Good afternoon. I hope I didn't bore you to tears this morning. I get another chance to, now.

The launch loop is an accelerator space launcher designed to move people and machines to orbit and beyond. A half hour is not enough time to tell you everything about the launch loop; I have an old paper on the conference CD, and you can find out more by looking at the website. We have a lot to go through; if you have complicated questions, we can talk about them in the hall or by email.

This is an old idea for me; I first presented it in 1983. But for many of you it is new, and those that saw the first presentation are getting Alzheimers about now, so it will be new for you, too.

Outline

Requirements
Moving Streams of Mass
Launch Loop Tour
Opportunities

We will start by discussing requirements - what should a launch system do? The launch loop is based on the physics of moving streams of mass, and things get pretty interesting when the stream moves fast enough. Based on that, we will take a tour of the launch loop, explaining a few of the features. And lastly we will discuss some of the problems of operating a launch loop, which we will think of as opportunities.

Launch loop requirements

LEO to Lunar transfer orbits

    Velocities from 8 to 11 km/s

Accelerations < 3 gees

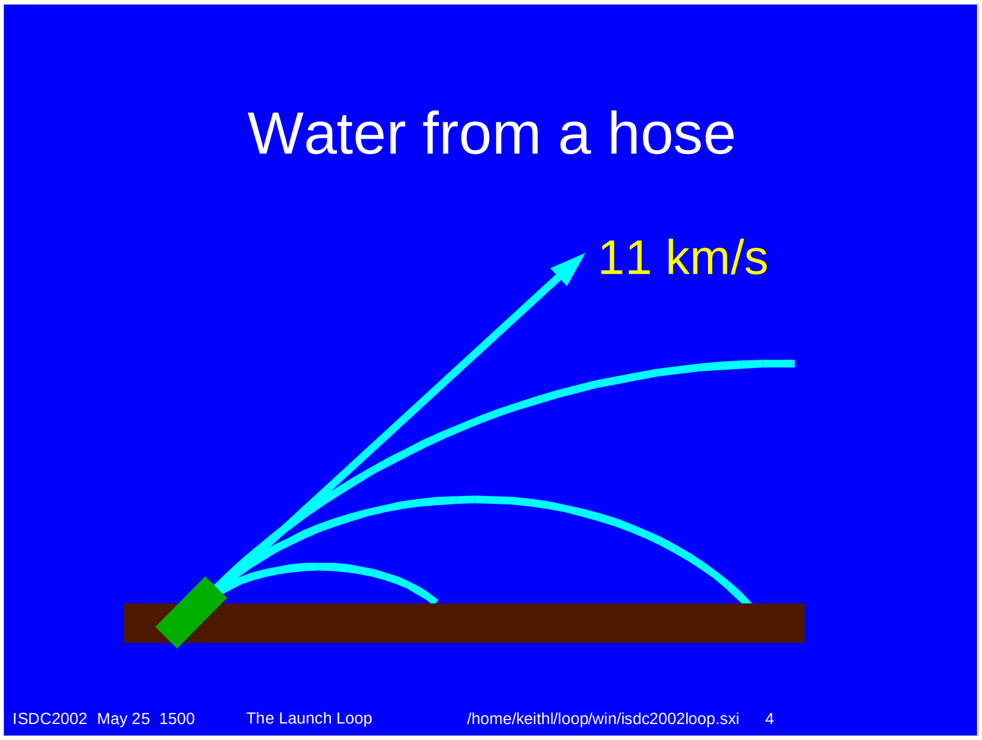
    2000 km length

Minimize atmospheric drag

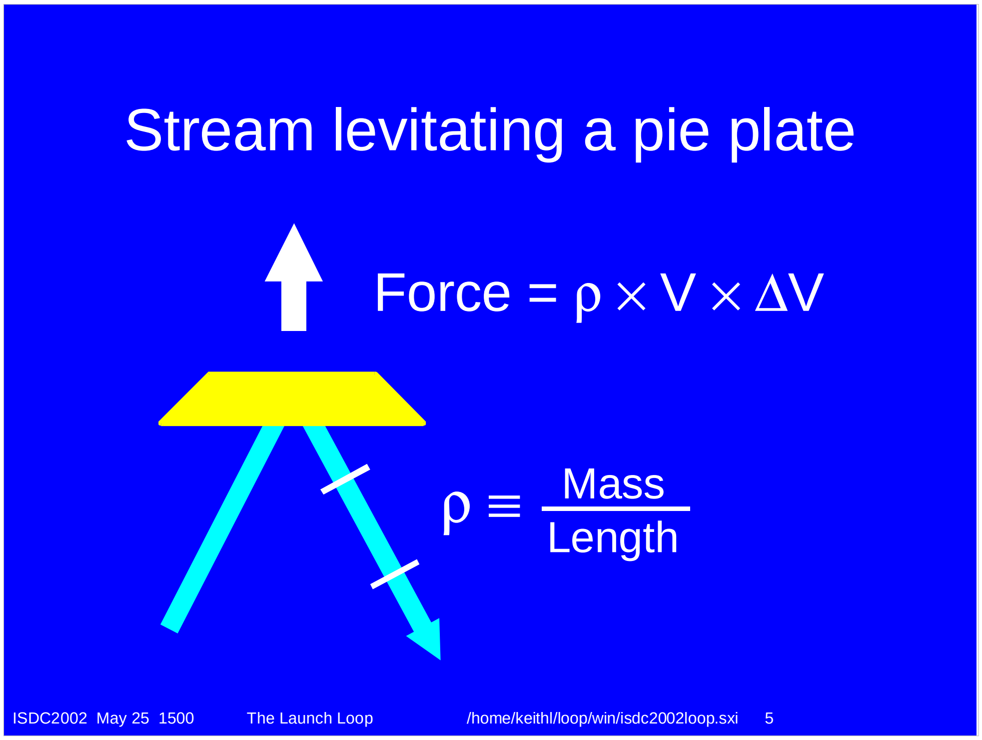
    80 km altitude

5000 kg payloads

A good earth launch system will be able to reach interesting orbits between here and the moon.
Low Earth Orbit or LEO, to translunar injection
We need to launch at velocities from 8 thousand to 11 thousand meters per second.
In order to ship people and machines, we need to limit acceleration to less than 3 gees, and that means an acceleration path 2000 kilometers long.
We don't want to waste velocity punching through the atmosphere, so our acceleration path should be at least 80 kilometers high.
And we need to ship decent sized payloads, along with the rocket motors needed for apogee orbit insertion.
We will launch at least 5 metric tons at a time.



Lets talk physics. Imagine a stream of water from a hose, It follows a parabolic arc. As the water moves faster, the arc gets bigger. If the water stream was perfectly formed, and there was no friction, the arc would keep getting bigger and bigger as the stream gets faster. At about 8000 meters per second, the arc lands halfway around the earth. If we moved the water at 11 thousand meters per second, the arc would never come back down.

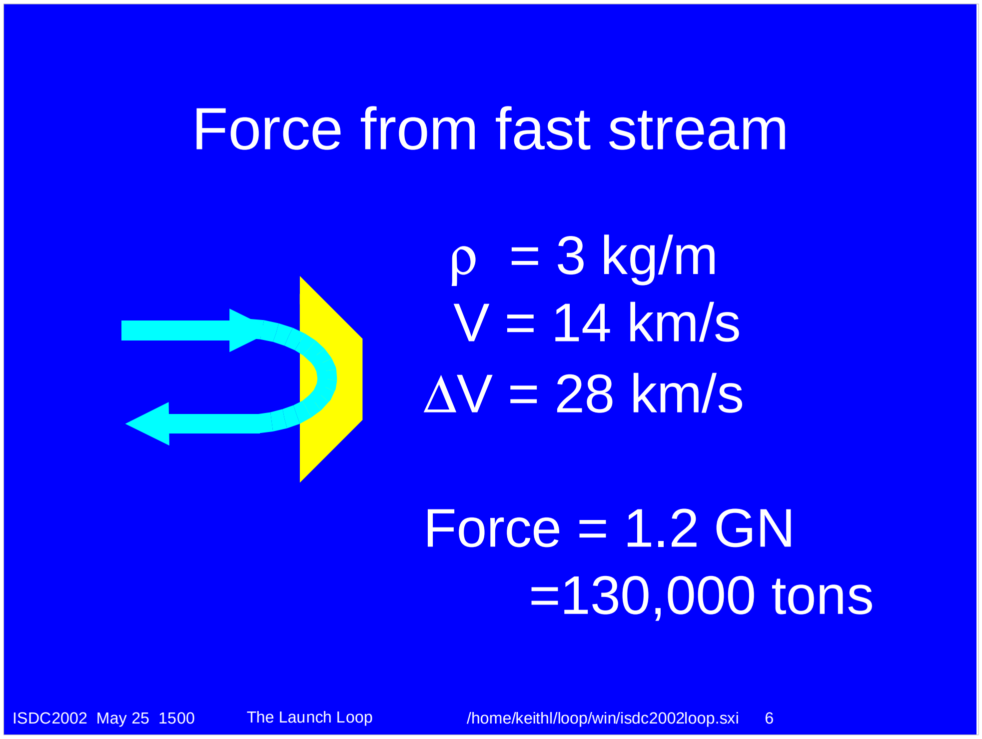


Now lets do another experiment. This time we will use the stream of water to hold up a pie plate. The stream is deflected, and undergoes a change in velocity.

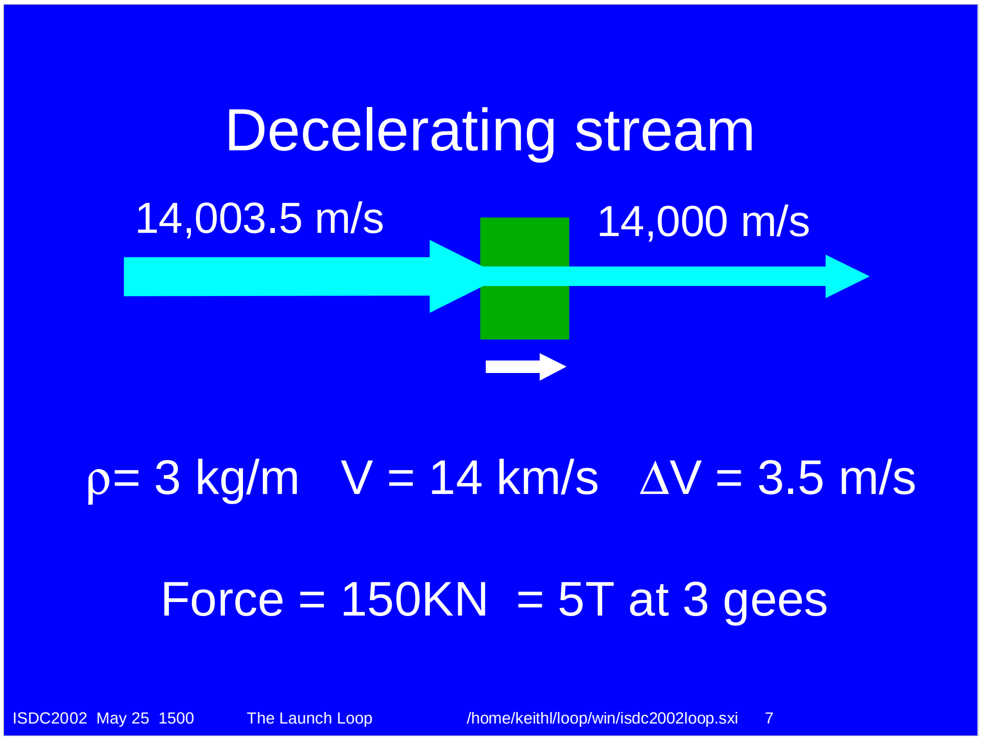
RHO is the mass density, or the mass per length. V is the velocity of the stream, so RHO times V is the amount of mass being delivered per second. Delta V is the velocity change.

This equation here gives the total force, which is the delivered mass per second times the velocity change.

When V and delta V become large, the force becomes large, too.



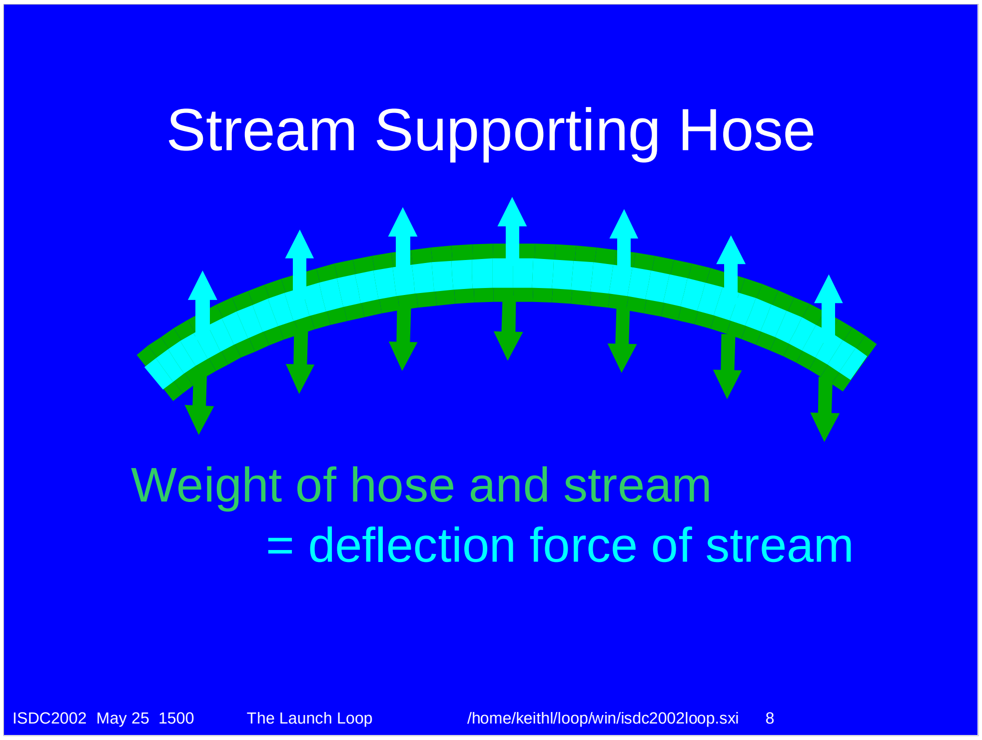
Assume a stream density of 3 kilograms per meter, moving at 14 kilometers per second, which is nearly double orbital velocity. If we deflect the stream 180 degrees, the delta V is 28 kilometers per second. The force necessary to do this is 1 point 2 billion newtons, or about 130 thousand tons. That is a lot of force, and we do encounter such forces in an operating launch loop.



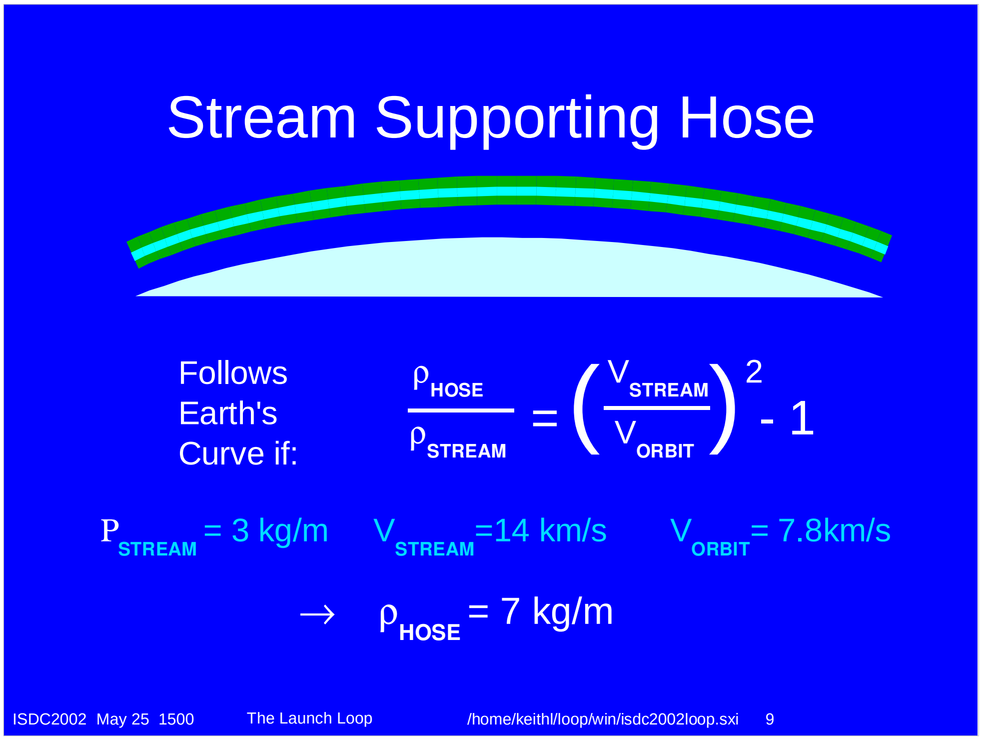
But we don't need to make that big a change. If we decellerate our moving stream by only 3 and a half meters per second, we generate a force of 150 thousand newtons, which is enough to accelerate a 5 ton mass at 3 gees.

Note that this wastes energy - the stream is losing 2 gigawatts of power, while the payload picks up power proportional to its slower velocity times the force. The result is a lot of heat, but fortunately a stream moving at 14 kilometers per second makes a pretty good heat sink.

This is how we will accelerate payloads with a launch loop.

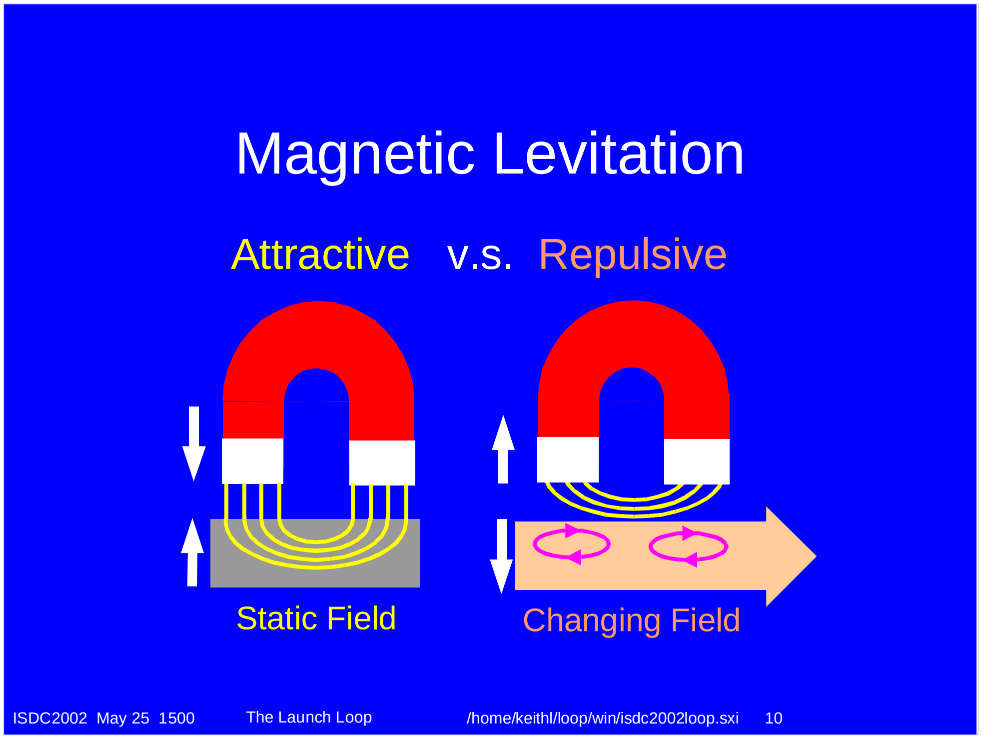


Moving streams can also hold up static structures. This stream is being deflected downwards by its own weight and the weight of the hose around it. Even a slowly moving stream of water will support an ordinary hose over short distances.



If the stream is moving fast enough, the deflection matches the curvature of the earth. A stream moving at orbital velocity, without a hose,follows a circular orbit. It never comes down.

If the stream is moving FASTER than orbital velocity, it can support a heavy hose. Our 3 kilogram per meter, 14 kilometer per second stream can support 7 kilograms per meter of hose. We can use this technique to support long structures far above the earth.

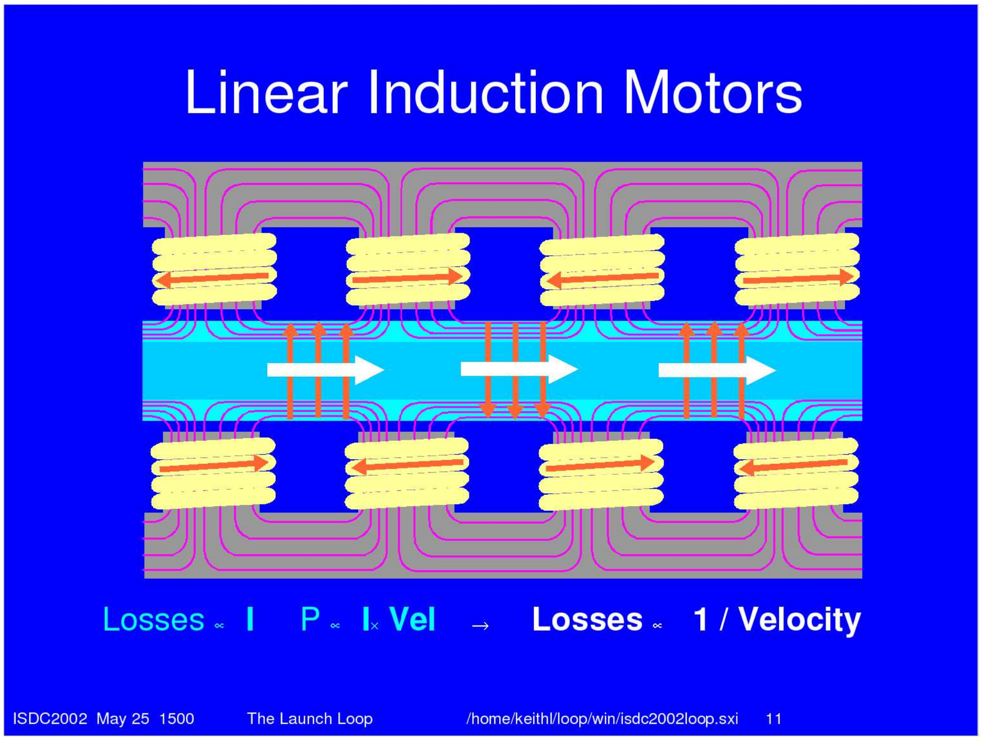


Of course, in real life you cannot use a stream of water in a hose. The friction would boil the water in microseconds. Lets replace the water with magnetic iron, a vacuum filled hose or sheath, and keep everything properly spaced by using magnetic levitation.

There are two kinds of magnetic levitation, attractive and repulsive. You all know about magnets being attracted to iron, and with high magnetic fields you can generate large forces.

The other kind of magnetic levitation is repulsive. When you move a magnetic over a conductor, you generate opposing currents, that try to resist the change in magnetic field. These currents force the field lines out of the conductor, and push the magnet away.

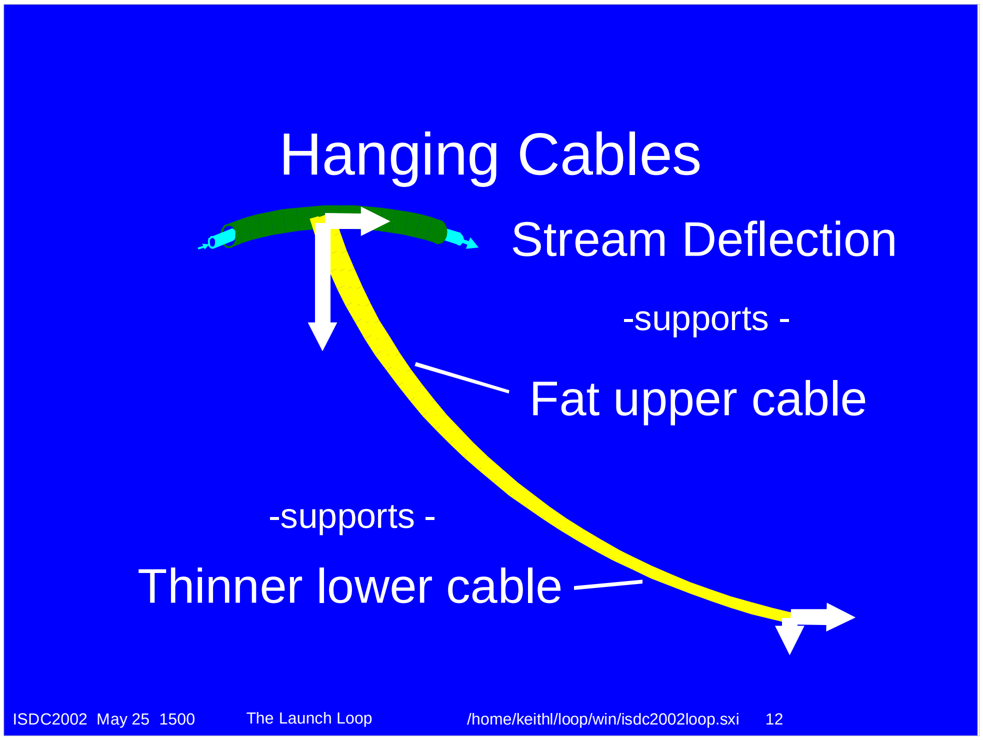
We will use both kinds of levitation in the launch loop.



We can also use magnets to speed up and slow down the moving iron. By pushing a magnetic field just a little faster than the iron stream, currents are induced in the iron that resist the change. The field pushes on the currents, and the result is a forward thrust.

At launch loop speeds, linear induction motors are very efficient. The losses are proportional to current, while the thrust power is proportional to the current times the velocity. Thus, the ratio of loss power to thrust power decreases proportionally to velocity. We can expect better than 99% efficiency for launch loop drive motors, which will be used to restore the power lost by payload launch and system drag.

The high efficiency also means that iron loops can be used for very efficient power storage for regional electric power systems.



Unfortunately, our high altitude stream and hose are unstable.

We will need to add correction forces, vertical and horizontal,

to keep everything lined up.

We could do that with rockets, but that is expensive.

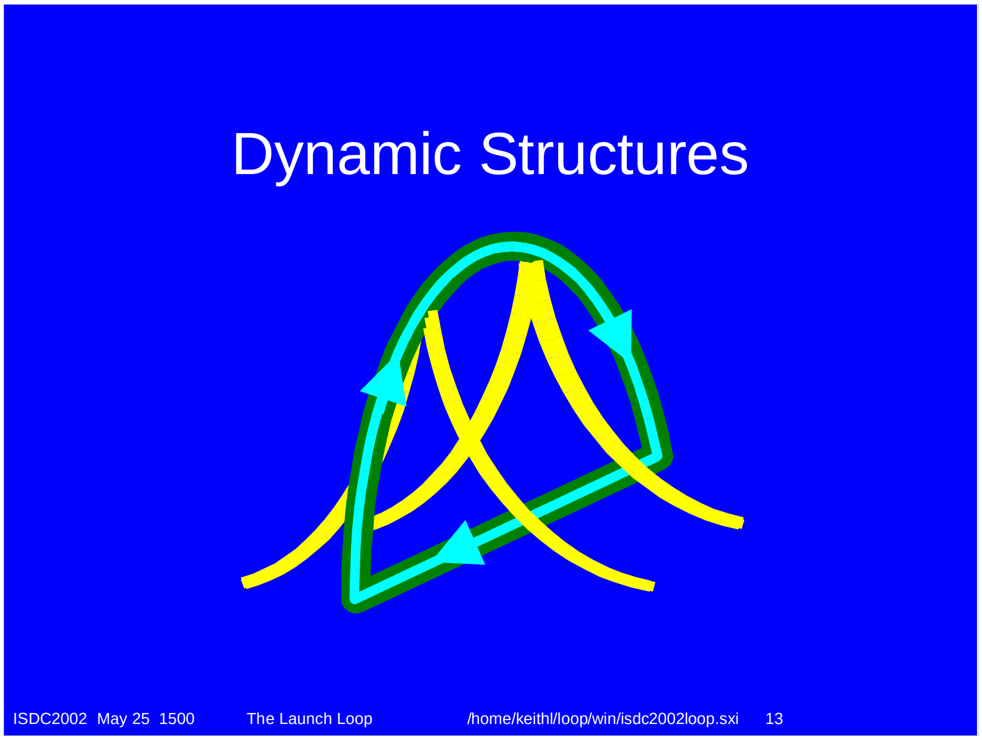
Instead, we hang long cables to the ground, and control the forces on them with actuators.

80 kilometer long cables can barely support themselves,

even with advanced materials such as Kevlar.

They must be tapered, so the fat cable on top can support the thinner cable down below.

The online paper describes the tapering of the stabilization cables in detail.



Bob Forward named the combination of these concepts "dynamic structures".

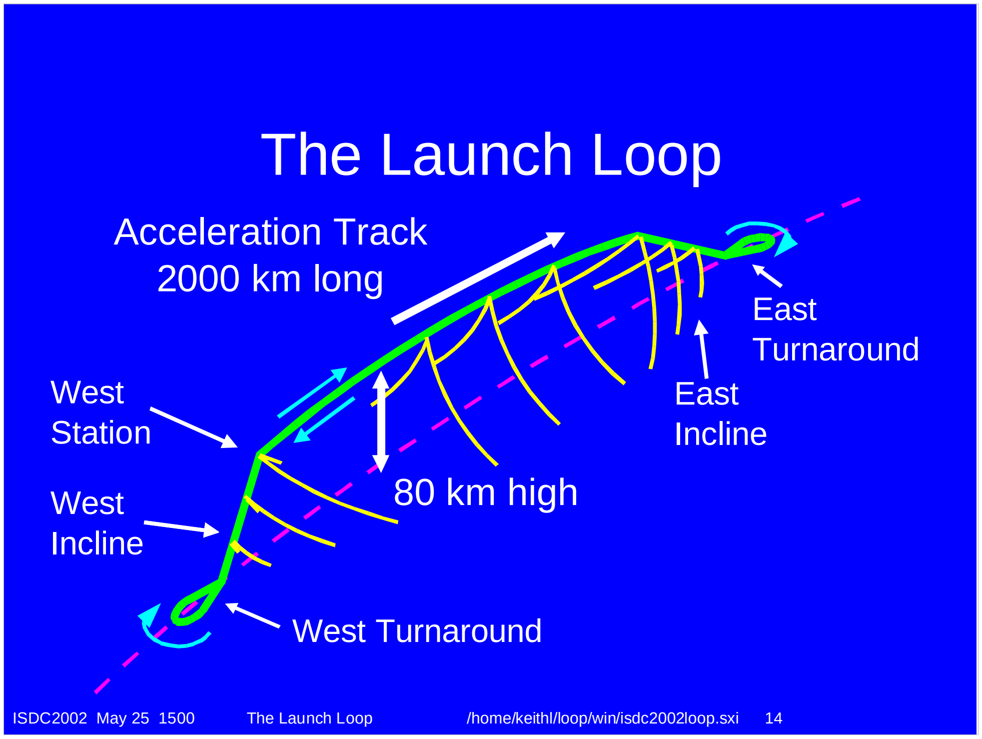
There are many kinds of dynamic structures - space towers, orbital rings, fountains of paradise, ringworlds, and so forth.

The mass stream, or "rotor", recirculates continuously at nearly constant speed. Motors restore energy lost to drag.

Without friction, the system uses no power.

The launch loop is a dynamic structure like this,

combined with a magnetic mass accelerator.



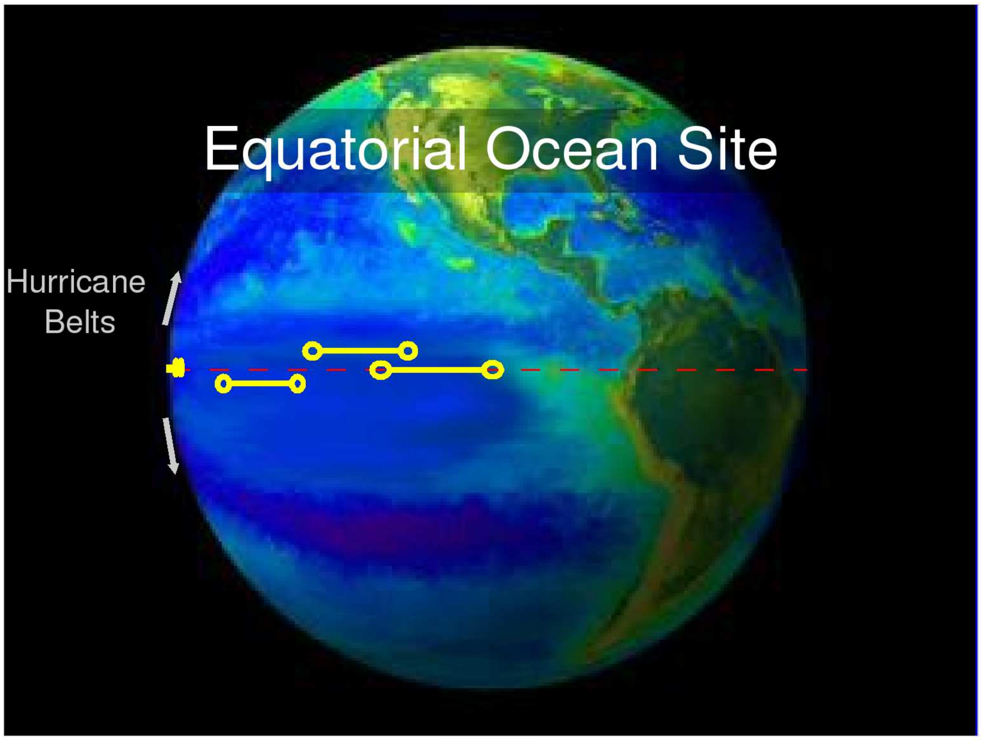
Here's an example of a launch loop.

The centerpiece of the system is the 2000 kilometer long acceleration track, which supports and accelerates payloads at an altitude of 80 kilometers.

The mass stream runs down the track, then down the east incline, around the turnaround at the east end, back along the acceleration track, then down around the west turnaround to complete the loop. The inclines are around 300 kilometers long, so the whole structure is around 2700 kilometers long.

The mass stream runs at 14 kilometers per second, so it completes the continuous loop in about 7 minutes.

Payloads are hauled up cables and placed on the track at west station, and launched to the east.



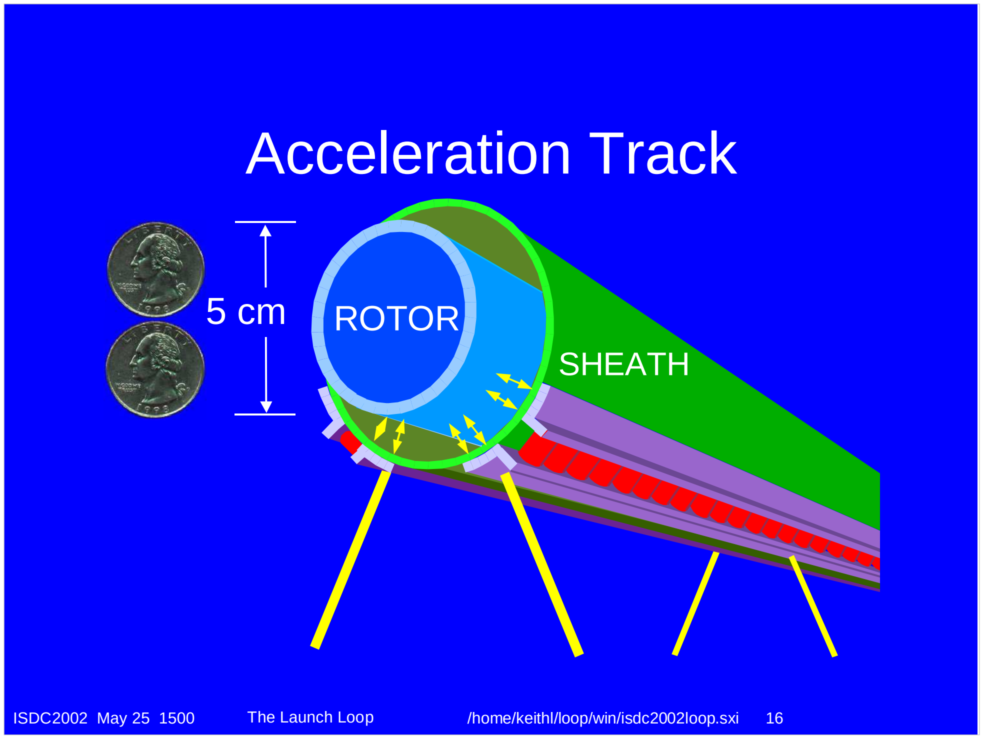
The best place to put a launch loop is in the equatorial Pacific ocean, due south of North America. We need a large, flat, uninhabited space with predictable weather. Although the ocean is a difficult environment, in the 5 degree band around the equator it is, as one meteorologist put it, BORING.

The hurricane belts start 5 degrees north and south, where there is enough coriolis acceleration to drive cyclonic storms.

We only need to contend with lots of submerged floats,

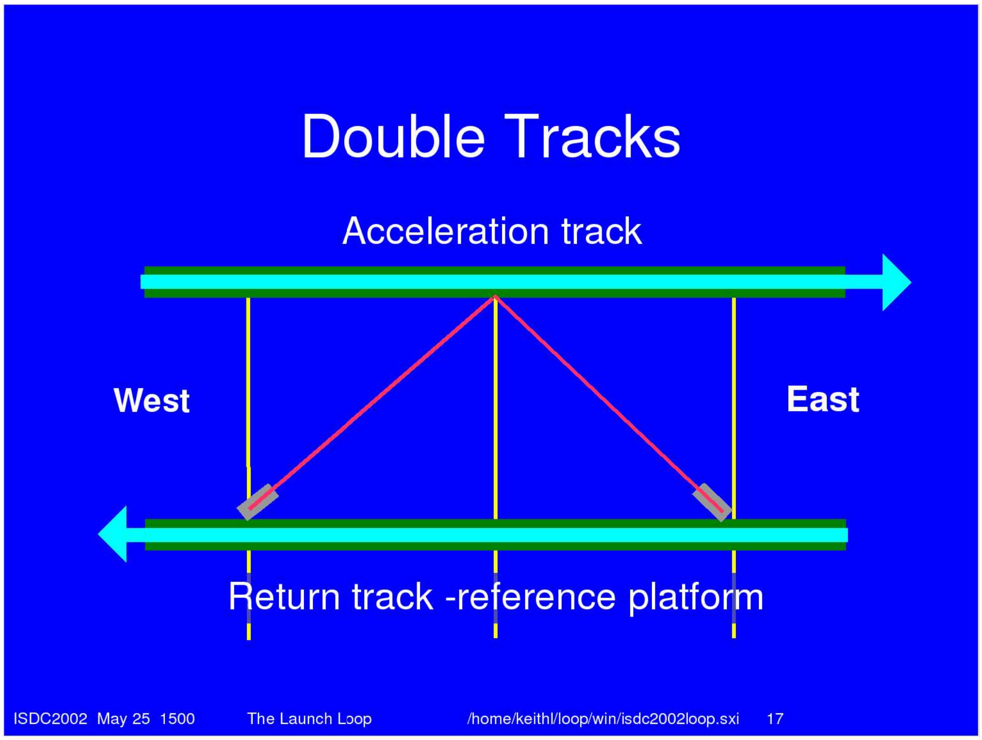
and fat steel cables to the ocean floor.

There is room along the equator for multiple launch loops. Someday, there might be hundreds, each shipping thousands of tons into orbit every day.



A 2700 kilometer structure is pretty big, right? Well, it is long, but the track section has a very small cross section. Here we show a cross section of the accelerator track. We call the mass stream the rotor, like the moving part of a motor. The hose is called the sheath or the stator. The whole thing is about 5 centimeters or 2 inches in diameter, about as big as two quarters, and smaller in diameter than a firehose. The vacuum sheath protects the rotor from the vestigal air drag at 80 km altitude, while magnets running along the outside maintain the spacing. The rotor is moving at 14 kilometers per second, and masses 3 kilograms per meter. The sheath, magnets, hanging stabilization cables, and other gear masses 7 kilograms per meter.

So don't think "building", think "power line" when thinking about the scale of a Launch Loop.



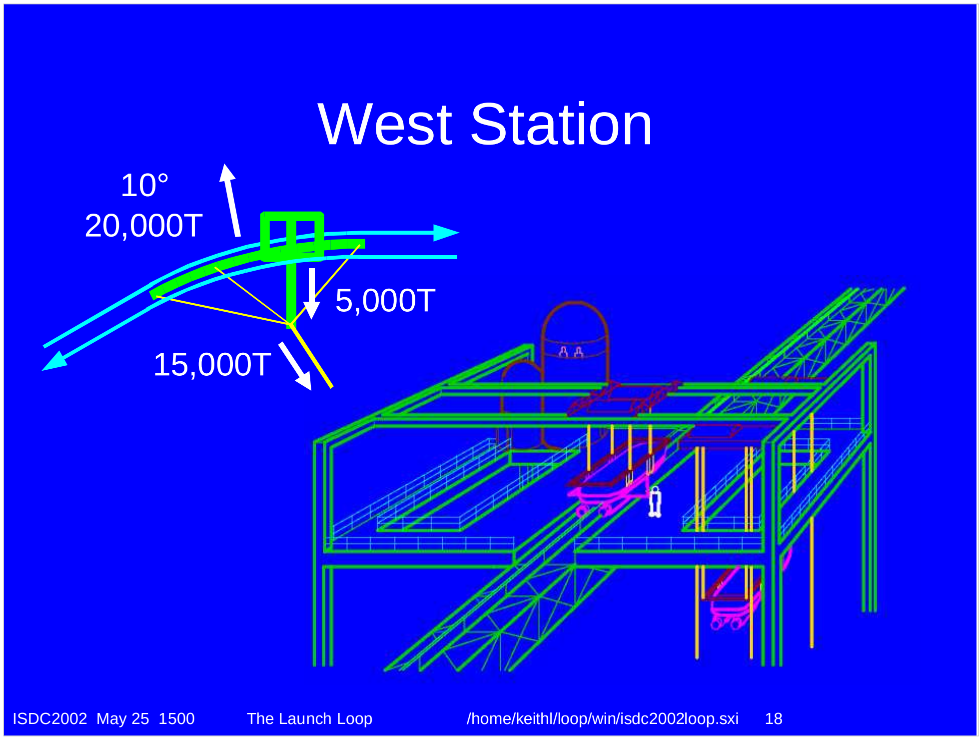
Payload launches will disturb the eastward acceleration track, jostling measurement gear and other equipment.

The rotor runs westwards along the same path as the acceleration track, only a few hundred meters lower.

The return track can be used as a stable reference platform.

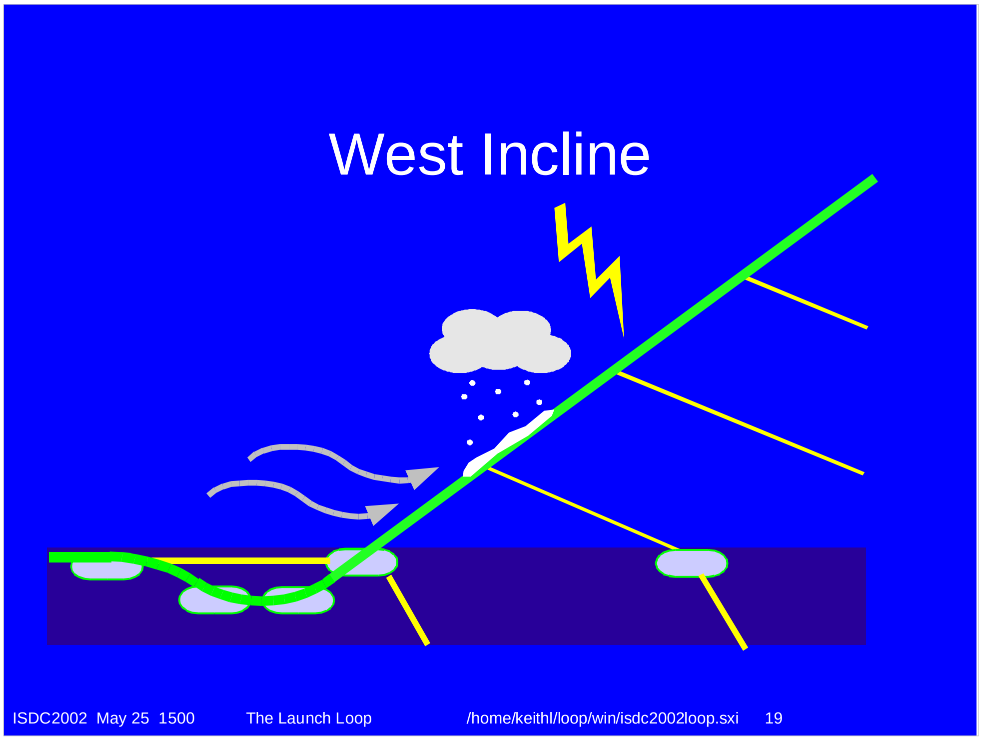
Laser distance measuring equipment, redundant communications, and other gear will be placed along it.

Again, I want to emphasize that the rotor is continuously recirculated and forms a closed loop around the Launch Loop, travelling both east and west along similar paths.



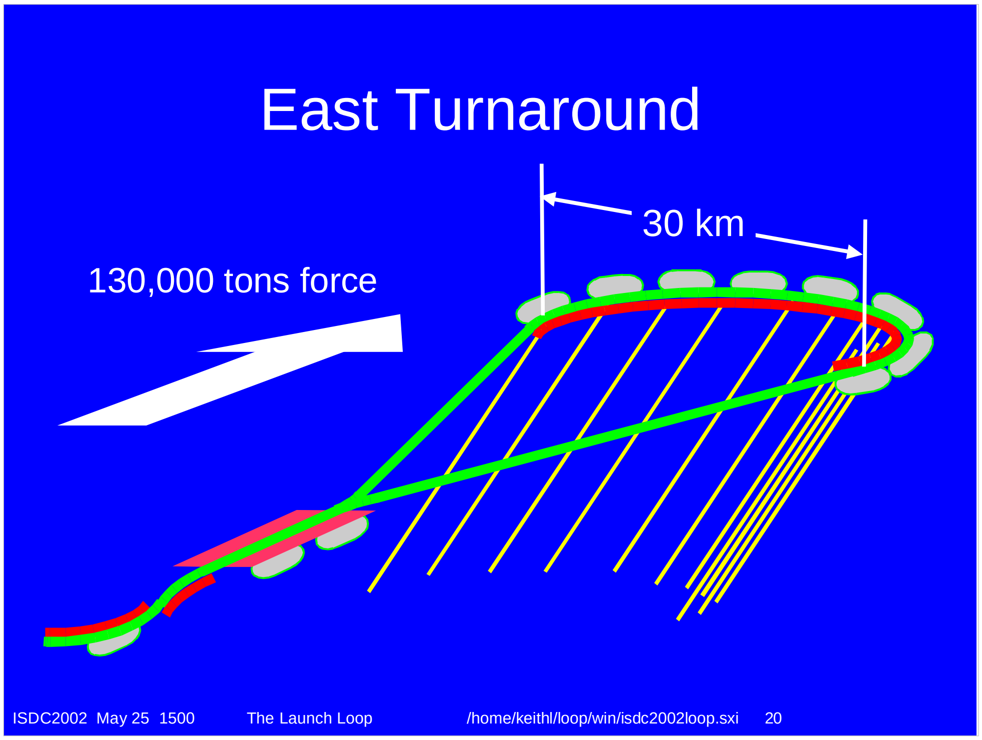
West station is where we load payloads onto the track to start their eastwards launch. West station is supported by a 10 degree downwards bend in the eastbound and westbound rotors. The total lift force is 200 million newtons or 20 thousand tons, while the station weight is 5000 tons. The rest of the force supports long stabilization cables to the ground, and the elevator system that lifts payloads to west station for launch.

West station is barely above the atmosphere - so though it is stationary, it is an honest to goodness space station. Workers will wear space suits -and parachutes.

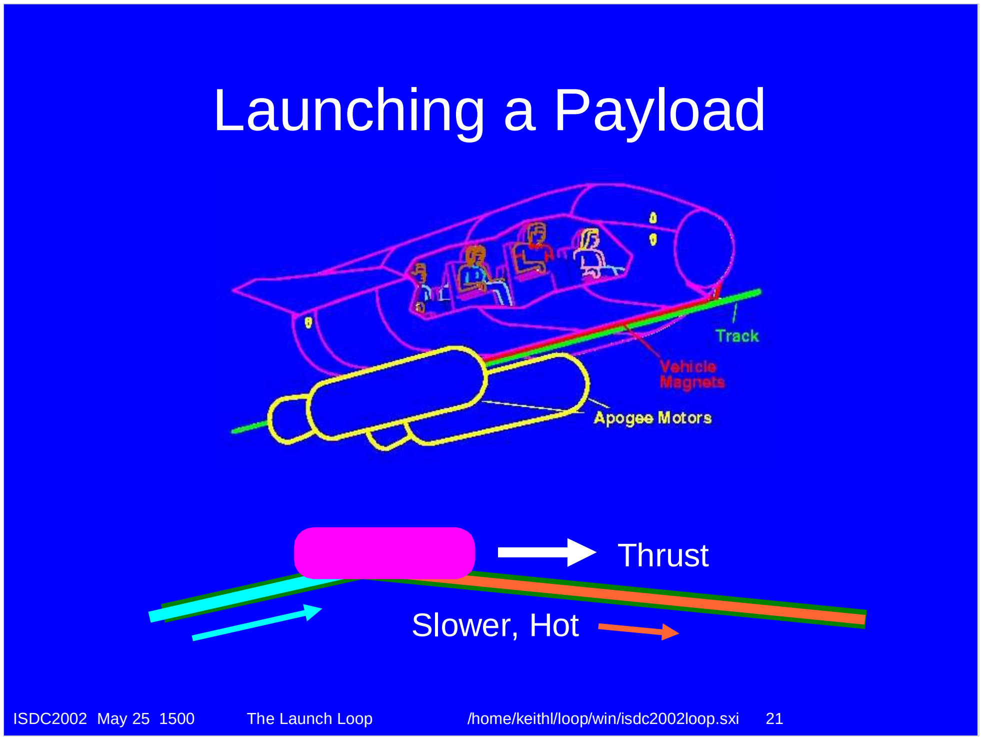


The rotor travels to and from the surface along the inclines, 300 kilometers from surface to the end stations along a 10 to 20 degree slope. At the lower end, the inclines pass through the atmosphere, and are subject to wind, rain, snow, and lightning. Additional heavy equipment is needed on the sheath for de-icing, lightning dissipation, weather measurement, etcetera.

The inclines set the scale for the launch loop; we need a minimal amount of mass to surface ratio to survive a wind storm. Larger systems are easier to stabilize, but cost more to build.



The turnarounds at the ends actually support the structure, as we will see later. The turnarounds at each end of the launch loop turn the rotor 180 degrees, which requires a force of 130,000 tons. This is also where we restore velocity to the ribbon with linear motors. Since the launch loop is built over open ocean, the turnarounds float below the surface of the ocean. They are supported by floats, and are anchored to the ocean bottom by heavy steel cables. The launch loop anchor cables can be shorter if the turnarounds are placed near islands or ocean ridges. By placing the entire structure perhaps 30 meters below the surface, we can avoid storm and wave action on these structures.



This is a six passenger payload for the launch loop. If the loop fails during a launch, we need to be able to safely reenter the passengers, hence the reentry shell and the wings.

Machine payloads require no more than wooden crates and a plastic fairing.

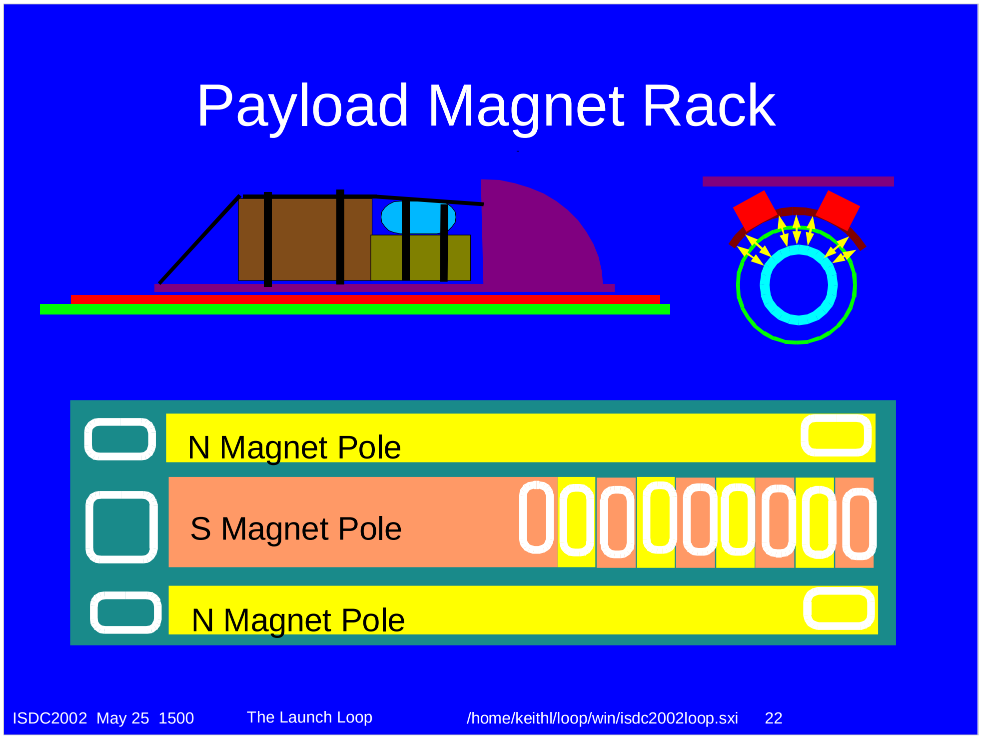
We also need rocket motors for insertion into the destination orbit., and for orbital plane changes. Since the launch loop launches only paralllel to the equator, it cannot reach highly inclined low earth orbits.

Tethers may work much better than rockets for apogee insertion; pay close attention to Dr. Hoyt's talk in the next hour.

The whole structure rides on a long rack of magnets, which combine attractive and repulsive levitation, designed for high drag between the payload and moving rotor.

The track both lifts and propels the payload. It is slowed slightly by payload drag, and excess energy turns into heat, raising rotor temperature by 80 degrees celsius.

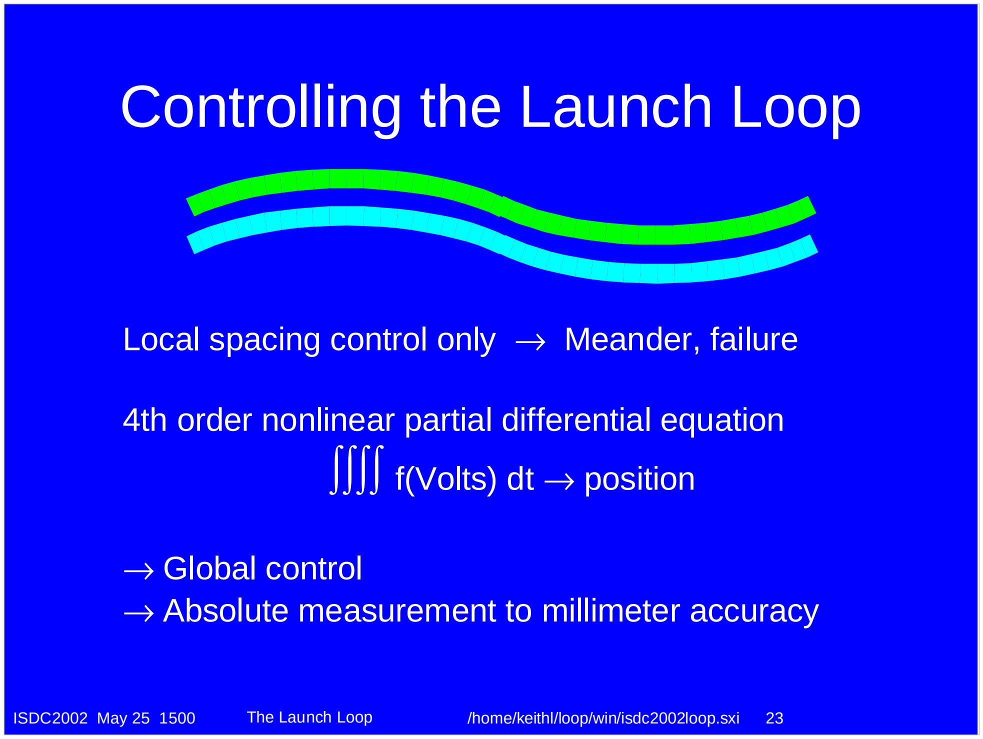
Rotor heating sets the maximum launch rate, since rotor cooling is limited by black body thermal radiation and the rotor iron becomes nonmagnetic above 1000 degrees Centigrade.



Here's an unmanned payload. As long as we strap our cargo down securely, we do not need special shrouds or re-entry shells. Just this plastic faring in front, to cut down the very small high altitude drag a bit.

This slide shows more details of a possible magnet rack. The rack fits over the sheath and rotor, and uses a combination of attractive and repulsive levitation to bind it firmly to the rotor, while maintaining the appropriate spacing. The drawing at the bottom shows one possible arrangement of magnetic north and south poles on the magnet, designed to induce strong currents and drag in the rotor.

The drawing does not show the apogee motors, which should be below the rotor. The center of mass of the payload should be near the rotor line so the payload is easier to balance.

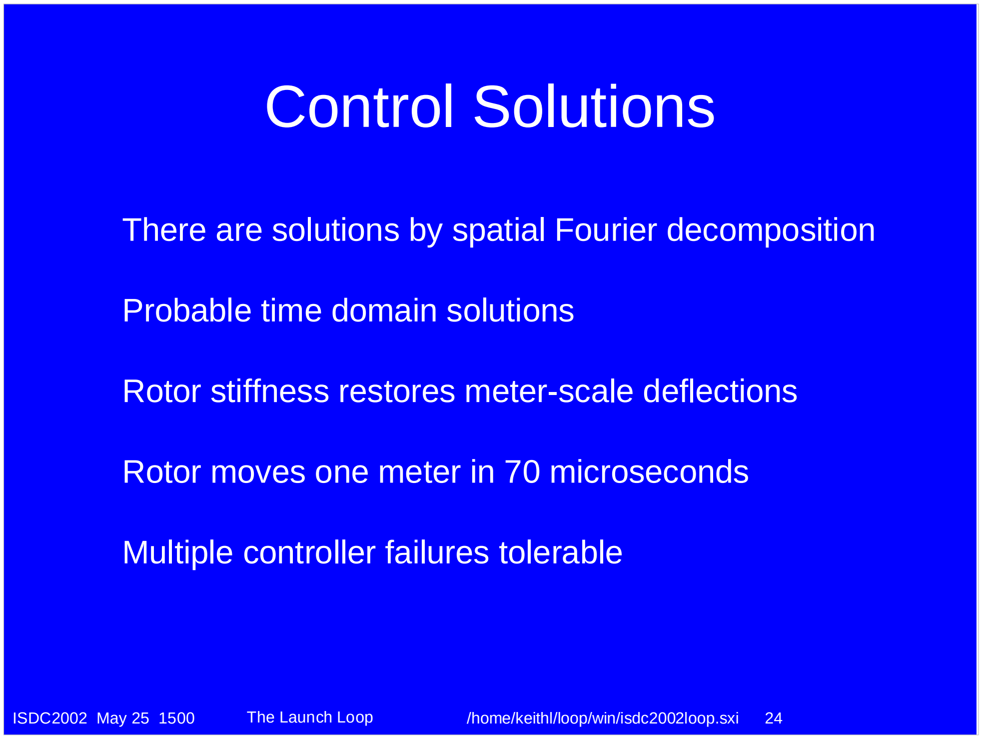


Control is the hardest part of the launch loop. We have continuous measurement, and continuous control of our magnets, but if we slip up by a few millimeters the rotor crashes into the sheath and the whole system vaporizes.

If we just pay attention to maintaining local spacing, we get meander, not unlike a river meandering in its bed, and again we fail due to instability.

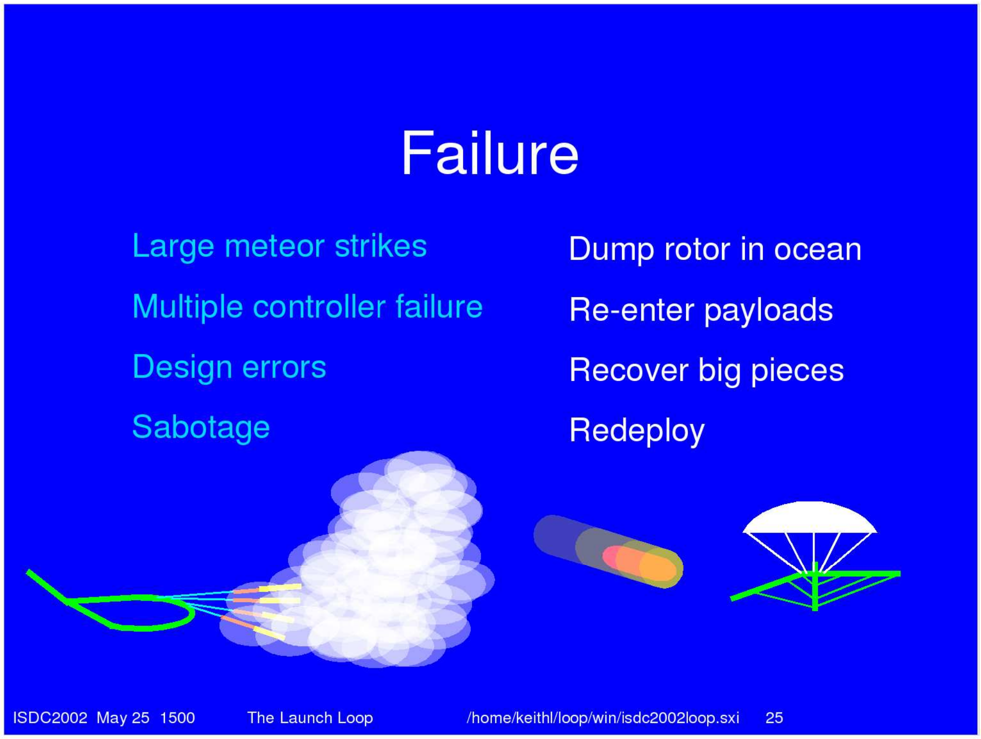
The system is described by a two axis fourth order nonlinear partial differential equation. A nasty bit of mathmatics.

We need global control, so local control sections know which way to push, and we need absolute position measurement over hundreds of kilometers to millimeter accuracy.



Fortunately, the math does show solutions using spatial Fourier decomposition. I am working on finding a time domain solution suitable for distributed DSP control. The rotor is a long pipe, and fairly stiff, so we don't have to control sections shorter than a meter or so. The launch loop is mechanical, and the rotor moves at only a few millimeters per microsecond, allowing us to make thousands of computations in the time it takes the rotor to move one meter.

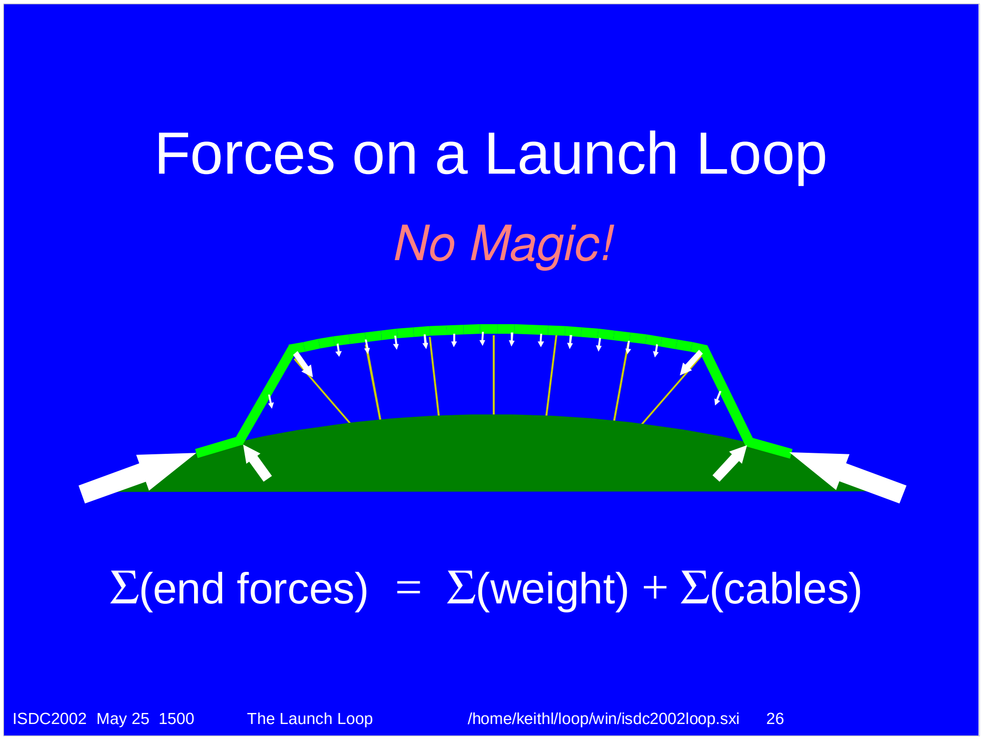
Best of all, although we need regularly spaced controllers to keep the launch loop stable, we can tolerate failures in many controllers in a row, or a few percent systemwide, without seriously degrading global controllability. The launch loop is very fault tolerant.



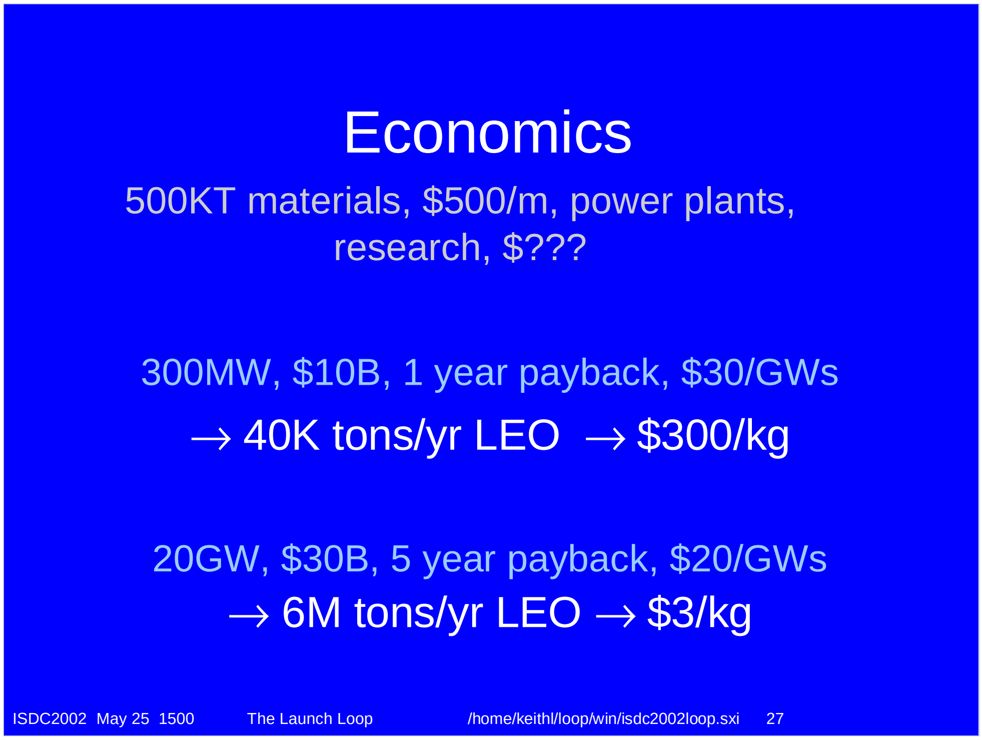
But there will be failures. The launch loop sticks up above most of the atmosphere - in time, a meteor or space debris will crash into it. We can lose too many controller sections in a row. Perhaps we forgot something in the design, and the launch loop finds a new way to go unstable and crash. Or somebody sets off a bomb or hits the incline with an airliner. It is a dangerous world.

In that case, we need to bring the launch loop down safely. There are people being launched and at the stations, and there is some expensive hardware up on top. The moving rotor stores a Hiroshima bomb worth of energy - that needs to be dissipated by dumping into boiling seawater. We need to safely re-enter the manned payloads, and safely recover the big high altitude sections, perhaps with parachutes.

Then, we reassemble everything, and redeploy the system.



Before I finish, I want to emphasize that the whole launch loop uses normal Newtonian physics, no magic forces anywhere. The whole system is held up by the forces applied to the ends. The vector sum of these forces equals the gravitational weight of the system, and the tension of the stabilization cables. The system rests on and is supported by the earth itself. It is nice to have a free structural component; in this case, it is a planet.



How much will it cost? I have no idea, but I can guess we will be buying materials that cost about 10 dollars a kilogram, assembing track structure at about 500 dollars per meter, building barges, floats, and electrical generating plants. The research will be expensive. We may have to bribe people. And our investors would like to turn a quick profit, of course.

A minimal launch loop system might have 300 megawatts of electrical generation, cost 10 billion dollars, require 1 year payback, and cost 30 dollars per gigawatt second for fuel. That minimal system could launch 40 thousand tons a year - hundreds of times space shuttle fleet capacity - at $300 per kilogram.

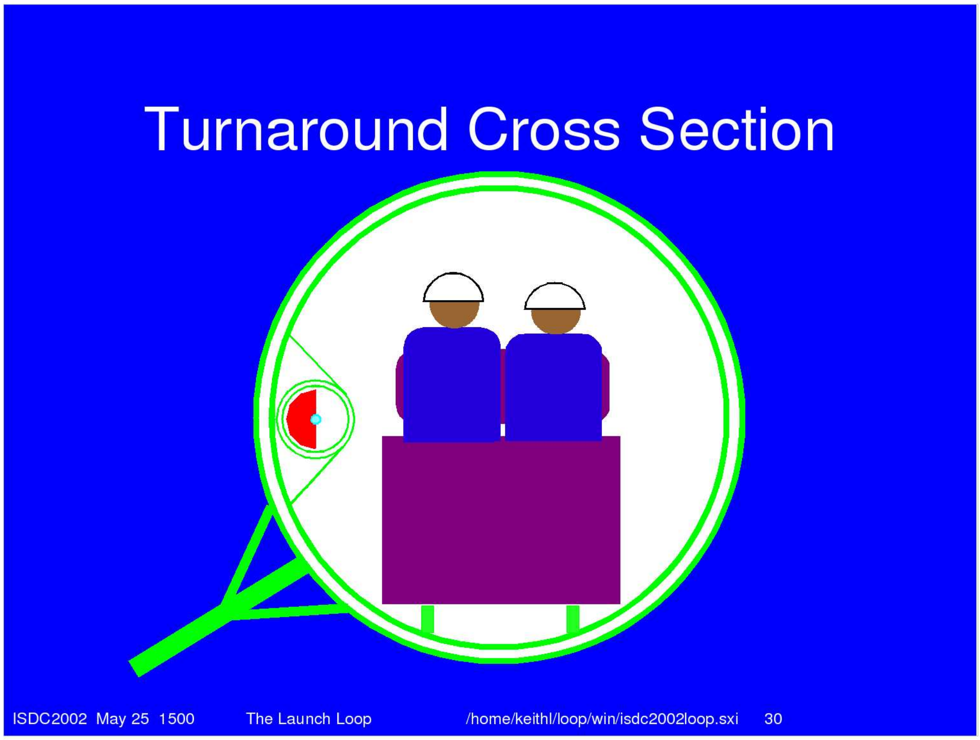
Later, with 20 gigawatts of power, and a 5 year capital payback time, and cheaper fuel, we can move 6 million tons per year, at a cost of 3 dollars per kilogram. And we can build hundreds of launch loops if necessary. Space, anyone?

Right now, we don't need that much space transport. But once we do, a launch loop can provide it cheaply. The system is safe for people and machines. We are using available materials and engineering techniques.

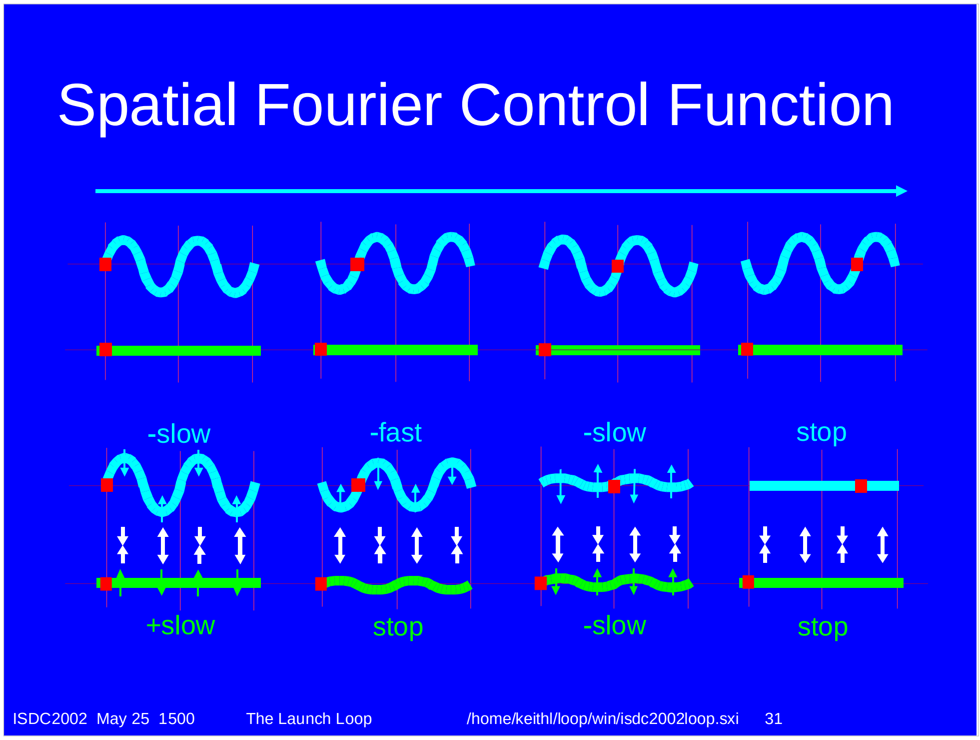
The system is thousands of kilometers long. Any man-rated accelerator launch system must be. But it is thinner and lighter than a single railroad rail or power cable.

Most importantly, there is NO MAGIC. No funny disappearing forces, no new physics, no antimatter, no gigantic national scale programs. We can build a launchloop if and when we want it. The Launch Loop will be there when we decide we want to be in space.

Extra Slides Follow



Here's a cross section of the turnaround section. The whole thing floats in this big steel tube, perhaps 30 meters below the ocean surface. The turnaround is anchored to the bottom of the ocean with these fat steel cables. This smaller double tube contains the rotor, and a high power electromagnet that pulls on the rotor with a force of four tons per meter. I show a couple of workers getting around on a track car for scale.



This is a 2 cycle segment of a continuous end-to-end sinusoidal variation in rotor position. By spatial Fourier decomposition, we can take any arbitrary variation and break it down into sinusoidal Fourier components, and correct each component separately - the results sum together, and the whole variation is corrected.

First note that, uncorrected, the rotor moves along, changing its phase in relation to the sheath 180 degrees every half cycle.

For the second set of plots below, we start taking out the rotor variation, putting velocity on both rotor and sheath. A half cycle later, after the phase changes, we add more velocity to the rotor while subtracting it back out from the sheath. Another half cycle later, we need to start decelerating the rotor, so we subtract some velocity from the rotor, while we start moving the sheath back down. Half a cycle later, we stop everything with both rotor and sheath corrected.