types of settlement we've worked on. This one is a torus, and it rotates and it gives you one G at the periphery as it rotates. And… it has a big mirror here, which shines sunlight into the center of the torus, where there are mirrors around here, and they reflect the sunlight into the inner wall of the torus, which is transparent so that it will have a source of sunlight or an energy supply for agriculture and for lighting. The idea was to try and make these habitats as much light… good human habitats as one possibly can. Next please. There is another picture of it with the big mirror. Next, please. Here's a close-up view, now, looking through the transparent inner wall of the torus and showing you the sort of structure on the inside. This is one atmosphere, of course, a normal atmosphere just like we have here. Next, please.

Here is another picture. Our artists get very enthusiastic about these concepts. And this the sort of, oh, a village if you'd like. See the condominiums and buildings of various types. A few parks. And way in the distance, there is the beginning of the countryside. Okay? There isn't much countryside. This whole thing is a mile in diameter only, and designed for ten thousand people. Next, please. Going further along, the torus comes to an agricultural area, where those things requiring the most light are on the top shelves. Down underneath, the things that require less light and so on all the way down. I think we have fish tanks there at the bottom for agriculture. Next, please. And, once again, the artists are enjoying themselves. Here is a recreational section of the torus, and some country homes, I think, and Lake Berryessa or whatever it may be. I have some questions here?

STUDENT 7: Where are they gonna get the mirrors up there?

BILLINGHAM: Make them.

STUDENT 7: You are going to make them? Where are you going to make them?

BILLINGHAM: Where? Right there.

STUDENT 7: Right there.

BILLINGHAM: Might be a little tricky. [laughter] You know, it was tricky when the Pilgrim fathers came over. They had problems. In fact, I think they had severe problems, if I remember rightly. Next, please. Here it is, in its greater glory, with a lot of celestial objects put there by our artists, which I'm not sure are supposed to be there. But here is the station. You can see some big silver panels. You can see all those chunks of rock stuck on the outside for radiation protection for shielding people inside from the radiation in space, cosmic radiation, which would be lethal if you didn't have protection. That's a standard torus. That was one of the first things that we took a look at. It's got to be a torus with only ten thousand people because it has to be… have a diameter large enough to enable you to spin it slowly to produce one G. If you have a little tiny thing, you have to spin very fast to use one G, but people don't like spinning environments. Yes, somebody had a question?

STUDENT 8: What is the transparent material that you would used?

BILLINGHAM: The what material?

STUDENT 8: The transparent material.

BILLINGHAM: Transparent material is glass. We make glass up there. Make everything, okay? Make buildings, make concrete, make anything you want. Computers, ball bearings, waterbeds, anything, okay? Now, there are other types… next, Dave, please. Now here's a different type of space settlement. This is a spherical one instead of being a torus, and this is probably for a somewhat larger population, fifty-thousand or something. Here is the sphere here, and it spins. Spins about the same central axis, spins like this, but it gives optimum gravity on the outside. Here is a magnet telephone module, like I showed you before. These things here are radiators which radiate waste […] space. Here's a big… these are big mirrors here and here to bring light into the habitat here, and down here we have lots of solar panels, and out on the end here are lots of *Star Wars* type of… [laughter] Next, please.

And here is looking in through one of the big windows of the rotating sphere, and the countryside is beginning to become apparent here, and here, of course, is the outside and the sun. Next, please, David. So here is the inside, if we focus a bit. Yeah, that's better. Here's the inside on the rotating sphere. You can see your entire population in villages and towns throughout the inside of the sphere here. Here's some people coming out of the side of the sphere for a picnic or something. I see a lot of bottles down here. [laughter] A lovely picnic. And here are all the different villages and different towns. Here is the *Altered States* annex here, [laughter] and other things I'm sure you'll recognize. Next, please.

So that's another one. Now you can also have cylinders, okay? And here is Gerry O'Neill's original concept from six years ago, of two rotating cylinders. These are very […] cylinders. They're ten miles long by one mile across, and they rotate in opposite directions like this. And each one has about a million people in it. They have giant windows down one side like this, and giant reflectors here which reflect sunlight through the window into the circle itself. Next, please. Here is the interior. The one with these vehicles. Those of you who know the San Francisco Bay Area will realize that this particular artist lives in the San Francisco Bay Area… [laughter] and this is rather like the San Francisco Bay Area, except that notice, suddenly, at this line here, okay, everything disappears and you have a giant window. Next, please. So here is another rather imaginative sketch of the inside of a forest area and a hilly area inside one of these cylinders, and then a window, of course, and then a window, and here is another area. There's a river I see here, and clouds, of course. Everything goes around in a... Your neighboring county, all right, is up there, one there, and one there, instead of being there.

So this is another option. This is my last slide, and it shows you if we could live in zero G, and there may well be ways of doing that, it shows you what it might be like in a zero-G township. One, literally, of course, one has no weight to get to one building to another. In principle, all you need do is step off like this and go like that, and you take off in a straight line and you arrive wherever you arrive. If you've been accurate, of course, you'll arrive where you wanted to. [laughter] If you're not accurate, then you'll arrive someplace else. To compensate for this lack of accuracy, one can strap to one's back little jets of compressed air, all right, and you can simply maneuver yourself. I think Buck Rogers… was it Buck Rogers who used to do this? Anyway, you can move yourself very simply around, as these people are doing with little tiny backpacks containing compressed air.

Here is… This is the American consulate here, and some people are having a picnic or coffee or something. You noticed that there are no chairs. They are sitting at a table merely because it's conventional, but there are no chairs. They don't need chairs. And, once again, you have to be very careful from getting up from the table too fast. You'll leave the American consulate whether you like it or not… [laughter] and you finish up half a mile across the thing. Very… The weightless Hilton here. Everything is in three dimensions, you see. One's no longer limited. If you're in zero G, you're no longer limited by this flat, 2-dimensional world we live in. Everything suddenly becomes… in the sphere, you can use all three dimensions and occupy all three dimensions because you can get around very easily. For the sake of not upsetting one's psyche, things are built as though there is a down direction. You can see everything looks fairly conventional. It looks as though things are down, and here is a tree on the left. It looks as though it's growing up. There is, of course, no up or down. And if you wish to, you can have trees growing sideways and you can have trees growing downwards, and we have here a whole collection of trees growing downwards because the occupants of that particular building prefer having their trees grow downwards.

DAVE: Will they grow in that direction, presumably?

BILLINGHAM: Yes.

DAVE: In zero G, they would grow in one direction?

BILLLINGHAM: There are two things which determines the directions in which plants grow, and one is gravity and the other is light. So in the absence of gravity, light is the only thing that determines the direction in which to go. If the light is uniform, it would just grow at right angles to whatever its is. If you wished to make it grow in a certain direction, you would simply have light over here that is stronger than light over here. There are endless opportunities here for interior decorators and designers.

Let's see, what else now? There's a fish tank here. There's great trouble with swimming pools, rivers, streams, and fish tanks because, in weightlessness, you'd lose it all in a very short time. So you see, no swimming pools. The fish tank is a complete sphere, all right, and the fish are not swimming horizontally, they're swimming in all directions because there is no gravity. Yes?

STUDENT 9: Aren't there going to be some problems as far as eating and drinking?

BILLINGHAM: Problems in eating and drinking? No. When the astronauts first went up, we made for them awful tube-like things to feed out of, okay? Like toothpaste tubes, and they had to squeeze food out of the toothpaste tube into their mouths, and the same thing for liquids. It's been found in Skylab that you can have a perfectly normal table, and providing that food has some sort of adhesive quality about it, it will simply sit on a plate, okay? What you want to avoid is absolutely dry things like, you know, potato chips and peanuts and, you know, things like that are terrible. They just go all over the place. But, by and large, you can learn to eat off a normal plate and without your steak floating away and, you know, be gone half a mile before you can do anything about it. With drinks, surface tension will hold the drink together, unless you knock it. If you knock it, the drink becomes a thousand blobules floating about. But if you don't knock it, then the surface tension will hold the liquid in place and you can drink it through a straw. It's much easier through a straw. Yes?

STUDENT 10: How about waste disposal?

BILLINGHAM: Waste disposal has been pretty much solved in Skylab by having air currents, okay, in the urinal or water closet. What you have is air currents going through like this, which takes the waste in a certain direction, and that's very important, okay? But it's been… technically, it's been solved. No problem. Yes?

STUDENT 11: [partially inaudible] That previous slide with certain flowers [...] the weather [...] in that large sphere […]

BILLINGHAM: Yes. Oh. Well, weather will be controlled. And if you want snow in a certain region, you can probably make snow. Maybe I shouldn't be quite so glib about the ease of doing all this. It's going to be… You'll have to get the right mass balance, you have to get the number of… the right ratio of carbon and nitrogen and all the other elements. You have to have things very tightly controlled, plus you'll have high […]. This is not like relying on the big reservoir that we have here on the Earth. Reservoirs of the air and the oceans and carbon dioxide and so on, everything here, the reservoirs are always full. So if you drop one of those reservoirs by a certain amount, you have to be very careful, because if we do it on the Earth, it may be insignificant, but if you do it here, it may be 50% of your CO_2 is suddenly gone, or your oxygen or… So you have… yes?

STUDENT 12: In a rotating type of habitat, wouldn't there tend to be low-pressure areas in the middle area… […]?

BILLINGHAM: No, I don't think the pressure would differ very much with different regions. What will happen, of course, is that as you walk out the side of one of these, or the end of these cylinders or spheres, gravity will get less and less as you go up. So mountain climbing has the reward that the higher you go, the lighter you get.

DAVE: Remember, you should have some more slides… There's one more.

BILLINGHAM: No. Oh, no; that was the artists again. [laughter] Do you want to see it? They decided… the artists felt so enthusiastic about all this, they decided to try and show, in allegorical form, people moving out into the new land. [pause; laughter] Back to Earth. Thank you very much. [applause]

DAVE: Any other questions? Michael? Go ahead.

MICHAEL: [in background, hard to hear] I have two questions. One has to do with time frame and […] in terms of time […] The second question is about international planes to pass though, like the […].

BILLINGHAM: Yeah, on the first question, the time business, it very much depends on who you talk to. If you talk to Gerry O'Neill, he will say that by the year 20… let's see, no, I'm sorry. By the turn of the century… No, I'm sorry. By the year 2012, one will have been able to put up the first large-scale colony, by which he means ten thousand people, and have a fully operational space server power system, which collects electricity from the sun in large quantities, beams it down to the Earth, comes into the national grids, and is paid for. Okay? And he believes that by that time, the whole endeavor will be able to pay for itself by returning electricity to the Earth, okay? A lot of people disagree with that, but that's his claim and he has some very good figures for it. It's just expensive, you know. It costs $200 billion to get to that point, but remember that by, according to him, by the time… I mean, that $200 billion is insignificant in terms of the sums spent over the years by people on energy supplies. And the point he makes is that it will pay for itself in electrical supplies now obtained from space, non-nuclear, okay, at about that time.

Other people say, you know, that this is nonsense. There's no way we can start building things like this until a hundred years from now. Our opinion is that if one really wanted to, you probably *could* do this. You would have to invest fairly heavily the rate of a few billion a year to put something up like this. But before you did that, you would have to be sure it would pay for itself. So that's the… what was your second question, Mike? I'm sorry.

MICHAEL: Something to do with the international control of airplanes.

BELLINGHAM: Oh. Yeah. This takes… brings us to the area of space law, and space law is one of the most fascinating of all… If any of you are lawyers or interested in sociology, space lawyers have been very active and I think it's a very good thing that they have been. There are already international treaties under the space law business. There are treaties, for example, with regard to, oh, returning astronauts. Astronauts have to come down in some other country; everyone promises to return them. There are treaties about the moon already. The moon is already off-limits as, I think, a real estate haven. I think it's designated now for scientific and international research purposes only, or something. There's going to be a treaty… there's going to be a new treaty on the far side of the moon fairly soon. A lot of treaties in the works on space itself and the occupation of space, and there are beginning to be treaties on the bodies… the various bodies of space. And the lawyers are getting very sticky about it, as well they might, I think. There are treaties already having to do with different bodies in the solar system; I've forgotten the details, but I do remember that the chairman of the Space Law Commission, the

International Space Law Commission is the Austrian delegate to the United Nations. His name is Jankowitz, and he's very precise about these matters. And we had a meeting at Princeton; he was laying down the law, literally, about what made sense and what didn't make sense about not disturbing bodies of different types in the solar system, and under whose jurisdiction they came, and all this sort of thing. And the very next lecture we had was from Brian O'Leary, who described removing an asteroid and then dismantling it and causing it to totally to disappear, and it occured to me that it's a very interesting juxtaposition of papers there, because, obviously, the legal questions are going to become formidable if things like this are ever done. I think everybody agrees that these types of things are probably going to be done on an international basis. Yes?

STUDENT 13: All right. When you were talking about it, it sounds a lot like a long-term approach, but after you use up all the asteroids, what are you going to use? Because we're still going to keep the space station…

BILLINGHAM: You raise a very interesting question. Resources are never infinite, okay? As we have turned the United States into a fairly organized place with control of resources, control of the environment, at least in some measure, and built lots of things, and so on. You know, so one thinks about the next frontier, and if it's the one I described, the immediate sentiment is that it is an endless frontier, it's an infinite frontier. But then the critics appear on the horizon, you see, and say, "But look, what are you going to do after you have used up Mercury and Venus and Saturn and Jupiter and turned them all into condominiums? And, you know, what's next? There is no more material." And that's right. That's right. So I think one message to anyone who thinks seriously about all this business is, you know, be very careful. Don't treat the new frontier like frontiers have been treated in the past. Somebody else had a question. Yes?

STUDENT 14: [indistinct] Yes, so what you see is a different primarily because of dollars, because of cost vs. other in[…] shared costs.

BILLINGHAM: I have no doubt that there will be both types of investment in space, in space, exactly as they are now. There's both public and private investments in quite large quantities in satellites. And the Intelsat Corporation, which grew out of COMSAT, is a classic example of the very best features of international cooperation that you can possibly have. It's, I think… I forgot the number, I think it's ninety-something countries that are members of Intelsat, and they all contribute to it financially. For ninety countries to have a common system working is something of a feat, but it works, and it works to everybody's best interests, and it shows that things can be made to work. It's not a part of the United Nations. It's a separate entity. So that's… And I can guess you can invest in Intelsat. I think they probably have shares. So it's a mixed private, public thing.

DAVE: Well, we'll call it quits for today. And those that have registered, and anybody else may come to the lectures, as you know, at nine and one for the next four days in the auditorium upstairs, and then the class will go elsewhere. See you tomorrow. Don't forget to sign up in the back here if you're registered.

[program ends]