FlexSail:
Engineering Technology Revolutions

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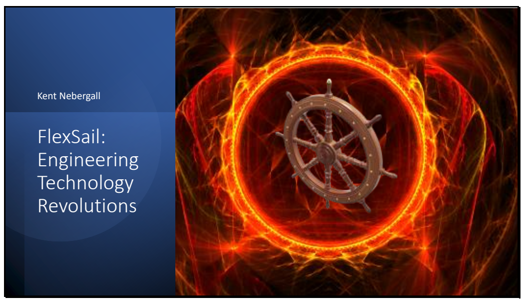
Slides and speech notes follow.

Slide 1



Hi everyone. This is about solar sailing and technology revolutions, and how to accelerate development of both.

Slide 2

<Introduction>
First, I want to break down how technology revolutions work, with the goal of engineering the ones we need for space settlement.
Second, almost as a case study, we will see how solar sail concepts are ripe for a technology explosion. The scale of this revolution is small enough we can engineer it ourselves. Yet it has dramatic implications.
If we force this revolution directly, we can compress several decades of progress into an aggressive timeline.

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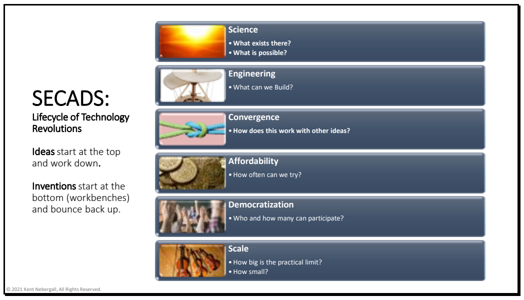

<SECADS>
Technology revolutions, and invention itself, have key components and a sort of life cycle.
So I came up with the acronym SECADS to explain each phase in order.
We start with science – what is possible and what exists already in nature?
Second is engineering, what can we build that extends what is possible in the physical world?
Science and engineering are the left and right feet by which technology development walks. But that's just the beginning.

As new concepts are invented, they become available for convergence.
Technology revolutions are typically several unrelated inventions that are used together in novel ways.
Convergence is often mistaken for invention. Some books even confuse the two terms. But convergence is just an important phase of it.
Convergence is the critical mass that ignites mainstream development.
Just as science and engineering work together, affordability puts technology in more people's hands, which in turn drives democratization and makes technologies mainstream. These cycles drive investment, which drives innovation.
Mature technologies are then scaled in size and power to fit different niches in the ecosystem.
I've been developing this for several years. It started as SEA, then SEADS, and finally SECADS.

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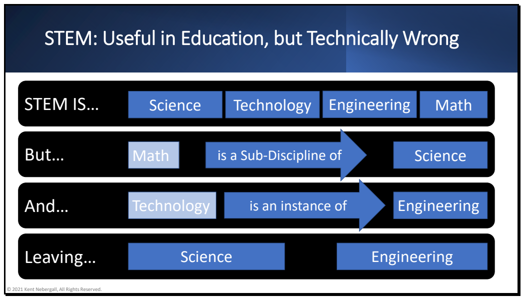

<STEM>
We often talk of STEM in education, or Science, Technology, Engineering and Math. It's good when deciding what to study. But it's not literally true. Math is a hard science, therefore it's not really a separate field. Technology is simply an instance of engineering. A technology from the 1950's is simply the balance sheet of production engineering at the time. This is why SECADS consolidates all this into just science and engineering. STEM is a useful concept for education. But SECADS is a useful concept after you graduate.

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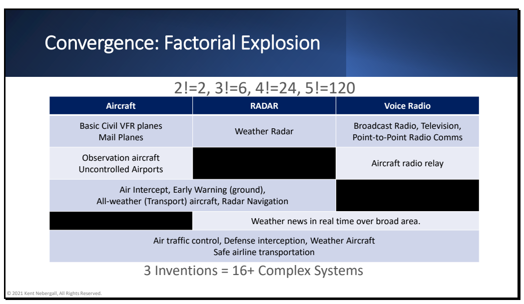

<Convergence>
We should take a second to understand why Convergence is so powerful. Here are three major inventions- Aircraft, Radar, and Voice radio.
If we had a factorial combination, they would result in 6 categories of technology. But they are more powerful than that. We have sixteen major categories of invention out of three building blocks over a fifty-year span.

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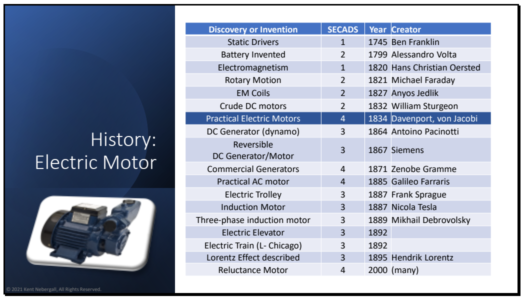

Discovery or Invention	SECADS	Year	Creator
Static Drivers	1	1745	Ben Franklin
Battery Invented	2	1799	Alessandro Volta
Electromagnetism	1	1820	Hans Christian Oersted
Rotary Motion	2	1821	Michael Faraday
EM Coils	2	1827	Anyos Jedlik
Crude DC motors	2	1832	William Sturgeon
Practical Electric Motors	4	1834	Davenport, von Jacobi
DC Generator (dynamo)	3	1864	Antoino Pacinotti
Reversible DC Generator/Motor	3	1867	Siemens
Commercial Generators	4	1871	Zenobe Gramme
Practical AC motor	4	1885	Galileo Farraris
Electric Trolley	3	1887	Frank Sprague
Induction Motor	3	1887	Nicola Tesla
Three-phase induction motor	3	1889	Mikhail Debrovolsky
Electric Elevator	3	1892	
Electric Train (L- Chicago)	3	1892	
Lorentz Effect described	3	1895	Hendrik Lorentz
Reluctance Motor	4	2000	(many)

<Motor History>
As a case study, here is the history of electric motors. Basically who invented what when.
I've assigned a number to each phase of SECADS, so 1 is Science, 2 is Engineering, and so on.
We start with a slow realization over half a century that something is going on with electricity.
What started as small workbench models to prove different minor forces grew dramatically for about 35 years.
Then when a practical electric motor is invented in 1834, we see a sudden jump in affordability. We now have an economic engine to drive the next sixty years of innovation. This drove investment in scientific experiments as well.
We then worked our way up from single-function experiments to systems that used several forces in combination to make efficient electric motors. Even today Reluctance Motors combine multiple forces in unique ways.

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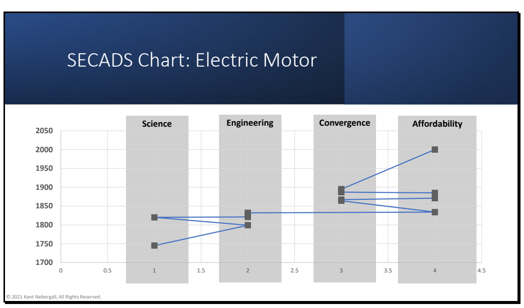

<SECADS Motor>
So I graphed this out. We have this sort of spark gap between science and engineering during the early discovery phase. This is to be expected.
But once it jumps to commercial-scale affordability, there is an economic engine to take it out of the lab and into the factory.
It goes across a sort of fire break. It then becomes a new spark gap between Convergence and Affordability.

This is true even before they become affordable for home use. That took up much of the twentieth century.

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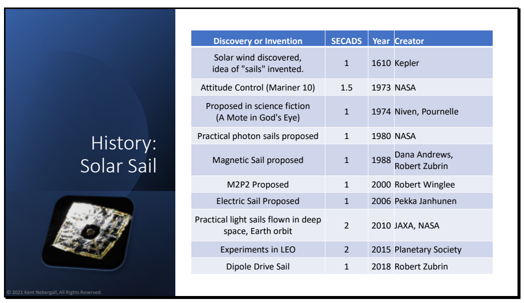

Discovery or Invention	SECADS	Year	Creator
Solar wind discovered, idea of "sails" invented.	1	1610	Kepler
Attitude Control (Mariner 10)	1.5	1973	NASA
Proposed in science fiction (A Mote in God's Eye)	1	1974	Niven, Pournelle
Practical photon sails proposed	1	1980	NASA
Magnetic Sail proposed	1	1988	Dana Andrews, Robert Zubrin
M2P2 Proposed	1	2000	Robert Winglee
Electric Sail Proposed	1	2006	Pekka Janhunen
Practical light sails flown in deep space, Earth orbit	2	2010	JAXA, NASA
Experiments in LEO	2	2015	Planetary Society
Dipole Drive Sail	1	2018	Robert Zubrin

<History Solar Sail>
So here is the history of solar sail concepts.
This started with a poetic thought by Kepler when they noticed the solar wind blowing comet's tails, much like Ben Franklin's observations of lightning in nature.
This became a practical experiment in 1973.
The idea has been stuck in fiction and engineering proposals for about five decades now. Note that Robert Zubrin produced two entire classes of solar sail mechanical theories.

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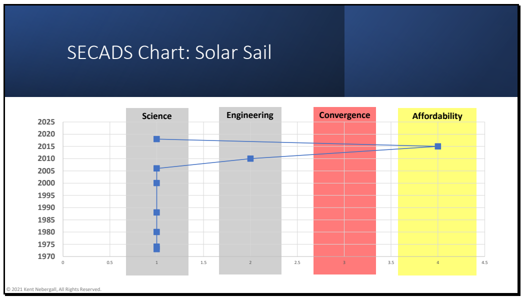

<SECADS Solar Sail>
If we graph this the same way, we see a lot of concepts. But only recently any low-cost flight experiments.
If you are wondering, we are currently between the year 1834 and 1864 on the motor timeline.
Note also that convergence hasn't happened yet.
So, let's change that.

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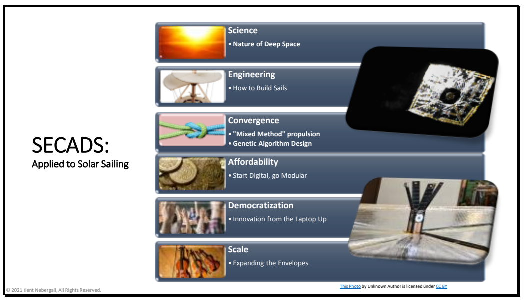

<SECADS Applied>
Let's apply SECADS as a methodology to solar sail design.
This is less like following a trail and more like building a road.

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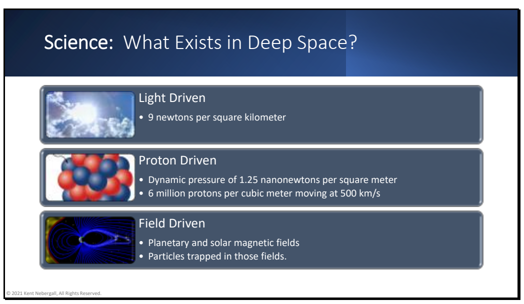

<Science Phase>
So as Kepler observed, there are forces to be harnessed in deep space.
There is light, of course.
But we also have proton driven systems that take advantage of the solar wind itself.
And then there are magnetic fields, particularly in Earth orbit, that can be harnessed like an electric motor.
Or we can build our own fields with onboard magnets.

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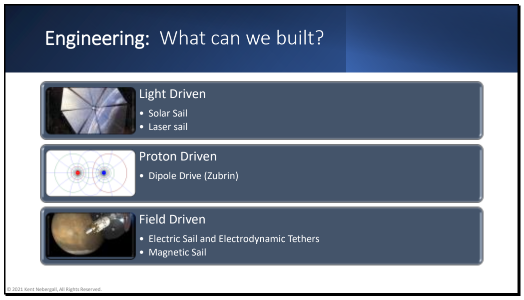

<Engineering Phase>
So each propulsion system has been invented in isolation from each other system. The magnetic confinement sail combines two forces – one natural and one artificial.

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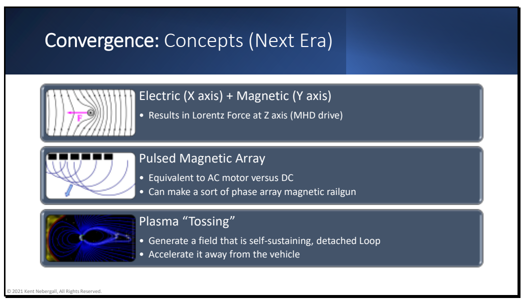

<Convergence Phase>
If we were to force a convergence wave, what would that look like?
One idea would be to use the Lorentz Force. If you put a magnetic and electric field at a 90 degree to each other in a charged media, you can force the working fluid or gas out the end on the Z axis via magnetohydrodynamics.
Speaking of magnets, what about pulsing magnetic or electrical fields a cross a phased array? Would that essentially be a rail gun for fields, but in three dimensions.
Note that some of these may only work in dense radiation belts, but that's a valuable niche in the space economy.
Lastly, we could capture solar wind in magnetic fields and accelerate the resulting bubble along a rail. This would be the magnetic confinement sail concept combined with a rail gun. You would build a plasma bubble, then blow it away with great force.

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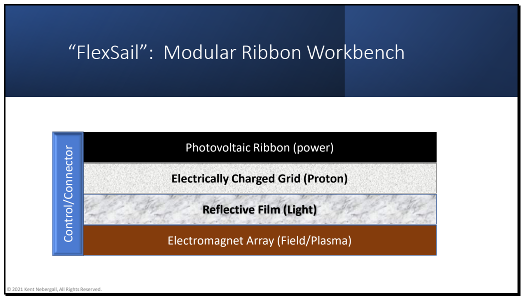

<FlexSail Workbench>
So we need a universal building block for such sail experiments, broken down to a very basic form. This is a concept for a ribbon that combines a solar power array, reflector, electric grid for Zubrin's Dipole Drive, and an array of electromagnets. The magnets and memory metals could deploy and reconfigure these ribbons and controllers in mid flight.
Interesting, but how should we make this convergence workbench?
For example, what is the best combination of each element in terms of size? And how should they be proportioned? And what is the best geometry?

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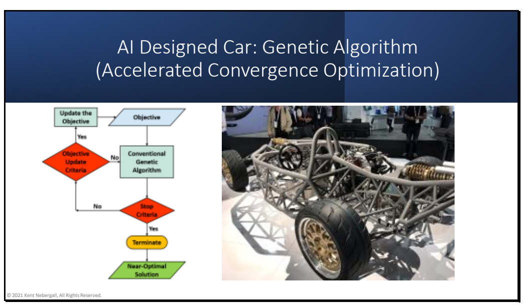

<AI Design Car>
A key technology for this sort of optimization would be the genetic algorithm.
Note that the race car frame above was designed in this way, and therefore looks more like the inside of a bird's hollow wing bone than a typical top-down blueprint.

We start by putting a version of the design in a solar wind tunnel computer model and simulate flight tests.
Then you make different versions with different sizes and shapes of array and have them compete based on performance.
The solar sail optimization system may come up with something similarly elegant like a dragonfly wing. Or something simple like a spinning disc.

But we would know a lot about the vehicle design before building anything at all.

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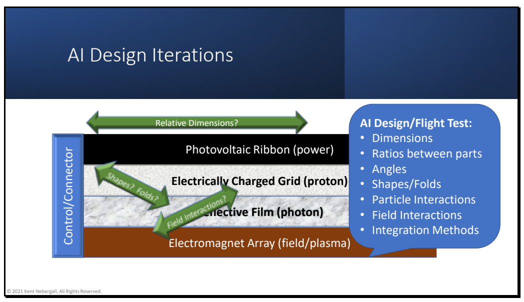

<FlexSail and AI>
Here are some of the parameters we can use for optimization, like angles, dimensions and so on.
We could make modular versions that reconfigure themselves for low earth orbit, the Van Allen belts, or deep space as needed.

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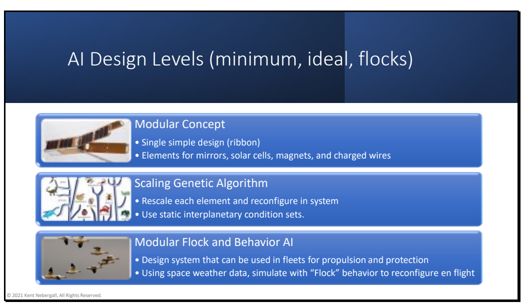

<AI Design Levels>
We can further advance this design with historic data from solar weather satellites. While a static model is good for basic optimization, a realistic model is better for practical flight.
We can go further by designing digital fleets of sails and seeing if they can flock like birds, with field effects shared across arrays of sails. This can be incredibly powerful at scale.

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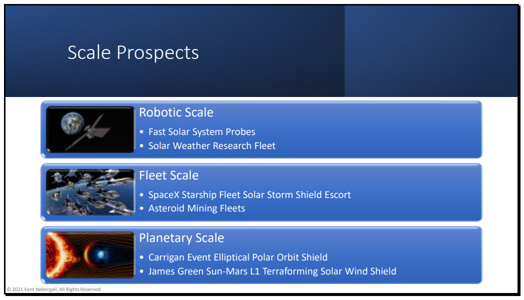

<Scale Prospects>
The obvious use of solar sails is for space probes that need to get somewhere in a hurry.
But what about making an escort fleet to protect Mars Settlement fleets of Starships that depart or return every 26 months? They could help deflect solar flares before they reached the crews.
There is also some thought of solar wind shields at Earth-Sun and Mars-Sun L1 points.

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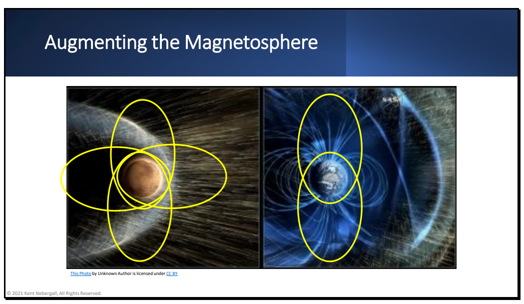

<Augment Magnetosphere>
At Earth, we have aurora because the same field that protects the equator and most of the planet channels that force into the poles. So massive solar storms start at the poles and work down to cause power grid failures.
What if we put magnetic fleets in elliptical orbits?. During a solar storm, they would turn the fields on over the poles to help shield the planet from direct bombardment over the vulnerable areas. They could then either deflect it then and there or contain it and release it high over the opposite pole before returning. Most storms would be short enough that the satellite would only get one or two chances to protect the planet.
A mars version could help protect that the atmosphere from solar wind. It can also have a third orbit to release plasma downwind. Or it could have a sunward orbit if the method is purely for shielding.

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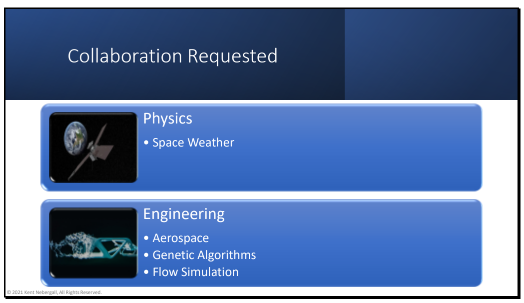

<Collaboration>
So now what?
If these areas are within your field of study, I'd be happy to work with you. Otherwise, I hope the lessons on technology revolutions help you find your own paths to invention.

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<Thanks!>
Here is my contact information.
Thanks! Any questions about either topic?