LUNCHEON PRESENTATION:

TRAVELING TO THE MOON AND BEYOND

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What I want to give here is just a short 10-minute description of what I've been doing over the past few years. And in the spirit of what John Lewis was discussing regarding getting young people involved in the field of space, I'll discuss the NASA Academy which I'm involved with this summer. Before I do, I'll just describe a little bit about my trajectory work some of you are familiar with.

In 1986, when I was at JPL, I had the opportunity to work with Kerry Nock. He's sitting here in the audience. At that time he initiated a project study called Lunar Get-a-Way Special (LGAS), and the purpose of that was to get a spacecraft to the Moon using electric propulsion, where it would search for water at the poles upon arrival. The engine was very small with the thrust equivalent to the weight you feel by putting a dime in the palm of your hand, and was an ion engine using Xenon gas which ionizes it by passing it through some electrodes. The small ions are accelerated creating a thrust. Solar energy was used to create the electric power. The spacecraft was very small, about the size of a small trashcan and planned to be released in the Get-a-Way Special canisters aboard the Shuttle. Using that kind of spacecraft it would take about a year to get to the Moon, which is a bit long. Also, by the time it got to the Moon it would be going at such a speed that the small engines could not create enough force to slow it down to be captured into lunar orbit. They were able to create .0004 meters per second in Delta-V, and you would need something like 800 meters per second. Thus, capture seems impossible by the usual methods. With continuous thrusting many days would be required to accumulate 800 meters per second, and by then it would be too late to achieve capture. The spacecraft would just zip past the moon.

The problem of achieving capture was found by locating regions about the Moon where the forces on a moving spacecraft all balance. These forces are the two gravitational forces due to the Earth and Moon and the centrifugal force. If the spacecraft were not moving at all, then this location would give the five Lagrange points. Once it moves, instead of the five simple Lagrange points you get a multi-dimensional region called a weak stability boundary. I found a numerical algorithm that located this region on the computer and mapped it out. To be in this region, you need the correct velocity. When this happens, the spacecraft is delicately balanced between the tugs of the Earth and Moon, and very, very weakly captured by the Moon. A maneuver has to be done, or the spacecraft will escape the Moon quickly. The beautiful thing about this boundary is that the maneuver is very tiny. So little fuel is needed for capture. A trajectory was found for the LGAS spacecraft to take it to this boundary where it was captured within its operating parameters.

The weak stability boundary can be thought of as a generalization of the notion of Lagrange points. It extends from the center of the Moon out to about 120,000 kilometers. For future missions it makes much more sense to go the weak stability boundary instead of the Lagrange points which are much more restrictive. The mathematics used in thinking about weak stability boundaries is called dynamical systems theory, which includes many areas of mathematics. At the time I did this for LGAS, the JPL and NASA philosophies were not in line with using chaos for space travel. It was new, and sounded risky since the trajectories were unstable in nature. Also, taking one year to get to the Moon was excessive. So, I was leaving JPL in 1990, and went to Pomona's Dept. of Mathematics as a visiting professor. I received my acceptance of that position in April of 1990, and planned to leave the field of aerospace.

There was however a lucky twist of fate. In the same month of April I also heard about this Japanese mission launched in January as two spacecraft attached together. The smaller one, MUSES B, was to detach and go off to the Moon, while the larger one, called MUSES A, was to remain in Earth orbit. This would have allowed Japan to be the third country in history to send something to the Moon. As it turned out, MUSES B didn't function as designed and contact was lost with it. Out of desperation they contacted me to see if my theory, called fuzzy boundary theory at the time, could find a way to get MUSES A to the Moon, since MUSES A had very little fuel in it to get to lunar orbit by traditional means. They indicated they would try anything, so I suggested the idea of using these boundaries. This led to a route to the Moon for Muses A from Earth orbit that led to weak lunar capture at the stability boundary, where the Sun had to be modeled as well as the Earth and Moon. Instead of 1 year, this route took only about 4 months. In April of 1991, they fired their engines and MUSES A, renamed Hiten, made it to the Moon on October 2 of that year, thereby vindicating my methodology. This route is now well known, and referred to as the WSB transfer, or the ballistic capture transfer. The SMART 1 mission of ESA is utilizing a weak stability boundary trajectory of the LGAS type, while Japan's planned Lunar A is utilizing the WSB transfer. This transfer saves a lot of fuel for lunar capture, and would be ideal for constructing a lunar base, where the cost of constructing a lunar base could be cut in half, as compared to using the three-day Hohmann transfer.

But you can do lots of other things with weak stability boundaries and they just don't exist at the Moon. Europa of Jupiter has one, and in 1997 JPL described a way to use this boundary to achieve low energy captures at Europa's weak-stability boundary. It exists about any planetary body which is in orbit about a more massive planetary body, e.g. about the Moon which orbits the Earth or about Europa which orbits Jupiter. It turns out that unusual trajectories exist which can be ejected from the Earth-Moon system which start as a resonance orbit about the Earth, in resonance with the Moon, which get pulled from this orbit into the lunar weak stability boundary, then through a complex motion, gets flung out to the boundary the Earth has with respect to the Sun, where it escapes the Earth with no fuel required. In this case a resonance orbit turns into an escape orbit. This saves fuel for escape. A simplified variation of this was used by Japan's Planet B mission currently on its way to Mars.

Another interesting phenomenon that was found in 1990 is called resonance hopping, where you'll be going around the Earth in a resonant orbit, in resonance with the Moon. Unlike the previous case, instead of interacting with the lunar boundary and being flung out to escape, you are flung onto another resonance orbit about the Earth - this time a different one. The first one was inside the Moon's orbit, the second is larger, on the outside of the Moon's orbit. So you have a jumping or hopping from one resonance state to another. I thought this was new, but the astronomer Brian Marsden in 1995 pointed out to me that comets can do resonance hopping. This hopping dynamics is sort of like quantum mechanics, where electrons jump resonant energy states. Resonance hopping about the Earth increases energy, while the reverse process reduces it. This would be a beautiful way to have spacecraft come back from Mars, and de-accelerate via resonance hops into smaller orbits around the Earth. There are many possible applications. By the same token, if you use resonance hopping to leave, you can decrease energy to Mars.

Before I end by discussing the NASA Academy, I just wanted to mention that there's another phenomenon that I'm studying which is very promising. This is motion about the Earth, for example, which remains nearly stationary for long periods of time, as one would do if moving near a Lagrange point. Except, in this case the motion need not be near any Lagrange points. It is near the Earth weak stability boundary. This should offer many interesting alternative locations to position spacecraft not available today.

I'll now shift gears and discuss something totally different. In 1997 I had the wonderful opportunity to meet the late Jerry Soffen, who passed away this last November. Jerry was a good friend of mine and to many people. He had many note worthy accomplishments, one of which he was the Project Scientist on both the Viking missions, and was responsible for developing NASA's astrobiology programs. I met him through another program he started in the early 1990's - the NASA Academy. This is a special summer program at a number of NASA centers, and Goddard has a central one, which is where he was located. It's really exciting. It is designed for mainly undergraduate students and they have the opportunity to visit the leaders of NASA, including the Administrator, Daniel Goldin, visit most of the NASA centers, see a shuttle launch, etc. They also do a group project.

They contacted me in 1997 when they were studying a lunar mission using the WSB transfer. Since then I have regularly lectured to the students in this program each summer. Last year Jerry Soffen asked me to be a dean of the Summer 2001 program, which I happily agreed to do. As John Lewis had been discussing in some of his talks, there is a shortage of young people with an interest in the space industry, and I feel that it is important to do what you can to get out there and motivate the younger people. The group project they are doing this summer is very exciting, and is called Bacterium 1. It was conceived of by Jerry Soffen, and the idea is to send a single bacteria to the surface of the Moon, in a tiny spacecraft on the order of a golf ball in size. It would get there by the WSB transfer. The goal of the mission would be to precisely monitor the moment the bacteria reproduces, thereby documenting the reproduction of another organism on the surface of another world! I was discussing this with Jim Burke, and he mentioned something similar studied by the International Space University a few years ago, called Space Babies, where a colony of yeast is sent into space somewhere to see how it reproduces in the space environment.