N91-22143

OFFICE OF AERONAUTICS, EXPLORATION AND TECHNOLGOY

ADVANCED INTERDISCIPLINARY TECHNOLOGIES

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Advanced Interdisciplinary Technology

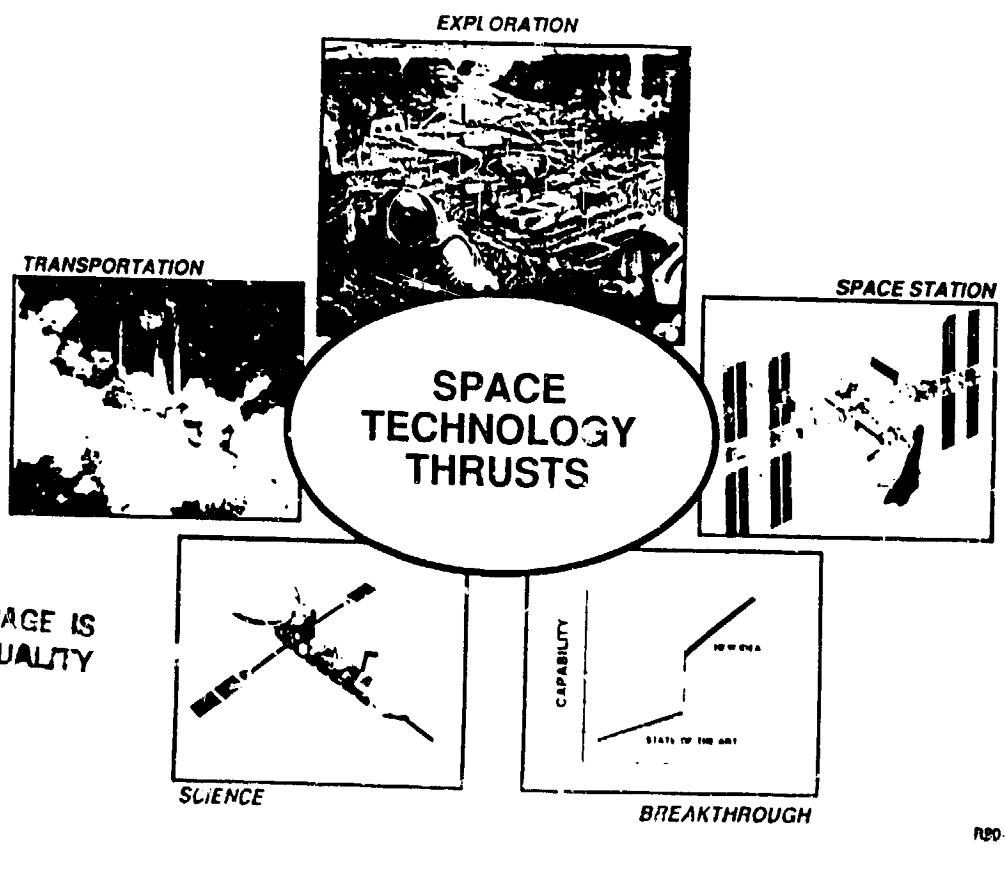
Presentation to
VISION 21 Symposium
at NASA Lewis Research Center
April 3-4, 1990

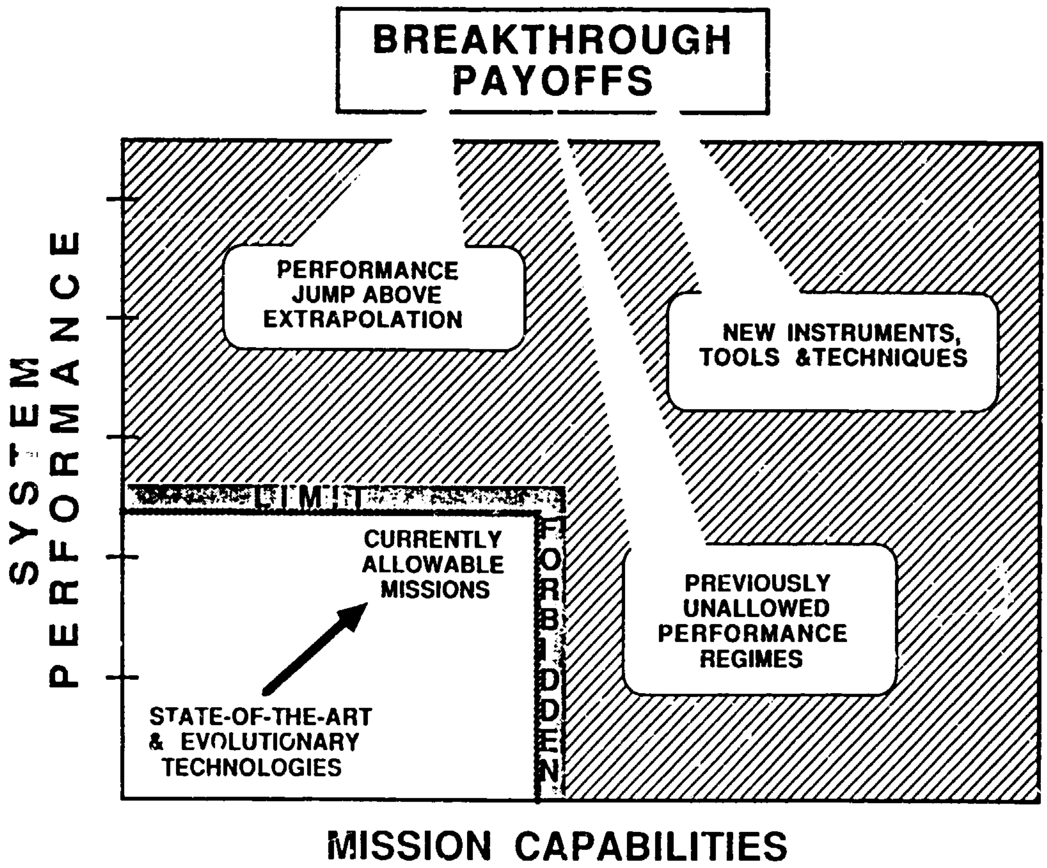
Advanced Interdisciplinary Technologies

OAET

- BREAKTHROUGH THRUST (Space R & T Assessment)
- BIONICS (Technology Derivatives from Biological Systems)
- BIODYNAMICS (Modeling of Human Biomechanical Performance Based on Anatomical Data)
- TETHERED ATMOSPHERIC RESEARCH PROBES


REACH


EXPLORATION
TRANSPORTATION
SPACE STATION
SPACE TECHNOLOGY THRUSTS
CAPABILITY
SCIENCE
BREAKTHROUGH



BREAKTHROUGH
PROGRAM ELEMENTS

ARTIFICIAL INTELLIGENCE
- MISSION OPERATIONS
- SCIENCE DATA ANALYSIS
- AUTONOMOUS ONBOARD CONTROL
- LARGE KNOWLEDGE-BASED SYSTEMS
- NEURAL NETS
- DISTRIBUTED KNOWLEDGE-BASED SYSTEMS

ADVANCED PROPULSION CONCEPTS
- ELECTRODELESS PLASMA THRUSTERS
- ELECTRON-CYCLOTRON RESONANCE (ECR) THRUSTERS
- HI-TEMP SUPERCONDUCTOR APPLICATIONS TO ROCKET ENGINES
- ADVANCED PROPULSION CONCEPT MISSION STUDIES
- ADVANCED FISSION / FUSION
- REMOTELY ENERGIZED (BEAMED) PROPULSION
- HI-ENERGY DENSITY PROPELLANTS
- ANTI MATTER

ADVANCED POWER CONCEPTS
- AMTEC (ALKALI METAL THERMAL-TO-ELECTRIC CONV.)
- FUEL CELLS (IN-SITU REACTANTS)
- LASER POWER BEAMING

ADVANCED MATERIALS & STRUCTURES
- ADAPTIVE STRUCTURAL CONCEPTS
- LONG DURATION SPACE LUBRICANTS
- ADVANCED INTERMETALLICS / COMPOSITES (HYPERSONICS)

ADVANCED SENSORS & PROCESSORS
- MICROELECTRONIC DETECTORS
- PHOTONICS (OPTICAL PROCESSORS)

ADVANCED RESEARCH TOOLS
- COMPUTATIONAL ANALY. & SYNTHESIS OF MAT'LS PROPERTIES
- TETHERED SATELLITE SYSTEM (TSS 2)

"THE HUMAN FUTURE DEPENDS ON OUR ABILITY TO COMBINE THE KNOWLEDGE OF SCIENCE WITH THE WISDOM OF WILDNESS"

Charles A. Lindbergh

BIONICS

OAET

OBJECTIVE

IDENTIFY ADVANCED, NOVEL TECHNOLOGY APPROACHES FOR FUTURE SPACE SYSTEMS BASED ON PHYSICAL AND CHEMICAL PROCESSES, STRUCTURAL PRINCIPLES, AND INTEGRATED FUNCTIONS USED BY BIOLOGICAL SYSTEMS

DESCRIPTION

IDENTIFY AND EVALUATE APPLICABILITY OF FORM, FUNCTIONS, AND PROCESSES OF SELECTED BIOLOGICAL SYSTEMS TO FUTURE SPACE TECHNOLOGY REQUIREMENTS.

DEVELOP PROCEDURES FOR DERIVING SPACE TECHNOLOGIES AND ENGINEERING APPROACHES FROM SELECTED CHARACTERISTICS OF BIOLOGICAL SYSTEMS.

APPROACH

CONTRACT A STUDY TO SURVEY & ASSESS THE STATE OF KNOWLEDGE OF BIONICS APPLICATIONS TO SPACE TECHNOLOGY (AWARDED TO RESEARCH TRIANGLE INSTITUTE - MARCH, 1990)

CONDUCT A NASA-WIDE TUTORIAL WORKSHOP WITH CHIEF SCIENTISTS, ADVANCED PROGRAM AND RESEARCH OFFICES AS PARTICIPANTS

ARC - MICHAEL McGREEVY

TECHNOLOGY & ENGINEERING DERIVATIVES FROM BIOLOGICAL SYSTEMS (I)

OAET

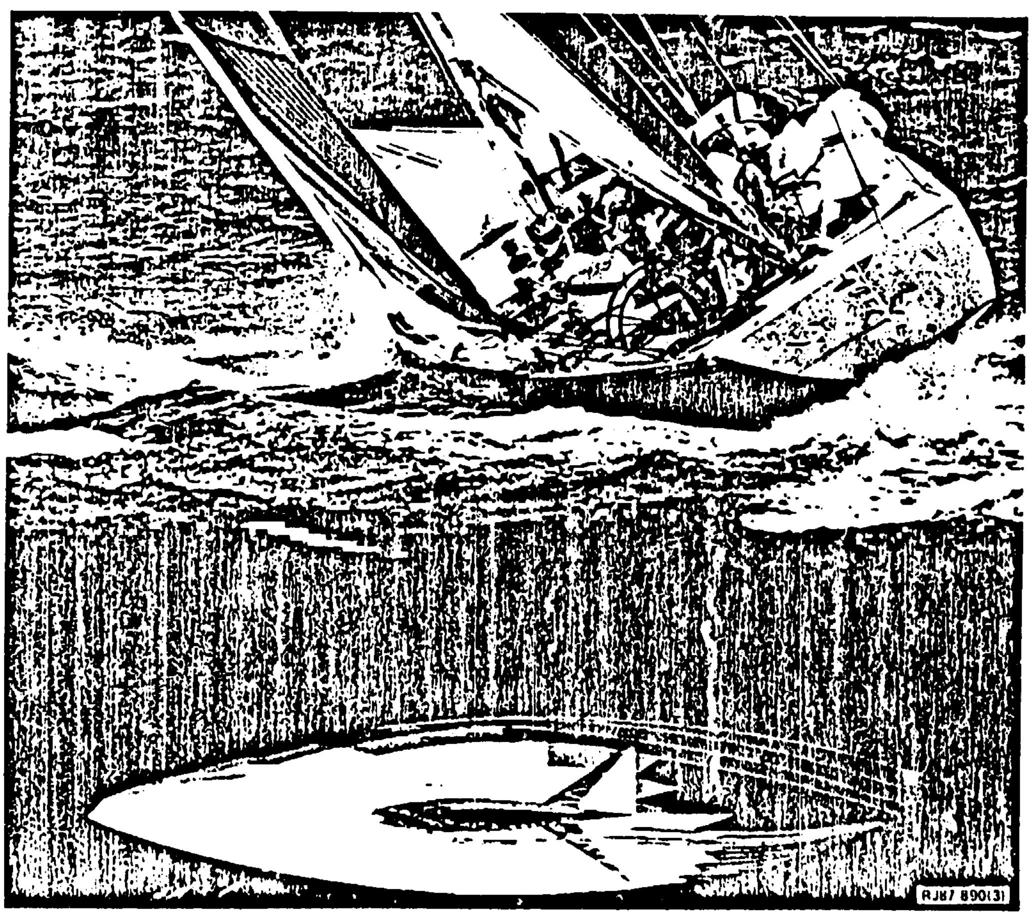
HYDRONAUTICS

FLOW EFFICIENCY - REDUCED DRAG

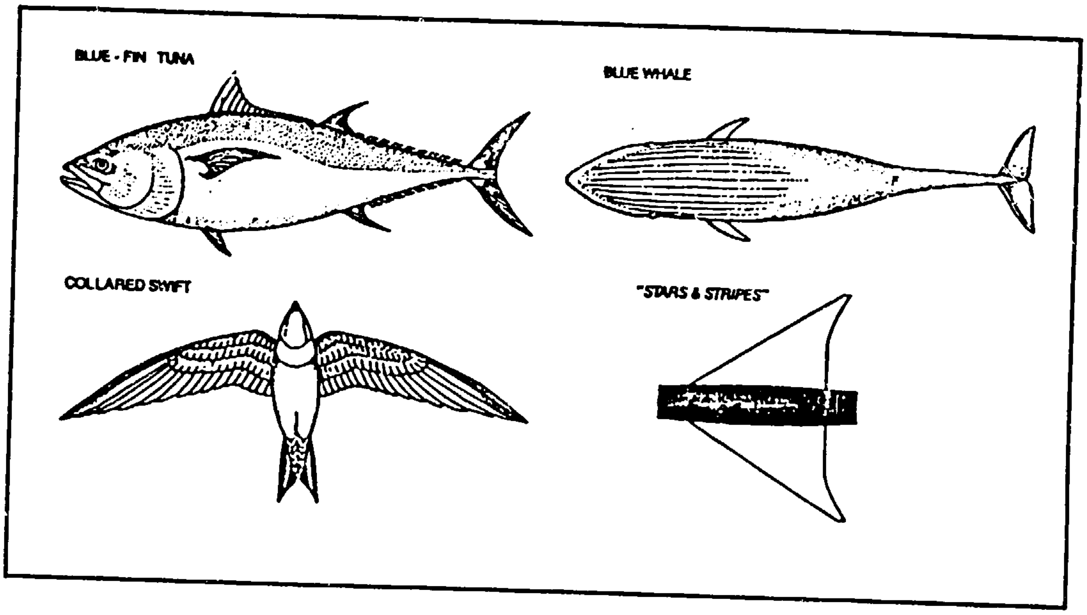
- O RIBLETS - Shark Skin (Stars & Stripes (S&S)yacht)
- O CRESCENT - Tuna, Whale (S&S keel wings)
- O POLYMER SECRETION - Dolphins
- O BARNACLE GROWTH RESISTANCE- Synthetic Fish Surface Protein Added to Ship Paint

AERONAUTICS

- O RIBLETS - Shark Skin
- O WINGLETS - Bird Wing Tip Feathers
- O CRESCENT WINGS - Whale Flukes, Shark & Tuna Tail Fins, Swifts
- O SERRATED TRAILING EDGES - Tuna, Swifts
- O VORTEX ENERGY UTILIZATION - Dragonfly



CRESCENT SHAPES FOR FLOW EFFICIENCY



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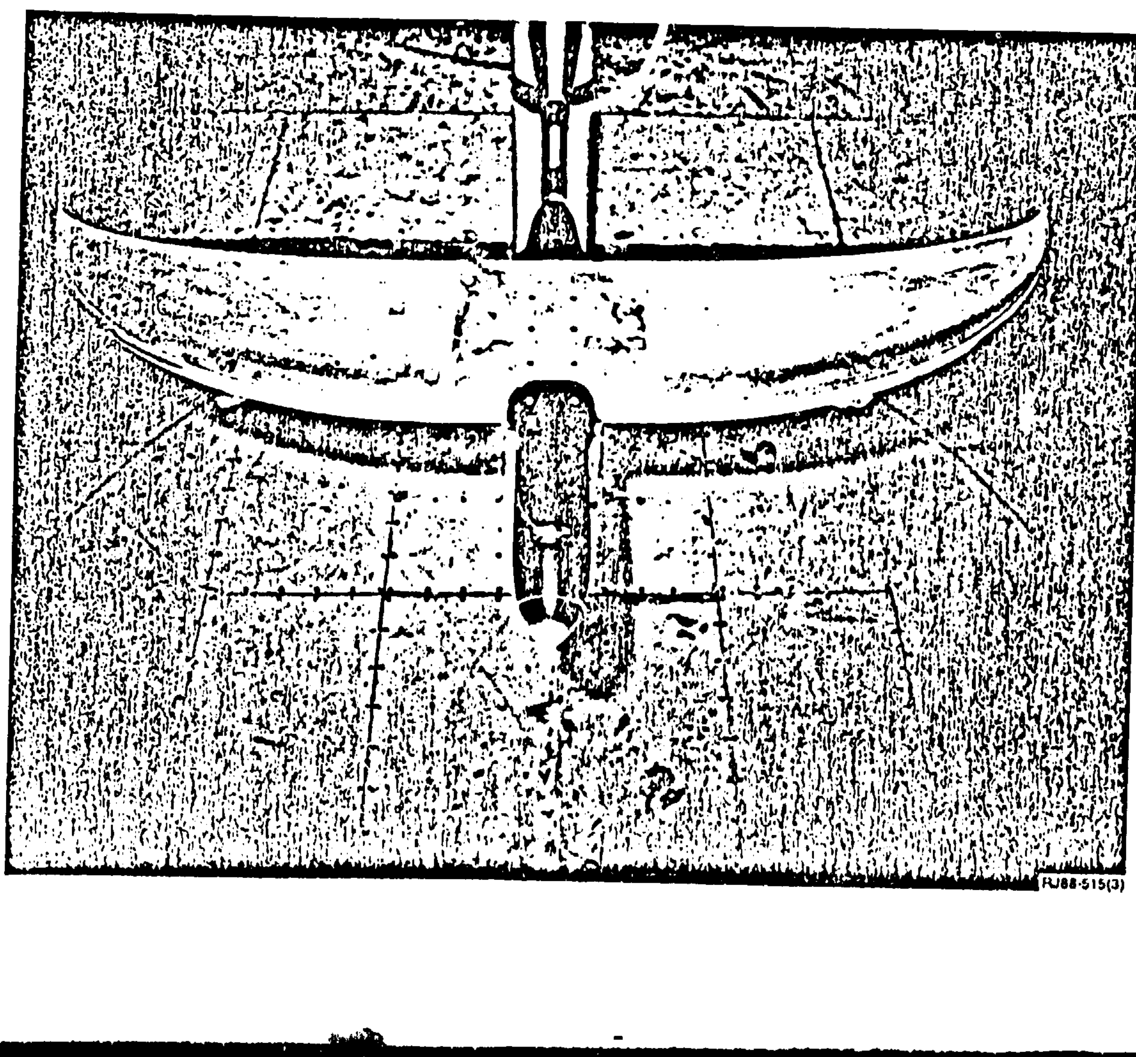


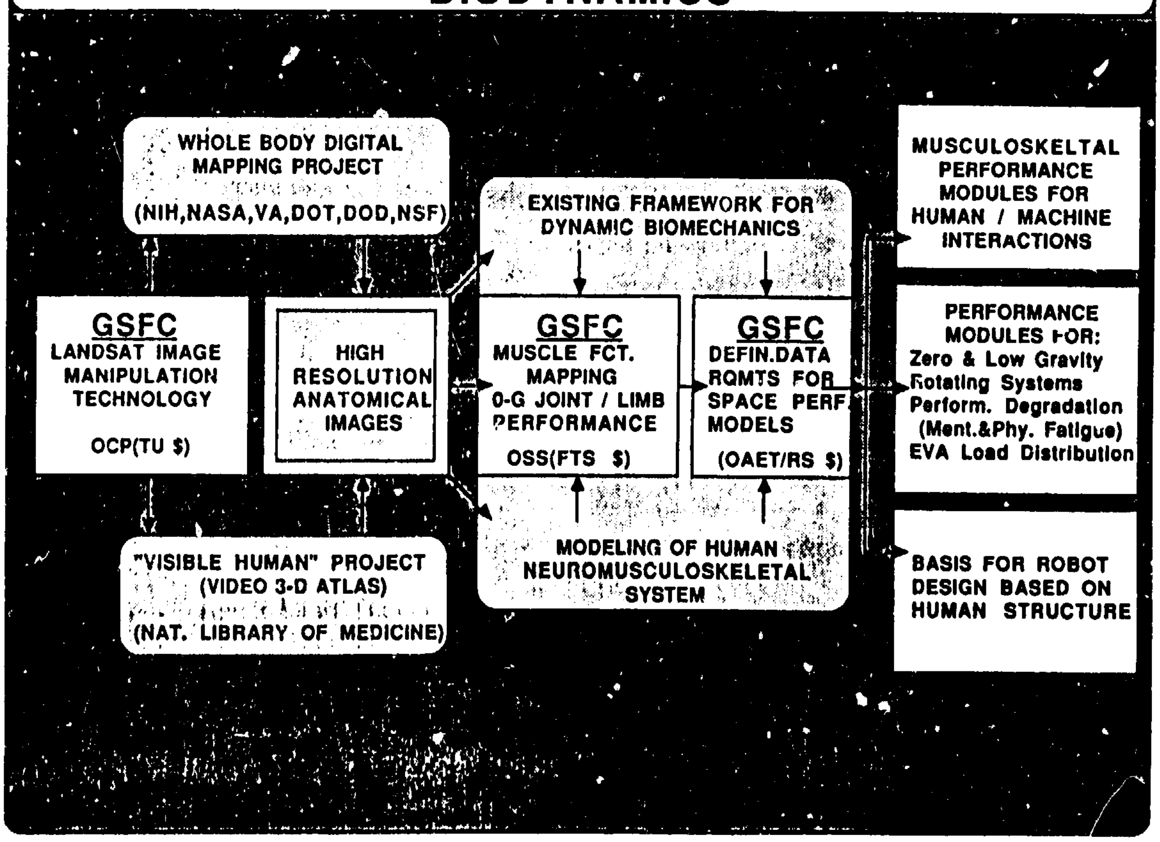
TECHNOLOGY & ENGINEERING DERIVATIVES FROM BIOLOGICAL SYSTEMS (II)

O-A-E-T

ASTRONAUTICS

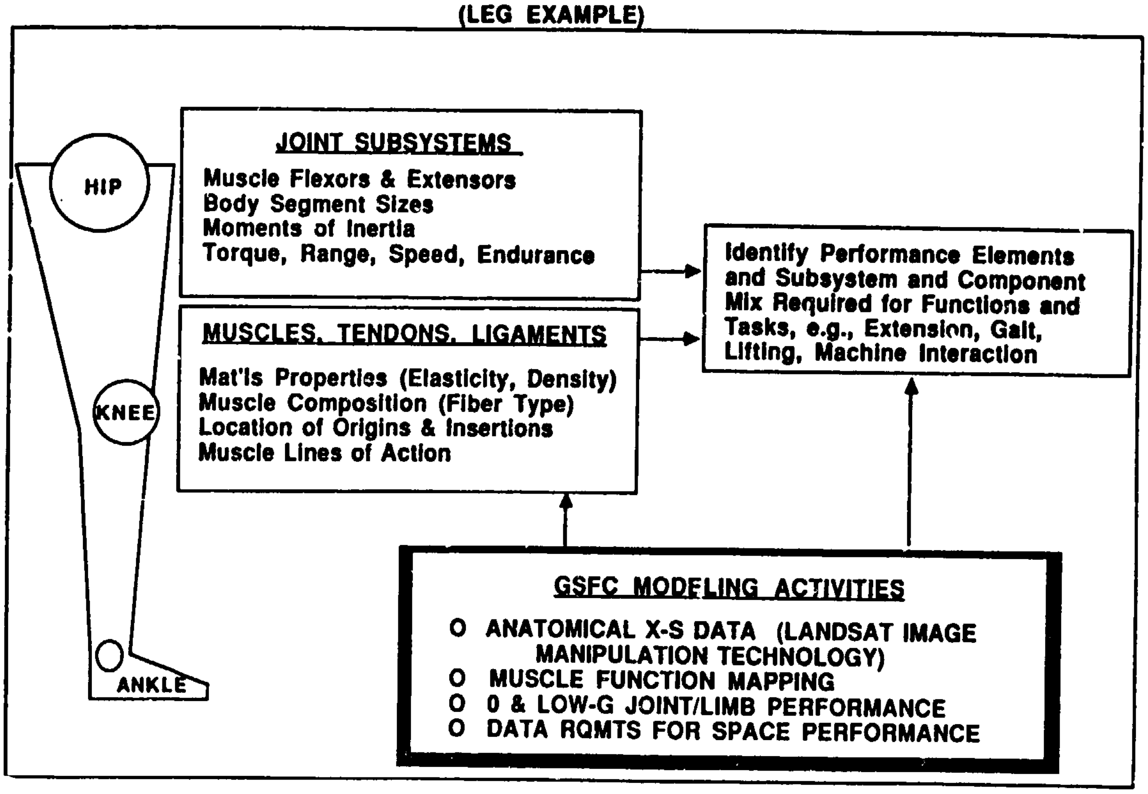
- O SENSORS - Eagle/Hawk Eye UV Protection, Moth IR Detection, Shark EM Field Detection
- O NEURAL NETWORKS/PARALLEL PROCESSORS Slug Brain, Rat Inner Ear
- O O2 & CO2 PROCESSES - Fish, Aquatic Mammals
- O SURFACE CHEMISTRY - (ADHESIVES) - Mollusks, Barnacles
- O SYSTEMS DESIGNS (STRUCTURAL STRENGTH/WEIGHT) Deep Sea Fish, Birds
- O LOCOMOTION - Insects, Spiders
- O CRYSTAL ENGINEERING (BIOMINERALIZATION) - Sea Urchin, "Magnetotactic" Bacteria, Shells, Bones, Teeth

BIODYNAMICS

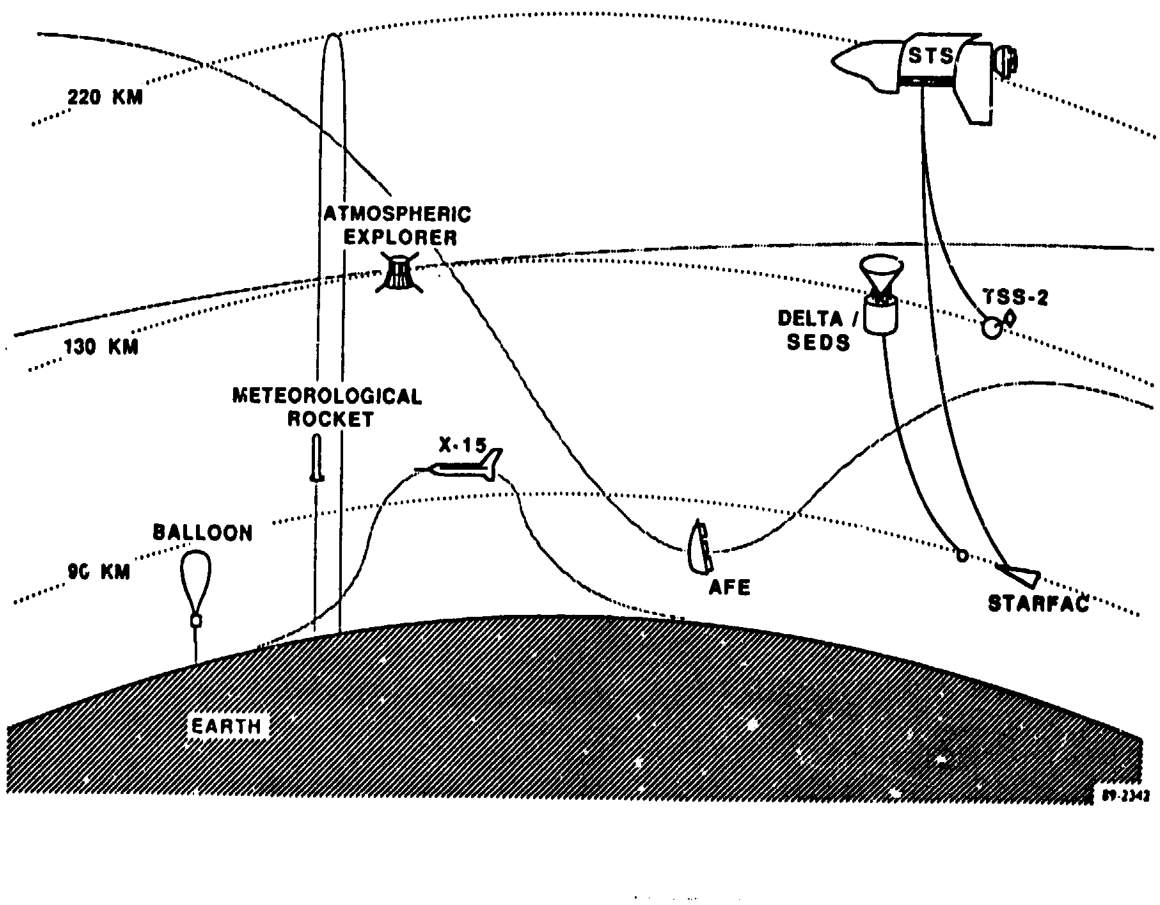


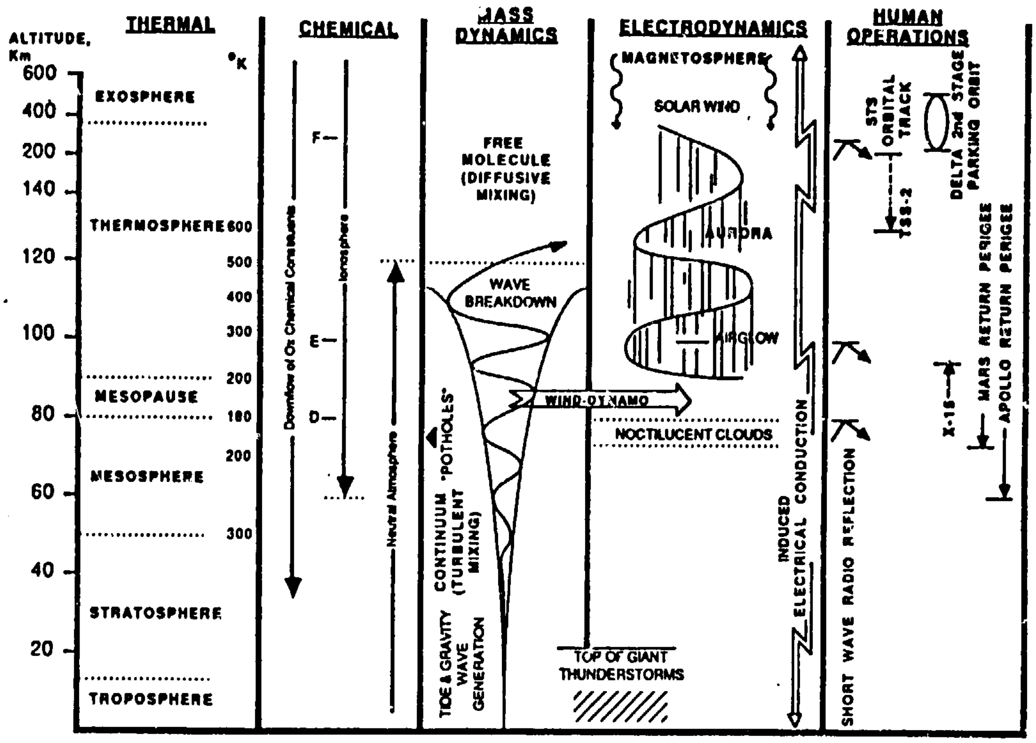
HUMAN NEUROMUSCULOSKELETAL SYSTEM ANATOMICAL MODELING OF DYNAMIC PERFORMANCE

(LEG EXAMPLE)



VEHICLE ACCESSIBILITY TO THE OUTER ATMOSPHERE





Activities in the Earth's Outer Atmosphere

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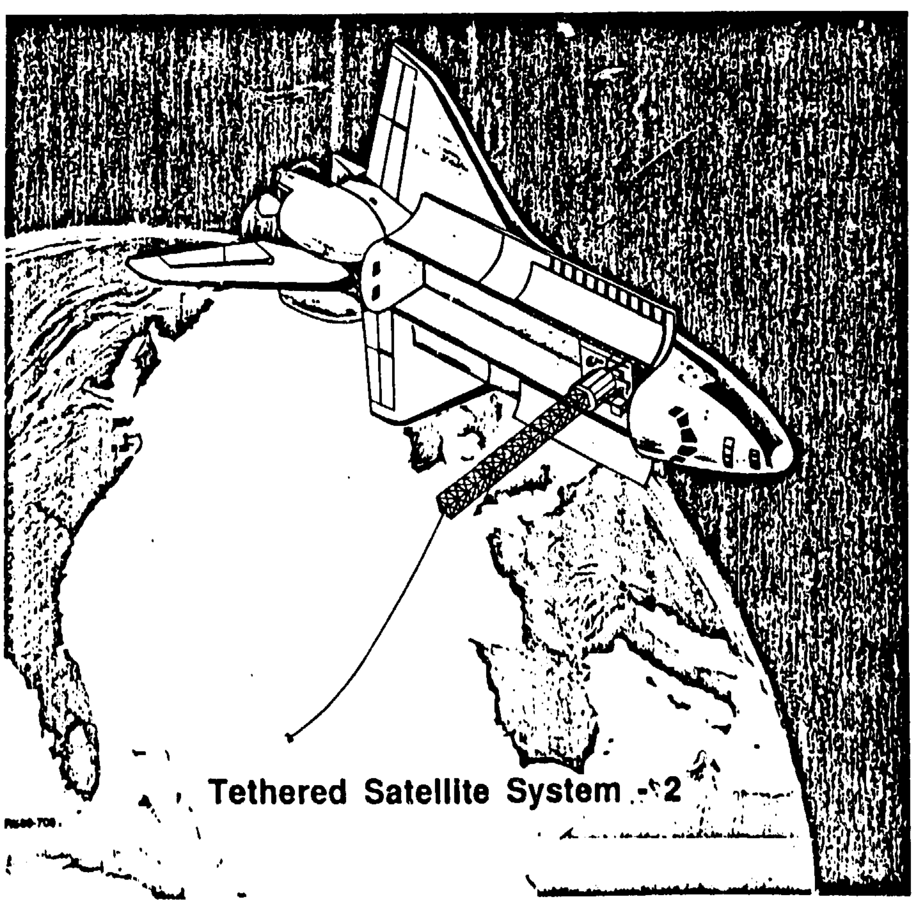

Tethered Satellite System -2

NASA L-85-7197

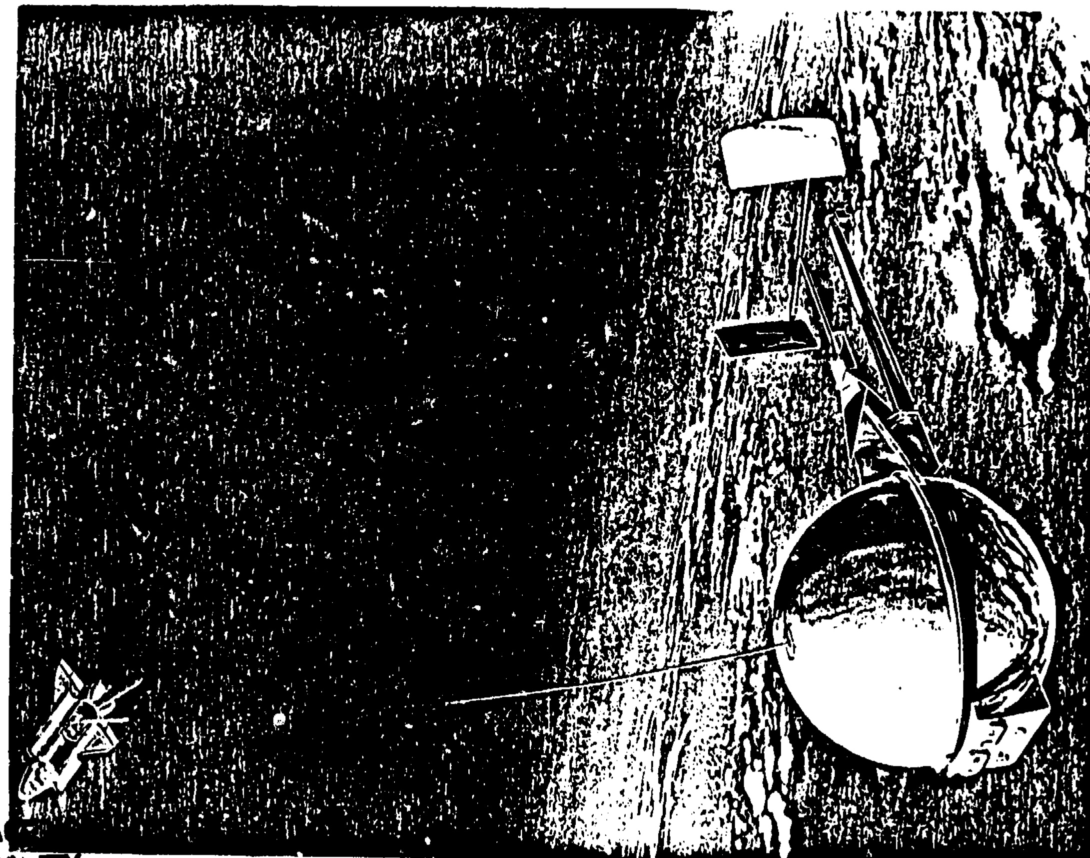

Figure 1. Tethered Satellite System (TSS-2) (Concept)

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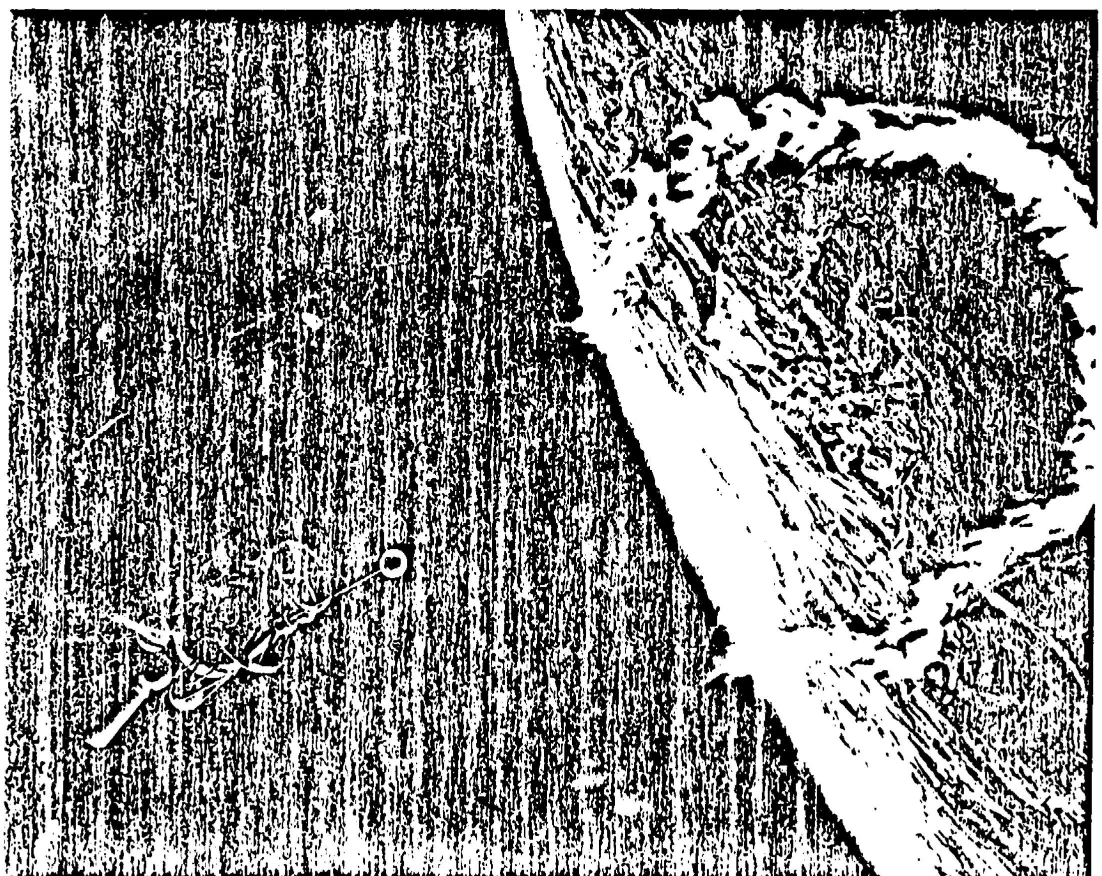

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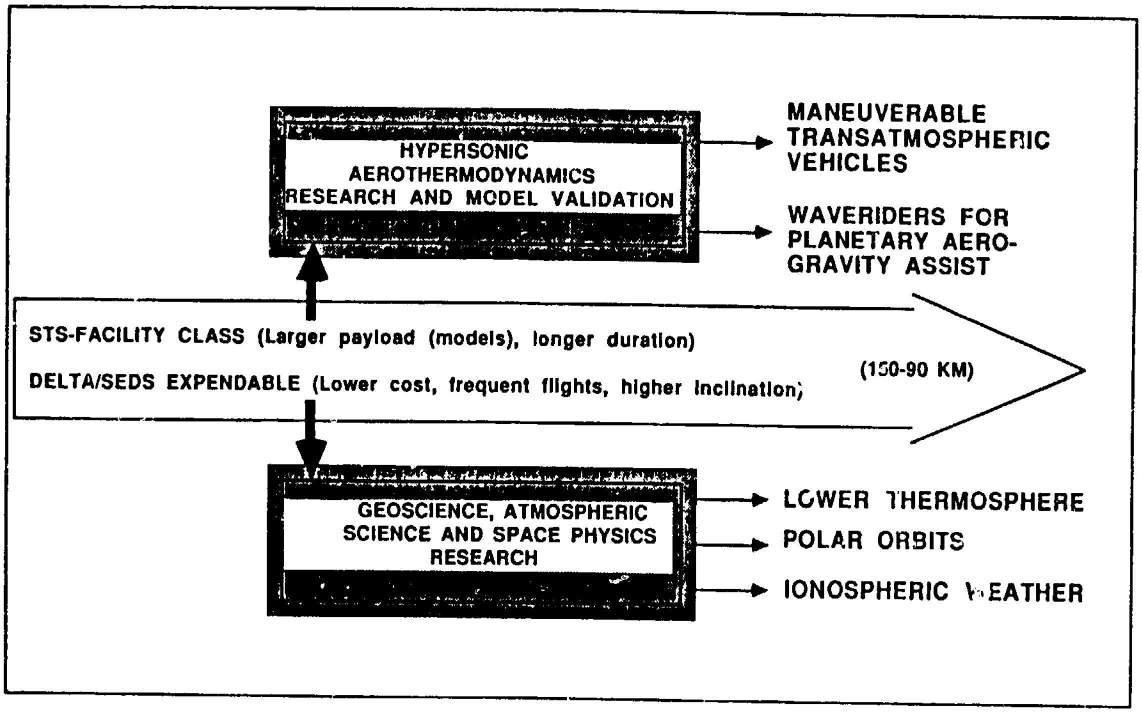
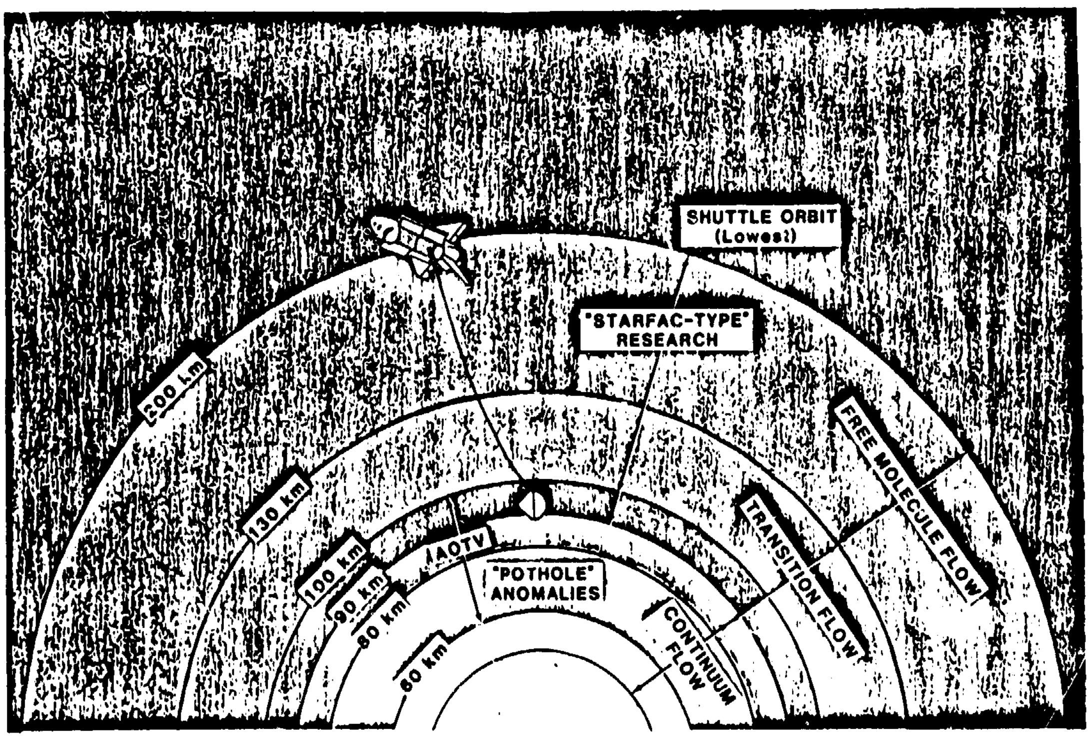
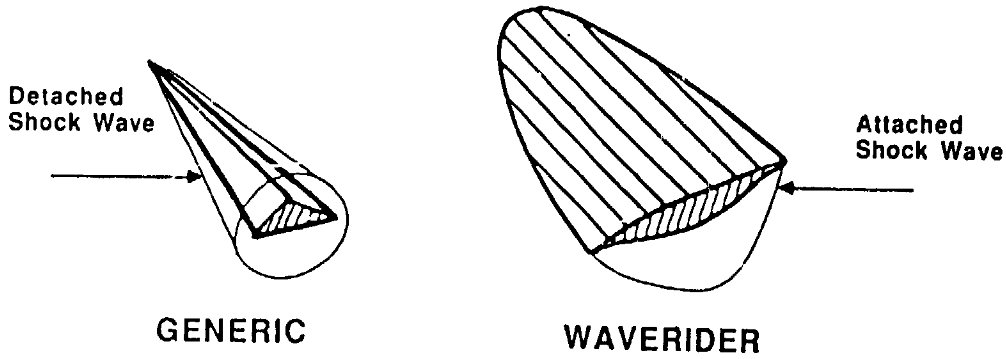
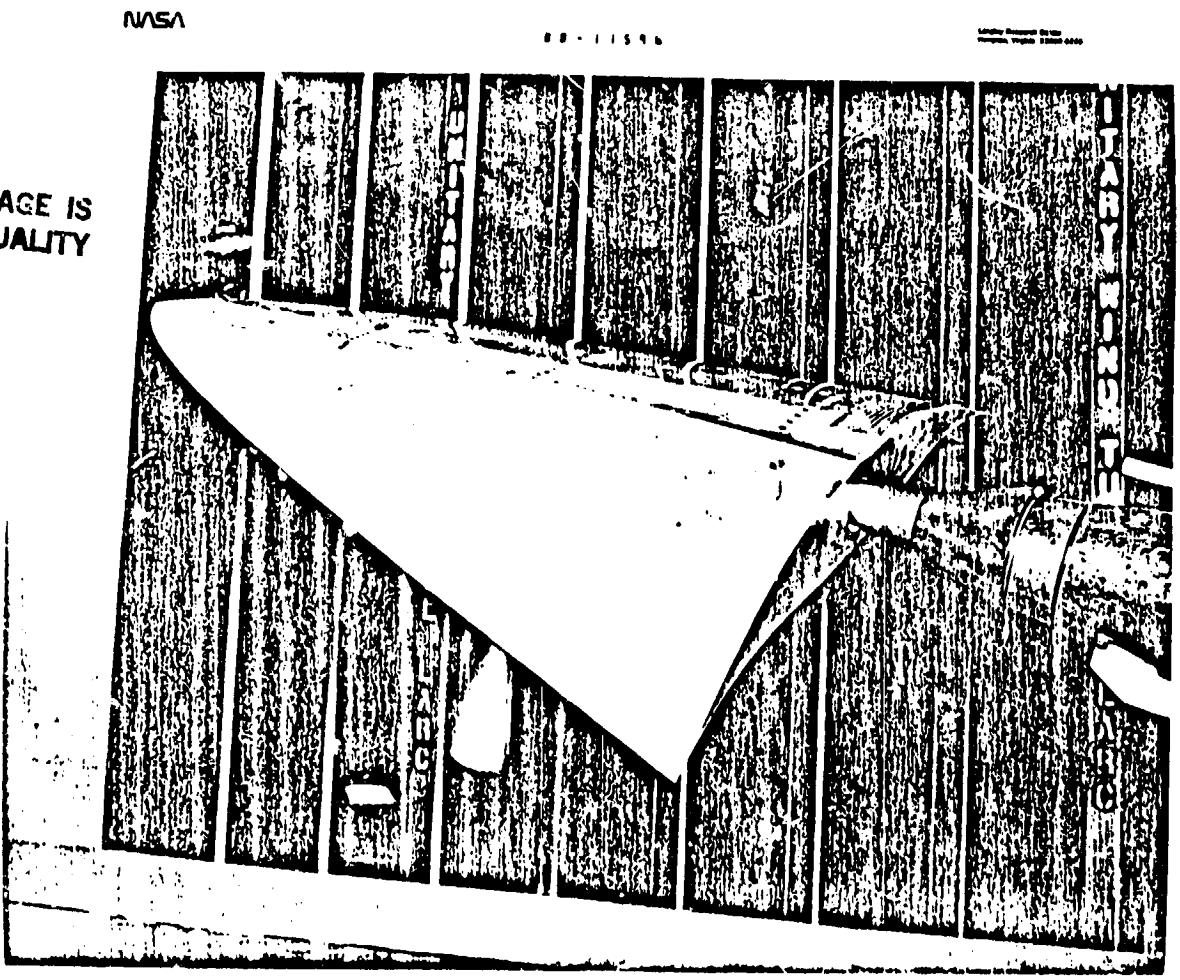
USES OF TETHERED ATMOSPHERIC SYSTEMS



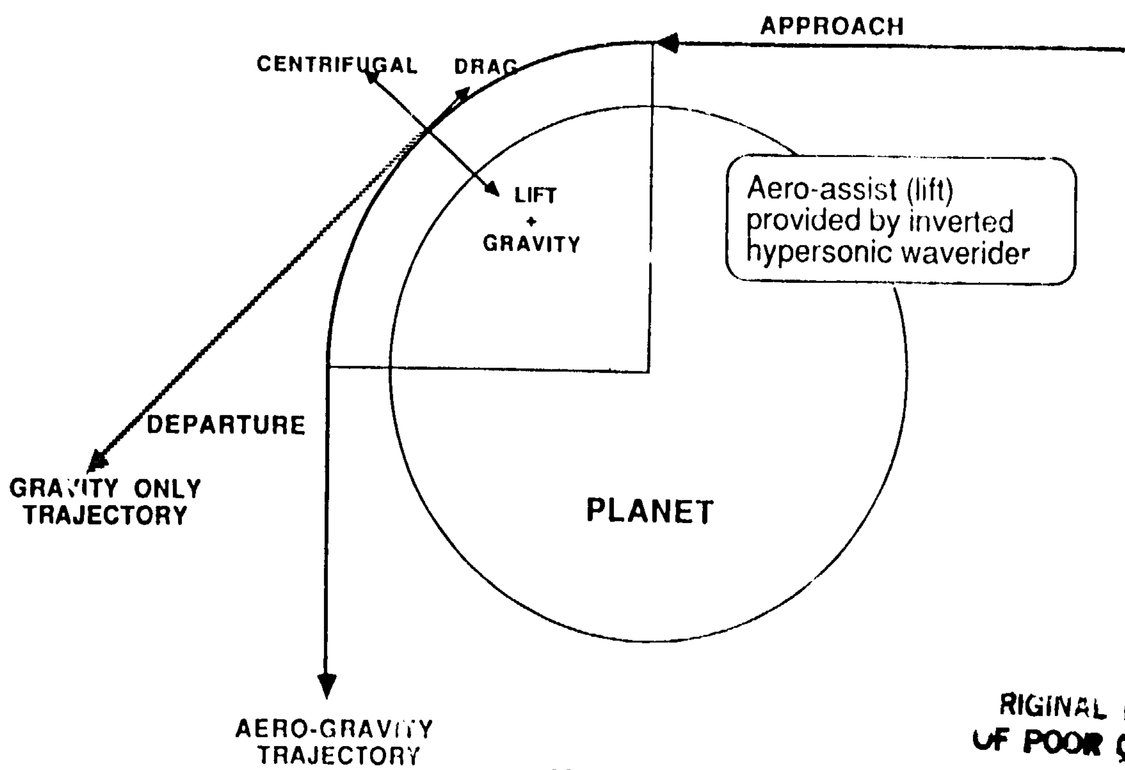




HYPERSONIC CONFIGURATIONS



ATMOSPHERIC TRAJECTORY-ASSIST FOR PLANETARY SPACECRAFT



SOLAR SYSTEM MISSION TIMES WITH HYPERSONIC WAVERIDERS

MISSIONS	JUPITER GRAVITY ASSIST	TERRESTRIAL PLANET AERO-GRAVITY ASSIST
SOLAR PROBE	DVEJS - 5 YRS	EVS - 4 MOS EMS - 5 MOS EVES - 6 MOS EVMS - 9 MOS
PLUTO FLYBY	EJP - 12 YR	EMP - 10 YR EVMP - 5 YR

HYPERSONIC WAVERIDER WITH L/D = ~10 AT M = 20 - 30
ATMOSPHERIC FLIGHT TIMES ~ 200 - 500 SECONDS

SPACE-TETHERED WAVERIDER MODELS MAY PROVIDE THE ONLY WAY TO DETERMINE FLIGHT CONDITIONS & VALIDATE CONFIGURATIONS AT THE EXPECTED MACH NUMBERS

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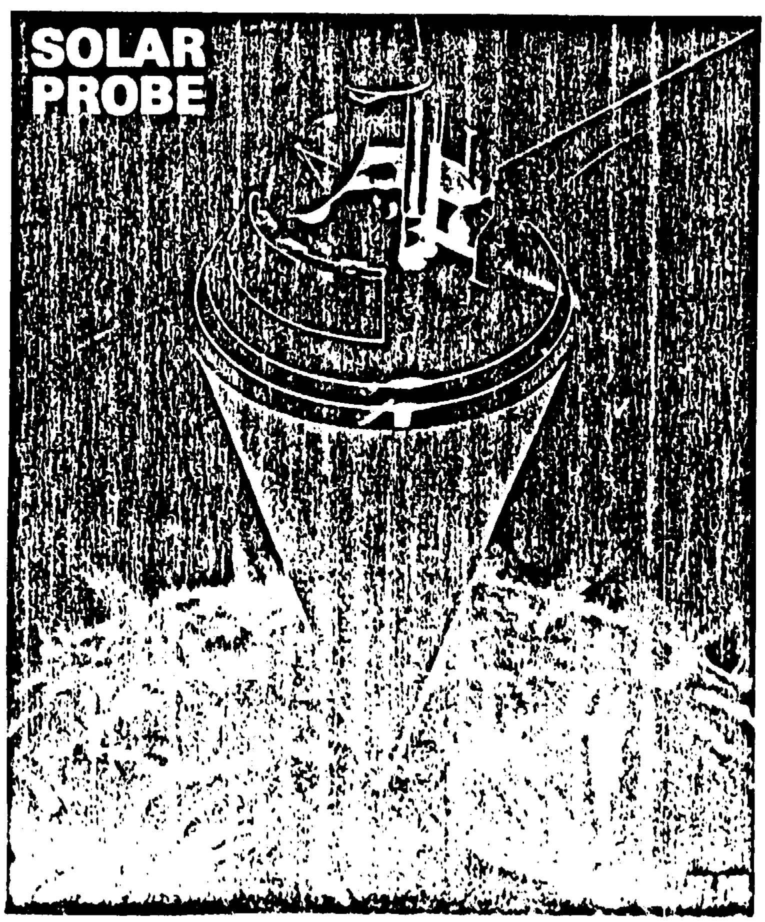
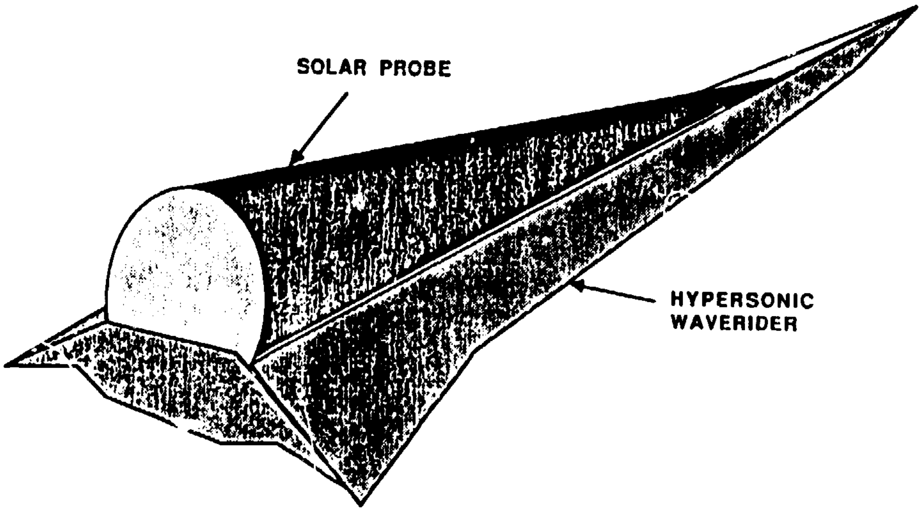
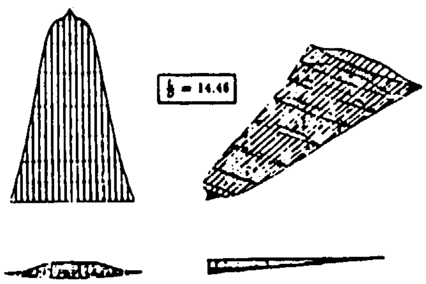
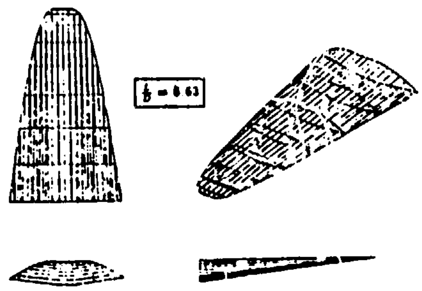


WAVERIDER - SOLAR PROBE SCHEMATIC

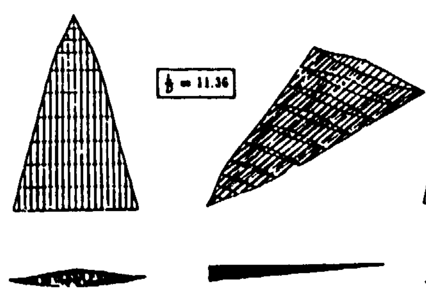




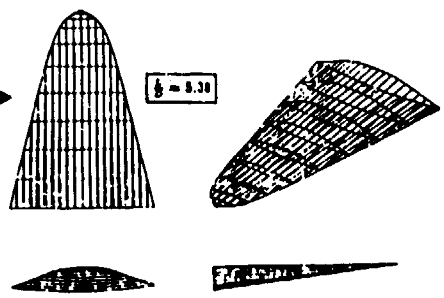
(a) h=30 km.



(a) h=20 km.



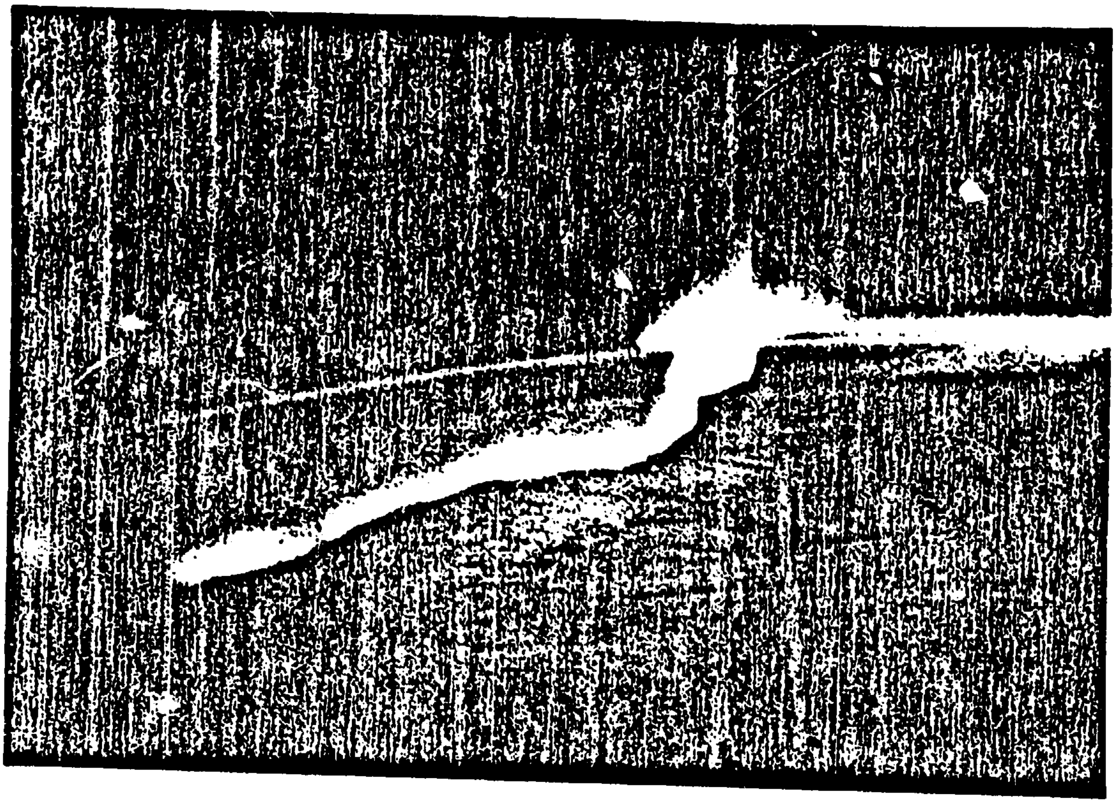
(b) h=76 km.



(b) h=30 km.

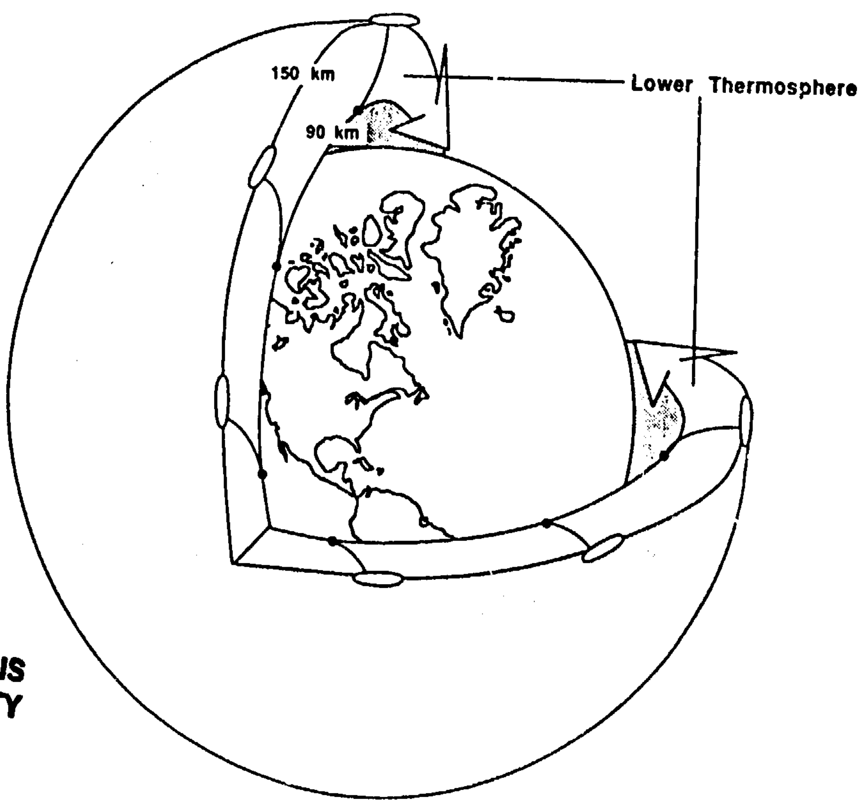
Figure 9: Waveriders designed for the Venus atmosphere, $M_\infty = 30$, $\theta_{cone} = 5°$.

Figure 10: Waveriders designed for the Mars atmosphere, $M_\infty = 19$, $\theta_{cone} = 7.5°$.



GLOBAL REGION ACCESSIBLE TO TETHERED ATMOSPHERIC SYSTEMS

OAST



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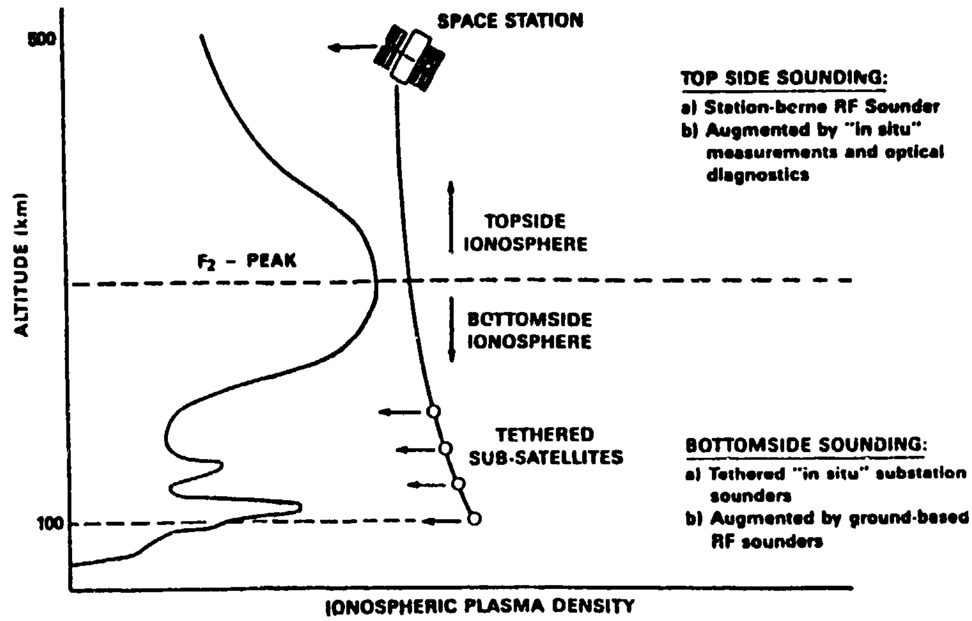
IONOSPHERIC WEATHER SPACE STATION (FUNCTIONAL CONCEPT)



Taken from "Technical Issues in the Conduct of Large Space Platform Experiments in Plasma Physics and Geoplasma Sciences", by Ed Szuszczewicz, an invited paper published in "Space Technology Plasma Issues in 2001", NASA JPL Publication 86-49, October 1, 1986.

III. Plenary Panel Discussion

Space Travel For the Next Millennium
PANEL DISCUSSION

participants: Geoffrey A. Landis (moderator)
Robert Forward
Marvin Minski
Theodore Taylor
Joel Sercel
Paul MacCready

Landis: The purpose of the panel discussion is to allow all of the panelists to comment on the various questions, and to argue with each other, I mean to discuss with each other, some of the various topics and get interaction among the various panelists. I have far more questions than we are going to have time to discuss during the panel, but, we will try to do as many as we can. Again, I'd like to mention that we would like all the panelists to discuss. If you have something to say about it we'd like you to just pop right in.

The top question on my list is directed to Bob Forward, but I will open it up to everybody. The question is: If chemical rockets are too expensive and nuclear propulsion is politically unfeasible then what is the most likely propulsion choice for manned travel in the solar system?

Forward: Well, it's solar electric and maybe solar thermal. But that is going to start limiting us as we get out further in the solar system and get further away from the sun. After that, why, there's sails and tethers. I would like to have both of those subjects not only explored in terms of building up our pile of paper stack of studies but actually get some real operational experience in space with some demonstration experiments. I think that's what we need more of is technology demonstration tests rather than complete scientific experiments. Unfortunately the present budgets of NASA aren't designed that way so we have a real problem that we need to turn around.

Sercel: I guess I would first question the assumption.

Forward: Of course, that's true. First question the assumption.

Sercel: The first thing we need to do is study that assumption; and the problem with nuclear propulsion is two-fold: First we have to identify the technical issues required to absolutely assure that it is safe and then we have to take the story to the public and make a convincing argument that it's safe. Now if we lose one or both of those battles then we need to consider other options. Solar energy is probably the best other option. As Bob pointed out, studies in solar electric propulsion show that performance is comparable to solar sails. As you know; there is a rough trade between solar electric and solar sails. And, for operations for launch vehicles in near Earth space, maybe beamed energy.

Landis: Ted, you may be unique in being an expert in both nuclear and solar propulsion. What are your thoughts?

Taylor: My thought is this: that I think it's likely that we can do everything we want to do out to somewhere around the middle of the asteroid belt with solar electric; possibly solar sails—and won't need nuclear energy for high performance. Beyond the asteroid belt there is some possibility of beaming by laser from close to the sun, but the receiving end of this (if it's Saturn or even Jupiter) gets awfully big; just because of the diffraction limit.

So what sounds good to me is to relegate nuclear propulsion to exploring, or doing whatever else we do, at the outer planets and make all of that, without exception, international. It is a little bit like the Baruch Plan for development of nuclear energy in the first place--that it should all be done under international auspices. But I would go a little further and say there is no reason even to have any nuclear power systems that have been started up before they get way out there. And then as long as it's not threatening, because it is being done internationally, we could make full use of it.

Minsky: There is a way of increasing the priority for nuclear, I think. If there is some urgency, like a war, people operate with different criteria. If there is genuinely going to be a threatening asteroid out there that was going to do some huge devastation, all the countries would band together and rational choices would be made with less politics to it. However to know that in six years something is going to come and zap you (I think that is beyond our forecast capability, but maybe we can convince somebody that even if it turns out to be false) then we might be able to accomplish your mission.

Landis: The next question is: "What are the pro's and con's of international cooperation versus international competition?"

Minsky: I think it's getting harder because nobody keeps their promises. It's not much help for the United States to offer people launching space when we don't have any. I think Ted is right, if we can get efficient fabrication on the moon I think that should be the first priority, although maybe asteroids are easier. Then you only have to send up unstarted nuclear. You're sending up materials that haven't gone critical yet and they are pretty harmless (although it could be hard to convince anyone of it). But, you know, if we wait about ten years it looks like everybody will starting to be nuclear again despite themselves. The threshold will have gone down just because of the fuel shortage.

Sercel: We looked at that with the Odyssey concept. Technically, it appears that one could use nuclear electric propulsion to do pilot exploration of just about any interesting target in the solar system this side of Saturn with round trip times of something like 5 years. So we took that analysis and said "What could we do with that with a space project that would challenge this nation well into the 21st century?" And one of the aspects that came up early in our look at it was the international aspects. So, I went back and reviewed, did some historical reviews, and if you look through history societies that have a high degree of contact with other societies have always been the ones that developed at the fastest rate. Presently, the world is sort of smaller than it has been in the past so there is always that kind of contact. But if you could design an international program that had the United States as sort of the center of it with each of the partners contributing parts, then that would put us at the center of this network. That would potentially be very enhancing for technology development.

Landis: On the topic of speculative ideas, what methods do you use to get new ideas seriously considered? A lot of people here have some wild ideas that they'd like to get some work done on. What do you do? Where do you go?

Forward: Well, the first thing to do is do a very serious study and get it published. The very fact that you've gone through the peer review helps a lot. But then you have a real long up-hill battle of going around and getting people interested in it. And keeping them interested in it and keep getting invited back and keep talking about the subject. I mean, after all, why do you think I wear these fancy vests? I want you to remember me, OK? And hopefully, remember the ideas. And if you keep talking to enough people, and enough *young* people, why, pretty soon the idea will get accepted.

But it takes years. Decades.

MacCready: I don't have any great ideas of how to do it; every case is a different case. You have to be lucky, and dogged and the times have to be right. The big problem is that so much of the resources get linked into long term giant programs. There aren't a lot of resources for getting started. Especially missing are discretionary funds that lab directors can allot to worthy causes. And when you've got to get into next fiscal year's budget, or the one after that, even to get started on the project, then things quiet down. So somehow diverting a significant amount, 5% or so of budget to high payoff and maybe low probability projects is very important, though very hard to do politically.

Forward: There is a program called the Small Business Innovative Research program which gets a certain percentage of every DOD and NASA budget. This money only goes to small businesses. A lot of people that I know who are interested in advanced propulsion have gotten some interesting programs started. The first year the first contract is $50,000 or less, but the second or third contract can be of the order of a quarter a million a year, and you can do a lot with a quarter million a year–if you can get past that first phase. So that is a program and those that are interested in furthering ideas of advanced propulsion, or something else, can use that program and people with ideas can form a separate company even though they still work for somebody else. In fact in one of the programs in antimatter research, this guy got together with a university professor and formed a small company and won a bid on a certain part of antimatter research. So that is a way to do it.

Landis: I might mention, however, that the Small Business Innovative Research program is very competitive and that if you are going to try to get a SBIR grant you had better put together a very solid proposal that that isn't something with big holes in it. You've better have figured out just what you want to do, and not propose ideas that you haven't thought out yet.

Minsky: When I was an Assistant Professor one day a person from Exxon showed up and gave me this check for $10,000 which he said was for discretionary research. It was pretty thrilling and lasted four years and ended up being worth about $300,000 because some student would want to do something and I'd say "well okay what do you need?" and he'd say "I need this gadget, or that," so we'd get it, and then it almost always turned out that something useful came, so I could charge it to the ARPA [Advanced Research Projects Agency] contract or something. But the leverage of small amounts, just trifling amounts, of money—so you can get the materials, so the student can prove that it's feasible, and then the visitor comes and says "OK we want that"; ONR comes around and says "Oh, we'd love you to include that under the real contract". Real contracts don't give you five minutes or five dollars to spend on "crazy things," so somehow you have got to get that $10k from some philanthropist, just a bit of discretionary money outside of the contract so that the auditor doesn't see. If you wanted you could take it home, I suppose, but that's not the point.

MacCready: That SBIR money really is important. Yesterday I met the guy who started the program and he's absolutely delighted with it and feels proud that he is a public servant that got that going and said that they have doled out more than two billion dollars now in how many years it has been going on. My company has done about a dozen of them, so far. I think the percentage of winners is not bad--it's one out of four or one out of six, not one out of thirty. And they really are after innovation and you do it as a small company and you are able to keep the proprietary rights for whatever you do which is a strong inducement.

For certain topics a prize is a very good way to stimulate development. Somehow if you put up a prize of a certain amount of money, it harnesses work a hundred times that amount of money--or a thousand times. It provides a focus and I don't know if people are after the fame or the money or what, but suddenly a lot of people start working on it. It turns out to be kind of hard to find just those challenges that you can have a prize with a good simple set of rules and the right criteria. That's not easy, but when you can then a prize is pretty good. You have to figure out somebody to put up the prize money, of course, but it's got some nice flavor and you only pay for winners.

Minsky: Recently a Japanese person came to me very discreetly and said "if they offered you a prize would you accept it?" which I thought was pretty funny. They don't want to make any mistakes. So he told me about the Japan Prize and I said "Oh, I suppose it is for my new Society of Mind theory." He sort of blushed and said "No, it's mostly for that paper you wrote in 1961!" So, I am not sure that prizes are that much of an incentive.

MacCready: People do some things for other reasons also.

Landis: The solar sail prize that was recently mentioned--for a race that may never even get started--seems to have stimulated quite a bit of interest.

Landis: Here is a question for Marvin Minsky. Joel Sercel talked a lot earlier about self-replicating robots. What are your comments on what Joel said? Is this something that is likely to happen?

Minsky: There are some very critical things, it seems to me. If you make the kind of robot I was talking about then you would make it out of exogenous materials. You know, maybe you can make all of the parts out of pieces of fused glass or metal--whatever you find on your asteroid or the moon.

The problem in self replication is usually that after a while you say "oh, I missed something." This robot is going to need a vidicon or a computer or a memory. I think that for the foreseeable future you can make self replicating systems that are pretty small and compact if you send the seeds--the vitamins, as Sercel calls them. A capable computer only weights a hundred milligrams. What does a 68040 weigh? It's a few milligrams, it needs some electricity--you're going to need some magic way of getting power. I should think a good robot could make thermal bi-metal junctions, if it knew enough. But I don't see any easy way to make a transistor factory right now. It seems to me you could make most of the mechanical stuff in a robot. Maybe the vitamins include little motors. I don't know how hard it is to make motors, but it seems to me that if we are talking about self replication, with a certain payload that we could do tremendous things right now. You have to ship the inside of the joint and the little computer, and all that is only a kilogram. And then you make all the gross stuff. These robots, clumsy as they are, ought to be able to fabricate the other clumsy parts of robots, and that's a big leverage. Maybe if you send five or six of them to the moon and a hundred kilograms of chips and sensors that's enough to make a big lunar factory--except for a few little critical things.

Landis: Joel, do you agree with that?

Sercel: Sure. When we were talking before I asked Marvin how long he thought it would take to make the first self replicating machine. My guess was fifty years; Minski said ten years, so I guess I am too conservative.

Minsky: But I think you are including making the vitamins too.

Sercel: No, I'm not, I'm assuming importing the vitamins.

Minsky: Well, I don't want to stick to ten years because when you are doing something ten years seems like a short time. I know I had this experience a couple of times in research. One of my really great students, Pat Winston, wrote a wonderful learning machine program--learning structural descriptions by example. It's sort of a classic in artificial intelligence. And this was a little program that would learn to build little structures; a little house, or arch, or a tower out of children's building blocks and we all thought that was a great thing and we just looked forward to the next graduate student who would take it another step and it was ten years. I don't know why, but if you have a good idea you can't order--or at least I don't order--a student to work on it. That never worked anyway. So, three or four years later another student understands the thing and starts to work on it.

Our PhD's usually took about six or seven years because they liked it so much hanging around the lab. So, you could think of ten years in leisurely basic research as just the average time between each idea and the obvious next step. So, when I said ten years I don't think I really meant it. And, fifty years might sound like a long time but it is just five steps of that sort. How many years between Newton and Feynman? Just about 300? And no one could say physics was crawling along in that time. It's a short time for major things, so who cares?

Taylor: One thing I feel compelled to say about self reproducing automata. There are pretty persuasive arguments that say that the gestation period, once we learn how to make these things, is likely to be nine months, or a year. The litter size could easily be ten. Question: what happens, when that population explosion takes off, a hundred years later? It seems to me that there are likely to be other people out there somewhere who at some stage come across this and a hundred years later, out goes a paving and reshuffling and redoing enterprise that goes out more or less spherically at about half the speed of light, or maybe closer to the speed of light, and redoes everything in its way. That must have happened. Question: are we in the middle of it right here? Right now? Were we produced by self reproducing automata?

Landis: That's partly an argument due to Frank Tipler. The point is that if there had ever been civilizations anywhere in the galaxy that sent out self-reproducing machines, they would have been here billions of years ago.

Sercel: I think it's clear that you're not going to program a self-replicating machine to reproduce in an uncontrolled way if you're intelligent enough to make one in the first place. I would guess that if some civilization had made self replicating machines, and a self replicating machine came into our solar system, it wouldn't necessarily start reproducing itself and take over the solar system. It might be out there in the asteroid belt watching right now.

Landis: Since we've sort of started on the subject of interstellar travel, the next question is: "Is the Orion, [which is the atomic bomb powered space ship which you see a model of over on the right], is the Orion concept still our best bet for an interstellar mission in the next fifty years, say, for a one-way, un-manned, fast fly by of Alpha Centauri?" And then as an addendum to the question: "Is it feasible to assume that a two hundred year trip time for such a mission could be realized without catastrophic failure of the space craft sub-systems?"

Taylor: Well, the interstellar version of Orion came out of Freeman Dyson. We thought we were thinking pretty big with a space ship that would deliver a thousand ton payload to Ganymede. We were pikers compared to what he did. He had a space ship which was several kilometers across; the bottom of it was several kilometers across. And what made it go was around a million ten-megaton H-Bombs. What this did was to take something perhaps the weight of loop Chicago off to Alpha Centauri. It was a very big concept. I think he did that for the sake of completeness, to say "Well what is the limit of this thing?" I mean, a million H-bombs are not completely out of reason. Johnny Wheeler had been pushing for that for years, that we actually build a million nuclear weapons in case we went to war in Europe.

Interstellar travel seems to require a violation of some of the basic principles that we hold dear. To make something to connect back to Earth within lifetimes... the energy requirements are huge. When you look at those numbers and talk about sending something that weighs, say, a hundred tons (which is awfully small for a voyage that long) up to, say, half of light speed, the energy requirements are on the scale of all the energy that has been consumed by human activity from the beginning of time. It's a whole different scale. Although we sometimes described it as an interstellar propulsion system, Orion never really was.

Sercel: It's worthwhile to point out that about every thirty years or so we double our energy consumption rate. In the process of that thirty years we expend as much energy as we have used in the entire previous history of man. So, if you do the back of the envelope calculation and assume that we continue to increase our energy consumption rate, it's only a matter of a few hundred years before we get to the point where a large interstellar mission is just a small fraction of global energy use. So, maybe the easiest thing to do is just wait.

Forward: Orion is the only interstellar vehicle that we could have built ten years ago. If, for instance we knew the sun was going to go nova or the Earth was going to die or something like that and we had send some of our seed off that's something we could have theoretically built, and built it a long time ago.

My effort over the last couple of decades has been to try to find some other way of going to the stars, other than using rockets. Now, many physicists have taken out the back of their envelope and proved that you can never get to the stars using rockets in ten years and they've done it and showed that you'd have to use up all the deuterium in the world's oceans as energy source and reaction mass, in order to send one interstellar vehicle to some star a hundred light-years away and bring it back. And you can prove that, and that's because you make the wrong assumption!

One wrong assumption is that you are going to accelerate at 1 g. You don't need to go at 1 g. You just need to go at 1 g for a year and then you are up to seven tenths of the speed of light and coast the rest of the way.

Another thing is, you don't want to use rockets for interstellar flight in the first place, and so the rest of my effort in this field has been to try and find some method of moving through space other than using rockets. One of them is the Bussard ram-jet, which unfortunately Dana Andrews and other people have tried to make work and found we can't figure out how to make the hydrogen scoop yet.

Another is to use beamed power. I have written two papers on this. One of them is on a space vehicle, starwisp, that only weighs twenty grams--less than an ounce--and returns color TV pictures from Alpha Centauri. Those kind of things don't violate any physics, and they don't use up all of the world's supply of energy. In fact, all it needs is a solar power satellite to get it there and get the images back. So, you can go to the stars without violating physics and not using up the world's supply of energy, but it's not going to be easy, and it's not going to be fast. These things only get up to twenty per cent of the speed of light, so the round trip mission takes 25 years to Alpha Centauri. So you can talk about going to stars, and it's fun. But we still need better ideas and it is what I hope to inspire in some of you younger guys here.

MacCready: There's another way of looking at going to the stars. It's not the approach that you're interested in here, perhaps, but if you put a small amount of money, (small compared to the amounts for the programs that have just been talked about) into investigation with radio telescopes, IR and optical, that have diameters that are sort of the diameters of the Earth, or by locating things on the moon and planets and so on, that you can get a huge amount of information about what's going on there. You are visiting them, but you are not visiting them by going there and bringing something back. You are visiting them by really looking at every bit of radiation that comes out.

Forward: My last novel was deliberately written to include an alien life form that would never have radio, and yet was very important to find because he had much more intelligence and had developed mathematics much further than we had. I deliberately did that because there are people like Barney Oliver and Sagan that say that the only way to do this exploration is by listening by radio and anybody that talks about flying to the stars is right off the back of the cracker box.

Taylor: I have to say that if the natives out there are friendly and have an urge to get up close to us, they'll come and get us.

Forward: But not if they don't have technology.

Landis: And if they are unfriendly and have an urge to get up close?

Taylor: I think if they are interested, that's a problem.

Forward: Do you think the whales will develop technology?

Taylor: Whoever is out there, if there is anybody out there, the chances of there being only a a hundred years from the invention of radio, and such are infinitesimal. They are either amoebic, or monkeys, or way ahead of us; not right where we are.

Forward: If you're underwater, you may not develop technology.

Landis: I've always wondered why the SETI people keep focusing on radio anyhow because obviously any intelligent life form would use the shortest wave length possible to communicate over interstellar distances. So, perhaps we won't find out anything until we get the gamma ray telescope up.

Forward: Or neutrinos?

Sercel: Well, since we're in the spirit of speculation here, we're talking about maybe you can travel by information is what Paul was suggesting as opposed to physically travelling, well if they've already built their self replicating machines and they are sitting on the asteroids waiting for us then all we have to do is get in contact with one of them and they can send the information required to make a human being back in their home world and we can then have human beings on their home world.

Landis: So they are just waiting for us to develop the receivers that can down load their life forms.

That leads to the next question, which is: "What kind of impact would the space Hubble telescope have on space exploration should it prove that nearby stars do have planetary systems?"

Forward: Is it designed to do that?

Landis: No, actually it is not particularly designed to do that, although some people have been proposing to try. There are other space telescopes coming up that might. One might have been the one that the Europeans launched, Hipparcos, but I guess it's having problems since the apogee kick motor failed to put it into the right orbit. If they don't put another one up, thre should be an Astrometric telescope up in a few years. This will measure the positions of nearby stars to a sufficient accuracy that they should be able to detect Earth-like worlds within I think a hundred light years and, if I am not wrong, Jupiter–size worlds within a thousand light years.

Audience: Haven't they recovered Hipparcos enough to get data despite the failure?

Landis: I've heard that they are getting a lot of data out of it, not nearly as much as they hoped but that they were getting good data and pretty soon we should learn something from this.

Sercel: It's worth pointing out that there is a good deal of evidence already of planetary systems around other stars. And that hasn't resulted in a revolution in our space program. For example, images of the star Beta Pictoris suggest some kind of planetary system, as well as some of the infrared data that came back from IRAS.

Landis: The IR signature really comes from pretty small particles. It's really dust that they're talking about.

Sercel: But it is suggestive of the first stages of accretion of planetary systems.

Forward: I don't know. Once we actually design a telescope that has the right kind of occulting disk to block out the major star and is well designed so the stuff leaking by doesn't louse it up and really finds a green planet..I think that once we have a picture of a green planet a lot of people will be very intrigued, I think, and interested in going there and that would be fun.

Landis: One of Bob Forward's papers on interstellar travel suggested it should be possible within the next many decades to focus laser light distances of light years with a lens a thousand kilometers or larger in diameter, an O'Meara 'para-lens.' O'Meara's intent in studying the possiblity of making such large lenses was to use them for telescopes. With a lens that size, you could not only detect Earth-like planets out to hundreds of light-years, but you could *map* them with hundred-kilometer resolution. So that if the planets are out there and we have the technology to get there via these laser-propelled ships, we'll know where we're going long before we do.

MacCready: Before we get off this, looking at the practical side, such projects are going to have to be government funded. The government is run by people interested in what happens during their term, not some far distant term. And although a few far-sighted things sneak through I think it is going to be very hard to do something where the results are going to come in thirty years later, or two hundred years later, with our political system. Or our economic system.

Forward: In my very first paper in interstellar flight, I pointed out that even if you could travel at the speed of light it would take you 4.3 years to get to Alpha Centauri, and either 4.3 years to come back, or for the information to come back if you decided to stay there. And that is 8.6 years, a half year more than the term of a president. So no interstellar mission will ever fly.

MacCready: Whereas if you have this super telescope you get the information right now.

Minsky: Maybe if we could ban re-election to all offices then this problem would change. That is probably the first priority.

Landis: Kennedy asked for a moon mission within a decade and that happened.

Forward: Yes-- but it's Nixon's signature.

Landis: What do you think the possibility is for non-government funded space exploration: including everything, SETI and all of that stuff? Do you think it's ever going to be possible, or are government agencies like NASA the only organizations that are large enough to fund space exploration?

Minsky: The D.D. Harriman problem. We need more immensely wealthy people.

Sercel: I would point out Orbital Sciences, Geostar, several other start-ups that are doing quite well in the space business. I think it looks better now than it ever has for non-government funding.

Forward: I think it is a real problem. Interstellar flight is non-profit. The real answer is multi-billionaires, yes.

Audience: There are some small scale amateur kinds of explorations are going on now, and I point out that the ham radio community has a number of satellites up that they are using for serious communications. They have been doing it essentially by being hitch-hikers on much larger satellites that have some nooks and crannies and will accept experiments on a non-interference basis.

Landis: Here's a question for Marvin Minsky: "What do you think the likelihood is of AI machine civilizations elsewhere in the galaxy? What do you think is the likelihood that we might evolve into a machine civilization ourselves?"

Minsky: Well, that's sort of Gregory Benford's field these days, and David Brin. It seems to me fairly likely that in a thousand years or so, or less, we'll turn into one. I just can't imagine a people as smart as us tolerating disease and senescence and all that sort of thing once the option becomes available. There's Hans Morovic's script for that in *Mind Children*. Some people will say, "no, I don't want to be machines" and they will have their choice and die out. There is this singularity in evolution and when we understand how to make ourselves into better hardware then some people will do it and some won't and that will be that.

Sercel: I guess I agree. The one thing I wonder about is whether you go green or go gray. The metallic approach or genetic engineer.

Minsky: I guess green is cheaper.

Forward: Yeah, I agree with it too. I usually say we already do turn our world over to little bitsy robots. And we do it because we trained them, brought them up to be human beings and believe in our culture and we trust them, finally, enough to go and retire and turn the world over to them. I don't see any difference between that and the act of training some kind of silicon little being and doing the same thing.

People argue, "but they're not made of meat." Of course they don't exactly say that, but that's really what we are trying to do: run a world with computers made of meat. And I think there are better ways of building intelligent beings.

Landis: I might add that makes the interstellar travel problem much easier because the time frames don't really matter. If it takes a thousand years to get to Alpha Centauri at a small fraction of the speed of light, that's OK, because you turn yourself off and turn yourself back on when you get there.

Forward: Yes, but I think one of the whole points about interstellar travel—that if it takes you more than fifty years to get there and you haven't completely eliminated all the other methods of propulsion, then by the time you're half way there, somebody is going to pass you up. Yyou don't really want to build a space craft unless it can get there in less than fifty years. At least not until we have run out of options on propulsion technology, and we are a long way from that.

Landis: That's OK, it's just different copy of you that's passing you up. So you just download your new copy onto the old one as you go by.

Forward: OK.

Sercel: With regard to machine civilization, one might observe that the transformation between biological civilization and machine civilization is not a distinct one, but it's a gradual process. And it's a process that's already started. We use automobiles for our legs, and we use tractors for our arms, and, in fact, considering the impact we are having on the biosphere (which is purely biological) it may be that machine civilizations and biological are not compatible and it may be the most natural place for a machine civilization to live is out in space where it is not interfering or destroying a pristine, delicately balanced biological environment.

Minsky: Where there is no polyethylene eating bacteria. That's in Larry Niven.

Landis: We're getting close to the end of time. Let me ask this one last question. "Should the Solar Power Satellite be used as a focal point for long range international space efforts? And, if so, what should we be doing right now?"

Sercel: I think the space Solar Power Satellite is a very interesting concept. It has some problems and it has some strengths. Where we stand right now is that we don't know enough about the technology options that can be investigated to really know whether it can be made cost effective and safe. So, if those studies conclude that it can be, then it would be a very interesting thing to pursue, but I don't think we have enough information to make that decision right now.

Forward: I'd rather see that we focus on some other goal. I mean, that particular choice isn't so obviously effective. We just really don't know. It has some very good points, as Joel said, but it's not so obvious as "Let's go to the moon" or "let's go to Mars". Those are things that aren't really trying to make a profit. You're just doing it for the heck of it.

Taylor: Before using solar energy collected in orbit will look in any sense economical for producing electric power, it will have first happened on the Earth's surface. In fact, if you want to see a candidate for a near-term revolution in energy production on the surface, I think a clear front runner is hydrogen produced by low-cost photovoltaic cells and then used as an all purpose fuel. There's a lot of attraction for a hydrogen economy. We can do it on Earth. In fact, we are right on the verge of being able to do it this decade at costs that will compete with natural gas. So, I guess I don't see what burning need the Space Power Satellite meets that we can't do cheaper, better, quicker on Earth.

Minsky: I have one concern. I wonder which projects we ought to do as soon as possible because rising population and the fusion of interests in world governments will come to the point where nobody dares do anything. There is a fear that in another twenty years a curtain will come down on all forms of exploration and everybody will be too careful to launch anything.

Landis: I regret we're out of time and so I have to close the discussion. I would like to thank you for participating, and I hope you enjoy the rest of the symposium.

IV. Poster Session Papers