Version 2.0 - minimum lasers

TITLE -------------------------

Good morning! John Knapman and I have been talking about ways to protect space elevators from atmospheric phenomena, and make them easier to protect from space debris.

John can't be with us today - he's at a family wedding. He hopes to join us next year. John writes most of the papers, I do most of the pictures, and we both argue with each other.

We work on classes of systems that Robert Forward named dynamic structures. Dynamic structures use the Newtonian deflection of ballistic matter, and clever control systems, to remain upright and stable.

SpaceCable --------------------------

Here's John's website - you can find some of his papers there. Space cables range from small to very large - here's one that might be many kilometers across. The purple line represents a stream of iron segments, moving very fast, **thousands of meters per second**. If that stream is deflected into a tighter curve than a natural ballistic, external force is necessary. We can use that external force to hold things up against gravity - a "levitation force" if you will. The whole system is held up by large support forces at the surface stations.

launchloop --------------------------

Here's my Launch loop website. Since 1980, I've been studying dynamic structures with really fast moving mass - **14,000 meters per second**, almost twice orbital velocity.

Launch Loop **stores enough momentum** and energy to launch **5 ton** vehicles to escape velocity, **10,000 tons per day**. But that is an awfully big first step - a lot of technology to develop all at once. And there may be show stoppers. We need to start smaller.

So what does this have to do with the space elevator?

astroBanjo -------------------------

In space, no-one can hear **Buzz Aldrin** play the **banjo**.

No atmosphere. Dynamic structures can put us above all sorts of atmosphere-related problems. Not just banjo players, but wind, lightning, clouds, and corrosion. Really extreme atmosphere problems, all stacked up, sometimes all at once.

Poisson -----------------------------

Hazardous events do not happen on a convenient schedule. Just because some event happens **on average** twice a day, does not mean that you have **12 hours** between them, or only **2** a day.

You should study the Poisson probability distribution. If you have an **average** of **2** events a day, you can have some days with **2** events, but you will also have days with **0, 1, 3, or 4** events, unpredictably.

Over **20 years**, you will probably have one day with **9** events, and might have a day with **10** events. You may have events spaced minutes apart. The system you design must deal with the unexpected, or it will fail.

anchorShip --------------------------

Here's a drawing of a space elevator anchor. Nice calm day, no gale force winds, no ships hitting the dock too hard. No salt spray on everything. No soot from ship smoke stacks landing on laser mirrors.

galapagosBoat -----------------------

The internet has many pictures of nice days on the equator. Here's a fishing boat off the Galapagos. Nice weather. A few fluffy white clouds. But don't let pretty pictures fool you. A space elevator is outside all year, including those miserable rainy days when we stay inside, and don't take pictures.

galapagosOrbit ---------------------

This is the Galapagos from orbit. From above, you can see there are big open sunny patches. You can also see big clouds that may take hours or days to pass overhead.

Everything in this picture is moving and turning. The trade winds blow west, but there are whorls and upward flows, gusts and shear, all sorts of complicated air movements.

cloudMap ---------------------------

Here's a worldwide map of average annual cloud cover. There is no place on the earth with zero clouds. Even the driest part of the Sahara has cloud cover **15%** of the time. No part of the United States has less than **40%** clouds.

SKIP cloudAnchor ------------------------
SKIP cloudGraph -------------------------

rainMap ----------------------------

Clouds make rain and ice and snow. There are low rainfall regions - The Pacific **ocean** off Ecuador and Peru is like that. No place on earth is free of rain.

Near the equator is the Inter-Tropical Convergence Zone. This is where moist air from the northern hemisphere moving towards the southwest meets air from the southern hemisphere moving to the northwest. At the I-T-C-Z, the moist air is pushed upwards, creating a long line of squalls and thunderstorms.

ITCZclouds -------------------------

Here's a picture from a ship traveling through the I-T-C-Z. Rainstorms and solid cloud. The wind is gentle and the sea is smooth, but the space elevator tether will be soaked in condensing water and ice as it passes through the clouds.

ITCZorbit --------------------------

This is a high orbit satellite photo of the I-T-C-Z during northern hemisphere summer - it is displaced far to the north. The equator runs through the Galapagos here.

ITCZseasonsMap ---------------------

This map shows how the center of the I-T-C-Z moves over the year, north in our summer, south in our winter. Although the center of the I-T-C-Z stays north of the equator in the eastern Pacific, the edges of this band can reach a few degrees south.

The map also shows the track of typhoons and hurricanes. Notice that the southeastern Pacific and southern Atlantic have no hurricanes. But there are still plenty of clouds, and occasional lightning storms. The equator is free of hurricanes, but it is not free of storms.

The place with the least rain, wind, and cloud cover is **8 degrees south, 120 west, due south of Seattle**.

wingice -----------------------------

High altitude moisture droplets can stay liquid below zero degrees centigrade. If supercooled droplets come in contact with a solid surface, they freeze onto it. This can rapidly ice up wings on an airplane. A space elevator tether passing through clouds will need frequent deicing, many times per week.

hail --------------------------

Thunderstorms produce hail in very fast vertical winds. Imagine the vertical wind speeds needed to hold these big stones aloft. Imagine what these falling hailstones might do to surface coatings on a tether.

lightningBolt ----------------------

Thunderstorms make lightning. If your space elevator tether is conductive (and most forms of carbon nanotube are) then lighting currents will heat it white hot, vaporizing adhesives and cross-tether structures.

lightningMap ------------------------

Fortunately, there is very little lightning at our preferred location, **120 degrees west, 8 degrees south**.

lightningMap2 ----------------------

Here's a closeup of the sweet spot. Notice that there are still little dabs of color in it. While the nearby lightning rate is very low in this area, perhaps the lowest on the planet, it is not zero. There is always some risk of lightning, and a space elevator tether can act as a lightning rod, drawing strokes for many kilometers around.

sprites -----------------------------

Cloud to ground lightning is not the whole story. Some lighting travels upwards into the very conductive ionosphere. These discharges are called **sprites, blue jets, and elves**. We only observe these phenomena below **100 kilometers**, and only above lighting storms.

However, a conductive tether into the magnetosphere may change that. The magnetosphere is conductive, so discharges far to the magnetic north and south of the tether may connect to it through the magnetic field lines.

storm -------------------------

Besides rain and lighting, wind and waves will pose a big challenge.

The wind is fractal - there is chaotic activity at all scales, from **thousands of kilometers** down to **tens of meters**. Circulating big winds move little winds within them, which moves smaller circulations, and so forth. When you feel gusting winds, what you are really feeling is smaller wind patterns **moved** towards you by larger winds.

L.F. Richardson, the father of numerical meteorology, said:

Big whirls have little whirls that feed on their velocity,
and little whirls have lesser whirls and so on to viscosity.

Practically speaking, that means that big winds do not come and go gradually. They throw a lot of fast wind shear at you.

windGraph ---------------------------

So how big can winds get? Because of friction, the wind at the surface does not move nearly as fast as winds at altitude. Here is a graph, not of wind speed, but of wind pressure - the density of air times the velocity squared.

At **10** kilometers altitude, the air is only 33 percent as dense as it is on the surface, but it can move extremely fast, more than **100 kilometers per hour**. Because the wind is fractal, it can vary rapidly in speed and direction. That can deflect the tether a lot, making space debris avoidance maneuvers very difficult.

benClimber --------------------------

And if your climbers are very light weight, wind will tear them to tiny bits. I don't know if we can build ultralight climbers like this one that Ben is proposing, but I do know that it will not survive **100 kilometer per hour** winds.

John and I propose an alternative, which will make climbers like this one feasible, and greatly reduce the other terrors the atmosphere may pose.

uwAtmo ------------------------

But first, where can you learn more about the atmosphere? The University of Washington, just a few miles from here, has some of the world's best atmospheric scientists. Approach them respectfully, and they may have some advice for you, perhaps even make some presentations here in 2012.

openNASA ----------------------------

I was at the Open Source conference two weeks ago, when **open.nasa.gov** went online. Their goal is to make every bit of data NASA has available to the public, as well as open source programs to process it.

pressureGraph ----------------------

The pressure of the atmosphere is simply the weight of the remaining atmosphere above you. If we can get above most of the atmosphere, we get above many difficult problems. John and I propose a **platform 50 kilometers high**.

At that altitude, we are above **99.9%** of the atmosphere and its problems. We can move the tether, and lift climbers, without air resistance. And the radar and optical visibility is much better.

But the world's **tallest structure** is only **800 meters** high; how do we build structures **60 times** higher with ordinary materials?

firehose ---------------------------

Here's an ordinary material - water. It is impossible to pile liquid water into a tower. Yet this water is forming an arch **20 feet** off the ground. If the water was inside a **frictionless hose**, it wouldn't even spread out. Look at the firemen struggling with it. Even a stream of water at a **few meters per second** generates a lot of force. Imagine something denser than water, going a lot faster.

def1m -------------------------

This is a stream of mass particles, <u>moving up, bouncing off a platform, and moving down</u>. As the stream bounces, it changes direction, and changes momentum. A change in momentum for a stream of mass makes a force. Here the stream is moving at **1 meter per second**, and lifting **one unit mass** as it changes angle by **60 degrees**.

I would like to animate these slides, but the presentation would be too many megabytes. So, move the particles in your mind, as a stream, left to right.

def2m -------------------------

Now, <u>move them twice as fast</u>. If the stream moves twice as fast, the velocity change is doubled. The amount of mass arriving and leaving also doubles. So the momentum change is **2 times 2 or 4 times** larger. That generates **4** times the deflection force.

def100m ----------------------------

If the stream is moving **100 meters per second**, the force is **10 thousand times** as much. If the stream weighs **1 kilogram per meter**, that is enough to support **1 ton at 1 gee**.

defHorseshoe ------------------------

So, let's use attractive magnetic levitation. With proper control, we can make the support force **almost frictionless**.

magLev ------------------------

There are two ways to ride on a magnetic field - either by **attraction**, or **eddy current repulsion**. Magnetic attraction is familiar to all of you - magnets are attracted to iron.

Magnetic repulsion occurs when **changing** magnetic fields make a current in a conductor, pushing back on the magnetic field.

Repulsive levitation dissipates power. Not very much - the **losses are less** than air cushions or wheels. The "flying height" is stable - the repulsion **increases** as the gap gets **smaller**. This kind of magnetic levitation is used in **maglev trains**.

Attractive magnetic levitation is unstable. The magnets want to snap onto the iron. Fortunately, the instabilities can be controlled by **measuring** the **spacing, then** adjusting the magnetic field with an electronic control circuit.

But we already need control circuits for stability. Let's use low drag attractive levitation.

defDistrib -------------------------

If we spread out the force and the magnetic field, and use a continuous tube of iron, the **eddy currents** are much **smaller**, and the **drag** is much **weaker**.

The **iron tube** is called the **rotor**.

Imagine the rotor flying by very fast, l**eft to right**, at **35 hundred meters per second**. It weighs **3 kilograms** per meter. It is pulled down by the magnetic field, not by material tensile strength, as in a flywheel. The tensile strength of the magnetic field is **independent** of rotor speed. The the magnets and structures do not move and do not add to the strain, so we are no longer nearly as worried about strength of materials.

oval -------------------------

We can **recycle** the moving rotor by running it in a **loop**. It must be in vacuum to reduce drag. **3500** meters per second is **Mach 10**.

These turnaround magnets at the ends generate enormous forces, and require significant power to energize. We them "ambits".

simplified -------------------------

We can add extra magnetic deflection on the rotor loop to **bend it upwards** in the middle. The rotor is forced upwards at **these four points,** forming two arches in the sky. **These two magnets** at the top deflect the rotor loop back down. The center magnets can lift **thousands of tons**.

forceMath1 -------------------------

How much force? Define **rho** as the linear mass density. The amount of mass delivered to the deflection is **rho times V**. For a **3 kilogram** per meter rotor, moving at **35 hundred** meters per second, that is **10.5 metric tons** of mass delivered per second.

Part of the velocity is vertical. part horizontal. The vertical velocity change is **delta V**, the difference between the **upward** velocity going in and the **downward** velocity leaving the deflection. The total force is **rho V delta V** .

forceMath2 --------------------------

From simple trigonometry, this transforms into this formula.

If the total deflection is **60 degrees**, this formula simplifies to **rho V squared**. For a **3 kilogram** per meter rotor, and **35 hundred** meters per second, the force is **37 million** Newtons, enough force to lift **3.8 million** kilograms. **38 hundred** metric tonnes.

forceMath3 --------------------------

Here's some other deflection angles, and the corresponding deflection forces. If the rotor turns **180 degrees**, The force is **2 rho V squared**.

forceMath4 --------------------------

The force to mass ratio for the rotor is very high. For a **60 degree turn**, the specific compressive strength is **V squared**. This is the same units as the Yuri, the tensile yield strength divided by mass density, and works out to **12 MegaYuri**.

But this is compression, not tension. The compression strength is metastable. Without active control, the system will quickly buckle and fail.

But other than the addition of modern electronics, this is all Newtonian mechanics, and Michael Faraday could have built one.

forceMyuri --------------------------

This proposal is for a **50 kilometer** altitude platform.
35 hundred meters per second rotor velocity is optimum.

We can probably go much faster. Large power storage loops will move at **8000 meters** per second. The compressive strength is **64** MegaYuris.

A launch loop runs at **14 thousand** meters per second, and has an equivalent compressive strength of almost **200 MegaYuris**.

There may be upper limits on operating speeds for dynamic structures, and a lot of development will be needed to extend them. But we will not need new materials, just better designs.

wholeLoop --------------------------

We can put these ideas together into a dynamically supported platform at 50 kilometers altitude, supported by a rotor loop traveling inside a vacuum tube.

The cross sections here are greatly exaggerated. Like a space elevator tether, this structure would be invisible from a distance sufficient to see the whole thing. Most of the structures shown are less than a meter in diameter.

The structure is aligned east to west, though there may be advantages to aligning it north to south. We will build it in the sweet spot, over open ocean, at **8 degrees south, 120 degrees west**. The southerly location reduces some remaining risks, and does not put significant extra force on the tether.

The **3500 meter** per second rotor follows a curving loop as we saw before. It is deflected twice at the top, once eastbound and once westbound. This supports a **6000 ton** platform, with the tether anchor, elevators, radars, and telescopes.

Lets go through the components of the system one at a time, then return to the platform.

At the ends of the loop are the ambits, where the rotor is turned 180 degrees by a large arc of magnet. That makes thousands of tons of force. They float in meter-sized floating tubes, anchored to the seafloor.

ambit ------------------------

The magnet arc diameter will be larger with conventional magnets, or smaller with superconducting magnets. The ambit may be **10 meters** below the waves. Long steel anchor cables descend to the ocean bottom, perhaps **5 kilometers** down.

ambitCross ---------------------

The ambit cross section looks like this. The large floating tube provides buoyancy, and holds up the anchor cables. The tube is like the underground tunnel of the CERN Large Hadron Collider.

The deflection magnet is represented by this red hemisphere, end on. The magnet and rotor are in a <u>double-walled vacuum tube</u>.

motors -------------------------

The rotor travels inside the vacuum tube through floating barges with linear motors and electric power plants. These add power to the rotor, which is removed by drag and by induction power generators on the platform.

linMotors ---------------------------

Linear motors are like everyday rotary motors, except they are unwrapped, with a front and back end. The rotor travels down the middle. High speed linear motors are more efficient the faster they go.

Loop structures make great power storage systems. In large sizes, they are far cheaper and more efficient than flywheels. This technology will help stabilize the national power grid in decades to come.

ramp --------------------------

The rotor tunnels make another dip underwater HERE, where curving ramps deflect the rotor skyward. The rotor and tunnel dive down **130 meters** below the surface, then curves upward to a **38 degree** upward incline. The pressure down there is about **13 atmospheres**, or about **200 PSI**, less than **20% of** the pressure in the Alaska pipeline. Above the ocean surface, the rotor travels up the incline section to the station.

Wind compensation cables are not shown. A system of cables hangs below the incline to pull it into the wind, so the platform is not moved by wind. In addition, cables may be needed to compensate for instability growth. John and I are discussing what those will look like, so it may be premature to draw them.

TrackRotorBuzz ----------------------

The rotor runs up the incline from the surface, through the atmosphere, and to the station inside a **double walled vacuum tube**. The lovely Buzz Aldrin joins us again, to demonstrate the centimeter scale of this tube.

I show three rotors rather than one. Dividing them up may help with repair and redundancy.

TrackRotor --------------------------

Here's a closeup of the inner and outer tubes, with the rotors traveling through them. The rotor is contained inside a vacuum tube, reducing drag. The outside vacuum tube provides redundant protection from leaks, as well as extra shock insulation against wind gusts. The outer tube is less than **30 centimeters diameter**, less than **1 foot**.

The incline runs diagonally from the ramp to the station, and is **90 kilometers long**.

platform ----------------------------

The platform on top is the reason for all this. This platform drawing is way oversimplified, with sizes greatly exaggerated for visibility. It will act as a suspension bridge, from these red arches of deflection magnets. The real platform will be a gossamer structure, with large gaps where we aren't supporting something.

The space elevator anchor platform is on the east end. This moves the bottom of the tether horizontally, and winding drums move it vertically.

50km cable elevators run to the surface. There are radars, pressurized workshops, and telescopes.

The platform is in the vacuum of space. Rather than work in clumsy space suits, most work will be done on the ground, or in pressurized work areas.

SKIP laser -------------------------

laserClose --------------------------

The platform can also hold a power laser farm, above the clouds. I'm told they are not necessary.

But if we do use lasers, perhaps for **LIDAR**, we need to cool them, as well as all the rest of our equipment. We cannot use airflow or black body radiation; far too much heat.

Instead, we can use circulating water and evaporation cooling. **1 kilogram** of water, lifted to 50 kilometers altitude with **half a megajoule** of ground-supplied mechanical elevator energy, can dissipate **2.4 megajoules** of heat at 50 km. Steam shoots downwards into the vacuum, and does not form clouds in front of radar and optics.

The water tanks hauled from the surface will also make good emergency radiation shielding.

spaceDebris -------------------------

We need to move the tether sideways to get out of the way of space debris. I haven't seen Peter's presentation yet, and he may have a better way to deal with it. But we need to know where ALL the debris is, and where it is going, very precisely, in order to get out of the way.

Our current debris-tracking networks are mostly radar based. They track low altitude objects much more precisely than high altitude objects. The sensitivity of radar goes down as the **inverse fourth power** of distance. Graphs like this underestimate the populations at high altitudes.

iridium -----------------------------

Even if we have complete and accurate catalogs of space debris, new debris is added all the time, sometimes quite a lot of it **from** unobserved collisions.

We must monitor the appearance of new debris in new orbits, continuously. Sometimes we may need to move out of the way of new and poorly characterized debris in hours.

seDisplace --------------------------

To get out of the way of space debris, we must move the tether sideways, in all four directions. Lateral displacements propagate upwards at a speed equal the square root of the **actual tether load** in Yuris, so a **25 MegaYuri** tether propagates upwards at **5 kilometers per second**. For an un-tapered tether without climbers, we need **6 minutes** for the movement waves to reach **2000 kilometers** altitude.

But climbers above can reduce the tension and increase the propagation time. Their **mass**, and the **mass** of heavier tether above, also hinders lateral movement. So we must move the bottom a lot to get smaller movements at high altitude.

Remember that Poisson distribution? Space debris will not show up on a regular timetable. Some days, we will have nothing to avoid. Some days we may have to avoid **9 objects**, perhaps one or two newly generated ones.

All this results in a logistic nightmare, best resolved by very good real time tracking, and an anchor that can move hundreds or thousands of meters, fairly quickly.

arecibo -----------------------------

The receiver platform for the Arecibo radio dish is a good model for moving an anchor. By changing the length of the cables with big motors, they can move the receiver platform east, west, north, or south.

anchorSuspend ----------------------

So, let's copy that idea. The actual anchor box will have a lot of complexities I am too lazy to draw. We can use four cables rather than three so that we have more movement range. Slewing the heavy anchor box will put some forces and torques on the platform. However, we can anticipate those forces, and compensate for them by launching forces up the stabilization cables from the surface. Those cables are not shown here.

The sides of the platform will have many large radar dishes. These will continuously pump megawatts of narrow band radar energy into deep space, and narrow band receivers will be tuned for the specific Doppler signatures of approaching objects.

If we can accurately predict the path of space debris, perhaps to 10 meters or less, we can reduce the number and size of the moves we must make. We want to collect data on the objects that will miss the platform, to improve our data tables. But it is critical that we carefully watch those few colliders that seem to be coming straight at us as they come over the horizon.

Platform radars are the best way to see distant or high altitude objects an hour or two away, determining which objects are a threat, and precisely how much to move the tether.

radar1 ------------------------

Radar dishes in vacuum will not be buffeted by wind, so they can be very flimsy. If the dishes don't turn, they can be lighter still. This means we can mount a lot more dishes.

radar2 ------------------------

These radars will have an imaging plane of radar transceivers at the foci of the dishes, like the photographic plates of a telescope. One dish can see a lot of sky. Hundreds of dishes can see all of it, with very high precision.

telescope ---------------------------

Telescopes? We got telescopes. Here are four telescopes with 10 meter dishes, modeled on the European Very Large Telescope Array in the mountains of Chile. Since our telescopes are not in wind and weather, they can be a lot lighter.

We can service them, ship parts up from the surface, and repair defects, but we don't have to clean the mirrors. We can use them for long baseline interferometry. We can use them in daytime. They can be connected with fiber optics to the internet. We can cool them with liquid nitrogen. The seeing will be as good as the Hubble and the Webb space telescopes.

The telescopes will mostly be used for astronomy, but also as very high resolution cameras for space debris and security threats, such as military jets and missiles. We can probably see the faces of airline passengers.

observeDeck -------------------------

We will have VIPs, atmospheric scientists, and perhaps even rich tourists, coming up for the view. At 50 kilometers altitude, the **horizon is 800 kilometers** away. With a decent small telescope, we can see airplanes an hour away, weather and ships a day away, and vast regions of clouds and weather. The atmospheric scientists will put lots of cameras and sensors up here.

This **isn't** space - that is another **30 kilometers further up**. This **isn't** zero gee - we are not in orbit. But for earth observation, this is better.

Some daredevils may **base jump** off the platform. They will have **more than a minute** of zero gee free fall before they hit dense atmosphere, then parachute down from there.

elevator ----------------------------

Cargo, water, and passengers will travel up the elevators in pressurized capsules. These **will** be pulley elevators with very strong cables - **Kevlar is 4 times as strong** as we need. Lets make the platform invisible and look more closely at the elevators.

elevator2 ---------------------------

The platform elevator cables will move continuously, at high speed, powered by electric motors on the surface. The up and down cables are separated by quite a distance on two different pulleys so they won't tangle when they stop.

There is a really cool trick for a single pulley system. If the air is clear, and low conductivity, the pair of cables can be charged up to **100,000 Volts**, and they will separate by electrostatic repulsion. Now we can start moving the cables, creating Coriolis forces that spread them wider.

Here's another cool trick. Rather than starting and stopping the cable for each capsule, we can mount the elevator capsules on motorized wheeled carriages. As the cable moves past, we can run the motors as generators, into huge resistive light bulbs. The drag lifts the capsules, accelerating them upwards, until they match velocity with the rapidly moving platform elevator cable.

Set the parking brake and enjoy the ride. As we approach the station, we reverse the process, slowly disengaging from the cable and letting gravity slow us down, feathering the drag as we coast to a stop.

With such a system, the elevator can approach the speed of sound. At **200 meters per second**, the trip from the surface to the 50km platform will take **5 minutes**.

surface -----------------------------

The surface platform is directly underneath the 50 km high top platform. The surface platform is much larger, and floats on the ocean.

Helicopter pads are easier to draw than ships and docks, so I am using lots of those. Imagine some docks as well.

Most logistics and **repairs** happen at the surface - few workers will be upstairs. Command and control will be half a world away, at the other end of fiber optic links. Like the European astronomers working the big telescopes in Chile, space elevator operations will be a day job, performed by professionals living in suburbia, in the US and around the world.

heightCost -------------------------

How high should the platform be? John and I chose 50 kilometers altitude, because it is above almost all of the atmosphere, below the space debris belt, and suitable for single stage Kevlar elevators. With a faster rotor, we can go higher.

Platforms **above 200** kilometers do not make much sense. They would be expensive, and hard to protect from space debris. At high rotor speeds, you might as well just build a launch loop.

I don't know what the actual cost multiplier is. Whether we multiply the Y axis by 10,000 dollars or a **million** dollars depends on the other systems, like power storage loops, that use the same manufacturing technology.

theEnd -------------------------

That's all for now. I'm sorry John couldn't join us this weekend, you would enjoy meeting each other. We will have pointers on our websites to web versions of this presentation, papers, and wiki pages with more details of platform technology.

Please look at our work on the space cable and the launch loop. We have other ideas applicable to the space elevator. We've certainly had a grand time stealing ideas from you folks!

Questions?