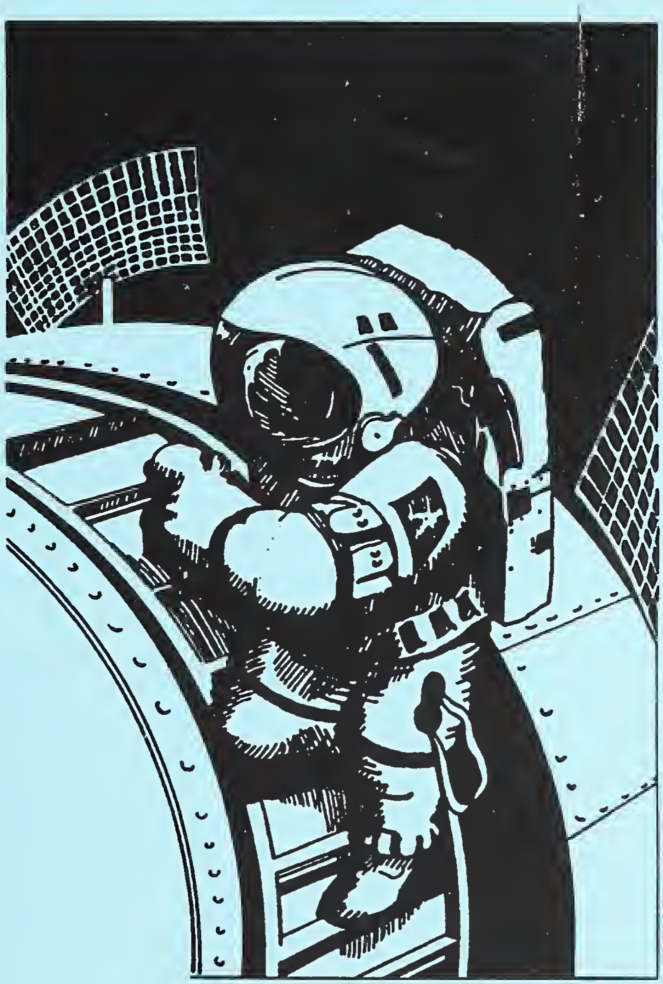
NISTIR 5255

National Institute of Standards and Technology Conference On

Reducing the Cost of Space Infrastructure and Operations

Part 1: Oral Presentations and Discussion



Building and Fire Research Laboratory
Gaithersburg, Maryland 20899

NIST

United States Department of Commerce
Technology Administration
National Institute of Standards and Technology

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National Institute of Standards and Technology
Gaithersburg, MD 20899

U.S. Department of Commerce
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Abstract

A conference was held from November 20-22, 1989 at the National Institute of Standards and Technology in Gaithersburg, Maryland for the purpose of discussing methods for reducing the cost of space infrastructure and operations. This was a multi-disciplinary group that included invited speakers from both within and outside of the traditional aerospace community. Specific comparison was made in the case of habitats and extravehicular activity with commercially successful undersea operations on earth which operate daily under more severe environmental conditions and with operating budgets on the order of 1/1000 that of orbital analogs. Other topical areas included chemical and advanced launch systems and institutional aspects including insurance and differences between top-down control and performance-based development of space infrastructure. The proceedings are published in two separate reports. Part 1, **Oral Presentations and Discussion**, is contained in the present publication and provides edited transcriptions of the invited lecture presentations and of the discussion which followed each presentation. Part 2, **Topical Papers**, contains prepared manuscripts which were submitted in advance of the conference and is available as a separate NISTIR report.

Keywords: advanced propulsion; cost reduction; unit cost; launch insurance; NIST conference; orbital habitats; space infrastructure; space suits; space transportation

List of Acronyms

ALS	Advanced Launch System
ASAT	Anti-Satellite Device
CFD	Computational Fluid Dynamics
DARPA	Defense Advanced Research Project Agency
DOC	Department of Commerce
ECLSS	Environmental Closed Life Support System
EMU	Extravehicular Mobility Unit
ETCO	External Tanks Corp.
EVA	Extravehicular Activity
FDU	Fairleigh Dickinson University
FTS	Flight Telerobotic Servicer
GD	General Dynamics Corp.
GPS	Global Positioning System
GSO	Geo Synchronous Orbit
GTO	Geostationary Transfer Orbit
ICBM	Intercontinental Ballistic Missile
ISF	Industrial Space Facility
IVA	Intravehicular Activity
Isp	Specific Impulse (seconds)
JSC	Johnson Space Center, NASA
LEO	Low Earth Orbit
LRT	NOAA Launch and Recovery Transport
LSB	Life Support Buoy
MITI	Ministry of International Trade and Industry, Japan
MMU	Manned Maneuvering Unit
NASA	National Aeronautics and Space Administration
NASP	National Aerospace Plane
NBS	National Bureau of Standards
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
OAST	Office of Aeronautics and Space Technology, NASA
OSC	Orbital Sciences Corporation
OTA	Office of Technology Assessment, United States Congress
OTV	Orbital Transfer Vehicle
RMS	Robot Manipulator System
ROV	Remotely Operated Vehicle
SDI	Strategic Defense Initiative
SDIO	Strategic Defense Initiative Office
SSI	Space Studies Institute
SSME	Space Shuttle Main Engine
STEP	Space Transportation Engine Program
UDMH	Unsymmetrical Dimethyl Hydrazine

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Preface

In the spring of 1989 work was underway at NIST to investigate practical and, perhaps more importantly, economical methods for autonomous boost and orbit stabilization of the Space Shuttle External Tank after Shuttle Main Engine Cut Off. The rationale for conducting such work was to remove, in a step by step fashion, the barriers inhibiting private enterprise from making use of what amounted to an immense space-rated pressure vessel capable of sustaining operations in orbit by people, that otherwise would be left to re-enter and burn up in the earth's atmosphere on each and every Shuttle mission. At the heart of this concept was large scale re-cycling to dramatically cut the costs of conducting commercial-industrial operations in space by making the best use of already paid-for public assets.

It was at this time that Thomas F. Rogers, Chairman of the Sophron Foundation and now, as well, President of the Space Transportation Association, suggested that NIST host a conference that would bring together business, government, and academia to discuss approaches to resolve the "Catch 22" of the expansion of the private sector into space:

a) The costs of going to space are enormous, very few humans ever get to travel there, and the infrastructure is built on a one-of basis. Consequently, outside of the satellite communications business, only the government can afford to conduct space activities; but

b) Since the government is willing to pay one-of prices, and since there is presently no established high-volume market calling for the use of space infrastructure, there is no incentive for aerospace companies to seek commonality and reap the economies of scale that would result from mass production. Therefore, the costs remain .... enormous.

There is a predictable corollary in that public support for such government civil space programs has decreased sharply precisely because only a very few privileged government astronauts will ever get to go to space. The average American taxpayer **will never personally experience being in space** unless the above cycle can be broken.

In the pages that follow you will find the proceedings of the conference on **Reducing the Cost of Space Infrastructure and Operations**, which was held at NIST on November 20-22, 1989. It is particularly poignant to comment that shortly prior to this conference a political event of historic importance occurred: the dissolution of the Soviet Union and the effective termination of the Cold War with the United States of America. Prior to this dramatic unfolding, space hardware was acquired largely in the interests of national security, and when such is the prime motivation, costs are secondary. With the removal of the specter of imminent confrontation between the superpowers there was optimism in November of 1989 that not only was the NIST conference timed appropriately, but that there existed a real opportunity to address, for the first time, the issue of how to sharply reduce the costs of doing business in space.

The NIST conference was by design multi-disciplinarian not only to the extent that experts in all facets of space infrastructure (transportation, habitats, EVA, communications, robotics) came as invited speakers, but also those from vastly different, and financially successful, terrestrial industries that comprise close analogs to the space environment. It was felt that this latter facet, in particular, would serve to cast immediate similarities in terms of operational requirements yet emphasize the stark differences in the amount of capital required and the operation costs between the two. The resulting discourse between the audience and the various presenters is provided in Part 1 of these Proceedings following a transcription of each live presentation. Many of the presenters also delivered prepared manuscripts including figures which in most cases contained substantially more technical detail than was possible in the oral presentation. For completeness these are included in Part 2 of the Proceedings along with a complete listing of the conference participants.

For various reasons the production of this volume was delayed. Given the intervening four years, and the many advances in technology in other areas, one might be tempted to conclude that, the issues discussed at the NIST conference would have become moot. This has, however, not proved to be the case. A curious period of response lag has followed the end of the Cold War. Space hardware is still procured, and manufactured much as it was before, only in diminishing quantities because of essentially static Federal space appropriations and continuing increases in the cost of living. DOD contractors have to re-structure in a period of sharply reduced defense spending. The Advanced Launch System (ALS) and National Launch System (NLS) programs were canceled. The NASA Space Station program was downsized both in capability and cost yet again, and its future remains tenuous at best.

Rather than mourn these events as further setbacks to the permanent establishment of humanity in space, they should be welcomed, for they represent the collapse of a system that bred high cost and produced no opportunities for common individuals to experience nor to make use of the unique environment of space. An opportunity now exists to reassess what businesses should be conducted in space for their economic merits alone and to consider how the likelihood of success of such endeavors could be maximized through the use of large scale production, cooperative ventures which seek to standardize and simplify fundamental infrastructure, and the tacit acceptance of finite risk of failure.

In this respect the proceedings of the NIST conference are more pertinent and valuable today than they were in 1989. In the enactment of Title V, Commercial Space Competitiveness, of the NASA FY 1993 Authorization Act, and the NASA FY 1994 Budget Amendment just submitted to the Congress by President Clinton, there are clear indications that the Federal civil space program is to focus much more sharply on economic objectives, and cost reduction is explicitly called for.

Throughout these proceedings, while the word "cost" is emphasized, it is "unit cost" that is implied, i.e., dollars/pound trnasported to orbit, dollars/cubic foot of habitable volume, dollar/kilowatt-hour, ... As these unit costs are reduced, so that more use can be made of space assets and services by many more space interests, then the total cost of space activities can be expected to increase. For then, much more would be going on in space than today.

Many individuals contributed substantial time and effort to the organization and conduct of the conference. In particular, I would like to express my sincere appreciation to my co-chairman Dr. Cary Gravatt at NIST and to the other session chairmen including Rich DalBello (then of the Office of Space Commerce, DOC, now at OSTP), Tom Rogers (Sophron/STA), and Ray Williamson (OTA). I am also grateful to Greg Barr (SSI) who generously offered to tape the conference, to the NIST Conference Facilities Office whose staff were unfailingly helpful, and to Marla Holloway who assisted with the production of the manuscript. Finally, special thanks are due to Ray Kammer, Deputy Director of NIST whose bold leadership enabled commercial space research to be conducted at NIST and for this conference to take place.

Bill Stone
NIST, Gaithersburg, MD
August 1993

Monday, November 20, 1989

Welcome -- *Sam Kramer, Deputy Director NEL*

I'm Sam Kramer, Deputy Director of the National Engineering Lab at the Bureau and I want to welcome you all here today to the conference on Reducing the Cost of Space Infrastructures and Operations. This conference has been organized and will be run by Co-Chairmen, Bill Stone and Cary Gravatt who are from NIST and I want to commend them for undertaking this project to bring people from many different interests together.

As I was thinking about telling you in just a few brief comments about what NIST is, it dawned upon me in the hall (and I don't have my history facts completely straight so please don't quote this in detail) we have a very close tie to the origins of NASA and concerns for space in that the early laboratories of NASA and its former organization are spin-offs of the National Bureau of Standards, our old organizational name, just as The Harry Diamond Labs of the Army is a spin-off of NBS, and the Department of Transportation Laboratories are a spin-off. So besides all the work we do ourselves we do serve as a breeding ground for some of the frontier technologies and when they start maturing we find that they sort of take off on their own. We create the embryo and it grows from here. I think we are in on the beginning of some great programs here with the conference topic.

NIST, as our organization is called now, was formerly the National Bureau of Standards. Our organizational name was changed with the passage of the Omnibus Trade and Competitiveness Act of 1988. That did a few things: it changed our name from the National Bureau of Standards to NIST; and it revised the priorities of the activities that we conduct. A lot of people seemed to think that it wasn't until 1988 that we were given the charge to be of aid and assistance to industry. The mission of being the Government's laboratory to support the US industrial sector goes back to the report that led to the creation of the Bureau in 1900 and the Organic Act in 1901 that established the Bureau. If you get a break and wander out to the front lobby you will find chiselled in the marble, the key phrase that mandated the creation of the Bureau and in there you will find the words as: "a Government laboratory to support and give assistance to US industry".

So there is nothing new, they just changed the priority in the new act and they moved the support of industry to the front part, with our other activities as a second item. We are the nation's measurement and standards laboratory and as such we do work with all of US industry and all of the other government agencies to provide the standards for measurement and the standards and the scientific base for the work that goes on and accounts for most of our trade and the ability to be competitive in the basic sciences and mathematics that is needed for the frontier technologies as we move ahead.

For instance, right now, on-going at NIST are many programs. While none of these programs have "space" in front of them, I am sure all of you here will identify very rapidly to the need that space programs have for the activities, such as: this past week we hosted again an annual event of bringing industry and government people in to see the latest advances in the automated manufacturing facilities and automation that takes place. We have a state of the art facility here, referred to as the AMRF - Automated Manufacturing Research Facility. That is a very large on-going program here and I would say just about everything in that program has its application whether it be: to the production of space vehicles, or to operations in space. We have a large program in computer interfaces for robotics and telerobotics. We have programs in machine vision, image analysis, and parallel processing, all of which can find immediate application in the space program. Our materials people are concerned with high performance material processing and characteristics and in fact our standard reference area, which generates the standard reference materials that are the basis for all measurement activities and quality control in this country, has produced SRMs in space. Although we didn't launch the missile, the only commercially manufactured product that is made in space -- space beads -- is sold through our Standard Reference Material Program. These beads are used in the calibration of precise measurements.

That is just sort of a quick overview of what we have going on here. Those of you who are familiar with NIST know we have a fairly open door policy here. We welcome you to the facilities. We welcome you to interact with all of our technical programs and to take advantage of what's going on here. Those of you who are new here, for the first time, we encourage you to talk to our people. There are many people here beside Cary Gravatt, Bill Stone, Helmut Hellwig, Chris Witzgal, and others who have worked directly on space related research. There are many people here from NIST who can at least link you up and act as, if you want to call it "the marriage brokers", to refer you to those areas that may be of particular interest to you. Our people are only too glad to discuss it with you, discuss their technical activities with you or even to set up for subsequent visits from you or members of your organization to NIST here. I am going to end my comments by saying we truly welcome you here. As I told Bill Stone, the people who came out today have a deep interest in the program because I don't think we could have picked a more difficult week to schedule a conference in the three days before Thanksgiving. So those of you who came we know are truly committed to the program and we hope that you will be able to take whatever you get here and convey it back to others in your organizations.

Again, thank you for coming and I'll turn the program over at this time to Bill Stone who will be chairing it for you.

Introduction -- *Bill Stone, NIST*

Thank you very much Sam. On behalf of the National Institute for Standards and Technology, the Office of Space Commerce - DOC, the Space Business Roundtable, the Space Studies Institute, and Co-Chairman, Cary Gravatt, I'd like to welcome you to a sunny day here in Gaithersburg, Maryland and to our conference on Reducing the Cost of Space Infrastructure and Operations. Many of you are no doubt wondering why the National Institute of Standards and Technology is holding a space conference. There are two reasons.

The first is that NIST is the only national laboratory with the specific mission of assisting US industry to be more competitive. One way we do that is by facilitating and improving interactions among all players in the field. As a neutral organization we are in a position to provide a forum for discussion of the present system as it relates to the space industry, Government polices, and practices.

Secondly, the time is right. There is a growing concern for our country's space future. The cost of space hardware and the conduct space activities are truly enormous, enough so that they have effectively suppressed otherwise strong and diverse interest by the general business community in conducting operations in space. Let me give you a few examples: the cost of placing a pound of anything in low earth orbit is between $5,000 and $10,000. That is just one pound. If you take a 100 watt light bulb and keep it lighted in low earth orbit for a year's time the cost of doing so would be approximately $100,000! Based upon the presently anticipated space station cost it can be estimated that a 3 x 3 x 2 m habitable office facility in low earth orbit would have to lease at a price near $1 million per day. Clearly, as long as such unit costs persist, the aspirations of the American public and many of those within the Executive Branch and Congress to see large-scale, private sector commercial and industrial activities take place in space, will simply not be realized.

Such staggering costs are not inherent in the space area. But with one exception they are the rule. For the space era developed during the time of military threat posed by the Soviet Union and when our national security interests are threatened, the financial cost of our response thereto is a secondary consideration. The cold war lasted for nearly two generations so that this near disregard for the cost of acquiring ballistic missiles, satellites, etc. has been woven into the fiber of the Department of Defense, the National Aeronautics and Space Administration, the aerospace industry and even some in the academic community.

The one reassuring example in space is that of the satellite communications business. INTELSAT, with COMSAT as its US member, has been in business for 25 years. Over that interval INTELSAT has worked hard to increase its market for satellite communications services and it has diligently searched out methods to reduce all its costs. As a consequence the inflation adjusted price of making a transoceanic telephone call has been reduced by some 100 times, an average price reduction of 20 percent per year. And its global system capacity has grown by some 800 times. Thus, for this and other reasons we have explicit cause to believe that space-related costs can be brought down, dramatically if professionals and business people are determined to see that they do. And if they go about bringing them down with persistence, imagination and energy, then business and profit opportunities will expand accordingly.

The 1989 Presidential Space Policy Directive, which was just issued on Friday, instructs the Department of Commerce, for which NIST is the chief technical laboratory, to:

"work cooperatively to develop and implement specific measures to foster the growth of private sector commercial use of space".

It is clear from the aforementioned, however, that no such growth will take place until the cost barrier is breached. It is to address this singular goal that we are assembled here this week.

The keynote speakers you will hear from during the next two days have between them several hundred years of combined experience in working in space and other airless environments. Their observations concerning how we might reduce the cost of conducting business in space will serve, we hope, as the basis for animated discussion during the various workshops and the identification of some of the options that should subsequently be considered by industry and Government to meet the goal of cost reduction.

Let me now give you a few notes about the conference. There will be four main sessions, two each day, which are described in the detailed notes in your conference kits, followed by a summary session on Wednesday morning. Generally the keynote speakers for a particular session will be divided into groups of three or four and will be seated at the panel table in the front of the auditorium, as we have it set up now.

Unless the session chairman determines that time is available, we request that you hold your questions until all members of the group have spoken, after which, time has been allotted to address the speakers either individually or as a group. We will have assistance available at the registration desk throughout the conference to make overhead transparencies for any of those who feel you need them to make a point.

The guest speaker at this evening's dinner is going to be Courtney Stadt, the Commercial Space Activities representative for the National Space Council. Deputy Secretary Murrin who was originally slated to be the speaker, is very interested in the conference and had planned to attend. However, the Census got him from 4 to 6 today in Suitland, Maryland, and we were not able to convince him that it is a beautiful, relaxing job to drive around interstate 495 at that time of day! He has only been in town six months but he learns fast.

There are four other chairmen who you'll be meeting for the various topical sessions:

- Tom Rogers from the Sophron Foundation and I will be co-chairing the first session this morning on orbital facilities and EVA;

- Rich Dalbello from the Office of Space Commerce, DOC, will chair the Monday afternoon session on Chemical Launch Vehicles;

- Dr. Cary Gravatt from NIST will chair the Tuesday morning session on Payloads and Institutional aspects; and

- Ray Williamson from the Congressional Office of Technology Assessment has generously offered to chair the Tuesday afternoon session on Advanced Launch Vehicles.

With that I will turn the mike over to Tom Rogers who will introduce the first speaker for the Orbital Facilities and EVA session.

CHAPTER ONE

ORBITAL FACILITIES

and

EXTENDED VEHICULAR ACTIVITY

SpaceHab Shuttle Module -- *James Beggs, SpaceHab, Inc.*

Introduction by Thomas Rogers: Good morning, ladies and gentlemen. I met James Beggs about half a dozen years ago; at that time he was the NASA administrator. Jim has graduated from the Naval Academy, been in the Navy, and has spent most of his life in the aerospace industry and in the Government. He was with Westinghouse Electric in defense-related engineering matters, with NASA as an associate administrator for advanced research and technology matters, then Under Secretary in the Department of Transportation. Just before that he had also left defense-related and air- and space-related matters to go to the Department of Housing and Urban Development so we have that unusual common element in our backgrounds.

Jim, before coming to NASA as the Administrator, Jim was the Executive Vice President at General Dynamics for several years. He came to NASA in 1981. He arrived shortly after the first flight of the Space Shuttle Columbia and I think it is fair to say that he had a great influence on all of the further shuttle operations and developments and a singular influence on the national decision to build a habitable structure in space, the space station. Since then, he has been out doing other things, most importantly leading the effort to establish a private sector business called Spacehab and perhaps that's the most important element of his professional background to be called upon today. I am pleased that Jim is here with us.

James Beggs: Thank you Tom. I am going to tell you a little about the Spacehab and then range over some issues that I think are important to discussing low cost -- or I should say lower cost, there is no such thing as low cost -- facilities in space, and talk a little bit about what we might do to make it easier.

I congratulate Bill Stone and the Bureau here, for the laboratory here, for organizing this conference. NASA and America's space program does indeed owe a debt to the old Bureau of Standards. The first Deputy Administrator, Hugh Dryden was an alumnus of the Bureau and served the space agency very, very well. As a matter of fact I don't think we could have gotten it off the ground had Dryden not been there in those early formative years.

Hugh Dryden was a remarkable man. I knew him but slightly but he was a man who was well versed and extremely competent in getting things done in Washington. As a matter of fact it became an old saw in the Agency that if you really wanted to get something done, if you really needed to get something done and you could go to Dr. Dryden and get him convinced that it was a good thing to do, with about three phone calls, he could get it done, and indeed he could. He was a remarkable man, and wherever Hugh is, and I am sure that he is doing his favorite engineering work up there in the great beyond.

"What gain we if we gain the thing we seek? Or, what win we, if we gain the thing we seek", to paraphrase Shakespeare. To quote you the second line of that, he said: *"a dream of breath, of froth, of fleeting joy"*, and may be some days as I am working on this I think that's about what it is that I'm setting about gaining. To be sure though, what we are trying to do in reducing the cost of getting into and operating in space is to try to remain competitive in this increasingly competitive world. And make no mistake about it, it will continue to be increasingly competitive.

As a matter of fact what's going on in Eastern Europe and in the Soviet Union almost guarantees that. Because as we all know the Soviets are offering access to space now, at a relatively low cost with an offer that is fairly long standing now to provide access to the Mir, their space station, and to do whatever they have to do to make that attractive to Western users. If you look at those costs, and they are well known now because the Soviets have been in almost every international conference offering their services for a fee, you will find that they are about half the cost or half the price, if you will, God knows what the cost is, and he's not going to tell us, and certainly not the Soviets either, it is about half the cost of what we have been looking at in the case of the Shuttle. So they are low indeed. I'm sure if someone comes in and competes with them at a lower price that they will match that and give us an even lower price on the international market because they are determined to break in. I don't look on that as being anything that is adverse or even very serious. There is a limited capability there. We should welcome them to the party and we should learn to compete, but we have on our part likewise got to learn to compete.

Let me tell you for just a minute what SpaceHab is. SpaceHab is a pressurized module which fits just aft of the mid-deck on the Shuttle. It is Shuttle-based and dependent upon the Shuttle. It doubles the volume of the mid-deck. As we all know from the first thirty-odd flights of the Shuttle, the Shuttle has now made more than 50 successful trips to and from low Earth orbit. (Editor) The mid-deck is some of the most valuable real estate in the shuttle. So it occurred to some individuals early on that to increase that volume would be a desirable thing to do and might even be something that you could do and make a go of it commercially, assuming that the desire, the demand for experimentation in the shuttle continued to grow, and indeed it has.

Therefore, our plan was to add that module. It is little less than two tenths of a load factor for the Shuttle. By adding that module aft of the mid-deck, we double the pressurized volume, making space for roughly sixty of the size modules that fit in the mid-deck, which in the scheme of things will accommodate about twenty-odd experiment opportunities, twenty additional experimental opportunities, on any Shuttle flight. Paying what the Shuttle currently is charging for transportation cost, and earning a reasonable return on the kind of money that we need in order to produce this module, means that we can sell a module for roughly a million dollars for one flight. That's not cheap. On the other hand as we add up the numbers on the Spacelab which is the only real competitor because the mid-deck now is almost totally filled up, there are a few lockers available but not very many, that's about half the cost of what it costs if you fly on the Spacelab.

In addition to that we believe that we can shorten the lead time of getting experiments into the Shuttle from what it is now, about three years' lead time, to maybe half that, 18 months. Maybe a tad less than that. How do we do that? We do that by integrating most of the design and development of the experiments into the module independent of the Shuttle and fit the SpaceHab into the Shuttle as a generic payload, slide it in if you will. It's not quite as easy as I've stated it but it can be done and we have been working with the NASA folks very closely to ensure that it will be done, and we believe that that's possible.

It is that shortened lead time that is probably just as important or perhaps a little more important than the cost advantage that we have over Spacelab. Most industrial experimenters who have spent money up front to develop an experiment want to fly, get results, and then fly again. If they can't do that on a reasonably close time schedule, they get very discouraged with investing the kinds of money in research and development that they have to invest to go into space. Spacelab has not been very good for them in that regard. So that's the need and the demand that we are serving. We have in the first three years, I guess, of our existence put into place the concept, done the design work, and are now cutting metal. We have two major contractors who will do this job for us, one Aeritalia in Italy who build the pressure vessel and you will recognize them, they are the people who built the pressure vessels for the Spacelab, and McDonnell Douglas who will do the integration here in the United States. They are also one of the prime contractors on the Spacelab.

We are well under way. We have a contract with NASA, the Space Shuttle Development Agreement, which requires that we pay the transportation costs each time we fly. They in turn will provide to us certain services and will manifest us as near as they can to the schedules that we would like. The first flight is in 1992. The first, very successful trip took place in mide-1993. (Editor) Nothing happens fast in this business.

So that in brief is SpaceHab. It is something we believe is viable from both a cost schedule and demand point of view. In order to do this we had to go out and raise a great deal of money. Indeed we are still involved in that and I expect that we will continue to be involved in keeping that money in place until we get through our first flight. You might be interested in how we went about that. In the first place there is not sufficient venture capital available for this class of investment in this country, to float it, to get the equity funding that you need, so we went abroad. We will raise a substantial part of the venture capital in Japan and Europe and Taiwan. We would have gone other places if we had not succeeded there. Thirty percent of the equity then will end up in foreign hands, and that percentage was an agreed to percentage going in--that is the US Government decided, in their wisdom, that thirty percent was about right. Well, maybe not right but acceptable. The rest of the money is leveraged off that equity investment from the commercial banks. We are still in negotiation with Chemical Bank in New York, which is the lead bank although they will syndicate this loan for the final term sheet and the final requirements to get the loan.

Once we get all of that in place and it is going together now, we will be in a position to go out and offer our services on the market to a consistent schedule and we believe that we will sign up very quickly a requirement or a market for about the first six flights. If we get through the first six flights we will be out of the banks, assuming all our financial projections are correct and they are probably not. Six flights is where breakeven takes place.

Now, what does the Government need to do or what does both the Congress and the Executive Branch need to do in order to make all this possible? First of all they need a very consistent policy on how one gets aboard the Shuttle or how one does things in any respect in space. This has not been a hallmark of our nation's space program. As a matter of fact since we first established costing and the various requirements one had to meet to get aboard the Shuttle or to fly into space in any respect in the early '70s when we launched the Shuttle program, I count at least six changes in policy. So in about 15 years we've changed the policy six times, that says we change it every two and a half years.

That's not good enough if you are going to attract commercial money and commercial activity into this field because the cost of that money is high and if you are going to pay it back and, above that, realize a return for your investors, you've got to plan on a consistent policy or at least some stability in the program for a ten year period of time. We have not had that. You'll hear from Courtney Stadt of the current administration this evening and if you don't hear I hope you'll ask him what the status of the current administration's space policy is because it is important that that be consistent with what has gone on in the past.

When I say consistent I am talking about consistency and pricing of the Shuttle and the other services that NASA offers: services such as the use of their facilities in the centers, and other places in their contractor network; the consistency in the way in which you gain access to NASA's facilities and the shuttle and space itself; consistency in the way they interface with the other Government agencies. The other Government agencies who are involved in space must perforce join in a policy statement and a policy commitment that will last for a long period of time.

The Congress, for its part, and I would hope that the Executive Branch and the Congress will get together on this, must be willing to, as well, commit themselves to a long term policy of sustaining the effort, sustaining it in the sense that they agree that this is a national need and a national requirement and they will budget for it, taking into account of course that there are always exigencies and emergencies and possibly even catastrophes. Within that framework you can go out and assure the bankers and assure the investment bankers as well, both commercial and investment bankers, that you are able to get from here to there.

Secondly, the government is probably going to have to do something about being the insurer of last resort. The Government has agreed in the past to pick up such things as third party liability above what is currently available in the market. That policy continues. I think the current level, that is set is about $500 million and above that if there is liability beyond that the government self-insures and I think that's an essential piece and part of anyone who is doing business in space.

But beyond that what happens when you go looking for leverage equity capital into the debt market is that commercial bankers who are not used to dealing in space ventures demand insurance of some magnitude to cover themselves in the event of any of a number of different contingencies, in short, contingency insurance. The only way you can get contingency insurance is to go to London and talk to the Lloyd's people, and it isn't easy.

The reason it isn't easy is the way the English have set it up. The English have a way of doing things like this: if you want to get insurance from Lloyds you have to hire yourself or get yourself a US broker, the US broker then goes to London and gets a London broker, the London broker then goes and talks to a contingency broker, also in London and the contingency broker then goes and talks to the underwriter.

If you can dream up a system that is more fraught with misunderstandings and difficulty I can't imagine what it is. It's like that little parlour game where you sit around a table and each of you whispered something in the ear of the person next to you and then what came out on the other end was never quite what went in, and the same is true here.

But Lloyds will insure any number of different contingencies including insuring against the US Government changing its policy! Which I found quite remarkable, and the banks demand it. It's very expensive, it runs up the cost. My point simply is that it seems to me that in the future -- it's too late for SpaceHab -- but in the future for those folks who are planning to do something like this, that it is only fair that the federal government consider self-insuring or insuring the commercial community against their change in policy. As I said earlier they have changed their policy frequently. The McDonnell Douglas folks will attest to that on things like the PAM (Payload Assist Module, Ed.).

There are some other things that the government needs to do. I mentioned the business of making available all their facilities. By all the facilities I mean all the facilities including the Commerce facilities as well. They are probably going to have to think through again how they do business with people who are in this kind of endeavor.

If you look back through history you will find that in every new endeavor the Government found ways of putting incentives out there to encourage commercial development. They did it in the early days of aviation with airmail subsidies. They did it in the early days of the railroads, before that with land grants. They did it before that with certain kinds of incentives to get people to dig canals in this country. In short, every era of new technology and new commercial development has been sponsored and to an extent incentivized by things that the federal government does. I think the federal government has to do a good deal of thinking on how they want to incentivize this particular piece of commercial development.

Having said that, I think the future is bright, for what we're trying to do. It won't be easy but I think there is a big demand out there, I think the whole world is interested in the, first of all in the low earth orbit, they're interested in getting up there and experimenting, they think there is money to be made, they think there is large commercial opportunity, they are all going to compete. God love this country, we've never been afraid to compete in the past and this one is one where we have a very significant advantage. We pioneered this area, we know it well and we should, properly so, continue to lead and continue to win the competitive battle. But there is some question and the jury will still be out there I am sure for some time to come until we have a body of policy and a body of procedure and ways of getting things done through the Federal Government because the Feds are key in making this whole thing go just as they were in every other form of transportation.

So it's important that they do that and make it possible. Set the framework, make it possible for people to operate within it. If they do that, we will as American enterprise always has, come along behind and do the job.

Our only problem is, if I conclude with the way I started with Mr. Shakespeare and say my favorite line:

> *"our doubts are traitors and make us lose the good we oft might win by fearing to attempt".*

And God love us we have never feared to attempt in the past and there are a lot of people out there who are willing to try on this one but we cannot doubt our ability to do it and we've got to continue to move. Thank you.

Industrial Space Facility (ISF) -- *Maxime Faget, Space Industries, Inc.*

Introduction by Tom Rogers: Max has spent almost his entire professional career working on aerospace matters in the government. He was at NASA for three and a half decades, did a great deal of the work basic to the eventual development of the Gemini and Apollo spacecraft, and did a great deal of engineering work on manned spacecraft projects in general. He left government employment about a half dozen years ago, and to my knowledge was the first one in the country who was determined to make a very hard run at the creation of a truly private sector space business outside of the satellite communications area. Max has learned a lot. I would trust that he would tell us about it.

Max Faget: I was asked to give you a short rundown on an industrial space facility but not to try to sell it. It sort of reminds me of telling a cat to play with a canary but be careful not to eat it. In that context, if you will, I'll attempt to not sell the industrial space facility.

Starting in the very early days of the [Federal civil space] program, as a matter of fact when we started the Apollo Program we considered Apollo to have two uses: one to serve as a manned laboratory in orbit and the other was to go to the moon. And shortly after we got the program started the President said we were going to get to the moon in this decade, that decade being the decade of the sixties. And with the urgency of getting to the moon, the space station aspect was dropped.

Ever since then, there have been a number of false starts and earnest starts on creating a manned space station. We at Space Industries would have liked to build a space station, but we decided the only thing to do was to build a "man-tended free flyer" which is like a space station but it is only visited during the time that a Shuttle would be attached.

The industrial space facility is designed to be operational after one launch. This is because of commercial considerations. It had to start earning money as soon as possible, and we designed it that way. It's going to be permanently located in space. It will be in an orbit similar to the one that the space station will fly in so that when the space station does get launched, the Shuttle can also supply, and/or resupply the industrial space facility. Whether it will be directly resupplied or resupplied using the space station as a warehouse is yet to be determined, but in the interim period of time it will be both launched and serviced by the NASA space shuttle.

The other thing, from a commercial standpoint, of course, is that we want it user-friendly, and I'll get into that later on. It is presently manifested to be launched in 1994 and of course as any good commercial outfit, it will be privately owned and privately operated.

It has a small propulsion system on it. Like the old riverboats, it uses steam propulsion. What we do is we evaporate and then superheat water and use the super-heated steam as propulsion. This is done from an economy standpoint, it's the cheapest kind of propulsion system we could find, primarily because what runs up the cost of propellents is that they are normally both toxic and highly energetic. Man has learned to live with water for all his life and so it's a rather peaceful fluid and we can get the specific impulse simply by using all the power from the solar rays to superheat that water in which case we would get about 180 seconds of specific impulse.

Inasmuch as the Shuttle ends up with excess water at the termination of each mission -- this is a byproduct of producing power of the fuel cells -- about half of the water that is used in the ISF comes free and consequently the effective specific impulse is probably higher than most bi-propellants

When the Shuttle leaves the facility of course, it will go back down to Earth and the facility will go on up to orbit. It will go to a high enough altitude so that three or four months later when the anticipated next Shuttle visit occurs it would have about decayed back to the 150-290 km altitude and it will make a small orbital adjustment in order to rendezvous with the Shuttle at the next node.

The elements that we must build to put the ISF in flight include a facility module, which is a large pressurized volume with room in it for housing the equipment. It produces power: 7 kW will be available to the users with peak power as high as 50 kw if additional wiring can be done. This is possible because we have fairly large batteries aboard which are reenergized during the sunlit side. By draining those batteries plus the power pump from the solar array we can produce sharp bursts of power of 50 kW.

The equipment of the users will be located in racks, modular containers and also on external ports, and utility accommodations at each of these areas will be made available. I'll get into that later.

There will be several types of auxiliary modules available. These may be of many configurations either to carry more equipment up or to act as a permanent addition to the ISF or fitted out for special purposes as the user needs.

Finally, there will be a docking system. It allows the Shuttle to dock with the ISF. The docking maneuver actually takes place using the arm that's on the Shuttle which grabs the industrial space facility and lowers it to the docking port where the hard docking is made. The docking system comes equipped with a small luggage container. There is room for two modular containers, each modular container will hold the equivalent of four mid-deck lockers, as far as user's equipment is concerned. This is very important because in spite of what you hear the Shuttle is not a user friendly thing. If you are putting cargo in the cargo bay, probably the last you'll see of it is something like a month before launch, and the next time you get a chance to look at it will be something in excess of a week after landing.

However, the crew compartment is available right up to the time of launch and immediately after launch and inasmuch as the passageway between the crew compartment and the docking system, of course, anything that is attached to the docking system has got late availability and early availability and consequently the little luggage compartment there is very nice. I might add that you had that situation also with the SpaceHab inasmuch as that's also available through the crew compartment and the SpaceHab people have recognized the situation as well as we have. See I am selling the Spacehab as well as this. Just to be fair.

User experiments will be accommodated in racks. These racks will be quite similar to the ones that are being built for the space station. As a matter of fact we have the Boeing Company under contract to build our racks and of course they are ones that will be building the racks for the space station. They will be different in some very slight details but as far as the users are concerned the equipment will be able to be moved from one rack to the other. We have the standard and high power. The high power rack merely means that we put extra-heavy copper busses in the high power racks so that if the very high power is needed, it will be available. The power that will be available to all racks is shared. We've got a power scheduling logic that will be examined and we can support numerous people but we have to schedule the power. Some users want the entire power of the ISF from time to time, others don't need very much. It turns out that seven racks operating over a four month period uses up about all the power when properly scheduled.

The external ports are of interest because a number of people have special uses for external ports. For instance an entire experiment can be made up and attached to the external port and there will be both power and communications available at the external port.

The next slide is a summary of all of the capabilities available to the user. Rather than take up time if people want to go into this they can look at the handout.

Next slide please. Here I have characteristic comparison of three different facilities. The ISF being a man-tended free flyer, the EURECA being a free flyer that is not man-tended or, in fact, it's really terrestrially tended because it's launched from the ground, it is left in orbit by one of the Shuttle missions, and then it's recaptured in a subsequent mission and brought back down by a different Shuttle. It has long duration, but as you see, it does not have high power and has a number of other facilities missing.

In the case of Spacelab, it's manned and it has a very large pressurized volume. However its got a limited amount of power. It just uses the excess power generated by the Shuttle and it of course is available right now and will be flown again in 1989 and is going to be flown in 1990.

Could we go to the next slide? In addition to being a microgravity laboratory, the ISF has other general applications. It can be used for an orbital test bed, both for checking out the operations as well as new technology. It's a platform for science, for observations, both cosmic observations as well as earth-looking and we believe it could be a big support to the international space station in giving the space station operations people a chance to learn about operating in space because in many ways the operation of the ISF and the space station would be similar. Finally, if the microgravity research proves successful, it will be really a cost-effective manufacturing facility.

Now that we are through all of that, I would like to get into some discussion of the implications of transportation costs. What I am going to talk about is cost, not price. It is very important to realize that there is a great difference. Price is what you charge people and it can either be more than the cost or less than the cost. Of course, if you want to make money it's got to be more than the cost. Normally when the Government does things in space and they charge, they charge less than the cost, which you might consider a subsidy. Of course, all of the commercial launches up until now that involved the use of the Shuttle, in one way or another were used has this aspect to them, simply because none of the acquisition costs of the Shuttle fleet were ever included and furthermore a lot of other costs were not recognized.

Material processing activity in space is unique in that it requires transportation from orbit back down to earth in addition to the launch transportation. Thus transportation cost is a significant factor in facilities employed in microgravity processing. In the case of ISF we made an estimate in which the total life cycle cost of the program included operating the ISF, it's acquisition cost, and the cost of transportation including the resupply transportation. The estimated transportation cost -- and I am not talking about price again -- was a dominant cost and might amount to two thirds of the total cost of the program. If NASA were to charge the full cost of operating the Shuttle, instead of just the out-of-pocket costs, which is all they charge, instead of their present rate, the transportation cost would be an even more significant factor.

The ISF can be classified as a space-based platform as opposed to terrestrial-based. Terrestrial-based platforms will include such things as Spacelab and the EURECA. EURECA provides a duration far greater than that of the Spacelab but does so at an additional cost of an additional Shuttle mission to retrieve it from orbit.

Terrestrial-based platforms must also include the cost of transporting the entire processing equipment plus the housing facility including its utilities in the round trip to space. Total transportation costs for these facilities are significantly greater than that for the space-based platform which requires only part of the equipment to be transported to and from orbit, once the facilities as deployed in orbit. On the other hand terrestrial-based platforms have the advantage of being accessible to much more manpower for servicing modifications and so forth than would a space-based platform.

The point of all this discussion is that even for platforms employing the most cost-effective transportation systems, such as ISF, the transportation costs dominate the total cost. The cost of space transportation and the cost of equipment transported into space are interrelated. The reason that equipment transported into space is so expensive is because the cost of getting that equipment there is expensive and consequently, the equipment must be designed to be as light as possible and as reliable as possible for its intended function.

At the same time transportation systems are designed to carry very expensive hardware into space and as a result must be made extremely reliable and consequently expensive. Since the inception of space flight, great strides have been made to improve the reliability of the launch systems with only casual attention to reducing costs. And as a matter of fact, we may argue that the cost to launch a vehicle may indeed be higher in inflation-adjusted dollars than the early versions which had a very high failure rate. Certainly the achievement of higher reliability is commendable; however, more attention needs to be placed on reducing transportation costs.

Could I have the next slide? This slide illustrates the economic considerations that would probably result if the cost of space transportation could be significantly reduced. You will notice that when transportation costs are reduced (you follow the arrow straight down) it decreases the cost of space products and services directly, simply because that cost increment is lower. But in addition, if you follow the plan on the right or the road to the right you will also notice that that would moderate this premium on light-weight designs, which is very expensive, thereby decreasing the cost of the orbiting facility which would further decrease the cost of the products and services. The result would be an increased variety in the quantity of products and services. There would just be a lot of things that would become economically feasible to do in space that wouldn't presently be considered feasible.

This would increase the market demand, the traffic and the total revenue, making space transportation a more attractive industry with the effect that the economy of scale would be realized and the economy of more competition would be realized, thereby further reducing the cost of space transportation.

The message here is, if we could get this system to go around to the right in the future, as opposed to going around to the left, the way it has in the past, then possibly we can indeed achieve a great deal of commercial activity in space and enjoy the benefits of lower cost all around. Thank you very much.

Space Phoenix Project -- *Thomas Rogers, Sophron Foundation*

Introduction by Bill Stone: I now have the pleasure of giving a proper introduction to my session Cochairman, Tom Rogers. Tom has been involved with various aspects of the space industry since its inception. He is a physicist, an electronics and communications engineer of the first rank, a private investor, the president of his family's operating foundation, the Sophron Foundation and was the Founding Chairman of the External Tanks Corporation. He organized the Communications Division of MIT's Lincoln Laboratory and headed the group that was the first to accomplish transmission of television signals via satellite. He has served as the Deputy Director of Defense, Research and Engineering, for the Office of the Secretary of Defense, where he was responsible for the development and deployment of the first global satellite communications network and for the beginning work on satellite navigation. He was the first Director of Research for the Department of Housing and Urban Development where he inaugurated Federal Urban Research and Development and help found the Urban Institute. He was a Vice-President of Mitre Corporation. For the past 15 years he has been a regular advisor to academia, industry and government. He directed the study of civilian space stations and the US future in space for the Congressional Office of Technology Assessment.

As an outgrowth of the OTA study, he originated the Space Phoenix Concept that is now being advanced as a major private sector civil space program, that, in cooperation with the federal government, would see scores of universities and companies advancing the prospects both for in-orbit research and the opening of the Earth-space frontier to the general public.

For those who have never heard a lecture delivered by a master orator I advise you to sit back and enjoy Tom's story of the Space Phoenix Program.

Thomas Rogers: Well the Gods looked down on the master orator and gave him a case of laryngitis so you can "x" out what Bill just had to say. Another thing that is influencing what I have to say today is the fact that Al Hill, who was to have spoken after me, very lately found that he could not be here and he asked me if I would do the best I could to put forth some of the work that he did for my Foundation several years ago, and I'll try to do that. I would say that Bill Stone is much closer to the engineering specifics of external tanks than I am today. Perhaps some of your questions can be directed to him.

I'll start by saying that I believe that there are clear prospects for a large, new, private sector space business. But the prospects suffer from two matters that bring us here. One is the enormous unit cost of space assets and space activities, and the other, our institutional structure in the government and the space industry that maintains these large unit costs. If we are to see large businesses conducted in space, I believe that we must think of three things: one, driving down unit space costs to much lower levels; we must think of volume, large volume in space activities and operations; and we must focus attention on in-space activities that have nothing to do with science or the solution of technological problems.

There are large numbers of things that can be done in and about space, if we get the costs down and we think big in terms of activity rather than in cost.

There are four reasons that can be advanced for doing things in space: cultural, social, national security, and economic. There are no social reasons for doing anything in space. There are cultural reasons. The United States supports symphony orchestras, parks, shelters and it supports scientists making inquiries in space and exploring the solar system -- but that will be, over the long term, a relatively minor reason for doing things in space.

The single largest reason for the United States having done what its been doing in space for the past 45 years, has been national security. We have had very, very grave concerns in our world about the existence of our civilization, our forms of government, indeed our lives, that have prompted us to do large numbers of things in space at great cost. Well, now we know that the Russians are not coming. The Russians are **not** coming. So we are faced with a zero order reconsideration, in my view, of everything we are talking about doing in space and how we do them.

The final reason, economic, is probably, in the long term, by far most important. Yet it has yielded only one large economic return to the country on its spendig in space of over $500 billion in the civil space area alone so far: satellite communications.

Why have we failed to secure an adequate economic return on our spending? I am not decrying the cultural returns, and the national security terms for one second, but I am going to talk at the National Bureau of Standards today, in economic terms.

The reason is simple, and it has been advanced earlier, <u>the awful cost, the awful cost</u>. I don't think that anybody outside of the space area has any useful appreciation of the costs of in-space infrastructure and activities. Everything that you have or do in space costs something like 1,000 to 100,000 times what their analogs cost at or near the earth's surface.

Now, clearly within the past several years, and most rapidly within the past few months we have begun to see enormous changes in our geopolitical circumstances in this world. I could hardly believe that I would live long enough to see the things that I have seen on television and in the newspapers in just the past month. My youngest daughter who has now gotten to the point where she has two young daughters, was an infant in arms and I chose a nickname for her, Charlie. When I saw the photographs in the paper and the scenes on television of streams of people coming through the Checkpoint Charlie and remembering what my life was like in dealing with the things that brought me to Checkpoint Charlie, it is absolutely breathtaking to me. What has this got to do with what I am speaking about today, why we're meeting today? Let me show you the first number, A, that I have here on the blackboard. The number is 20,000. I am going to put a dollar sign in front of it and I am going to add three more zeros and then three more zeros, and then three more zeros. I would judge that to one significant figure in the last 45 years, the last four and a half decades, the Unites States of America alone has spent $20 thousand billion protecting our civilization, our forms of government, our way of life. Twenty thousand billion dollars!

Now, I started out life poor. I watched every dime, so did my family and my friends. When I got through college I went into a secret laboratory and entered a sort of paradise. I had no restrictions whatsoever placed upon me about getting materials, laboratory instruments, equipment. I could even take cash from an office and go out and make quick ready purchases. Cost never entered into anything that I did. We were at war, people were dying. The war was over in 1945, and by the end of 1945 I found myself working as an engineer on television receiver design. In that new world all my signals were reversed. Every day in one way or another, I found out that I should pay attention to costs because costs influenced prices and prices influenced sales and sales influenced revenues and revenues influenced profits and profits influenced my company and my employment and my salary. The loop was closed. Very interesting.

By 1948 I was back in a secret laboratory supporting the Berlin airlift. From then on until 1964 I didn't become concerned with cost ever again. I worked on the SAGE - the Semiautomatic Ground Environment of the air defense universe. I worked on the Atlas Intercontinental Ballistic missile. I worked on the Polaris weapon system. Cost never entered. Once in a while the word appropriations entered but we all knew that it was somebody else's responsibility, was fought out of the political domain and had nothing to do with what we were doing.

Then one day, in 1964, at the end of a meeting with the Secretary of Defense, where I had done what I had come to Washington to do, and that was to describe to him the kind of international satellite communications system, that in my judgement and in the judgement of my co-workers, was what the United States should have. He stood up and said: "I'm absolutely impressed. I agree. But what's it going to cost?" Well I told him, and he says: "I am not going to pay that". I asked: "what do you mean?" He said: "I want it, but I don't want it that badly". Shock!

Within 30 days we were back in his office offering him another system design that had essentially the same operational capabilities and cost 30 percent of what the first cost number was. I never forgot it, and he never let me forget it.

Then I went to the Department of Housing and Urban Development where it was the role not to do things yourself but to support the housing industry, to support urban development. Not to do it yourself, but where you had to deal with costs every moment.

These are just general statements of background that tell me why we must be here, and why we now in the aerospace industry and the Government offices that connect with the aerospace industry are facing a zero order, **Zero Order** requirement to change perspective and to change the way we go about doing things. What you now hear in the newspapers about space are Mars and the moon. That's not the news. The news is that the Russians are not coming. The news is we must now again be prepared to deal with costs and the only way to deal with them is to see them driven down not by just 2 percent or 20 percent, or 2's but by orders of magnitude. And that can be done. There's no question about it but the difficulty is that we spent this enormous amount of money in an unbelievable, hardly imaginable, manner. We have two generations of professionals who in the aerospace world have grown up as I did not having to be concerned with costs. We talk about them but we do nothing about them.

Now I would like to refer to what Max had to say and emphasize it, because it is important for you in NIST to appreciate this: that the cost of transportation, space transportation, is the driving cost for everything else.

You might then well ask: "Well, then why bother to sit here?" This is the Department of Commerce, it isn't NASA, it isn't the Department of Transportation. It comes about for the following reason. Let me turn to B.

If you do the arithmetic correctly and you sum up, as physicists say, over all stationary space you will see that the acquisition of the shuttle fleet cost the American public some $40 billion. If we were to amortize that cost over the lifetime of that vehicle's fleet at today's borrowing costs, again to about one significant figure, the cost is about $4 billion a year. That's the amortized acquisition cost, not the O&M cost -- when you hear people talk about the cost of space transportation it is almost always the cost of operations and maintenance. But by far the biggest cost is the amortized annual charge against the acquisition of the vehicle fleet.

In the two maximum space launch years before the Challenger disaster, the United States of America put 600,000 pounds of things into low earth orbit per year for two years. We continue at close to this annual rate today. (Editor)

Now divide $4 billion a year by two thirds of 600,000 lb, i.e., let us assume that we have a new vehicle fleet coming into being and it will transport about two thirds of the payloads, the other third being brought up by expendable launch vehicles. Assume that it will cost the same amount to acquire this that the Shuttle fleet did. We'll be talking about dividing the number of $4 billion a year by 400,000 lbs. a year and the answer is $10,000 a pound, that would be about what it costs today. So we are dead in the water. **We are dead in the water.** If O & M costs were to go to zero we would have done nothing in the next generation of vehicles needed to reduce the launch cost. Unless, we can change the denominator. That's what I am working at now and that's what the Space Phoenix Program is about.

I don't know what to do about the space transportation business. I literally don't know and I don't know anybody else who does, and that should be clear by reading what people write about it.

[A most important change has taken place in the space transportation area since the Department of Defense has initiated an aggressive technology development demonstration program focusing on fully reuseable surface-to-LEO vehicles. It has awarded an initial contract for a single-stage-to-orbit (SSTO) suborbital 1/3 scale model vehicle to McDonnell Douglas. And this "skunkworks" element of Lockheed has undertaken an analogous, fully reuseable SSTO program as well. (See the last talk by Steve Hoeser.).]

I do know though, that if you can increase the amount of activities in space so that the denominator goes up to a much greater number, say by a factor of ten, then the cost of transportation, at least the acquisition part, will come down by factor of ten. And I do believe that there is the possibility of imagining, of seeing large amounts of civil activity, private sector activity in space that would call upon private sector payment for things going on in space that: (a) has nothing to do with science; (b) nothing to do with technology; (c) nothing to with anything that you might have heard about here this morning as we look to the first things to go up in space, i.e., the first things people have to do in SpaceHab, and in the space station, and in the Industrial Space Facility. If you look beyond that to what could be going on in space you can imagine large private sector activities having nothing to with science, research, exploration. But in order to do that the costs must come down. Closed loop.

That's why we are talking about bringing down, at least I am, the costs and that's why I'm urging and prompting the Department of Commerce to take a specific interest in this, and this is why I am devoting so much of my life to the Space Phoenix Program.

The Space Phoenix Program is one that addresses the question of getting the unit costs down so that the activities in space can be allowed to increase. We observe that every time a Shuttle trip takes place, just about the time that the main engines cut off, the large external fuel tank (ET) of the shuttle is released and it falls back slowly and then with increasing velocity to the Earth's surface where it is destroyed. That external tank is 150 feet high, it's 28 feet in diameter, it has a pressurized volume of some 70,000 cubic feet made up of a 20,000 cubic feet oxygen tank up near the top and a 50,000 cubic foot hydrogen tank toward the bottom, and about 5,000 cubic feet of unpressurized volume between the two pressure vessels.

If one could obtain an external tank in orbit, it would have been paid for by the Government to act as the strong back down at the launch point and as the reservoir for the fuels. The Government would have gotten good value for the ET price and you would have avoided the cost of bringing the tank nearly to orbit because the tank when it is let go, it is within about one or two percent of injection velocity. That means that you could start in business, in space, with a cost avoidance of hundreds of millions of dollars. That is one of the essentials of the Space Phoenix Program: that you can start putting things into space at very low absolute dollars and because of the enormous volume, the enormous surface area of the tank, and the relatively low unit costs, it becomes the equivalent of raw land here on the earth's surface.

I was the first Director of Research in the Department of Housing and Urban Development and I am always aware, in the space universe, of finding myself in space where there's nothing there. Short of the moon, there's nothing there. So the Space Phoenix Program is addressed to putting something there, to banking raw land in space. But since in space you must live, you must breath, if you don't have an atmosphere you must think in terms of volumes and so you can think in terms of the raw land in the form of pressurized volume. And again the object of the Space Phoenix Program is to get large amounts of pressurized volume in space at low unit cost.

The program has been under way formally since about 1986. It has three organizations which make it up: The University Corporation for Atmospheric Research (UCAR), which is a group of some 60 universities and other research organizations which address studies in weather and climate, which want to do a great deal more work in space and would hope that the price of so doing can be brought down.

It has a Foundation. The Foundation is charged with providing financial income from the intellectual property generated by the scientific research work of UCAR.

Then there is the External Tanks Corporation, the private sector part of the Space Phoenix Program. The first two groups UCAR and its Foundation are not for profit. They are the ones who deal with the Government in the discussions about obtaining ETs. External Tanks Corporation is charged with obtaining the resources and applying them to do something valuable with the tanks once they are in hand.

We have put together the beginnings of staff, we have gotten agreements with the government, we have gotten modest amounts of equity capital, we are making studies of the tank, particularly its stabilization and movement in orbit, and we are now in discussions with the Government on a second agreement. The first agreement gives us access to five external tanks without any changes or influence on their use in the Shuttle trips of which they'll be part. We are going to use the tanks in suborbital fashion. We are going to get into the unpressurized volume that lies within the envelope of the tank, between the oxygen and the hydrogen pressure vessels and put scientific equipment in there, and so on. We expect to get a lot of experience with that, as well as cash flow, and to use that to lead to what we are now discussing with the government, having access to another five tanks or so to begin with in orbit.

Our studies would tell us that, from the time you start, and that's a long time after the time you think you've started or should have started, but from the time that you actually start you ought to be able to, within some three years or so, put one of the tanks into orbit to demonstrate the fact that you can do it, kick it up to another two or three hundred kilometers additional height to show it could be in a long-term safe orbit and bring it down within a footprint laid out for safety reasons on the ocean surface.

Another two or three years after that, assuming again you start both at the same time we should be able to have a habitable facility in low earth orbit, the first of which we would be devoted to amplifying the scientific research capabilities being made available along with other things on the space station and in the extended duration orbiter of the government. While the

Space Phoenix goals remain sound, ETCO has not yet been abot to obtain the larger amount of venture capital that the program required [Editor].

External Tank Habitat -- *Thomas Rogers, Sophron Foundation*

Let me turn now to the paper that Al Hill sent to me. In 1982 I agreed to conduct a study for the Congress on civilian space stations and I was reminded again, having been somewhat away from the space area for a while, of the great, indeed basic, importance of space transportation and the cost thereof it has on all our space aspirations. I talked to many people about the space transportation business and went through things of this nature in my mind. At that time, just by chance, I ran into Jim Fletcher [Dr. James Fletcher died about a year ago. He had joined the Board of the External Tanks Corporation after leaving his government position., Editor] who was the most recent NASA administrator whom I worked with on the Atlas Program years ago on Pennsylvania Avenue and he said to me: "Tom, I understand you're working on a space station study", I said: "yes". He said: "By the way" he said, "what do you think about use of the external tank in orbit". I asked him what an external tank was. Well he lectured me and I made the acquaintance soon thereafter of people in NASA and the university universe who were making studies of the possible additional in-space use of the Shuttle fleet's external tank.

I asked a great number of people two questions during the OTA study: (i) "What do you think about the possibility of getting additional use out of the external tank?" Almost everybody would say: "That sounds like a reasonable thing to do", with varying degrees of enthusiasm. There were very few people who said that this was a poor idea.

My second question was: "What are you going to do about it?" The answer was: "Nothing".

So I took advantage of the fact that my private operating Foundation -- I am the president of my family's operating Foundation -- could cause studies to be made. While I was at OTA working on that study, I had a group of aerospace engineers make a study for the Foundation of what would be involved in putting an external tank into orbit and then turning it into something useful there. Al Hill was the leader of that study. The study should have taken about a half year. It took about two years and the reason primarily was that they thought appropriations, not cost, and every time we would have a meeting we would all end the meeting by saying: "That's right, yeah, low cost", and then we would have another interim period in which the costs would go back up again. It took about two years to get some of the results which I will show you.

I will say two things about what I am going to now: because of my voice and the fact that so much time has gone by, I would just step my way through the view graphs and try to answer your questions, but would again refer to the fact that Bill Stone is a lot closer to this business now than I am.

Here was the charge given to the aerospace study group. The basic consideration was, given the opportunity to have an external tank put into orbit, how long would it take, and what would it cost, to turn it into a very, very basic, very, very low unit cost, useful warehouse? We took the simplest idea that you could imagine for having something of this kind in space -- a warehouse -- and focussed on that. May I see the next slide.

This is a line drawing of what was decided to be worked on, two external tanks, with modules attached to the back of them. The external tanks are the two cigar-like structures. Moving up to the left, you can see solar panels extending from either side, and the Shuttle coming up bringing the things to make this come about.

Now,the next view graph. You have to do some very very basic things to the external tank which hopefully, I say hopefully, you can do at the Earth's surface before you go up. I think it's fairly clear. Hopefully on Mondays, Wednesdays and Fridays, we say it is clearly easier to work on these things in the tank at the Earth's surface from engineering or fabrication considerations. On Tuesdays, Thursdays and Saturdays, we say it is obviously easier to do this in space because if we do it on the ground we have to deal with the present institutional arrangements for doing things in the space area. I don't want to say any more about that at this time.

In brief, this was the way four or five years ago that it looked about how we would develop the tank in space. We would have one of these modules attached to the external tank that had within it everything that you needed for life support, stability, communications, power, navigation, whatever. And it would be placed at the rear of the tank. Since then we have become more convinced that what we rather should do is to learn how to put things in the unpressurized, inter tank volume and work from within it in space to get into the hydrogen and the oxygen tanks through their entry ports, and do a great deal more of the work in space without the requirement of the additional module. Again, Bill knows more about that than I do. Next viewgraph.

Considerations as to attitude control led to the conclusion that the use of a constant sun pointing attitude was to be preferred. The next view graph.

You must also give attention to such things as micrometeorite penetration of the surface of the tank, the thermal control of the tank and there were analyses made and the conclusion was that you should be prepared to wrap materials around the external tank, in order both to give additional protection, and to give better thermal control. I might say, without going into it in detail, that our views about what should be done to protect the lives, safety and the working functions of people in space are markedly different from anything you will hear from the government. They would rather come from the civil engineering universe and the operations of people here on the earth's surface, that have to place their lives on the line at times and who have to pay what it takes to reduce the hazard of so doing to the point where they are actually able to do them and do them in a business fashion.

The conclusion that was reached in the study at that time, you can see laid out before you. But if we consider that report (by the way those few viewgraphs come from the report of some 150-odd pages in length) could be considered as a Phase A study from which you will then go on to conduct the analogs of what NASA would call a Phase B and a Phase C study. Then you could imagine the work being accomplished in something like five years. The next viewgraph.

These show the more important considerations of the so-called program "drivers": issues that were the things that we had to pay the most attention to. For those of you who are particularly, as we all are to some extent, interested in matters affecting costs from an engineering point of view, particularly in the operations point of view, those are considerations well worth keeping in mind. The next viewgraph.

What this says is that, if you add to this, the cost of money, capital, and if you add to this, the cost of the required government reimbursable space transportation, that you ought to be able to make those minimal modifications and outfittings to an external tank that would allow people to use it as a warehouse or a basic structure for laboratory facilities or whatever for some $70 million. I would double the number, life being what it is. So we are talking about the practical possibility of seeing some 70,000 cubic feet if it be one ET, or 140,000 cubic feet if it be two ETs, facilities of spartan capability, safe, reliable but spartan in its outfitting for something of the order of a few hundred million dollars. Now those costs in terms of the cubic feet involved are very, very, very low cost. They do not include the cost of any equipment or any additional outfitting that the individual user might want to add, but we believe that these are not unreasonable numbers.

The Space Phoenix Program is a broader and longer range program than either the SpaceHab program or the Industrial Space Facility Program. Again, what we are trying to do is to lay down the analog of raw land in space, with the Space Phoenix Program acting to obtain, on the one hand, agreements with the government and, on the other, private capital to enable us to do that and then to have ETCO act as a wholesaler, a real estate developer. ETCO will put in the raw land, the basic betterments, the basic structures and then be prepared to deal with any user who wants specific things. If you want it painted white, white you get; or mauve, mauve you get -- costs are a little more than white, but mauve you get. In other words a very different view of how to go about the matter of encouraging space commercialization in low earth orbit.

The final observation I would make to start the discussion is specific to the matter of the conference and to the interests of NIST. A general statement is that Space Phoenix welcomes, and I would underline welcomes, the Department of Commerce's decision to see that it's scientists and engineers will be, to some extent, laid to the purpose of assisting industry as Dr. Kramer pointed out today. And from the one specific viewpoint of trying to help the aerospace and other industries now to learn in this new world about how to drive down unit costs. It's the key, in the sense that we don't know what to do about space transportation. We've got to work on the infrastructure and that is the key to why it should be Commerce instead of Transportation or instead of NASA.

I would suggest it's worthwhile discussing NIST thinking about doing one or more of three things in its R&D program here and we can debate these. One is that when an external tank is delivered to orbit, almost all of the fuel that it was charged with at the Earth's surface has been burnt. All of the oxidizer, and all of the hydrogen has been used up, almost all. What's left is mere 10,000 pounds. But a mere 10,000 pounds of fuel at low earth orbit is worth something like $30 to $50 million. Since there will be something like ten Shuttle trips a year, that's the better part of a half billion dollars a year. I personally expect to continue to be in operation for at least another 20 or 30 years because we don't know how to replace it with anything better at a cost that we can afford. There we have the practical possibilities of salvaging literally $10 billion for the country. That is something which is there, and this study by Hill & Company started off by saying let's vent it. "We've got to get rid of it for people to be in it so let's vent it." That's one thing that the Bureau could look at. How could we make that fuel available to Max Faget, how can we make it available to Jim Beggs, or anybody else in orbit. Learn how to capture it, store it, use it.

Another thing, how can we better learn how to do EVA in space? How can we learn better how to grapple with these structures in the way that we do on the ground? How can we learn better in the case of the ET. To have people use this intertank unpressurized volume as the base of operations for that and all other nearby tanks, and then have the tanks themselves used as a base for other things going on in space. We have got to learn how to have assemblers up there. Smart, tough people able to put things together, able to take them apart and move them apart when their life is at peril. Where today it costs so much to deal with the fact that their life is at peril that you can hardly use them for doing anything. That is the zero order consideration in the matter of seeing space exploited and getting its cost down.

Then, finally, how to get the life support system costs down. You see the proper cost of a Shuttle trip is something of the order of $500 million. If you send five people up there it's $100 million apiece for a round trip. That sounds like a very great deal of money, and of course it is, but once the person is in space the person uses up ten pounds of atmosphere, food and water every day at least, and that costs $10,000 pound, etc. So even if we could get the cost of transportation down by a factor of ten or even a hundred, it isn't very long before the cost of life support, keeping people up there, over the long run, you appreciate that it's the life support cost that wipes you out.

For those who are not concerned about keeping people up there, that's a rather academic point. But from my perspective, and I won't go into this, there is only one payload that we've got to look at, only one, and that is people. It will not be test equipment, it will not be the spheres that you talked about (NIST SRMs, Ed.), it will not be things given to scientists to explore the universe. It will be people. That is the most important payload, and so we've got to learn how to get large numbers of people up there safely, to do interesting things, maybe useful things, but at least interesting things, and to have all those paid activities coming from the private sector, not the government. Let me stop at this point.

Aquarius Habitat -- *Glen Taylor, NOAA*

Introduction by Bill Stone: The next session that we have is a little bit different. In the introduction this morning, I mentioned to you that some of our speakers had extensive experience in other airless environments. The parallels between undersea exploration and space exploration have often been drawn. It is in fact generally recognized that the undersea environment is substantially more hostile than the vacuum of space, in many respects. One comparison between these two environments that few have ever dared make is the cost of doing business in these respective locations.

Specifically, I am referring to the costs associated with design, construction and daily operations of habitable facilities, and manned and unmanned activities which must take place outside these habitats as part of their scientific and commercial missions. If you will now bear with us, we are going to embark on an interesting digression into the world of undersea science and industry. As we do so I ask that you reflect upon the novel approaches which have been successfully implemented by some very sharp engineers working under restricted budgets, under budgets quite different from those customary to the aerospace world, and consider how such approaches might impact upon the cost of industrial space activities.

With that background I would now like to introduce our next speaker who is Glen Taylor. He comes to us from the National Oceanic and Atmospheric Administration. Glen received his BS degree from Clarkson College of Technology in 1969 where he majored in electronics and industrial distribution. He worked subsequently for three years at General Electric's Research Park in Syracuse, New York, and other locations. In 1972 he retired from GE, and left upstate New York for the Caribbean where he became a diving instructor and a commercial diver working in Jamaica, St. Croix and the Bahamas. In 1986, he joined the National Undersea Research Center as part of the Aquarius Project as its first diving supervisor, and is currently Assistant Operations Manager for AQUARIUS, which is the United States preeminent undersea and saturation diving research base.

Glen Taylor: I have to warn you about divers. We were talking out in the hall that divers of course love to go diving, but they love one thing even more than doing it: they love talking about it. Given that, I was questioning Dr. Stone's wisdom in inviting three or four divers here till I learned that Dr. Stone is himself a pretty accomplished diver.

But actually it was an astute decision because as he pointed out there are many parallels between the undersea environment and the environment of space. Eugene Cernan, the former astronaut who had been to the moon twice, visited the Aquarius Habitat on the ocean floor in 1988 for the television program Good Morning America and if you'd like to see a tape of that, we will be running it in the break room.

After touring the Habitat on the ocean floor and experiencing the neutral buoyancy afforded by being in the water, he told us that he felt as if he had been there before. I hope that this introduction to the Aquarius Habitat System will make you feel as if you've been there before as well.

If I could have the first slide. The National Undersea Research Center at Fairleigh Dickinson University supports and conducts research utilizing manned submersibles, remotely operated vehicles called ROVs, drilling rigs, shore-based laboratories, and a saturation diving habitat called Aquarius. The program is funded by the National Oceanic and Atmospheric Administration (NOAA) through the Office of Undersea Research and this program is an extension of a highly successful habitat program called the Hydrolab which operated in the Bahamas from 1971 through 1977, and in St. Croix from 1978 through 1985.

I made a pilgrimage to the Hydrolab which is currently at the Smithsonian in the National History Museum if any of you would like to visit it. It's a really interesting display and gives you some of the vital statistics on one of the preeminent habitats that logged more saturation diving, more missions, and more scientists than all the habitat programs in the world combined. There were approximately 60 other habitat programs, so it's a fairly impressive record.

The rationale behind having scientists live for extended periods on the ocean floor to conduct research has to do with the comparison of the bottom time allowed a diver from the surface. Such a diver is limited to about an hour or so at depths of about 50 or 60 feet and as working depths increase the allowable bottom time is decreased rapidly so that a diver going to about a 100 feet has less than 25 minutes available before he must surface to avoid the bends. I think Dr. Hamilton will tell us a little more about that in physiology.

Scientist divers living in the Aquarius Habitat, however, may conduct working dives to depths of 95 feet for up to six hours for one excursion. After returning to the Habitat for four hours they can then go out again for an additional three hours down to 95 feet. So you can see that in a single 24-hour period they can have 9 hours in the water column down to 95 feet, which is a significant amount of working time. Shorter times are also available beyond that depth but they are still far, far greater than the amount of time afforded a diver from the surface.

For example, at our maximum working depth, which is 150 feet, our divers are allowed to stay over 40 minutes before they have to return to a depth of 50 feet. They can still stay in the water column but they have to be at 50 feet. So, over 40 minutes is allowed down to 150 feet. A diver from the surface would have about 5 minutes before he or she would have to return to the surface. At the end of a mission, which is typically ten days to two weeks a single 16-hour and 20 minute slow reduction in the inside pressure of the Habitat, this is called decompression, will allow a diver/scientist to return directly to the surface.

The Aquarius Mobile Habitat System consists of the Aquarius Habitat, which you see at the bottom of the picture, and a life support vessel, which you see at the top on the surface of the water. It also consists of a shore-based facility from which the operations are run and some other assorted hardware.

Here's some of the assorted hardware. First, there is the Launch Recovery and Transport (LRT) Vessel. It's used to transport the Habitat to a new location. We have not done that yet but we are contemplating doing that in probably 1991. So, part of the proposal for next year will be what it will take to move the Habitat to a new research location.

The LRT supports the base plate and the Habitat for transportation. For you engineers in the room, it might be interesting to note that the Habitat arrived in St. Croix in 1986 and the base plate and the LRT, the Launch Recovery and Transport Vessel, arrived over a year later and they had never been mated before. They had never seen each other before, they were constructed at different times and places, and the first time they went together absolutely perfectly.

At the deployment site, the base plate is lowered to the sea floor and then the Habitat is lowered and then winched down to the base plate. It turns 90 degrees from its orientation on the LRT to afford a more stable configuration on the ocean floor, then the LRT is taken to a storage location.

Here you see a photograph of it just prior to mating. It's being winched down hydraulically to the base plate. This is as it mated with the base plate on the ocean floor and you can see at the top of the picture the silhouette of the LRT. The LRT is about 100 feet long, 50 feet in beam and has a large moon pool that the Habitat is lowered through.

This is a picture of the Life Support Buoy (LSB), on location off St. Croix, where it is right now. The Life Support Buoy contains a 100 kW generator, high and low pressure compressors for air and an environmental control unit for a controlling the temperature and relative humidity within the Habitat, a reverse osmosis, fresh water unit which converts sea water to fresh water and pumps it down to the Habitat, a hot water heater so that the aquanauts can take hot water showers which are greatly appreciated after six hours in the water column, and a back up generator/compressor, which used to be the primary generator/compressor for the Hydrolab, that's a 7 kW unit. The LSB also contains communication equipment and a scientific data collection station, as well as instrumentation for monitoring the Habitat and the Life Support Buoy systems. The LSB is unmanned at all times during the mission except during decompression. Decompression is controlled from the Life Support Buoy.

All these systems are monitored from the shore-based station at a computer and the data transfer is done by VHF radio and pocket radios. No wires, no hard wiring except as a back up.

I forgot to mention that the Habitat weighs 80 tons in air, is virtually neutral in the water, and can be ballasted very easily, positive or negative. The base plate weighs 116 tons.

The Aquarius Mobile Habitat was designed by Perry Submarine Builders of Riviera Beach, Florida. It was constructed in Victoria, Texas by the Victoria Machine Works. It was originally intended for use at 120 feet off Catalina Island under the management of University of Southern California and Dr. Hamilton mentioned that he had some of the design responsibilities at that point.

The habitat arrived in St. Croix in 1986 and was substantially modified by the staff for use as a mobile saturation habitat in warm water. We ripped out a lot of the old plumbing, we ripped out hot water suit configuration and redid a lot of the electrical and electronics to provide more access for the scientists to the water column for instrumentation and power needs.

The habitat received certification from the American Bureau of Shipping and is inspected once a year in the water by the ABS. It was launched in September 1987 and we had a dedication ceremony in December of that year. Then we began scientific missions in 1988 and ran seven missions. They were typically about 14 days long, when the scientist and one staff member would live and work in the Habitat and out in the water column for about 14 days.

In 1989 we completed six research missions and we had three missions planned for September, October and November and those missions unfortunately had to be canceled. We had a little wind and rain in September which forced us to cancel those missions. The wind and rain was named Hugo.

We did carry out research before, during, and after Hugo so we have some opportunistic data which we collected on a hurricane. The Aquarius is currently located on the sand floor of a submarine canyon off the north shore of St. Croix in the Virgin Islands in 60 feet of water. St. Croix is right here, this is Puerto Rico and this is the Dominican Republic over here. That's St. Croix. Hurricane Hugo went right through Guadeloupe, right through St. Croix off the north, and then went to North Carolina, we understand.

The habitat consists of a pressurized vessel which interestingly enough is approximately the same dimension as the Industrial Space Facility. This part of the Habitat is the pressurized part and this is the unpressurized part. This part is called the main lock. This part is called the entry lock, and this part is called the wet porch.

The wet porch is always at ambient pressure. It is full of air and the air is at the same pressure as the sea water and that's what keeps the sea out. The entry lock and main lock can be pressurized to pressures greater than ambient. For example, we can close the hatch and use the Habitat to treat decompression sickness in an aquanaut, blow down to greater pressure. We can also use the main lock and entry lock in a depressurized mode up to atmospheric pressure. This allows us to get in there between missions, close the door and blow to atmospheric pressure where we are unlimited in the amount of time that we have to work on the sea floor bottom. So we can look out of the window and look at fish, but the staff or myself can work for long periods, unlimited time in the Habitat at one atmosphere pressure.

When we get done with our work day, we blow the Habitat interior pressure back down to ambient, open the door, get in to our scuba gear and come back up to the surface to go home for the night.

Some details here: in the main lock you can see three bunks visible. This is a port elevation: looking from the port side this is a starboard elevation, so that is why it's just turned around. We have six bunks so the Habitat can accommodate six individuals; usually it is five scientists and one member of the staff. We have a galley area, a view port, and it's quite comfortable inside, quite large.

This is a detail of a corner of the wet porch, and this is where the scientists come and go to the ocean floor to do their work. You just step down into that little bathtub there, and you are out in the ocean and you can don your scuba gear at a convenient tank rack and go off and do your work, again up to six hours, down at 95 feet. That's the wet porch.

This is a detail of a portion of the entry lock. I am using a VHF radio there. In addition, we have communications with the shore base via a sound tower telephone. This is a small, closed circuit television station. We have four channels that we beam to the shore and we do that through a single co-ax by converting the signals to RF and then using ordinary televisions to convert the signal back and we keep an eye on the main lock, on that area of the wet porch where the scientists are coming and going. We also keep an eye on boat traffic with a camera up on the life support vessel which sweeps the horizon. We have one other camera which is out in the water column, actually two others, one tethered for scientific use and the other tethered for operational use to keep an eye on the scientists as they work. That's the entry lock. That also contains a laboratory space for microscopes. We've had scientists take gas chromatographs in there and all manner of equipment. It also contains a head and sinks.

This is the main lock looking toward the bunk room. In the far room there is the bunk room and some details here. This is the galley, this is a view port here that is two feet in diameter. This is euphemistically called a refrigerator. It actually just keeps things kind of cool, it is difficult to refrigerate things at two and a half atmospheres.

This is a microwave oven. Meals to be eaten hot are sent down frozen and we put them in the microwave and heat them up so we have one hot meal a day. Lunch is sandwiches or luncheonmeats, those sort of things, breakfast cereals, normal things. Food and materials are sent down to is in pressurized containers.

This is a television monitor. It has to be kept at one atmosphere because of the danger of implosion to a CRT tube. That monitor can be used to watch what the tethered video is seeing out in the water column. We have a VCR that can record what that camera is seeing and they can also, for recreation, play video tapes.

We have diver communications here. We use both scuba that is self-contained, autonomous gear. We also have hose diving, whereby we supply air and communications to the divers out in the water column. They can be as much as 1,500 feet away from the Habitat and still have communications with the Habitat, with the safety boat above them, and with each other. That's proven very useful. They can transfer data or dictate notes back to an associate who is inside the main lock typing the data on to a computer directly.

As far as the costs go, I will tell you that we have hardware costs and software costs, the capital costs. The Aquarius system breaks down somewhat as follows. The habitat, just big round figures including some design costs, development costs, is about five and a half million dollars that launch recovery and transport vessel was about a million dollars, the Life Support Buoy, LSB, about a half a million dollars. (the LSB was originally a confiscated drug boat which we picked up in Miami and then modified. We had to take a lot of this cargo out, clean out the powdery stuff, kept getting runny noses in there but ..). The Habitat base plate costs about a quarter of a million dollars. Actually, what really was the big expense in the base plate was simply the lead. The current annual operating budget, the software part is about 2.8 million dollars. That has been stable since the beginning of the program in 1986.

We run with an operational staff of approximately 15 individuals. I tried to do a pie chart, breaking down the costs, but they varied considerably from year to year based on the mission, based on availability of people, and based on some capital costs. We also had administrative costs, maintenance costs which were significant, personnel, science, capital expenditures and consumables.

In addition, the average cost per mission, and by that I mean the funding that's provided to the researchers to carry out their particular research averages about $26,000 per mission. If you divide the operating budget by the number of saturation hours, in other words when a mission is actually ongoing and people are on the bottom, what does it cost? Taken the total budget for the year, we are looking at about a $1,000 an hour for a saturation mission for a crew of six. ... and 16 hours of decompression done on bottom in the Habitat during which they can continue research and collect data and about two to four days of post-mission work.

When discussing the cost of any program, some mention must be made of the productivity and in the case of saturation habitat programs, productivity is usually measured by the time spent by the scientist working in the water column. This overlooks the fact that the data gathering and research continue when the aquanauts are inside the Habitat.

Another measure of the productivity is the quality of the science performed and the number of papers issued. I dug up some figures from the Hydrolab Program. It was considered extremely productive, and extremely cost effective as far as comparisons with: "What would it have taken to have done a lot of the research using access only from the surface?" Some of the research was impossible; drilling programs, and a lot of the pharmacological work that was done on bottom, and so forth.

I think this record will stand for quite a while -- 55,000 hours. Our new program, which is the National Industry Research Program, FDU runs, that have resulted was also a continuation of these figures.

Scientists who participated in the missions between 1978 and 1985 who were Hyrdolab users and who returned to use the Aquarius Habitat were unanimous in their appreciation of the sophistication and comfort of the new Habitat. One scientist on a mission I was on commented to me, that Hydrolab was like camping out in a pup tent, this was like staying in a Marriott or a Hilton Inn by comparison. I use that same analogy. He said that he thought that his scientific productivity and the productivity of the other scientists would improve markedly with use from the Aquarius. A quote I remember was he said: "I can think down here. In the Hydrolab because of the spartan conditions, the high humidity, the lack of an effective environmental control unit, thinking was not usually what you tried to do, what you tried to do was survive".

Because of how uncomfortable the Hydrolab was, we felt that a lot of the hours in the water column would not have been there if the Habitat was more comfortable so that in the Aquarius, we were a little worried that they'd be too comfortable and might want to stay in Habitat but that hasn't happened. Knowing that they can return to a comfortable environment, they tend to stay out longer; fear did not materialize. Improvements over the old Hydrolab system included an effective environmental control unit for temperature and humidity, increased work, living and storage space and provisions for the use of computers and other very sophisticated instrumentation. There are very few scientific instruments which we can't somehow accommodate in the Habitat. We've even put a fume hood in the wet porch to accommodate some work that was being done on the bottom and we typically have scientists who want to use radioactive material and some pretty nasty toxic substances: Curare and Trototoxin to mention a couple. We just developed new parameters for how they are to handle that kind of thing.

Environmental monitoring and the control of decompression used to be done by the scientists in the Habitat but they are now done by operational staff, either the Habitat technician or shore-based operational staff. That relieves the scientists from burdensome and scientifically unproductive housekeeping chores. They still have to wash their own dishes, though.

Newark FDU has a mandate to establish research programs for the assessment, protection development and utilization of US underwater resources. Some of the research themes that are addressed by scientists using the Habitat are global and oceanic climatic processes; pathways and the fate of materials in the ocean, including pollutants and nutrients; biological productivity and living resources, in other words, fisheries kinds of things; coastal, oceanic and estuarian processes; ocean lithosphere and mineral resources: we've had several sedimentologists, geologists and other people use the Habitat; and ocean services and technology.

We've been asked to look at trends for the purposes of this conference. We've seen a number of trends, in fact, the Aquarius Habitat itself, the design of that habitat was the result of a lot of input from users of the first generation of habitats. Various conferences and user groups recommended to NOAA (this was published in a 1973 NOAA Manual), 25 things that they would like to see in the next generation of Habitats. Looking at that list, I counted up 22 which had been incorporated in the Aquarius Habitat. It's made a significant difference to the productivity of the scientists.

A lot of the suggestions had to do with improving the Habitat environment and those have gone a long way, just making a nicer place, more comfortable place, a place where they can get a full night's sleep, has been a big break.

In addition, we are encouraging the trend toward automating certain aspects of data collection, especially the use of data loggers, video systems, and computers. Scientists are utilizing computers both for data processing, word processing, data collection and experimental manipulation.

This mission was Mark Patterson's mission. You can see in the background there they've got a Macintosh computer, the CRT has been removed and, in this instance, a great white shark has been substituted for the CRT. They were using a liquid crystal display. It needed to be back lighted and the easiest way they found to backlighting it was to tape it to a view port. It was always a little disconcerting to be looking at data and seeing a fish swim by in the background. In the foreground, in front of this scientist, he's looking at a video monitor and he is talking to an aquanaut in the water column for focus and exposure so that it can be adjusted by the aquanaut. We've also found that data loggers used to passively collect environmental parameters such as current measurements, light, temperature and other oceanographic data, have proven extremely useful, especially when they can be integrated with the data that the scientist is interested in. Then the data can be dumped and analyzed while the scientists are still on the bottom. That allows them to change the experimental parameters during the mission.

We've expanded the use of visual data collection with handheld underwater cameras, tethered video systems. The trends in this area include the use of computer software for image enhancement and analysis such as surface area measurements to determine growth rates and that sort of thing. Another trend is the use of ultralow light level video cameras for use at night.

Since this conference has to do with low earth orbit, I thought I'd mention the following, and that is that although the Aquarius Habitat is at what might be interpreted as an extremely low earth orbit that is 60 feet below sea level, I would of course say that it had to be thought of as geosychronous.

NASA has recognized its usefulness as an analog for a manned space station already. Two researchers, Douglas Smith and another researcher, Barbara Canke, both of NASA Ames Research Center, are utilizing the underwater laboratory in a study of human factors as they might apply to crew selection for a manned space station, and also in work station design. And Doug gathers taped records using our closed circuit video cameras to see how workspace is utilized and also to see how we fight down there. We always wear our NASA shirts when they've got the tape recorder on and we say: "Doug Smith, what a guy, what a guy", a lot.

Another researcher, Johnny Conklin who is also with NASA is studying our decompression techniques using ultrasonic bubble detectors as a model for decompression necessary for EVA work in space, and that work is going very well.

I hope this introduction to the Aquarius Habitat System, our space station at the edge of inner space, will help provide insights to further the goal of reducing costs of space operations at the edge of outer space. Thank you very much.

Hardsuits, ROVs -- *Jim English, CANDIVE Services*

Introduction by Bill Stone: Thus far we have talked about habitats, the pressurized operations bases which will be necessary for commercial manned orbital work. Although there is substantial research at NASA and elsewhere in telerobotics it is unlikely that man will be completely relieved of the need for periodic extravehicular activity in the foreseeable future.

Many approaches are available, when considering the development of the first industrial spacesuits. The question we pose during the next 45 minutes to one hour will be: "What is the most appropriate choice for industry".

The EVA problem can be summarized by stating two general choices which must be made when all the factors are considered equal, and that is: the composition and pressure of the habitat atmosphere; and the composition and pressure of the atmosphere used in the spacesuit. These will directly affect such factors as the decompression which may be involved if a suit is operated at lower pressure than the habitat, the dexterity available to the user and the overall cost.

The country's only presently operational spacesuit is the Shuttle EMU which operates at 4.3 psi internal pressure. It's been used for mission durations of up to seven hours. One problem with the Shuttle suit is that it requires a time-consuming decompression schedule to be carried out prior to an EVA mission since the Shuttle normally operates at 14.7 psi while the suit operates at 4.3 psi. This is basically a saturation decompression problem. Generally this is a two step process: in the Shuttle cabin pressure is decreased the night before a mission followed by a five hour oxygen pre-breathe, immediately before the EVA.

In an effort to resolve the decompression problem and permit immediate egress from the space station, which is intended to be operated at 14.7 psi, NASA has vigorously pursued research leading towards a no-decompression spacesuit.

Two different designs have been looked at so far. The first is known as the Mark III and work is being done on this design at JSC. It's designed to operate at 8.3 psi internal pressure and utilizes a mix of hard and soft suit technology.

The second design, known as the AX5, is a full hard suit made from machined aluminum with fluid rotary joints that can operate at pressures up 14.7 psi. An additional goal of the new suits is that of ease of donning and doffing while you are in space and long term maintainability while on orbit for periods of up to a year. I might add the interesting fact that, following a Shuttle EVA mission right now, it costs approximately six months and $300,000 to refurbish a suit. That's done for each mission.

It must be understood at the outset that there is only one reason for having a man or a woman outside the habitat instead of a robot. We will hear about robots tomorrow. That is the instantaneous physical interaction with a particular task at hand. The degree of dexterity capable of being commanded by the EVA astronaut is critical and unfortunately directly tied to the internal suit pressure.

The simple problem of grasping an object in space requires that work be done by muscles of the astronaut's hands in order to counteract the opening moments caused by the internal pressure; that's for soft suit design, or to overcome residual friction in the joints of a rigid shell glove. Those astronauts who have carried out EVA missions in excess of six hours have reported that the range of the life support subsystem was not the controlling factor in terminating the mission. It was hand fatigue, and this was for a 4.3 psi glove.

Generally one can expect that the cost of the suit will increase as the internal pressure is increased. I remind you that, from a business point of view, there is a strong economic factor driving the choice of habitat internal pressure, which will directly affect the bearing on EVA problems. That simply put is: higher internal pressures lead to both increased structural weight as well as increased weight of the pressurizing atmosphere. If the weight of the pressurizing gas sounds incidental, consider that it would cost $15 million in Earth-to-LEO transport costs alone, to bring the air needed to pressurize an external hydrogen tank to one atmosphere using the figures suggested by Tom Rogers earlier.

Less cabin pressure means less capital investment. The use of a lower cabin pressure also permits an alternate solution to the decompression problem. So you have three options: you have a high pressure cabin and a low pressure suit; you have a high pressure cabin and a high pressure suit; and a low pressure cabin and a low pressure suit.

As you listen to our speakers during the next hour we ask that you consider these various options from a business point of view. That is, suppose it was your company that had to pay the bills to build the habitat and buy the suits and operate both.

Our next speaker was to have been Phil Newton from CANDIVE, out in Vancouver. Unfortunately Phil, like many of us, myself included, has acquired some of the maladies of this time of year and he has sent one of his able bodied engineers, who is Jim English, the Special Projects Manager for CANDIVE Services.

As Manager of Special Projects, Jim is responsible for all aspects including operations of advanced diving systems, major marine construction projects, diving systems design, and installation of specialized research and development work.

He has been involved with diving since 1958, was one of two men who made the first saturation dive in the Arctic in 1974, and has been involved in a number of pioneering, deep water operations involving remote vehicles, submersibles, and ADS. You see the undersea industry also has its curse of acronyms -- that stands for Atmospheric Diving Suit.

Jim has been specifically involved in the development of engineering and technical protocols for such proprietary devices as the submersible Deep Rover, which was used last summer in Crater Lake at 600 m depth, and the atmospheric diving system, the NEWTSUIT. I might add that Jim will talk at length about this, but the NEWTSUIT is a light weight, one atmosphere diving suit that protects the wearer from the outside pressure while still permitting mobility and dexterity. The parallels between one atmosphere diving suits and hard spacesuits are obvious.

Jim has generously travelled all the way from Vancouver to be with us today, and to discuss his experience in this area and some of the quite different approaches he and Phil Newton have taken to on-time and under-budget financing of high technology development projects.

Jim English: The first thing I need to say: Phil asked me to apologize for his not being here today and I hope I can entertain you as well as he can or he usually tries to do because he is quite a talented speaker.

I feel a little bit like a fish out of water, which is fairly normal for someone in my business, I guess. We have had very limited exposure or involvement with the outer space industry to date. Although there are a lot of similarities, there are some fairly significant differences.

What I am going to talk about today, specifically, are some of the cost effective measures that we undertake to complete some of the high-tech projects that have come our way. I am going to very briefly mention two manned submersible projects and then I will spend a significant amount of time talking about our innerspace hard suit, the NEWTSUIT. If I could have the slides please?

CANDIVE is a commercial underwater service company, the key word in there being "commercial", and I will keep the commercial short. We used to call ourselves commercial diving companies, but that no longer applies because of the nature and variety of tasks that we are asked to undertake.

Our business is putting men to work safely and cost effectively in hazardous environments, and to use a phrase that Tom Rogers used earlier, our men are continually working in situations where there are lives are in peril and it is our job to keep them safe and make sure that they are productive. I will suggest that within our industry, and I know within our particular office, you will probably find several volunteers on very short order to go up to help assemble a space station.

The work tasks that we undertake are quite varied and the details of each particular type of operation are almost infinite. The tasks include marine salvage, a little bit of underwater construction which is involved with welding, concrete work, mechanical assembly, and so forth, and we actually do quite a bit of destructive work in the use of explosives of all types for both salvage operations, heavy structural cutting, and so forth.

After we've blown something up, we sometimes have to inspect it and maintain it and repair it. We do a lot of underwater nondestructive testing using all of the conventional surface techniques from gamma radiography to magnetic particle testing and we get involved, in a lot of cases, in a little bit of underwater deception to go along with our other activities.

This is a hybrid submersible that we designed and built for a movie called the Abyss, which was out this summer. This particular unit was 15 feet long and 15 feet wide and weighed about six tons and was powered by a remotely operated vehicle hidden in behind so that the actress didn't really have to fly the thing. It utilized a Deep Rover shell as its main component in the forward section.

We also get involved in some very basic scientific research and an almost endless range of other special projects. The work can be very simple from untying a [cable] knot on first examination although sometimes the scale of the knots exceeds what we anticipated in the first place. We never did figure out how the rig's anchor cable got a knot like that in it, while they deployed it. It looked like a fairly complicated procedure.

We also undertake a lot of complex subsea interventions associated with the offshore oil and gas industry. I stole this picture again from the Abyss because in our normal working environment offshore in the Beaufort sea, and the North Sea and the Gulf of Mexico very seldom do you get the opportunity to actually take a picture of where you are working.

A lot of the subsea tree interventions that we undertake actually happen below the mud line working in zero visibility conditions and in condition of extreme cold and just generally hazardous.

The biggest problem that we have to overcome in our line of work is not necessarily the specific task that the end effector or the hand has to achieve, but it's the need to get back or the method of getting safely to and from the worksite. This is a rather unique worksite that's a 48 inch fiberglass liner running off-shore. Unfortunately our job is to go down the inside of this liner approximately 2,000 feet from the entrance and complete some work in some 200 odd feet of water which presented us with a fairly interesting decompression profile due to the angle of the lay of the pipeline. There is one of our fearless innerspace technicians coming up on the escape board, we pulled him back up outside the line following his decompression profile. That was one of our more interesting commuting projects.

The method of diving chosen can be varied and for each one of these I could go on for hours about techniques and procedures. They can be simple air diving to depths of a couple hundred feet. They can be long saturation dives to depths normally not exceeding 1,000 feet although experiments have been done with ambient pressure dives to 2,300 feet, using hydrogen mixtures. They can use various and sundry, what we would call, methods of commuting to the work site. These include diving bells, which transfer the divers to and from the worksite so that they can decompress safely on a relative secure surface support complexes, although some of the offshore rigs lately haven't had too much success in staying afloat or not blowing up.

We also use a variety of flying "eyeballs", such as remotely operated vehicles, the low cost version of which are generally restricted to visual and acoustic imaging systems. Full work, remotely operated vehicles which are bigger, heavier, have manipulative capabilities for on-bottom intervention and we use a lot of specialized tools; I don't know whether you can see it in this picture. This is a specially built, remotely operated vehicle that was designed for attaching and drawing an anchoring device into the side of this little iceberg here so that it could be towed out of the path of a Mohr drilling unit.

We also use submersibles such as the Deep Rover. This is a 3,000 foot rated acrylic hulled submersible, one man operated. We have gotten recently heavily involved and very successfully involved in personal submersibles such as the atmospheric diving suit, the NEWTSUIT and this is one that I will be talking about at some length in just a couple of minutes.

We often have to gang up on our projects. We just finished a job in Niagara Falls, New York involving three submersibles, two ROVs and two surface diving crews simultaneously in one hydroelectric facility inspection operation.

This conference is specifically to address cost effectiveness of space-based operations and equipment. The parallels between our industry and space are similar in that we are dealing with an airless environment. However, we are dealing with buoyancy and weight as opposed to weightlessness and significant excursions from home base. I thought the best way to describe how our industry reacts to projects is to give you a very quick summary of two specific manned system projects that we undertook.

In early 1980 we had the opportunity to be awarded a diving surface contract for 2,000 feet of water off the coast of Boltin Island. This was drill rig support. The contract called for a one atmosphere manipulator bell, equipped with a spatially corespondent force feedback manipulator system for manned interventions at depth.

I would just like to make a little aside on this particular manipulator system. It has recently been contracted by Martin Marietta to provide four manipulator systems for the FTS Ground Simulator Facility, and this is, in our opinion, the state of the art as far as the man/manipulator systems in the underwater industry and has direct space applications.

Getting back to the ARMS bells, the arms bell itself had been designed and built. We had built three units previously. The fourth unit, ARMS four, was required to be completely built from scratch in order to meet the time schedule. The client gave us a total of eight weeks from the date of order to date of delivery of the system, tested off the coast of Boltin Island.

This presented some fairly serious logistical problems, considering that we didn't have a hull and we didn't have any of the support systems other than the manipulator itself.

During the eight week period, we acquired a bare pressure vessel from another diving bell system. We designed and built the battery pod and other related external pressure vessels, buoyancy modules, propulsion systems, power systems, navigation systems, control hardware and life support systems.

In the fifth week we also delivered and installed the launch and recovery system, including umbilicals. This was installed on board a drilling unit in a shipyard in Boston and during the sixth week of the program, the bell was delivered to St. John's, Newfoundland for interface to the vessel and handling system, which all arrived on the seventh week.

The ship left port three hours ahead of sailing schedule with the two systems on board. During the 36-hour cruise to the drilling location off Boltin Island, the two systems were interfaced. We made the first test dive to 2,000 feet within 12 hours of arriving at the drilling location and commenced working dives 12 hours after completion of that test dive.

The entire project required a total budget of approximately $1 millon Canadian from start to finish and we estimate that this was about 30% higher than it would have been if we had taken a period of about six months to build this system.

I should also point out that this entire project was initiated and commissioned and completed based on three telephone calls, one meeting in Rio de Janeiro to look at the rig that the system was going on and one follow up meeting in Newfoundland.

We didn't actually sign a contract until six weeks after the first well was drilled. One of the abilities that we have in our industry is to respond on very short notice.

The second project, which is an example of a production of a reliable, man-rated system on a cost-effective budget and schedule, was the Deep Rover construction.

This 3,000 ft rated acrylic hulled submersible was conceived by Mr.Graham Hawkes, who is a pioneer in the area of one man atmospheric diving systems. In a combined team between Deep Ocean Engineering, which is Graham's company, and CANDIVE, we detailed, constructed and assembled the submersible in our Nova Scotia facilities over a period of 18 months.

The total cost for the Deep Rover submersible including all manipulator systems, launch and recovery hardware, deep water tether management systems and umbilicals, surface control complex and the submersible itself was approximately $1.8 million (Canadian). This system was delivered fully certified and tested to Lloyds register requirements for the class of manned submersibles.

Just as an aside, a typical Deep Rover mission, such as we undertook at Crater Lake, or for marine construction or salvage work, runs at a cost of about $600-700 per hour.

This is just a critter that decided to inspect the Deep Rover and tried to fly away with it on one of the jobs we were on.

Atmospheric Diving Systems: These are not new to the underwater world and they were first conceived and started to appear in patent applications and other publications in the early 1800s. Atmospheric Diving Systems are really a marriage between a man, a submersible, and a remotely operated vehicle and they are often described as personal submersibles or submersibles that you wear. Atmospheric Diving Systems are very compact, rapid transit systems. I will just very briefly go through a dive comparison. On the right is a typical saturation dive to 1,000 feet of sea water using helium/oxygen mixtures that would take approximately 17 or 18 hours of compression time in order to get the man delivered safely and efficiently to the work site. In contrast, an atmospheric diving system can deliver the man to the same depth in a period of five to ten minutes.

On the decompression side it's even more outstanding. Decompression from saturation is approximately 24 hours per 100 foot of exposure. This can vary from anywhere from 9 to 10 days from 1,000 feet, assuming that you have no physiological problems with your divers.

Again on the left, a total ascent time for an Atmospheric Diving System is less than 10 or 15 minutes. The application of Atmospheric Diving Systems to our industry is primarily supported by economics as well as safety. With the saturation system the total dive cost for a 15-day mission to 1,000 feet of water would approach approximately $500,000, plus a capital cost of $3-4 million for equipment.

That's for a small saturation system. As a comparison, to say a space station, in the North Sea, there are several multi-service diving vessels and these are large, semisubmersible drilling units that are dedicated strictly to saturation diving interface. Systems on board these rigs cost anywhere from $20-30 million and they have the capability of maintaining 26 men at a depth of 600-700 feet. They are under pressure and manned 365 days a year and there is one system in operation in the North Sea right now that has had men under pressure continuously for over six years.

These systems typically require a 50-60 man crew to support a 26-man saturation team and with support vessel costs and everything else included, these operations run approximately $300,000-400,000 per day.

By similar comparison an atmospheric ADS dive to 1,000 feet of water would cost less than $50,000 for a typical five day mission with a capital purchase of two complete systems, two complete handling systems and all the topside support equipment of less than $1 million.

This barge has a 600 foot rated saturation diving system on board that was used for some work off the coast of British Columbia over the last two or three years. You can see the support tethers, the gas storage at the stern of the barge, the diving system in the foreground. This entire barge is replaced by two ADS suits and a five man crew. The economics are self-explanatory.

This is Phil Newton who can't be here today. He made me promise I would at least show you a picture of his face, so there he is in all of his glory. Phil has been involved with atmospheric diving systems for years. He is shown here in front of the very first actual working atmospheric diving suit which was produce in 1927 by Joseph Poresk and it was used to salvage bullion from the wreck of the Lusitania, off the coast of Ireland. As is normal in our business, we like to do things for money. Someone came to Poresk and said: "Hey, we want dive on this wreck, there is lots of money involved in it, if you can build us a suit that will allow us to do that work you can keep half the gold".

Poresk didn't know that it had never been done before, and he says: "Sure, I can do that", and he did. He built this suit which is in the British Science Museum at the present time, completed his contract, took his money, and stuck the suit in the henhouse. In the early 1960s the suit was removed from the hen house in England and taken over by a company called, DHB Construction, and they essentially took the original Poresk designs for joints and used modern materials to produce the first of what became known as the JIM suits.

The JIM suit has a magnesium alloyed body, stainless steel and aluminum limbs based on ball and socket and piston-like joints for mobility. These suits weighed approximately 2,000 pounds and had an operational depth of 2,000 feet.

This cutaway shows the general proportion of the suit. You can see it's very similar to a spacesuit in all concerns. Early suits used oral, nasal, lung powered scrubbers for carbon dioxide removal. That has since been replaced by powered scrubbing systems, and you can see the manipulator systems, which I will talk about in a few minutes in what we are using for our end effector hand modules.

It's very significant to be able to watch a man working in a 1,000 of water. We did some 12-hour dives up in the Arctic in 1976 in about 900 feet of water and spent that time on bottom and were able to bring the man back to the surface and take him over to the tent out on the ice and have a beer to sort of celebrate his success. That's pretty significant be able to see that. The limitation with the JIM suit (and I will have to move away here for minute) is its working environment for its manipulators and arms was an area approximately 20 inches square, located roughly from the waist to the mid-chest level. So any task that had to be done underwater with a Jim suit had to be set in this kind of a range, and the range of motion of the arms was essentially restricted to this area. The leg motions were also very restricted and walking was extremely difficult in the suit.

So, we decided that we had to improve upon that dexterity and mobility in order to improve the application of the atmospheric diving suits for underwater use. I should point out that there were 15 or 16 JIM suits and JIM variations. Another one was called the "WASP"; it was the same design only it used thrusters for mid-water mobility. Of these 15 or 16 units, all of them are still working on the commercial offshore oil industry at this time.

This is a typical JIM joint of the second generation. We had increased mobility in this particular joint due to stacking of individual ball and socket sections. However, you will notice the big drawback is that this is the elbow section and the elbow section doesn't move and the forearm section and upper arm sections move, which is rather silly if you think about it because the joints are at your elbow and not in the middle of your forearm or in the middle of your upper arm.

Phil decided that he was going to take the atmospheric diving suit from this level where he got initially involved in it to this level, which is the light weight, shallow water, version of the NEWTSUIT which we are expecting to have available sometime within the next year.

Phil went right back to basics. He sat down with his carving tools one day and said "let's have a look at this one". This was a real, working, underwater system but as you could tell it was probably limited to depths by something called "exposure to pressure". They were very effective manipulators, however.

In our approach to things and Phil's in particular, what he did was to get a big bag of modeling clay and some putty, and he took his carving tools that he normally uses to do his totem carving and jewelry carving, which is very common in the northwest coast, and started working on prototype mock-ups for the body portions of the suit. At the same time, he was working on examining hard engineering parameters and combining this with his intuitive skills and intuitive design capability to produce a working system.

This involved a lot of detailing of joint concepts, and the NEWTSUIT operates on a fluid-filled, rotary joint, very much like the AX5, and he has had a continual dialogue with the people at Ames, over the last number of years, as they proceeded down parallel paths. All this, of course, very informal.

Being a very old and experienced diver, Phil's sort of concept of range of motion requirements is that he wanted to be able to scratch his nose, and he also wanted to be able scratch other things, which will remain nameless.

We produced a plastic prototype, which was basically built in the shop for a cost of about $4,000 and this was used in order to get the geometry of the suit right and work on joint diameters, and so forth. We don't do a lot of preliminary engineering or design analysis and so forth. Basically we get an idea, go get a couple of pieces of plastic or off-the-shelf spheres, cut them in half (some of these things were the clear plastic spheres that you see the Salvation Army collecting money in at Christmas time) with rotary joints attached to them, and build one and try it and see if it works and it doesn't cost you a whole lot to change it. We made further refinements in joint configurations, geometries, concepts for the molds and the casting forms that would be required. We put joints in the hand pods, just to see whether or not that would improve performance or not and went through several iterations of inexpensive, plastic, light-weight versions of the suit in order to play around in dry atmospheres.

About early 1985 we really decided that the joint design had progressed to a point that we felt that we could form a separate company called International Hard Suits Incorporated to design, market and develop the hard suit. This company was funded on private venture capital and is a publicly traded company on the stock market.

A key decision that we made in the formation of hard suits was that we decided that the NEWTSUIT would be commercially available to anyone that wanted to buy it. In previous developments CANDIVE built and designed its equipment for in-house use, to give us a competitive market edge against our competitors. In this case, we felt that it was extremely important for the NEWTSUIT to evolve properly and in a competitive atmosphere by having it available to CANDIVE's competitors in the commercial offshore business and that has proven to be a very valuable decision. The concept of having several companies competing with the same type of hardware stimulates development of novel and innovative applications of that hardware for undertaking task assignments.

International Hardsuits started out with a crew of three men, consisting of Phil Newton, a design engineer named Mike Humphry, and a very high quality precision machinist called Bernie Schmidt. The three of them produced (from sketches made on the back of napkins in pubs around north Vancouver as well as some drawing board work) joint designs that would function at a depth of a 1,000 feet with zero leakage and low torque. The joints that we've produced to date have a rotational torque of less than 1.5 foot-pounds at an operational pressure differential of 650 psi.

The first suit was developed from welded sections of aluminum spinnings. These were all used because they were commercially available, off the shelf. We didn't have to spend a lot of money on spinnings and castings, and the particular joint sections were machined out of solid blocks of aluminum. This was to avoid expensive mold costs until we resolved the final joint details.

This is the first prototype suit. Its major problem as far as Phil was concerned was that it was too small for him to get into. So, we had to correct that situation with our new larger suits.

We selected a waist entry for the NEWTSUIT prototype because of the machining considerations although all of our plastic models now use the rear entry as is being used in the AX5. We anticipate going back to the rear entry system for our light weight shallow water suit.

The prototype suit was put in the water in 1986 and it worked far beyond our initial expectations. I would like to show a very brief video tape now of the suit during its second underwater trial.

We did a number of tasks with the suit in the initial trials and we also played with Beluga whales in the aquarium. It was quite fun to see the NEWTSUIT being dragged around by the Beluga, they thought it was a new toy to play with and that was our operations manager, our general manager of International Hard Suits in the suit for the press and demonstration.

Our next step was to take the prototype into the production phase, and this involved using aluminum body castings and refining the joint designs so that we could have reproducible, easily manufacturable, components in the suit. There are over 1,800 individual components in the NEWTSUIT.

Due to the tremendous pressure differentials encountered, small tolerance variations are very critical to the suit design and the evolution of the suit now that it is in full production, has been such that we are able to eliminate or reduce the tolerance requirements for some of the key functional elements.

This is the first suit that we delivered to Draeger Work International. While you may be familiar with Draeger in Germany, they are our international marketing agent for International Hard Suits and they have marketing rights world wide except for North America and Japan. To date we have delivered eight NEWTSUITs. We have in-house orders for 26 suits, and we are anticipating our production running anywhere from 12 to 14 suits per year, over the next five years.

The suit is currently undergoing trials in Gussy and Hamburg, Germany, with the support of Draeger, and I've mentioned we have been successful in performing a variety of underwater tasks in currents of up to 1.8 knots. We will be doing the same tasks at full operational depths commencing in January.

All the suit components are certified by Lloyds Register of Shipping and are fully tested and certified in our in-shop facilities.

Since we are discussing costs, I'll go back a couple of slides here. The new suit as you see it, the basic suit retails for a cost of $300,000 per unit. The retail price has in it, a 40-60% profit margin for our company. A complete system, including one year operational spares, replacement joints, topside control console, topside launch and recovery system, control vans, umbilicals and everything else to make the suit go underwater retails for approximately $500,000.

During an operation offshore we would recommend the use of two suits on any job so that you have one suit standing by as an emergency rescue capability for the first suit.

The suits weigh approximately 425 pounds each, they are rated to 1,000 feet of water depth and we anticipate improving the operational depth to 1,500 feet sometime this winter.

In the meantime we have a few new developments. I will skip through these very quickly, so we can get on back on schedule. Phil and Mike are working on a shallow water version of the NEWTSUIT. This shallow water version looks very much like the full size or the full depth NEWTSUIT. We are anticipating that we will be able to operate at a depth of 300 feet of water for mission durations of 6-8 hours with a total suit weight in air of approximately 80 pounds. We hope to be able to carry the suit in two duffel bags and expect the suit to retail at approximately $60,000 per unit.

If we are successful in achieving these design objectives, we feel that the NEWTSUIT or the shallow water NEWTSUIT will be as big an impact on the commercial diving industry as the Aqua-lung was on the scuba industry.

Another development coming on in the NEWTSUIT, in January, is a thruster pack which is our equivalent of the MMU. This unit will be attached to the suit and controlled by the operator of the suit and it will retail for a cost of approximately $40,000. This will give us excellent midwater mobility.

Our experiments have shown us that we have approximately 75-80% of the dexterity of a conventional ambient pressure diver working at depth. This is based on feedback from our divers who have been doing in-water tests. Our current suits use simple hand enclosures with very simple three finger and two finger plus hook hand mechanisms. We find these very adequate for doing most of our underwater tasks. These tasks include rigging, placement of explosives, doing and undoing quick connect hydraulic hose connections, and so forth and we feel that these are adequate for the time being but they are by no means the end objective.

One particular item that Phil is very interested in working with is the pre-hensor. I don't know whether there are other people here who are familiar with this manipulator system developed at MIT. It relies on a series of shafts and rings in order to give a very usable and very effective hand grip. The problem is that it does not easily lend itself to sealing at the pressure boundary.

Our control system for the thruster pack is comprised of pressure-sensitive resistors. These cost about $5 a piece and you can control all sorts of neat things with them. Phil's present design objective is to incorporate these pressure-sensitive resistors into a design for an electronic hand which may incorporate some of the pre-hensor characteristics.

This is our version of the "man in the can", a 300 foot rig submersible that we sell for $40,000. It is capable of diving to 300 feet of water with a manipulator and navigation systems, fully ABS certified for manned diving, and is aimed at the tourist market although some creative people have some other ideas on how to use it.

I guess it is about time to wind down here. CANDIVE has been very successful with the development of new, innovative underwater technology. Until the advent of the NEWTSUIT, we did all this work to meet our in-house needs.

For the projects that I outlined, like the Deep Rover and the Arms Bell, and the NEWTSUIT, some of the key ingredients in cost effective completion of the projects have been the utilization of off-the-shelf technology. We don't reinvent the wheel unless it is necessary. We go to the store. If we can build a submarine using half the parts from Canadian Tire, or from Fred Myers, or something like that, we don't feel like we've done a good design project. We also concentrate on very simplistic design; we feel that the simplicity provides reliability, ease of operation, ease of maintenance and also ease of production. This simplicity is not really easy to achieve in all cases.

We also rely on accepted engineering design practice and codes. We don't overengineer any of our projects unless we have to. Our paramount concern in all cases is the safety of the individuals involved in the projects. That, I think, is where the key to some of our success in cost-effective completion of the projects is, in that everybody is involved in the project right from the initial design right through completion and testing of the system. We don't really consider it a lot of fun to build and design all these neat toys and gadgets unless we get a chance to play with them ourselves. I think that for some of our systems, the involvement of the individuals is almost fanatical. It also leads to a very autocratical and dictatorial design process where you have one or two key individuals who have the ultimate authority over both financial control and design control for any particular project.

Just in closing, this is our first flight simulation test for the manned submersible, Space Rover, as we are going to call it. We did these in-flight tests at Crater Lake last year, and we use an HMU, which is a Helicopter Maneuvering Unit, to provide its mode of force.

Hypobaric Physiology -- *R.W. "Bill" Hamilton, Hamilton Research, Ltd.*

Introduction by Bill Stone: Our next speaker is Dr. R.W. "Bill" Hamilton of Hamilton Research, Ltd. Bill has been working as an environmental physiologist for a quarter of a century, sometimes for the Union Carbide Corporation's Ocean Systems Laboratory but for the last 12 years as an independent investigator and consultant.

His current interests in applied physiology are decompression and G-forces. But he has also worked on space craft cabin atmospheres, diver performance, rapid compression, the use of neon as a diving gas, survival equipment for diving bells lost in deep water and other esoteric projects, including the development of hyperblank decompression tables for near saturation missions at 100 meter depths.

He and his colleagues established the main fire safety principals for hyperbaric chambers. With colleague Dave Kenyon he has done a wide variety of decompression tables computation, including ones for Habitat Diving, in the NOAA Diving Manual, Deep Heliox tables, Deep Air Diving tables for the Swedish Navy, Tables for closed circuit rebreathers and some high tech dives.

He took a year off in 1968 to fly F-100s in Vietnam, so he is a very diverse individual. His main preoccupation these days is the decompression program, DCAP, which is installed in several laboratories all over the world.

Bill has offered to lend us some thoughts this morning on how man's physiological tolerance can be used for improved space operations.

Bill Hamilton: Jim English has tried to put decompression physiologists out of work. If we could figure out how to pay for the propulsion engineers to move manned space flight out of the first phase of using fireworks for launching, and thereby lower the cost of putting things in orbit it might then be beneficial to consider some ways to improve the efficiency of manned activities there. This presentation looks at the physiological requirements of supporting productive men and women in earth orbit, both inside spacecraft and during EVA. And suggest some ways to save, weight and/or money in doing it.

The main concerns here are to provide enough pressure for the respiratory system to work and to prevent decompression sickness. These are probably the main physiological problems overall and conveniently are the ones where the most cost savings are likelyto be achieved. Other physiology matters are: space motion sickness, acclimation to 0-G, both in orbit and on return, protection against radiation, G-forces during launch and some other more mundane aspects of life support. Methods to improve on present approaches to these latter items are not immediately obvious but a fresh look at equipment design and concepts will no doubt pay off across the board.

For the record, I've not called up NASA to find out what's wrong with the toilet or the like, so there are no doubt many other things that can be done in a less costly way if we have a chance to start over. I'll review the physiological necessities in terms of pressure, oxygen and fire safety, speculate on efficient cabin pressure, offer some thoughts on inert gas and CO_2 level and present still another idea on how to make a space suit. Although not exactly physiology, I'll also have a suggestion on how one might get around during EVA with less costly equipment.

Masculine pronouns are interpreted to include both genders. Could we put the first slide up?

A word about units. In discussions with European and Japanese colleagues about the space station, it's frankly quite embarrassing to have to apologize for NASA's hard-headed attitude about requiring the use of English units. This could lead to a long and serious editorial involving inviting Americans to try real hard to join the world before this century is over, but we have other priorities at this moment. I could not, however, let pass this opportunity to make a statement on this regrettable attitude.

In the long haul, as we are talking about cost, working in SI units will payoff, but we have to face the facts that for the present venture we are probably better off sticking with the familiar but somewhat inconvenient ones in most engineering matters. However, because the presentation talks a lot about pressure let me introduce a handy pressure unit, the kilopascal, kPa. The atmosphere is the fundamental reference point for physiological pressures. The metric equivalent, the bar, is used everywhere else. That is the bar is one percent or so smaller than the atmosphere but that is physiologically inconsequential.

A bar is 100 kPa, which makes the KPa very handy for physiological pressures since it is one percent of an atmosphere. This shows some of the key points on these scales and we'll talk about some of these specifically as we go along.

The physiological effect of a gas in most cases is a function of its partial pressure. The partial pressure of a gas component is defined as the fraction of the component times the total pressure. Our species has adapted to life at a pressure of one bar, in some cases, somewhat less, with an oxygen fraction in the breathing gas of 0.21. This is the atmosphere used in the current Shuttle and other spacecraft. A less costly atmosphere might well be used.

There are several considerations in planning the atmosphere. The primary need is for an inspired partial pressure of oxygen adequate for normal functioning. This can be as high as an 18,000 foot mountain, but there is a big cost for that. Something more reasonable would be about a 12,000 or 14,000 foot mountain as shown in this figure for the proposed space cabin.

We've learned the hard way that a fire safe atmosphere is desirable. Carbon dioxide, water vapor, and, on very long flights, carbon monoxide and some other things have to be removed. The inert gas component of the atmosphere, while necessary for fire safety can cause decompression sickness during the reduced pressures encountered during EVA.

The next concern is reduction of the pressure of the space suit. The minimum pressure for normal performance is regarded as about 20 KPa or 3 psi. But at that pressure, there is higher risk of decompression sickness, DCS, if that person is saturated with atmospheric air. The standard method of dealing with this is to denitrogenate by prebreathing of pure oxygen. This may take up to eight hours for the full transition just mentioned and for a susceptible person.

A potential saving can come by operating the spacecraft at a lower pressure. The weight of the pressure hull is proportional to the pressure rating and this could be a significant part of the weight that has to be placed in orbit. It is probably less than we might wish, however, since the necessary structure can support most if not all of the current pressure. But there are other advantages to a lower pressure such as decompression for EVA and the weight of the gas. As it is now, selecting the atmosphere will have to be a set of compromises. First we need an adequate partial pressure of oxygen. We are accustomed to 0.21 bar P_{02}. However, a significantly reduced pressure is adequate for normal function, especially with acclimation or at a higher oxygen fraction, but raising the oxygen fraction increases the fire hazard.

This presents us with a large set of compromises, and we are just looking at several options from the ones that have been chosen. As a talking point, let me suggest a pressure of 60 kPa or just under two thirds of a bar. We would raise the oxygen to 25 percent or slightly more. This would mean we would need a good fire suppression system, proper procedures and materials for preventing fire. This should make it possible to do EVA with little or no prebreathing. It would not require prebreathing to go to that pressure, that is to go into the spacecraft cabin itself, but there is some risk of mountain sickness. We would have a good chance of going on EVA with a just a little prebreathing.

Let me talk a moment about CO_2. Since we are looking for even small savings, it might be worthwhile to reassess the CO_2 level maintained in the cabin. I've not checked actual levels in previous space habitations, but know that, for a couple of reasons, the standards for CO_2 level in a breathing atmosphere are unnecessarily low. One reason is that it's relatively easy to remove CO_2. The other reason is that this is the way we've always done it. The traditional limit is 0.5 KPa, about a half percent sea level equivalent. But a level of 1-1/2 percent will not be detected, physiologically, and man adapts quite well to even higher levels. The gain in running at 2 percent would be a smaller fan and the ability to use the absorbent at a lower level of efficiency, that is you can use it up. This could save a kilogram or two and could save power by intermittent operation of the scrubber. The mild acidosis could actually be helpful to someone breathing at very low pressure. Also this would allow absorbent no longer suitable for use in the space suit to be fully used up in the cabin scrubber.

Decompressing for EVA is a major factor in the choice of the cabin atmosphere. The person saturated with air at one bar would have a significant and unacceptable risk of getting DCS when pressure is reduced to about a half bar or lower. NASA has tentatively abandoned work on its hard suit. But you know already, you just found out that you can buy a better one from CANDIVE.

Soft suits are generally 3.5 to 4.3 psi. But these require extensive prebreathing. NASA's current approach is to lower the pressure in the whole spacecraft to 2/3rds of a bar overnight so that an hour or so of prebreathing is enough. We see no reason why a low pressure cannot be used all the time, perhaps with a better inert gas. I'll come to that in a moment.

Let me mention now the first really new suggestion: it is for something called the space activity suit. Almost 20 years ago, the respected physiologist Paul Webb demonstrated for NASA that a space suit could be made like a leotard with a bubble helmet and that such a suit could apply counterpressure to the body, using stretch fabric. This suit has the added advantage that it allows the body to control its own temperature by sweating. Sweat will be highly efficient when evaporating into space. Far less energy is wasted on the suit than with a conventional spacesuit and there are fewer limits to the range of motion.

The suit works. Physiologically, it's been demonstrated. It has a counter lung and a full coverage helmet. The prototype was tested at an oxygen breathing pressure of 23 kPa or 170 mm of mercury and an external pressure of 2.8 kPa or 21 mm of mercury about 80,000 feet equivalent and it works. I have a picture of the suit;, it is not of very good quality, it looks just like a person in his "long johns" with a helmet on. There's really nothing to this thing. There are problems with it, however, but they are mostly mechanical. That is, physiologically it'll work. The suit's hard to don, and it has to be individually tailored, but it folds up small enough to be stored in the helmet. If you've dealt with storage with one of the current suits, you know what I'm talking about.

The case for neon. It stands to reason that if a less soluble gas is breathed then it should be easier to decompress without the risk of decompression sickness. Limited experimental work with pigs has shown that neon appears to be more favorable than nitrogen. From what we now know it appears that neon, as the inert component, would allow decompression to suit pressure without prebreathing. Neon is expensive but if it could eliminate or significantly reduce the need for prebreathing, then it would be affordable.

Neon is obtained from air by distillation. A much less expensive gas than pure neon is available from an earlier step in the air distillation process. It is called neon 75 or crude neon and it's a mixture of 75 percent neon and 25 percent helium. Helium alone was tried as the inert gas in some early Gemini profiles, and was found to be no better than nitrogen, but this was for a short saturation profile. Since it's only 25 percent of the mix, and for other reasons, we feel that a less expensive neon mix might work. It would not work if cryogenic storage is to be used. One additional cost factor here would be that experimental work would be needed to confirm the benefit of neon and determine the pressure change that can be tolerated. Enough work has been done to know that it's OK to use but we don't have it finely tuned yet.

What about rescue and treatment? In the event that an astronaut does develop decompression sickness as a result of EVA it would be desirable to treat him by recompression. NASA's making one of the EVA locks on the space station capable of being compressed to 3 bars, which will be adequate for most contemporary decompression sickness treatment profiles. One aspect of this plan, which might be improved upon, is what I call the "rusty barge philosophy". Basing the methods on well established principles developed in the diving field, where weight is cheap and technology is low, in contrast the space craft weight is very dear and high technological is plentiful. The issues are complex, but I encourage taking a fresh look with a new perspective.

A more difficult task would be to treat a person exposed for a short time to high vacuum, where the result is ebolism, the boiling of body fluids. The danger from such an exposure is, at least in the short term, due to lack of oxygen, not bubbles. This means rescue has to be in process within three or four minutes for the worst case exposure, but could be slower for less serious exposure, like a small leak. The victim would be stabilized as far as oxygen is concerned at about 1 bar, but further compression would be necessary to resolve bubbles.

The school of NASA watchers to which I belong believes that this can be effective and encourage pressure capability to at least 6 bars. NASA selected 3 bars and rightly so: because of the way they are building their hardware. It will be extremely expensive with very little return if they made it greater. But I think an inflatable bag, such as are now commonly available for remote treatment of diving related bends, could make this pressure available and would encourage that that be considered on any long-range, serious EVA project. By the way re the Space Activity Suit concept: the only really vulnerability of it is the helmet and breathing bag. A snag in the suit itself would not cause any serious problem.

I've got one more thing to suggest. This is my "space walking stick" idea. The astronaut on EVA today is really connected to a small spacecraft [MMU, Ed.], that thing on his back, expensive, heavy, complex, and it requires very high control philosophy to squirt the propellent out from two or more different places and have the person go straight and not spin around and everything. Taking a little bit of a lesson from divers like Bill Stone, who goes through an underwater cave with an electric scooter that he holds in front of him with propeller on it, I suggest perhaps that if we made a device about like this stick, with a pistol handle on it, a proportional trigger, and some nozzles out in the front that would point off to the sides and not squirt right back at the astronaut, then he might be able to pull himself along through space, without having to have a very complicated backpack.

Now, once you get going, eventually you also have to stop. One way is to turn the thing around the other way. But this could be a problem. I think that if we actually also had a forward facing nozzle, that given the control and the fact that it's a customary type of movement, then I think you would be able to stop effectively without spinning around, with a sufficiently, well-adjusted control of the squirting. This uses a proven ergonomic design, a pistol grip, and I think it's worth a try. I can only speculate that it might work. Thank you.

EVA Life Cycle Costs Issues -- *Paul Marshall, NASA*

Introduction by Bill Stone: We have two people who have made special trips here from NASA, to give you a briefing on current space suit work at NASA. The first will be Paul Marshall who will discuss the Mark III being developed at JSC.

Paul is presently detailed to the Space Station Office at NASA Headquarters from the Johnson Space Center in Houston, where he has worked since 1980. At JSC he worked with the Crew and Thermal Systems Division, with life support thermal control, and EVA hardware, both for the shuttle and the space station programs.

Recently he was assigned to the Space Station Freedom Program Office, and he is currently serving as the EVA Systems Manager. He has generously offered, on short notice, to provide some remarks on EVA life cycle cost issues.

Paul Marshall: I appreciate the opportunity to talk to this group today. Bill's right in that there are several different issues that make the environment that I work in, and several in this room have worked in the past, quite different from the commercial environment. In thinking about those differences this past weekend, in preparation for today, I recognize that the most fruitful thing that I might be able to spend time with today is, instead of talking about specific technological solutions, to go back to the system engineering approach and try to discuss the factors that I see are most important in dealing with EVA as a commercial concern on some of the future commercial initiatives that may be emerging.

In approaching this, I wanted to point out the major items that I can see, so far, in really just a short look at a very different economic reality here. This certainly is not a list of the only considerations but ones that have affected our decision process in NASA in dealing with optimization of the EVA capability, for example, for the Space Station Program.

The overriding issue with EVA for the life cycle cost of EVA for the space station, is the amount of weight-to-orbit or the cost of weight-to-orbit, as mentioned several times today. That cost is enormous. NASA is faced with those similar realities and the number one thing that we've been dealing with, I guess, in trying to minimize that weight-to-orbit is for the EVA capabilities that we provide for the vehicle, of the weight that we place in orbit for the accommodation for those capabilities, to keep that weight in low orbit. We have a situation at this point where the historical solution that we've used is to allow the transfer both up and back of significant amounts of weight in critical systems hardware, EMUs (space suits) especially. The launch costs and orbit return costs, certainly for the commercial environment, would be very important and the consequent maintenance of hardware on orbit becomes necessary.

Second thing, I guess, is ground processing and ground training. The on-orbit use life also enters into this in the reliability of the hardware, the amount of on orbit spares, the amount of on orbit storage, all of which are very critical parameters. The ground training in our environment has been very cost-intensive at this point. Most of our EVAs are single-purpose. They've required a tremendous amount of training just to get our crews to the point of assuring success for those missions.

Certainly a major suggestion that I would propose to a commercial group such as this is to take a good hard look at the kinds of tasks that are being proposed to be done while in EVA and to the possibilities for standardization of those tasks and equipment. A tremendous savings can be gained not only in ground training but in other areas that I will mention in just a moment.

The third thing is the EVA overhead, associated with going out EVA. Certainly the first parameter, time-to-vacuum as touched on by Mr. Hamilton, is important. The overriding parameter there has been the prebreathing penalty. Other concerns are the maintenance and servicing time, the on-orbit stay time for permanent vehicles (for the permanent basing of EVA capabilities), the amount of maintenance, the amount of servicing time and the amount of human intervention required to effect those things and the consequent acquisition cost of the servicing equipment on board the main vehicle.

For extended missions with a crew based in orbit for very long periods of time, we also see a significant cost of on-orbit training. In the past, at least with the Shuttle system, we have also incurred a significant amount of IV observer time to assist EV crewmen not only in watching for hazards but assist them in conducting the tasks themselves. This certainly is another area of task complexity, where improvements or task standardization are needed.

The cost driver for the commercialization initiative as I see it is EVA overhead. The goal needs to be effectiveness and efficiency of conducting the EVA itself, and to minimize the number of sorties to accomplish the required objectives. How much EVA is required? Again, we must go back and identify the mission and understanding that ahead of time, and how that trades against the nature of the hardware being serviced. It was mentioned several times today, that the interaction or the synergism between the manned systems and the robotic systems, needs to be considered in order to optimize the presence of people in space.

Again, I really can't emphasize more, for a forum such as this, the benefit of standardizing the tasks and understanding the equipment, ahead of time.

And, of course, the RE is the acquisition cost for EVA hardware. We are faced with very large acquisition costs in our world, due to the manrating protocol: the assurance of crew safety and assuring the performance of the systems that we are trying to fly. Certainly involved with this are technology maturity, and the integration of that technology. Going to the cost of the EMUs, I'll just try to deal, very quickly, with those areas that drive life cycle cost.

The EMU is basically a two subsystem device: 1) The suit itself, the anthropomorphic pressure containment system (that provides the dexterity and mobility required), and 2) a life support system. In the weight-to-orbit calculation both are strong drivers. For the life support system, the consumables usage, in acknowledging the economics of consumables availability, would drive you to consideration of regenerable and nonregenerable resources.

Also closed versus open. It's not obvious in the commercial field that's it's necessary to have a totally closed life support system. We have used vehicle-based life support capabilities through umbilicals in the past, at some expense of the crew effectiveness, and the amount of time that we spend EVA.

Certainly in weight-to-orbit increases when ground refurbishment is utilized following each mission. Another way of saying this is that the on-orbit stay time capabilities of EVA equipment are very, very important.

The current orbiter EMU is optimized for a limited mission life. It's reliability and maintainability considerations were optimized knowing that every two or three weeks or in between shuttle missions, the equipment was going to be made available to the highly trained technicians and engineers on the ground who could service it. Certain volume savings and some additional complexity was added to take advantage of those economics. We have a very different environment with the space station program now. We need to maximize the amount of weight that we can keep in orbit, and to reliably operate under those conditions.

In the ground processing area, very quickly, reliability needs to be maximized and the use of limited life components need to be minimized. Maintainability and modularity all help reduce the launch weight characteristics and simplify the on orbit check out and on orbit sizing of that equipment. An issue that the commercial field definitely needs to face in identifying EMU requirements for their own missions is to understand what range of human sizes needs to be accommodated.

In the area of EVA overhead the dominant factor is the prebreathing requirement, as Dr. Hamilton mentioned. Variables which affect this include cabin pressure, suit pressure, and whatever safety factors are considered acceptable for the environment. Really little further needs to be said beyond what has already been said. The principles are clear and it's a clear trade off for the missions involved.

EVA overhead. The overriding factor here is the crew comfort and the effectiveness that the crewman has in the accommodating or accomplishing the objectives: maneuverability, dexterity, temperature control, fatigue, the duration of the EVAs. These factors also affect how often we can go out EVA.

Other very important things are lighting restraints, safety provisions, and other psychological parameters that allow the crewmen to work effectively in the hazardous environment.

In the area of acquisition costs, again, just to enlighten there, the technology selection is key in acquisition costs. The design maturity, the simplicity of the integration, modularity of the integration, all are overriding factors and the factors of manufacturability that this forum is very familiar with also contribute to that. It also is a trade sometimes between manufacturability and some of the other capabilities and characteristics that I've mentioned previously.

Advanced Space Suits at NASA -- *Kurt Lomax, NASA Ames*

Introduction by Bill Stone: Kurt Lomax has made a long trip out here from California. He's working at NASA Ames and is both a marine biologist and a mechanical engineer. He has had experience in center biochemical systems and diving systems, and is currently conducting research in portable life support equipment for the new 8.3 psi Advanced Space Suit at NASA Ames Research System.

Kurt Lomax: This is my first trip out to this part of the country and so far it's been pretty exciting. I appreciate being asked to give a presentation here and will go ahead and start.

The purpose of a space suit is to supply pressure so that your bodily fluids don't escape and cause decompression sickness in the form of bubbles. The pressure, however, is extremely less than the diving problems that the NEWTSUIT sees at a 1,000 feet. What's the pressure, nearly 400 psi? Is that correct? We only have to look at 8.3 psi pressure differential across the suit. It's a very simple task to build a pressure container to do that. So, compared to diving, we have a real simple problem.

Some other requirements are: we have to supply oxygen; we have to scrub CO_2 out of the system; we have to give a certain amount of mobility that duplicates the human body anthropomorphics; we have to provide radiation protection from the harsh environment of the space station, to Mars and the moon.

We also have to provide thermal protection. Here is another difference from the diving industry. Usually divers need to add heat to their system; we have to find a way of getting heat out of our system. When the suit's in space, it's essentially in a vacuum. In a vacuum, its like being in a thermos bottle, it retains the heat very well.

The goals in the advanced suit program were to build a suit that required no prebreathing as is required now on the Shuttle, thereby avoiding decompression sickness; to provide the radiation and thermal protection; and to provide long-term functionality, perhaps 90 day stays on the space station, eight hours a day for EVA. As was mentioned earlier, the cost associated with the Shuttle suit and the time that is required to turn the Shuttle suit around to get it back up on to orbit after only a few hours of use, is astronomical. We need to be able to size the suits to different astronauts in orbit, we had to have a reliable design and reliably reproduce a design that could be easily inspected for leaks, for possible fatigue of the structure. I think we've done that in the AX5.

The problem all along -- from Mercury, Gemini, Apollo, Skylab, all of the moon missions in Apollo and in these advanced suits -- has been the gloves. The suit functions perfectly well at 14.7 psi, or even 20 psi. We had no need to go that high. We pressurized the most critical segments in it to 130 psi before they broke, so the problem's not the pressure here. The problem is using your hands in space, which is the only reason to get the man outside in the first place. So, whether it's the space activity suit, or any of the [other than his/her thumbing ability] proposed suits, the gloves are the problem. Next slide.

This is the AX5, as is. It's all aluminum, hard body. Each element was machined out of solid chunks and the gloves, you can see there, are very inadequate. You can't even pick up a pencil with them. They are just a prototype that happens to fit on the suit right now.

Rear entry hatch: constant volume, has a low leak rate. The Shuttle suit leaks, I am told, about 750 ml of gas per minute. This suit leaks at about 50 ml per minute, although we have designed in a higher leak rate in the bearings to solve some of the problems when the suit is used in underwater simulations. It's highly flexible, in fact you can take the toe of the boot and bring it up and touch it to the chest of the suit. That's how flexible the suit is.

The bearings, as you can see in all of the points, these are rotary bearings, here, here, etc. I think there are 36 bearings in all, each with a double seal, very low torque, and when you bend your arm, it stays bent if you want it to stay bent, whereas a fabric suit has a neutral position. If you bend it from there, it wants to spring back to the neutral position. So you always have to fight it unless you have your arms in a neutral position. This suit has no neutral position -- or you can say all positions are neutral. Next slide.

This is how the suit is made. This was machined out of a solid block of aluminum that started out at 1,500 pounds. When we were done, it was 19 pounds. This could be done in any facility that has a CNC machine of this size. We have the tape, you just walk in and ask "How much?" It uses normal machining procedures. In fact, the thickness of the shell was determined to make it easy: 0.070 inch thick. This is the hard upper torso. You are looking at the helmet and a side bearing an arm hole. We've also proven that these elements can be cast as designed. Next slide.

There are a variety of ways that we can construct the suit shell, to provide us with different characteristics for different environments. The double hulled structure will most likely be needed for the space station environment, to protect from micrometeorites and radiation. We need at least a quarter inch of aluminum to protect from radiation, and if we divide that 1/4 of inch up into two layers and set them a certain distance apart with a vacuum between them you get thermal protection plus micrometeorite protection in that the meteorite has to blast through two walls instead of just one. We've done experiments that determine what's the optimum distance and the optimum thicknesses. Next slide.

O.K, this is not a fake picture. This shows the sizing capabilities of the suit. This is the same suit, two different photographs cut out but as you can see there is a lot of difference. This guy is an engineer that worked on the neutral buoyancy test facility. You'll see it in a minute, I think he is 6 foot 6 inches and she is 5 feet tall. It's amazing, he's got sizing rings here, here along his arms, you can't really see them well, the glove is covering them. There are sizing rings here in the torso, here in the leg and here. Everything else is consistent in the suit, in fact all the sizing rings, ... well, these fit inside these, and then these in the upper arm will fit inside these, and these in the lower arm fit inside the ones up there. So, you can have the entire capability except for the waist sizing rings in a cylinder that is 8 inches round and about 6 inches high, to change from here to here. So storage for different sizing capabilities on this is very small.

This is the Ames version of the Neutral Buoyancy Simulator. We call it the neutral buoyancy test facility. It takes four people to run it: we have the hoist operator, one of the safety divers, another safety diver and a test director, in the form Bruce Webbon down behind the wall. It's 9 feet deep and 11 feet in diameter. It is not quite big enough for what we want to do all the time, but it suffices. I think this was the very first test of the AX5 going in the water.

There are a lot of similarities, in diving like this, to space. The suit's in neutral buoyancy and behaves as if in space. However, the subject that's inside the suit is in 1 gravity. If he is standing up in the bottom of tank in the suit, he is standing up on the bottom of the suit. He is not floating around as he would in space. Here he's lying on the back, and full gravity is pushing him into the back, which makes the suit perform a little differently, but not much. We've done tests on the KC135 and found that there are some significant differences but you can overlook them if you really want to, while you are in the water.

As for cost reduction, you can see that if something can be machined in almost any machine shop over and over again, time after time or cast in a casting facility, cost of production would become very low.

I have to admit that we don't always look a lot at the costs when we are thinking about things at the research facility, and it's hard to imagine getting it below what the NEWTSUIT's been able to come up with. They've got some pretty amazing numbers for their productions. Thank you.

Question & Answer Session: *Orbital Facilities and EVA*

Question: *This could be addressed to either Jim or Max, I guess, because you've both got the same problem. Both of your business plans are very dependent on NASA's Shuttle being able to supply you with launches when you need them. It's kind of like the old story about the second marriage. It might be the triumph of hope over experience. What gives you the confidence that NASA's going to be able and willing to do that?*

Max Faget: Let me say that, for a very short question, be prepared for a very long answer. To begin with, you asked me what gives me the confidence that NASA will do all that, and quite frankly, I don't have very much confidence. As probably many people realize, it's been a very difficult time for our company to negotiate some kind of a deal with the government. We're continuing to try, and hopefully we'll be able to work something out.

As far as Shuttle launches are concerned, we're now manifested for a flight in 1994, in February. NASA will have the fleet of four Shuttles again. They're not doing any more commercial launches, that is they're not launching anything for commercial customers who want to put geosynchronous satellites up, which is one of the things that they were doing, and the military has told NASA that they do not plan to use the Shuttle anymore in the future. Consequently, I do not perceive, until the time of the space station that there will be a great shortage of NASA launch options. As a matter of fact, it might turn out that there will not be enough kinds of cargo to carry now in the Shuttle under the present ground rules at least, to justify the kind of launch rate that I think NASA would like to achieve.

We all know that the main cost of operating the Shuttle is the cost of operations, and that the per flight cost is probably less than the cost of keeping the Shuttle system going, that is the expendables, the tank that gets thrown away, the solid rocket boosters, and the kind of repair work that has to go along with the orbiter when the Shuttle goes. Actually just a few tiles need to be changed out, and other kinds of stuff, primarily associated with things like the main engine and hydraulic system.

I certainly think we can fit within the Shuttle schedule for 3 or 4 flights a year without creating the need to buy another Shuttle, or anything like that. The Industrial Space Facility is a facility that will provide NASA with the opportunity to do a great number of experiments, not just microgravity and material processing experiments, but also engineering experiments and other things like that. We have a great deal of interest expressed by foreign users which would be willing to buy room on the facility if it was made available to them. So we are working to set up a new deal on ISF and I frankly am not going to talk about that at this time because its... I think that what's happened to us before is that we had too much hype and too much press, as opposed to working it out quietly.

Question: I have a question for Mr. Lomax. I've read that in order to provide adequate shielding from radiation, it takes like 9 solid centimeters of aluminum or 5 meters of lunar soil. I was wondering what type of material, and how much you would use in a hard suit? Do those figures seem accurate to you?

Kurt Lomax: I'm certainly not an expert in the radiation environment at the station. We were just talking about this a few moments ago with someone else. To my knowledge, a quarter inch of aluminum should suffice at the space station, but that's just my recollection.

General Comment: You're probably mixed up. It's the radiation environment on the Moon.

Kurt Lomax: Yes, the space station and the Moon and Mars are really all very different radiation environments.

General Comment: There is a radiation belt above the Earth. If you get into that radiation belt, you get pretty serious radiation. If you're beyond the radiation belt, you can get serious radiation from the solar wind and solar events. Underneath the belt, you're like underneath an umbrella. You're in pretty good shape.

Question: Isn't there a routine where you avoid solar flare periods for EVA.?

Kurt Lomax: Yes, I don't believe that that quarter inch, as I recall, has taken into account the incidence of solar flares. I think that's just nominal radiation.

Question: You get enough notice on those to avoid them?

Kurt Lomax: Well, hopefully.

General Comment: I think you get about twenty minutes notice of the radiation from the Sun.

General Comment: We had a solar flare predicting network up during the Apollo mission, and you get something like about 24 hours from when you can first detect these things, both from hydrogen analysis telescopes looking at the Sun and also by radio disturbances which come later. But you look at the hydrogen analysis emission of the Sun. I don't know exactly what they look for but I know we paid for about 8 telescopes that do this, and you can get a warning, an early enough warning of the event. The solar wind does not travel at the speed of light. It's travels at a much slower rate. The particles in there are going fast but they're swirling around each other. Of course, it is more like a wind than radiation. It takes some time to get there.

General Comment: Well, of course, there is the aspect of cosmic radiation. That is what you are required to shield against on the moon for very long times. Presumably, you'll rotate a crew fast enough so that they don't build up; I think it's about 50 rems per year of cosmic radiation, or was the last time I looked.

Question: *Most of these infrastructure type of proposals, whether it's external tanks, ISF, or SpaceHab, all require government participation or acquiescence or the government is a partner in it, some active participation by the government in what is a commercial venture, at least supposedly a commercial venture. Given the sort of great debate that's raging now, to have industrial policy or not to have industrial policy, and what is the role of government, do you see space as falling into that general argument or should space be excepted from those rules. And philosophical debates about the role of government, or what do you think the government's proper role is with respect to things which are commercially speculative, and which in some manner impact the government's own programs?*

Max Faget: That's a very interesting question from a number of standpoints. There is, as you say, there is no strictly what people call a commercial market, where you are either creating a product in space or you're creating a service in space, which is sold in the commercial world on some competitive basis. In other words, we would be competing with terrestrial products and services or other companies manufacturing in space, with the exception of the communications satellites which are now and have been for over 25 years operating on a commercial basis, and operating profitably.

With the beginning of the Shuttle program, and I want to go back to that because that is what started what you might call a new commercial era, where people like ourselves perceived opportunities for some commercial ventures in low earth orbit in space, and incidentally, most of these commercial ventures in low earth orbit in space are also associated with two other factors. One is two-way flight: flight into orbit and flight back down; and also, to some extent or other but not exclusively, some manned participation in those flights. With all of that put together, I think you're right. The situation has not developed as fast as hoped for, where such a thing would take place. As I said earlier, the main stumbling block to that happening has been that the cost of launches has not come down, as it was anticipated that it would be when all this started. NASA was talking about selling Shuttle launches at the beginning of the Shuttle program for $8-10 million a launch, and soon it went up to $12 million and then to $18 million a launch. It's been going up ever since. Now those periods where they were talking $12 million a launch and $18 million a launch, I remember those periods quite vividly, and they were also talking about 50 launches a year, and they were talking about operating the launch system on more of a commercial basis. But they have operated the launch system. Consequently, the cost of what some people term the standing army associated with operating this tab has gone up by a big factor, and the number of launches per year has not materialized as it was anticipated.

So we're at least an order of magnitude off, perhaps even more, in anticipating costs of launching. That does not answer your question. It kind of explains what the situation is. However, if you want to look to the future, in my opinion, we can keep on skimming along like we have, with the cost of launches going up, and I truly believe, they have really gone up. I can remember, at the beginning of the Atlas program, that the Air Force was charging NASA two and a half million dollars per Atlas launch. What they wrapped into that number, I'm not completely sure, but that was the number that we were talking about then. Of course there's been a lot of inflation since 1958. That was when I got that number, 30 years ago, and one could even say the inflation factor was 10, although I believe it was more like 6. But I would love to buy an Atlas launch right now for $25 million dollars, I'll tell you that.

So, we've improved the reliability of our system, but we have not really found a way to reduce the cost of launching. As a matter of fact, we found ways to increase it. What I'm trying to sayis; unless we find a way to inject the commercial culture into the space arena, we will have been one of the outstanding space pioneering countries but we will be in the backwash sometime in the future when space is really in play. And that's about the only reason I can think why the government ought to find some way to subsidize truly commercial enterprises, not second hand, old government launch vehicles that are being launched commercially.

Tom Rogers: I think I have two observations. The first is specific, as far as I have anything to do with it, that'll be positive and absolute, and that is that the External Tanks Corporation is not to ask for any money from the federal government. As a matter of fact, right now, the federal government is into us for money. We had to put money in an escrow account. And the reason's a very simple one. When you get a formal handshake, or go for a formal handshake with the government, in which money is involved, you lose control, completely lose control.

The second thing I would say is that there are two things that I do believe the government can do, and I think the chances are less than unity it can do the first, and it's only now beginning today to do the second. Let me read to you from the National Space Policy that came out the end of last week. Page 60 says "Commercial Space Sector Guidelines: "Utilize commercially available goods and services to the fullest extent possible, and avoid actions that may preclude or deter commercial space sector activities except as required by national security or public safety."

Now I don't think those words are very much different in the Bush Administration from the words in the Reagan Administration, as I recall. They weren't paid any attention to, by and large, in any effective sense by the federal executive branch during the time of the previous space policy, and I don't believe they'll be paid attention to in this administration. I could be wrong, but as Max would simply say, if the federal government, instead of going out with detailed specs and engineering instructions to the world, went out and said, maybe to CANDIVE: "Hey tell us how you would do EVA and tell us what it would cost". The likelihood of that happening approaches epsilon which approaches zero. But, I just simply say it for the record that's what the President of the United States has said. Go to it.

The other thing that the federal government can do, but not now anybody within the federal government is doing, is to try to address the matter of reducing unit costs. The ultimate goal must be to reduce the cost of space transportation. Anybody that's looked at this business at all knows that no matter what else you do, you're operating, at least today, at the margin because the cost is so enormous, absolutely enormous. And it skews around all of the things the engineers would think of doing. It just introduces a rationale all of its own that's irrational because of that great cost.

I don't see the aerospace industry and those elements of the federal government that deal with it in the space transportation area today able to do anything about it. They just can't do anything about it. The Shuttle acquisition program cost $40 billion. And the burden of proof is on anybody in the aerospace industry, to come in and say that you can have a better Shuttle for less money. By the way, it's got to be less than maybe a factor of ten before you can start talking because the amortized cost of the acquisition of the fleet drives the total cost of transportation, not the O&M, which is what you hear about all the time. But I think that there are a lot of things that could be done in the creation of markets up there that would prompt people to enter the space transportation business, maybe the ones that are in it now, but there are a large, a growing number of people that are in the business of talking about making launches for $10 million. But if you talk about ten launches a day to somebody that thinks that getting a launch every two years for $10 million is a victory over all the forces of evil and oppression, you really just break his mind. So what I would hope for is that if you can get private sector things such as the Industrial Space Facility, SpaceHab, and Space Phoenix customers doing things up there, you'll begin to start people in the space transportation area thinking very, very differently about what could be done about cost and reliability and schedule.

And the very last thing I will say, is that if you have the costs come down, there can be very realistic prospects of doing things in space that have nothing to do with the conduct of basic research, nothing to do with exploring the planets, nothing to do with demonstrating arms, doing all of these things. Completely different, but the price has got to come down. That's my opinion.

Question: *I would like you to continue in that vein and be a little bit more specific. This is a speech I've heard and read for, I'm 30 years old, so for 25 years of my life. Everybody says when the costs come down, all these wonderful things are going to happen. But let's make this best case scenario...*

Tom Rogers: Excuse me, we didn't say they're going to happen. What I am doing is describing to you the existence theorem. Unless the costs come down, you can be guaranteed they're not going to happen. I am telling you from where I sit, if the costs come down, all kinds of things can happen.

Question: *I am asking you specifically what's going to happen? Who are going to be the customers?*

Tom Rogers: My first answer is it's none of your business because we are in the private sector, not as one friendly engineer to another. But let me tell you what the zero order answer to your question is. Somebody asked me, I think during the coffee break, the same question you asked, and it goes like this. There are nearly innumerable number of polls that have been conducted of the American people who are dealing with the subject of space. Almost invariably the questions are: "So what do you think about space? What do you think about what's going on? Do you think the Government ought to do more?" The answers to these questions are: "Space is sort of neat, sort of interesting. It's nothing very important anymore, you know, we've got really important problems and opportunities but, in the long run, for the children and maybe new industries, it's fine." "What do think about what the government's doing now?" "It's too bad about what happened to that school teacher, and so on?" "What do you think about Neptune?" "What Neptune?" Good question. " Well, do you think the government is doing enough, do you think it's doing too much?" The answer almost invariably comes out, a third of the people say it ought to do more, a third of the people say it is doing enough, a third of the people say it ought to do less. OK?

Those are all of the polls that you hear about. Those are all the polls that are quoted, and they go up and down by 5 percentage points or so. Now, I am going to tell you about another poll which has been conducted three times in the United States and once in the United Kingdom. The question was different, fundamentally different, qualitatively different. The question was: "What do YOU want to do about space -- not the scientific community, not NASA, not the aerospace industry, not the Soviet Union, but what do YOU want to do about space?"

Do you know what the answer is? I'm pleased to tell you. The answer in the three polls in the United States of America and the one poll in the UK is :"I want to take a trip to space." That answer was given in all cases by between 40 and 45 percent of the adult population.

I'm going to let you in on a secret. Nobody in Washington knows about those polls, or if they do, they don't give a good goddamn. I once met with a great Cabinet officer for whom I worked. He called me up and said: "Tom, I have a problem here". I said, "Sure." We talked. This was four or five years ago. When we were all finished he asked, "What are you doing these days?" I said, "Well I am working on space." He said, "What the hell are you doing that for?" I said, "You know, there are some interesting things..." He said, "Look, I know what you've been doing. You've been wasting your time. Working on space..." And I said, " Well, Bob...", and I told him about these polls. I said, "That's what's turning me on" He said, "You mean to tell me that 40-45% of the United Statesof America adult population...?" I said, "Yep". He said, "That's 80 million people." "Yep." "All adults?" "Yep." "All voters?" "And the government isn't doing anything? I can't believe it. I can't believe it. Washington cannot be that stupid. Since I left it must have fallen into a black hole...".

That's your answer. That's the zero order answer. By the way, take the number 80 million, multiply it by 3, which is the world saying "We want to take a trip to space", adjusting for economics, annualize it by dividing by 20. You're talking about 10 million people a year, going up in space. Do you know 10 million people a year that would go up in space? No, so divide it by ten, aw, hell divide it by another ten, that's 100,000 people a year. The airlines wouldn't know what to do with it even a small number, that's small change. They lose that many bags a week. 100,000 people. Multiply that by 200 pounds apiece, that's 20 million pounds of payload. That's 30 times what we're bringing up every year. So, please, I really do believe in what I'm saying. And as soon as these costs come down, you can bet your everloving bippy, there are going to be things that are going to go on up there that we aren't even thinking about today. You believe it. I'm just not going to tell you. You ask yourself, supposing I could get up there for $20,000. You know what you can tell them. I stayed up there, I paid no more than I would pay for a hotel suite at the Willard or the Plaza on Central Park South. You figure it out what you would do. You can think of a lot of things to do.

Question: What is, or should be the role of the Department of Transportation in space?

Tom Rogers: Well, I don't exactly have a view. I don't know. Anybody here from the Department of Transportation? No, then I can speak freely. I think I gave you my zero order answer, and that is, anybody that's in the business now... Are you a former, you're a former Air Force officer, aren't you? Army? Well, OK, you won't understand this but if you were Air Force... If you were an Air Force man, what you do when you were told about intercontinental ballistic missiles? You knew you laughed like hell or you would go crazy. What if you were a Naval admiral and somebody said, talked to you about submarines that would launch ballistic misses? Very few people who have spent 20, 30, 40 years of their professional life becoming the world's experts in something, can turn themselves around to doing something completely different. And so, my general answer is there probably isn't very much they can do, the people that are there now. As a matter of fact, if you ask about the Department of Transportation, I have had some association with them in the past about air traffic control, and I just decided two things. One, I wouldn't live long enough, and two, I'd walk every time I got a chance. You're talking about trying to get people to do things that are very, very, very novel. We, as human beings, aren't very good at that to begin with, and we were in large scale bureaucracies, whether its the government or whether its MIT, or whether its Proctor and Gamble, or AT&T.

Now I do think that Courtney Stadd's little group in DOT, Courtney was really trying to be helpful, and he did a few things. I heard he was going to be back on the Space Council, I might ask him.

Question: Two points that I'd like to digress with just briefly, if you would. There's a launch services purchase act that is currently before Congress, if you have any comments about that, if you're familiar with it. The second is the possibility of tax credits for investments in space infrastructure.

Max Faget: Well, both of those things will help. Certainly the launch service purchase act is meant to cover a lot. I hope that this will take place, that those launch services will be procured in a completely entrepreneurial culture. But I'm afraid that it will be so wrapped up in the government's peculiar requirements that we won't bring the cost of launch services down very much, just buying launch vehicles. But the intention certainly is proper.

I think the best way the government could bring the launch, cost of launch down right now, is to start a very dedicated program, one that would last for some years, wouldn't be a stop-and-go program, dedicated to developing good rocket engines, liquid rocket engines. Up until now the obsession has been on trying to build high performance, liquid rocket engines such as SSME and so forth, as opposed to building a workhorse engine. No one has got a liquid rocket engine for sale here that the small entrepreneurial company or even a venture launch service company could go out and raise money and build a launch vehicle around.

That would be a low cost answer simply because you have your choice of engines that actually were designed and developed twenty or thirty years ago for an Atlas and a Titan. The idea would be that with a five or six week procurement cycle, you can buy an engine that took about ten or fifteen years to develop. Well, a launch vehicle's the same way. Designing and building that so that you can stick your engine on is piece of cake compared to designing and building an engine. Well, what we do is we put all our future emphasis on designing better launch vehicles. We were dissatisfied with the launch vehicles we had in the past so we (pardon me Mike), such esoteric things as NASP and single stage to orbit and dual-mode propulsion, all brand-new things that are going to solve the age-old problem you can't get over, which is you've got to have the equivalent of 30,000 feet a second to get into orbit, and the age-old solution has been to use two stages. That's the way it's going to be from now on. We have to decide to live with it and make it something that is simple to do and rather inexpensive.

If we had a reusable launch vehicle, and if you're going to make it reusable, you've got to carry the reusability overcoat or whatever it is to get you back down to Earth, as well as the launch system, so that you just take that much off the payload. But still, so you need a system that essentially puts an awful lot of payload in orbit, and you've got to have two stages to do that. I can't see how you can do it with one stage, whether you put wings on it or not. You can fly it up there or otherwise. But if you can do that, and you can make that engine reusable, you should be able to get the thing, in time, down to a fairly low cost operation, if you compare it with the cost now. In an airplane that's built today, a jet airplane that's built today, during its lifetime, the value of the propellant, the fuels, (excuse me, I've got to get back to Earth here), the total value of the fuel that it will consume during its operating life, probably exceeds the value of the airplane ... because they operate six and seven hours a day, and burn a lot of fuel while they operate. I would imagine that if you looked at a launch vehicle from that standpoint, you say, well during its lifetime, it ought to... Essentially when you launch the thing, you're looking at how much does it cost to fill it up with fuel as opposed to how much does it cost to get it up there, or get it on the launch pad where you can fill it up with fuel? If you drive the costs of acquisition, operation, and everything else to be, somewhere even within a ballpark of the cost of the amount of fuel you use per flight, the cost of fuel per flight...

Now an airplane, you fly an airplane, the cost of fuel for an airplane is something like 20 or 30% of the operating cost of the airplane, depending on whether the price of oil's going up or down. If you look at a launch vehicle in that case, and if you'd use reasonable fuels like methane or kerosene plus liquid oxygen, which are fairly inexpensive fuels, you can see that the cost of getting Joe Blow Citizen up on orbit is not too expensive. It's a real cost. It would get down near $50,000. It'd take more than 200 pounds, Tom. You've got to take your luggage, and you've got to bring enough food up there to feed you while you're there. You ought to figure on maybe 500 pounds per passenger. But still, I think that you can get the cost down to maybe even $50 or $100 per pound. Not this century but maybe in 40 or 50 years, if you can ever get to the point where you can convince people that they have to launch millions of pounds into orbit every month instead of maybe a million pounds once a year. And then you can get a vehicle that could be operated time and time again to bring people up into orbit, and bring them back down again. I really think you could get it down, the cost to where the tourist industry, which may be the ultimate driver, which is what Tom said, would really put you in space.

Tom Rogers: In the space business today, you're caught in a Catch-22. There's really very little that goes on in space that doesn't cost too much. If we only do one of everything -- one Viking Lander, one Hubble Space Telescope, one space station -- you can't get the cost of anything down if you buy them one at a time. Imagine what the first prototype in Detroit is, or the first television set. You can't. You've got to have volume. The answer is, always in the aerospace industry and the government office, that it costs too much. Well, of course it costs too much because there's no volume. Now everybody knows this outside of the space industry. The airplane part of the aerospace business knows this. I can remember, you go into aerospace companies, and you talk to airplane people, they know what you're talking about immediately. You talk to space people, they're from a different universe. I'll just stop at this point. We've got to start thinking about volume operations. Volume operations, that allows you to get unit costs down, or conversely, if you get unit costs down, you can think about volume operations. They go together.

Question: *I have a question for Max. Along that same line there, you're suggesting the development of a generic engine by multiple commercial developers for vehicles. Is that the way I read it? And if so, what kind of thrust level would you recommend for such a generic engine?*

Max Faget: You know the details already. There are companies like Space Services in Houston and OSC, Amroc, who have gone out to the financial world, and they've gotten investors to put money in. They're going to provide launch services on a commercial basis, and they're all looking at the same little niche, which is a launch vehicle that might put something up that is in the neighborhood of 1000-2000 pounds in orbit. I think the Pegasus went up to maybe 700 pounds in orbit. But pretty soon, that cracks. These poor people are handicapped, terribly handicapped, because in order to put 1000 pounds in orbit, you've got to have a guidance system, you've got to have two-way communications, you've got to have everything that goes with the guidance system, attitude sensors, you've got to have actuators, control electronics, everything that you need on something that's going to put 1,000 pounds in orbit. From a cost standpoint, it's a hell of a handicap. From the weight standpoint, it's also a handicap. Of course, the actuators will be bigger for a big vehicle, but the same kind of amplifying electronics are required, the same kind of inertial sensor is required, so these people can't make the big launch vehicle because they can't afford the liquid rocket engine, because they're too expensive. Now if the government wanted to do something, they could get an engine. I really think that unless you're talking about something that would put maybe 100,000 pounds in low Earth orbit, you're not going to achieve the full benefits of scale. You could maybe compromise on 50,000 pounds in orbit, which is about the ALS kind of number that the government's talking about.

Question: I mean, they already have the closest equivalent you can get to a mass production engine. That's the RL-10 which is about $2 million, or somewhere in that ballpark. But that's obviously not enough to make your launch, so how much higher than that do you have to go?

Max Faget: The RL-10 is an excellent engine. The burn's cool, you can operate it a long time and you can operate it many times before you have to tear it down. It could be scaled up probably without a lot of cost. It's a good engine. I don't know whether, in mass production certainly the cost would come down. What is needed is a comparable hydrocarbon burning engine of some kind or other. We all have our goals. I'll tell you one of my personal goals is: I'd use methane. Methane and oxygen, they're very compatible because they have virtually the same volume. You don't have to worry about one fluid creating a problem with the other if they're in thermal contact, and also methane is a very inexpensive.

Question: Just as an aside... on the RL-10 engine, they did do a design a long time ago for a 200,000 pound thrust version of the RL-10 where they directly scaled it up, and that had something like... relatively simple scale up.

Max Faget: Well, I don't know. I don't know that much about that. I thought there might be trouble scaling up the RL-10. I would imagine for technical reasons, it's tough to get much above 60,000 pounds, but 60,000 pounds is plenty. You put three engines of 60,000 pounds and you do great.

Glen Taylor: I just have one comment. You were talking about tourism in outer space, and in the diving industry right now, in the last two years, there's been something on the order of thirty tourist submersibles produced and marketed around the world, where we're taking people on submarine rides for $100, $200 a crack. You get to go to 300 feet of water, then 1500 feet of water for a couple of hours, and there's a huge market there for that. That's why we're looking at building a one-man submersible for $30,000, and we expect to see them hanging off the back of many of these big yachts you see down in Miami or anyplace else. There's just one hell of an industry out there for taking tourists on trips. And, quite frankly, we'd rather do that and make a lot more money at it than we would going down the insides of pipelines.

CHAPTER TWO

CHEMICAL LAUNCH VEHICLES

Introduction - *Richard DalBello, Office of Space Commerce, DOC*

I've been going to space conferences for about ten years now and there's been a dramatic decline, not the energy level but in the happiness level of these conferences. I think it began particularly around the Challenger time, people have been getting increasingly morose, ever since. I think I want to suggest that it be mandatory that 20 percent of all space conferences have an undersea component, just so that people can look at something that is actually going on energetically and that all space conferences have to have Tom Rogers as a speaker.

Well, now we come to the part where you get the bad news. Which is space transportation. You've heard everyone tell you that it's got to get cheaper. Well, I'll tell you the punch line right now, it's not going to get cheaper very fast. There is a tremendous amount of work going on, we've got three different people, who are going to tell you three different things, very interesting in that they're coming from completely different areas. We've got several major programs going on: the Air Force/NASA Advanced Launch System Program, which is a way of looking at the whole system, taking all that we know about advanced materials, advanced technology and all we know about operations based on our past experience in trying to drive the cost down.

We've got NASA's Shuttle C program, which you are going to hear about tomorrow, which says, hold it, even if you leave the costs alone, and you dramatically increased what the vehicle can carry, you'll reduce the cost per pound. That's another program you'll hear about.

You'll hear about some exotic technologies tomorrow: the Ram Cannon and Laser Propulsion. There's a lot going on but there's no magic bullet out there yet.

Today we are going to hear three different interesting cuts. We have Bob Lindberg from Orbital Sciences, who's going to tell us about the Pegasus Launch Vehicle, and what Pegasus is looking at, that is, marketing small satellites. What they are basically doing is saying: "We are not going to reduce the cost per pound. That's not the problem we are focusing on. We're going to solve a different problem. We are going to look at the function on orbit. How do you get the function on orbit for the most reduced cost?". That's a very interesting question, they've got a very interesting solution.

We have Ekerd Winerick, from Arianespace who is with us. The tack they are taking is: "The vehicle's going any way and someone else has already paid the tariff: can we fit on secondary pay loads or can we adopt the Ariane vehicle to carry mini satellites, another exciting topic".

Finally, Ed Bock from General Dynamics is going to tell us a little bit about how General Dynamics participation in the Advanced Launch System Program, the Air Force/NASA joint program, has been proceeding and I think some of the novel integration and operational concepts they've been working on.

Our next speaker will be Ekerd Winerick, who is the Director of Engineering of Arianespace here in the United States. In that position he is responsible for marketing and sales in the U.S. of the Ariane launch service. Mr. Winerick has been with Ariane since 1983 and since 1988 he's been assigned to the headquarters here in Washington. He is going to discuss minipayloads and secondary payloads.

First, thank you for the opportunity to be here. I am replacing Dr. Doug Haydon who is unfortunately very busy today and he asked me on Friday afternoon to prepare something on this subject. I have no handouts but if you are interested, I will make some available.

As to reducing costs to the degree just discussed, I do not know if I carry the answer here. But we have figured out how to achieve extra performance from the range of vehicles we have. This slide shows an overview of the family, involving Ariane I, II, III, that have flown in the past. We are now flying on the Ariane IV series which comprises six different versions. We anticipate upgrading to the Ariane V in the '95 or '96 timeframe. So, currently, we will speak about this family of vehicles. If you take the commercial markets and existing spacecraft, we have adapted the launch vehicle in such a way that it mates either in single launch mode or in dual launch mode to one or two spacecraft existing on the market right now.

It is curious how the spacecraft evolved. There are sometimes single launches which are under manifested in terms of launch vehicles, so that we thought it might be useful to offer the extra performance on the market, and so we tried to figure out how we could do that. This is basically what we found out, in terms of categories. We have the usual categories, I speak in tons, and not in pounds, sorry, between 2.2 tons and 4.2 tons which is the example of the last launch, Intelsat VI class spacecraft, the Hughes spacecraft, and they are built by the well-known, main spacecraft manufacturers.

In the middle and the second part are the 1.2 and 1.8 ton payloads, an example of which is the PAM-D or PAM-D2 class. Then we come to two categories of satellite and I think Pegasus [Orbital Sciences Corp., Ed.] knows these very well: first the minisat class between 200 and 600 kg and then the microsatellite, 50 kg. We wanted to try to find out whether we could do something for microsats or minisats knowing (and I should say this first), we are not at all interested in this business as a commercial business, we do it purely, we build it in a way that we recover our development costs. It is for us not at all any commercial business as it might be for example, for OSC or some other companies.

We have also developed a solution called ASAP which stands for Ariane Payload Adapter, and I would like to go first through a few photos. They speak better than words. On the upper part of the launch vehicle we have a dual launch structure which utilizes the same adaptor. You also find it on a single launch vehicle on the third stage where this conical-shaped adapter was the point where we thought it would be useful to fix a horizontal platform. This is the solution we have now offered and a few customers have taken the opportunity of booking a launch. It was the EUROSAT from the University of Surrey in the United Kingdom. This was a small satellite of a mass of 40 kg, with a limited dimension, which is limited by us in terms of payload volume. They use it for communications, and technology demonstration for storing and forwarding digital communication.

The second one which will fly on our platform, which by the way is now rescheduled for January 14, is the microsat from Amsat, which is well known, or I should say that Amsat knows Arianespace well since we have already flown two bigger Amsat spacecraft in other structures.

This is also a very small spacecraft. You see 10 kg, very reduced size. That's what it looks like. We do not yet have a photograph, because the spacecraft are still in preparation and not yet mated. You see the SPOT, the Earth observation satellite and around it are these six spacecraft on the ring structure.

Another view of the structure, on the plane here. We attach a ring here on the third stage and it's rigidified in the area of the small spacecraft, where you see the hole.

Another view of this, you see the ring structure this time, introduced into what we call the outer cone, on which we will fit the fairing or the dual launch structure. Basically the spacecraft will come here with another adapter, conical shaped, and the small spacecraft will be placed here.

This was the first approach we intended to fly. These missions generally are suitable for low earth orbit at 700 km circular, Sunsynchonous orbit, as for SPOT. This is number two. SPOT number three will fly in '92. Then we have another mission which is a mission joint NASA/French space agency mission which is called Topics/Poseiden which is a 63.5 inclined orbit, also about 800 km, so you see very few very low altitude missions, so that I cannot right now say, whether we willbe able to offer a lot of opportunities, but who knows? Tomorrow there might a candidate for another low earth orbit mission and we can offer six places.

That is the first solution. The second solution was to say, the launch vehicle itself is designed for GTO. It's an overall system which is designed once at the beginning for GTO, 200 perigee and 36,000 km apogee orbit, inclined at 7 degrees. That is the standard orbit with the standard Ariane launch vehicle. We could offer also extra payload capacity for a nominal GTO launch and you know possibly that we have a lot of them because we launch many communications satellites which go first to the GTO.

So we said, if somebody is a candidate for going to GTO, either remaining on GTO or then later on, circularizing itself into the GSO, we could also offer the remaining payload capacity. We thought it could be called minisatellite. The same voice which took OSC with Pegasus was also the thinking of that because we said the current generation of communications satellite might be too big. In fact, it's not true, if you speak with people like INTELSAT, GTE, AT&T, these customers think that the existing size of satellite, of spacecraft will remain as it is. But there might be a few applications where these satellites, in any case would be too tall, too big and too heavy. For this solution, we thought there might be a possibility, and I would propose that to you. I also have questions for you, would that be a solution for you to fit on Ariane? The technical specification, if you wish I can give you them in detail. Basic environmental conditions are the same then for the main payload. That means the characteristics of the launch vehicle remain the same in terms of thermal and dynamic environment.

We have also developed this "saucer". The height is 1 meter, and I will show you what it looks like. Same principal or nearly identical for the ASAP platform. The ASAP platform was fixed here right here somewhere, in which case the adapter was directly here. In this case here, we rehoist the adapter and leave roughly 1 meter in between at the disposal of a cylindrical structure which also disposes of a volume for possibly solar panels or antennas or things hanging around. Also thinking of possible geoinsertion with a small AKM, we thought it might be useful in this case to have space available for an AKM, whenever this is needed.

So this is our proposal to the world of small spacecraft builders, whoever they are. This might be interesting for Fairchild or Marconi. At the time, years ago, Marconi talked about the same concept. This solution could also be implemented with a Titan or with Atlas. It is not in my opinion, a unique Ariane solution. Using an AKM, completely integrated and in this case, we could fly two of those small spacecraft.

I will also tell you our constraints. The constraints for this solution, coming from this solution, is once again mass limitation. That means that you will have an overall mass of 600 kg for 60 to 80 kg payloads which the mass here will come essentially from the heavy cylindrical structure able to support this 3.8 tons. Why 3.8 tons? That is our single launch payload capacity.

Question: *Excuse me, before you take that slide off. What is the diameter? It's not 1920 meters, surely.*

Ekerd Winerick: No, no sorry. It's 1.920. You could use already flight-qualified, 1920, or 1,920 mm diameter separation interfaces which are already qualified on our system. So, two things are qualified right now. Two separation planes, this separation plane and this separation plane are qualified. It's available through Arianespace, or could be developed or bought directly, purchased directly by you from the builder. I think it is Aerospaciale in France. This is the payload volume. So you have an exterior diameter of 3,500 mm, then a smaller section 1,935, that's essentially around the separation interface.

That is our proposal. In terms of price, the price is $600,000 for the six spacecraft. It will be possible that for the next flights, having amortized the development costs, that we will lower this price, which, as I said at the beginning we do not expect to make money with that.

The second configuration is a little bit more expensive. Why? Because we induce certain constraints on the main passenger which is really the paying passenger. First, the minisatellite should be inert or transparent as we say, with respect to the main payload, with all respects including separate radio links during launch phase and things like that. In this case, the price comes from a step, the jump between two configurations. Remember we have different configurations of the Ariane launch vehicle. If the additional required payload capacity makes us a jump from a 42p to a 44p, you pay for two boosters. That's basically the philosophy. If we go from four solid boosters to two liquid boosters, you pay the difference. That's basically where the price comes from. Once again, here you just pay what we have to change in terms of launch vehicles.

Question: *Would you clarify that microsat price?*

Ekerd Winerick: $600,000 for six. We have six places on the platform.

Question: *And all six places, you get that for $600,000, or is that $600,000 a place?*

Ekerd Winerick: $600,000 for the whole adapter. That means $100,000 per payload.

Question: *Except the first guy pays: he pays $600,000? Unless there are two people. It's $600K for a ride.*

Ekerd Winerick: In any case we will not fly with just one spacecraft on it. We have to put dummies on and in that case it is not efficient.

That's basically our solution. A final few pictures: That is the inner ring where you see the equipment, the brain of the launch vehicle, and exterior cone, the internal cone, the spacecraft would be that, on a dual launch mode, would be this shape, but sitting a little bit higher.

This is a view of the GE Astro satellite. There you see the dual payload structure just to familiarize with the constraint you might have. If you are inside this part here, you sit underneath, behind that. That means your integration is over once this ring is lowered and fitted to that. So that's an operational constraint. Once you leave the preparation buildings you are completely inert. You are sitting here somewhere behind, and this will be lowered, the whole composite here is going to be lowered on to the third stage. And that's another view of the third stage, being lowered with a payload fairing and the upper composite with it. Then you go for roll out. You are always without contact at that moment. You have a few hours during the transfer where you have no contact with your spacecraft but it is a controlled environment.

I'd like to talk a little bit about the Advanced Launch System today, and to reinforce some of the comments that were made by this morning's speakers. I first want to start out with some slides, talking about, "Why does the United States need something like an advanced launch system?"

I think there are three answers to that question. The first is, to: significantly reduce the time needed to place national security assets into earth orbit. Right now integrating a spacecraft and getting it launched takes anywhere from 3 to 9 months. When you are talking about the ability to see and hear what is going on in troubled spots in the rest of the world, that's too long.

The second one is the one we've talked a lot about today, and that is, to: significantly reduce the cost of space launch systems and significantly means at least an order of magnitude.

The third one is: if the United States plans to be a space transportation provider in the next century for other than our own government, we need to do some serious things. We cannot live with 30-year old launch vehicles. We are doing very well, but we can't live with 30-year old launch vehicles forever. We either have to rebuild them piece by piece or we need to start with some new concept that significantly reduces the cost and keeps those costs competitive.

Can we do this without something like an advanced launch system? I think the answer to that is "no". We're making a lot of improvements in our old launch vehicles, but when you are dealing with 30-year old technology there's a limit to what you can do. It's a practical limit. You can continue to improve those until you've essentially got a brand new launch system. I guess we could do that, but I think that's a fairly inefficient way to do it.

Why? Why are we in this situation? Because our current launch vehicles were designed, literally, without any consideration for cost. We are modifying them now with cost considerations in mind, but initially they were built with costs as, at least, a third order situation at best.

Haven't we previously tried to improve operability and lower launch costs? No, not as a driving requirement for a new launch system.

The next slide amplifies on that just a little bit. Where have our launch systems come from? How were they developed? The first ones were all ICBMs, Thor (now the Delta) Atlas and Titan. These were all performance-driven vehicles, they all had single payloads, which were strategic war heads, they all were operable from a standby status, they were not designed with any consideration of cost really, they were all performance driven.

The second category of launch vehicles, which are no longer with us, are the Saturn class. These were safety driven. No flight failures were to be tolerated, and that was a national priority, national prestige program. It had a very rigorous ground and flight test program to make sure that goal was achieved, as it was, and cost was not a constraint. There are some very interesting stories, when you talk to people who were dealing with NASA and Congress at that time, that NASA came in and said: "Here's what it would cost" and Congress said: "Yeah, you're sure that's enough?" Can you imagine that happening in today's environment?

The third category is launch vehicles that are specifically developed based on demonstrated new technology. I put the Shuttle in that category and I think most NASA missions fall into that category. These are typically reusable, and man-safety driven. The bottom line is that when you're using launch vehicle development as a platform to demonstrate new technology you usually have high risk and high cost. Eventually, in a second or third generation, using that technology you become cost effective. But the first time out of the barrel, the chances of that being a cost-effective system are very, very small. These things should be done, it's an important way to focus technology, but we shouldn't expect those systems to be low cost the first time out of the barrel.

With that, let me discuss ALS a little bit. The integration concepts that will be discussed today are all basic tenants of the Advance Launch System or ALS. ALS is being developed by an Air Force/NASA and contractor team as America's next generation transportation system. The basic goal of ALS is to meet a broad range of our 21st century cargo launch needs with a more reliable, much more operable, and significantly lower cost system.

How broad a payload range? We'd like a launch vehicle system that encompasses our current Shuttle capability of about 40,000 pounds to low earth orbit up to as much as half a million pounds to low earth orbit. Who knows what the future holds? We need a launch system which can handle a broad range; we do not know what kind of capability we are really going to need.

How reliable? If the cost of failure is included, in other words if you worry about how much a failure really costs, a launch vehicle reliability of between 0.98 and 0.99 is required to obtain a minimum cost system. The Shuttle was down for 2-1/2 years after its failure, Titan was down over a year. Considering all the costs associated with the stacked up payloads, inability to fly the missions you have to fly, the cost of getting back on line again, that's extremely expensive. Assume therefore, that including the cost of failure, you need a very reliable system, 0.98, 0.99.

How much more operable? Put that next slide up, please. Current launch vehicles typically take nine months, integrating launch and payload. ALS needs to do it within one month. Vehicle time on the pad is not to exceed five days. One way to get operations costs down is to reduce the amount of time anybody has to play with it.

Figure 1 shows some of the operability features needed to satisfy the Air Force mission assurance goals. This includes the operability requirement, 90 percent confidence of launch, 95 percent of the time, the ability to fly through failures and provide search capability. We typically tend to operate most of our systems now utilizing their maximum capacity. When we lose a payload, it takes us first of all a long time to get back up operating again, and when we do we can't fly off the payload backlog. So we need to get back on line again, and we need to fly off the payload backlog at a faster rate. We need to be able to launch on schedule. I've covered the other things.

The third question is how much more affordable do we have to be, how much less expensive. Congress has mandated a goal of $300 dollars a pound of payload to low earth orbit. This is at least in an order of magnitude reduction over current launch vehicle payload prices.

The challenge presented by these goals is not trivial. To meet them we certainly must be innovative, and in fact our approach probably has to be revolutionary. We obviously must make substantial departure from our current methods, and the basic culture of launching rockets must change. Can I have the next slide please.

Culture is perhaps the most interesting problem facing us. This was talked about this morning. I think it's taken us at General Dynamics about four years now. About a year ago, three years into this basic program, we finally understood that cost had to be the major driver in going about this. We've all talked about low costs systems before, but we don't design for low cost. We typically say: "Well, yeah that's something we ought to think about, it's a good thing to do".

About a year ago we came to the conclusion that low cost was the focus that had to be used to design a launch vehicle for the next generation. The engine companies had a worse time than we did. They have now understood, finally. NASA I think is still struggling with the concept. We have been performance driven in this business for 30 years, and everybody knows that we are always performance driven and it's tough to get people to change their minds. You can't ignore performance, but you can't let it drive everything you do.

Operations need to be streamlined. Vehicle integration and most check out must be accomplished in a factory, that's the Final Assembly Facility, FAF, way in the background there, under process controlled conditions. We tend to want to build our rockets on the pad; we've got to quit doing that.

The distance between the factory and the launch pad must be small to eliminate concern regarding the vehicle's condition following its transfer. We literally build most of our launch vehicles twice. We build them once in the factory, take them apart, ship them to the pad, rebuild them on the pad and usually go in and violate most of the systems to see if they're still OK. We've got to stop doing that. On-pad checks must be simplified and automated and performed without intrusion into the vehicle's operating systems. Don't repeat factory checks. The number of people involved in launch site operations must be significantly reduced. Routine automated events and check outs must replace tests. We must eliminate rocket scientists at the launch site. Got to stop having folks in white coats crawling over our launch vehicles. Now the slides indicate some of the features I have already talked about: maximum off line, in parallel processing. We need to make sure we treat the operations that we do in the launch cycle just like we do vehicle systems. We have assigned reliability to them and understand exactly how those are being met.

We need to do things like installing and checking out rise off umbilicals in the factory so that it is a completely integrated system and all you have are hard connections, once you get out to the pad. So the rise-off function has already been checked out in a controlled, process environment in the factory.

Clean pad. As soon as you put a service tower up there, you'll have people crawling all over it and all kinds of other things and you'll lose control. You need to have all major services going through the base of the launch vehicle and you need to try to minimize the number of payload services that you provide and those should be standardized. That's a tall order because until now the payload community, the spacecraft folks, have literally dictated what the launch vehicles provided us. This is another big cultural change that's going to be tough. I was glad to see that Arianespace is showing folks what kind of payload volume they can use for a low-cost ride. We need to do the same thing on interfaces, and services for spacecraft and say: "Here's what you've got, see if you can make your spacecraft fit that". That's going to be a tough cultural change.

Continuous health monitoring from the time we initially check out the vehicle in the Final Assembly Facility all the way out to the pad and on to launch.

The challenge presented by these goals is not trivial. I've indicated a whole bunch of good things to go do here. That's fine, these are all lofty concepts, but how do we achieve them with a system as complex as today's launch vehicle? The answer to that is, "by consciously designing the system to be a lot simpler". Fairly straightforward, easier said than done, and in certain instances, elegantly simple.

Many of you probably remember the big dumb booster proposed by Aerospace Corporation in the late 50s. The basic idea was that a very large vehicle could be cost effective if its basic design was sufficiently simple, simple as in pressure-fed engines, steel plate propellent tanks, etc. ALS has adapted the big dumb booster approach by designing for low cost rather than high performance, but has updated what the big dumb booster design did to take advantage of the technology that has matured and has been proven during the intervening 30 years. This chart shows a pretty good comparison of some of the things that were done in the big dumb booster design that have been adopted by ALS. Some very simple things: structured stable tanks, large design margins, streamlined operations, rugged engines. The big dumb booster design used storable propellants, we've gone with hydrogen/oxygen. Thirty years ago, hydrogen/oxygen was brand new technology, it's not any more. Hydrogen/oxygen gives you inherent good performance, and is environmentally clean.

Pressure-fed engines, we've gone with low-cost pump fed engines, a gas generator cycle. There is no test experience, no test history with large pressure-fed engines.

There are a couple of things we've done that the big dumb booster couldn't do: engine out from lift off. We have engine out capability through the entire flight. We start all the engines on the pad, all the engines on the pad on parallel burn vehicles, I'll show you in a minute, start all the engines on the pad, monitor their health, make sure they are all working correctly and then release the vehicle for flight. That essentially doubles the effective engine reliability, because the transient start up is one of the big causes of engine unreliability.

These inherently high-performance propellants, hydrogen and oxygen, are used in all stages of the vehicle. This provides the flexibility needed to incorporate cost-reducing design and processing changes into engines, valves, avionics, actuators and other high-value components. What I mean is thaton a high-value component, you can afford a performance hit in weight, in higher speed, in engine and chamber pressure as long as that performance hit on that component drives the cost of that component down enough so that the equivalent upsize in the vehicle you need accommodate for that reduced performance in that component gives you a net lower cost. We've looked at processing, manufacturing techniques on engine components that reduce our costs by a factor of ten. It has been done by Pratt and Whitney, and Aerojet. There have been in some cases 4, 10, 15, 20 percent weight increases associated with that. The vehicle has to grow, you can carry more propellants, but the engine cost reduction is a lot greater than the rest of the vehicle cost increase. So you end up with a net cheaper vehicle. You can do the same thing on avionics, valves, etc. That's what we are trying to do.

Technology such as built-in tests and health monitoring are used to automatically perform vehicle check out. The next slide shows the dramatic advantages that can be obtained compared to the manual techniques used on the 30-year old launch vehicles today, the use of automated check out techniques and built in tests. What that essentially says is that you can get an 84 percent reduction in the amount it takes to do a typical check out which you incorporate with built-in tests. Built in tests are tough to incorporate on today's existing launch vehicles, because all the flight components are qualified and those sensors are not built in. So that's something we can do on the next generation of launch vehicle.

We've also made the vehicle's basic design much simpler, by using parallel rather than serial stages, all engines can be ignited on the pad. By using pad hold down, engines can be fully checked out before the vehicle is released and committed to flight. Even so, we have designed for full engine out capability from lift off. These actions substantially improve mission reliability.

Travel stages also permit a high degree of core and booster commonality. We use identical engines, **identical engines**, on both stages. That's not optimum, that's not performance driven, that's cost driven. Avionic actuators and fluid system components are also identical on core boosters. Identical propellent tank volumes and diameters on the core and booster provide a high degree of structural and fluid system commonality, not necessarily identical, but commonality. Put the next slide up, please.

Parallel stages also support a family of vehicles approach to accommodating future payload growth. Multiple liquid boosters: four are shown here, you can theoretically put on up to six, can be attached to the core, to increase payload capability to half a million pounds. You can use stage-and-a-half vehicles on the low end to do the low end payload capability. This concept cost effectively supports little return or modest exploration initiatives.

The family of vehicles concept also provides another interesting benefit: all of our current stable of existing launch vehicles have become performance driven. Most of them were to start with, but they've all become performance driven because payload requirements have steadily grown to exceed current vehicle capability. This helps keep launch costs high because vehicle modifications to accommodate steadily increasing payload demands is expensive. In other words, you get into a closed loop: every time we increase vehicle capability, payloads grow, and then we have to go through and find more performance in that vehicle. The Atlas has been through about six or seven major performance improvements, engines, more propellants, etc.

It's interesting to look at the MA5 engine, which is what the Atlas uses, and I think the thrust level now is twice what it started out to be when that engine was initially developed. Other existing launch vehicles have the same kind of history. That's very expensive. Both the nonrecurring costs and the fact that you have got a performance-driven vehicle. Very expensive.

So, by adding a family of vehicles, like this, you can stay out of that mode. By designing the family knowing that you always have another configuration when the payload grows, you can go to the next most capable family member.

Will these innovative concepts allow us to meet ALS goals? Based on the work performed so far, the answer is "yes". Basic changes to our approach to launch vehicle operations are made possible by a simpler cost-driven vehicle concept that can capitalize on maturing technology or mature technology. That makes our goals realizable. We must try to stay out of the trap of using brand new unproven technology which increases the risk and usually drives the higher cost. ALS offers an opportunity for the United States to be the major world-class space transportation provider in the 21st century.

To emphasize some of the operability features of what we need to do with launch vehicle systems, I brought a tape which was put together by one of our competitors, Boeing Company, which also is working on ALS. I want to give credit where credit is due. They have used a very nice technique of comparing air craft operability with launch vehicle operability. The contrasts are rather startling, and I think the tape is worth watching. It's a 7 minute tape. If you could roll the tape now, please. I think it's a nice visual but there is a real message there too, we've got to change the way we do business, we've got to make it more routine.

Rich DalBello: Why don't we open up to questions here. If I may take the chairman's perogative and ask the first question. I happen to be a big fan of the ALS program. I wish it were a commercial program, rather than a government program. I realize that there are certain problems there but one of the questions you always hear people ask about translating government's needs into the commercial range as well, transferring the government's needs into commercial launch service contracts. What if the government was willing to make its needs to say, for the space station or moon, Mars or some other large initiative available to you in the form of a commercial contract? Would you respond with a commercial vehicle, versus something beyond your capability at this point?

Ed Bock: I don't think so. Right. The government is known for it's lack of constancy of purpose, particularly in space. I think we'd be hesitant to invest the kind of money involved in a new launch system without some kind of guarantees. I think it's been talked about already, a lot of our key transportation elements over the last several hundred years have either been subsidized directly or indirectly by the government. Whether or not that's appropriate for something like ALS or not, I don't know. That's the path they started down, whether or not they'll continue down that path is to be determined. It's also a very complex decision: whether or not something like ALS can survive in much more restricted budget [Subsequently, the ALS program was cancelled, Editor], is anybody's guess.

Rich DalBello: One more quick question: Assuming that an ALS kind of program goes on and that eventually a contract is let and someone actually builds one of these, what happens to everyone else? If you do the things that you say you're trying to do, does everyone else go out of business?

Ed Bock: We are not really aiming at the low end of the vehicle launch market at all. The smallest we've looked at is about 20,000 pounds of payload to earth orbit. Any lower than that, and you run in to severe problems. We are not talking about the real low end, we are talking about probably, from practical standpoints, 20,000 to 40,000 pounds to low earth orbit as the low end. There's still a lot of room for entrepreneurship.

Rich DalBello: You've just put your major competition out of business?

Ed Bock: Well, that's OK. That's probably not OK, but the approach on the engines is constructive. Three companies are working on the STEP, Space Transportation Engine Program, for ALS. It's going to be a modular engine, much like a jet aircraft engine, major pieces of the engine are built in mass production runs separately, then the engine will be assembled and fired as a total integrated engine. So it looks like there will be a chance for all three of those engine companies to be major players in production of that engine. I think the Air Force intends to take a similar approach to ALS. Right now, the three contractors who are working on ALS are General Dynamics, Boeing and Martin Marietta. Martin Marietta has teamed with McDonnell Douglas. I think their intention is to somehow, through some process, have everyone have a piece of that action. Now, how do you do that and maintain better competitiveness of performance to keep the costs down, not to incite them, those goals? It's going to be a real challenge for the government to structure that kind of program.

Question: *Do you have any comments about Soviet launch capability, any kind of lesson learned about their systems?*

Ed Bock: Yeah, the Soviets are interesting. Their satellites don't last very long, and they have developed the capability of replacing satellites very quickly. I guess we have evidence with some of our reconnaissance that they have gone from having nothing on the pad to having launched something in less than 24 hours. They've rolled out horizontally, cleared the pad, fully integrated the launch vehicles, right from the pad, put in the propellants, and did the launch. They did that in 24 hours. I don't remember the numbers but during the Falkland Islands crisis, they put an incredible number of payloads up in one month. They fully reconstituted all of their communications, intelligence gathering satellites over the Falklands, to see what was going on. Of course, at that time we couldn't launch anything. It's incredible what they do.

The horizonal versus vertical processing is interesting. That's a whole other story. Turns out, that the reason they use horizontal is because they are not in Florida. It's cold where they are, and they have to be inside, and buildings that are tall are a challenge. It's cultural: they went horizontal to stay out of the weather, and we went vertical because it was nice and warm in Florida. We build on the pad for that reason, because it's warm, and they're built inside because it's cold. Very interesting.

Question: *Does ALS have requirements for manned rating?*

Ed Bock: We have a requirement that says that we should not preclude manned compatibility. Which means launching a manned space craft sometime. It's an unmanned cargo launch vehicle but if somebody decides to put manned cargo on it for whatever reason, we are not supposed to have a problem doing that. We've looked at that, we really don't have a problem.

Question: *Both you and the video tape said 10 or 12 minutes to orbit. Can you clarify that, please, I don't believe it?*

Ed Bock: It takes 10 to 12 minutes to get to orbit! The first stage burns about 65 to 68 seconds, then there is a short coast period and then the second stage burns also somewhere between 65 and 70 seconds. I don't have the precise numbers off the top of my head. Then we coast for about 8 minutes. When we are doing that coasting, we are trading off velocity for altitude, and so when we ignite the first stage, it will go into low earth orbit, when we ignite the third stage we'll already have orbital altitude but we are subnormal in velocity, the third stage burns for again about 65 seconds and at the end of that 65 second burn you are in a normal altitude, normal velocity orbit.

Tuesday, November 21, 1989

CHAPTER THREE

PAYLOADS AND INSTITUTIONAL ASPECTS

Introduction - *Cary Gravatt, NIST*

This morning I would like to continue on the subject of cost reduction, and looking at a series of subjects which didn't group together quite as well as launch vehicles, and extra vehicular activity as we did yesterday. But all touch on cost or offer approaches to reducing cost.

Our first speaker this morning is Joe Engelberger the father of automation robotics and machine processes, which not only have played a significant role in the development of robotic activities and machine shop functioning in this country, but are an important component of work going on here at NIST at this time. You may have noticed all the posters over here on the side as you walked in; if you have a chance, you might enjoy reading them. Just last week we had a three day meeting on AMRF, that's the Advanced Manufacturing Research Facility which is our automated robotic machine shop and test bed for the machine shop of the future. It was built in large part by the developments of Joe Engelberger and in some way supervised, though not directly, but at least overseen by him since he served on visiting committees and evaluation panels for the Bureau for a number of years.

He is the founder of the Unimation Corporation, which was the manufacturer of Unimate industrial robots. Subsequently, he sold that to Westinghouse. Westinghouse still manufactures it, as far as I know. Joe then took a brief leave of absence and formed a small company, Transition Research Incorporated, which is still looking at robotics and automation and the services that can be provided and he has been very prominent in describing his thoughts concerning robotics in space and the opportunities that affords. I think this talk will tie in very well with what we saw yesterday for the undersea exploration and some ideas that we picked up there. I would like to introduce Joe Engelberger.

Thank you. Ladies and gentlemen, I would like to set my scene by quoting Arthur C. Clark, he said:

"... *Creatures of flesh and blood can only explore space and weight control over an infinitesimal fraction of it. Only creatures of metal and plastic can ever really conquer it.*"

That's the theme. Before I add some flesh to that idea I would like to give you two anecdotes. In January of 1986, I was the speaker at a workshop, the Robotics Workshop, Johnson Space Center, and I discussed the technologies and the opportunities for robotics and that being a dinner talk, I thought I'd make light of it, in a way, and I said that, "You know, in the industrial robot field, we try to save money. We try to prove there's economic justification for the robots. We look to try to get a payback in less than three years. By your own numbers it is costing $35,000 an hour to put an astronaut in space and $115,000 an hour if that astronaut were to be out in EVA". I said, "I happen to know that you have designed this Shuttle so it takes three people to fly it, but I don't think it takes congressmen and school teachers to fly it". And then I said, "Suppose we take four people out of the Shuttle, and we robotize their activities and leave three in it. So, that says, on a five day mission, with four people out, the payback would be something like $20 million. That suggests that it would be a very simple calculation: we pay for our robot in the morning".

After I gave that talk, two of the big guns, in this field, Rubenstien and Thompson of North American and McDonnel-Douglas came at me, and they said, "You've got a long hard day before you get us to put any robots into any of our vehicles. We're going to build that space station, and we're going to build it the safe way, with people". January 28th, one week later, the Challenger exploded.

Now another anecdote related to the same thing. Before I spoke, I was given a VIP tour of the facility at Johnson Space Center which was fascinating with a full scale shuttle and experiments being run with the RMS, the Robot Manipulator System. I was particularly impressed with the simulator. Because in the simulator you can sit in the control house and, just like in a flight simulator, you had panels which showed you the scenes outside and you could operate with two control sticks, first the arm and then the end effect with the other control stick and I was told that every astronaut got 100 hours of training in that simulation unit to understand how to run the arm. It was wonderful because you could not only operate the arm and see where it was in front but you could have what they call, "God's eye view". You could look at it, in simulation, from a 1,000 feet above and look down on how it was working.

They told me that Sally Ride had 300 hours of training because she was the designated operator of this robot arm. They were very proud, and they said when she came back, you may recall just during the flight before the Challenger, Sally Ride was up there, you may have seen on television, this big hunk of frost was out on the side of the shuttle, and she used the RMS to knock that piece of frost off. When she came back she took trouble to go in to see the people in the simulator room and she said, "You know, when I was up there, it was exactly like it was in the simulator, I just wanted to thank you for the wonderful training".

Now, my argument is, if it was exactly like it was in the simulator, what in hell was she doing up there, why wasn't she down here doing that.

In the NASA tech briefs of this month, November 1989, a Martin Marietta VP for FTS [Flight Telerobtic Service, Ed.] is quoted:

"... The FTS will enable astronauts to direct routine assembly and maintenance work without leaving the shuttle or space station".

Why are they up there?

Now there are arguments. One of the arguments is, "Well, if you are down here there's a transmission lag time". It can vary from a half a second up to two seconds. Sometimes it has to go through a booster station. So in that range a half a second and two second delay, I don't see any reason why the thing shouldn't be preprogrammed and have the astronaut sitting on the ground and monitoring what is happening in those programmings. Two seconds is not bad if you are just overriding something that's already been preprogrammed. The data range of information coming back, I believe is 300 megabits, so what we should have our astronauts do is sit in a nice comfortable lounge suit, like William Shatner, and watch the robot and have his hand on the red button and then periodically say, "Now a little left, a little right".

My charter today included talking about the state of the art. For that I'd like to use some slides, just to make the argument that robots have made their mark and these are all things that the robots are now doing. All the software is in place and all the hardware is in place and any industrialist who is not doing these things and a few others by now is undoubtedly losing money.

"Fettling": It's an English word. It covers a multitude of sins: it's grinding, polishing, buffing, fur removal, all those things lumped together is fettling. It makes a shorter list. That's just one place where robots are now seeing heavy use.

I am not supposed to hawk anything here so I will leave that to MIT Press, but this slide and next one is the index of a book called: <u>Robotics in Service</u> that I have just written. It's important for this discussion to say that this is where we are with these technologies. It is the growth of research in sensory control systems, anatomy, and artificial intelligence that will give robots a better chance to do their thing.

I am personally distressed by what I consider to be NASA arrogance. Somehow because of vast amounts of money they think that it's possible to transfer this wonderful technology, that will come out of space research, down to some terrestrial place. I think that with less arrogance, they would consider that the flow of technology should go both ways. There are a lot of things happening down here which could be very powerful if transferred up to space.

I believe that the source of the misconception, as best as I can reconstruct, is that NASA, being absolutely innocent when it went into robotics, asked, "How did this all happen". Well, the first thing they saw was that the nuclear field had something like robots when they had remote manipulators. So there was the man and this loop and he manipulated in an unstructured environment, pouring chemicals and handling dangerous objects at a very, very slow pace. So that must have been first.

Then, a little bit later came these autonomous devices called robots, but that's a more advanced thing you can't have that right away. So what we should start with is telerobotics and then they said, "Well, what better than telerobotics. Why not have the astronaut stick his fingers into gloves and let him feel what is going on out there and put a helmet on his head that displays the scene and we'll virtually transport him to where he is working without having him go there, and we'll call that telepresence."

I have a story that I tell people, I say, "If you ask a NASA researcher in robotics where is left of the area, they will say it's right over here". It's the hard way and it's not the way to do it. The way to do this is to say that the robot could be preprogrammed for everything, one of the other arguments here is, "Well, it's an unstructured environment". It's true it's hard for robots to deal with unstructured environment. But I doubt there's anything with a better data base than the thing that we send up to space. That's another misconception: it's not unstructured, it is one off. There's a big difference between unstructured and one off. You could try everything down here, put the programs into the robots and monitor. I'll show you some more about those, show how that is done.

Another thing that we'll have to look at is the EVA characteristics, where we think we need astronauts in EVA. I've heard from NASA's own figures that they can look forward to about two hours in every 24 hours of productive work from an astronaut put into that hostile environment.

It happens that, in my youth I was a diving officer in the Navy and I learned in a hard hat and gloves how terrible it is to get something done with three fingered gloves. All I've been told is that it's much more difficult in a space suit. I am going to come back to the space suit.

See, what I suggest is that we take this FTS concept and we use it in the robotic mode. Now, the minute you do that, you could make those robots a lot less expensive. You need less reliability, there isn't anybody to be hit by the robot, you need less safety because there aren't people involved, you can use redundancy, you can use redundancy in the gross case. Have a lot of cheap robots. In New England we have a concept that is called a "cultch pile". You probably all have cultch piles too. You know, you have a little piece of wood left over, you have some wires left over, you kind of stuff them away in the back of your brain, remembering where in the cellar you got these things, and when you need it, you stick your hand in the pile and you pull it out.

Maybe that's the way to build a space station: shoot the stuff up there, tether it all together. When you have a robot that has something wrong with it, put it on a tether, hang it off the side and use it for spare parts. Have a lot of them. You know the only thing that the robot eats is power, doesn't eat anything else, doesn't create any waste.

Let me give you some examples. This is the second part of this book. These are the kinds of things and service applications that I think represent the tremendous challenge for robotics. Terrestrially you'll see that there's "power surgeon", "power nurse", "fast food attendant", "gasoline station attendant".

This is a picture of the first man ever who enjoyed brain surgery at the hands of a robot. There he's gone into a CAT SCAN machine. There's his head from the other view, his head is locked in that ring and as he's moved through there, a doctor sits at a monitor and he puts a cursor where he says the tumor is. Now computation goes on to tell that robot arm in coordinates of the tool in the hand, in those coordinates where that tumor is in the man's brain. The robot moves down to the spot. The doctor, of course is monitoring, he is in charge, he is a neurosurgeon. He knows what he saw in the picture. He knows what the robot is doing when the robot gets to the right place he decides, "Yes it's OK to drill a hole".

That's the first picture with the robot's finger in his brain. After that hole is drilled, the doctor, that device you see there, sets up a shoulder at the right height so that when he puts the probe in, whether it's a biopsy need, a radioactive medicine, or what have you, it goes to precisely the right location for depositing the medicine. I saw the 26th procedure a few months ago. The neurosurgeon said he can do the procedure in 40 percent of the time that it would normally take with stereotactic frames set up to do this. He said he hits the spot to within two thousands of what he's after. When the procedure is over they effectively put a band aid over that 1 mm hole. Now, if you look at what that is, that's a vision system. That's what a CAT SCAN machine is, a vision system, and a robot arm doing something very, very precise on human tissue.

The same procedure, this is just a mark up now, but the same procedure has been used now for spinals. This is very interesting from the point of view of space. The patient goes into a CAT SCAN machine and they determine where the disc is that they want to inject the medicine, or the filling material and the patient comes out and the robot just puts the needle in the patient's back. Now, the problem is that patient's been breathing. And even though he or she is strapped in the chair, it might not be in the same place, when it gets out. So they put the person back into the CAT SCAN machine and they find out where the needle is with respect to where the doctor wanted it, and then the patient comes out. Because the doctor has such a close correlation between those two points, he can physically move it that little bit to get it exactly where he wants before he injects the substance. Out of the five times that it has been done, three of them required no correction. But for two of them the doctor had to move the needle.

Now let's look at what that means in space. Suppose you program the robot down here to do a procedure, and it was under 1-g conditions and they get up in space and there's been a shift, it's called a frame shift in robotics. All the astronaut has to do is to say, "Yes, that's not quite right, I'll move my camera around a couple places, look it over, do a frame shift and now let the robot carry out that same program."

Just to continue, this is a program sponsored by IBM and The University of California at Davis: how do you do a bone joint replacement? In this case they're using a robot and this is an industrial set up to begin with. That's a bone femur and it is being drilled out under computer aided control to be the mirror image of the prosthesis which will go in there. The problem today in putting in a metal part hip replacement, is in producing a precise socket. They put cement all around it since it generally does not match. After a few years that cement breaks up if the patient has been active at all and the whole operating procedure has to be repeated.

When this is done with robotics it'll fit so tightly the bone will grow into porous metal and you won't need any cement at all. You're not going to do that operation with people, with doctors, certainly not with astronauts.

This is a stationary picture of a simulation that we did for NASA and Boeing. What happens if you want to use robots in inventory management? The logistics module was a scale model of a section of a logistics module with different size containers. The inventory, I believe, was 10,000 items for the space station. Obviously this is a 1-g terrestrial thing. The black ring is supposed to represent an airlock. The two industrial robot arms of this nature have hand-to-hand coordination. They have cameras on their wrists, so they can open any drawer and look into the drawer, pick out the items, put it in a post box, bring it to the airlock, give it to the astronaut (in the shirt sleeves). In the environment, it can also take big experimental containers out in their entirety and pass them through, and I think it is one of the clearer things that NASA has adopted, managing 10,000 pieces of inventory, knowing where they are all the time is just an ideal computer/robotics activity.

Well, this is only one of the many many sketches of what the space station at one time will look like. It's my contention that it could be built by robots. We are supposed to try to think of what you can save.

Let me start out. It's my understanding that FTS now has budgeted something like $303 million. I hear numbers of up to $800 million to complete the project. I know that it started out at $120 million, but I don't know how much has been involved in astronaut safety, in reliability of just having a few of these, and in creating this thing so that it works with a telepresence. For example, I know an awful lot is being done to make the thing stiff, from a dynamic point of view, and I am quite confident in space you can deal with a more flaccid structure. If you use sensory perception on a robot, rather than a human in the loop, the only thing you really need is low hysterises, high resolution (because in sensory perception you close the loop) around the sensory perception.

The Environmental Control Life Support System, (ECLSS) had a budget increase from the $307 million to $401 million this year. At the same time it was being stripped of capability. The closed loop, the life support system, was supposed to be regenerative. Now that's been abandoned. Some habitability goodies have been taken away. There's no trash compactor. The trash compactor has been deferred, the refrigerator/freezer, the washer/dryer, the dishwasher, they've been deferred. One expects that the showers are still on board and the human waste collection is still there. Not only has this cost gone up, but the launch weight has increased by 6,600 pounds and the resupply, because it's not a closed system anymore, has gone up by 2,470 pounds, every 90 days.

The cost of putting people up there is not only astronautical, it's astronomical. We ought to get off the preconceived notion that astronauts are essential. What has happened is that NASA has grudgingly accepted the robots because they will add to the astronauts capability. In fact, I've heard recently there's some statement now that it's even a little bit more attractive than that, "We don't think we can get the whole job done in the amount of time available to astronauts, and therefore, we really will need the robots". If we had only assumed instead that robots are essential and we gave them all the capability we can, we'd have a much lower cost system.

Suppose Congress would issue an edict, "You can have a space station but you can't use people to build it or man it". Would NASA quit? Would we not go ahead with a space station?

I believe what has happened is that NASA and others, certainly not NASA alone, have what I call a Colosseum Syndrome. They're quite confident that if no one is being thrown to the lions, no one's going to come to the spectacle. They must fear they can't get their money if they don't put people at risk.

You know, I look around here and this is a pretty small audience. How big do you think this audience would be if we were talking about contracts we were going to give out? That shows you what the problem is. What a dull subject it is, saving money.

Anyway, I want to offer some hope. The Air Force, for example, is getting its licks in and some discussions and joint efforts are being conducted with NASA. Now look, they have to do maintenance, they have orbits which are entirely different than the low earth orbit of the space station. We've got to go there with robots. When you have to do that, and that's the only way, that's the direction it would go. So time, as the thing drags out, time is on the side of robotics. If we were to do this wonderful thing of cooperating with the Russians and decide that we're going to Mars and bring back samples, I think the Russians would lean to using robots.

I even think that, at this late date, with maybe a couple billion dollars behind us, you can change this mission to be unmanned. It could still be done without losing very much of the past expenditure. You know, right in this shop, NIST has done some excellent work on the control architecture, there's something called NASREM, the NASA/NBS, prior to NIST, Standard Reference Model for Telerobot Control System Architecture. This is very good stuff. We are happy with it too in a terrestrial mode that the hierarchical control is a very good one and the fact it pays lip service to this telepresence means nothing to me, because it's excellent as a way in which to operate an autonomous robot.

Well, as I read the situation now I am encouraged and I give you my last slide as a measure of my encouragement. Thank you.

Question: Can you discuss future robotics that will be used by SDIO?

Joe Engleberger: Well, I was saying the Air Force position is very logical in doing the supervised autonomy and that's the way to go. There's no question about it. I don't know why we don't do that, but it can be done. You take a thing like surgery, that's supervised autonomy.

Question: Say we could get a hanger up there, about 27.6 feet in diameter, long enough to put things into. Couldn't you put some relatively cheap robotic emulators inside there that would be protected from all elements of the space environment except the microgravity and hard vacuum, couldn't you put, as you say, a number of relatively cheap ones in there that could be manipulated from other parts of the space station and work from the ground? They could do most of the tasks preparing things?

Joe Engleberger: Part of the robot program in space will include robots in the controlled environment for some of the inside tasks. You know, the astronauts spend a bulk of their time taking care of their creature comforts. They've very little time left to do any work. So therefore, if you use robots, and we did (we had a group that studied this for Boeing as one of the different tasks we could do inside) remember the minute it's a robot it's not so tough. The space environment compared to the tremendous spectrum of things you have to face in industry, is defined very, very clearly. It is true that an astronaut could be up there in another location. That's this time lag business. We have to have him up there to run the robot so we don't have a time delay. But I'd say as long as you can have the astronaut run it, why not have the astronaut down here.

Question: It's like running for a fly ball. If something is moving you have to have your timing just right. Then the time delay is a problem. Once you get something fixed, where it's not going to drift away from you time delay goes away as a problem, it stays there. What I was saying, therefore, is the problems now that we are looking for EVA, if we could get them inside, then we could use robots which are developed right now, we wouldn't have to modify them for the space environment, thermal extremes, the radiation, etc. We could put a bunch of cheap ones inside ...

Joe Engleberger: The only distinction would be because payload is expensive, you would probably make the robots lighter than they are right now. Industry just will not reduce that much weight to put a robot into space but it's not so difficult to do. Another reason, for the same reason you said, you could take very low forces and move very large masses and get them to the places so that in theory we could have robots inside the vehicle or outside the vehicle: just don't drop anything. You know, move it to the right place and fasten it in that place, have the robots have three appendages so that they can move around so they don't have to float to space. They can always be moving themselves and moving things around. There's no reason why you can't have vast memory of everything you can possibly imagine. Try it down here. Then you can always up link it. Suppose you suddenly have something happen up there and we didn't think of it before hand. Stop for a moment. Don't do anything right now, sit tight, now we go back to the laboratory. We take our FTS or the littler one that you're talking about and we generate a new program. So there's no time lag problem, we generate it, if we like it, beam it up. Now we sit and monitor it and watch how it does that. So the human brain is in this loop, it's just doesn't have to be real time in the loop.

General Comment: I would like to make one observation and try to make it seriously and gently. You started by quoting Arthur Clark. I don't know the precise source of the quote but 500 years before the birth of Christ, the Greek poet or playwright said: *"Man is the measure of all things, Man is the measure of all things"*. All technology, the kind we are talking about at this moment, or others, is used for one or the other of two purposes. One, to allow a man or a woman to do what they are doing, better; or to relieve that man or woman from the burden of doing it so that man or woman can to do something else. I think that it's time that this awful, wasteful argument about man and machine could be dispensed with. What you are doing is invaluable. But it drives people who are trying to put people in space for their end, not a means, to an end, crazy. And for no good cause. What you are doing is absolutely valuable, but I don't think it should be interlaced with the, "If people want to go to space they must be nuts". That's the only reason why we are doing things in space. The only reason.

Question: One more question on your robots for EVA, where do they get the power? I mean, do you attach wires into the space station or how do you get power to these robots and how do the robots know where they are?

Joe Engleberger: Well, there's a lot of technical issues there. But certainly, an umbilical cord gives you quite a sphere of influence there. You could certainly use transmission communications to tell you where it is. I can tell you on terrestrial terms that we have a robot that knows every place in a hospital that's 12 stories high. It has a map on board of the whole hospital, drives around, avoids obstacles, calls elevators by itself, goes up and down elevators, talks to people and so forth. I admit, it has gravity going for it. But, up in space, it can use its vision to find out where it is, and the power, if it is not umbilical, could be through battery support. One of the things the FTS will do in due course is be mounted on a vehicle. The vehicle will be jet propelled to different locations to do its work, and that's important. When you have more locations to get to, that's a navigational thing which is not dissimilar from navigating an entire vehicle. So you control it to get it to where it's going and that's part of it.

Battery power would handle an awful lot of manipulation tasks and where it needs an awful lot of power it can do exactly like we do now. It goes home and recharges.

Question: *Suppose you were a private company who is considering operations in space. You want to build a private habitat or something like that. If you had to pay for the bills, what operations would you consider right now to be tractable with robotics and what changes would be necessary in industrial robotics that are available now in order to do those tasks?*

Joe Engleberger: Remember the first thing I said. I am not going to make a habitat at all. I am going to start out by saying that I want to do the experiments that we want to do up there with only robots doing it. That changes the whole game plan when you do that. There's another thing, another example to consider. We have something up in space doing an awful lot of experiments right now. It's called "Long Duration Exposure Facility". It was put up there by the Challenger. (By the way, the Challenger is not around to go gather it.) I believe we've got to go pick it up by February of 1990 and if we don't pick it up by then it'll have drifted too low for space Shuttle safety reasons to go get it. So we will lose the whole thing. I would say a nice project would be to take an unmanned vehicle, to go up and rendezvous with it and deliver only one thing: deliver a power module so that we can boost it back up again to a better orbit, give us more time. Unfortunately, it was always planned to be gathered up and brought back rather than to take the information from it alone. If you built it in the first place to take the information, you probably wouldn't get the all those sample sheets back that the kids in high school are going to play with. But you'd probably get the data. If you start out and ask, "What are the things we want to do other than to have peoplein space?" You know, one of the things that a Congressman just said was, "I think the space station is the greatest scientific research facility". On the basis of the last word I've heard from NASA, it has become the most expensive recreational facility.

Go ahead in the first place and ask "What is it you want, give me the experiments you want to do." For those experiments I think can be done by robots in that facility, we'll task to robots. Now they won't be existing industrial robots because it's just terribly wasteful in weight. There are some other things to consider, such as in zero gravity you want to be able to hold on. You will probably need a three arm robot that'll have the same capabilities that FTS has. For work inside the vehicle, it will need to have appendages no longer than human appendages.

Question: *What do you think something like that would cost a private company to develop?*

Joe Engleberger: Well, let me say this, the bill now for the FTS is $303 million to develop it. It would be a very good investment for the government at least, to give someone else a competitive charge such as: you build something we can use in space, and it will not have telepresence; it will not have astronauts; it will not support astronauts; not require any safety; and, I want you to spend 15 percent of what we have for the FTS". And I am telling you they'll come up with something very, very good, whoever would have that charge.

I haven't ... because we lost the contract. The orbit maneuvering vehicle could have been operated from the ground as well as space and that could have done the mission that you talk about on the moving satellites and capturing it, refueling it, and doing all these other things.

Payload Sensors - *Carl Schueler, Hughes SBRC*

Introduction by Cary Gravatt - I would like to take a slight excursion here in the next two talks to look into the consideration of components that go in the space craft to do a particular function. The first of the two is a look at sensors. My first exposure to sensors, no pun intended, had to do with the Landsat Program. I became familiar with Hughes Santa Barbara Research Center, the organization that had developed the Thematic Mapper on the Landsat system, Landsat 4 and 5 and is currently participating in developing sensors for Landsat 6. The thematic mapper is a mechanical and electronic marvel, as big as a desk and most of the people that described it to me who had seen it operated or operating, or heard it operating in the engineering test model in Santa Barbara, said you wouldn't believe that the thing would work. There's a mirror slapping back and forth, I forget at what rate, but at a fairly rapid rate, which leads me to believe that Santa Barbara knows quite a bit about the development of sensors. Recently they've been doing a considerable amount of work not only on highly sophisticated senors but looking at smaller sensors for a particular application and in general reducing the cost of the sensors that are used in space.

Our next speaker is Carl Schuller. He is with the Santa Barbara Research Center. He is the Manager of their Advanced Development Program. He has a Ph.D. in mathematics, he has been associated with Hughes, and another organization for a considerable period of time. I look forward to hearing what he has to say about his and Hughes' work in sensors.

Carl Schueler - I'd like to point out that I was appreciative of receiving from Dr. Stone, a letter describing, in essence, what we were supposed to present at this conference, in outline form. I was most appreciative of that because I wasn't sure precisely the nature of the talk that was desired. Fortunately there was an outline contained in that letter and I was able to generate an outline based on that one which I think follows the formats that have been discussed so far in this conference.

It was pointed out to me that the audience may or may not have a background similar to mine. In many cases, you will not be familiar with the specific technology that we work on in Santa Barbara Research Center. So, I would like to spend some time discussing that technology before looking at the cost angle. My particular background has been on developing sensor concepts that meet certain performance requirements.

There are a broad range of sensor technologies. Our background in Santa Barbara is primarily associated with one major facet of sensor technology, so I'll start by reviewing, very briefly, the range of sensor technologies that one can consider and then focus on a representative sample that we know something about. Cary, referred to the Landsat Thematic Mapper and that's a representative specific sensor within the broad category of electro-optical images with which we are most familiar.

Now I'll move on to look at the applications associated with the use of these sensors and the requirement trends, that is, what are the current customers are asking for? As we progress in to the future, are we moving towards more advanced concepts or are we able to take advantage of the existing designs and therefore keep costs actually moving downward or are they going upward? Within the discussion of those technology trends, I will try to identify cost implications and to make some specific recommendations that we feel may be most applicable in terms of developing sensors and keeping the costs down.

Well, as I mentioned at the very beginning, there are a number of technologies that are associated with the development of sensing systems for space applications. These four include, active microwave radar, many of you are familiar with radar, the concepts include scatterometers and synthetic aperture radars. The scatterometer in general is a real aperture radar. A radar that simply operates very much like a standard optical camera, except it uses relatively very, very long wave lengths, and it's an active system. It sends out a signal, it receives a signal return echo and then defines information about the object that's being sensed by the echo. Very much like sonar that was used in WW II, on submarines, except this is with electromagnetic signals.

The synthetic aperture radar on the other hand, contains very, very fine resolution using the long, relatively long, electro-optical/electromagnetic wave lengths associated with radar signals. Some of these wave lengths are in the meter range, yet using very, very large apertures that are synthetically generated over the orbit of the space craft, one can obtain unusually high or fine spatial resolution down to the exact centimeters, if designed.

But I won't talk about those. Because that's none of our business. Tacit microwave sensors are very similar to the active systems that I just described except that these are passive systems that receive emitted, long wave electromagnetic radiation from the ground, long waves in the centimeter range. They are just outside the range of thermal energy. These operate very much like the passive electro-optical systems that I am going to speak about except just in a slightly longer wave length regime.

Sounders and surface radiometers used by the National Oceanic and Atmospheric Administration are typical of these particular types of sensors. Active optical sensors are systems that operate in much the same way as the active radar systems, except that the electromagnetic energy that is sent out as a pulse and then retrieved back as an echo are very very short electromagnetic wave lengths, in fact, visible wave lengths, and the system is usually some sort of laser system so lidar is very much like radar.

Scatterometers and altimeters are typical types of gadgets used in this particular category. The altimeter works basically by sending out a pulse of light and measuring the time of flight of the echo return from space to ground, therefore getting an estimate of the altitude. These are accurate to within centimeters at an altitude of several hundred kilometers.

Finally, passive electro-optical systems include nonimaging spectroadiometers and imaging cameras and multispectroadiometers. I am going to talk primarily about this particular aspect of the four sensor categories.

These particular instruments are much more common to our every day experience. Their average SLR camera is a good example of a passive, electro-optical sensor. All four of the sensor categories share a common base of technology and design principals. It varies in technology, mechanical structures, and cooling systems which are required in almost every case. Power subsystems, and electronic systems generate heat, and have to be cooled. In some cases the sensing elements, particularly the thermal infrared sensing elements associated with some passive electro-optical sensors, have to be cooled to very low temperatures for noise reduction reasons.

Power systems and electronics are used across the board for radars, for lidars, for passive microwave instruments and passive electro-optical sensors to convert the sensed electromagnetic energy into electrical signals and then to convert those electrical signals to digital signals that can be transmitted to the ground. Precision mechanical propellants are used in all four sensor categories and finally sensing elements of some kind are common to all four.

The design principals associated with developing concepts in each of the four categories are again common. Ray tracing analysis associated with the development of optical systems, even in the very long waves, associated with the meter range, synthetic aperture radars or in the very short wave associated with ultraviolet electro-optical sensors, is a standard design procedure.

Dynamic structural analysis usually using computer models such as NASTRAN or CADCAM have to be used in all categories of sensor type.

Finally, analog and digital signal processing and analog and digital control system theory are used for any one of the four sensor types. As a result, in principal one can talk about any one of those four categories and one is talking about development technologies that are common across the board. So it's not necessary to discuss all four, and of course it would take a lot longer than 20 minutes to do so.

Passive electro-optical sensors satisfy two criteria: first of all they are representative, it's a representative sample of the four sensor categories that I mentioned. Then second, Santa Barbara Research Center and Carl Schuler are most familiar with this particular category of sensor technology. So, we'll focus on electro-optical sensors for this particular talk.

Cost control is both important and at the same time quite difficult in the context of the electro-optical sensor technology development and I think this is probably true of the other three categories as well. Cost control is important because passive electro-optical sensors are popular. There are quite a number of advanced missions being proposed or having already been approved for NASA and the National Oceanic and Atmospheric Administration as well as other agencies of the federal government and commercial operations that are contracting to us a substantial number of passive electro-optical instruments. So it's important to try to keep the costs of development of those instruments, and the launch of those instruments as low as possible.

The earth observing system, the EOS, is the monitoring component of global change for the United States. A part of the mission to planet earth, the earth probe missions that were mentioned yesterday are also planning to use electro-optical sensors. The planetary program, such as the Cassini mission, which was just approved, I think the week before last, will use a number of different types of passive electro-optical sensors. The National Oceanic and Atmospheric Administration (NOAA) operates the National weather mapping program and the geostationary platforms that provide the daily TV news reports with information on the clouds, and dynamics associated with the earth's global weather patterns. All these programs use passive electro-optical sensors as their base, therefore cost control is quite important.

Cost control, however, is difficult. The reason it's difficult is that every time there is a new mission requiring a new sensor, that sensor has to perform better than its predecessor on that similar mission, almost in every case. But in any case its spatial resolution and pointing accuracy has to be improved substantially, at the same time radiometric accuracy, that is the accuracy with which a passive electro-optical sensor can measure the light that is emitted by the earth in long wave lengths or is reflected by the earth in the short wave lengths, has to be very fine.

Finally, spectral discrimination. The accuracy with which the instrument can measure electro-optical energy in very, very fine spectral intervals of the color spectrum has to be improved. Improvements in all three of these categories are particularly difficult. It's one thing to improve in one category and be backlogged in others. But to ask for improvement in all three is particularly difficult. This increase in demand for performance naturally means a better quality sensor and that makes cost control particularly difficult. That's often the way.

For those of you who are not familiar with passive electro-optical technology, Cary mentioned one particular instrument: The thematic mapper. Here's a picture of the proto-flight thematic mapper. This is the thematic mapper that is mounted on Landsat 4, which was launched in 1982. Landsat 5 was launched in 1984. This thematic mapper therefore has been in orbit since mid-1982 or about seven years. It's still operational.

I was one of those people, Cary, that was standing in the back lot of the Santa Barbara Research Center in 1982, in February, when we were testing the engineering model thematic mapper in the back of a moving van. We mounted it on a moving van, set it up on a turntable, took it out to the East Sierra Nevada and took pictures of the mountains, including Mt. Whitney, from the back of that truck, with the engineering model thematic mapper, the instrument that was built just before this one.

In that scanner, which is located back here, you can see where my hand is pointing, this instrument is pointing downward. That is this area right down here, it's the entrance aperture;

that's the lens of the camera, pointing that way towards the ground. This back here is the radiative cooler that cools the long wave detectors in the cold focal plane of the thematic mapper. This thing right here is called the earth shield. The purpose of this earth shield is to prevent heat from the earth from getting to the radiative cooler. The radiative cooler is pointed, of course, away from the sun so in effect, towards cooled space.

The aperture here points to the ground and scans the earth by means of a scanner, which Cary referred to, and Cary said that scanner was climbing back and forth at a frequency of about 14 times per second. It makes a lot of noise. It goes clackety clackety clack just like that. It's hard to believe that something like that could last for several months, much less seven years. But in fact the instrument has been in operation for seven years and is still operational. So is the instrument on Landsat 5.

Landsat 6 will have an instrument very similar to this except for just a few improvements in performance. In particular, a finer resolution and chromatic band that will provide 15 meter resolution as opposed to the standard 30 meter resolution provided by this instrument.

For those of you who perhaps have not seen imagery from one of these instruments, I thought I would show you examples of imagery that can be made with the thematic mapper and with some of the other instruments that are either in orbit, or proposed to be in orbit. You can see some of the improvements in the quality of the performance of the instrument that I was talking about from these pictures.

This is a simulation of imagery from Landsat 6 taken by digitizing 1 meter resolution aircraft data, taken over the Washington,D.C. area. If you squint your eyes, you can sort of make out some details. For example, right down here, you can sort of see that's the Pentagon. If you try real hard. Up here you can sort of make out the Washington Mall area. Well, at 30 meter resolution of course, things are blurred out quite a bit. So one can improve that if we go to the resolution of the French SPOT system at 20 meters then we can more clearly make out those two details that I just pointed out. The Pentagon in the lower left corner and the Washington Mall at the top center.

Finally if we go to 5 meter resolution, which is associated with a proposed sensor that was discussed in a recent Office of Technology Assessment report on commercial news gathering from space, we in Santa Barbara Research Center proposed the design for a very simple but very fine resolution instrument. Simple because, although it provides very fine spatial resolution, the instrument was designed for very broad spectral capability and relatively coarse radiometric accuracies. The instrument was a small and relatively inexpensive concept in spite of the fact that it provides such fine resolution -- much smaller, in fact and much less expensive in fact, than the thematic mapper.

The thematic mapper weighs about 550 pounds, about the weight of my Honda 750 motorcycle and it's about the same size. Whereas the sensor that would create this 5 meter imagery could be a much much more compact instrument weighing perhaps less than 100 pounds.

Spatial resolution is not the whole story. Spectral signatures are really the key to the application of these kinds of sensors. Spectral signatures are explained in concept by this chart, I think in a graphic way that is easy to interpret. As you can see, vegetation, soil and water have different spectral characteristics. Vegetation has a strong reflecting speed just beyond the visible light spectrum at about 1 micron. The visible light spectrum extends out to about 0.65 micron in the red and, as you can see, vegetation has another small band in the green and that's the reason vegetation looks green to our eyes. But vegetation doesn't look green to a thematic mapper. Instead vegetation looks infrared to a thematic mapper because that's where the strongest reflection peak is. If our eyes could see out to this range, then we would be able to see this reflecting speed.

At any rate these reflected curves distinguish one characteristic on the ground from another and that information can be used to distinguish information at fairly coarse spatial resolution. One particular application is crop identification. This set of pictures here will illustrate the application of the spectral discrimination capability with the thematic mapper using alfalfa and sugar beets in the Orange County area just below the Salton Sea above San Diego.

Over here at Band 4, which is about 1 micron, we see two fields that look identical. In Band 5, which is measuring the light relfectants from the ground at 1.65 microns, instead of about 1 micron, we see that the relfectants of the alfalfa is higher than the relfectants of the sugar beets. This is due to the water content of the leaves in the sugar beet plant that lower the relfectants at 1.65 microns. So, with the spectral capability associated with the sensor, we can discriminate one crop from another.

With that introduction to the concept of use of these kinds of sensors, let me take a look brief look at the applications. The applications extend beyond news gathering, which actually perhaps has not been used, as a proposed application, I don't know if it will ever become a reality. Those of you who have heard the various discussions about this concept of using these sensors for news gathering perhaps will understand the difficulties associated with that application. But there are a lot of other applications that have been used and are being used by NASA and the National Oceanic and Atmospheric Administration, very actively, over the last 20 years, and are planned to be used extensively, over at least the next ten or twenty years, in Hughes' Earth Observing System Program and others.

Common and important applications being funded by NASA and NOAA include: Atmospheric applications to measure cloud cover; to measure particle and aerosol content in the atmosphere and so forth, and land surface applications, such as the one I just illustrated with the crop identification example, using imagining radiometers; volcanic and oceanic applications, using thermal radiometers and visible imaging radiometers for plant identification on the surface of water using the blue visible range of electromagnetic relfectants, and finally, for geological surface identification, mineral identification and so forth, imaging spectroradiometers with very fine spectral resolution in many spectral bands to identify various complex spectral signatures associated with various minerals.

These applications drive the technology requirements. Here I show a time sketch, moving forward in time from left to right, from what I call the Landsat/GOES Era. Landsat you already know about, GOES is the Geostationary Operational Environmental Satellite program sponsored by NOAA. I call that now, by "now" I don't really mean today; what I mean is over the last ten years or so.

Moving forward to the Earth Observing System Era, the future, this would mean the late 1990s, the early 21st century. The current applications were discussed in the previous chart. The current requirements are shown right here, on the left. In the atmospheric area 3 km vertical resolution of atmospheric layers is required with 3 degrees centigrade temperature mapping accuracy for ocean surface identification, for atmospheric profiling, and temperature mapping and 4 km pointing from geosynchronous orbit. That is pointing of the sensor to any 4 km square on the earth, plus or minus 4 km from a particular location.

Moving to the future, we see that 3 km vertical resolution is shown on the chart as not changing and going again to 3 km but that's a mistake. The chart should have said 1 km. So we are moving from 3 km vertical sounding resolution in the atmosphere to 1 km vertical resolution in the future from 3 degrees centigrade accuracy of temperature measurement to 1 degree centigrade accuracy and from 4 km pointing accuracy to 1 km pointing accuracy. These are substantial performance improvements.

The Landsat-inspired sensors provide general land classification capability with just a few spectral bands at fairly broad spectral discrimination. This is moving forward to the EOS area with a Moderate Resolution Imaging Spectrometer known as MODIS and a high resolution imaging spectrometer known as HIRES, one sponsored by Goddard Space Flight Center, and the other sponsored by JPL for vegetation classification of subtle biotic change requiring primarily, many more spectral bands at much finer spectral resolution. The advanced, very high resolution radiometer in the coastal zone, color scanners, shown on the left provided a half degree centigrade water sea surface temperature mapping from space and 1 km instantaneous field of view from polar orbit. This is the spatial resolution on the surface of the water. The MODIS and the sea viewing wide field sensor proposed by Hughes Santa Barbara will have to provide 0.1 degree centigrade temperature mapping: a five-fold improvement in temperature mapping accuracy for the sea surface and twice the resolution capability in terms of spatial characteristics from 1 km to 500 m resolution.

Finally, HIRES and the Japanese Intermediate Thermal Infrared Instrument, the ITI, need to provide more exact classification of minerals, rocks and soils than we have been able to do with the thematic mapper.

The general technology implications associated with this move from current requirements to future requirements are illustrated in this chart. I am not going to go into all the details of this chart; I'll simply indicate that the key sensor categories are listed on the left. In the middle, I have summarized the future requirements, presented on the previous chart, and on the right, I summarize the implications, in terms of technology. At the bottom, I have given "the bottom line". The bottom line is that in terms of the three types of performance requirements that we can be asked to provide, either spatial resolution, radiometric accuracy or spectral discrimination, it's the latter two that are being asked for, predominantly, rather than spatial resolution improvements. So in terms of the EOS era and the growth of requirements asked for by NASA and NOAA, focussing on those requirements alone, and really focussing now a little bit within the broader context of all of the potential applications of this kind of instrumentation, the technology is being driven in terms of spectral and radiometric capability.

What does that mean? Well to understand that, I have a chart here which illustrates the technologies that are the basis of a typical electro-optical, passive electro-optical imaging sensor. These include: a mechanical subsystem, the structure, the scanner, and the pointing subsystems and the cooling capability associated with the sensor is one key subsystem technology area.

The optical subsystem, is comprised of the telescope that actually focuses the image of the ground on to the focal plane or film plane associated with the camera. The spectral discriminator which comprises some sort of mechanism for filtering out the light and making images in certain spectral bands is the second subsystem. The focal point itself, which in a Nikon camera would be film but, in these systems, is very much like a Sony CCD video camera, we use solid state detector technology on a focal plane is a third. And finally, the electronics that converts the output of the detectors into electrical signals suitable for transmission to the ground is the fourth subsystem area.

In all of these areas the technology is being pushed in terms of performance. Cost is important but difficult to control, for the reasons that I've already mentioned. I'll talk about that now from subsystem to subsystem in a little more depth. I'll start with the optical subsystem, then move on to the focal plane and finally finish with mechanical and electronics subsystems very briefly.

In the optical arena, the basic requirements trends are shown in the top section of the chart. We're being driven towards very broad spectral coverage from the very short wave visible range to the very long wave thermal range. We're being driven to very high through put. The radiometric requirements are improving. We've got to get as much signal through the system as possible. So we are seeking at least 50 percent transmission of light through the optical system. Wide fields of view. We've got to cover wide fields of view on the ground. That means that we have to have an optical system that provides a very wide field of view at the same time.

And, finally, in some cases in spite of the emphasis on spectral and radiometric performance, we are being driven to still better spatial resolution. The implications associated with these requirements are shown in the bottom of the chart. Firstly, the broad spectral coverage pushes us to reflected forms. That is, we can't use lenses which don't transmit thermal radiation. We have to use mirrors that reflect it.

Here is an improved 3 mirror unobscured form that passes all the light that's incident on the first mirror through the focal point. Your standard reflector telescope that you might use best for viewing stars has a big element in the center of the telescope that blocks a lot of the light that would otherwise get to your eye. You want to move that off to the side so that the light comes into the main mirror and all of it gets back to your eye. To do that requires these off-axis mirrors, but the problem with using the mirrors is that it is very difficult to align them. There are something like 20 degrees of freedom associated with each mirror in a three mirror form like this, and that is because of all the very complex shapes associated with wave forms. They are not only deforming statically, they are actually wavering on the surface. There are a lot of degrees of freedom.

You have to use a computer technique that aligns the telescope. We can do that at a relatively low cost these days by automated techniques that were not available just ten years ago. Although the cost of developing adaptive mirrors is high, much higher than the cost of developing spherical mirrors, the cost to align a multi-mirror telescope now is no higher than the cost of aligning a very simple spherical mirror system was, say, 10 or 15 years ago. But 10 or 15 years ago, the cost of aligning an adaptive mirror form was infinite because we couldn't do it. So, in a sense, (maybe with tongue in cheek) I can say that we've brought costs down from infinity to reasonable, in this particular telescope application. Tongue in cheek, ok?

Finally, spectral resolution requirements also demanded advanced technologies in the spectral discrimination arena. The thematic mapper which was built in 1978 used interference filters that were designed using techniques very similar to those used to design analog electronic filters. These filters are good if your resolution requirements are not too fine. As resolution requirements get finer we have to use advanced technology.

These advanced technologies are quite expensive to develop; but once developed, the manufacturing cost to utilize them is not necessarily much higher than that associated with developing custom design filters that provide much more coarse spectral resolution performance.

In order to provide, on the focal plane, detection of the signals from a very wide field mirror telescope we have to have a big focal plane. A big focal plane, measuring light from the ground, wants to take advantage of as much time as possible to look at the ground. So, we want to put detectors all across that focal plane. That means we have got to make a lot of detectors. So the focal planes for these advanced concepts are getting bigger and bigger. We are having to create large focal planes using a lot of detectors.

The first generation system, such as the thematic mapper, provided something like a total of 100 detectors for the entire focal plane. Now we are being asked to provide something like 10,000 detectors for a focal plane. Advanced concepts in the future will probably require something like a million detectors in the focal point, and yet we are being asked to do this without increasing the cost of developing these focal planes, by the same order. And we are reasonably successful in doing so, as illustrated by the next chart.

Here the typical second generation concept where we have constructed a quarter inch by quarter inch, little array of detectors, 128 detectors on a side, a total of 16,384 detectors at a cost that is about the same as the cost of developing a single array of maybe 16 or 20 discreet detectors for the thematic mapper for the Landsat program some 15 years ago, normalized to current dollars. So all of the costs of the focal planes are not going down. But the cost of the detectors are going down substantially.

With all those detectors, we need a lot of electronics to read out the detectors. All those detectors and all those electronics generate a lot of heat. With a lot of detectors, and in a thermal infrared system, they have to be cooled to very low temperatures for noise performance reasons. And the electronics and associated cooling that is required by them, requires substantially increased cooling capacity. With longer life requirements generated by the new mission specifications, we need not only high cooling capacity but also long life associated with the cooling mechanisms.

Passive cryogenic systems, that is systems that use boil off, liquid helium or liquid nitrogen, are very reliable, and they can cool to very low temperatures. But they are inherently limited in life and they are quite heavy to launch into space.

Passive radiators such as are used on a thematic mapper are extremely reliable, and last essentially forever, but they have limited cooling performance capability. If you want both, long life and very high cooling capacity, you've got to go to active refrigeration.

This is a technology that is extremely expensive to develop. This is a technology that is not only expensive to develop, it takes years and years to develop and test on the ground to make sure it works. We are going to have to continue to spend quite a bit of money to build the cooling capability required by the mission specifications that are being generated for future missions. There's really no way around it.

The improved requirements generate demand for better instruments. They are still expensive to launch, so we have to keep the weight down. You can keep the weight down by using lighter, stronger materials in the structure and by miniaturizing the electronics. But the lighter weight materials are expensive, the miniaturization is expensive. So, the cost of developing these instruments will climb.

It's going to be a challenge to keep those costs from climbing rapidly. Cost and weight really have to be traded with performance. Mission requirements are going to continue to get more difficult to meet and for good reason: scientists want to do better science. To do better science they've got to have better data. Operational applications of remote sensing satellites are demanding better data for good reason: you want to do a better job of managing our resources and for understanding the atmosphere for weather prediction and so forth. So we are going to ask for better performance.

Better performance means higher costs. Longer life associated with any instrument means higher reliability, higher reliability means more backup systems in the sensor to guard against failure and deterioration of components. That means cost goes up too.

Cost is correlated to mission requirement growth rates as we go from one mission specification to next. If those requirements ask for better performance, you've got to develop new designs. New designs cost money. The Japanese have taken care of this problem by just not asking for better performance. The sensors we build for the Geostationary Meteorological Satellites acquired by the Japanese, Nos. 1-4, and currently we are building number 5, essentially the requirements have not changed over the last ten or fifteen years, and we are using the same designs that we originally developed back in the 70s.

The NOAA weather satellites are asking for improvements in performance but these improvements are evolutionary in nature so the cost associated with developing new NOAA weather satellite sensors should be rising at a relatively higher rate than the Japanese but not dramatically so. If we were to ask for revolutionary improvements and requirements then, of course, the cost would go up faster.

At this point I thought I would give sort of a brief recipe on how to control costs to finish this talk.

Number one: Specification should be concise, but more important than concise specifications is: it really ought to be stable. That is, once we get a specification, if it's changed every six months during the development of a sensor concept, clearly that impacts costs. It's like a guy who is building a house and every two weeks he is telling the contractor to make a change. Well, if you've ever done that, you know that the cost is going to go up; it's no different with sensors.

On-site management: Schedule equals cost. Every time something has to happen on site and we have to go back to the government, or back to the customer, for approval, that takes time and time costs money.

Tailored reliability and quality plans: Rather than taking a boiler plate reliability and quality plan from program A and applying it to program B without checking the requirements closely, one should tailor those specifications according to the mission requirements and mission life, to make sure that the reliability and quality are not being overspecified. This would have substantial impact on cost.

Finally, streamlining program controls and documentation are very important. Don't ask for more program control or documentation than absolutely necessary because that paper work is quite expensive. I guess a paraphrase of all of the above is: give me the concise specifications, don't change them, leave me alone and let me do my job. Thank you very much.

Question: *What are your present costs per pound for the manufactured spacecraft?*

Carl Schueler: I'm going to restrict my attention just to the satellite sensor itself, in this case, the electro-optical sensors. It is difficult to give you a cost per pound estimate. The reason is that, perhaps, although the cost is certainly proportional to the weight in many cases, if the weight is being forced down and at the same time the technology is being forced up, in terms of performance, miniaturization and so forth, the cost per pound may tend to increase for a smaller instrument. But as a calibration, the thematic mapper weighs roughly 500 lbs and costs roughly $50 million. So what's that? About $10 thousand a pound, probably. That's just a rough estimate based on that particular system.

Question: *I have a two part question. I believe that for a lot of satellites, the manufacturing cost is almost an order of magnitude more than the launch delivery costs, so you've got a fairly efficient sensor there. I guess the real question is: if launch delivery costs were lowered significantly, and the weight restrictions that you're currently under for the spacecraft were lifted so that the weight was no longer so important, what would happen? Would spacecraft costs go up or down? Assuming that people still want the improvements and capability but you're no longer restricted to weight, or volume.*

Carl Schueler: That's a really good question. I think that the cost of developing the sensor should go down. A lot of attention is paid to weight reduction. For example, the use of special materials to construct the sensor. We use special materials in the construction, not only in the structure but also in the optical system. Very lightweight materials are sometimes required such as Beryllium. Beryllium is extremely expensive, very hard to get, very hard to machine. I think there's only one decent vendor left, maybe two, that can do really high-quality work and their prices are extremely high because they have the monopoly in the market. So, yes, in principle the sensor costs should go down.

Question: *Carl, is that cost you just quoted a recurring number or a development number?*

Carl Schueler: It's a very rough order of magnitude estimate.

Question: *Which one?*

Carl Schueler: The $50 million.

Question: *No, I mean the development of the sensor, the one time cost, is it a non-recurring or a recurring cost?*

Carl Schueler: I would say the average of both. Keep in mind that what I am talking about are sensors that are not built for multiplicities of replication. The thematic mapper at this point is on its fourth, really third generation, that is three flight models, total, OK? Not 25 or 30. If we were to build them in volume, the cost would go down. So, in a sense, you can think of it as an average of recurring/non-recurring costs with quite a bit of non-recurring included.

Question: You only build one of each?

Carl Schueler: We built three thematic mappers, including Landsat 6. It's not a high volume production business.

Question: You don't go with spares?

Carl Schueler: Yes, there's an engineering model that was built originally for the Landsat program which is still in fact at Santa Barbara Research Center and it has some components on it that may potentially be used, plus there are spares of various components and subsystems on the shelf, some of which are being used for Landsat 6.

Question: Back to the cost thing. If we gave you double the weight budget, double the power budget what could you do with the cost of the spacecraft?

Carl Schueler: You're asking for a quantitative ratio.

Question: I think both of us are the centers in all of this. The launch vehicle guys have been lousy for about 40 years. And the spacecraft guys have gotten worse and worse, the Hubble Space Telescope, the Galileo, I mean they are sort of monstrous. I mean I don't know what... I do know what Galileo's cost us.

Carl Schueler: I'm going to have to kind of hold back. I've given an answer already, qualitative, and now you are asking: "give me the quantitative answer". I better hold back, because that's dangerous territory. The answer can range over quite a range, depending upon the particular requirements of the mission, and so forth. So, I am really uncomfortable trying to pin that down to give you a quantitative answer. I apologize for that.

Question: What is the direction of lower costs?

Carl Schueler: What kinds of things must be done in order to bring the costs down? Is that what you're asking?

Question: Yes.

Carl Schueler: Clearly, standardization and commonality, use of heritage and existing designs, where possible, can bring costs down dramatically.

Question: Can you illustrate that with the Japanese satellite?

Carl Schueler: Yes, the Japanese satellite is a good example and in fact another example, that I can draw from that, is that the original design for that instrument was done for the NOAA program for the Geostationary Operational Satellite Program. The development costs for that satellite were actually borne by the original NOAA contract. Then the Japanese, I believe this is correct, essentially bought the non-recurring development or engineering costs associated with getting a replication of that instrument for their satellite. Over time NOAA's requirements evolved. They originally asked for just an imaging instrument that could provide images of clouds for TV news broadcasts. That evolved to a requirement for measuring the temperature profile of the atmosphere and that required a sounder capability in addition to an imager. What was done was, rather than designing a whole new instrument, which would have been quite expensive, what SBRC did was to design a sounder add-on to the original instrument. The original instrument was called the VISSR, Visible Imaging Spin Scan Radiometer. They asked for an add-on of an atmospheric sounder so what was built was an atmospheric sounder capability that was added on to the original instrument. So rather than redesigning the whole instrument, we added a new design to it. That kept the cost of the new instrument down and that new instrument is now know as the Visible Imaging Spin Scanning Radiometer Atmospheric Sounder, acronym VISSRAS or VAS. So we've taken a long acronym and made it even shorter than the original acronym. That's not cost reduction, that's acronym reduction.

Question: A comment on some of the other comments before, concerning the impact of more volume available and more weight available for reducing costs. A word of caution, I do hope things change but we used that same argument back in the early '70s, with the space Shuttle. It didn't work.

Carl Schueler: Thank you very much.

Small Component Costs - *Helmut Hellwig, NIST*

Introduction by Cary Gravatt - The third talk is to be presented by Dr.Helmut Helwig, who started his career at the National Bureau of Standards in Boulder Colorado, associated with our Time and Frequency Division. He ended up heading that division and it's within that division that atomic clocks and all time standards are kept. He left NBS and joined a small company manufacturing atomic clocks for commercial, military and satellite use and it's based on that experience that he agreed to give us some thoughts and considerations on cost reduction in high technology projects. Evidently, that venture was successful because the company was bought out and in the process of being bought out, Helmut put on his golden parachute, pulled the rip cord and gently settled back in to NBS to the Office of the Director. He's responsible for programs, budget planing and long-range strategic planning. In talking to him about this conference, I got to discussing costs and he said he thought he could look back at some of his history and give us some insight into one particular system.

Helmut Hellwig - My background is time and frequency on the technical side. I will dwell much less than the previous speaker on the technical intricacies of what I am doing but I need to introduce it. My main emphasis will be on cost from an angle which the discussion has touched upon but none of the speakers has touched yet.

You noticed, and Cary pointed out, that our talks are all sort of interesting displays here. The problem is, scientifically, you can do the nanoseconds or even picoseconds, but hours and minutes, that's human convention, so you know, you're a little lost, scientifically. One of the principal purposes of having this kind of precise time is navigation. The Apollo program and many space programs, especially the interplanetary probes and a lot of things on this earth, are not possible without precise time. Precision down to nanoseconds can be critical, especially when you have to know where you are, as for example in rendezvous and position finding scenarios. The application of the technology I am talking about is the Global Positioning System. That's a triservice, Air Force-championed program. I believe it is the largest deployment of satellites today, by a long shot. It has two production characteristics. This is a picture of the scope of the Global Positioning System: it's the earth surrounded by a lot of satellites in about a 20,000 mile orbit. The number of satellites, varies between 18 to 24 operational satellites, plus spares in orbit, spares on the ground, plus replenishment requirements. So it's a huge program by space standards.

What does it do? It allows you to find the position anywhere on the surface of the earth, or in air, to a few meters accuracy, absolute. Relative precision down to centimeter or millimeter accuracy is possible. That means you can find two positions purely from the satellite signals down to this kind of precision without reference to anything. It's used today. It's essentially operational. It had test phases as early as about '81. It's essentially operational or becoming fully operational now. It has been used, for example, in the interactions with Iran and in the Persian Gulf. In fact if you think about how we spread those mines and found certain things there, it's because of this system. It's also used to do precise time transfer between here and Boulder, Colorado, and many other applications.

The company I was heading was building the clocks. Now this is one of the things we built. That's a cesium atomic clock, the heart of the Global Positioning System. Each satellite carries two of those. The size is about this big, weight is about 30 lb, and costs about $10 thousand/lb. It's a very sophisticated piece of electronics: there are about 2,000 different electronic parts in it. The total part count is of course higher. So, it's a very complex piece of electronics.

That's a similar box, that's the commercial clock, which my company built and sold as a catalog item. In fact, that clock sort of preceded the space clock. I am coming now to the heart of what I am trying to talk to you about. My company is in a reasonably rare position in that we build the same technology commercially as well as for space and we build them not only as a one shot design, or a few items of design, but we build them for production purposes as well and I am going to compare them.

The company in question here employed about 140 people when I left, and the business was about 45 percent commercial, and 55 percent military aerospace, with the Global Positioning System program being the single largest piece of business of the company. We built not only these boxes, we also built receivers, oscillators, and test equipment in support of some of the automic frequency measurements. We built them for civilian applications, laboratory, as well as field applications for oil exploration, for scientific experimentation, for communications, for television stations, radar applications, and the military and, as I mentioned, for space. We also build oscillators, by the way, for Landsat.

What I am talking about from my experience is applicable not only to an Air Force program but to a NASA program as well because we have very similar experiences. I'll start up with the bottom line, and that's a generalized statement, not yet specific. If I look at what we did and look at the cost or price, I am aware of the difference between cost and price and let me just say that the profit margin, the price above cost, was higher in the commercial, than in the cost-controlled military aerospace projects, where profit is not acceptable to the government, at least not above certain levels.

It's a commercial item. Any of the things I mentioned: oscillators, atomic clocks, receivers, test equipment. Our experience was that if you do sort of a militarized version and/or some specialized application, the cost escalates by 50 percent to as much as a factor of five. If you do the same for space flight, it's a factor of ten to twenty. If you go for single shot designs, the big ones can be two orders of magnitude, a factor of a hundred more expensive. I am talking here about making things after the design is completed.

The big question is, why? So in the example I am now going through, and I will end with a cost comparison table, what are the cost drivers? It is a factor of 12 in this particular case. These are close to real numbers. The cesium clock module I just showed before from the slide was in the catalog at about $25,000, not a cheap piece of equipment. By normal instrument standards, that's an expensive piece of instrumentation. A similar NASA/GPS module, $300,000. Why?

Before I answer why, let me dispose of the design phase differences. There are non-engineering requirements. I listed sort of a good selection, I think. For the space-rated version, you have to redesign the thing because of performance-requirements, and because of form-fit-function adaption to the spacecraft requirements. There has to be some analysis reliability. You have to deal with the parts. You have to do failure modes analyses. You have worst-case circuit analysis. You do have to do the qualification and you have to do a lot of design reviews of all kinds.

The bottom line of this experience is that if you start even with the same technology, an understood technology, not as the previous speaker was talking about such as an enhancement of the technology, but rather an existing, proven technology and you have to do the redesign because it must, for example, operate through a radiation burst or something like this, then the cost goes up.

If the clock, as a clock functions the same way as it has functioned before, does the same nanosecond time keeping, our experience was that the total cost to go through this redesign, required for space is about equivalent to a repeat of developing the original technology, a couple of million dollars. So I am not preloading now. What I am going to do with this couple of millions of dollars.

So we are through with the redesign now, for the purpose of my talk. So what's now the cost driver if you enter, say, production? You have as a result now of the redesign somewhat different physical requirements. You have somewhat different systems requirements, ranging from connectors to other things. I'll go into more detail on each of these. You have to meet specific manufacturing requirements which are mostly imposed on you. You have production control requirements, also imposed on you contractually and you have test requirements, probably imposed, partly, but obviously, needed. Then there are a lot of procedural requirements. By the way, before I forget to mention this, the number of units produced in all cases, the commercial as well as the military, as well as the GPS space flight unit, was 50 to 100 units in one run. So we are not talking about one of these or three of these.

Physical requirements. There are real physical requirements. The thing has to be in a vacuum as opposed to the original design for air. That's sometimes not necessarily trivial because in the unit which we are building, this atomic clock, you have a number of high voltages, you have to have a number of very low noise requirements so the change from air to vacuum environment does change some requirements of a functional nature of the unit. You have to withstand vibration, at least survive vibration at ten decibels. There are radiation requirements, not only radiation of an accumulated dosage but also from the close by burst of a weapon.

Reliability had to be analyzed. There were weight restrictions and there were power restrictions, largely during a start-up. If you go to the systems requirements, in order to fit on the spacecraft there were physical dimension requirements not only just of the overall dimensions, but dimensions such as the base plate which had to have a certain flatness to match to the spacecraft to allow thermal cooling of the unit. Command/control had to be operable from the ground, at least in the turn-on sequence and also in some certain modes of operation which the unit was capable of and which could be commanded from the ground. There were monitors and diagnostics needed. Electromagnetic interference with the rest of the spacecraft was a big concern as were hazards in the sense of damage to the rest of the spacecraft. There were largely materials requirements but later we had also an interlude where we had to prepare a unit for use on the space Shuttle and then the human hazard requirements came in.

Manufacturing requirements. We couldn't use the parts we were used to using. We had been given a special parts list for this particular program. We had to deal with the specific technology, namely the cesium beam tube which is inside, and the quartz crystal oscillator which had a crystal in it. Of course, you cannot find it in any parts handbook and you have to deal with those in a specific way to get them accepted. We had particular screening requirements. We had to maintain an as-built configuration and we had, of course, a lot of requirements if rework was needed. Sometimes rework was demanded when it technically wasn't needed.

Let me dwell on that. I remember very vividly an incident where we had to rework something because we built it to revision D of something and somebody then discovered that revision E was needed so we had to rework to conform to revision E of the documents and nobody could find any technical reason for that, but that's what the paper said.

Production control requirements. Controls on everything. Let me not dwell on that. I think many of you are familiar with that. You controlled everything down to the detail, from the vendors to the equipment to the parts.

Test requirements. Each unit had to go through its acceptance test routine. We had special test equipment, which essentially was a form of automation and let me make a very positive remark. That actually has helped. That actually was a separate investment, which I am not loading here on this unit. This investment is not loaded, it was an off-line contract, like a development contract. It was ultimately about a million or a million and a half dollars to develop special test equipment, but that actually saved a lot of work and money. So all this is folded it into it. We of course had our test plans and procedures and when things went wrong we went through the routine of an orderly, mandated, prescribed, failure analysis and corrective action.

Then we had procedural requirements. Lots of witnessing and audits of technical, financial and quality nature. Usually, at least two levels, the prime was doing it and the government was doing it, and of course, we as a company were doing it. So we typically had three groups of people doing sequentially or simultaneously, usually sequentially, the same thing, looking at things, looking at books, looking at anything. Of course, one should not forget that there was a proposal and, as you all know, a substantial effort is required to create a proposal. If you lose it, it's wasted. If you win it, you still have to recover the costs, somehow.

I think that the amount of customer support needed is often overlooked. Customer support not only for technical reasons, but support to the customer because the customer needs support to his customer. So it's a multilevel support scenario.

And then of course the vigilance of both the customer and the government at the plant. Acceptability of the company as it functions, not only at the beginning of the contract but throughout the contract.

Well, what does that all do? I'll try to put numbers on it. Remember that we had this number here: it was twelve times the commercial cost, the catalog cost for essentially the same piece of equipment. In the left column, I tried to give you the elements which were related to an additional cost because of each of these six groups of requirements: physical requirements, escalated by 1.1 times the commercial cost, same with the systems requirements. The manufacturing requirements stick out with 2.8 as the largest single element. Production control requirements are next with 2.2p, test requirements with 2p, procedural requirements with 1.8p. If you add it all up you have 11p in added cost and, of course, what the thing cost in the first place, 1p, so there you have your factor of 12p. [Editor's note the suffix "p" is used here to denote the original cost of the commercial product. Thus. 2.2p = 2.2 times the entire cost of the original commercial unit.]

Now that's my opinion on the right side. I extract all those things which do not add technical value to the unit as compared to the commercial unit, i.e., no addition of technical value. If I subtract all those, which in other words means I am trying to conceive here of a unit which could be built for space flight meeting the particular requirements of this particular spacecraft in this particular program, and meeting all the performance requirements as a clock, I came to the conclusion that you have a cost escalation of about 30 percent. This means roughly a doubling of the parts cost, because the parts cost in the commercial unit was about one third of the cost, so 0.3p means you double the parts cost.

Systems requirements: 0.2p. Again this is largely in parts which had to do with, for example, latching relays being used instead of semiconductor switches, things like that which were changed because of radiation and systems interface requirements.

Test requirements: There are, of course, more testing requirements than for commercial units. You have to go through a thermal-vacuum test, there's nothing you can do about that; it's a requirement and it has to be reasonably formal. So I estimated that that is about a 50 percent cost escalation. If you add it all up, you come up to a unit which would cost double the commercial, and would have done the same job as the one that cost 12p.

Maybe I should leave it at that. Maybe just with a passing remark: that one customer, which was the German NASA, did buy a hardened unit from us, specifically, sort of modified for us for their purposes, which did cost them 2p and they flew it on the last Challenger flight as part of a navigation experiment. As far as I know it's still working back in Germany. So it went up and came back and did the navigation experiment, I think rather successfully. There is a publication on it, I will reference it in my text. Thank you.

Question: Which part of this program was fixed price versus cost?

Helmut Helwig: The whole thing was fixed price. What I am talking about was a fixed price contract.

Question: And you anticipated the 12p?

Helmut Helwig: Yes, you know how fixed price contracts work. You know you go through the whole cost analysis. They were sitting in our plant for two months, going through the books and then the government came and sat another month and looked through our cost analysis of the program, which was based on a preproduction run of five units. Before we went into this scale of production, we had a preproduction contract for five units. So we knew roughly what it would cost.

Question: Did they also have an override on you that said, if you had overestimated that they were going to cut you down on profit?

Helmut Helwig: The company, as far as I know didn't make... I left before the whole thing was totally completed and it didn't look very profitable.

Question: You used an interesting expression on GPS when you talked about determining position without reference to anything. What does that mean?

Helmut Helwig: No land reference. You can have an airplane going across the ocean and the airplane in three dimensions will know its position to better than its size. Much better than its size.

Question: But the three dimensions have to be with reference to something

Helmut Helwig: Well, to the satellite signals, but you don't need any reference to a clock, you don't need a clock, you don't need any radar tracking to any object. So two planes could approach each other and not communicate with each other over the ground, and know their positions to sort of a small fraction of their wing size.

Question: I'd like to thank you. You very nicely answered the first question I was going to ask, which would have been what would the cost have been if somebody could come without all of *these special requirements? I would like to ask whether the process of adapting the commercial unit to a space unit would have been easier and/or cheaper if somebody had come in and said, "We'll fly one or two or three units for you to test in space, before you have to start giving us the ones that will stay in orbit.*

Helmut Helwig: If a program like this would be totally requirements driven, in other words give us a unit which meets this set of specifications, we will also prove it by live tests on board a spacecraft, but the company would be left alone in how it costs its units, how it builds its units, and how it tests its unit, like in a commercial scenario, them the cost would be at most, 2p.

Question: *Excuse me, is there nothing that you would look back on now that, from all of this government interference, benefitted. Did any of those guys ever discover anything that was really worthwhile to you in the program? Was it completely a waste?*

Helmut Helwig: In the production program, I don't think value was added by any of the additional requirements. In the development design phase, which I didn't talk about, there was a lot of useful interaction and I believe there, intense partnerships between the government and/or the customer and the designer is in order and useful, and I think that is essentially what the previous talk was implicitly saying. There is nothing wrong with coming up with a better design and having a lot of help in coming up with it. So I have good memories I think on the precursor phases to this project.

Question: As an engineer that's the most fun of course, designing to new requirements. We love to do that. That's what we're in business to do but it's expensive.

Helmut Helwig: If I may comment on that, I ultimately decided this could be a talk to be given to you because I anticipated that this conference would essentially revolve around cost, which I think it did, especially from last night's discussion. Let's suppose we have now really better access to space and we can do a lot of things in space and we may have even cheaper launch capabilities. We still have to worry how much it then costs and what our approaches would be to reduce those costs once we are there. I got exposed when I joined the company to, I think, to a fairy tale. Namely, that once you've gone to production, and you build no more than one of these and two of these the economies of scale will come in. Yes, some come in but you still lose an order of magnitude, as compared to the normal commercial practice on the ground. I want to push this in your direction as a concern, because here's a program which came as close to true production as I've seen it.

Question: *Could this device now be redesigned? I believe there is a future for this sort of device. Could it now be redesigned so you get way below 1p by relaxing the requirements on the clock and relaxing weight, relaxing power, etc.?*

Helmut Helwig: No. Except if you relax performance, clock performance. Again, the commercial experience is that, (and that's not speculation on my part) the commercial requirements are not more than of the order of a couple of 100 units per year. In fact, I think the total production world wide of the three companies which supply this kind of unit today is about a 1,000 units, commercial. That's the price that has sort of has developed in the commercial competition among the three companies, and it is on the order of $30,000 now. This will only come down if you have an order of magnitude escalation in the numbers of units. Here the economy of scale is important. How much could it come down, since you mention it? The unit is about as complex as a modern color TV from a technology view point. But modern color TVs are built by the millions. This is built by the hundreds. Therefore, being built by the hundreds, we don't have dedicated machinery as in the television industry which can crank out this stuff semi- or fully-automatically. We have a lot of people doing things. And I don't see how you can get away from it, that's the cost driver. It involves a lot of labor still.

***Question:** How would the government, in your view, minimize this intrusion and still satisfy itself that the product it's going to receive is reliable for its purposes?*

Helmut Helwig: Ultimately, on the commercial scenario, which cars do you buy, which washing machines do you buy? Ultimately, I think it's a longer-term process between the buyer and seller, so that in certain brands and in certain companies you have trust that what they say will last and perform will do so. So that's the ultimate test I think. How can the government achieve this? Well, once you have a production scenario like here, which has been going on for a decade, I think this relationship of trust has already developed. Actually, it developed a couple of years ago, that this kind of hardware is OK, and the company has a vested interest to remain the main supplier for this kind of hardware, so there's no built-in driving force to lower quality or lower cost. How can you ultimately assure it? Put emphasis on the final testing. I think the final testing is probably an important thing, especially if both parties would agree on a meaningful test. In other words, you really devise a 100 percent representative test and verify the unit before it flies. I think that's the only thing I can think of.

***Question:** I would like to add that there's something possibly better than what you've described. I think there are real positive things that can force reliability. First of all, I don't know how you measure reliability when you talk about ones and twos and even tens. There's something you can do as a proxy for reliability. I'll give you a certain number of dollars if your machine works. If your machine doesn't work you give me some of that money back and then I don't care what your test procedures are, the risk is on you not on me.*

Helmut Helwig: I absolutely agree with you. In this particular program, it has been attempted. The problem is, it has been attempted in addition to all the other controls. So it's a bottom line, further cost escalation really, with not really the effect you are describing. But what you are describing is, of course, a means by adding financial risk. I am glad you mentioned that. Put the company at risk, then of course people will say, "Well, if the company is penalized they still have a lousy spacecraft". If the thing fails. Well, somewhere you cannot get away from risk and somewhere a little bit of trust might come in too.

Introduction by Cary Gravatt: We will now look at three presentations which are institutional in nature, not quite so technical as previously, but looking at different ways of achieving possible cost reduction, relating to space business. The first of these has to do with insurance.

John Cozzi, Vice President of Caroon and Black Inspace, is an expert on space insurance. Insurance is a major component of the launch and operations cost of any spacecraft. Some of our trading partners have been using it as a way of offering attractive space launch packages. So, I am certainly pleased to have John with us and hear what he and his company's thoughts are regarding insurance and ways of looking at cost control from an insurance point of view.

John Cozzi: Thank you Cary. I look into the audience and I see fewer faces than this morning. It's usually the kiss of death when you put an insurance discussion right after a coffee break. Seems like there are a lot better things to do than come in and listen to this dry subject. But I think space insurance is a little different, it's a little bit more exciting, a little bit more dramatic than you might imagine.

It's very much a pleasure to be here today, to address all of you in the audience whose interest is space development. I'm here today to address, specifically, the topic of space insurance, it's historical development to date, and what the space business community can do to affect its future development positively.

Suffice it to say that the decade of the '80s has not been a good one for space insurance. The cumulative world-wide markets are today in a net loss position. It's also not been good to those space business entities, either established or developing today, which are bearing the burden of past catastrophic losses. There is much room for improvement and it is certainly within our capability to do so.

I'd like to take a brief moment, if I could, to expand the topic of discussion both here and in the following workshops, from insurance to risk management, a term I am sure many, if not all of you, are familiar with. Risk management is a comprehensive term which includes, in addition to insurance, risk transfer and retention of risk for self-insurance by a business entity. These three basic elements all represent a cost of doing business in space. In the grand scheme of risk-sharing for space business ventures to date, risk retention and risk insurance have sometimes been the lesser of all evils, alternatives to commercial insurance. In the event of hard market insurance conditions where premium costs are high and available insurance capacity low, which occurred dramatically in the mid-part of this decade, there may be no alternative to risk retention and transfer if a space business venture is to proceed. In times of softer market conditions, risk retention and transfer can complement and even enhance a commercial insurance program.

A derivative mind-set of the premise of risk retention is that of risk control. Risk control, that is the process by which both the frequency and severity of losses are controlled and reduced to some expected and acceptable level, has been and must continue to be an essential part of all future space efforts, both commercial and governmental. Risk control must be a priority interest of the space venture in order to protect space resources and continuity of operations, and to buffer the financial interests of the insurance underwriter who would indemnify for the occurrence of these exposures. In short, risk control is in the interest of all parties concerned, both insurers and self-insurers.

Let me depart from this risk retention and risk control concept for just a minute and turn to the main element of our risk management theme, that of commercial insurance. In any industry, there is no doubt that a stable and affordable insurance market is important to the continued success of that industry at large. The purpose of insurance is to distribute the losses of the few to the many by the allocation of reasonable and stable premium charges to the many. In this manner insurance costs should comprise a reasonably minor percentage of a business venture's overall cost and could be counted on for the most part to remain predictable if not stable. Space insurance to date, however, can be characterized as the losses of the many shared by the few.

Following the unexpected, catastrophic space losses of the mid-80s, concurrent with the space telecommunications industry shake out and consolidation, drastic premium increases were allocated to a shrinking base of operational entities. These premium increases, being approximately four to five times higher than the absolute market lows of the early 1980s, were so significant that they essentially represented, and in fact were treated as, a capital cost of the project. This unfortunate accumulation of losses from 1984 to 1988 represented a statistical aberration in the context of overall operational launch history. There was no apparently accurate way to gauge whether and how quickly performance statistics would improve. As you can imagine, confidence in the capabilities of both launch vehicles and spacecraft systems sank to extreme lows as every major western world launch vehicle and several spacecraft types experienced significant losses.

Given the central theme of this conference, that of reducing the cost of space infrastructure and operations, we need to identify and understand the basic nature of insurance costs in order to effectively plan their reduction. Each dollar of insurance premium represents allocatable elements to pay for losses, depreciation and operating expenses and hopefully leave enough remaining for profit. Cumulative space losses to date, by most all accounts, consumed all the net written space premiums collected and have in fact exceeded these collectively by a factor of approximately 1.5, i.e., 50 percent, exclusive of depreciation, operating expenses and profits. The basis of these loss statistics are primarily founded in the performance results of launching and operating commercial telecommunications satellites, the initial and to date most successful exploitation of commercial space opportunities. Nonetheless, telecommunications satellites represent the essence of concerns for doing any type of business in space. The two basic concerns are: (i) launch vehicle and upper stage systems must deliver a payload to its operational orbit; and (ii) the payload must function to its design specifications for its planned lifetime.

The system failures of the 1980s which produced the large insurance losses are attributable to the failure by these systems to achieve either of these two objectives, with perhaps failure of launch systems representing historically the greater percentage of the losses. More recently, though, significant failures have occurred to satellite systems, the consequences of which can be as extensive as a launch vehicle failure, what we in the industry call a total loss or constructive total loss.

The upshot of all this discussion on losses is that since losses represent the entire premium dollar and more, by better controlling or preventing losses we can effectively reduce costs whether we are concerned with insurance or self-insurance costs. By improving the reliability of launch delivery and payload systems, we can reduce our risk management cost basis.

Unfortunately, past losses have created a premium rating environment today at levels higher than the historical averages would suggest reasonable. While conditions in the space insurance marketplace are, in fact, softening, the risk premium rating levels, that is premium levels are improving, and insurance capacity world wide is increasing, current and future buyers of insurance continue to feel that significant reductions from current levels are justifiable and are necessary. Certainly from the standpoint of comparative risk, today's launch insurance premium rates for geostationary orbit launches of approximately 17 to 20 percent of the value desired to insure are not appropriate in the context of low earth orbit applications. The low earth orbit rating would naturally be lower since the propulsion phase risk from low Earth orbit to geostationary orbit are not present. But despite this fact, rating levels are still viewed from the insurance buyers prespective as being higher than the expected failure probabilities.

Herein lies a main source of disagreement between the buyers and sellers of insurance today. Given the fact that failure probability statistics, based on recent launch vehicle and payloads, are improving and approaching historical averages, are we witnessing the beginning of a positive trend in space system performance or is this once again a statistical aberration?

Having been burned already by writing space insurance policies at premium levels insufficient to cover losses paid, some underwriting markets are now only gradually reducing premiums as space systems performance gradually improves, thus reflecting cautious optimism of recent results.

Other underwriting markets, on the other hand, view what's going on in a skeptical manner and would prefer to hold the line on rating reductions. In an effort to improve the financial results of existing telecommunications operations, or to make financially viable the start up of new enterprises, the insurance-buying community is insisting on even lower premium rating levels in anticipation of continued excellent performance results. The reality of it all is that these good results have paid off, fostering better rating environments and as such now is the time to explore those actions which can be taken by the insurance buyer to continue the trend towards a lower insurance cost basis. These same actions would also effect a lower insurance cost basis. Steps which we can take to reduce the cost of both are individual and collective in nature.

I'd like to first discuss those actions which a particular enterprise could undertake to better control their own risk costs. As I previously mentioned, the essence of the space risk is in the technology utilized, i.e. the hardware and software systems. It may seem a simple statement to make, but it's undeniably true that proper project management of technical risk is essential. Whether it is dependency on in-house expertise or hired consultants, focus on the proper design, manufacturing, and testing of space systems is the essence of risk control.

The success of the technical implementation of a business plan is directly related to the quality of program or project management. Proper project management begins with the choice of an appropriately-qualified vendor. Qualification begins with the evaluation of the vendor's prior experience, the quality of its design and production resources, and the nature of its quality control and product assurance programs. Also essential to the selection process is the degree to which any given vendor is willing to accept liability for product performance failures.

Let me digress for just a moment and talk about risk in general and its treatment. The classic risk management textbook categorizes risk treatment into three basic categories: risk avoidance, risk retention and risk transfer.

Risk avoidance, for example, could be practiced by developing a terrestrial means of testing or producing a product as opposed to a space-based means to avoid the hazards of space transportation and the space environment. Probably a recent example of this is electrophoresis, which held out a lot of promise from the standpoint of developments in space, but was superceded by terrestrial accomplishments.

Risk transfer is a treatment alternative whereby unwanted risk is off-loaded either through contract provisions to another entity or to the traditional insurance marketplace.

After all of the above, risk retention is that which resides intentionally or unintentionally with the self-insured. An appropriate distribution of risk, one where each party to the endeavor is encouraged or incentivized to put forth their best effort, is the ideal.

Much has been written and discussed in the past, that space system vendors have assumed a disproportionately small amount of risk and that the bulk of product failures have been borne by either the insurance or the owner/operator communities. Whether this criticism is valid or not, more recent satellite procurements have resulted in either a greater percentage of risk being assumed by the vendor or the vendor being contractually restricted from purchasing insurance coverage to protect his contract incentive payments for good performance. Make no mistake about it. The ability to contractually impose greater liability for a performance failure upon a vendor is a powerful risk management tool.

Aside from contractual remedies, design considerations to improve the reliability of a particular payload, if cost effective, should be considered for payloads, particularly those destined for low earth orbit environments. The inclusion of design features which permit reuse through in-orbit servicing and repair and/or retrievability not only optimize capital investments but also serve as salvage potential to space underwriters. Knowing that a damaged or failed payload can be retrieved and/or repaired, whether terrestrially or in orbit, can reduce the severity of insurance pay outs.

Redundancy of critical components which are susceptible to failure is certainly another design consideration which we utilize today in telecommunication spacecraft. Regardless of the application, it makes sense, assuming there are no onerous tradeoffs. Redundancy, particularly in mission critical areas, is of primary concern to underwriters today.

Use of proven technology is another design consideration that has positive reliability implications and thus insurance savings potentials. Use of flight-proven hardware reduces investment in developmental costs and increases the confidence level for successful operations. However, advancing technology in space systems to lower costs and improve capability and reliability has been and will continue to be a primary objective of the manufacturing industry. As such, the use of new and unproven systems or components will continue but must be balanced by judicious design, manufacturing and testing methods to ensure continued reliability.

While all the above cost reduction considerations are in a sense micro in nature, that is, specific and controllable by each particular venture, there are efforts that could be brought to bear by the combined space industries influence, to reduce insurance cost. A consolidated industry position could, for example, exert sufficient influence upon the U.S. government to treat its procurement of space systems as a commercial purchase, including, or at least not precluding, contractor-provided insurance. Such a position would increase the space insurance market's book of business as government contractors would seek to lay off some or all of this risk. The increased premium flow, along with an increased statistical base over which to more reliably assess loss statistics, would no doubt be encouraging to underwriters. The combination of reasonable loss statistics, improved reliability, and an evident stream of future premium income would encourage and increase insurance capacities in world-wide markets. The greater numbers of insurance players and their capacity would no doubt foster a healthy, competitive environment, one conducive to cost containment.

One other issue causing concern today, particularly for the low earth orbit enterprise is that of space debris. Caused by decades of both governmental and commercial, national and international space activities, this is a situation that may make itself felt. The magnitude of the problem is such as to require a joint government/industry effort lest it becomes a deterrent to conducting business in low earth orbit by increasing the probabilities of loss by collision. Today, the collision factor in evaluating space risks for insurance is not significant, particularly in geostationary orbit where there is much less orbital debris. The psychology of the insurance industry is such though, that concern will likely remain minimal until a loss occurs.

Another area where industry should call upon government for continued oversight and action is in the maintenance of a level playing field with regard to foreign competition and launch liability insurance requirements imposed by international treaty obligations. Foreign government support of launch vehicle liability risk should be consistent with ours. This means that the U.S. government should review financial responsibility requirements imposed on industry via the Commercial Space Launch Act periodically to insure reasonableness.

I've mentioned in this brief 15 minutes, and do look forward to discussing in the workshops later on, several ways in which insurance costs can be reduced. There are those who believe that risk retention and/or high insurance costs are an unfortunate but unavoidable element of conducting business in space. I, in particular, don't share that view. One need only look at the evolution of the commercial aviation business in this country, and the attendant concerns of the availability and cost of aviation insurance. What was once the view that this was an activity whose hazardous nature put it outside the purview of commercial insurance, has proved to be false. Technical and procedural advances, improved aviation reliability and safety have improved such that the level of aviation risk decreased. Needless to say, insurance, after an ominous start, found a home in the aviation business. Insurance at reasonable cost will find a home in the space business as well. If one puts aside the excessive losses over the past five years and looks back to the operational days of the U.S. government's Atlas, Delta and Titan launch vehicle programs, one will find success probabilities well into the 90 percent plus levels.

The technology capability exists to successfully develop space. Whereas, however, past government efforts focussed on reliability and safety at great expense, private industry must and will accomplish those dual objectives in an efficient and profitable manner, and with commercial insurance at its side. Thank you.

***Question:** Let me identify myself. I'm the Republican Counsel of the House Science Committee. Is there any type of legislative remedy you think that's necessary now?*

John Cozzi: Well, perhaps my naive knowledge of the Commercial Space Launch Act would lead me to believe that the basis exists now for the government to encourage the space industry through a variety of means, whether it is just procedures that they set out to encourage the commercialization of space by private industry or whether it's the encouragement, in the sense of government moving more towards commercial space purchases, I think that's all there. It's a question of implementation.

***Question:** I am not an attorney but I believe that, in order to have the government take insurance and not be a self-insurer, as it has been in the past, that it will probably take legislation to do that. I think that is something that should be done. I don't know if you are* *aware that the Department of Transportation's Office of Commercial Space Transportation already has a report out which recommends that the government indeed become a taker of insurance for many, many reasons. As I said before, I think it is definitely necessary. It will expand the base of the insurance, and help the insurance industry and reduce the government cost. For example, if we have a failure rate of say, 10 percent, then every government program concerned with launching is only getting 90 cents value out of every dollar budget that's given to it because it is basically a self-insurer so it has to set aside that pot of money.*

John Cozzi: You think it should pay 20 percent premiums to make up for that shortfall?

Question: Well, the kind of analyses that we have been doing indicate that with the current launch vehicles, current levels of reliability, that the place that insurance will settle for communication satellite businesses is somewhere in the premium range of 17, 18, 19 percent.

John Cozzi: Against a 10 percent loss?

Question: *No, not against a 10 percent loss. For example, if you develop a business plan for communications satellite businesses and you put into this business plan the considerations of the launch vehicles, the reliability of the launch vehicles, their upper stages, and the reliability for the success rate of the satellites working properly when first put into orbit, you find that the return on investment without insurance is a certain value; if you are a self-insurer, it has a certain value. You find that with insurance, taking insurance, at a premium of about 17-18 percent, you get the same return on investment, as without taking insurance. So that's why I say the insurance levels will settle for 17, 18, 19 percent level with the current technology.*

John Cozzi: Let me just add to this if I could. It wasn't too long ago, maybe two or three years ago that, again with regards to telecommunications satellites, the insurance premium rating levels for any of the, let's talk about the expendable launch vehicles, was well into the 20 percent levels. At one time it had gone up to as high as to 28-30 percent -- that was what was quoted for telecommunication satellite launches, but it was rejected by the buyer who decided on self-insurance. I think the market had to test the upper levels to see at what point people would decide that self-insurance was a viable alternative, maybe not necessarily desirable, but from a cost standpoint it made more sense. Since that time, and concurrent with very good results, at least from the standpoint of the Ariane launch vehicle, which has really been the workhorse up until just recently, performance results have improved dramatically. We have had a couple of failures. We've had satellite failures so the emphasis has gone, kind of, from the launch vehicle problematic area to the payload on the satellite area but, nonetheless, the performance results are improving. So much so that there's an increase or rejuvenated interest on the part of the insurance markets to get back into space, or if they are already in space to increase their capacity available, thus, fostering a somewhat more competitive environment, a better environment. Right now today, as I mentioned, launch insurance premiums are in the neighborhood of 17 to 20 percent, and by most accounts, I think it would be fair to say that the historical average for telecommunications satellite launches is probably somewhere between 12 and 15 percent. So we are moving down to those historical averages. Very gradually, very cautiously. As long as we don't have a series of catastrophic losses over the next couple of years, I can see us gradually moving into that arena. Yes, sir?

Question: What is your estimate of capacity today?

John Cozzi: Today there is probably better than $200 million in insurance capacity which is represented by the sum total of world-wide markets, being U.S., London, and European for the most part.

Question: That's launch insurance capacity, not liability capacity?

John Cozzi: That's launch insurance capacity, that's correct. As to liability insurance, I don't know whether that really has even been tested yet, but it would appear that there is sufficient capacity to satisfy what the U.S. government is going to impose on the commercial launch vehicle providers which is $500 million. There may be more available out there, but nobody has really tested the market yet and that's the only tried and true way to come up with a finite number. Yes, sir?

Question: Has any risk retention group been formed and, if so, is that an answer, and if not, why not?

John Cozzi: There's been a lot of discussion in the last five or six years on the part of various organizations to explore the possibilities of self-insurance, that is risk retention. Just recently, within the last year and a half, three large international organizations, INTELSAT, INMARSAT and UTILSAT joined forces to explore the possibilities of setting up some sort of a, let's call it, a self-insurance facility. And for a variety of reasons it was deemed not do-able. Whether those were good, hard and fast reasons, I don't know. Or perhaps it was just the desire of each organization to control its own destiny and not really be held accountable for somebody else's losses even though that is the whole point of setting up a facility of that nature. It's been discussed traditionally in the insurance industry whenever you have a hard market condition, where insurance is difficult to buy or expensive to buy, there's a lot of talk along those lines. It seems as though once the efforts to overcome the inertia and get those discussions going, by the time they take hold and you find yourself in the middle of a discussion, the insurance market improves and hence the reason for setting up or discussing that in the first place is kind of gone. So it's been discussed a number of times, it may very well be a topic of discussion in the future, I think it can make sense.

Question: On a recent visit to China, we were discussing this problem with the Chinese who are offering their Long March rocket. They cheerfully admitted that they have a failure in one in every ten launches. They said they were going to do their own self-insurance. Is that actually in effect? Isn't that going to really bias the market?

John Cozzi: Well, yes. Certainly, as another example. First of all, there isn't a lot known about the Chinese offer, any specifics about the Chinese offer. They discussed through a number of entities that they would provide some sort of either a re-launch guarantee or a refund, if you will. What really backs that up, what the mechanism is that the Chinese would use, whether it be commercial insurance or government guarantees, isn't well known but going back to the 1985, '86, '87 time frame, the Arianespace organization basically took that same position, and it came to be that they established their own re-launch or what they call the Launch Risk Guarantee Program. At that time it was not supported and I don't believe it is today, but I am not sure; but at least at that time it was not supported by the commercial insurance marketplace, which did not react favorably. I mean, they viewed it as, perhaps, an intrusion into their particular domain, although at the same time they weren't necessarily willing to provide the extent of coverage that the organization did at the premium rating levels that it did. So it does create some consternation.

Question: *It is only fair to point out that the re-launch, even though it's a form of insurance, just covers the launch and not the payload.*

John Cozzi: That's correct.

Question: *With the payload costing $100 million on a $50 million launch, the latter is just a small part of it.*

John Cozzi: Exactly, it is just a portion of the overall risk. You've got the launch costs and you've got the satellite cost, the payload cost that goes from initial ignition of a launch vehicle to some period of time in orbit, typically a launch insurance policy is written for 180 days. What that did was it took the traditional launch insurance coverage arena and notched out a portion of it, so that the satellite owner ultimately had to go out, if he deemed it necessary, had to go out to the insurance market and build coverage around that launch vehicle guarantee.

Question: *Can you say something about the other problem with the insurance concerning the commitment of the insurance industry more than 90 days or several months in advance of a launch?*

John Cozzi: If you went back, again going back to the real pit of the hard market situation in '86/'87, insurance markets were unwilling to commit their capacity at a fixed rate, any sooner than about three months, or roughly three months before the launch event that was to take place. There were a number of reasons for this. There was extreme skepticism over the reliability of launch vehicles, and underwriters wanted to have the opportunity to reevaluate their thinking if there were intermittent failures. Of late, the insurance market situation has softened to the point where it's not inconceivable to write coverages a year or a year and half in advance of the launch event. For that matter there are, with the advent of what we call multiple satellite programs, somebody like an INTELSAT organization who had a five satellite program could write an insurance policy that would span, let's say, two years to include all those launches. So the commitment from the standpoint of the insurance community was both substantial before the event and to a significant period of time following.

Question: *But that causes a basic problem. If I want to build a communications satellite, it's going to take three years to build the satellite. I go to the bank, try to borrow the money and the bank asks, "Well, where's your insurance policy?" "Hey I can't get one." They say, "Well, come back when you can get one". So there's a basic, fundamental problem here which right now looks like it is being relieved somewhat as long as launch vehicles don't fail again. As soon as they fail again, then we may be back to the same old problem, the insurance industry being somewhat gun shy of making long term commitments. Now is there a possible role for the government acting in a situation like that, as an insurer of last resort to try and help stimulate the commercial industry?*

John Cozzi: I suppose one could conceive a role, but I think that's been discussed in the past. For various and sundry reasons the government has decided that it was not its particular domain and that they didn't want to step in and act in the role of insurer of last resort.

General Comment: *That would automatically make them the insurer of first resort.*

General Comment: Not necessarily. If there were something developed with respect to the premium that you had to pay for the government policy.

John Cozzi: I don't know that it has really been deemed necessary. Certainly the insurance industry takes the position that it can work through the problems, on a very slow, pragmatic basis to date.

Question: *The insurance industry can work through the problem, but the question is, can the satellite industry work through the problem?*

John Cozzi: It's been a difficult problem, there's no doubt about it. As you said, it is getting better, but it's a very gradual process and I think that underwriters' mindsets are such that they are, to some degree, still dealing in the past and reeling from the catastrophic losses, and the true players are still there, and they are gradually increasing their capacity and gradually lowering their premium rating levels as performance statistics improve gradually, and it's very much an incremental improvement process. I should add also that, from the standpoint of liability, launch and in-orbit liability, through the Commercial Space Launch Act legislation the government has stepped into the position of insurer, not necessarily of last resort but a mid-level insurer above $500 million in losses, up to $2 billion in losses. So, in that sense they have taken some action.

Question: *I understand that, since licensing of launches came into effect, the business of trying to get insurance well ahead of the launch is now limited by the fact that insurance orders are issued by the Department of Transportation only shortly before the launch. That's now driving the situation we just now heard about. What is typical now in terms of the timing of these insurance orders.*

John Cozzi: I don't know.

Question: I've heard that SSI recently had one something like 60 days ahead.

John Cozzi: We work with SSI and from the standpoint of the small launch vehicle operator. SSI was caught in an unusual situation in that they were really the forerunner for the launch vehicle industry as far as DOT setting insurance standards. And while they were in the process of trying to conclude some insurance arrangement for their first Consort I launch, there was a lot of debate going on in Capitol Hill as to what really should be the government imposed liability requirements or financial responsibility requirements. And as a result it was just a last minute decree that came out of DOT that said, "This is what you'll insure to". From the standpoint of the larger launch vehicle vendors, McDonnell Douglass, or General Dynamics, or Martin Marietta, I get the impression that the levels of insurance, the financial responsibility which could translate into insurance, are pretty much set already. For example, we also represent General Dynamics and as such have put in place insurance with long-term implications that would satisfy those government requirements, with the capability of being able to alter those insurance programs should the government decide either to increase or decrease the financial responsibility levels.

Technology Transfer -- *Steven Morgan, CIT*

Introduction by Cary Gravatt: Our next speaker is Steve Morgan of the Virginia Center for Innovative Technology. We at NIST are certainly interested in these activities for several reasons: one of which is the legislation, the Omnibus Trade Act, that changed our name, added a responsibility of dealing with small and mid-sized businesses and dealing with state entities, such as CIT, so we made an effort to become familiar with what's going on at the state and local levels, certainly following the Virginia area, and we are very much interested in seeing the progress they've made with respect to space. This is Steven Morgan.

Steven Morgan: Thank you very much. I think the biggest testimony I can give to CIT's program is the fact that I moved here from Florida to run it, and I keep telling myself that Virginia's still in the South, but it was 15 degrees windchill this morning. I do have a cold. If I cough or sneeze in the middle of a presentation, I hope you won't be offended.

I'd like to start out by giving you a little bit of a background of what CIT is, with the first slide there. In fact, CIT is not a state agency. We are a non-profit corporation, and we are the operating arm. We like to say we are not a state agency, we are an agent for the state. We are the operating arm, the sole operating arm of the Innovative Technology Authority, which is a state agency that was founded by the General Assembly in 1984, and essentially what the Authority does is they give us money, and we do their work for them.

The Authority consists of a number of the presidents of several universities in Virginia and other appointees appointed by the governor, which form the board of directors of CIT. There are a few additional people on the board of directors of CIT. Our specific charter is to harness the technological resources in Virginia for economic and commercial benefit. We do this through a number of methods, some of which are obviously (or hopefully you'll come to see after the end of presentation) applicable to space. But in general, we work with universities in the Commonwealth of Virginia, companies throughout the world and other Virginia agencies such as our Department of Economic Development, and our Small Business Financing Authority in order to bring technology out of the laboratory into commercial application. In other words we try to build partnerships, frankly, to make things happen. Go ahead to the next slide.

You may be familiar with CIT in form, if not in concept from our complex near Dulles Airport. CIT is housed in the tower facility on the left, and we share the facility. We own the facility but we share parts of it with the Software Productivity Consortium, which is a consortium of a dozen aerospace firms doing software R&D. Go ahead to the next slide.

Essentially CIT is a brokerage firm or a middleman, trying to develop some long-term working and active partnerships between business or university systems and government. What we attempt to do is provide a certain type of support, at critical places or paths, along the innovation cycle which is the next slide, where we believe that some management and some funding can provide some value-added support to technology development and commercialization. As you can see, we've broken up the so-called innovation cycle into three areas, coming up with development, basic research, and applied research to develop a technology; the transfer period which is when that technology is taken out of the laboratory and attempted to be made into demonstration projects, pilot projects, and what have you, and then on through commercialization, where it's actually turned into a commercial product. Go ahead to the next slide.

In order to support our work at CIT, we have a number of programmatic mechanisms. CIT is run somewhat like a matrix organization, in that we have management functions over each of these different types of programs: the co-funded R&D at our universities which is essentially in support of the development portion of the innovation cycle; joint development and demonstration projects which is the transfer portion of the innovation cycle; and the various business assistance programs which support the actual commercialization phase of the innovation cycle. As I said we have managers that manage certain CIT programs that address all of these issues functionally, but we also have folks like myself, who concentrate throughout all of these areas on a particular topical field. My particular field is space. We also have programmatic functions in the environment, biotechnology, manufacturing technology and some other areas as well.

To get right to the point, now that you know a little bit about the background of CIT, CIT has been interested in space industry development for a few years. In 1987, at the request of Governor Baliles of Virginia, CIT convened and sponsored the work of the Commercial Space Group for the governor, which consisted exclusively of a panel of about 30 or 35 business executives from around the State who had an interest in space industry development or high technology industry development and this group came up with a number of recommendations, which CIT was asked by the governor to go forth and implement.

Some of the things the group found, that provide a basis and a direction to our effort, were that there was already a fairly strong position in Virginia in space technology. Virginia universities, for example, receive over $30 million per year in R&D support from NASA alone, in addition to some DOD work and other industry support that is strictly space related. That's quite a lot of money.

Also recommended by the group, and which Governor Baliles has done, was the creation of the Space Business Advocate, which is a central point of contact in the Commonwealth, since we are an ombudsman between the space industry and the Government of Virginia. CIT works very closely with the Governor's Space Business Advocate, in setting up its plan and carrying out its program.

As I said, with this space group's review, CIT sat down and developed an actual strategy and plan of action. One of the first steps that we took was to try to identify those fields where we had something to offer. You can see at the lower end of the slide there that we identified small satellites and their associated technologies, which would include various subsystems for the small satellite field and a launch capability, launch support for small satellites. We have also identified Vantage point industries, which are satellite communications, navigation and this sort of thing. We are also interested in space materials and structures which would include composite materials and the development of such materials into structures for use in space vehicles, including space stations, and we also include, under that rubric there, robotics and teleoperation. There are innovative space business issues including risk analysis, insurance and financing.

Having identified the fact that we either have a large industrial base, or significant base anyway, or particular strengths in our university community to address each of these areas, we then developed a number of programs and activities that we are involved in, in order to enhance the development in those areas.

In particular, and I will go down these in order with the technology development portion coming first, one of the things that we do with our space fund is we set aside a certain amount of money each year whereby we co-fund R&D in Virginia universities with industries to do technology development. I have listed a few of the specific projects that we've funded in the recent past and the associated agencies or companies that have helped to co-fund this work. What we do in this approach is, we work actively with companies by going out and seeking companies, or of course distributing literature. Folks come to us and we attempt to arrange a working relationship whereby the company or the outside agency will put in a certain amount of money, CIT will put in a certain amount of money and have research and development conducted, usually in a Virginia-based laboratory, by Virginia university researchers and researchers on loan, or some other kind of arrangement from the company or agency with which we are conducting the project. Thereby we think that through this program we reduce the R&D cost to companies, and to some degree, we reduce the risk. The risk is reduced by the fact that we are paying for part of the bill and if the results don't come out quite as satisfactorily as you'd hoped, you haven't had to put all of your own money up for it. It also tends to reduce some of the risks associated, as you are all probably aware, of doing research with a university. There are certain frictions there, a certain amount of inertia, and we're willing to pay part of the freight there in order to make these partnerships develop.

Usually, those involve one-on-one relationships or very specific application areas where we might have several parties involved, but they're usually a very specific piece of technology development or research in an industry trend, such as our small satellite study, the potential market for small satellites, which was recently completed. There are some other areas, however, wherein several companies or several agencies or organizations might be interested in pooling their resources to conduct R&D and sharing the results with each other. We are in the process right now of setting up the Virginia Space Development Consortium in order to do that.

This is along the same lines of a NASA Center for the Commercial Development of Space but, rather than focusing on a particular area, we are focusing on the four areas that I mentioned earlier, the industry areas. We are working with five of the universities in Virginia that do the bulk of the NASA-funded R&D. The purpose of the Consortium is to harness the capabilities which have been built by that federal R&D funding for commercial benefit. In other words, we've got wind tunnels, hypersonic flight wind tunnels, etc. We've got laboratories on composite materials and structures, robotics labs, all of which have been essentially bought and paid for with federal R&D money, and this Consortium is going to provide a mechanism by which industry can access those facilities and pool their money to do specific research projects.

CIT is committing a quarter of a million dollars a year for the first three years as seed money into the pool of funds in order to support the consortium. I would also like to point out, at the risk of making this sound like a sales pitch, that we do work with companies throughout the world on this through our technology development programs, and also in our technology transfer programs; we do not work exclusively with Virginia-based companies. So, we are open to the world on that score.

As an example of a technology transfer or demonstration project which is along the next phase of the innovation cycle, we've got a number of projects going on, perhaps the most visible of which is the VASTAR satellite project that we are co-sponsors of with Orbital Sciences Corporation. OSC is the contractor on the VASTAR project and in fact this is an OSC-driven project. The long and the short of it is that Orbital Sciences wants to break into the small satellite applications market. Everybody is familiar with the Pegasus and the Taurus, and their launch vehicle capability, but Orbital wants to become a satellite manufacturer.

How can we reduce the cost and risk to them breaking into this market? Well, one of the ways is by working with them and buying some of their unproven technology. CIT is paying a quarter of a million dollars for the design of the first in a series of their DATASAT satellites which are essentially a small, low Earth orbit, store and forward communications satellite, this has an omni-directional antenna. Orbital intends to put up a network of these satellites to provide continuous communications coverage from low Earth orbit for certain applications areas that a store and forward communications system could handle.

What CIT is doing is buying into their first project. In return for this, Orbital is going to essentially give all of that money back to Virginia in the form of matching grants that CIT and OSC will fund in Virginia universities to conduct research projects involving research into the characteristics of the satellite, its signal and the actual operational characteristics of it.

Also a number of specific applications projects, such as, we are going to have a series of buoys floating around in the Chesapeake Bay gathering environmental data. As a satellite passes overhead, these buoys will relay up information to the satellite that, in the past, had a herd of graduate students rowing out in a boat to gather manually. Well the technology is such that something, about the size of this microphone, can be placed on top of these buoys; that is enough hardware to communicate with the satellite and relay the data up that way. So, we are going to be doing a few pilot projects at the Virginia Institute for Marine Sciences involving this approach.

Getting back to the point of this conference, what does this do for Orbital Sciences Corporation? Well, it allows them to reduce their risk and their costs in breaking into a new market area, small satellites, by having essentially a first customer. Beyond being just a first customer, we're also working with them on developing and funding the development of and also providing research support from Virginia universities for development of their ground station, the low-cost transmitters that will be put on the buoys, and that type of technology development. We are co-funding applications projects with them which are going to demonstrate the viability of this system.

I think one of the observations from the audience, before the break, was tha one of the problems is being able to convince the commercial market that a new space business is viable, and we hope that some of our R&D projects in the long run, such as when Orbital goes out to market its system and people have questions of, "How do we know this is going to work?" They'll be able to hold out the papers and the results from these Virginia-sponsored projects as tangible evidence that this network and this system does work, it functions with known characteristics. That will thereby give them a competitive edge in the market.

It's just lucky for us that Orbital happens to be based in Fairfax. We could have done this with any company, in fact we are negotiating similar projects with other companies, not all of which are based in Virginia.

So, I think that's a tangible way that CIT and the State is helping a business grow and reducing the risk of breaking into the space market. I also think you will notice that a quarter of a million dollars for a satellite project is not a lot of money. That's one of the reasons why we are interested, very much so, in the small satellite market, the small launch vehicle market. We think that there's a real chance for cost reduction there and, therefore, democratizing space, getting more people involved in it.

We will now move onto some specific business assistance programs that CIT is involved in. The first is the Virginia Small Business Financing Authority. This is in fact not a CIT venture or CIT program, but we work very closely with them. The Authority is a separate State agency in Virginia that raises funds for small businesses. Unfortunately these do have to be Virginia companies or have an operation in Virginia. Low-cost loans, loan guarantees, and various other financing routes as available through tax-exempt bonds. Then CIT itself has a number of other business assistance programs, including our innovation centers which are essentially business incubators. In fact, in February or March of 1990, we will be establishing a Space Business Incubator, an Incubator at CIT headquarters devoted solely to assisting small space companies start up in Northern Virginia.

We also have a separate program supporting SBIR winners in Virginia. We provide certain amounts of R&D assistance and co-funding assistance, particularly to SBIR Phase I winners to help them be successful in Phase II awards, and to Phase II winners to help them actually go forth and commercialize the products that they've developed.

That's a very large program. To give you a feeling for the scope of this, our total budget for space per year is on the order of $2 million. The Small Business Assistance Program is a similar program. So, within CIT there's about 4-4.5 million dollars per year that could be tapped for space industry development.

We have a memorandum of understanding with Langley and Goddard which provides a framework for a number of things, including technology transfer. Also, something that I'm very interested in is the development of Wallops Island as a commercial launch facility. We'll talk about that more in just a moment.

We are also forming a Virginia Business Roundtable, in the Norfolk area. Some of you may be familiar with the roundtables, some of you more than others. I know at least one person in this audience who has run a roundtable in the past. We are forming one, mainly to involve Virginia's business community in space, to begin to educate them and make them aware of what opportunities there are in space enterprise for them. It's a fact that the Virginia banking community and to some extent the venture capital community in Virginia is fairly conservative and we want to use the roundtable to try to help educate them in the ins and outs of space, and we are basing it down in the Norfolk area which is essentially the heart of the business portion of Virginia.

I'll talk a little about our plans for the Wallops Flight Facility. We get asked about this a lot. In fact there are a number of states that are involved in space port activities, Florida being one, Hawaii and Virginia. We haven't talked much about what we are doing on the space port side of things because, frankly, we have been working on building a market for the type of launches that we expect would be appropriate to go out of Wallops, that is the small satellite market and this sort of thing. It's a question of which comes first: the access to space or the applications. I happen to personally believe that access to space is the most important component but on the other hand it's hard to convince people to actually go forth and spend money and do R&D on a series of small launch vehicles if there is no perceived market for them, so we've been working on the other end to date, and of course we'll continue.

However, we are coming up to the end of a feasibility analysis or an assessment of the existing facilities, that we commissioned with respect to the Wallops facility. We have a contractor who is going to be finishing this up by the end of the year and presenting us a baseline of what is out at Wallops right now; what is the existing infrastructure; and what is the mood and the interests of the Wallops management in supporting commercial activity. So far, we have gotten very good feedback from the folks out at the Wallops Island facility and I will be going out there at the end of the month in order to meet with them face to face to discuss what the State might do.

Now, one of the things that we are very cognizant of, that we are very interested in at CIT is not getting involved in a project unless there is some tangible benefit that we can bring to industry that wouldn't otherwise accrue. In other words, why get a quasi-government agency involved in the thing if you are not going to do any good. We don't want to be just another layer of bureaucracy. That's one of the reasons why we are being so cautious about getting involved with Wallops.

However, there is a precedent for the State of Virginia to be involved in this type of activity. There is something out in the western part of Virginia, known as the Virginia Inland Port, which is a State-operated multi-modal or inter-modal port facility. It's got everything but the ships. There are rail yards there, a confluence of highway systems, where people, companies from everywhere west of Virginia in the US, which includes the rest of the country, come and deliver their goods for shippage overseas and import as well. But the State handles and pays for, underwrites the cost of, actually taking this material out to Norfolk for shippage via the sea. So it's a multi-modal port facility that is essentially the seaborne segment that is transparent to the user. It's handled by the State. We are looking into how that operates and how that mechanism was set up by the State as we design what we may or may not do at Wallops.

In particular, there are essentially a range of opportunities that we can get involved in with regard to Wallops and again, as I mentioned, unless we feel that we can significantly contribute to cost and risk reduction, we won't do that. Of course, the easiest thing to do is something that we've already done and that is facilitating the use of the existing facilities by something no more difficult than introducing and setting up and arranging meetings, hosting meetings with representatives of companies that wish to use the facilities and the appropriate folks at NASA, and we've done that in the past in a number of cases.

The next step in this range is upgrading and promoting the use of new facilities, be this a new launch complex, an extension of the runway facilities at Wallops in order to handle something like the Pegasus, or some of the newer vehicles like the Taurus or some of the other unflown vehicles, all the way up through the construction of completely new facilities, payload processing facilities, payload storage facilities, clean rooms and this sort of thing. I think that leads to an important differentiation between simply providing a launch complex and a space port.

The goal of the space port approach is not just to provide another launch pad for industry to come in and use at its own risk but to provide a number of mechanisms and facilities whereby the State or the operating agent of the space port reduces the risks and shares the cost, which thereby encourages industry to use the facility.

I think one of the things that we try to avoid talking about at CIT and in our space efforts is this whole issue of cost per pound to orbit. We think that with the growth and the development of the small satellite industry, where you have very capable satellites but satellites that are targeted for a very specific application or mission, this whole issue of cost per pound tends to be misleading. The point is, "What is the total cost of your mission, to get your space segment up and available for commercial use?" Then you are going to have recover that cost in a commercial way, so, there's a lot more involved there than just sheer cost per pound.

I did forget to mention, but just in case you are interested, for example, the VASTAR satellite weighs less than 40 pounds. This is a very small bird. Anyway, this is getting off the subject. What we are trying to do with the whole issue of a space port is to assist industry by providing certain facilities or certain services that would actually reduce the cost of access to space.

Some of the obstacles that restrain us from doing more is that we are currently prohibited from taking an equity position in a company that we may be trying to assist. In some states, as I know in Florida, there are entities that do take equity positions in start-up companies. Our board will not permit us to do that yet. There is nothing in the enabling legislation for CIT that prevents that but our board has prohibited it. However, we are working with the Virginia Small Business Financing Authority to be able to do that through their means instead.

Also, working with universities presents some timing problems and availability problems but companies that are used to doing that are fairly used to that; and then again that's one of the reasons why we co-fund the research.

As I mentioned earlier, the Virginia finance community is somewhat conservative, and they view space, even today, as being a very risky proposition to invest in. We do have what we call our Technology Transfer Program at CIT and I thought I'd mention it just briefly. This is a program quite similar to other technology transfer programs around the country, whereby we are taking technology that's available from many sources and working with businesses to help them use it.

We are working this through our community college system throughout Virginia. We have about 40 percent of CIT's total resources devoted to this technology transfer sector. One of the things we are doing with regard to space technology is to work with our Technology Transfer Center directors, each one of which is based at a college in these areas in order to plug them in with the NASA technology utilization community.

In conclusion, "Does CIT have a pretty nice space program going?" The answer is "NO". We are not a space program. We don't seek to become a space agency of any kind. What we have at CIT is an economic development program, and we just happen to have a significant portion devoted to the development of space enterprise, and that's there and available. And of course the whole point of this exercise, and one that the State is interested in, is to reduce the cost to business of doing business in space and hopefully in Virginia or with some Virginia participation in it. That is the entire point of what it is that we are trying to do.

You should be aware, as we've mentioned a few times, that there are other states that are also involved inthis. Florida of course, is a leader in that area. Hawaii has a major effort under way, centered mostly around the launch complex that they hope to build. Also, just about ten days ago, Texas appointed a commission on space, which is going to begin taking some action, although it is still unclear as to what they will do. There are many other states, in fact almost every state has some type of economic development, high-technology industry development or university/industry R&D program that have fairly significant funding available for companies to use.

I think the message, for a conference like this, is that space-oriented businesses ought to take advantage of the resources that may exist in their state. Furthermore, it may be worth your while to contact some of the states that have space-specific support mechanisms and R&D support and see if you can't develop some kind of working relationship with them, even though you may not be based there. As I said, we work with our consortium and with our space fund, funding projects with companies throughout the world, so that's something to keep in mind. I think what all this boils down to, or adds up to, is that this is another source of resources that the space enterprise community has at its disposal to help it reduce the economic risks and reduce the cost of breaking into the space business or breaking into a new area in the space business. Thank you very much.

Question: The first comment is that -- did I understand that you are newly joined, when did you join CIT?

Steven Morgan: In July.

Question: I was pleasantly surprised to read the final draft of the George Mason study on this whole thing. It said some very useful things in it and was particularly objective. I must say I was surprised, I see George Mason in other contexts, and I think you have a real winner there. I just applaud that.

The second thing is that I was a member of Governor Baliles' group and I was the one who, late at night, threw myself on the barbed wire and said "What we don't need is a space advocate, what we do need is space business advocate." At the last half of the night that modest little word was inserted there. The reason is that there was a great deal of discussion, and I see some of it's still here, about involving the universities in a very important fashion, indeed a fundamental fashion. I love the universities, been there myself. Remember what universities do. Two things: they pass on the knowledge of the ages, and they generate new knowledge. Now they could also be cajoled, at the margin, into doing other things, but by and large that's what they want to do, and they either do those things well or not. If you want to get universities involved, and you hear a lot of stories about MIT, and Route 128, and Silicon Valley, it requires some genius. Genius. It's not an institutional arrangement which really sees to economic effectiveness. You've got to have a genius that on the same day can convince the assistant professors and the graduate students, if they are passing on knowledge at at the same time "We've got to fix this tank, carton or something like that". So, I would just suggest that you, be very careful to find the geniuses.

Now, I have a question. I find the most fascinating thing that you said was that you have, as I understand, a memorandum of understanding with Langley?

Steven Morgan: We have one, yes.

Question: What are you going to do? Do you know what the MOU says?

Steven Morgan: Well, I do. It establishes points of contacts naming CIT as the contact within Virginia and points of contact within Langley and Goddard to carry out future developmental activities, particularly with regard to the university community and industry. It's a fairly broad framework, by establishing points of contact and they have an agreement to agree, kind of a thing. A lot of it's motherhood and apple pie, but it does specifically call out the technology utilization program, tech-transfer, that sort of thing and also the development of programs that will specifically benefit the commercial space industry. Those are two focal points within the MOU. That's the extent of it. It's up to us to work with some of the existing CIT programs, like the tech-transfer centers, and some of the other things that we are doing to organize or to set up specific project agreements with the NASA centers on a case by case basis. So the MOU's themselves are fairly broad.

Question: *The nice thing about getting a handshake with Langley is that Langley is far enough away from Washington. It's like this part of the Air Force up at Elmendorf, Alaska. That's far enough away so that they can avoid contamination if they put their minds to it. You want to start out right with them down there.*

Steven Morgan: I wouldn't touch that one with a ten foot pole.

I would, however, like to comment a couple of things on your first two comments though. The study that you are referring to was the Small Satellite Study that was done at George Mason. In fact, this is an excellent example of agency, industry and university cooperation. The research was conducted by a senior research fellow at GMU whose name is Larry Stern. Larry is on loan to George Mason for two years from NASA, where he's the director of Strategic Planning in the Office of Space Flight. He is a 30-year NASA man, so he knows the business and he came to GMU with an interest in looking into the innovative side and the space enterprise side of things, but he brings that background with him. It doesn't seem to have affected his thinking process too much, to respond to your latter comment. The university threw in the support facilities and two Ph.D. students in economics there to assist Larry in the research, and Rockwell and CIT funded the research and we are coming out with a bound book which recounts the study. If any of you are interested in it you can leave me your card and I'll be happy to get you one of the sign up forms for that. It should be out by the end of the month, in fact it's at the print shop right now, being printed.

The other thing with regard to your comments about the university community is that we have an excellent relationship with the universities, which is something that I found not necessarily to be the case with some other similar institutions in other states. I think part of the reason for that is that we've got the presidents of six of the biggest schools in Virginia on our board of directors. By nature, we keep them happy, one way or the other, but at the grass roots level, the working level, where myself and Mike Miller and some of the other people at CIT actually go and work with the professors, that's where we at CIT really add some value, at least I would like to think so, in this process. We don't just introduce business to the university and say, "Hope you can work something out" and then go home. Instead, we work with them. "Let us know and we may be able to co-fund your research," but we work with them. When we go to industry we are familiar with who is doing what in the universities, what their work load is like, what their research history is, who are the new, good research assistant professors who can get involved, so we bring that to the industry. On the other hand, we work with the universities to make sure that they don't take on tasks that are not appropriate for a university or impossible to accomplish. Or in some cases we'll help them hire people for projects that are devoted specifically to that project and don't have any teaching duties, and that sort of thing. So, we take a very active, interactive position with the schools and industry which I hope adds some value to that relationship. Thank you.

Quality and Cost -- *Curt Reimann, NIST*

Introduction by Cary Gravatt: Our final speaker this morning is Curt Reimann who has held positions at NIST as Director of the Center for Analytical Chemistry and Deputy Director of the National Measurement Laboratory which contains most of the physics and chemistry parts of NIST. Two years ago, he took a special assignment to establish the operations of the Baldrige Quality Award, which was formed to honor American companies for progress in quality, and named after a former Secretary of Commerce. In this position, Curt has had the opportunity, for two years now, to see quality in applications from, I think, a hundred or so companies each year, from which the awards were picked. Probably more than anyone else, he has the opportunity to see what American companies are doing in the way of quality. We'd like to pick his brains a little bit about what's being done good and where can we seek improvement and possibly cost savings.

Curt Reimann: I would, in outline, just to make a few remarks about the Baldrige Award, a comment or two on the criteria, listing some of the first two years' experience, commenting on quality and costs and then something on the conclusions.

First, the award is driven by the need to improve U.S. competitiveness. Market share is certainly the major issue and cost reduction is a factor in that, but clearly not the only factor. The combination of the desirability in the market plus competitive price, together adds up to the quality component of the US competitiveness. The award exists by law. Its purposes are fairly straightforward. It's not only recognition but awareness and sharing of information. That sharing of information is now going on like crazy, and I think it's the biggest short-term benefit from the establishment of the award.

The categories are in manufacturing, service, and small business and it's a public/private partnership with a strong sponsorship from the private sector, a capitalization of over $10 million. The government is the convener and the catalyst and developer of the main program, and so on. The award criteria have been strategically designed to represent the national value system for quality, to try to put some substance behind TQM and so forth. That's the rage now, so, we are in the middle of that national effort to develop a kind of consensus standard for world-class quality. We are trying to develop a diagnostic system because for all of the applicants we not only say "yes" or "no" as to whether they get an award, we have to give them a detailed feedback report with strengths and areas for improvement. Obviously that's a very important diagnostic assignment.

Closely connected to that diagnostic assignment is the information transfer. The criteria are in widespread use around the country not only for awards but also for self-assessment. Any company wanting to do a sort of health check on itself would profit from getting copies of our award criteria which are very detailed and now have a lot of consensus behind them. It's a useful device to try to come to a good agreement on what we mean by quality and also what key steps should be taken to foster quality. It is continuing to evolve, and that's again the exciting part. As we learn things, we factor them into each subsequent year.

The framework for those criteria is shown here. All of the system elements are laid out in the boxes, and all of that information is available, again in the guidelines, so, I won't go through the details. All of the customer-related issues, the result-related issues, benchmarking, competitive comparisons, planning, and so on, are all spelled out in some detail in the criteria. Together these elements form the essence of the definition of total quality management that we are invoking on behalf of this national award. The information at the bottom just gives a summary of what the respondents have to address in their applications for awards.

In the first two years we've had five winners out of 12 possibiles. We can give up to two awards per category. Earlier this month we had the award ceremony and President Bush gave awards to Millikan and Company and the Xerox Business Products and Systems component of Xerox. In 1989, Motorola and the Commercial Nuclear Fuel Division of Westinghouse were winners in the manufacturing category. A small business called Globe Metallurgical was the small business winner. In neither year were service awards given, and this year no awards were given to small businesses. Last year only one award was given to small business. It's a very, very tough standard and the winning companies are putting in an enormous effort nationally.

I had a session yesterday with somebody from Motorola, and they have given something like 300 presentations on the award. A small business winner went past the 110 mark last week. These companies are sharing information and hard data on their quality systems, including some economic data around the country. So it's really working in a very positive way, beyond our expectations.

Turning to the issue of quality and cost. The award winners have documented major cost reductions in parallel with their quality improvements. One of the controversial issues centering around quality, "Is quality something you pay for or is quality something that reaps a dividend?" The data are increasingly compelling to indicate that there are actual reductions in costs associated with quality improvement. The reductions are coming from reductions in scrap and rework. A great deal is being wrung out of administrative operations: in some cases, elimination of most or a good part of middle management and giving greater empowerment to employees. There's a lot of elimination of non-value added steps, particularly through reduced cycle time. In fact we are finding that the award winners are pursuing continuous quality improvement by leaps and bounds and not incremental or "baby" steps as is sometimes the folklore of continuous quality improvement.

Motorola is documenting, in many areas of its operations, 68 percent improvements per year and they are pursuing factors of ten and a hundred over three and four year periods. They estimate that from improvements introduced just in the last two years, they have $250 million of savings in just the manufacturing part of their operation and they are beginning to collect data from the service side of their house.

One of the award winners, Globe Metallurgical, won another award last year for productivity improvement. They were able to document 367 percent improvements in productivity over a two or three year period, and clear, large savings in labor, in their metallurgical productions. Reduced cycle time: the gains here have been factors of ten and more, associated with quality improvement, owing to the fact that in all of the steps leading up to final production they have wrung out non-value added steps and they have eliminated scrap and rework, and so the first time pass throughs are enormously higher. So the models that these companies represent, in terms of cost savings, give one considerable hope that with better availability of the information from these companies, other companies will learn to reduce costs associated with manufacturing and delivery. The quality improvements are the obvious ones: response time, reduced product defects, and improved service. That's no surprise.

Another interesting set of findings, not quite associated with this award, but the PIMS, a group in Boston, Profit Impact of Marketing Strategies, has shown that companies that pursue quality as a principal strategy have twice or more the profit margins of typical companies in their same industries. Recently we've learned that in the Deming Prize, which is Japan's quality award, over the years the historical record has been that the Deming Prize winners have twice or more of the profitabilities of typical Japanese companies in their industries.

So, there's a mounting body of data that indicates that quality pursued across the board in the sense of total quality involving all operations and employees is a major cost reduction strategy.

In conclusion, I would say that we're seeing, based on the first two years, that cost reductions are indeed achieved, that all operations must contribute, otherwise they do get suboptimization, with problems passed from one unit to another without reductions in the overall cost of doing business. Cycle time is turning out to be a very important driver of quality improvement.

The elimination of non-value added steps and also the mistake proofing of steps is also a major factor in improving the integration of functions, particularly in the earlier stages, where design is important in order to head off down-stream problems. What we are seeing nationally, in company after company, including many companies that have not yet applied, but are preparing to apply for the award, is that total quality is the preferred route to productivity improvement. In other words, some of the productivity improvement efforts of the last couple of decades have sputtered for a variety of reasons, not the least of which is very often labor and management head knocking. Also, it tends to focus on technology replacing workers, and that hasn't worked in a number of famous instances, whereas the route, based on total quality, seems to be involving workers in a very positive way. The combination of worker involvement plus the focus on the end product rather than individual steps is yielding productivity improvement as a dividend, even though productivity improvement per se was not the original target.

That, in general terms, is where we stand at this point. As I mentioned at the outset, it was not a goal under the legislation, the way the legislation is written, to focus on quality cost.

That tends to be a very controversial item. We are hoping to get an analysis, perhaps a long-term analysis, of award winners here and in Japan, and perhaps in some of the other strongly contending companies, to get a better handle on what productivity gains and what cost savings are associated with improved quality, and then presumably those techniques that are most generic and mostly adaptable from company to company, based on employee type and so on will become clear. That information, through NIST and other organization, can get out to the benefit of all. That's about it. I would be happy to answer any questions on this subject.

Question: *From a particular perspective of this conference, are you in a position to say anything at all about the space industry?*

Curt Reimann: No, not really. We're not allowed to give out any information on applicants outside of the winning companies nor do we have any mechanism in place for studying particular industries. I think that would be premature in the history of this program, which has had a minimal involvement of enough companies in any industry to draw such conclusions. It is fair to say that the companies that have taken a beating in competition with the Japanese are on the leading edge of promoting quality. They have learned the earliest to pursue total quality techniques. Outside of that, I don't think that there are any big generalizations by industry.

Question: *How many people at NIST work on this quality award committee, and how long do you have to read the applications and make your decisions?*

Curt Reimann: Well there are three technical people plus administrative support. We don't do any of the evaluating, we do the convening, we bring together the team. This year we had 134 people from industry serving on the evaluations committee. The winning companies had about 400 hours of evaluation each. The near-winning companies had almost that much and then on down it dropped down to perhaps a 100 to 150 hours for those that were weeded out early. It's an exhaustive evaluation that results in a feedback report to the company. Last year's feedback reports were very positively received. A number of companies have made major changes, based on the feedback reports that they received. It's a major undertaking at the national scale. We have over 1,100 people now who are interested in serving on the evaluation committee, and all those have to be screened, to select the team for 1990, and so on. We have to train them all, 20 at a time, using case studies, and evaluation processes. It's a multi-step process. I think the contending companies this year had about 16 different people looking at their applications at different times in the process. So, there needs to be a broad base of input to each final decision.

Question: *I would like to answer the first question, using Curt's work and linking it to my talk. I think what Curt said, which is relevant to the aerospace industry, is elimination of non-value added steps and I gave you examples of those, and focussing on the end results, which came out nicely in the discussion. And I think the third one is the integration, especially designed with manufacturing which I think is also a sore spot in aerospace.*

Cary Gravatt: I thank all the speakers and attendees for a very interesting set of sessions this morning.

CHAPTER FOUR

ADVANCED LAUNCH VEHICLES

Introduction by Ray Williamson: My name is Ray Williamson, I am with the Office of Technology Assessment, and while I've got the podium and the mike, let me just do a bit of a sell job of some of our recent work on space transportation. You heard from Rich DalBello yesterday who actually was the Project Director who started this project on space transportation. When he went over to Commerce I took it over, and am trying to finish it up at this point.

Basically, so far we've published four different reports: Launch Options for the Future; Reducing Launch Operations Costs; Big Dumb Boosters; and Round Trip to Orbit. Many of you may have seen them already. If there is anybody here who would like to get a hold of copies of any of these, see me afterwards, and I can either tell you how to do it or, in certain cases, make them available to you.

We have, coming up, a report which will be on spacecraft design, specifically toward reducing the costs of spacecraft and then our final report on the overall study which we hope to see out in January or February will sort of summarize everything, bring it together. The spacecraft report we hope to have out in December or early January, but if you leave me with your card, I'll make sure you get notification of those.

It's my pleasure to introduce to you at the beginning of this Advanced Launch Vehicle Session, Mr. Michael Weeks who is with NASA and who will talk to us about the National Aerospace Plane Program. Mr. Weeks has spent the last ten years in government service, for seven and a half as Deputy Associate Administrator of Space Transportation Systems, in other words the Shuttle. He joined the Office of Aeronautics and Space Technology as a Deputy Director of the National Aerospace Plane Office two and a half years ago. Before that he was at the McDonnell Aircraft Corporation, and earlier than that with IBM and with Perkin Elmer. He has been in the space program for a long time and we are going to hear from him about the National Airspace Plane Program.

Mike Weeks: I always like to have the rules of engagement clearly understood. I always kind of introduce myself as just a Junior Engineer C, fresh out of graduate school. You'll notice in the introduction, I'm careful to state that I worked at McDonnell Aircraft Corporation. That was before its merger with Douglas. It's sort of like being in NASA from the mother center down there at Langley. You know that's the mother lode that the Johnson Center came from and the space task group and so forth.

I am a little different in that I spent all my life in industry, prior to coming with the government. Probably the best thing about that is that if you are reasonably prudent you built a big enough estate so you can afford to live in Washington.

One of the things that's bothering me, and you'll see that in the speech a little later, is that NASA was formed as you know in 1958. I happened to be at McDonnell Aircraft and hired as my deputy a young man named John Findly Yardly. We've been friends for 45 odd years or whatever. He made the serious error with me, at one of these black tie affairs ten years ago, of asking, "Are you working hard?" I said, "No, not particularly." He said, "Why don't you come down and help me run the Shuttle Program?"

I did that for seven and a half years. It's a killer job. Our new boss there at OAST, is Arnie Aldridge. I told him the other day, "You've done your penance." At IBM it was kind of standard that you never put a man in a killer job like that one for more than three or four years. You outspanned them so they could at least know who their wife is, meet the kids, take the kids to a baseball game every once in a while, just so you know who they are.

Another hot button of mine that you will see a little bit later is that nationally, as well as at NASA, we've lost some of our verve that we knew so well in the case of the early days of NASA. For example, this little company in St. Louis, that won the Mercury Program... actually, John Glenn was put in orbit 37 months after the contract was awarded. Now usually, these days at NASA we can get the RFP out about by then. Maybe that's a little too fast.

Another little interesting thing is, of course, as you all know, the Apollo went to the moon in eight years and two months. I don't believe we could even come close to that again. I believe the Manhattan Project started about 1939 or '40, and, of course, two different bombs were dropped on Hiroshima and Nagasaki, two completely different designs in '45.

I don't know what the hell is wrong but something is wrong, and we'd better start working on fixing it. Of course, there was somebody yesterday, who said that, "We are always responsive. In the case of Gagarin and Glenn and the going to orbit in the case of Sputnik, we really did have to respond". Of course, in the particular case of Sputnik, the Von Braun team really brought that home for us, even though the management in Washington was screwed up in not letting him to do his thing. Somehow, in someway, we've got to get back to where we are, not taking so terribly long to do everything.

I do believe in the space business; the really crucial thing is the launch vehicle thing; and we are awfully tied to the Shuttle. It's costing us an awful lot. Eventually it's either going to be a heavy lift vehicle like the Shuttle C, like Energia is, or it's going to be ALS. The only thing I can say is that I sure hope we move out somehow, someway, because you really don't have a space program, if you don't have a big vigorous, strong, launch vehicle program.

One of the things that we did during the Shuttle program, the standard thing, is endlessly try to get more performance. We made a change to the solid motor to get 3,000 more pounds of payload. That took us two and a half or three years. We redesigned the external tank and got 7,000 pounds out. But the point of all this is that we just get ourselves in a box and we end up, like Ekerd Winerick said, that we just don't start out big enough. His chart showed that he was going to deliver 37,000 pounds in the first one and you only used 34, and that's exactly the right kind of philosophy. I think his use of the same engines for all his machines, probably is very sensible.

One of the things I learned when I was at Aerospace Corporation, and we had the pleasure of inventing the Manned Orbiting Laboratory, is that the thing that we did wrong there is that we kept inventing. We've been inventing on the Shuttle too. Doing so is really a very undesirable thing. I think that any of you that haven't read, you should read, and you'll see me bring it up again a little bit later, is this book by a guy named, Magaciner or something like that, "The Silent War". If we don't learn, and we better get cracking, if we don't learn, that this is a world competition and not just an American competition, we haven't learned anything.

Now, as you will see, when we come to the chart on the materials consortium, I am deeply convinced that with the Air Force, we have outMITIed many in Japan. You are going to see that we've got five of the big primes of this nation and they are outstanding companies, two of them propulsion and three of them airframe, just outstanding in the cooperation and the way they are working, a $140 million program of materials and structures consortium is a thing of beauty. It is just outMITIing MITI, it's outSEMATECHing SEMATECH and that's what we've got to do. It isn't the way I grew up. When I grew up, we fought tooth and nail with Lockheed and North American and Grumman and so forth, it was just a bitter competition, but the world isn't like that any more. We have to work with each other in the U.S., much differently than I grew up doing.

As we were talking earlier, we've got to get these launch costs down, and I think it's economy of scale that is going to do it. These 39,000 pounds that the Shuttle is putting up to 220 nautical miles, we've got to get in a big class of 100, 150, 200, 250,000 pounds -- like Energias before we've really made it.

With that little introduction, so that you'll know where I am coming from, I am a deeply competitive person and you'll see that in the second half. Every now and then people think people know what they are talking about. I don't particularly want you to completely ignore everything I say, but let's just take Lord Kelvin. He said, "Heavier than air flying machines are impossible". Well, that probably wasn't, and isn't true. I kind of like it because I am kind of a baseball fan. Ruth made a big mistake when he gave up pitching. So, let's go on.

The real big problem in the NASP thing is the air breathing propulsion. You're going to hear that we are spending a large amount of money on advanced materials, and a large amount of money on CFD and I go back so many decades that I am not... well, CFD is just another weapon of war in a technical problem area. It is not a cure-all because, until you have the genuine test data, and in reality NASP is going to be a flying wind tunnel, particularly beyond Mach 8.

Question: What's CFD?

Mike Weeks: Computational Fluid Dynamics. Of course, I don't want more actively cooled structures on this airplane than we absolutely have to have. In fact we actively cool, as you know, the SSME, and we get endless leaks and we are endlessly putting helium through the system to see whether we can figure out where the leaks are and do something about it or not, depending upon what the facts are.

This really is true. I am very impressed. We go every six months to the three airframers and the two engine guys. They are of course, Rockwell, General Dynamics, McDonnell, and Pratt and Whitney and Rocketdyne and they are just endlessly making improvements. We've got to quit that pretty soon, 'cause we've got to go ahead and build the airplane starting March 30, 1993, which is the new Quayle/Bush position -- we have delayed two and a half years, and you'll hear something about that.

And of course, the testing and everything is just going faster and faster. It takes, as all you industry guys, of course, know, it takes quite a while before all the wind tunnel models are in tests, and one particular company has 20 big models, some of them four or five feet long to test engine out, on and off, and so forth. That's very important. We're testing, we will test more than the Shuttle did, and the Shuttle had 70,000 wind tunnel tests.

At the NASA centers we have 300 people doing technical work, and facilities galore. The one thing that NASP is doing is: the Air Force facilities at Arnold, the Air Force facilities at Wright field, all of our facilities across NASA, the industry facilities which are considerable, the Navy facilities up here at White Oak all of them are giving very high priority to NASP and that makes it a lot of fun. And of course what is kind of dramatic is this outMITIing of MITI by those five guys (it's the same five up there) they share the $140 or so million we've put into it, and they have got about 120 second tier people across the nation and some outside the nation helping. It's dramatic, it's a dramatic accomplishment.

Now there are a lot of people, in fact, who were kind of embarrassed about this "Orient Express" that got into President Reagan's speech. I wish that had not happened but what's done is done. The NASP is not an Orient Express. That has hurt us badly with Senator Barbara Mikulski because she said, "There are those fat cats going to the Orient at Mach 2 or 3 or 4" and it isn't that at all. It's not an operational vehicle. Some people have pushed the NASP that way, but it is not. We hope we'll get to build two airplanes and a good test probe. Of course now I put this picture in because some people say we're going to go from conventional runways. That's bullshit! We're going to have a big hydrogen bottle; you are going to have a big oxygen bottle at the runway; you are going to have a good engine run up situation; and you are going to have a good check out facility. God willing, it won't be like what we have at Cape Kennedy, but you won't take it from LAX and O'Hare, etc. We'll have one place, Edwards where that's done, to start with. That's going to be about a $150 million operation.

We are going to finish Phase II. That's where we are now, and Phase III is build and fly. That date is presently March 30, 1993.

Well, this is how it's organized and that's sort of standard in these days. We have the NASP Interagency Office in the Pentagon. We have a principal deputy out at Dayton, etc.

Now I am going to show you three charts and because of security (this particular one is McDonnell's I believe) and they are not for real, because they are classified so we can't show you the real one. That's General Dynamic's. One thing that is interesting about them all is that in these devices that have to go Mach 25 or so and breath air up to 15 or so, you really have to control the air so that it enters those inlets efficiently. You know, about 50 feet down the way and you don't want it too distorted and you've got to be very careful so that you don't get, like with the SR-71, an engine out. With our vehicle we might go ass over teakettle particularly, if it's an outboard engine. These are not the real configurations, but they are what we give PR people, so that they have something.

Of course, we have got two engine companies who have two different approaches, Pratt has a two dimensional approach, Rocketdyne as a three dimensional approach, and they are good engines. I have to compare this, for reasons of having been on the Shuttle for so many years. The real thing we are doing is, the Shuttle gets the hell out at no higher than 700 or 800q lbs/sq ft., whereas in the case of NASP we are going to fly the bottom of that blue thing, when we get the high performance and that occurrs about 2,000-2,500q. So we have to fly in there to gobble up all this oxygen from the atmosphere, and when we're really getting the high performance we are going to be pretty close to that line of 2,000q or 2,500 gobbling up every molecule of oxygen we can find and then somewhere in this region we will go on out. It depends upon the design of the different configurations. We might exit and go on out as early as 15 or as late as 20 or even maybe a little later.

We go to orbit in about twice the time the Shuttle does. Here's the chart that is really kind of a favorite of mine. It tells you why everybody in the world is so interested in these air breathers. Right here, the solid rocket motor on the Shuttle is 297 I_{SP}, and the SSME is 444. You can get up in this class of 4,000, and you can see out to 2,000 or so out here at Mach 10 or 12. This is what Joe Shea in his report to very high-level people at the Defense Science Board said. This is what he calls the quantum jump in performance. That's why Japan and Germany and even France now are writing a paper about using air breathing for the first stage.

Now, another thing that is very important for everybody to understand. Today, as you well know, the SR-71 is a Mach 3 machine. Here we have this whole air breathing domain that gives these I_{SP}'s that are 10 or 13 times bigger, a factor of 10 that somebody was talking about earlier today, and there aren't any air breathers from 3 on out here to the right hand side. When we build this flying machine and we get two or three years of flight tests and know just how good this is, then we will know. Maybe we'll want to build a Mach 4 military strike airplane. Maybe we want to build, I'll show you a chart later, an inlet of Lockheeds. The Soviet's said they were going to have TU204 in Paris two years ago at Mach 5. I think they've come off of that kick. They've finally got realistic, I guess. Here's what our friends in Germany are proposing and expect to achieve: about Mach 7 for their two stage device. Some of us, including General Henry and Mike Weeks, believe that there will be reconnaissance machines out in this class.

Of course, a number of the studies show that you ought to switch and go on out to about Mach 15 and not go all the way to the top. The important point is that this whole domain of air breathing is wide open. The world sees it. It's really kind of simple. Whoever can figure this out as to how to best plan this and make it work is going to have a big leg up over the next 20, 30, 40 years. And I probably will retire by then. You know I am getting old enough that I ought to retire in 100 years from now.

There are people at NASA that claim I worked on this. Not true, but I have worked on things like this in between. This brings me to the second part, and I've really got to hurry.

Here's the Soviet space Shuttle -- like ours, in some ways, and unlike ours in some ways, with their four strap-ons. They take that strap-on and make the space fighter. That's an SL-16 and that's the thing that went into India, and the French systems there, Hermes and their Ariane 5. Japan has their H2 and their Hope, and West Germany has their Sanger. The important point is that all the rules are changing, and I love that because I don't like rules. I like to be able to figure out how to design something that does what needs to be done. Air breathing is getting all mixed with rocketry and it's left to the student to figure out how the hell to make it best.

Anyhow, hypersonics: Sanger 2 is proceeding; the Soviet's, I think like this, that's their engine testing facility, and of course they've said Mach 5 but I think they're coming lower now. As you know Gulfstream assigned the thing at about 2.2 to build a transport for a corporate jet, and of course Japan has their JNASP about ¥2 trillion. That's about $15 billion. That's a realistic kind of a number. They've got six engine cycles and various studies over there. They are building facilities. Their Hope, which is of course an orbital thing, but their Hermes is short of orbital and this is their H2. They're really pushing the aeronautics.

The flight test of this device is going to be fun, since at Mach 15, that's the turning radius. It's going to be fun.

I have to spend just a little bit of time on this chart. These are the five contractors, the ones who are sharing the $140 million. They've each picked out an area, and this is where I am deeply convinced we're outMITIing MITI because the data are just coming in at great speed.

We have about 6,000 people across the nation both in industry and universities, and government working like little beavers, because everybody likes it, it's a lot of fun. Let's skip all these next accomplishments, a lot of very good accomplishments.

The Space Council decided to slip us two and a half years. Of course, we've got to go back to them before they'll let us spend the $5 billion plus on the airplane and of course they've raised the money and we like that.

We've decided to do a lot more ground engine testing in this two and half year slip, and of course we'll do a lot more materials and structures [testing, Ed.]. NASA is contributing a lot of very able people and a lot of facilities.

If any of you wish, just give me a note and I'll have Margot send you this. This is that inlet that Lockheed made for us, a Mach 5 inlet and we are testing that in a 10 x 10 up at Lewis to see how good it can be Mach 5. Rocketdyne has put this facility in at their own expense because they believe in this hypersonic world.

I believe that we really are leading the air breathing race with this NASP thing and I guess SR-71 will contribute, and so forth too. I believe that there are a bunch of missions as that chart says. I think the missions will come once we know it'll work, and I think the world sees this high I_{SP} quantum jump. That's the message there.

What I think is very disturbing as a nation, is the worldwide vehicle launch competition. What bothers me a lot is that I think this thing is, well, they're national monuments. Ours is somewhat that way too. Everybody seemingly needs to say, "If they are a space faring nation they've got to have a launch vehicle" and that's having a big effect there and you know it's kind of like the 747, DC10, Airbus competition and you know it's not going to be very cost effective. Even China's gotten three launches, I guess.

This is a chart that shows the SL-4. If I were in Russia and got to build all of these (about a 1,000 of these have been launched, SL-3 and 4s). I would love to have the contract to build all of those thrust engines, you know? And of course, there's Energia and I presume those might be parachutes in these operators. Here's Proton which you can buy for about $25 million a launch and I hear they are talking about putting it at Cape York, over in Australia. There's their Buran on their launch vehicle to get you there and they did a good job in designing that, I think.

Here are our friends from France. They are coming out soon with Ariane 5, and they've got loads of Ariane 4s. They've got 80 percent of the business now, since the Shuttle accident. Japan of course is working hard on H2. That's an all Japan vehicle, whereas this one's got a lot of Douglas in it. They are forbidden to sell those if they've got Douglas in them, that's why they want the Hope and the H2. There is Long March 2. I didn't have a picture of Long March 3, I wish I did. And of course, the Soviets and ourselves. The only people who are really competing with us in the big heavy stuff, are the Soviets, which I think is a crucial thing. Of course there's a lovely Shuttle picture.

I just wanted to show you this thing over here a minute. You can get this in a space museum over at the headquarters. The only thing that I bring it for is, here is a G1E, which is the Soviet's. There is our Saturn 5, that's their G1E which of course was not successful, but it's the only picture I've ever seen of what the Soviet's were trying to do in competing with us on going to the moon. You can get that for six bucks over at the space museum in Washington.

Isn't it regrettable that we had 250,000 pounds of payload to low orbit for Saturn 5 and now we don't have it any more, and so the only thing that's in this arena is the Soviet's.

This is their big launch vehicle, the Energia, and of course they've launched their Buran unmanned. Everybody (I shouldn't put India in there) but everybody has launched using hydrogen. When I was talking to the Chinese, they were so happy that they'd beaten the Soviets to launching hydrogen, even though it's a third stage engine, and a little one, they were just as happy as clams.

So, there is this plethora of competition and then I put the NASP conclusions back one more time, just to remind you that I would find it incredible if we don't find missions between Mach three and fifteen, as soon as we prove that this damn air breathing will really work. And, I won't answer your questions about what I think the launch costs will be for a NASP because it's way too early, it's just way too early to determine. The important thing is to figure how to make this stuff work. [Subsequently, Federal support for NASP was reduced sharply, Editor.]

Ray Williamson: Thank you, Mike. I am told that we can take a little bit of time for questions as we go along. So if you want to raise some questions with Mike.

Question: *Mike, a couple of years ago, cost reduction was a stated objective of NASP but I didn't hear anything about that today. Is it a significant objective?*

Mike Weeks: Peter, when our Administrator Truly and Air Force Secretary Don Rice were testifying they avoided, like the plague, the words: "cost and schedule". I think the only sensible thing for me to do is the same thing. Even though there isn't a reporter in the room, I'd hate it to go back to Truly and say: "Oh, Weeks said he could do that for x billion dollars. He'd probably say: "Weeks, OK, go out and do that firm fixed price" and then I'd be SOL, wouldn't I?

Question: *I'm talking about result in operational payload dollars and pounds, not cost of development.*

Mike Weeks: In my opinion, it's far too early to tell whether single stage to orbit is truly better than two stages to orbit.

Question: *When I hear these Mach numbers like Mach 15 or Mach numbers that they give for the Shuttle, does that mean at the altitude that the craft is at or are they referenced at sea level?*

Mike Weeks: No, it's the altitude that it's at. And I guess if you are precise, the Mach number to low orbit at an altitude of 100 miles is 26.3, I think, but most always it's rounded off to 25, that's good enough for highway work these days.

Question: Do you have any idea of the size of the payload that it's going to take up?

Mike Weeks: Well, in our case, we had 10,000 pounds of payload on the first four missions of the Shuttle and we will need to instrument NASP more, I think, than we did the Shuttle. So, we'll be carrying probably 10,000 pounds of instruments, and that's the real payload for the early flights. We are not trying to design a prototype or a production machine. We are trying to make a device that will figure out how this air breathing works from Mach 3 on up to orbit and that's one hell of a task. When we get to Mach 15, air breathing, we are going to take the weekend off.

Ray Williamson: Thank you very much.

Shuttle-C Vehicle -- *Randall Furnace, NASA*

Introduction by Ray Williamson: The schedule that you have calls for Ed Grabris to speak to us next about the Shuttle C. However he was unable to be with us and so at the last minute Randall Furnace agreed to step in for him. He is with NASA headquarters in the Advanced Programs Development Division. He works with Ed to manage the NASA Program Planning for Shuttle C and the Advanced Launch System (ALS). He's been at headquarters for a year as part of a management training program from Lewis Research Center in Cleveland.

Randall Furnace: I am not Ed Gabris. He did intend to be here, he wanted to apologize for not being able to make it. My name is Randy Furnace, and I work with Ed at headquarters. What I wanted to talk about, what Ed wanted to talk about, is Shuttle C. That's what we are on the agenda for. What I think I will do is speak for a short time about Shuttle C and then a little bit more about ALS. Mike mentioned both of those programs saying that he hopes we can get started on one or the other or both. So do we, that's what we are working towards.

Shuttle C, the concept of course, for anybody who is not familiar with it, is to take existing Shuttle hardware, the external tank, the solid rockets, and essentially boat tail modifications, removing the tail structure, for instance, and adding to that a new payload carrier or cargo bay element that would be designed from scratch. It would have the same diameter as the Shuttle cargo bay and would be about 22 feet long. Essentially the area that's taken up by crew on the Shuttle would be available for the payload.

One of the advantages of this vehicle is that it can use existing facilities. The whole purpose of Shuttle C is to come up with a heavy lift vehicle, something that can lift significantly more than the Shuttle, relatively quickly, without starting over from scratch. What it will do is utilize all of the Shuttle facilities, with minor modifications.

The next picture is an artist's conception of a launch. It would not look a whole lot different than a Shuttle. Here's the reference mission, what we call it, or what we would assume to be a reference mission. The first part follows very closely what the current Shuttle mission is into orbit, the difference being, when you get on orbit the cargo element deploys the payload and then returns and burns up. There is no intention of bringing that back, like you would bring back a Shuttle and reusing it, or in that case reusing the engines or the avionics. There is a study going on to see what it would take to bring back the engine module with the avionics in some way and reuse those, but the baseline mission is to just throw them away, which is not a low cost move. It's more of a convenience move.

This really is a photograph of a mock-up, the engineering design unit it's called, which currently exists down at Marshall and it's a full-scale mock-up of what the cargo element and boat tail would look like to be used for payload fit checks and that kind of thing.

The driver on Shuttle C again is not necessarily low cost; the dollars per pound won't likely be significantly different than the Shuttle. What it does give you is a capability to put up to 150,000 pounds in the low earth orbit, with the three engine arrangement. Now, the mock-up you see right there uses two engines. Both options will be available in the program. They're both being designed into it.

Q: What's the lift capacity of the two engine?

Randall Furnace: About 90,000 pounds, if you bring on advanced solid rocket motors, which is the current NASA project underway, those each go up by about 11. I think the two engine system is getting closer to 100,000 pounds to LEO.

One thing I would like to show you is a chart that we put together for comparison purposes trying to get an idea of what is our current lift capability. What's NASA's current capability to orbit? We've looked at the four primary vehicles, and what is considered the maximum launch rate and lift capability to a 160 mile orbit. They are all within 10 percent or 15 percent of what people would argue is the maximum.

As you can see, the total is about one and a quarter million pounds to orbit per year with all four systems up and running to full capacity. The reason I wanted to bring that up is, we put together another chart, in this case it was for the ALS program. We wanted to look at a few things: one is, what is our upcoming need based on? This chart is put together for what the Air Force does based on the SDI deployment and that's the big spike. If you want to ask yourself if SDI is deployed, what kind of a load would it put on our systems. Well the predicted load is up around five and half million pounds a year during those years of deployment.

One thing that's not on that chart is the work that's going on right now towards the Mars/Lunar Initiative NASA Programs. Those results are not out yet, but preliminary estimates indicate a Lunar program would require on the order of two million pounds a year, and a Mars program, something like three million. Either way, looking back at that last chart you can see that we could have a need of two to three times what we currently have a capability for. Shuttle C is one way to meet the needs between now and the year 2000. It's a vehicle that could be ready soon.

With that I would like to show you a few charts on what the other option is, the Advanced Launch System. That program currently has three contractors working in parallel and working on concepts, all of which are very similar at this point. It's a liquid engine, hydrogen/oxygen system. It's a cost driven, and reliability driven system. The idea behind it is to maintain the reliability of, essentially man-rated systems. This is not as you see it, man-rated but to maintain that reliability with planning for a ten to one reduction in launch costs, going from the current $3,000/pound down to a target of perhaps $300/pound launch costs.

It will utilize what we call a family of vehicles. The idea being what you might think of as interchangeable parts coming up with basic core structures that can be mixed and matched to give you an entire range of payload capability from nearly Shuttle capability of 40,000 to 80,000 pounds all the way up at the high end to 300,000 pounds. I believe right now they are looking at closer to 200,000 but it can certainly be pushed up to the 300,000 pound range.

This chart will show one of the reasons that the costs can be kept down. In addition to interchangeable parts, and simpler design, it's a system that puts everything at a launch site. At the upper left here is the actual assembly facility for the vehicle. Components are brought in by rail or by truck, assembled at the site, brought into the vertical integration facility where they are stacked. Some of the smaller configurations are using solid motors. Those will be stacked at that point and then brought into the cargo integration facility where the payload is loaded and then they are taken out to the pad.

A big driver to keep the cost down on this type of vehicle would be simplifying the interface between payload and launch vehicle. The current program manager in California is taking the approach that we will design, at this point, what he calls four boltholes. It's an oversimplification but basically saying to the payload people, "We are giving you something to mount to and not much else. Design your payload to be able to be put in there within five days of launch and be self-sufficient". It's a major new outlook on launch vehicles, to baseline the vehicle for low cost. As you can see, everything is there, essentially at the launch site. In that schematic representation they are closer to the pad than the launch control center.

Finally, the schedule on that program as it looks right now is, we are currently just into the Phase II concept design. Development would start out in the 1992 time frame, and we are looking at an initial operating capability around the year 2002, 2003.

One final word is, if you are wondering what the status is of both Shuttle C and ALS. Both are design projects at this time. Neither has been given a new start for production and we're currently working to try to make that happen, but at this point they are both waiting new starts for production. [Subsequently, public support for an SEI Moon-Mars program and/or a large Strategic Defense Initiative space segment program waned, and neither the Shuttle C nor the ALS has gone forward, Editor.] That's what I have to say. I would be glad to take any questions.

Question: *Why is it taking so long? You discussed a wait of 11 years until this ALS or the Shuttle C, why does it take so long?*

Randall Furnace: ALS takes so long because it has to start from scratch. That program, in order to keep the costs down, is a technology development program right now. It seems funny that you go to simpler technology and it takes time develop it.

Question: *What technology?*

Randall Furnace: Engine technology is a big drive. Engine and airframe are the big drivers. The engine technology: It's a simple, single stage engine without boost pumps, with minimal parts. There may be a four to one reduction in the number of parts in an ALS engine from a Shuttle engine.

Question: With this Shuttle C, if the main engines are going to be discarded, is it possible to build them more cheaply than the current Shuttle engines that have to be turned on and off?

Randall Furnace: If you make the modifications to the current engine, the cost will go up tremendously. The plan right now is to use Shuttle engines and Shuttle engine components that have already flown near their maximum amount of flights, so that in that way you're throwing away an engine which is near the end of its life.

Question: When will Shuttle C be available?

Randall Furnace: That will depend on a new start; it depends upon whenever we get the go-ahead.

Question: Suppose you got a 1991 start?

Randall Furnace: If such a thing happened it would be around the fall of '94 before the first test flight. It's a relatively short period of time because so much of it exists.

Question: If "x" was the amount of NASA, genuine NASA effort going into getting Shuttle C and ALS approved a few months ago, what would you say is the amount of effort NASA is putting into those two programs now in view of the Lunar/Mars Initiative and the changes in national environmental priority caused by that. In other words is there any difference, is NASA trying twice as hard to get Shuttle C and twice as hard to get ALS approved or is there no difference?

Randall Furnace: I would say at the moment, if anything, those attempts are on hold for the next few months just to see what comes out of this Lunar/Mars Study. The Lunar/Mars Initiative Study is expected to come back with recommendations about what kind of launch vehicles we need, and at that point NASA will begin to push hard, whichever direction.

Question: So at the ALS project management level, there hasn't been any firm direction given in terms of the Lunar/Mars Initiative requirements?

Randall Furnace: Right, that's because there are no requirements yet. The study is on-going. I believe they are reporting to the Vice President soon, within a month. But until that happens, the Space Council hears the report and NASA goes back and digests what came from that report.

Question: We went last Friday.

Randall Furnace: It's imminent, its happening now.

Question: *I have a comment. This comment is just to expand on your answer to Peter Woods. I think manufacturing, particularly low cost manufacturing, is a key technology to ALS, in particular. That's what they always told us when we were working on it. You seem to have kind of two points there, and there's a whole spectrum of things in between that I don't see and, I don't quite understand that. You've got the Shuttle C with a 50 foot payload bay and then you've got ALS over here, you're kind of selling them as two competing programs. I don't understand why that's the case. Why wouldn't you start off with Shuttle C and then evolve it into ALS as the technologies come along? And it's not necessarily a bad Shuttle C. It might be something that you need for Lunar/Mars or Shuttle Z or Shuttle Z prime, or whatever you want to call it that's got some volume, which is going to be a real problem, not lift per se.*

Randall Furnace: That's a good point. There are a lot of people within NASA that feel that that is the way to go, considering that, at best, C could be available at the beginning of '95 and ALS not until 2002 or so. NASA right now is trying to establish "What need do we have for heavy lift launch vehicles between 1995 and 2002. If, from that, we determine that we have a definite, solid need for a heavy lift launch vehicle in that period, that would be a big driver to start Shuttle C and not to the detriment of ALS, for instance.

Question: *Are these two programs viewed as competitors within NASA?*

Randall Furnace: They often view each other as competitors, I think because of the shrinking budget situation. There are only so many dollars to go around, and so the two programs often view each other as competitors. As it turns out in the Advanced Development Division both programs are under the same person, so we treat them not as competitors at all. We are pushing equally hard on both.

Question: *Were you aware of the studies that were done back in 1982-83 and I believe the first part of '84 by the Air Force Space Systems Division on looking at what is now called the Shuttle C and the various configurations for return and those sorts of things?*

Randall Furnace: I think the Shuttle C program people have those studies.

Question: *You said they were doing those studies...*

Randall Furnace: I think more so than studies. I think what they are doing now is working on actual details of how that configuration could be brought back.

Question: *OK, so it's the next step beyond that?*

General Comment: I was working at United Technologies' Space Flight Systems when they were working on their version of Shuttle C, and a suggestion that I have doesn't seem to get through to anyone is: "why don't you specialize Shuttle C to go to the Space Station or any transportation node and then recover the expensive elements of returning orbiters?" That way, you have a one-way reusable vehicle.

Randall Furnace: Some people have looked into that. I know some people at Marshall in the Shuttle C program have addressed that issue of trying to maintain the cargo element or parts of it or the engines or the avionics and bring them back. The Space Shuttle main engine people are very leery about that. That engine is so sensitive. They don't feel that having one of those engines sit on orbit, for instance, for a period of time would be practical. Now, bringing it back is another story. I know they looked a lot into restarting it on orbit for an OTV. I guess I don't know the answer to bringing it back. That's a good point.

Question: *Shield it with some kind of enclosure. The hard vacuum is not going to hurt it by itself. It's an easy thing to do: at the space station you can have some kind of thing to shield it from the radiation and the solar thermal effects.*

Randall Furnace: You'd have to look at the cost of bringing it back and the cost of refurbishment compared to throwing it away. Thank you.

Laser Assisted Launch -- *Jordin Kare, Livermore National Labs*

Introduction by Ray Williamson: We'll now move to a radically different kind of launch system. Dr. Jordan Kare will talk to us about laser-assisted launch. Jordan Kare received his Ph.D. in Astrophysics from UC, Berkeley in 1984, and since '85 he's worked with the Special Projects Group at Lawrence Livermore, where he's worked on several projects, including X-ray holography and high-power optics since 1987. He's also been the technical manager for the SDIO's program in Laser Propulsion. I understand that if people want to chat a little bit after his talk about the recent proposal for the Inflatable Mars Habitat, then he'll be glad to talk about that.

Jordin Kare: There was an interesting comment that was made at the end of the session, towards the end of the session yesterday, I think by Ed Bock. He had been asked what the follow-on, after ALS was and I if I recall the response was, "Until the laws of physics are repealed, we are stuck with chemical rockets to get from ground to orbit".

Well, I have a button at home that says obstensibly in the accents of Mr. Spock from Star Trek, "Captain, I cannot change the laws of physics but I can find you a loophole".

Laser propulsion isn't exactly a loophole, but it's an end run around some laws of physics and it's a different way to get to space. It's not exactly a new idea. It's been around since the invention of high-power lasers, back in the late '60s, early '70s.

The idea is very simple. Build a rocket with an inert propellent, nominally water ice. This may be a plastic, something similar, instead of hydrogen and oxygen or something else energetic and therefore dangerous to handle. Provide the energy for that propellent, not by chemical combustion but by a laser beam from a big laser that you can put far way, i.e. you can leave on the ground. The laser can be as big and as heavy as you want. It can get it's power out of the local power grid or out of diesel generators, or whatever you want, and sends its energy to the vehicle on a beam of light.

You make the rocket as simple as you can, both to reduce its own costs and to make the scaling to small sizes as favorable as you can. You make it as small as you can, sort of practically limited, either by the mission requirements or by the laws of physics, and as cheap as you can so that the capital costs are reasonable so that the operating is simple--you throw the vehicle away. You get back the payload capability that you need by launching lots of these things because you pick one up, you put it in the laser beam, 15 minutes later it's in orbit. Take another, put it in the beam, 15 minutes later it's in orbit; and you can do that, if you want to, 30,000 times a year.

I'll be talking about a reference system, a sort of minimum system that you can build. It has a 20 megawatt laser. It launches 20 kg at a time. 20 kg isn't much, but 30,000 times 20 kg is 600 tons a year. That's more than that total launch capability of the Shuttle and all the expendables we can build. And that's the smallest laser propulsion system.

How do we do it? Well, the key is, and I'll emphasize this a couple of times, all the hard parts stay on the ground. That's what makes this practical, both to develop and to operate. Arthur Kantrowitz who started the whole process is fond of saying, sort of after Chinese fashion, and he coined the 4P principle, "Let's leave everything on the ground, but payload, propellent and protons, period".

The actual concept that's involved is something that we call a "planar thruster". This is pretty simple to visualize. Imagine, sitting on this table in front of me, a squat cone, a meter and a half wide, a meter high. The base of the cone is a block of ice, reinforced maybe with a little bit of fiber material, so that it's structurally a little stronger than what comes out of your refrigerator, with a payload sitting on top. Hit it from the bottom with a pulse of laser light, vaporize a thin layer of material heated up to high temperature. It will expand, push against the base and give you thrust. It doesn't need a nozzle, the expansion is one dimensional for many times the initial layer thickness, if the layer is thin, maybe a centimeter thick, compared to the radius of the vehicle.

Getting rid of the nozzle does a lot of things. For one thing it makes it an extremely simple vehicle. It really is just a block of propellent with a payload on top. It means no temperature limits. You can run it at as high a temperature as you want. It's ideally regeneratively cooled. All of the stray radiation goes into the next bit of propellent, to get evaporated. That means you can run a high specific impulse. We are trying for 800 seconds specific impulse -- twice the specific impulse of liquid rockets, three times the specific impulse of solids.

It has another advantage. The base of the vehicle doesn't care where the laser beam comes from. So you can have a vehicle like this, the laser beam shooting this way and the vehicle going that way. Or more particularly you can have a laser beam going this way and the vehicle going that way, so you can fly directly in to low earth orbit, without a circularization motor, a kick motor, or of any kind.

A key point: if you take the beam and move it a little off center, you make more thrust on one side than on the other, so by controlling the beam from the ground, you can steer the vehicle. The vehicle doesn't need a guidance system. As a matter of fact it doesn't even really need a guidance system in the sense of telling where it is because you know where it is and what its attitudes are by where the laser is focussed on it. You are tracking it optically with great precision. By looking at the scattered light back from the vehicle, you can tell its orientation. At most you may want a very simple telemetry package with a few sensors around the rim to help you focus the beam on the vehicle, to tell you what your beam quality is, essentially.

There are a few other tricks. I just mentioned that, down here, we have a particular scheme we've been concentrating on to get the high specific impulse and to efficiently couple the laser into the thrust. It's called the double pulse thruster. Essentially one laser beam evaporates a bit of material, the next pulse of the laser heats that material to high temperature. That's how we get the high specific impulse. But it's not necessary; the key is the simplicity of the vehicle, not the high performance.

If we can get 300 seconds specific impulse, that's enough to fly to orbit. It means the mass ratio isn't very good. You have 20 times as much propellent as payload but ice is cheap.

You do need a 20 megawatt laser utilizing a 10 micron wavelength, i.e., in the far infrared. That can be either a free-electron laser, which is how Livermore got involved in this because we're one of the sets of people building big free-electron lasers for the Strategic Defense Initiative Organization. Or, if you want to be cheap and dirty about it, you use ten-year old technology, big electric discharge pumped, CO_2 lasers that we've known how to build since the '70s.

The specific impulse is 800 seconds, 40 percent efficiency -- 40 percent of the laser energy ends up as kinetic energy of the exhaust. You need a 10 meter diameter telescope which isn't very hard to build these days. It would have been 10 or 15 years go, but there's a 10 meter telescope being built in Hawaii, the Keck telescope for astronomy. It's a UC-Cal Tech project. It actually has more performance than we need in every respect except power handling capability. The astronomers really don't need to expect to get megawatts of starlight coming in. If they do, we're in serious trouble for other reasons.

The vehicle starts out, two meters, maybe one and a half meters in diameter, a few hundred pounds. You can run it as a ramjet up through the atmosphere using the air around it with a very simple sort of sheet metal duct to steer the air where you want to go, and a base plate behind the block of ice. Fly it up through the atmosphere to maybe 20 km, drop off the sheet metal, fly as a rocket up to 100 km, turn over at an angle to the beam and fly downrange. When you run out of propellent you are maybe 1,000 km downrange. Your maximum acceleration is just before you run out of propellent, 5 or 6 g's. By the way, while going through the atmosphere, you're going real slowly. You may not even get supersonic anywhere in the atmosphere. You burn out 1,000 km downrange, 10 to 15 minutes after you started, and your payload is in orbit.

What's so good about it? It's cheap. We've been talking here, the lowest number I wrote down here is $300/pound to orbit coming in the far term of a mature ALS system. We start with the very first, smallest system at $250 per pound and work down from there. It's powerful. I already said the smallest system launches 600 tons/year if you want it to. You can build a bigger system. It scales up a little better than linearly. The cost of the laser in the smallest system is only about half the cost of the system. I'll give you the details on it in a minute. As you scale up, it's mostly the laser that gets more expensive.

Also the performance tends to get a little better as you go to bigger systems. It's a flexible system. You can launch on demand. If you are launching once every 15 minutes somebody can walk up with a payload, put in the in the beam and it's in orbit. Paraphrasing the Dominos' pizza people: "In orbit in half an hour or it's free!"

If you are running at high specific impulse, you can launch to any orbit you want to. At 800 seconds impulse you don't need the few hundred meters per second from the earth's rotation. You can launch the same payload prograde or retrograde. You can launch almost as much payload to Earth escape or geosynchronous transfer. You can do other kinds of tricks. I'll mention a little more later. You can do orbital maneuvering on satellites that are already in orbit, boost them into higher orbit or into geosynchronous transfer.

It's safe, reliable and gentle. Again, most of that arises because the hard parts stay on the ground. That means that you can test everything extensively. If you have an o-ring fail, you go in and replace the o-ring in the laser. Your vehicle doesn't land in the ocean. If a vehicle does land in the ocean, it's $1,000 loss, not a billion dollar loss.

Incidentally, you can do lots of tests too. If you are planning on launching 30,000 vehicles a year you can launch a 1,000 times before you take your first paying payload. I don't think there's any other vehicle that's been discussed that can make that sort of claim. That also means that it's easier to demonstrate reliability. It's easy to insure. We had a talk on insurance. Range safety is mostly there to make sure your rocket, if it goes out of control doesn't fly over somewhere you didn't want to. These vehicles are inert. If there is a problem, if the laser fails, the vehicle is not going to turn sideways and go someplace else; the worst it can do is keep going in a straight line and land somewhere. So, all you need are narrow launch corridors, not launches out over an ocean. Even if the worst happens, and you lose control of the vehicle, and it falls somewhere, it's an inert vehicle that weighs less than a Cessna does and we put up with the occasional Cessna crash. It doesn't need to have a gasoline tank on board, and it has only moderate accelerations.

The last point here, and this is something I want to make very clear. This is at least potentially a near-term system. We have proposed going from where we are now to having a working launcher in five years. That would be a compressed program but not an impossible one. Again, the hardware is on the ground. You can test it. You can tinker with it. You find a problem you can rebuild it. You don't have to test fly the thing. The time scale is within the decade certainly, if we decided to go ahead with this now. I don't know quite that we can beat Shuttle C into orbit, but we can certainly beat ALS there, I think.

Obviously the question is what can you do with something like this? What can you do with a limit of 20 kg, or that sort of size payload? Well, one thing is, there are things that you can launch in that size package. We haven't done a lot of that except for the microsatellite community. But there are microsatellites that will fit within that that have been launched. Obviously our interests right at the moment, and the reason SDIO supports it, is because it is a launching mechanism for Brilliant Pebbles, if you want to do that or perhaps even more important, a launching mechanism for Brilliant Pebble Decoys. You may not want 30,000 brilliant pebbles in orbit but you may be very happy to have 30,000 decoys to make it real hard for somebody to find the brilliant pebbles and shoot them down. If you are not quite so defense-oriented, you can put up communications satellites, packet switching communications satellites, scientific microsatellites. How many people would like to land a few hundred, 10 kg sensor packages on Mars before we send a manned mission there?

Reconnaissance microsatellites, sensor satellites are also launch candidates. There is an interesting opportunity to do on-demand launching. Something happens in the Middle East, something funny is going on at Chernobyl, wherever you want to pick, 45 minutes later, you have a satellite go over with a camera at a 100 km altitude, 15 minutes later another one, 15 minutes later another one. The Russians did that once with small boosters launched once an hour to put cameras over an Arab/Israeli conflict a few years back. I don't think we would care do to it very long at Scout or Pegasus launch costs but we could do it with laser propulsion.

That market is significant but it does have some limits. In the long run you want to be able to build things in space. This is where the connections, specifically to space infrastructure, are critical. Right now we don't have any way to do anything with 20 kg pieces in space. Not only would it be too expensive to send an astronaut out to collect the things and do anything with them, but you'd use up more than 20 kg maneuvering fuel to do it. But again the technology exists to do it. If you can build a brilliant pebble and you've seen the newspaper reports: those would be capable of going out and rendezvousing with something that's dodging them and actively trying to avoid them at many kilometers per second relative velocity. It would be smart enough to have all its own sensors, all its own intelligence, all its own actuators, be completely autonomous. And you could certainly send out a little autonomous retriever vehicle that goes out and collects a friendly and cooperative gadget that's travelling at a relative velocity of a few tens of meters per second, latch on to it, bring it back and stack it in the air lock where the astronaut could collect 50 of them and put them in the galley that contains next day's lunch or whatever.

Incidentally, if you are trying, for instance, to provide logistic support to Space Station Freedom, there is the limitation that you can't launch to a single orbit all the time, unless both you and that orbit plane are on/above the equator. But there's enough cross range capability with the laser. It can launch to orbits that don't go directly over the laser. They can be offset a little bit. You can launch 4 to 8 payloads a day to any given orbit. Now, 8 payloads a day is 50 tons a year, two Shuttle loads, two to three Shuttle loads worth of supplies going to Space Station Freedom. Prompt delivery, incidentally, is very valuable, something that Federal Express has demonstrated. Some of my friends at NASA tell me that one of their big headaches with the space station is logistic support. You have to have spares of everything, because it may be three months till you can replace the left handed widget that somebody just broke. If you can send it up this afternoon, you don't need to keep them up there.

I mentioned orbital maneuvering. That's a way to connect this to larger payloads. You can push big satellites around because you can do it over many orbits. In fact, you can do that even with lasers that are too small to be launching lasers. A megawatt size laser will push a one ton satellite from low orbit into geosynchronous transfer orbit in a month. Bigger laser, shorter time, and you can do this for many satellites at one time, each one as it goes over the laser.

I'll just mention debris clearing because that's a big problem these days. If you're building a laser this sort of size, all you have to do is tap on things in low orbit, give them a little bit of impulse and eventually you can put them into an orbit that will re-enter, so a laser has lots of applications.

What are the disadvantages, since I was requested not to make this an advertisement? I should at least put the disadvantages up front. The main one is, it's not a proven technology at this point. We have laboratory experiments that demonstrate that it works in principle, and in fact at lower efficiencies than we've seen.

But we don't have the equivalent of even a sounding rocket or even flying a brick up to the ceiling. The reason for that is a matter of resources, the amount of money that's been invested in laser propulsion is somewhere between three and four orders of magnitude less than has been invested in rockets, depending on how much of the laser development you count in. And it's an order of magnitude or so less even then than in things like rail guns.

There is however, a fairly straightforward path from where we are now to demonstrating technology. Essentially, the path is to go from the small scale laboratory experiments we are doing now as part of the SDIO program, and have been doing for the last two years, to a pulse experiment. Most of the lasers we have to work with only put out single pulses, or pairs of pulses from two lasers. We need to modify one of the few existing large lasers that puts out a series of pulses for a few seconds to put out the pulse format we need, and demonstrate sustained thrusts, begin to engineer the thruster as opposed to just learning the physics of the thruster. That's five to ten million dollars, depending on how much modification of the laser we need to do, and whether we need to build one of our own.

The step after that is to build a subscale laser, a megawatt or two megawatt laser system with a smaller telescope on it, say a 4 m telescope instead of a 10 m telescope. That system would be capable enough to demonstrate all of the technology including, for instance, controlling a vehicle at long range, enough to fly a small sounding rocket up through the atmosphere, maybe even put a token 500 g payload in orbit or something. It tests all of the physics. It's also big enough to use for satellite maneuvering, if you've made it robust enough. That system will cost about $50 million, and is the entry threshold for commercial-use satellite maneuver. Once you've proven that the thing works, you talk about building a launcher.

The other disadvantage is here, before I go too quickly. I mentioned the small payload size. As I say, you can scale up, but you spend more money. With the sort of money we've spent on the space Shuttle or the sort of money that we are planning to spend on ALS and NASP and these sorts of things, you could build a system that launches more than a ton at a time and launch it in the tens of thousands of tons per year into orbit. The challenge of course, for the near term though, is to find useful things to do with small packages.

A final disadvantage is that the laser is something that's sort of inherently limited to near-Earth space. If you put collectors on the vehicles and use somewhat larger telescopes, you might reach out as far as the moon, but it's not a way to push something out at Mars.

Since we were asked to talk specifically about the costs, I can tell you what I based my figures on. The capital cost of the system is the laser telescope, the power plant, the adaptive optics and tracking, and the support structures, the buildings and the roads.

As I say, you can use a free-electron laser but that's still sort of the experimental technology. If you want to do it right now you could do it with an electric discharge CO_2 laser. You could call up AVCO Research Labs in Everett, Massachusetts, and they will tell you what it'll cost to build any size CO_2 laser you want. Their estimates run from $5 to $10 a watt. The most recent estimate with a little margin added on (because AVCO has a tendency to underquote things, just a trifle) is $185 million to build a 20 megawatt laser. Rule of thumb, you have a kilogram of payload per megawatt of laser just to make it clear that you can scale that on up as far as you want.

The telescope I mentioned, the Keck telescope, is being built for less than $100 million complete with the observatory that goes with it. The laser is about 15 percent efficient. You need a little more than a 100 megawatts of electricity. That's an amount you can pull off the national power grid. In fact I gave this talk once a couple of years ago to a friend of mine who worked for Consolidated Edison in Chicago, and he came up to me afterwards and said, "I can give you half a billion watts, if you can give me 20 minutes notice".

If you are in an isolated spot, because the launch site does need to be on a mountain top, mostly to get the laser above as much of the water vapor in the atmosphere as possible, maybe you want to just bring in diesel generators. That might be cheaper than running a power line. If you build a really big system, of course, you want to talk about giving it its own base load power plant.

Tracking and adaptive optics are all within the state of the art for a long wavelength system like this and we get to ride on the back of all the technology for adaptive optics and high power optics that's been developed by SDIO in recent years, and before that for defense purposes with big lasers. At four cents a kilowatt hour reasonable electricity cost, the useage cost comes to about $250/kg, or $120/lb. Add the cost of amortizing the laser, the operation and maintenance, and that's about $300/kg at 30,000 launches a year. A total $550/kg, $250/lb.

That's a way to get to orbit. The challenge is to figure out, as I say, how you use those 20 kg packages to do the things that you now do in much larger packages, but I think if you had that sort of an incentive, a 10 or a 20 to 1 cost advantage, you could find a lot of ways to divide things up into 20 kg packages. It's actually fairly easy to divide astronauts into 20 kg packages, but they don't work too well afterwards. There are some limits.

That's the end of the presentation.

Ray Williamson: Why don't we open for questions and after the questions we'll have our coffee break and come back here to finish up with the last two speakers.

Question: *Two quick questions: one, has laser propulsion been demonstrated in any way at all, like a little car on wheels, or something, you hit it with a pulse, and it goes?*

Jordin Kare: The SDIO program has been running since 1987, sort of two and a half years now. We have done small experiments, table top experiments, kicking little copper plates, little disks of various propellants around with single laser pulses. We can measure the performance that way, it's not as high as we'd like. We can get either low specific impulse at 40 percent efficiency or the 800 seconds impulse at about 10 percent efficiency. But we think we know where the problems are. We haven't done something like run a thruster with a pound of thrust for five minutes, which is the next step.

Question: *The next question, as I understand it, the vapor that comes off from one pulse interferes with the laser with the next pulse. Is that why you pulse it or how do you get around that problem?*

Jordin Kare: That's not really a problem. Generally, with most of the scanners that you would use, the vapor coming off is transparent to the laser unless it's ionized. As long as you leave enough time between pulses or unless it's in solid form, where the chemistry and the absorption properties are very different, as long as you leave enough time between pulses so that the gas cloud cools off enough to be un-ionized, its transparent to the next pulse. There's some turbulence there, but since it's close to the vehicle it doesn't affect you. If you try to propagate the beam another 1,000 km you'd have trouble, but it just has to hit the vehicle.

Question: *Since this is a good device for taking debris out of the low orbits, isn't it quite good as an ASAT, Anti-Satellite Device?*

Jordin Kare: It's not particularly good as an ASAT because it takes a whole lot to knock something out of orbit. You want to hit it on a number of passes and give it a little bit of ΔV_o. It's not absolutely useless as an ASAT, but if you want to build an ASAT you build it with very different parameters. It's one of these things: yes, you can use the Shuttle as an ASAT if you want to by running it into somebody's satellite but it's not an efficient way to do an ASAT.

Question: *The ability to stay tracked on a small object at long range, is that proven?*

Jordin Kare: That's proven in some sense. People did experiments at Maui, for instance to track the Shuttle. That was the famous one where someone programmed in the height of the mountain in feet instead of in miles and the Shuttle thought it was flying under a 3,000 mile high mountain. The problem is not terribly hard if you have a cooperative target, or if you have something that will help you by carrying a little retro reflector, or as I say, maybe some very simple telemetry, to help you aim your beam. It's a lot trickier if you're working at short wavelengths like the SDIO weapons are and, of course, if you are shooting at a target that's doing its best to confuse you, instead of trying to help you.

Question: *Maybe you could talk a little bit about the Mars Mission and Livermore's concepts for that and then we will take our break. We won't take any questions after that.*

Jordan Kare: Laser propulsion is not the only space and space-economizing and infrastructure-related thing that has gone on in our group. We have a long-standing interest in various inexpensive ways to get to space, inexpensive ways to use space. In the past little while, over several years we (mostly my boss, Lowell Wood) have made various proposals, , to do space missions inexpensively. A project called the Columbus Project proposed a few years ago to do a Lunar Base. A similar thing was the Olympia project a year or two ago to do a Mars mission at low cost.

Recently some other people (I wasn't involved with it) have proposed a way to do a Mars mission with enough detail so that the numbers are filled in: the cost, what the mass budgets are, and so forth, but obviously limited by the fact that we couldn't put thousands of people on the project. So, it's an outline in some sense. The basic idea is to use expendable boosters, essentially upgrades of Delta and Titan that have been proposed to SDIO for various missions. Various industrial groups have proposed being able to build them the near term they would probably not meet NASA reliability specs, but that would be acceptable for the purposes we want to use them for.

Those launch vehicles give you a near-term launch capability of about 50 tons at a time to orbit. We then build a space station that is inflatable, that is, a soft space station. It flies completely assembled and ready to go, but folded up so that it fits into one launch vehicle. It arrives on orbit. It's inflated. It can be checked out and the astronauts transfer to it. A principle of the whole mission is that you do essentially no assembly in space and absolutely no EVA unless you want to do it as a mission enhancing-thing. It's not a mission requirement.

We then set up a space station. Optionally you can go to the Moon, land a similar inflatable structure as a Moon base, and use some very simple technology, essentially light-weight, cheap solar arrays to generate about a megawatt of power on the Moon, and use that to bake lunar material. Lunar material has about 300 parts per million of water. Crack the water, have hydrogen and oxygen available, ship that back up into space to give you extra propellent. You can do that if you want to. It makes the whole operation cheaper, but it's not a mission requirement. Again, it's a way to enhance the mission.

If you don't do that, you simply bring propellent up in the form of water from the ground, crack it with solar power and electrolysis. Again, use inflatable structures as tanks, build a Mars vehicle in orbit. It's not really built; it's carried up and inflated for all practical purposes.

Launch to Mars, hydrogen and oxygen propellent, in to either high Martian orbit or, again, as a mission enhancement, land on Phobos or Demos, depending on what you choose. Send a lander down to Mars that aerobrakes going in. Actually, at the moment I've only had one discussion about this...I can't even remember whether or not it's a mission requirement but at least you have the option of again having an on-Mars processing plant to make fuel for the ascent stage.

You carry six people, as I recall, to Mars. Two of them stay in orbit, four of them go down -- I won't swear to that, I'm doing all of this off the cuff. The stay is for essentially a year, then turn around, come back off Mars. You leave most of your base behind and it's designed so that all of the base is a space station, the Mars base. The Moon base carries enough supplies to keep the crew alive for ten years. There's also always a return capability at any time. So, all of the different pieces always have a mechanism where everybody can climb back in the capsule and leave for Earth immediately.

Fly back off of Mars. Rejoin your vehicle left in orbit. Come back to Earth, aerobreak to come in to Earth orbit and come home. The whole project as I say, is costed out and scheduled out. One of the more impressive numbers, for instance, is that the basic module for all of the stations in orbit and on the Moon and the Mars is basically about a 5 m x 20 m inflated structure with several floors in it, and a central corridor which gives access to all the floors and provides all the necessary interface connections and so forth.

We've gone out and talked to the people who would make it. It's essentially a giant space suit, it's similar to space suit material: kevlar strength member layers and various sealing and insulating layers. You can go out and order something like that and they'll build it for you, I think, for less than a million dollars, ready to package in the nose of the space craft and send up. Of course, you won't have done the full sort of test series and all of that but this program is premised on the notion that you are trying to do this in a fashion which is safe but not absolutely safe, reliable but not absolutely reliable.

The schedule for the whole operation is a ten year schedule, starting any time. The cost for the whole operation is $40 billion to put four people on Mars and bring them back.

Ram Accelerator -- *Abe Hertzberg, University of Washington*

Introduction by Ray Williamson: We have two more talks, and we'll continue with the same routine of having a talk and then a short question period afterwards.

Our first speaker of the last two talks is Professor Abe Hertzberg from The University of Washington and he'll be speaking to us about the Ram Accelerator. He got his BS from Virginia Polytechnic, MS degree from Cornell University and began work with the Curtis Wright Corporation. He has a long, and I know from previous experience with Abe, distinguished career. He worked at the Cornell Aeronautical Laboratory and has been involved, for many years, in fields like gas dynamics, physics of high temperatures, gases and lasers, serves on a lot of different panels and so forth. I first met him when we were doing a solar-powered satellite study at OTA, a number of years ago, and he helped us out with some work on that. Since then I have seen a number of his talks on the ram accelerator and I look forward to hearing of the progress that you've made on that in the meantime.

Abe Hertzberg: I have learned something at this meeting and its something we seem to have forgotten. Space has already really paid for itself. All we have to do is notice some of the things that have already worked like communications satellites, the weather satellites. The weather satellites have saved more lives just in the area of the Gulf of Mexico than can be really considered . People are not expendable, it's not a question of whether one man or a thousand dies. It's just that they can be saved, and if space can do it, they should be.

In an effort to, hopefully, make space cheaper, I am working on a new method of propulsion with some of my students and a couple of professors at the university. This is probably the cheapest talk you are going to hear, because no matter how I do the accounting it's hard to work it up into the million or two million dollar class that's been expended on this project to date.

We have had an awful lot of fun. We are going to make a ramjet fly at Mach 30. And, by the way, just for the hell of it, the world's fastest ramjet is in the basement of my lab. In fact it runs virtually between my feet, underneath the floor. We have, indeed, shown positive thrusts at Mach 8.5. In fact 10,000 g's worth of thrust to accelerate the ramjet at that speed. I guess it does work. We started off with thinking about a conventional ramjet. A ramjet, as you know, flies supersonically through air for the most part. You have a system of oblique shock waves, a normal shock wave which raises the pressure. You have to then inject fuel, mix it, burn it and bring it out through a nozzle.

Now the real problem is right there. You fly through air. We thought about it for a while and decided, a ramjet's really a nice, simple thing. Let's make it even simpler. We will have no on-board fuel in our center body. We'll instead premix the fuel and oxidizer ahead of it. Rather than have a cowling on the ramjet, we'll have a long tube and the body of the ramjet will be mounted in the tube.

Everything looks the same. We have the premixed fuel and oxidizer, oblique shock wave system, normal shock, combustion, simply go to what we call thermal choking. The heat does raise the Mach number in the subsonic region between here and there and finally it will choke it.

The important thing is this part that is the trick to this device. I don't want it to fly through air. Air is terrible stuff. It's got all that nitrogen in it, which is doing you no earthly good, as far as the ramjets are concerned, except increasing your drag. It insists on having a speed of sound all of its own and it also gets thinner, the higher you go. So we decided we would take a look at something that looked very simple to begin with and premix the fuel and oxidizer. We would elect to make the ramjet power through our world.

Now, if I reversed everything and had mostly hydrogen out here with a little oxidizer, the speed of sound of that gaseous combination is four times that of air. All of a sudden I have a divisor to my Mach number. Instead of flying at Mach 30, I only have to fly at Mach 9 to be at the equivalent of 30 in the air. We examined this, and of course did a lot of calculations, most of which turned out to be wrong. They usually do. Lacking experimental data, we decided to build a device and then we ran into the first negative reflex.

Everybody we took it to said it won't work. Finally, we found one guy in the Air Force, who said it might work: you've done a couple of things for us in the past, Abe, some have actually even worked. So, we'll give you a few bucks and you make it work.

SDIO threw me out the door. The Air Force dragged them back in, and it went like that, back and forth. A year or so later we got the contract, but that's the way things happen in the real world. In fact, we got the first contract about two weeks before it was due to expire. And then, we almost spent all the money in those two weeks because I owed everybody in the world.

We set up a simple facility. We borrowed some old pieces of shock tube and we launched the vehicle in this tube. We have a helium dump tank, we used helium as the driver to get it up to supersonic speeds and a little acceleration section, heavily instrumented. Then we have what we call the honesty measurements. We would measure the velocity after the device left the tube and, by very standard techniques, we caught it in a box full of old rugs. Well, you can get old rugs very cheap. Everybody's pleased to get rid of them, they don't know what to do with them. They do stop and break up the vehicles very nicely.

This is sometimes called a ram cannon, but it really isn't a cannon. The pressure acting on the vehicle in the tube would be approximately like so. We would see a couple of shocks reflecting and then we would get the normal shock rise, and then the pressure would drop, and the pressure pulse would run down the tube, pushing the vehicle ahead of it.

Now in a regular cannon, the pressure rises continuously behind the shell so that the breach always has to take the highest pressure and, of course, that's why guns are tapered and also that's why guns are limited because this pressure can get so high that there is no way to push it out the end.

Ours is different. There's also no recoil because it turns out that the flow is moving backwards from the projectile; though it actually, for awhile, is moving forward with the projectile, the wall knows what it's doing and the heat blowing on the wall is really rather light. The friction is practically non-existent on the wall, but over the vehicle you have to take it into account. But more importantly, it's scaleable. We can scale this from 22 caliber sizes up to what we're considering for a space launch, a meter diameter tube.

All of our energy is already in the tube. It is waiting to be picked up and used as it is needed. People were worrying about detonation waves going through the tube, blowing everything up on its exit. I finally had to tell them the truth, that the worst thing that this thing could do would be to actually work! The pressure this would generate would be much higher than any detonation wave. You have to design for it. Facts of life.

So we built the projectiles that looked like this. That beautiful picture there looks almost as flashy as some that I've seen at this meeting which proves I didn't take it. In Germany at ISL, I showed them one of the projectiles, they dashed off and within half an hour, they brought this back. We stabilized the projectile by having rails on the projectile. This is so we could fool around with throat dimensions, a slender cone, a little magnetic disk here which serves to mark the position of the projectile in the tube when we need to. One back here to show whether they would stay together or not. Unfortunately, we do use up one projectile per shot and that's why the crude aerodynamics on the fins. It still runs like crazy though. Let's take a look at some of the results.

There they are. Our method of grading the mixture down the tube was just to change the mixture ratio to increase the speed of sound by adding helium, or nitrogen. In fact, for some of our shots where we started at 700 m a second, we put CO_2 in it. We made the vehicle think it was going at a higher Mach number than it actually was. Later on we make it think it's going at a lower Mach number than it really is. So it's flying in our world. When we raise the pressure, we want to increase its acceleration. We drop it when we want to decrease it.

This is a record of the data we get per run. You can only measure it in time. That's a projectile scaled to the time and that's the throat, right there, that's the tail end, that's magnetic. Then we measure the pressure, and it goes up here, to what I now consider the choke point, and the pressure does drop, so it wasn't quite how we calculated it.

Combustion seems to take place behind the projectile. It really doesn't make any difference whether it does or not. It belongs, it occurs, somewhere behind here. It does give us quite a bit of thrust. As you can see, there's the pressure in front of the projectile, there's the pressure behind it.

This is at about two clicks. Notice the Mach number is only 3.7 because it's flying with a lot of helium. 3.7 is a nice Mach number for a ramjet. Then we started to get better at taking data. May I see the next slide please?

In this run we had sort of an anomaly. We are pleased with that theory, in fact a little arrogant about it, but here was a shot, with this particular mixture (I've forgotten what the run number was) only 23 atmospheres in the tube. This is our error. It goes much higher than we had calculated it. It seemed that the physics involved here was being taught to us by our teacher in the lab; we hadn't really figured that out for ourselves.

In fact, this is run number 460. I think we are at about 700 now, in the same tube by the way, slightly different from rail guns. The detonation speed in that gas, interestingly enough is below 2,500 m/second, about 2,200 m/second. Sound speed you notice very markedly. Pressures are constant. We have just one diaphragm, and off she goes and rises, goes to what we call a transtet, and we are now going faster than the detonation wave speed of the gas.

We call this transdetonative behavior transtet, and we have now operated this in the three modes that we know, with the same projectile geometry. We have to go ultimately faster than the detonation wave in the gas. Of course that's rather slow, even for the fastest gases. We have CFD calculations, if you believe those things. I seem to remember CFD was used to predict the size of lasers for laser fusion. They only missed by a factor of 10,000. I hope we do a little better with the NASP, I mean with scramjet. I think you agree that a lot of testing is going to be needed. The best teacher is in the lab.

Here we are, operating in that region. The velocity is fairly low, but this is a transdetonative run. The character is slightly different. Some of these pulses are artifacts of the pressure transducer. Some of them actually seem to be pressure oscillations. Again you see a sharp spike of luminosity. I find it difficult to correlate this with anything, but mostly we know that we do form soot behind the projectile. We're seeing blackbody radiation. That goes as T^4, so a minor temperature difference gives us very striking phenomena there.

We are instrumenting a transparent section now to see if we can get a better understanding of the combustion phenomena around the body. But it does work, and it was sort of fun to make it work, though I have to admit, I cannot take any credit for making it work. The people that deserve the credit are the students.

Here I'm an old codger professor, reaching the age of irascibility and should have been retired a long time ago but too lazy to quit and even too lazy to work, so I let them work. But they don't know it can't work. We had all kinds of experts coming in and telling us it's not going to work, and I would have to agree it's quite possible, you may be right, the students didn't know this. So, for the first 100 runs, we had nothing, nothing worked. We would have these research conferences around 5 or 6 o'clock in my office, every evening, before we started on the pizza runs, but they thought I understood everything. I am not a big enough man to admit that I don't understand everything. So, my colleague, Dr. Brook, and I would hum at each other and said well, clearly, you are right, Adam it's clearly that, we'll put thermo throck on the heterodyne and inverse the quadratis. You've read Ferble's paper on that subject, I think you are right. And the students -- this is really quite true -- they kept us working. We were ready to sell the project. People accused me of being secretive about it. I didn't want people to know that I was working on anything this dumb! So, in the beginning we were terribly secretive, and we had a lot to be secretive about.

Finally it did go. At that time, I was in between contracts with the Air Force, or SDIO, or the Navy, I don't know. Everybody has done a little piece of this, including some companies, because you get your money where you can, particularly when you have an unpleasant project. We got a one year contract every two years, which in the university world is hard to live by. We do a lot of scheming, and have good bookkeeping, but we finished the contract three days before it actually arrived. It gives you a great feeling of relief. I was sitting in General Emertson's office and there were about five guys there all looking at me with total fury, because I was taking some money out of somebody else's budget for some other accelerator device. All they wanted was to see me to go somewhere and die.

A lot of this story is true, by the way. One of the guys across the table looked at me and said, "What will it take to convince you that it won't work?" "During this contract if I can't double the energy of the projectile coming into this barrel, I'll quit, I won't bother you any more." "Good let's give him the money to get rid of him." So, they gave me a few bucks. The students and we had sort of figured out how to make it work. We called it the starting trick. By the way, since we didn't do this under contract, I ain't telling it to nobody how we did it. We do have a patent on it and all that but it's really very simple, in retrospect. Always things are simple in retrospect, and that turned out to be very simple.

We do have to limit our velocities. I think one of the pictures you showed, had a velocity of about 2,500 m/second. That's about all we can do in the university. That's a fairly high velocity and the students... They have these silly rules in the university. You are not supposed to kill any students who are paying tuition. Frankly, they are very brave. I had too many things blow up in my face during my life to not respect high pressures and high velocities. They don't know that. They've never had it blow up in their faces. We are operating ultra-safe. That's why the relative pressures are in that range. Remember everything that happened in the twelve meter length of my tube would have happened by going to 250 atmospheres within 1.2 m. The maximum acceleration we measured in my lab nonetheless is 30,000 g's.

Yes it works, and it works rather well. We do have CFD calculations. This is an Eulerian code, full chemistry, hydrogen/oxygen mixture, and it shows positive thrust up to maybe 11 km/second. That happens to be escape velocity.

So what are we going to do with this thing, other than what the military wants to do with it? I think what they want to do with it is fairly obvious. So, one of my students came up with a drawing of what we'd really wanted to do with it from the very beginning. While we both agree and disagree on many things that we've heard here, one of the things that we agree on is that for carrying people and delicate electronics up into space, that should be a certain class of vehicles. But why use something like a new four wheel drive Mercedes Benz? Man, I looked at the price on those. They really are something terrific, to carry coal, or carry garbage to the garbage dump. We treat the lowest class of toilet paper, or fuel, water, everything the same way we treat the human brain or very delicate electronics.

We want to build a pipeline. We believe that the projectile has to be of a certain length because elementary calculations show, and a lot of people have been wrong on this, that if you try to launch at too high an acceleration, you will require a very short projectile. So, we have to limit ourselves to about 1,000-2,000 gs. This is a launch tube that is 3 or 4 km long. Can you build a tube that long? The answer is yes, look at the Alaskan pipeline. The wall thicknesses are almost the same. Can I keep it straight? The answer is yes, go look at Boeing's jig for the 747s. You know they that they are manufactured in a big drafty factory. There is no way that that jig for the 747 wing construction is going to be at constant temperature throughout. (There's even a view foil on that problem, I mean a chart on that problem, outside.) It's a very active jig. There are a great many lasers and hydraulic motors working overtime to keep the jigs stabilized as they put that wing together so that when it fits on the wing. It's very important.

Anyway, we would indeed have an active stabilizer. I had John Hedgepeth, my favorite structures man work on this. He said, "No problem" and it's a cartoon. We can make all the claims and we even made this claim, and that's the biggest part of the cartoon. Remember, as an object lesson, we were sort of told numbers like that about the Shuttle originally. I don't know, honestly if this is going to be cheaper, but I do think it's worth looking at and we are working on that now.

For example, this is one of our cargo launchers. By the way, when you get up to this size, you can stop worrying about losing a lot of velocity due to drag. Your ballistic coefficient is so high that you end up with 90 percent of your velocity going up through the atmosphere. It's actually easier to go up than come down, because you slow down coming in and you're at the slowest speed, the numbers just worked out that way.

We have to have an on-board fuel system. We thought we could get away without it but common sense dictates that this is going to have to be automated to the highest level. Fortunately, it lends itself to automation. In fact the whole Brilliant Pebble concept is based on cheap component technology and they are getting cheaper every day.

Now, I can go out and buy a Macintosh that could run the whole Moon program, probably could run every trajectory that they ever did in the early days of the Moon program in a half hour. But we will have to go through orbital maneuvers to get it into a storage orbit. We fire, that's Phase one. We go up through the atmosphere, of course go into a parabolic orbit unless we want it to go hyperbolic. That's another story. We have to get a little kick here to bring it around. We use atmospheric braking. Very neat idea, whoever thought that one up.

Then come around and finally have a kick and we're in a parking orbit near as possible to the space station without interfering with it.

We don't want to leave the debris in that region. Approximately half the weight will be payload. We're talking about a metric ton payload; that was chosen arbitrarily. I gave my students a design problem, and that's what we used. I don't know whether that's the best or the worst. I can't make that argument until I do some systems analysis, and even then I won't know it. I'll think I know it, which is the most dangerous thing.

There's a picture of the projectile flying at about two clicks. Interestingly enough, as we expected, since the relative Mach number in the tube is low, there is no blunting of the nose. The fins seem to be intact. It's going straight as a die.

By the way, you are looking at a very interesting piece of technology archeology. We had so little money in this project that we had to rescue, from a junk heap, an old image converter camera. One of the very first ones, and you can't find the blueprints for it. So, one of the young men, being very energetic, called up the guy whose father worked on this and the guy got us the blueprints. They put it all back together and they got it working. That's not a bad picture. It's about a microsecond launch, so it's a little blurred, but it's moving fast, as the next picture will prove. That's a quarter and that's the hole this projectile made. I mean, a projectile like this would make going through an inch or so of steel an easy trick. We've been through about an inch and a half, and that's the ram accelerator.

The point I am trying to make is it's a scaleable device. In any of these devices, including the rocket, it is never the cost of fuel that runs it. It's never. I can launch this thing effectively about twice a day because that's when the space station will be overhead. I want to store things. There'll be debris left in orbit, but I plan on shipping that to the Moon because I noticed on a chart out there in the hall, the Moon doesn't have much carbon. We can just ship some carbon to the Moon so it'll be there when we need it. I can go through all the scenarios. It might even work. It might be cheap. I think it's worth working on to the point that we can find out whether or not it is.

There are other uses. And indeed, one of the most important uses, it's a very neat testing tool to test these brilliant codes that are going to get us up through the scramjet regime. That alone I believe has created some interest in NASA. And by the way, Ed Gabris gave us the money to do the first little study of the launch thing. We are under contract with Wiseberg to take some visualization photographs to see if we can duplicate this with our code. Thank you.

Question: *Combining a bit of an idea from the laser propulsion, you are probably going to get some heat in that nose cone. Instead of having a separate fuel and oxidizer if you had a big* *chunk of ice in there, that heat would vaporize that and perhaps you can use that as an apogee kick motor.*

Abe Hertzberg: Well, we were thinking of using transpiration cooling at one time, but the cost... in other words I couldn't cost it out. We only lose 15 kg of mass going up through the atmosphere and through the tube, out of two metric tons. So, there really isn't that much there. But I haven't really looked at the numbers. What we did was take a rocket researcher's UDMH, those little motors they use for landing on the Moon, things like that, steering and scale it to our purpose. They were a great help in that.

Question: *You said 30,000 g's. I was just computing that one slide you said 1,700 m. In half a meter, that's 300,000 g's. Am I doing something wrong?*

Abe Hertzberg: Sorry for the confusion. That was from the diaphragm point where we took that picture. That was for our own use, I should have stressed that, thank you.

Question: *That wasn't the acceleration?*

Abe Hertzberg: No, no. We get that when we slow down.

Question: *So about 30,000 g's?*

Abe Hertzberg: That's the best we've done. It's getting pretty hairy around there.

Question: *Am I correct in assuming that you've still got to have a sonic speed injector mechanism, even when you scale this thing up?*

Abe Hertzberg: No, no. Once you get working, how to make it work better becomes a little more obvious and we have what we call the high Mach number, zero velocity start. We do not propose to use an initial accelerator. We'll start at zero velocity and go all the way up as a supersonic ramjet. That's my paper for next year. So I can get over to Europe and have some good food. Thank you.

Space Ship Experimental (SSX) -- *Steve Hoeser, General Research Corp.*

Introduction by Ray Williamson: Our final talk today is on the subject of the Space Ship Experimental, the SSX, and will be presented by Steve Hoeser, who is a Space Systems Project Analyst. Steve did graduate work at the University of Wisconsin, Eau Claire, with studies in advanced life support systems and small orbiting laboratory concepts. He spent four and a half years in the Air Force as a Space Systems Operations Officer and most recently is Program Manager for a classified space capability. He is currently with the General Research Corporation supporting the Strategic Defense Initiative Office on a Boost Surveillance and Tracking System and other classified programs.

Steve Hoeser: I plead guilty. I stole this chart but since I put it together in the first place, I figured it was appropriate, and OK, to use it. As it indicates, it is the National Space Society Executive Summary. It's a way that I thought we could kind of bring this whole thing together. If we are going to talk about infrastructure, particularly space infrastructure, there really are four elements, and that's the axis foundations or principles that govern the space infrastructure, the types of services that you could possibly provide as well as the activities. A lot of focus has been on the area of the activities. What I am going to concentrate on is the axis, because if we can't get there, we can't do any of the other things.

The way I'd like to get there today is to talk about what we call the Space Ship Experimental (SSX). In particular, I think it's important to note that what we are talking about here, in our mind, is a world competition. If we want to get right down to it, the United States, and our leadership in space today, is really being challenged. If we want to maintain preeminence in that field, to help develop space infrastructure, then we have to meet that competition.

What I want to talk about today are three areas. First, I want to set the stage by talking about a basic, fundamental change in the philosophy of how we look at getting to space. In other words, I want to talk about the philosophy of true space ships. Secondly, I'll give you an overview of the Space Ship Experimental, what it is, how it might operate, and finally, answer the bottom line question? Why could we do this today?

The fundamental difference between the type of single stage to orbit that we are talking about here, or a NASP, or any other single stage to orbit vehicle is that we've got to change our ideas, primarily, we are talking about a space transportation system that is saveable. As I go through this, I hope to give you an appreciation of how this is fundamentally different from the way we do things today. Importantly, the types of things that you see here, we don't do these things with launch vehicles today. The very fact that we save a launch vehicle or a booster, rather than a transport, gives you an indication that we really don't understand that getting to orbit with an aircraft-like operation means it must be fail safe, operate through failures, the types of things that we normally, everyday think about in commercial transports and aircraft.

What do we mean by continuous intact abort? That means, throughout its operation in the flight, you can bring back the vehicle, intact, through potential failures. In the SSX, what we are talking about here is the ability to operate through a failure. As illustrated here, a vehicle such as we're talking about today, has the capability to abort. Now, the way the vehicles operate today, they don't operate in a fail safe manner. When they don't work, they fail to operate and they fail to operate catastrophically. The term that we coin for this is an ammunition philosophy. And not too many people like to ride on ammunition because if it doesn't work, it doesn't work catastrophically. We want to operate through a failure.

The second thing we want to talk about is a true man/machine blend. The system here has to be able to be operated either manned or unmanned. This idea of man-rating a system is hogwash. It's lunacy. And it only has come about because we took ICBM missiles and used them to launch people into orbit. That's ammunition folks. That's what takes reentry vehicles and military payloads, and shoots them at people. We're talking here about a space transport vehicle. And you don't man-rate a transport, you certify a transport. Just like we do with aircraft.

I was hoping that somebody before me would address this problem. The ALS folks have this as one of the primary things they want to address. The mere fact that we use 9,000+ people to operate the Shuttle is an indicator of the problem. That's the number that NASA would provide; the number in reality is closer to 15,000 people. That's 15,000 people whether the Shuttle flies or not. You've got to pay them, you've got to pay their insurance. You've got to give them a livelihood and, as anybody in the aircraft industry will tell you, you don't make money by having a vehicle sit on the ground. What we really want to get down to is something like what the airlines have: about 149 people, maybe 150. By the way, that 149 people includes not just the pilots and other people who fly in the plane, but we are talking about ticket agents, the baggage people, that's total numbers. If you want to make a different analogy that some people might think is a little bit more accurate, let's look at an advanced aircraft operation. Can't tell you where any of these numbers came from, but most of you can probably guess. The system has eight aircraft. Has about 48 people per aircraft, that means about a 385 man army and the vehicle flies about 400 times a year. So, even at that, that's a significant decrease -- by at least an order of magnitude or more than what we have today. The fewer people you have, the less costly is your system. And that is what we are talking about here today. The figure of merit is cost.

Now the other part is, if we are going to use a rocket vehicle, or a similar type of vehicle, the question is: "How can that operate like an aircraft, especially in the type of vehicle that we are talking about?" In this case, rather than using wings as our primary abort mechanism, we want to operate this vehicle so that you have enough engines, like we do on commercial transports, so that if one goes down, you can still operate the vehicle. If you've done your work well, and you have a good thrust-to-weight ratio engine, you can lose an engine and still get to orbit, still conduct your mission. Two engines, you might have to hover and ultimately land the vehicle. But in this case, you want to be able to fail safe. Again, the vehicle has to work through potential failures.

I think an important part of what I said before was that we are not going to rate this system. We are going to flight certify it. How do you flight certify a vehicle that you fly once and dump in the ocean? You can't do that, but with a single stage to orbit (SSTO) transport that you use again, and again and again, you can work a flight test program. There was an analogy made, I am trying to remember who made it, earlier here, Dr. Kare. He said, "You can keep the program cost low because you can test this thing on the ground". Well, in fact that's almost what you are doing with this vehicle. You're testing it in its initial phases to gain confidence in a captive mode. Maybe another, say ten tests down the road, you bring it up and hover it for another 10 more times and land it. That's probably the most critical thing you're going to do. You're working literally up the flight envelope to gain confidence in that vehicle.

I think the bottom line of this whole thing has to be the idea that the system has to be flexible and reliable. I think it was CPS up in Cambridge, which is a group that looks at the commercial viability of commercial launch systems, they had an article in the Washington Post about three months ago. I called and asked them what was really the bottom line? There were two bottom lines: scheduling and cost, in that order. I found that kind of interesting, because I always thought that the cost was the bottom line. According to them, the fact that you have to schedule your flight up to two and a half years before you even get on the system and then you may not be able to fly it when you want to, is probably one of the biggest drivers in the commercial payload industry. They want to be able to do what they do on airplanes. "I've got to get this thing up there, we can schedule it, maybe tomorrow, so let's put it on the next flight out." That's the kind of scheduling flexibility that you want to have. A vehicle that flies every day or every two days or something like that to give you that kind of flexibility.

From the standpoint of safety, you want to be able to literally land anywhere. If you have an abort problem, you want to able to land without the aid of the long extended runways --- maybe on a 300 ft pad. If necessary, you might end up aborting in a parking lot, or out in the middle of the field... But that kind of flexibility gives you the kind of safety incentive that many insurance companies are looking for. You can save not only the payload but the vehicle itself. I've already talked about the rapid turnaround, but the other consideration that a vehicle that doesn't expend stages, doesn't drop things on people's head, could literally be launched from anywhere. You'd be able to launch from anywhere: from the middle of the United States and virtually any azimuth.

Comment: You're missing a zero on your runway length?

Steve Hoeser: What was the number 1,500 ft. 15,000 ft, you're right.

Now this is the basic vehicle concept, as we have today. It's a base line concept. As you can see, it's a blunt cone shape, very simple to design, very few sharp edges. That gives you an advantage in structures. And the structure is the key to single stage to orbit. You have to get a low mass fraction. The bottom portion of the vehicle is where the fuel and oxidizer is. That's where the fuel is. The cargo bay sits above that, and above that you have the command module. Notice I didn't say pilot module, I said command module. The vehicle should be able to fly either manned or unmanned. It doesn't matter. It's a man/machine blend. Whether the commander is sitting in the cockpit or he is sitting on the ground controlling it through the communications nodes really doesn't matter.

In operation, this is a simple cartoon diagram of the operation. Vehicle launches up to 2.5 max g level, injects into orbit at nominal 130 nautical mile orbit, goes through whatever operations it needs, does a de-orbit burn, descends and reenters. The majority of the energy is dissipated via aerobraking, at a nominal height of between 170-25,000 ft. You make sure that the engines begin to idle, and we come down to about 250 ft/second via aerobraking. At this point the vehicle is extremely light, so you don't need much fuel to land it. Even with a payload, it's extremely light. And then you come down to landing at a 300 ft diameter launch pad. If you use a GPS triangulation you can literally get down within centimeters of your exact set of devised coordinates.

This picture here gives you kind of an idea of the other benefits associated with a vehicle like this. There are no large gantries with this system. Your ground operations are fairly simple. Operation-wise, the vehicle can be loaded, unloaded, pretty much like a cargo transport would, but it has the features that we talked about in the central philosophy of really what we are looking for in a space transport. It has the capability to do engine out. It's a fully reusable stage. It's a single stage. One stage to build, one stage to test, one stage to maintain and keep people certified in maintenance, and one stage to operate. The vehicle can be tested, incrementally. Each vehicle can be flight certified. You can test it over and over again. It should pass. Most of the time they should pass, sometimes they don't. They go back and they get fixed. And finally, as I've said, it can be either manned or unmanned.

What has been proposed is really in the same genre as the NASP folks were talking about. In the near term we've got more than just a vehicle to demonstrate here. We have a whole philosophy of flight operations for a space ship, a real true space transport to demonstrate here. So what we have proposed is a x-oxide program, where we build a vehicle, where we don't have a specific performance parameter in mind. We take the technology which is available, and the NASP program office has provided a lot of that. (I'll show you that in a few minutes.) We're talking about just a few flight vehicles. We take them out and we fly the pants off them. See how they work. We learn from really operating these systems, in the same way the physicists and the people in the lab really learn by doing. That's what we are talking about here. Going back and doing the types of x-op, x-type programs that have been done for aircraft. And you can do that with this with this kind of vehicle. Because you can take it off, fly it once, twice, maybe three times a week. The goal is to eliminate that standing army. If you don't do that virtually everything else in this whole regime is nix-mox. The vehicle we are talking about may involve 25-30 people per vehicle for operation.

The question of readiness always comes up. If this is such good idea, why haven't we done it before? In fact, I have a back up chart that shows this concept and virtually all single stage to orbit concepts that have been looked at since the early '60s. The thing that has held us back is that the technology has not really been available to build such a vehicle. In fact, I was directly involved in a program at the U.S. Air Force Space Division, Office of Plans. We looked at all the ways of getting to orbit via single stage. Horizontal takeoff, horizontal landing; vertical takeoff, horizontal landing; vertical takeoff, vertical landing. And what we came down to, as the bottom line was structures and materials. We couldn't build a system light enough to give us a program in which we could justify the funding of such as effort at that time. There were other efforts going on at the time, NASP ended up being the spearhead for this activity. And, in fact, it has been their work, probably more than anything else, over the past ten years, if you go back to the start of the work at DARPA, that's really made this type of vehicle feasible.

The other areas, of course, that have advanced significantly, are avionics and support processors. The fact that they're smaller means they use less power. That again translates into the lighter weight of the total vehicle. Next chart.

Here is a chart from Langley showing empty weight to payload weight. Now this is a slightly different figure of merit than is normally used. Most engineers, including myself when we first started to work at this, wanted to see how well this vehicle could perform -- but that's really not the bottom line. The bottom line is operational flexibility and low-cost operations. The figure of merit, empty weight to payload weight really gives you an idea of just how much and how complex the vehicle is going to cost, associated with the kind of payload it can put in orbit. Now, again, this was a NASA recommended study, that came up with this as a recommended different way of looking at how these launch vehicles stacked up against each other.

As you can see, at this point we are talking Shuttle-type structures. These are percents in weight reduction, compared, as I said, to the Shuttle. These are the current staff/ALS aim points. This is the kind of aim point that NASP was originally working for. I couldn't comment if these are still the same numbers, but it's interesting to note the kinds of curves you get on this. In fact, the kind of SSX weights that we are talking about are 20-25 percent. You'll find that a single stage versus two stage vehicle, they really almost converge at this point, so the differences between those is not as significant.

The other thing I want to talk about is fundamental change in the way we look at, operate, and test space transports. We are really coming up against the kind of legacy in the launch vehicle arena that we've talked about. There have been a number of speakers this morning that have talked about bureaucratic resistance.

In the SSX program to date, it has been interesting that, within the last two months the technical arguments against this concept working have virtually dissolved among the expert community. What has not dissolved, and in fact is rearing its ugly head tremendously, is the question, "How the heck can you do this type of program in five years?" It's virtually impossible in the current environment. It's going to cost you 40 percent more than you save. We project the cost for this program as under a billion dollars if you do it in the government.

So what we are coming up with is this legacy of the ballistic missile launch family. We are bucking up against their ideas of what a launch vehicle should be. Until we can overcome that, we probably won't be able to do this program or any other single stage to orbit vehicle program.

I've given you a brief overview of the SSX today, trying to keep it within the allotted time. The key is that we are talking about a change in philosophy. We are looking at these things as transports, true space ships, not launch vehicles, not boosters. If we follow that philosophy, we have to have a system that's saveable. It can abort intact, bringing back its payload, whether its men or machines, fully intact and safely. It has to have an operation which is flexible enough to give the customer the kind of flexibility and operations that he wants.

I have not touched on low-cost operation but we've run more than a number of cost models. If we talk about a vehicle that itself costs around $250 million, and we assume a 10 year life cycle for this system, with operations costs of approximately 10 million dollars per year, then, with the vehicle operating about twice per week, and say we have five vehicles (just to pick a number) we are talking in the range of about $350-375/pound. Now if you operate that vehicle more often, which is interestingly the case of the single stage to orbit vehicle, that price comes down significantly and can come down well below $100/pound, around $50/pound. I mentioned before the rule that the guys in the commercial aircraft industry figured out a long time ago; you don't make money with the vehicle sitting on the ground. You make money and you get your payback from the vehicle that is operating and flying, doing its job, which is to transport things.

I gave you a brief overview of the SSX in its general configuration. Finally I'll try to answer the key question that's always asked: "Why can we do this now? Why we can do it now is the structure technology, the long pole in the tent, has now been chopped down to an area that we can handle. The problem, interestingly enough now, is that of providing the kind of propulsion that we would be needed for this vehicle. Now, luckily, that is not a technology problem any more because we are dealing with something that's well understood. It's twenty-year old technology. It's just putting that technology into the type of engine configuration that we would need for this class of vehicle.

That concludes my presentation, except to point out one key thing. As I mentioned, if you'll look at the world market for launch, everybody wants to build their own launch vehicle. The systems that we have had in the past, and have today have been adequate. However, if we want to maintain our lead and our competitive edge we need to go to something that gives us 747- or DC3-like operations for space. We contend, as do the folks at the NASP Program

Office, that a single stage to orbit vehicle for the class of payloads that we are talking about here, 10-20,000 pounds, could give you that type of capability.

Question: *To get $50/pound to orbit, there are a couple minor issues that come up, that may be you could help me understand. How many engines, for example, do you have on this vehicle?*

Steve Hoeser: Between six and ten.

Question: *Between six and ten. What's the thrust of each one?*

Steve Hoeser: For a 20,000 pound payload system, there is a gross lift-off weight of 500,000 to 600,000 pounds. That's for 20,000 pounds and then you calculate the thrust to weight ratio associated with that. It will be somewhere above that, say 750,000 pounds

Question: *Per engine?*

Steve Hoeser: No, no, total.

Question: *So about 100,000 pounds per engine?*

Steve Hoeser: Approximately. They don't exist. That's one of our big problems. We don't have engines in the class that we need for this vehicle. So, it looks like we are going to have to build a new engine.

Question: *You've given the impression that because we have structural weight down a little bit ...*

Steve Hoeser: That's been a long pole up to date. Yes.

Question: *Yeah, well, for the last four or five years, the main impediment to getting launch costs down has been the development cost of an engine and the operations costs of an engine and, regardless of whether its expendable or reusable, these have been the dominating factors, as long as I've been involved in this business. Until you've addressed that, your argument that you get launch costs of $50/pound is kind of suspect, in my opinion.*

Steve Hoeser: I disagree with that. The reason I disagree is you're considering that we are going to be developing this engine in the normal way that we are forced into developing engines today, without any relaxation of the extended test cycles that's required for a new engine. Remember what we are talking about here is a prototype, experimental-type system. Now there's nothing to say that you can't take an engine up to preliminary flight certification levels. What is normally done with it? You take it out and put it on a test stand and run the heck out of it, right? Who's to say that test stand might not be the vehicle itself? We are not going to throw these engines away, remember, this vehicle is going to operate over and over and over and over again.

Question: *How many uses are you going to get per engine?*

Steve Hoeser: That's a design factor right now. I would consider...

Question: *You have all these design factors enter into that $50/pound.*

Steve Hoeser: I wish Del Tischler was here. He'd tell you that there's absolutely no reason today why we couldn't build a rocket engine that would operate over the life of the vehicle, the life of the airframe. He knows engines a heck of a lot better than I ever hope to. In the cost analysis we did, we changed out engines three times over ten years.

Question: *Couple of questions. What kind of g loadings do you see in your entry profile, and is there any significant difference between this concept and Gary Hudson's Phoenix concept other than the fact you're incorporating advanced materials?*

Steve Hoeser: This is not the Garry Hudson Phoenix. In fact if you want to use the Garry Hudson Phoenix as an example, I can also go back and describe the "beta concept". We can go all the way back to RITA, Reusable Interplanetary Transport Approach. The SSX SSTO is the most advanced version of an ongoing concept for vertical takeoff and vertical landing. Garry Hudson was a perturbation in that system.

Question: *What's different about it? It looks just like a Phoenix briefing to me. The only difference I see is that we've got NASP materials. Is that a difference?*

Steve Hoeser: That's a key difference. In fact the Phoenix was one of the concepts that we looked into at XR when I was there. He gave us some numbers and the types of materials that he had available, and the analysis that was done said that the risk associated with that type of material didn't give you anywhere near the margin you would need for system development. So the decision was made to put this thing on the back shelf because it was being done in other areas, and when those advances were made it should be looked at again.

Question: *I want to make a couple of general comments. One, you showed that chart of percent improvement in structures weight with ALS needing a 20 percent improvement I guess I question ...*

Steve Hoeser: That was not my chart. That was a NASA Langley chart.

Question: *I don't know where those data came from. We are showing something on the other side of zero. We're saying we don't need to be as weight conscious as the Shuttle does and other current expendable launch vehicles.*

Steve Hoeser: That's an older chart too. I wouldn't doubt that that's true.

Question: *That sort of emphasizes the point I wanted to make: that NASP and SSX are performance-driven designs in the ultimate sense. NASP has the advantage that it has very high specific impulse since it uses atmospheric air. You don't have that advantage. You have to have an extremely efficient structure.*

Steve Hoeser: No, as a matter of fact we have to have a less efficient structure than the NASP folks, because we don't spend time in the atmosphere. We don't have the heat loadings that those guys do.

Question: *You have a different set of problems, but your structural weight sensitivity is absolutely critical. If you miss it by just a little bit, you end up with zero payload. That's been the problem all along with single stage to orbit vehicles. So, sensitivity is the thing that drives you and that's performance driven and you're right on the razor's edge all the time.*

Steve Hoeser: As I said, we can debate this all day, and that's going to be debated until a vehicle like this flies.

Question: *Your operability goals are excellent.*

Steve Hoeser: Yeah, that's because those are ALS operability goals, too.

Ray Williamson: We'll take one more question and then call it a day.

Question: *I didn't see any engine bells there, so that's the aerospike engine, right?*

Steve Hoeser: That baseline configuration is an aerospike but that doesn't necessarily mean it has to be an aerospike engine, especially in the preliminary vehicles.

Question: *Would that landing gear that you have it carrying there, would that be capable of supporting a fuelled vehicle?*

Steve Hoeser: No, you'd have those in retracted form before you would launch. Incidentally, there are copies of a paper that covers not only the things I've covered, but a lot more of the technical details that may answer some of the questions we had back here about engine specs. It's called Space Ship Experimental by Maxwell Hunter who, unfortunately, could not be here today, so I guess that. like the Shuttle C fellow, I'm a stand-in for the day.

Ray Williamson: Thank you very much. That concludes this session.