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#### The plan’s key to launch efficiency---that boosts planetary science and space-based astronomy.

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1. Introduction

Proposals for a momentum transfer based launch system are not new. Konstantin Tsiolkovsky, credited with the concept of multi-stage rocket vehicles, also proposed the orbital tower. Much later Yuri Artsutanov inverted this idea to suggest a geostationary satellite with a counterweight and a tether extending to the Earth’s surface. This so called ‘space elevator’ was first published in 1960 in Komsomolskaya Pravda and later discovered independently in the US when the term ‘skyhook’ was coined [1]. The structure was shown to be stable against the effects of lunar tidal forces and payload motions, and functions by extracting energy from Earth rotation [2]. The problem is that no known material has sufficient strength to construct a space elevator in Earth orbit.

Difficulties with the space elevator led to the proposal of the asynchronous orbital skyhook [3]. (The original concept was credited to John McCarthy at Stanford.) This is an extended orbital structure that rotates so that each end periodically comes to a low altitude and velocity, at which instants the system is easy to access. Initial studies advocated configurations that place a low demand on the tether material properties, as this was thought to be the principal challenge. To replace energy lost during launch it was proposed that the skyhook be used to return a similar quantity of material from orbit to Earth.

Detailed studies of the asynchronous skyhook [4, 5] addressed engineering aspects of the tether and docking mechanism. They proposed a set of configurations in which access is provided by a hypersonic vehicle operating at a speed of at least 3.1 km/s (Mach 10). This high speed of the access vehicle reduces the skyhook rotation rate and so places less stress on the tether material.

Hypersonic flight technology is not yet capable of providing routine access to the high Mach number regime. By contrast, several reusable vehicles are available that provide access to suborbital flight trajectories using combinations of air-breathing and rocket propulsion [6, 7]. High strength fiber technology has also made substantial progress with the incorporation of carbon nanotubes into the molecular structure [8]. This suggests a need to review the orbital skyhook concept with a focus on configurations that allow low speed access. It is also necessary to explore different approaches to energy replenishment that do not require access to a repository of orbiting material.

Section 2 reviews the skyhook concept and estimates the parameters of a practical launch system. Expressions for the skyhook mass properties are obtained in Section 3 for the case where centripetal force is the dominant source of tension. The dynamics is modeled in Section 4 assuming the structure remains linear, with the tether mass properties represented by a compact object at the mass centroid. Electric propulsion is proposed as a mechanism for energy replenishment in Section 5, and the feasibility of supplying propellant for the thrusters is explored. Section 6 describes the advantages of a skyhook launch system for future planetary science missions, and Section 7 summarizes the main results.

2. Concept description

An orbital skyhook launch system involves three phases, each exploiting a different physical process. It begins with the delivery of a payload by suborbital vehicle. Docking occurs at one of the skyhook endpoints when it is near minimum altitude and velocity. The suborbital vehicle is required to attain only a small fraction of the energy needed for orbit, and does not need to operate in a hypersonic flight regime. It can therefore employ mature airframe and propulsion technologies, making it easier to design for efficiency and reusability.

The second phase is momentum transfer from the skyhook to the payload [9]. After docking the payload gains energy as the skyhook rotates, reaching a maximum after half a cycle. If the payload is not released energy transfers back to the skyhook in the second half of the cycle as it returns to minimum energy. By selecting when the payload is released, it can be placed into an elliptical orbit or on an escape trajectory. Note that if the payload is released at a subsequent minimum energy point, the skyhook energy and orbit are left unaffected. This means the vehicle is transported around the Earth at orbital velocity, with the only energy cost being that of gaining access to the skyhook.

In the third phase energy drawn from the skyhook during launch must be replenished. If the payload mass is small relative to the total system mass, the orbital perturbation is also small. In this case the structure remains above the atmosphere through subsequent rotations, and energy replenishment may occur over an extended period. Electric propulsion is proposed for this purpose. It provides a small thrust with a large specific impulse, and therefore high propellant efficiency. Propellant can be delivered with the payload to supply thrusters at the skyhook endpoints, but it will be shown that a better approach is to apply thrust at the skyhook mass centroid.

Of interest here are skyhook configurations that offer low speed access. Ideally the endpoint speed should match the orbital velocity relative to Earth’s surface. In addition, acceleration during launch must not be excessive. For a skyhook in a circular equatorial orbit with radius R and orbital frequency Ω the endpoint ground track speed and acceleration are given by:

vM=RΩ−Lω−465

aM=RΩ2[(1−L/R)−2−1]+Lω2

Here L and ω are the skyhook half-length and rotation frequency, and Eq. 2 includes the acceleration components due to gravity, orbital velocity and skyhook rotation.

Specifying the endpoint velocity and acceleration yields two implicit equations for the skyhook parameters. With a nominal orbital radius of 8000 km the skyhook length is small enough to apply the limit L≪R. Then for a minimum energy state at zero velocity and 40 m/s2 acceleration, the skyhook parameters are L=1090km and ω=0.006s−1 . This system can be accessed at zero velocity by a vehicle capable of ascending to an altitude of 532 km. Moreover, the maximum acceleration experienced during launch is similar to that of a conventional launch vehicle.

One of the skyhook endpoints is at minimum energy when the structure is oriented radially. This state occurs with a period τ=π/(ω−Ω) corresponding to a ground track distance of 3176 km around the equator. The orbital parameters could be adjusted so this distance is an exact fraction of the equatorial circumference, in which case the minimum energy states occur above fixed points on the equator. These locations are natural sites at which to establish bases to operate the suborbital access vehicles.

3. Mass properties

The skyhook configurations of interest here have an endpoint speed near orbital velocity to allow access at low energy. The high rotation rate means tension is mainly due to centripetal force, with the field gradient contribution being negligible.

Consider a symmetric skyhook comprising two equal masses m connected by a massive tether of length 2L and define the origin at the center. The tether cross-section is a(r) and the tether material has uniform density ρ and ultimate tensile strength T . For a skyhook with rotation frequency ω the tension σ at radius r obeys:

σ′(r)=−ρω2ra(r) E3

Substituting a(r)=σ(r)/T and noting that a(L)=mLω2/T this equation can be solved for the tether cross-section:

a(r)=mLω2Texp[χ2{1−(rL)2}] E4

Here χ2=ρω2L2/2T is a dimensionless parameter characterizing the skyhook. By symmetry the mass centroid is at the origin. This structure may be generalized to describe a set of asymmetric configurations with unequal end masses at different distances from the centroid. The symmetric configuration has the benefit of offering two opportunities to access the skyhook in each rotation cycle, but asymmetric configurations allow access to a greater variety of launch trajectories.

The tether mass MT and moment of inertia IT are given by:

MT=2ρ∫L0a(r)dr E5

IT=2ρ∫L0a(r)r2dr E6

Evaluating the integrals and simplifying:

MT/m=2π−−√χexp[χ2]erf(χ) E7

IT/mL2=π−−√χ−1exp[χ2]erf(χ)−2 E8

The limit χ→0 represents a material of infinite strength, in which case the tether mass and moment of inertia vanish. Adding the contributions of the two end masses leads to expressions for the mass properties of the entire skyhook:

M/m=2π−−√χexp[χ2]erf(χ)+2 E9

I/mL2=π−−√χ−1exp[χ2]erf(χ) E10

These expressions for the skyhook mass properties indicate the dependence on tether material properties, and provide key parameters for dynamical modeling.

An important feature of a tether is the taper factor, the ratio of maximum to minimum cross-section area. A tether constructed from low strength material has a large taper factor, indicating its impracticality. The nominal skyhook described above with a carbon fiber tether has a taper factor of 237, in which case the diameter at the centroid is about 15 times that the end points. If the tether had the properties of carbon nanotubes the taper factor reduces to 3.3. The properties of any future tether material are likely to fall within these bounds.

Table 1 indicates the mass properties of the nominal skyhook for several tether materials. Notionally high strength materials like steel and diamond are excluded by the very large taper factor. Aramid fibers like Kevlar are possible but the total mass is large. The strongest carbon fiber offers a solution with a skyhook mass about 4600 times the endpoint mass. If materials with still greater tensile strength become available, such as by incorporating carbon nanotubes or colossal carbon tubes into the tether material, the taper factor and skyhook mass can be much smaller.

Material Density (kg/m3) Strength (MPa) χ2 Taper Factor Mass (MT/m) Moment (IT/mL2)

Steel 2800 8000 2693 67.7 1.2 × 1025 2.9 × 1027 3.1 × 1023

Diamond 3500 2800 26.7 4.1 × 1011 3.9 × 1013 2.7 × 1010

Aramid fiber 1440 3757 8.2 3629 1.05 × 105 783.4

Zylon (PBO) 1560 5800 5.75 315 6421 96.1

Carbon fiber (T1100S) 1790 7000 5.47 237 4596 75.8

Carbon nanotube 1340 63,000 0.45 1.58 5.46 5.06

Colossal carbon tube 116 7000 0.35 1.43 1.70 5.93

Table 1.

Tether mass properties for various materials (from Eqs. (4), (7) and (8)).

For the skyhook configuration described here the endpoint mass is regarded as the maximum payload capability. This assumes the endpoint mass may be replaced by a docking mechanism of negligible mass to capture the payload. Engineering margins have not been included in this analysis, but the nominal configuration is a ‘worst case’ in the sense that skyhook rotation is specified to allow access at zero velocity relative to the Earth. If the access vehicle provides a horizontal velocity component the rotation rate is smaller, in which case the taper factor and skyhook mass are also decreased.

4. Equations of motion

Skyhook length is a significant factor in the dynamics because field strength is not uniform across the structure. This differs from most problems in astrodynamics where the object of interest is small compared to the field gradient length scale, or the system can be simplified by assuming spherical symmetry.

Here the skyhook is assumed to behave as a rigid body, kept in tension by the rotation and experiencing no stretching or bending. The validity of these assumptions depends on the tether material properties, but they are sufficient for the present purpose. The structure is expected to remain linear due to the large centripetal restoring force that counters any bending.

The equations of motion of a rigid body are typically obtained by a Lagrangian method using the mass properties. This formulation ignores the field gradient effect, which is important for skyhook dynamics. To see this note that the skyhook structure experiences a moment due to the two arms being subject to different field strengths according to their proximity to Earth. If the skyhook were treated as a single compact object this behavior would not be represented.

The skyhook system is modeled here as three objects connected by tethers of fixed length L as illustrated in Figure 1. The central object has the mass properties of the tethers as calculated above. This formulation represents the physical extent of the skyhook in a non-uniform field. It is also a good approximation for the mass distribution of the tether if it has a significant taper factor, in which case much of the mass is concentrated near the centroid. Based on these considerations a Newtonian formulation is used for the analysis.

Figure 1.

Skyhook geometry with the tether mass and moment of inertia represented by a compact object at the mass centroid.

The system state is described by a six element vector comprising the skyhook centroid location r=(r,θ) and orientation angle φ and their derivatives. The endpoint locations are specified by the vectors r1 and r2 which are functions of the state vector and may be written as follows where t̂ =(cosφ,sinφ) is the skyhook orientation unit vector:

r1,2=r∓Lt̂ E11

The gravitational force on each mass is projected through the centroid to obtain the net radial and azimuthal forces, and onto the normal for the torque:

Fr=−(GMEr21m)r̂ 1.r̂ −(GMEr22m)r̂ 2.r̂ −(GMEr2MT) E12

Fθ=−(GMEr21m)r̂ 1.θ̂ −(GMEr22m)r̂ 2.θ̂ E13

τ=−(GMEr21m)Lr̂ 1.t̂ ′+(GMEr22m)Lr̂ 2.t̂ ′ E14

Here t̂ ′=(sinφ,−cosφ) is a unit vector normal to the skyhook. In circular polar co-ordinates the acceleration is:

r¨=(r¨−rθ̇ 2)r̂ +(rθ¨+2ṙ θ̇ )θ̂ E15

The skyhook equations of motion are then:

r¨−rθ̇ 2=Fr/(2m+MT) E16

rθ¨+2ṙ θ̇ =Fθ/(2m+MT) E17

φ¨=τ/I=τ/mL2{π−−√χ−1exp[χ2]erf(χ)]} E18

Evaluating the vector dot products and re-arranging:

r¨=rθ̇ 2−GMEm2m+MT12r{(1r1+1r2)+(r31+r32r21r22)cos(θ1−θ2)+2rMTm} E19

θ¨=−2ṙ θ̇ r+GMEm2m+MT12r2(r31−r32r21r22)sin(θ1−θ2) E20

φ¨=−GMEm2I(r31−r32r21r22)sin(θ1−θ2) E21

The skyhook trajectory was obtained by numerical solution of these equations of motion for the nominal parameters. The endpoint altitude and ground track speed are shown in Figure 2. Note that the minimum energy point occurs at zero ground track speed at an altitude of 532 km. The specific energy of a stationary object at this altitude is about 5% of one in orbit. The configuration could be altered to allow access at a lower altitude, but it may then incur an unacceptable risk of collision with satellites in low Earth orbit.

Figure 2.

Altitude (dark) and ground track speed (light) of a skyhook endpoint.

During launch momentum transfers from the skyhook to the payload, perturbing the skyhook orbit into an ellipse. This perturbation is small if the skyhook mass is much greater than the payload mass, as is true for most tether materials. If the tether material is sufficiently strong the skyhook mass can be small enough for the orbital perturbation to be significant. This can be overcome by placing ballast mass at the centroid.

5. Energy replenishment

After launch it is necessary to replenish the skyhook energy and circularize the orbit. If the orbital eccentricity is small there is no interaction between the skyhook and the atmosphere, so this may occur over many orbits. Electric thrusters are proposed as a suitable technology for maintaining the skyhook orbit. They produce thrust with a high specific impulse, and therefore utilize propellant very efficiently.

The preferred location to apply thrust is the skyhook centroid. A force at this point maximizes energy transfer, the rate of work being the product of the thrust and orbital velocity V0. The skyhook is also very robust at the centroid, and with a local acceleration near zero it is the optimal location for solar arrays to power the thrusters. Note that mass at the centroid does not affect the skyhook structure or energy transfer rate. This means the propulsion system mass and efficiency is of no concern. The key thruster performance characteristics are the efflux velocity and mass flow rate, which together determine the propellant quantity and time needed to achieve energy replenishment.

Electric propulsion has been developed for tasks that require a small thrust with high specific impulse. Examples include orbital transfer and deep space missions, for which ion thrusters are the preferred technology. Energy replenishment requires a high specific impulse and sufficient thrust to limit the replenishment time. A magnetoplasmadynamic (MPD) motor is best suited for this purpose. MPD thruster technology is developmental, but their performance can be inferred from experimental demonstrators.

An MPD thruster creates an electric current in plasma in the presence of a magnetic field. The field may be generated externally by coils or intrinsically by the current itself. In either case Lorentz force acts on the plasma and expels it at high velocity. Laboratory MPD thrusters have demonstrated 5 N of thrust with a mass flow rate of 60 mg/s [10]. The MPD thruster is a compact and robust device, but it operates most efficiently at high power levels in the order of 1 MW. It is estimated that a practical MPD thruster could achieve a thrust of 2.5–25 N with an efflux velocity of 15–60 km/s [11].

A thruster with efflux velocity VE and mass flow rate ṁ acting at the centroid can replenish the launch energy EL=m0V20/2 for a payload m0 in a period TR given by:

TR=EL/Ė =moV0/2VEṁ =mP/ṁ E22

The ratio mP/mo=V0/2VE is the fraction of payload mass that must be reserved for propellant to replenish launch energy. For an efflux velocity of 50 km/s this ratio is 0.07. This means the amount of propellant needed to replenish launch energy is only 7% of the payload mass. With a realistic mass flow rate of 0.4 g/s the time needed to replenish the energy used to launch a 1000 kg payload is about 2 days. This can obviously be reduced by operating several such thrusters in parallel.

The quantity of propellant needed for energy replenishment is much smaller than the payload mass, but it must be delivered to the skyhook centroid. This can be achieved by having the skyhook launch a transport vehicle into an elliptical orbit, after which it uses conventional propulsion systems to perform an orbital transfer maneuver and rendezvous with the centroid. The analysis concludes by demonstrating that it is possible to deliver propellant efficiently to the skyhook centroid.

Skyhook endpoint kinematics is characterized by near uniform circular motion for both the orbit and the rotation. The velocity may be determined by adding the two rotational velocities as illustrated in Figure 3.

Figure 3.

Skyhook orbital geometry and payload velocity at detachment.

vr=−V0sin(α)+Lωsin(α+β) E23

vθ=V0cos(α)−Lωcos(α+β) E24

The triangle in the figure is fully specified, so all angles can be expressed in terms of the skyhook parameters and endpoint radial coordinate. If the payload detaches at a speed less than escape velocity it enters an elliptical orbit with a periapsis, apoapsis and eccentricity given by:

rP=(2r−v2GME)−1(1−e) E25

rA=(2r−v2GME)−1(1+e) E26

e2=1−r2v2θGME(2r−v2GME) E27

The transition to a circular orbit can be achieved with a bi-elliptical transfer maneuver [12]. This involves a prograde impulse at apoapsis to increase the periapsis, followed by a retrograde impulse at periapsis to circularize the orbit. The maneuver can be implemented with a series of small impulses over several orbits, but the single orbit procedure serves to illustrate the process. The velocity changes at apoapsis and periapsis are given by:

ΔVA=2GMErA−2GMER+rA−−−−−−−−−−−√−(1−e)GMErA−−−−−−−√ E28

ΔVP=2GMER−2GMER+rA−−−−−−−−−−−√−GMER−−−−√ E29

The initial orbit depends on the skyhook configuration and its orientation when the payload is released. For the nominal skyhook most orbits have a periapsis smaller than Earth radius, necessitating an impulse during the first orbit to increase the periapsis to avoid reentry into the atmosphere. Only a small impulse is needed for this purpose, which can be provided by a conventional rocket. The rest of the orbital transfer maneuver can be achieved efficiently by employing low thrust electric propulsion over multiple orbits.

To illustrate the process consider a vehicle that is released from the skyhook at an orientation angle β=1.6 radians. It enters an elliptical orbit with periapsis 5550 km and apoapsis 71,400 km. A velocity change of 68 m/s at apoapsis increases the periapsis to 6500 km, sufficient to avoid reentry. This can be provided by a chemical rocket with a propellant mass fraction of 0.03. Subsequent circularization of the orbit at the centroid radius requires a velocity change of about 2.8 km/s which can be provided by electric thrusters with a propellant mass fraction of 0.06. This means a reusable vehicle can be used to transport propellant to the skyhook centroid, with only 10% of the initial mass expended as propellant during the journey.

6. Planetary science

Planetary science and space-based astronomy demand increasingly complex infrastructure, and the high cost of launch limits the scope of experiments. A more efficient launch process would allow larger vehicles to be constructed and more ambitious experiments to be undertaken. The orbital skyhook is a fully reusable launch system with high propellant efficiency, and which can be constructed using current materials technology. It can deliver payloads directly to Earth orbit, or to a trajectory for transfer to lunar orbit.

Access to orbit is the first stage of any planetary science mission. Typically a launch vehicle places the spacecraft and its propulsion system into orbit to await the appropriate time to commence interplanetary transfer. Because of the high launch cost a low energy trajectory is usually employed. This restricts the available launch window and increases the transit time. With a more efficient launch process it would be possible to use a larger and more capable propulsion system, and thus to allow a less efficient trajectory. This flexibility could be used to deliver a larger experimental payload, conduct more frequent missions, or achieve a reduced transit time.

An emerging ambition of national space programs is a return to the moon, often extending to the establishment of permanent bases on the moon and in lunar orbit. Planetary science is unlikely to be a primary driver of this initiative, but it stands to be a significant beneficiary. For astronomy the moon offers a low gravity environment free of atmospheric and ionospheric effects, Earth based radio emissions, and interference due to the large number of satellites in low Earth orbit. A skyhook launch system that provides efficient transport to the moon would allow astronomical experiments with far greater sensitivity than is possible with terrestrial instruments.

Lunar orbit is also a favorable location from which to launch planetary science missions. It is close enough for easy access but at a significantly higher energy than low Earth orbit. Complex modules constructed on Earth can be delivered efficiently by the skyhook, while fuel and water can be supplied from the moon at a much lower energy cost. Vehicles returning from the moon could dock with the skyhook as it approaches a minimum energy state, using it to decelerate in preparation for a low speed re-entry while also returning energy to the system. The use of an orbital skyhook for efficient transport to and from the moon is therefore a key enabler of future planetary science missions.

7. Conclusions

The orbital skyhook derives its advantage principally from using different propulsion technologies in the various physical regimes experienced during a launch. The payload gains energy by momentum transfer from the skyhook, with this energy being later repaid over an extended period. This overcomes the large energy threshold associated with a launch by drawing from a repository and replenishing it efficiently by electric propulsion.

The focus here is on skyhook configurations that allow access at a low speed relative to the Earth. These can be accessed much more easily, but necessarily rotate rapidly to counter the orbital velocity. This means centripetal force dominates the tension, making it is possible to obtain simple expressions for the skyhook mass properties. With a carbon fiber tether the skyhook mass is about 4600 times greater than the endpoint mass, which represents the maximum launch payload. The skyhook mass can be greatly reduced if a stronger tether material were to become available.

Because the skyhook is an extended structure in a non-uniform field, it is subject to forces and torques that vary with orientation. To represent this behavior the skyhook was modeled as a linear structure comprising two masses connected by an inelastic massive tether. The tether mass properties were represented as a compact object at the mass centroid, and a Newtonian formulation used to obtain the equations of motion. These equations were solved numerically to confirm their validity and investigate the dynamics.

Skyhook energy lost during a launch can be replenished by an electric thruster acting at the centroid. The MPD motor is a suitable propulsion technology for this purpose, and was shown to be capable of achieving energy replenishment in a reasonable time with high propellant efficiency. This result holds regardless of the size and efficiency of the propulsion system because the energy transfer process depends only on the efflux velocity and mass flow rate.

Applying thrust at the centroid is beneficial because the structure is most robust at this point and the local acceleration is near zero. It is necessary, however, to transport propellant to the centroid and a mechanism is proposed to achieve this. A transport vehicle is launched by the skyhook into an elliptical orbit, after which it executes an orbital transfer maneuver to rendezvous with the centroid. This process can be accomplished with a high propellant efficiency using available propulsion systems.

The endpoint mass represents the maximum skyhook payload capacity. This envisages the endpoint carrying a docking mechanism of negligible mass that can accept the payload. The skyhook mass scales linearly with the endpoint mass, and so also with the maximum payload. When an initial system has been established it can be used to launch material to add to the structure to increase the payload capacity. This process is likely to be limited by the access vehicle payload capacity, at which point there is no benefit in further increasing the skyhook mass.

Planetary science requires increasingly elaborate experiments. Improved launch efficiency allows more ambitious missions to be undertaken, with larger propulsion systems to deliver more massive experiments to the planet of interest with sufficient propellant for soft landing on the planet surface. The renewed enthusiasm of national space programs for a return to the moon could provide the incentive for construction of an orbital skyhook to provide efficient transport to and from the moon. This would make it possible to conduct astronomical observations from the moon with a sensitivity far greater than is possible from Earth, and to exploit lunar orbit as a base for launching future planetary science missions.

#### Planetary science enables identifying and avoiding ‘great filters’---mathematically proven extinction

Joshua Zelinsky 15. Professor in the Mathematics Department @ Iowa State University, writing on Less Wrong, a forum dedicated to the exploration of existential risks. 04-19-15. “Astronomy, space exploration and the Great Filter.” Less Wrong. https://www.lesswrong.com/posts/dxuKW7DzKKeTf6arW/astronomy-space-exploration-and-the-great-filter

Astronomical research has what may be an under-appreciated role in helping us understand and possibly avoiding the Great Filter. This post will examine how astronomy may be helpful for identifying potential future filters. The primary upshot is that we may have an advantage due to our somewhat late arrival: if we can observe what other civilizations have done wrong, we can get a leg up.

This post is not arguing that colonization is a route to remove some existential risks. There is no question that colonization will reduce the risk of many forms of Filters, but the vast majority of astronomical work has no substantial connection to colonization. Moreover, the case for colonization has been made strongly by many others already, such as Robert Zubrin's book "The Case for Mars" or this essay by Nick Bostrom.

Note: those already familiar with the Great Filter and proposed explanations may wish to skip to the section "How can we substantially improve astronomy in the short to medium term?"

What is the Great Filter?

There is a worrying lack of signs of intelligent life in the universe. The only intelligent life we have detected has been that on Earth. While planets are apparently numerous, there have been no signs of other life. There are three possible lines of evidence we would expect to see if civilizations were common in the universe: radio signals, direct contact, and large-scale constructions. The first two of these issues are well-known, but the most serious problem arises from the lack of large-scale constructions: as far as we can tell the universe look natural. The vast majority of matter and energy in the universe appears to be unused. The Great Filter is one possible explanation for this lack of life, namely that some phenomenon prevents intelligent life from passing into the interstellar, large-scale phase. Variants of the idea have been floating around for a long time; the term was first coined by Robin Hanson in this essay. There are two fundamental versions of the Filter: filtration which has occurred in our past, and Filtration which will occur in our future. For obvious reasons the second of the two is more of a concern. Moreover, as our technological level increases, the chance that we are getting to the last point of serious filtration gets higher since as one has a civilization spread out to multiple stars, filtration becomes more difficult.

Evidence for the Great Filter and alternative explanations:

At this point, over the last few years, the only major updates to the situation involving the Filter since Hanson's essay have been twofold:

First, we have confirmed that planets are very common, so a lack of Earth-size planets or planets in the habitable zone are not likely to be a major filter.

Second, we have found that planet formation occurred early in the universe. (For example see this article about this paper.) Early planet formation weakens the common explanation of the Fermi paradox that the argument that some species had to be the first intelligent species and we're simply lucky. Early planet formation along with the apparent speed at which life arose on Earth after the heavy bombardment ended, as well as the apparent speed with which complex life developed from simple life, strongly refutes this explanation. The response has been made that early filtration may be so common that if life does not arise early on a planet's star's lifespan, then it will have no chance to reach civilization. However, if this were the case, we'd expect to have found ourselves orbiting a more long-lived star like a red dwarf. Red dwarfs are more common than sun-like stars and have much longer lifespans by multiple orders of magnitude. While attempts to understand the habitable zone of red dwarfs are still ongoing, current consensus is that many red dwarfs contain habitable planets.

These two observations, together with further evidence that the universe looks natural makes future filtration seem likely. If advanced civilizations existed, we would expect them to make use of the large amounts of matter and energy available. We see no signs of such use. We've seen no indication of ring-worlds, Dyson spheres, or other megascale engineering projects. While such searches have so far been confined to around 300 parsecs and some candidates were hard to rule out, if a substantial fraction of stars in a galaxy have Dyson spheres or swarms we would notice the unusually high infrared spectrum. Note that this sort of evidence is distinct from arguments about contact or about detecting radio signals. There's a very recent proposal for mini-Dyson spheres around white dwarfs which would be much easier to engineer and harder to detect, but they would not reduce the desirability of other large-scale structures, and they would likely be detectable if there were a large number of them present in a small region. One recent study looked for signs of large-scale modification to the radiation profile of galaxies in a way that should show presence of large scale civilizations. They looked at 100,000 galaxies and found no major sign of technologically advanced civilizations (for more detail see here).

We will not discuss all possible rebuttals to case for a Great Filter but will note some of the more interesting ones:

There have been attempts to argue that the universe only became habitable more recently. There are two primary avenues for this argument. First, there is the point that early stars had very low metallicity (that is had low concentrations of elements other than hydrogen and helium) and thus the universe would have had too low a metal level for complex life. The presence of old rocky planets makes this argument less viable, and this only works for the first few billion years of history. Second, there's an argument that until recently galaxies were more likely to have frequent gamma bursts. In that case, life would have been wiped out too frequently to evolve in a complex fashion. However, even the strongest version of this argument still leaves billions of years of time unexplained.

There have been attempts to argue that space travel may be very difficult. For example, Geoffrey Landis proposed that a percolation model, together with the idea that interstellar travel is very difficult, may explain the apparent rarity of large-scale civilizations. However, at this point, there's no strong reason to think that interstellar travel is so difficult as to limit colonization to that extent. Moreover, discoveries made in the last 20 years that brown dwarfs are very common and that most stars do contain planets is evidence in the opposite direction: these brown dwarfs as well as common planets would make travel easier because there are more potential refueling and resupply locations even if they are not used for full colonization. Others have argued that even without such considerations, colonization should not be that difficult. Moreover, if colonization is difficult and civilizations end up restricted to small numbers of nearby stars, then it becomes more, not less, likely that civilizations will attempt the large-scale engineering projects that we would notice.

Another possibility is that we are underestimating the general growth rate of the resources used by civilizations, and so while extrapolating now makes it plausible that large-scale projects and endeavors will occur, it becomes substantially more difficult to engage in very energy intensive projects like colonization. Rather than a continual, exponential or close to exponential growth rate, we may expect long periods of slow growth or stagnation. This cannot be ruled out, but even if growth continues at only slightly higher than linear rate, the energy expenditures available in a few thousand years will still be very large.

Another possibility that has been proposed are variants of the simulation hypothesis— the idea that we exist in a simulated reality. The most common variant of this in a Great Filter context suggests that we are in an ancestor simulation, that is a simulation by the future descendants of humanity of what early humans would have been like.

The simulation hypothesis runs into serious problems, both in general and as an explanation of the Great Filter in particular. First, if our understanding of the laws of physics is approximately correct, then there are strong restrictions on what computations can be done with a given amount of resources. For example, BQP, the set of problems which can be solved efficiently by quantum computers is contained in PSPACE, the set of problems which can solved when one has a polynomial amount of space available and no time limit. Thus, in order to do a detailed simulation, the level of resources needed would likely be large since one would even if one made a close to classical simulation still need about as many resources. There are other results, such as Holevo's theorem, which place other similar restrictions. The upshot of these results is that one cannot make a detailed simulation of an object without using at least much resources as the object itself. There may be potential ways of getting around this: for example, consider a simulator interested primarily in what life on Earth is doing. The simulation would not need to do a detailed simulation of the inside of planet Earth and other large bodies in the solar system. However, even then, the resources involved would be very large.

The primary problem with the simulation hypothesis as an explanation is that it requires the future of humanity to have actually already passed through the Great Filter and to have found their own success sufficiently unlikely that they've devoted large amounts of resources to actually finding out how they managed to survive. Moreover, there are strong limits on how accurately one can reconstruct any given quantum state which means an ancestry simulation will be at best a rough approximation. In this context, while there are interesting anthropic considerations here, it is more likely that the simulation hypothesis is wishful thinking.

Variants of the "Prime Directive" have also been proposed. The essential idea is that advanced civilizations would deliberately avoid interacting with less advanced civilizations. This hypothesis runs into two serious problems: first, it does not explain the apparent naturalness, only the lack of direct contact by alien life. Second, it assumes a solution to a massive coordination problem between multiple species with potentially radically different ethical systems. In a similar vein, Hanson in his original essay on the Great Filter raised the possibility of a single very early species with some form of faster than light travel and a commitment to keeping the universe close to natural looking. Since all proposed forms of faster than light travel are highly speculative and would involve causality violations this hypothesis cannot be assigned a substantial probability.

People have also suggested that civilizations move outside galaxies to the cold of space where they can do efficient reversible computing using cold dark matter. Jacob Cannell has been one of the most vocal proponents of this idea. This hypothesis suffers from at least three problems. First, it fails to explain why those entities have not used the conventional matter to any substantial extent in addition to the cold dark matter. Second, this hypothesis would either require dark matter composed of cold conventional matter (which at this point seems to be only a small fraction of all dark matter), or would require dark matter which interacts with itself using some force other than gravity. While there is some evidence for such interaction, it is at this point, slim. Third, even if some species had taken over a large fraction of dark matter to use for their own computations, one would then expect later species to use the conventional matter since they would not have the option of using the now monopolized dark matter.

Other exotic non-Filter explanations have been proposed but they suffer from similar or even more severe flaws.

It is possible that future information will change this situation. One of the more plausible explanations of the Great Filter is that there is no single Great Filter in the past but rather a large number of small filters which come together to drastically filter out civilizations. However, the evidence for such a viewpoint at this point is slim but there is some possibility that astronomy can help answer this question.

For example, one commonly cited aspect of past filtration is the origin of life. There are at least three locations, other than Earth, where life could have formed: Europa, Titan and Mars. Finding life on one, or all of them, would be a strong indication that the origin of life is not the filter. Similarly, while it is highly unlikely that Mars has multicellular life, finding such life would indicate that the development of multicellular life is not the filter. However, none of them are as hospitable to the extent of Earth, so determining whether there is life will require substantial use of probes. We might also look for signs of life in the atmospheres of extrasolar planets, which would require substantially more advanced telescopes.

Another possible early filter is that planets like Earth frequently get locked into a "snowball" state which planets have difficulty exiting. This is an unlikely filter since Earth has likely been in near-snowball conditions multiple times— once very early on during the Huronian and later, about 650 million years ago. This is an example of an early partial Filter where astronomical observation may be of assistance in finding evidence of the filter. The snowball Earth filter does have one strong virtue: if many planets never escape a snowball situation, then this explains in part why we are not around a red dwarf: planets do not escape their snowball state unless their home star is somewhat variable, and red dwarfs are too stable.

It should be clear that none of these explanations are satisfactory and thus we must take seriously the possibility of future Filtration.

How can we substantially improve astronomy in the short to medium term?

Before we examine the potentials for further astronomical research to understand a future filter we should note that there are many avenues in which we can improve our astronomical instruments. The most basic way is to simply make better conventional optical, near-optical telescopes, and radio telescopes. That work is ongoing. Examples include the European Extreme Large Telescope and the Thirty Meter Telescope. Unfortunately, increasing the size of ground based telescopes, especially size of the aperture, is running into substantial engineering challenges. However, in the last 30 years the advent of adaptive optics, speckle imaging, and other techniques have substantially increased the resolution of ground based optical telescopes and near-optical telescopes. At the same time, improved data processing and related methods have improved radio telescopes. Already, optical and near-optical telescopes have advanced to the point where we can gain information about the atmospheres of extrasolar planets although we cannot yet detect information about the atmospheres of rocky planets.

Increasingly, the highest resolution is from space-based telescopes. Space-based telescopes also allow one to gather information from types of radiation which are blocked by the Earth's atmosphere or magnetosphere. Two important examples are x-ray telescopes and gamma ray telescopes. Space-based telescopes also avoid many of the issues created by the atmosphere for optical telescopes. Hubble is the most striking example but from a standpoint of observatories relevant to the Great Filter, the most relevant space telescope (and most relevant instrument in general for all Great Filter related astronomy), is the planet detecting Kepler spacecraft which is responsible for most of the identified planets.

Another type of instrument are neutrino detectors. Neutrino detectors are generally very large bodies of a transparent material (generally water) kept deep underground so that there are minimal amounts of light and cosmic rays hitting the the device. Neutrinos are then detected when they hit a particle which results in a flash of light. In the last few years, improvements in optics, increasing the scale of the detectors, and the development of detectors like IceCube, which use naturally occurring sources of water, have drastically increased the sensitivity of neutrino detectors.

There are proposals for larger-scale, more innovative telescope designs but they are all highly speculative. For example, in the ground based optical front, there's been a suggestion to make liquid mirror telescopes with ferrofluid mirrors which would give the advantages of liquid mirror telescopes, while being able to apply adaptive optics which can normally only be applied to solid mirror telescopes. An example of potential space-based telescopes is the Aragoscope which would take advantage of diffraction to make a space-based optical telescope with a resolution at least an order of magnitude greater than Hubble. Other examples include placing telescopes very far apart in the solar system to create effectively very high aperture telescopes. The most ambitious and speculative of such proposals involve such advanced and large-scale projects that one might as well presume that they will only happen if we have already passed through the Great Filter.

What are the major identified future potential contributions to the filter and what can astronomy tell us?

Natural threats:

One threat type where more astronomical observations can help are natural threats, such as asteroid collisions, supernovas, gamma ray bursts, rogue high gravity bodies, and as yet unidentified astronomical threats. Careful mapping of asteroids and comets is ongoing and requires more continued funding rather than any intrinsic improvements in technology. Right now, most of our mapping looks at objects at or near the plane of the ecliptic and so some focus off the plane may be helpful. Unfortunately, there is very little money to actually deal with such problems if they arise. It might be possible to have a few wealthy individuals agree to set up accounts in escrow which would be used if an asteroid or similar threat arose.

Supernovas are unlikely to be a serious threat at this time. There are some stars which are close to our solar system and are large enough that they will go supernova. Betelgeuse is the most famous of these with a projected supernova likely to occur in the next 100,000 years. However, at its current distance, Betelgeuse is unlikely to pose much of a problem unless our models of supernovas are very far off. Further conventional observations of supernovas need to occur in order to understand this further, and better neutrino observations will also help but right now, supernovas do not seem to be a large risk. Gamma ray bursts are in a situation similar to supernovas. Note also that if an imminent gamma ray burst or supernova is likely to occur, there's very little we can at present do about it. In general, back of the envelope calculations establish that supernovas are highly unlikely to be a substantial part of the Great Filter.

Rogue planets, brown dwarfs or other small high gravity bodies such as wandering black holes can be detected and further improvements will allow faster detection. However, the scale of havoc created by such events is such that it is not at all clear that detection will help. The entire planetary nuclear arsenal would not even begin to move their orbits a substantial extent.

Note also it is unlikely that natural events are a large fraction of the Great Filter. Unlike most of the other threat types, this is a threat type where radio astronomy and neutrino information may be more likely to identify problems.

Biological threats:

Biological threats take two primary forms: pandemics and deliberately engineered diseases. The first is more likely than one might naively expect as a serious contribution to the filter, since modern transport allows infected individuals to move quickly and come into contact with a large number of people. For example, trucking has been a major cause of the spread of HIV in Africa and it is likely that the recent Ebola epidemic had similar contributing factors. Moreover, keeping chickens and other animals in very large quanities in dense areas near human populations makes it easier for novel variants of viruses to jump species. Astronomy does not seem to provide any relevant assistance here; the only plausible way of getting such information would be to see other species that were destroyed by disease. Even with resolutions and improvements in telescopes by many orders of magnitude this is not doable.

Nuclear exchange:

For reasons similar to those in the biological threats category, astronomy is unlikely to help us detect if nuclear war is a substantial part of the Filter. It is possible that more advanced telescopes could detect an extremely large nuclear detonation if it occurred in a very nearby star system. Next generation telescopes may be able to detect a nearby planet's advanced civilization purely based on the light they give off and a sufficiently large detonation would be of the same light level. However, such devices would be multiple orders of magnitude larger than the largest current nuclear devices. Moreover, if a telescope was not looking at exactly the right moment, it would not see anything at all, and the probability that another civilization wipes itself out at just the same instant that we are looking is vanishingly small.

Unexpected physics:

This category is one of the most difficult to discuss because it so open. The most common examples people point to involve high-energy physics. Aside from theoretical considerations, cosmic rays of very high energy levels are continually hitting the upper atmosphere. These particles frequently are multiple orders of magnitude higher energy than the particles in our accelerators. Thus high-energy events seem to be unlikely to be a cause of any serious filtration unless/until humans develop particle accelerators whose energy level is orders of magnitude higher than that produced by most cosmic rays. Cosmic rays with energy levels beyond what is known as the GZK energy limit are rare. We have observed occasional particles with energy levels beyond the GZK limit, but they are rare enough that we cannot rule out a risk from many collisions involving such high energy particles in a small region. Since our best accelerators are nowhere near the GZK limit, this is not an immediate problem.

There is an argument that we should if anything worry about unexpected physics, it is on the very low energy end. In particular, humans have managed to make objects substantially colder than the background temperature of 4 K with temperature as on the order of 10-9 K. There's an argument that because of the lack of prior examples of this, the chance that something can go badly wrong should be higher than one might estimate (See here.) While this particular class of scenario seems unlikely, it does illustrate that it may not be obvious which situations could cause unexpected, novel physics to come into play. Moreover, while the flashy, expensive particle accelerators get attention, they may not be a serious source of danger compared to other physics experiments.

Three of the more plausible catastrophic unexpected physics dealing with high energy events are, false vacuum collapse, black hole formation, and the formation of strange matter which is more stable than regular matter.

False vacuum collapse would occur if our universe is not in its true lowest energy state and an event occurs which causes it to transition to the true lowest state (or just a lower state). Such an event would be almost certainly fatal for all life. False vacuum collapses cannot be avoided by astronomical observations since once initiated they would expand at the speed of light. Note that the indiscriminately destructive nature of false vacuum collapses make them an unlikely filter. If false vacuum collapses were easy we would not expect to see almost any life this late in the universe's lifespan since there would be a large number of prior opportunities for false vacuum collapse. Essentially, we would not expect to find ourselves this late in a universe's history if this universe could easily engage in a false vacuum collapse. While false vacuum collapses and similar problems raise issues of observer selection effects, careful work has been done to estimate their probability.

People have mentioned the idea of an event similar to a false vacuum collapse but which occurs at a speed slower than the speed of light. Greg Egan used it is a major premise in his novel, "Schild's Ladder." I'm not aware of any reason to believe such events are at all plausible. The primary motivation seems to be for the interesting literary scenarios which arise rather than for any scientific considerations. If such a situation can occur, then it is possible that we could detect it using astronomical methods. In particular, if the wave-front of the event is fast enough that it will impact the nearest star or nearby stars around it, then we might notice odd behavior by the star or group of stars. We can be confident that no such event has a speed much beyond a few hundredths of the speed of light or we would already notice galaxies behaving abnormally. There is a very narrow range where such expansions could be quick enough to devastate the planet they arise on but take too long to get to their parent star in a reasonable amount of time. For example, the distance from the Earth to the Sun is on the order of 10,000 times the diameter of the Earth, so any event which would expand to destroy the Earth would reach the Sun in about 10,000 times as long. Thus in order to have a time period which would destroy one's home planet but not reach the parent star it would need to be extremely slow.

#### It solves warming

Glen Hendrix 19. Engineer, refinery heater designer, science fiction writer. 5-13-2019. "The Environmental Advantages of a Space Elevator." Medium. https://medium.com/predict/the-environmental-advantages-of-a-space-elevator-91a355e3d68c

Climate change is big. It’s bad. Don’t let anyone tell you otherwise. It’s going to be a rough few hundred, maybe few thousand, years for humanity. The short term view is not encouraging. The fossil fuel energy companies are going to fight tooth and claw to keep selling combustibles. The long term view is more optimistic. As the adverse affects of climate change begin to multiply and intensify, naysayers will be silenced, and social pressure will mandate change. Will it be enough soon enough? Hard to say. If mankind ever gets this CO2 problem under control, we will be looking at different ways to do business that protects the Earth in a more proactive manner, keeping the environment as ideal for life, all life, as possible.

A space elevator may be the key technology for mankind to have it’s cake and eat it, too while the Earth’s climate rebalances. With a space elevator, all the nasty industrial processes that require a lot of energy and cause a lot of pollution could take place in orbit around the Earth. The end products of those orbital industries could then be more easily and cheaply transported to Earth via the space elevator.

A space elevator could also preserve planetary resources. The materials needed for these myriad industrial processes may not even need to come from the surface of the planet. Most can be found in the asteroids or on the Moon. Need fuel? Load up an orbital tanker from a methane lake on Titan, one of the moons of Jupiter. Need water. Find an asteroid made of water and mine it. It is estimated half the water in the oceans came from a bombardment of water-bearing asteroids. Need metal? Nickel-iron asteroids are plentiful. Need energy? Build focusing mirrors for heat and solar panels for electricity.

How does a space elevator work? Take a piece of string with a weight on one end. Pick the string up by the weightless end and spin around until the weight is straight out from your body. A ladybug makes an amazing landing on the string and starts walking out the string to the counterweight. You are the Earth, the string is the elevator cable or tether, the weight is the counterweight, and the ladybug is the car that goes up and down the cable. It’s not a perfect analogy, but it gives a good idea of what and where the major parts are. The counterweight would be about 60,000 to 90,000 miles up from the Earth’s surface. The center of mass of the whole thing should be at geosynchronous orbit, about 22,000 miles up. Now quit spinning and sit down because you’re gonna be dizzy.

Currently, carbon nanotubes are in the running to be the material that can withstand the tremendous stresses of this application. Someone just has to figure out how to make a 60,000 mile long ribbon of the stuff with no imperfections. Meteoroids and space debris are a major problem. Protective measures must be implemented. A major clean-up of our space debris may be in order before we invest in such a mega-project as the space elevator.

With the polluting industries moved to orbit, imagine the Earth as a giant natural park. Yes, we’ll live here, but not as obtrusively as before. One counterintuitive idea would be a further consolidation of humanity into supercities. Megalithic structures would house humanity. Supercities could eliminate untold millions of miles of transportation because everything and everyone is so much closer. Walking would be the preferred mode of transportation along with personal electric scooters and elevators.

It would free up a lot of land for planting trees and other plants to sequester CO2. Meat would be grown or fabricated in a lab. Multistory greenhouses would grow our vegetables and grains. Supercities would be connected by high speed underground subways like Hyperloop. Other means of transportation will be electric drones and hybrid airships that can flip between heavier and lighter-than-air modes of flight.

#### Extinction

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Catastrophic climate change

Though by no means certain, CCC causing global extinction is possible due to interrelated factors of non-linearity, cascading effects, positive feedbacks, multiplicative factors, critical thresholds and tipping points (e.g. Barnosky and Hadly, 2016; Belaia et al., 2017; Buldyrev et al., 2010; Grainger, 2017; Hansen and Sato, 2012; IPCC 2014; Kareiva and Carranza, 2018; Osmond and Klausmeier, 2017; Rothman, 2017; Schuur et al., 2015; Sims and Finnoff, 2016; Van Aalst, 2006).7

A possibly imminent tipping point could be in the form of ‘an abrupt ice sheet collapse [that] could cause a rapid sea level rise’ (Baum et al., 2011, p. 399). There are many avenues for positive feedback in global warming, including:

• the replacement of an ice sea by a liquid ocean surface from melting reduces the reflection and increases the absorption of sunlight, leading to faster warming;

• the drying of forests from warming increases forest fires and the release of more carbon; and

• higher ocean temperatures may lead to the release of methane trapped under the ocean floor, producing runaway global warming.

Though there are also avenues for negative feedback, the scientific consensus is for an overall net positive feedback (Roe and Baker, 2007). Thus, the Global Challenges Foundation (2017, p. 25) concludes, ‘The world is currently completely unprepared to envisage, and even less deal with, the consequences of CCC’.

The threat of sea-level rising from global warming is well known, but there are also other likely and more imminent threats to the survivability of mankind and other living things. For example, Sherwood and Huber (2010) emphasize the adaptability limit to climate change due to heat stress from high environmental wet-bulb temperature. They show that ‘even modest global warming could ... expose large fractions of the [world] population to unprecedented heat stress’ p. 9552 and that with substantial global warming, ‘the area of land rendered uninhabitable by heat stress would dwarf that affected by rising sea level’ p. 9555, making extinction much more likely and the relatively moderate damages estimated by most integrated assessment models unreliably low.

While imminent extinction is very unlikely and may not come for a long time even under business as usual, the main point is that we cannot rule it out. Annan and Hargreaves (2011, pp. 434–435) may be right that there is ‘an upper 95 per cent probability limit for S [temperature increase] ... to lie close to 4°C, and certainly well below 6°C’. However, probabilities of 5 per cent, 0.5 per cent, 0.05 per cent or even 0.005 per cent of excessive warming and the resulting extinction probabilities cannot be ruled out and are unacceptable. Even if there is only a 1 per cent probability that there is a time bomb in the airplane, you probably want to change your flight. Extinction of the whole world is more important to avoid by literally a trillion times.

#### Plan solves launch debris---extinction

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All objects in HEO reside beyond the geostationary orbit (GEO). The orbital period at GEO (w'hich is aligned with the Earth's equator) is equal to the Earth’s rotational period. As a result, from a ground observer’s perspective the satellite resides at a fixed point in the sky, with clear advantages for uses such as global communication. Activities at HEO are considerably less than at LEO and MEO. Earth's orbital environment does contain a natural component - the meteoroids. These pose little to no threat to space operations - the true threat is self-derived.

The current limitations of spacefaring technology ensure that every launch is accompanied by substantial amounts of space debris. This debris ranges in size from dust grains to paint flecks to large derelict spacecraft and satellites. According to NASA’s Orbital Debris Program Office, some 21.000 objects greater than 10 cm in size are currently being tracked in LEO. with the population below 10 cm substantially higher. Most debris produced at launch tends to be deposited with no supplemental velocity - hence these objects tend to follow the initial launch trajectory, which often orbits with high eccentricity and inclination. However, these orbits do intersect with the orbits of Earth’s artificial satellite population, resulting in impacts w'hich tend to produce further debris.

The vast majority of the low-size debris population is so-called fragmentation debris. This is produced during spacecraft deterioration, and in the most abun- dance during spacecraft break-up and impacts. The first satellite-satellite collision occurred in 1961. resulting in a 400% increase in fragmentation debris (Johnson et al.. 2008). Most notably, a substantial source of fragmentation debris was the deliberate destruction of the Fengyun 1C satellite by the People’s Republic of China, which created approximately 2.000 debris fragments.

As with collisions of ‘natural debris’, debris-debris collisions tend to result in an increased count of debris fragments. Since the late 1970s, it has been understood that man-made debris could pose an existential risk to space operations. Kessler and Cour-Palais (1978) worked from the then-population of satellites to extrapolate the debris production rate over the next 30 years. Impact rates on spacecraft at any location. /, can be calculated if one knows the local density of debris p, the mean relative velocity vrei\* and the cross-sectional area ct:

[[EQUATION 13.5 OMITTED]]

Each impact increases p without substantially altering vrel or o. We should there- fore expect the impact rate (and hence the density of objects) to continue growing at an exponential rate:

[[EQUATION 13.6 OMITTED]]

Kessler and Cour-Palais (1978) predicted that by the year 2000, p would have increased beyond the critical value for generating a collisional cascade. As new collisions occur, these begin to increase ^jjp, which in turn increases resulting in a rapid positive feedback, with p and I reaching such large values that LEO is rendered completely unnavigable.

This has not come to pass - LEO remains navigable, partially due to a slight overprediction of debris produced by individual launches. The spectre of a collisional cascade (often referred to as Kessler syndrome) still looms over human space exploration, as debris counts continue to rise. Without a corresponding dedicated effort to reduce these counts, either through mitigating strategies to reduce the production of debris during launches, or through removal of debris fragments from LEO. we cannot guarantee the protection of the current flotilla of satellites, leaving our highly satellite-dependent society at deep risk.

What strategies can be deployed to remove space debris? Almost all debris removal techniques rely on using the Earth’s atmosphere as a waste disposal sys- tem. Most debris is sufficiently small that atmospheric entry would result in its complete destruction, with no appreciable polluting effects. Atmospheric entry requires the debris fragments to be decelerated so that their orbits begin to intersect with lower atmospheric altitudes. Once a critical altitude is reached, atmospheric drag is sufficiently strong that the debris undergoes runaway deceleration and ultimately destruction.

There are multiple proposed techniques for decelerating debris. Some mechani- cal methods include capturing the debris using either a net or harpoon, and applying a modest level of reverse thrust. These are most effective for larger fragments, and especially intact satellites (Forshaw et al., 2015). Attaching sails to the debris is also a possibility if the orbit is sufficiently low for weak atmospheric drag.

The Japanese space agency JAXA’s Kounotori Integrated Tether Experiment (KITE) will trail a long conductive cable. As a current is passed through the cable, and the cable traverses the Earth’s magnetic field, the cable experiences a magnetic drag force that will de-orbit the spacecraft.

Orbiting and ground-based lasers can decelerate the debris through a variety of means. For small debris fragments, the radiation pressure produced by the laser can provide drag. A more powerful laser can act on larger debris fragments through ablation. As the laser ablates the debris, the resulting recoil generated by the escaping material produces drag and encourages de-orbit.

A more lateral solution is to ensure that launches and general space-based activity no longer generate debris. These approaches advocate lower-energy launch mechanisms that do not rely on powerful combustion. The most famous is the space elevator (see Aravind. 2007). Originally conceived by Tsiolkovsky, the ele- vator consists of an extremely durable cable extended from a point near the Earth’s equator, up to an anchor point located at GEO (most conceptions of the anchor point envision an asteroid parked in GEO).

‘Climber’ cars can then be attached to the cable and lifted to LEO, MEO and even GEO by a variety of propulsion methods. Most notably, the cars can be driven to GEO without the need for chemical rockets or nuclear explosions - indeed, a great deal of energy can be saved by having coupled cars, one ascending and one descending.

Space elevators would solve a great number of problems relating to entering (and leaving) Earth orbit, substantially reducing the cost of delivering payload out of the Earth's atmosphere. The technical challenges involved in deploying a cable tens of thousands of kilometres long are enormous, not to mention the material science required to produce a cable of sufficient tensile strength and flexibility in the first place. The gravitational force (and centrifugal force) felt by the cable will vary significantly along its length. As cars climb the cable, the Coriolis force will move the car (and cable) horizontally also, providing further strain on the cable material. The relatively slow traversal of the biologically hazardous Van Allen Belt on the route to GEO is also a potential concern for crewed space travel.

Whatever the means, a spacefaring civilisation (or at least, a civilisation that utilises its local orbital environment as we do) must develop a non-polluting solution to space travel, whether that is via the construction of a space elevator, a maglev launch loop, rail gun, or some other form of non-rocket acceleration. If it cannot perform pollution-free spacecraft launches (or fully clean up its pollution), then it will eventually succumb to Kessler syndrome, with potentially drastic consequences for future space use, with likely civilisation-ending effects (Solution C.13).

#### Space col is key to avoid extinction---only the plan solves

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Space colonization is not only the subject of fiction but of serious science too. The late physicist Stephen Hawking argued that unless colonies were established in space the human race would become extinct. There are several natural phenomena beyond our control that could spell our obliteration. Over a long enough period of time our planet is vulnerable to catastrophic meteorite strikes, or getting exposed to the deadly radiation of a nearby supernova explosion. As our Sun burns its fuel it will start to expand and, in a few million years, will scorch Earth. We can also self-destruct by waging nuclear war, or by tilting our planet’s climate towards a runaway greenhouse effect. Space colonization is therefore the ultimate insurance policy of long-term human survival[4].

Physics and Biology: how to solve the challenges of interstellar travel

But colonizing space is hard. Three are the main problem categories for humans surviving away from Earth over an indefinite period of time. The first, and probably easiest to solve, is finding a place suitable for colonization. Our solar system provides several possible habitats, the most obvious ones being of course the Moon and Mars. The Jovian moons could also be colonization targets. The Artemis Project[5], a private venture to establish a permanent, self-sustainable human base on the Moon, has proposed the Jovian moon Europa as an alternative future habitat, given the possibility of a hot interior and a liquid ocean of water under the icy surface, both of which could provide for a sustainable human base. Colonizing the Solar System could be a stepping-stone for venturing to worlds beyond, of which there are aplenty. In 2009 NASA launched the Kepler space telescope to discover Earth-size planets orbiting other stars in habitable zones. More than 1,300 planets have been discovered so far, in about 440 star systems; the nearest planet may be “only” 12 light years away. Based on Kepler’s findings scientists estimate that there could be as many as 11 billion rocky, Earth-like planets orbiting habitable zones of Sun-like stars in our Galaxy. The possibilities for expanding humanity’s reach in the cosmos are truly astronomical.

The second problem category is how to get to these other worlds: space travel is a hugely challenging technological problem. After more than six decades of space engineering we are still dependent of heavy rockets that burn chemical fuel to get us out of the Earth’s gravity. Perhaps the greatest innovation so far is the reusable rockets pioneered by Elon Musk’s Falcon 9 and Jeff Bezos’s Charon. Having reusable rockets significantly lowers the cost of space flight. According to Elon Musk it costs $60 million to make the Falcon 9, and $200,000 to refuel it, so theoretically by reusing a rocket multiple times the cost of each flight lowers every time it flies. There are of course additional costs for refurbishment after each flight that must be factored in, but reusing rockets looks like the most practical way to advance space technology today. Alternatively, we could have a space elevator carrying people and equipment on low orbit, an idea envisioned by the pioneering Russian scientist Konstantin Tsiolkovsky back in 1895. Researchers in Japan’s Shizuoka University are presently advancing the concept by using two mini satellites to test elevator motion in space. Moreover, the Obayashi Corporation, which will build Japan’s largest tower, has put together a space elevator proposal that will take people from Earth to an orbiting space station. However, the solution requires 60,000 miles of cable made of carbon nanotubes or an as-yet undeveloped material.

[[IMAGE OMITTED]]

Owing to developments in quantum computing in the next ten years, we may be able to exponentially advance the production of materials for constructing space elevators, as well as for developing new rocket fuels; and thus dramatically reduce the cost of space flight. By harnessing near-infinite computing power and accessing calculations at quantum level physicists may be able to unlock the mysteries of dark matter and dark energy, and probe deeper into the fundamental structure the universe.

#### Existential resource wars are coming---signaling that space access will cheapen is key.

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Human civilization currently faces many serious dangers. The most immediate catastrophic threat, however, does not come from environmental degradation, resource depletion, or even asteroidal impact. It comes from bad ideas.

Ideas have consequences. Bad ideas can have really bad consequences.

The worst idea that has ever been is that the total amount of potential resources is fixed. It is a catastrophic idea, because it sets all against all.

Currently, such limited-resource views are quite fashionable among not only futurists but much of the body politic. But if they prevail, then human freedoms must be curtailed. Furthermore, world war and genocide would be inevitable, for if the belief persists that there is only so much to go around, then the haves and the want-to-haves are going to have to duke it out, the only question being when.

This is not an academic question. The twentieth century was one of unprecedented plenty. Yet it saw tens of millions of people slaughtered in the name of a struggle for existence that was entirely fictitious. The results of similar thinking in the twenty-first could be far worse.

The logic of the limited-resource concept leads down an ever more infernal path to the worst evils imaginable. Basically, it goes as follows:

1. Resources are limited.

2. Therefore, human aspirations must be crushed.

3. So, some authority must be empowered to do the crushing.

4. Since some people must be crushed, we should join with that authority to make sure that it is those we despise rather than us.

5. By getting rid of such inferior people, we can preserve scarce resources and advance human social evolution, thereby helping to make the world a better place.

The fact that this case for oppression, tyranny, war, and genocide is entirely false has made it no less devastating. Indeed, it has been responsible for most of the worst human-caused disasters of the past two hundred years. So let's take it apart.

[[FIGURE 12.1 OMITTED]]

Two hundred years ago, the English economist Thomas Malthus set forth the proposition that population growth must always outrun production as a fundamental law of nature. This theory provided the basis for the cruel British response to famines in Ireland and India during the latter part of the nineteenth century, denying food aid or even regulatory, taxation, or rent relief to millions of starving people on the pseudoscientific grounds that their doom was inevitable.1

Yet the data show that the Malthusian theory is entirely counterfactual. In fact, over the two centuries since Malthus wrote, world population has risen sevenfold, while inflation-adjusted global gross domestic product per capita has increased by a factor of 50, and absolute total GDP by a factor of 350.

Indeed, it is clear that the Malthusian argument is fundamentally nonsense, because resources are a function of technology, and the more people there are and the higher their living standard, the more inventors, and thus inventions, there will be—and the faster the resource base will expand.

Our resources are growing, not shrinking, because resources are defined by human creativity. In fact, there is no such thing as “natural resources.” There are only natural raw materials. It is human ingenuity that turns natural raw materials into resources.

Land was not a resource until people invented agriculture, and it is human ingenuity, manifested in continuous improvements in agricultural technology, that has multiplied the size of that resource many times over.

Petroleum was not originally a resource. It was always here, but it was nothing useful. It was just some stinky black stuff that sometimes oozed out of the ground and ruined good cropland or pasture. We turned it into a resource by inventing oil drilling and refining, and by showing how oil could be used to replace whale oil for indoor lighting, and then, later, by liberating humanity with unprecedented personal mobility.

This is the history of the human race. If you go into any real Old West antique store and look at the things owned by the pioneers, you will see things made of lumber, paper, leather, wool, cotton, linen, glass, carbon steel, maybe a little bit of copper and brass. With the arguable exception of lumber, all of those materials are artificial. They did not, and do not, exist in nature. The civilization of that time created them. But now go into a modern discount store, like Target. You will see some items made of the same materials, but much more made of plastic, synthetic fibers, stainless steel, fiberglass, aluminum, and silicon. And in the parking lot, of course, gasoline. Most of the materials that make up the physical products of our civilization today were unknown 150 years ago. Aluminum and silicon are the two most common elements in the Earth's crust. But the pioneers never saw them. To the people of that time, they were just dirt. It is human invention that turned them from dirt into vital resources.

There are things around today that clearly could become major resources but are not yet. Uranium and thorium were not resources at all until we invented nuclear power, but we are going to have to do a bit more inventing to get all the bugs out so as to unleash their truly vast potential. The same thing is true for solar energy, which needs to be made cheaper if it is to become truly practical as a baseload energy source. But this is happening, year by year, through innumerable inventions, great and small. Other enormous resources, more distantly in view, await the invention of ways to use them; for example, there is deuterium in seawater that could provide fusion power; there are methane hydrates and stratospheric winds. Today, the revolutionary new resource is shale. Twenty years ago, shale was not a resource. Today, as a result of the invention of new techniques of horizontal drilling and fracking, it's an enormous resource. In the past ten years, we've used it to increase US oil production 120 percent, from five million to eleven million barrels of oil per day. In the past twenty years, America's gas reserves have tripled, and we can and will do that and more for the world at large.

So the fact of the matter is that humanity is not running out of resources. We are exponentially expanding our resources. We can do this because the true source of all resources is not the earth, the ocean, or the sky. It is human creativity.

It is people who are resourceful. It is for this reason that, contrary to Malthus and all of his followers, the global standard of living has continuously gone up as the world's population has increased, not down. The more people—especially free and educated people— the more inventors, and inventions are cumulative.

Furthermore, the idea that nations are in a struggle for existence is completely wrong. Darwinian natural selection is a useful theory for understanding the evolution of organisms in nature, but it is totally false as an explanation of human social development. This is so because, unlike animals or plants, humans can inherit acquired characteristics—for example, new technologies—and do so not only from parents but from those to which they are entirely unrelated. Thus, inventions made anywhere ultimately benefit people everywhere. Human progress does not occur by the mechanism of militarily superior nations eliminating inferior nations. Rather, inventions made in one nation are transferred all over the world, where, newly combined with other technologies and different mind-sets, they blossom in radical new ways. Paper and printing were invented in China, but they needed to be combined with the Phoenician-derived Latin alphabet, German metal-casting technology, and European outlooks concerning freedom of conscience, speech, and inquiry to create a global culture of mass literacy. The same pattern of multiple sourcing of inventions holds true for virtually every important human technology today, from domesticated plants and animals to telescopes, rockets, and interplanetary travel.

Based on its inventiveness and its ability to bring together people and ideas from everywhere, America has become extremely rich, inciting envy elsewhere. But other countries would not be richer if America did not exist, or were less wealthy or less free. On the contrary, they would be immeasurably poorer.

Similarly, America would not benefit by keeping the rest of the world underdeveloped. We can take pride in our creativity, but in fact we would be much better off if all other people had as good a chance to develop and exercise their potential, and thus contribute to progress, as we do.

Nevertheless, so long as humanity is limited to one planet, the arguments of the Malthusians have the appearance of self-evident truth, and their triumph can have only the most catastrophic results.

Indeed, one has only to look at the history of the twentieth century, and the Malthusian/national social Darwinist rationale that provided the drive to war of both Imperial and, especially, Nazi Germany to see the horrendous consequences resulting from the widespread acceptance of such myths.

As the German General Staff's leading intellectual, General Friedrich von Bernhardi, put in his 1912 bestseller Germany and the Next War:

Strong, healthy, and flourishing nations increase in numbers. From a given moment they require a continual expansion of their frontiers, they require new territory for the accommodation of their surplus population. Since almost every part of the globe is inhabited, new territory must, as a rule, be obtained at the cost of its possessors—that is to say, by conquest, which thus becomes a law of necessity.2

Having accepted that war was inevitable, the only issue for the Kaiser's generals was when to start it, and they chose sooner rather than later so as not to give Russian industry a chance to develop.

Thus in 1914, the unprecedentedly prosperous European civilization was thrown into a completely unnecessary and nearly suicidal general war. A quarter century later, the same logic led the Nazis to do it again, with not merely conquest but systematic genocide as their insane goal.

To be perfectly clear on this point, the crimes of the Nazis were not just committed in secret by a few satanic leaders while the rest of the good citizens proceeded with their decent daily lives in well-meaning ignorance. In point of fact, such blissful ignorance was not possible. At its height, there were more than twenty thousand killing centers in the Third Reich, and most were discovered by Allied forces within hours of their entry into the vicinity—as the stench of their crematoria made them readily detectable. Something on the order of a million Germans were employed operating these facilities, and several million more were members of armed forces or police units engaged in or supporting genocidal operations.3 Thus nearly every German had friends or family members who were eyewitnesses to or direct perpetrators of genocide, who could, and did, inform their acquaintances as to what was happening. (Many sent photos home to their parents, wives, or girlfriends, depicting themselves preparing to kill, killing, or posing astride the corpses of their victims.) Moreover, the Nazi leadership was in no way secretive about its intent; genocide directed against Jews and Slavs was the openly stated goal of the party that eighteen million Germans voted for in 1932. On March 20, 1933, less than two months after the Nazi assumption of power, SS leader Heinrich Himmler made it clear that these voters would have their wishes gratified, by announcing the establishment of the first formal concentration camp, Dachau, at a press conference. Furthermore, the implementation of the initial stages of the genocide occurred in public, with systematic degradation, beatings, lynchings, and mass murder of Jews done openly for all to see in the Reich's streets from 1933 onward, with the most extensive killings, such as those of the November 10, 1938, Kristallnacht pogrom, celebrated afterward at enormous public rallies and parties.

So the contention that the Nazi-organized Holocaust took place behind the backs of an unwilling German population is patently false. Rather, the genocidal Nazi program was carried out—and could only have been carried out—with the full knowledge and substantial general support of the German public. The question that has bedeviled the conscience of humanity ever since then: How could this have happened? How could the majority of citizens of an apparently civilized nation choose to behave in such a way? Some have offered German anti-Semitism as the answer. But this explanation fails in view of the fact that anti-Semitism had existed in Germany, and in many other countries such as France, Poland, and Russia to a sometimes much greater extent, for centuries prior to the Holocaust, with no remotely comparable outcome.

Furthermore, the Nazi genocidal program was not directed just against Jews but also at many other categories of despised people, including invalids, Romany people, and the entire Slavic race. Indeed, the Nazis had drawn up a plan, known as the Hunger Plan, for depopulating Eastern Europe, the Balkans, and the Soviet Union through mass starvation following their anticipated victory, on the insane supposition that by ridding the land of its farmers they could make more food available.4 It should be noted that the partial implementation of this plan in occupied areas not only caused tens of millions of deaths but contributed materially to the defeat of the Third Reich, as it made it impossible for the Nazis to mobilize the human potential of the conquered lands on their own behalf. But not even such clear practical military and economic considerations could prevail against the power of a fixed idea.

In other words, as the Nazi leadership itself repeatedly emphasized, the genocide program was not motivated by mere old-fashioned bigotry. It certainly took advantage of such sentiments among rustics, hoodlums, and others to facilitate its operations. But it required something else to convince a nation largely composed of serious, solid, dutiful, highly literate, and fairly intellectual people to devote themselves to such a cause. It took Malthusian pseudoscience.5

Hitler himself was perfectly aware of the central importance of such an ideological foundation for his program of genocide. As noted Holocaust historian Timothy Snyder wrote in a September 2015 New York Times op-ed: “The pursuit of peace and plenty through science, he claimed in Mein Kampf, was a Jewish plot to distract Germans from the necessity of war.”6

Once again, to be clear, the issue is not whether space resources will be made available to Earth in the proximate future. Rather it is how we, in the present, conceive the nature of our situation in the future. Nazi Germany had no need for expanded living space. Germany today is a much smaller country than the Third Reich, with a significantly higher population, yet Germans today live much better than they did when Hitler took power. So, in fact, the Nazi attempt to depopulate Eastern Europe was totally nuts, from not only a moral but also a practical standpoint. Yet, driven on by their false zero-sum beliefs, they tried anyway.

If it is allowed to prevail in the twenty-first century, zero-sum ideology will have even more horrific consequences. For example, there are those who point to the fact that Americans are 4 percent of the world's population yet use 25 percent of the world's oil. If you were a member of the Chinese leadership and you believed in the limited-resource view (as many do—witness their brutal onechild policy), what does this imply you should attempt to do to the United States?

On the other hand, there are those in the US national security establishment who cry with alarm at the rising economy and concomitant growing resource consumption of China. They project a future of “resource wars,” requiring American military deployments to secure essential raw materials, notably oil.7

As a result of acceptance of such ideology, the United States has initiated or otherwise embroiled itself in conflicts in the Middle East costing tens of thousands of American lives (and hundreds of thousands of Middle Eastern lives) and trillions of dollars. For 1 percent of the cost of the Iraq War, we could have converted every car in the United States to flex fuel, able to run equally well on gasoline or methanol made from our copious natural gas.8 For another 1 percent, we could have developed fusion power. Instead, we are fighting wars to try to control oil supplies that will always be sold to the highest bidder no matter who owns them.

[[FIGURE 12.2 OMITTED]]

Figure 12.2. Self-fulfilling prophecies. In 1912, the theoreticians of the German General Staff said it was inevitable that Germany would have to wage war for living space. In 2001, American geostrategists proclaimed we would need to fight for oil. Both were wrong. Both set the stage for disaster. Much worse could be on the way if such zero-sum ideology is not discredited. Image courtesy of Friedrich von Bernhardi, Germany and the Next War, trans. Allen H. Powles (London: Edward Arnold, 1918); Michael T. Klare, Resource Wars (London: Methuen, 1989); Graham Allison, Destined for War (Melbourne: Scribe Publications, 2018).

There were no valid reasons for the first two World Wars, and there is no valid reason for a third. But there could well be one if zero-sum ideology prevails. Despite the bounty that human creativity is producing, there are those in America's national security establishment who today are planning for resource wars against peoples who could and should be our partners in abolishing scarcity. Their equivalents abroad are similarly sharpening their knives against us. This ideology threatens catastrophe.

Today there is a dangerous new anti-Western, antifreedom movement in Russia led by fascist philosopher Aleksandr Dugin, who is attempting to expand it worldwide. (He is doing so with significant success. The American “alt-right” and a host of similar European “identitarian” nativist movements all draw heavily from Dugin's ideas.9 The basic idea is to both balkanize the West and undermine its commitment to humanist ideals by invoking the tribal instinct.) It is the contention of the Duginites that the world would be better off without America, or any other country with liberal values. Indeed, I was present at a conference on global issues held at Moscow State University, Dugin's home turf, in October 2013, when one of his acolytes got up and gave a fiery speech denouncing America for its profligate consumption of the world's resources, including its oxygen supply.10 Such ideas amount to a call for war.

Do we really face the threat of general war? There seems to be no reason for it, and in fact, there isn't. People all over the world today are actually living much better than they ever did before, at any time in human history. But the same was true in 1914. Let us recall that a mere thirty years ago, the world was divided into two hostile camps, ready to spring into action on a few minutes’ notice to destroy each other with tens of thousands of nuclear weapons. That threat vanished—not because of any change in real human circumstances, but due to the disappearance of a bad idea. It can just as quickly reappear with another. As in 1914 and 1939, all it takes is the belief that there isn't enough to go around—that others are using too much, or threatening by their growth to do so in the future—to set the world ablaze.

If it is accepted that the future will be one of resource wars, there are people of action who are prepared to act accordingly.

There is no scientific foundation supporting these motives for conflict. On the contrary, it is precisely because of the freedom and affluence of the United States that American citizens have been able to invent most of the technologies that have allowed China, Russia, and so many other countries to lift themselves out of poverty. And should China (with a population five times ours) develop to the point where its per capita rate of invention mirrors that of the United States— with 4 percent of the world's population producing 50 percent of the world's inventions—the entire human race would benefit enormously. Yet that is not how people see it, or are being led to see it by those who should know better.

Rather, people are being bombarded on all sides with propaganda, not only by those seeking trade wars, immigration bans, or preparations for resource wars, but by those who, portraying humanity as a horde of vermin endangering the natural order, wish to use Malthusian ideology as justification for suppressing freedom. Such arguments sometimes costume themselves as environmentalist, but that is deception. True environmentalism takes a humanist point of view, seeking practical solutions for real problems in order to enhance the environment for the benefit of human life in its broadest terms. It therefore welcomes technological progress. Antihuman Malthusianism, on the other hand, seeks to make use of instances of inadvertent human damage to nature as an ideological weapon of behalf of the age-old reactionary thesis that humans are nothing but pests whose aspirations need to be contained and suppressed by tyrannical overlords to preserve a divinely ordered stasis.

“The Earth has cancer and the cancer is man,” proclaims the elite Club of Rome in one of its manifestos. This mode of thinking has clear implications. One does not provide liberty to vermin. One does not seek to advance the cause of a cancer.

The real lesson of the last century's genocides is this: We are not endangered by a lack of resources. We are endangered by those who believe there is a shortage of resources. We are not threatened by the existence of too many people. We are threatened by people who think there are too many people.

If the twenty-first century is to be one of peace, prosperity, hope, and freedom, a definitive and massively convincing refutation of these pernicious ideas is called for—one that will forever tear down the walls of the mental prison these ideas would create for humanity.

### Spinoffs ADV---1AC

#### Advantage two is SPINOFFS

#### Regardless of completion, meaningful investments in Space Elevator construction catalyze nano-materials innovation---it’s unique because it attracts funding AND attention.

Liam O’Brien 16. University of Wollongong. 07/2016. “Nanotechnology in Space.” Young Scientists Journal; Canterbury, no. 19, p. 22.

Nanotechnology is at the forefront of scientific development, continuing to astound and innovate. Likewise, the space industry is rapidly increasing in sophistication and competition, with companies such as SpaceX, Blue Origin and Virgin Galactic becoming increasingly prevalent in what could become a new commercial space race. The various space programs over the past 60 years have led to a multitude of beneficial impacts for everyday society. Nanotechnology, through research and development in space has the potential to do the same. Potential applications of nanotechnology in space are numerous, many of them have the potential to capture and inspire generations to come. One of these applications is the space elevator. By using carbon nanotubes, a super light yet strong material, this concept would be an actual physical structure from the surface of the Earth to an altitude of approximately 36 000 km. The tallest building in the world would fit into this elevator over 42 000 times. The counterweight, used to keep the elevator taught, is proposed to be an asteroid. This would need to be at a distance of 100 000 km, a quarter of the distance to the moon. The benefits of such a structure would be enormous. 95% of a space shuttle's weight at take-off is fuel, costing US$ 20 000 per kilogram to send something into space.

However, with a space elevator the cost per kilogram can be reduced to as little as US$ 200. Exploration to other planets can begin at the tower, and travel to and from the moon could become as simple as a morning commute to work. Solar sails provide the means to travel large distances and incredible speeds. Much like sails on a boat use wind, the solar sail uses light as a source of propulsion. Ideally these sails would be kilometres in length and only a few micrometres in thickness. This provides us with the ability to travel at speeds previously unheard of. Using carbon nanotubes once again, a solar sail has the capability to travel at 39 756 km/s which is 13% of the speed of light! This sail could reach Pluto in an astonishing 1.7 days, and Alpha Centauri in just 32 years. Space travel to other planets, other stars, could be possible with solar sails. The Planetary Society is funding for a space sail of itself, and has successfully launched one into orbit. NASA has also sent a sail into orbit, allowing it to burn up in the atmosphere after 240 days. Investing time and resources into nanotechnology for space exploration has benefits for society today. Materials such as graphene are being used in modern manufacturing at an increasing rate as the applications become utilised. Carbon nanotubes will change the way we think about materials and their strength. These nanotubes have a tensile strength one hundred times that of steel, yet are only a sixth of the weight.

Imagine light weight vehicles using less petrol and energy as well as being just as strong as regular vehicles. With potentials to revolutionize the way we think about space travel, nanotechnology has a bright future. As a new field of science, it has the capability to push the human race to the outer reaches of our galaxy and hopefully one day to other stars. It will inspire generations of explorers and dreamers to challenge themselves and advance the human race into the next era. As Richard Feynman said in his 1959 talk 'There's Plenty of Room at the Bottom' "A field in which little has been done, but in which an enormous amount can be done. There is still plenty more to achieve.

#### Specifically, it’s key to commercialization and workforce retention---solves cancer AND an impending data crunch

Tarek R. Fadel & Michael A. Meador 16. Fadel is with the International Technology Research Institute; Meador is with the National Nanotechnology Coordination Office. 01/2016. “The Role of Chemical Sciences in the National Nanotechnology Initiative: Accomplishments and Future Direction.” ACS Symposium Series, edited by H. N. Cheng et al., vol. 1220, American Chemical Society, pp. 23–38. DOI.org (Crossref), doi:10.1021/bk-2016-1220.ch003.

Materials with Ten Times the Strength of Steel and a Fraction of the Weight

Years ago, the symbolism behind a carbon nanotube space elevator (15) not only captured the imagination of many, but offered a window into how nanotechnology could enable a revolution in the development of ultra-high strength structural materials (16). Recent research on advanced materials has achieved key milestones for structural applications in the aerospace and defense sectors requiring high strength, lightweight properties (17). Single-walled carbon nanotubes for instance have been shown to exhibit Young’s modulus of approximately one terapascal, fifty times that of steel, tensile strengths in the range of fifty to one hundred gigapascal, and specific strengths up to three-hundred times that of high-carbon steel (18). In practice, carbon nanotube-based sheet materials have been introduced by Nanocomp Technologies, Inc. to help protect vital components of the Juno spacecraft (19). Another example is the use of cost-efficient advanced nanocomposites by Lockheed Martin Corp. onboard the F-35 Joint Strike Fighter (20). Nanocomposite materials are also believed to be used in the fuselage of the Boeing 787 (21).

Early efforts in the utilization of carbon nanotubes to develop high strength materials involved their dispersion in a variety of polymers. While significant progress has been made in this area, the improvements in mechanical properties overall have been limited by agglomeration of the nanotubes as loadings above a few weight percent (22). A more promising approach that has gained attention over the past few years is to incorporate the nanotubes directly into fibers that could be used as drop-in replacements for more conventional fiber reinforcements in composites. Carbon nanotube fibers have been prepared using a variety of methods, including dry spinning from vertically aligned nanotube arrays (23) and nanotube aerogels (24), and wet/solution spinning from lyotropic solutions of carbon nanotubes in strong acids (25) and polyelectrolytes (26). The tensile properties of these fibers are controlled by two competing factors—Van der Waals forces that hold the nanotubes together and the low coefficient of friction of carbon nanotubes that causes them to slide against each other under tension. Improvements in the tensile strength and modulus of these fibers have been demonstrated by introducing cross-links between nanotubes using functionalization (27), e-beam irradiation (28), and a combination of these approaches (29).

While considerable progress has been made in developing high strength carbon nanotube fibers and utilizing them to make ultra-high strength composites (30), much work remains to raise the properties of these bulk materials to those of individual carbon nanotubes (31). Chemical sciences (including informatics) can play an important role in not only minimizing cost of production of these nanomaterials and composites, but also in engineering robust dispersion, stability, and quality processes to enable scalable production of bulk forms of these nanomaterials (31). Advances in synthetic chemistry (including polymer sciences) and understanding of structure-property relationships are also critical to achieve precision-crafting of such materials while maintaining strength properties at the macroscale.

Storing the Library of Congress in a Device the Size of a Sugar Cube

Our world today generates an astronomical amount of data. According to an analysis from the Economist (32), accumulation of data is growing at a compound annual rate of 60% and keeps on increasing. When former President Clinton referred to “storing the Library of Congress in a device the size of a sugar cube,” he introduced a target for information storage that moves along a rapid current of data inflation (for reference, the Economist estimated in 2010 that all the catalogued books in the Library of Congress amounted to 15 terabytes (32)). In order to amass this flood of digital information, some research has focused on shrinking the spatial dimensions of devices’ individual bits. However, such approaches could have limited success due to device scaling challenges (33). From a chemical sciences perspective, engineering new molecular approaches by altering the information storage medium holds significant promise in achieving Clinton’s data storage challenge. For example, researchers from IBM and the German Center for Free-Electron Laser Science recently succeeded in storing one bit of data in as little as twelve atoms. This nanostructure was engineered by aligning two rows of six iron atoms on a surface of copper nitride at a temperature near absolute zero (34). Although a proof of concept at the time, the resulting storage density could be potentially about a hundred times greater than current hard disk drive technologies (about 50 to 100 Terabits per square inch).

Rapid advancement in the synthesis and sequencing of deoxyribonucleic acid (DNA) has also paved the way for novel alternatives to magnetic and optical storage mediums (35). Indeed, chemical engineering of complex DNA nanostructures has been demonstrated in structural biology, biocatalysis, and drug delivery-related applications (36), and the per-base cost of DNA sequencing has plummeted by about a hundred thousand-fold over the past decade, far outpacing Moore’s law (37). Now, DNA-based storage media are being demonstrated by various research groups. Notably, Church and colleagues at the Harvard Medical School and the Wyss Institute of Biologically Inspired Engineering published in 2012 a strategy to encode arbitrary digital information in DNA, and outlined how each gram of DNA could store 455 exabytes of data (one exabyte is one quintillion bytes) (38). These researchers achieved 5.27 megabit-size coding from a book into roughly 55,000 oligonucleotides and successfully sequenced the data that was stored in the DNA medium.

Other efforts to develop new information storage medium have explored building binary data into strands of synthetic polymer. Control of monomer sequences at the molecular level allows for encryption of any desired sequence in the polymer chain, where monomers or functional side-groups could be regarded as information bit (39). For example, recent work by Roy and co-workers intentionally assigned zero or one values to monomers, which were then assembled in a specific order to store information into the polymer (40). This approach relies on the use of two successive chemoselective coupling steps, and can be easily sequenced using mass spectrometry.

Overall, further advances in nanotechnology-based information storage will occur by continuing to exploit the intersections of the chemical sciences with engineering, physics, and biology. Considerations of data security and protection of privacy should be an essential design component when developing these technologies.

Detecting Cancerous Tumors before They Are Visible to the Human Eye

Cancer continues to plague the world. According to PBS’s Cancer: The Emperor of All Maladies, “more will die from cancer [in the U.S.] over the next two years than died in combat in all the wars the United States has ever fought, combined” (41). Although more options for the treatment of various cancers have been developed, an important issue remains with the earlier detection of tumors in patients, which is central to the success of cancer therapy (42). For example, more than 80% of patients diagnosed with lung cancer present a metastatic form of the disease (43). In early stage cancers, various biomarkers are present in the bloodstream at low concentration, as well as cancer cells from primary tumors, known as circulating tumor cells (CTCs) (44). In this case, advances in sensor nanotechnologies could make early detection of CTCs and tumor biomarkers a clinical reality: for example, with magnetic nanoparticles that are functionalized with an affinity ligand, or polymer nanoparticles with long circulation time (43).

In vitro nanotechnology-based devices for the early detection of CTCs are now being offered at the clinic. For example, Veridex’s CellSearch® uses a ferrofluid reagent that consists of nanoparticles with a magnetic core surrounded by a polymeric layer and coated with target antibodies (45). After capture and enrichment, fluorescent reagents are added for identification and enumeration of CTCs. This system aims to provide a rapid, precise, and reproducible platform to capture CTCs of epithelial origin from whole blood and help determine patient prognosis (46). The CellSearch® platform was shown to detect as little as 5 CTCs per 7.5 ml of blood (47), and is currently being used to aid in the monitoring of patients with metastatic breast, colorectal, or prostate cancer.

An alternate method for the earlier diagnosis of cancer focuses on the detection of tumor biomarkers. For example, the VerigeneTM system by Nanosphere is an automated platform based on disposable test cartridges (48). Samples loaded onto the cartridge are treated for nucleic acid extraction, purification, and hybridization, which is carried out using oligonucleotide-conjugated gold nanoparticles. Although not currently approved by the FDA for clinical applications in cancer, Nanosphere’s development of the Verigene platform provides the capability to quantify markers indicative of certain tumors at very low concentrations using high-sensitivity protein diagnostics (femtomolar range) (49). Preliminary work demonstrated clinical relevance in bladder, kidney, and prostate cancers (50). Google Life Sciences is researching similar efforts by developing an in vivo nanoparticle-based sensing platform that can detect cancer biomarkers directly in the bloodstream (51). A magnetically-active wearable device would then attract and count the target-bound nanoparticles to monitor the progression of the disease.

A hallmark of nanotechnology-enabled drug delivery has been the capacity to exploit a phenomenon known as permeability and retention (EPR) effect (52). Tumor vessels have indeed bigger fenestration pores than normal vasculature, and tumors’ lymphatic drainage network is inadequate to clear macromolecules that enter in the tumor area, thus both contributing to accumulation of systemically administered macromolecular compounds, including nanoparticles (53). New techniques are now being engineered to take into account this unique tumor microenvironment for imaging applications, although not necessarily at the single-cell level. For example, Merrimack Pharmaceuticals’ MM-DX-929 is a nanoliposomal particle system functionalized with polyethylene glycol (PEG) and encapsulating copper-64 for positron emission tomography (PET) imaging function (54). MM-DX-929 is being developed as a “companion system” that helps identify patient populations who would best respond to liposomal chemotherapeutics (55).

While the examples highlighted above illustrate the progress made towards nanotechnology-enabled tumor diagnostics, it is important to note that the biological signature of cancer cells is highly heterogeneous and indeed varies from patient to patient (even within a cancer type). Identifying a correct combination of biomarkers for a particular cancer can be therefore particularly challenging. Future progress in nanotechnology-enabled cancer diagnostics should be synergized with advancements in genomics, protein engineering, and tumor biology.

NNI 2.0: Fueling the Engines of Creation

While investments in fundamental nanoscience and engineering will continue, the second era of the National Nanotechnology Initiative, dubbed NNI 2.0, will provide greater focus on realizing the full benefits of progress made in basic and applied research, including advances in each of the Clinton challenges highlighted above. According to the latest review of the NNI by the President’s Council of Advisors on Science and Technology (PCAST), “this next technological generation will see the evolution from nanoscale components to interdisciplinary nano-systems and the movement from a foundational research-based initiative to one that also provides the necessary focus to ensure rapid commercialization of nanotechnology” (56). So far, over twenty billion dollars have been invested by the Federal agencies participating in the NNI towards fundamental and applied nanotechnology R&D; world-class characterization, testing, and fabrication facilities; education and workforce development; and efforts directed at understanding and controlling the environmental, health, and safety aspects of nanotechnology (13).

A Renewed Focus on Commercialization

Transfer of nanotechnology research into commercial applications requires advancements in manufacturing technologies that are scalable and cost-effective, as well as access to and retention of a skilled workforce (13). One of the four goals of the NNI is to “foster the transfer of new technologies into products for commercial and public benefit.” A range of public and private initiatives to accelerate the commercialization of nanotechnology have produced new activities that address manufacturing challenges, promote the formation of new businesses or success of early stage businesses, and development of a skilled workforce (57). For example, a recent NNI-sponsored technical interchange meeting on Realizing the Promise of Carbon Nanotubes: Challenges, Opportunities, and the Pathway to Commercialization (31), focused on identifying the technical barriers to the production of CNT-based bulk and composite materials with electrical and mechanical properties nearer the ideal, and exploring ways to overcome these barriers.

Another example is the work by NNCO with the small- and medium-sized business community to coordinate a series of publicly-available webinars that identify challenges and successes in the commercialization of nanotechnology and provide information from the public and private sectors to help address these challenges (58). NNCO is also supporting Federal agencies participating in the NNI to launch multiple new activities aimed at educating students and the public about nanotechnology, including image and video contests highlighting student research (EnvisioNano), a new webinar series focused on providing nanotechnology information for K-12 teachers, and a searchable web portal of nanoscale science and engineering resources for teachers and professors on nano.gov.

All Nanotechnologies on Deck To Solve Grand Challenges

On June 17, 2015, the Office of Science and Technology Policy (OSTP) issued a request for information (RFI) (59) and an accompanying blog post (60) seeking suggestions for Nanotechnology-Inspired Grand Challenges for the Next Decade. As an element of President Obama’s Strategy for American Innovation (61), a Grand Challenge is described as “an ambitious but achievable goal that requires advances in science and technology to achieve, and that has the potential to capture the public’s imagination.” Some historical examples of Grand Challenges have been President Kennedy’s call to put a man on the moon or the Human Genome Project. Under the auspices of the NSET Subcommittee, Federal agencies participating in the NNI, working with OSTP and the NNCO, developed several examples of nanotechnology-inspired Grand Challenges. These examples were included in the RFI and covered broad topics in the areas of health care, electronics, materials, sustainability, and product safety.

An important component of these Grand Challenges is harnessing public–private mechanismsto achieve the commercialization of nanotechnologies. PCAST, in their most recent triennial assessment of the NNI, recommended “that the Federal Government transition its activities toward facilitating commercialization by directing the formulation of specific nanotechnology Grand Challenges. The Grand Challenges framework—a partnership between the public and private sectors—can drive scientific advances to revolutionary commercialized products” (56). A priority was also placed on ensuring that these Grand Challenges have a specific set of criteria, including: a well-defined goal inspiring different sectors and addressing an issue of significant societal impact; a measurable end-point and a finite lifetime; and a network of activities that will drive scientific ideas to commercialization and catalyze new discovery for technologies of the future. As representatives from OSTP and NNI member agencies review these submissions, a priority will be placed on establishing a process to engage with leaders from industry and private organizations to take on a Grand Challenge topic.

#### **New storage tech solves the coming data crunch---extinction**

Dr. Robert Shapiro 9, Professor Emeritus and Senior Research Scientist in the Chemistry Department of New York University, “A New Rationale for Returning to the Moon? Protecting Civilization with a Sanctuary”, Space Policy, Volume 25, Number 1, p. 1

1. Introduction: two worthy causes

1. The past decades have seen an explosion in the production of scientific data and cultural material. By force of necessity they are being stored in digital form. Older materials are also being converted to digital form, allowing much of humanity access to a treasure of science and art that can readily be explored and utilized. However, this new storage medium is more fragile than paper, both because of its inherent nature and of its greater vulnerability to local disasters and global catastrophes. If our cultural heritage were substantially damaged or lost, our civilization could not function, and humanity would be reduced to a barbaric state. A measure of protection could be gained by the construction of facilities which would preserve our heritage, and assist in the reconstruction of society after a catastrophe.
2. A generation ago human beings walked on the Moon. The Apollo program may have resulted as a by-product of competition between nations in the Cold War, but it produced media coverage and images that were inspirational. However, no further purpose emerged from that presence to stimulate the imagination of the public, and no further human expeditions beyond Earth orbit have been launched since that time. Several years ago President George Bush announced the Vision for Space Exploration [2], which involved a return of humans to the Moon. Economically emerging nations have also indicated an interest in lunar exploration. But the reasons provided have not really justified the expenses involved. In the absence of a transcendent purpose, the prospects for human expansion into space remain uncertain. We believe however that the construction of a substantial lunar base as part of a program to ensure the survival of human civilization on Earth is a goal that would link and justify purposes (1) and (2). This would literally be a marriage made in heaven.

The following sections briefly describe the emerging data crisis and explain the nature of the proposed remedy.

2. The digital age of information storage

Digital storage is common in certain areas of science where enormous quantities of data are being generated, for example by the various genome sequencing projects and by the Large Hadron Collider at CERN, in Switzerland [3]. These data, which may consist of many terabytes (1012 bytes), are generated and stored in digital form, with no existence on paper. Other huge compendia of knowledge have accumulated more gradually. Until recently they were housed as multiple volume sets that challenged the storage space of university libraries.

For example, Chemical Abstracts Service has provided a short account of papers published in the significant journals of chemistry, and kept a record of chemical substances. By 2007 it had listed 27 million journal articles and patent record summaries and over 31 million chemicals [4]. In its first year of publication, 1907, the Abstracts required three volumes of ordinary size. I examined one in the New York University library several years ago and found that its yellowed and brittle pages could still be used. The library's shelf collection extended through 2000, a year in which Chemical Abstracts consisted of 95 much larger volumes. For the years 2001 and on, online coverage was offered. A similar story applies to many original journals from which the Abstracts were compiled. Electronic subscriptions are replacing paper ones, and even the older volumes are being scanned and converted to electronic form. Some new journals are appearing only in electronic form.

A similar story could be told for other areas of science and most other academic disciplines as well. In 2004, for example, Google announced an agreement with a number of outstanding research libraries to convert their holdings into digital files that could be searched over the web. This was called “a step on a long road toward the long-predicted global virtual library” [5].

The same fate may be in store for cultural materials that are objects, rather than printed text. Images of the object may serve to preserve some of its value, should the original be destroyed. One ongoing project is taking place in St. Gallen, Switzerland. The collection of rare early medieval manuscripts in the Stiftsbibliothek is being digitized, page-by-page, by a team of scanning experts which seeks to insure that the original objects are not damaged [6]. A quick visit to the library's website produced a reasonable reproduction of an obviously tattered but legible page. Natural history museums contain vast collections of unique specimens and fossils, images of which are in some cases being prepared for storage in digital form [7]. Some efforts are also underway to prepare state-of-the-art digital representations of paintings from major museums [8].

The various attempts to preserve our cultural heritage are uncoordinated and, in many cases, unfulfilled. For example, the effort to digitize the Harvard College Observatory's unique and extensive collection of astronomical photographic plates had run out of funds by mid-2007 [9]. There does appear to be some gradual movement toward cohesion, but for the most part on a discipline-by-discipline basis. As a civilization we seem much more concerned with generating data than preserving it. This is unfortunate, because our developing forms of storage and backup are extremely insecure.

3. The need for systematic backup

While some ancient and medieval texts have survived to this day, requiring only secure storage, computer-stored knowledge appears quite perishable. In the absence of the test of reality, various estimates have been made of the typical lifetime of the various discs, tapes and drives used to store our data. It varies from less than a decade to perhaps a century. Simple failures in maintenance pose another problem. A survey found that 12% of the internet addresses cited in three prestigious medical and scientific journals were extinct two years after publication [10]. Even if suitable long-lived materials were created and websites were maintained, continual obsolescence of the software would pose a problem. We face this on a personal level, where the VHS format for films has given way to DVD, with further improvements yet to come. I still maintain my collection of vinyl phonograph records because I have preserved an obsolete machine to play them.

On a much larger scale, the Sanger Institute sequencing center, near Cambridge, UK has left a quarter of its space vacant, in anticipation of the next generation of data storage machines. The data in the obsolete older machines will be migrated to the new machines in a piecemeal fashion, with additional space created by the removal of the sections that have given up their function [3]. The timely installation of new software also appears essential. As noted by professor Clifford Lynch of the University of California School of Information: “machines will often be compromised if updates aren't applied; this can mean data destruction or corruption” [11]. Unlike ancient manuscripts which have survived for centuries in unattended storage, the data collections of the future will require continual attention from trained staffs. Skilled individuals will be required not only to update the software and hardware, but to control the environment.

For example, massive banks of supercomputers generate considerable heat: “Two floors of the Sanger data center are devoted to cooling. The top one houses the current cooling system. The one below sits waiting for the day that the center needs to double its cooling capacity” [3]. Heat represents the worst fear of computer systems administrators. If power was shut off, and emergency backup power failed, immediate shutdown would be needed to prevent data loss and damage to components [3].

Such circumstances essentially compel data centers to keep copies of their holdings. “Disasters such as Hurricane Katrina, which destroyed labs and computing facilities, are important reminders that data need to be backed up frequently and comprehensively in diverse and distant locations.” [11]. An example is furnished by an internet data archive which stores copies of public pages posted on the world wide web since 1996. The three-archive “mirrors” are housed just south of the Golden Gate in San Francisco, at the XS4ALL data center near Amsterdam and under the New Library of Alexandria in Egypt. [3] We might note that these sites are located in an earthquake-prone zone, a flood plain and a region of political instability.

We inhabit a world where hurricanes, earthquakes, floods, epidemics, famines, local power failures, civil disturbances and riots, limited wars and terrorist attacks are increasingly common. The production of backup copies of data in duplicated facilities protects the data from destruction by such local disasters and from equipment failures. On our current trajectory, it seems likely that much of our data will be backed up, but in a haphazard fashion, discipline-by-discipline, with some collections falling between the cracks and left unprotected. Some unfortunate losses may take place, but civilization will not fall because of them.

#### Cancer mutates---extinction

Amy **Rolph** **12**. Washington State University, citing Dirk Schulze-Makuch and David Darling, astrobiologist and astronomer. 03-18-12. “9 Strange Ways the World Really Might End.” Seattle's Big Blog. <http://blog.seattlepi.com/thebigblog/2012/03/18/9-strange-ways-the-world-really-might-end/?fb_xd_fragment>

Catastrophometer Scale 7.5: The enemy within (Pandemics)

Our body is in constant competition with a dizzying array of viruses, bacteria, and parasites, many of which treat us simply as a source of food or a vehicle for reproduction. What’s troubling is that these microbes can mutate and evolve at fantastic speed – the more so thanks to the burgeoning human population – confronting our bodies with new dangers every year. HIV, Ebola, bird flu, and antibiotic-resistant “super bugs” are just a few of the pathogenic threats to humanity that have surfaced over the past few decades. Our soaring numbers, ubiquitous international travel, and the increasing use of chemicals and biological agents without full knowledge of their consequences, have increased the risk of unstoppable pandemics arising from mutant viruses and their ilk. Bubonic plague, the Black Death, and the Spanish Flu are vivid examples from history of how microbial agents can decimate populations. But the consequences aren’t limited to a high body count. When the death toll gets high enough, it can disrupt the very fabric of society. According to U.S. government studies, if a global pandemic affecting at least half the world’s population were to strike today, health professionals wouldn’t be able to cope with the vast numbers of sick and succumbing people. The result of so many deaths would have serious implications for the infrastructure, food supply, and security of 21st century man. While an untreatable pandemic couldstrike suddenly and potentially bring civilization to its knees in weeks or months, degenerative diseases might do so over longer periods. The most common degenerative disease is cancer. Every second men and every third women in the western world will be diagnosed with this disease in their lifetime. Degeneration of our environment through the release of toxins and wastes, air pollution, and intake of unhealthy foods is making this problem worse. If cancer, or some other form of degenerative disease, were to become even more commonplace and strike before reproduction, or become infectious (as seen in the transmitted facial cancer of the Tasmanian Devil, a carnivorous marsupial in Australia) the very survival of our species could be threatened.

#### Independently---tech from the AFF spills over to effective megacity infrastructures.

A.V. Tarelicheva 15. А. В. Тареличева, professor at the Moscow Architectural Institute. 2015. “Лифты будущего,” or “Elevators of the Future.” Московский архитектурный институт (государственная академия), pp. 386–388. Translated by Truf.

\*\*\*ORIGINAL\*\*\*

Большой потенциал имеет также еще одна, более ранняя концепция инженерного сооружения — космического лифта. Идея была впервые озвучена Константином Эдуардовичем Циолковским в 1895 г. и в дальнейшем получила развитие в работах Юрия Николаевича Арцутанова. Космический лифт — система, которая в теории могла бы осуществлять переправку грузов с Земли на орбитальную станцию при помощи троса. Отправка оборудования и необходимых грузов с помощью ракет-носителей обходится очень дорого, в то время как основные затраты на космический лифт будут приходиться только на монтаж конструкции, что в целом позволило бы снизить стоимость доставки грузов на космические станции во много раз.

Конструкция гипотетического космического лифта основана на использовании троса, протянутого от Земли до самой орбитальной станции. Один конец троса находится на поверхности Земли, а другой, благодаря центробежной силе, закреплен в обязательно неподвижной точке, находящейся выше геостационарной орбиты, например, противовесом. Так конструкция сможет оставаться в фиксированном положении, а груз при транспортировке будет ускоряться за счет вращения Земли (рис. 2).

В идеале, космический лифт сможет проявить себя не только на Земле, но и на Луне, и на Марсе.

К сожалению, на сегодняшний день строительство космического лифта невозможно в силу отсутствия материалов заданных качеств и должных технических навыков. Если говорить про главный элемент — трос, то от него требуется большая прочность и низкая плотность, при этом материал должен быть экономически оправдан, ведь длина троса будет достигать сотни тысяч километров. В теории наиболее подходящим материалом являются углеродные нанотрубки. С недавних пор тема космического лифта снова обрела популярность, и ученые по всему миру начали проводить исследования в сфере космических лифтов и осуществлять пробные запуски роботов-подъемников по тросам на небольшие расстояния. Так, с 2005 г. NASA спонсирует проведение ежегодных соревнований Space Elevator Games2 . Участники должны представить разработанный ими материал для троса, который должен быть на 50% прочнее прошлогоднего образца.

Конструкция космического лифта в теории сможет не только работать по своему прямому назначению, но и послужить отправной точкой для проектирования лифтов без ограничения по высоте. В далеком будущем эта система сможет обслуживать города, даже если те разместятся на высоте десятка километров от земли.

Необходимость в изобретении новых конструкций лифтов сейчас актуальна как никогда раньше. Однако к этой проблеме хотелось бы привлечь не только инженеров и ученых, но и архитекторов, поскольку в своей практике они встречаются с этой конструкцией с другой стороны — со стороны людей. Архитекторы, возможно, смогут посмотреть на проблему под другим углом и предложить смелые идеи, исходя из собственных представлений о пользе и функциональности, которые в будущем смогут воплотиться в жизнь благодаря инженерам и ученым.

\*\*\*TRANSLATED\*\*\*

There is enormous potential in another, even earlier engineering concept – the space elevator. The idea of the elevator was first voiced by Konstantin Edwardovich Tsiolkovskii in 1895 and was developed further in the works of Yuri Nikolaevich Artsutanov. The space elevator is a system which, in theory, might have provided for the transportation of freight from Earth to an orbital station through the use of a tether. The ferrying of necessary loads using rockets is very expensive, while the principle expenses for the space elevator are associated with the construction, dramatically lowering the marginal cost of freight delivery to orbit.

The construction of a hypothetical space elevator is based on the use of a tether stretching from Earth to the orbital station at the other end point. One end of the tether is located on the surface of the Earth, and the other, thanks to centrifugal force, is attached to a stationary point located above geostationary orbit, for example, through the use of a counterweight. As such, the structure can remain in a fixed position, and the weight can be accelerated up the tether through the rotation of the earth (figure 2). Ideally, such an elevator may be useful not only on Earth, but also on the Moon and on Mars.

Unfortunately, the construction of a space elevator is impossible today because of the lack of materials possessing the requisite characteristics as well as a lack of necessary technical skills. With respect to the main element – the tether – a high strength and low density is required, all through the use of a material that is economically justifiable, if the tether is to stretch hundreds of thousands of kilometers. In theory, the ideal material for this purpose is the carbon nanotube. The topic of space elevators has attained a new popularity of late, and scientists around the world have begun research in the area of space elevators, including by performing test launches of climber robots along short tethers. Since 2005, NASA sponsors the annual Space Elevator Games2. The participants must present a material they have developed for the tether, which has to be at least 50% stronger than the previous year’s sample.

The construction of the space elevator can theoretically serve not just its primary purpose, but also serve as a point of departure for the design of elevators without height limitations. In the far future, this system can service entire cities, even those that extend tens of kilometers above the ground.

The need for the invention of new elevator designs has never been more urgent than it is today. This problem demands the attention not just of engineers and scientists, but of architects, because they frequently encounter this set of designs from another perspective: that of ordinary people. Architects may be able to look at this problem from a new direction and make brave proposals stemming from their perspective on utility and functionality, which may then be brought to life by engineers and scientists.

#### Caps all impacts

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By the mid-twenty-first century the world’s cities will be home to approaching eight billion inhabitants and will carpet an area of the planet’s surface the size of China. Several megacities will have 20, 30, and even 40 million people. The largest city on Earth will be Guangzhou-Shenzen, which already has an estimated 120 million citizens crowded into in its greater metropolitan area (Vidal 2010).

By the 2050s these colossal conurbations will absorb 4.5 trillion tonnes of fresh water for domestic, urban and industrial purposes, and consume around 75 billion tonnes of metals, materials and resources every year. Their very existence will depend on the preservation of a precarious balance between the essential resources they need for survival and growth—and the capacity of the Earth to supply them. Furthermore, they will generate equally phenomenal volumes of waste, reaching an alpine 2.2 billion tonnes by 2025 (World Bank)—an average of six million tonnes a day—and probably doubling again by the 2050s, in line with economic demand for material goods and food. In the words of the Global Footprint Network “The global effort for sustainability will be won, or lost, in the world’s cities” (Global Footprint Network 2015).

As we have seen in the case of food (Chap. 7), these giant cities exist on a razor’s edge, at risk of resource crises for which none of them are fully-prepared. They are potential targets for weapons of mass destruction (Chap. 4). They are humicribs for emerging pandemic diseases, breeding grounds for crime and hatcheries for unregulated advances in biotechnology, nanoscience, chemistry and artificial intelligence.

Beyond all this, however, they are also the places where human minds are joining at lightspeed to share knowledge, wisdom and craft solutions to the multiple challenges we face.

For good or ill, in cities is the future of civilisation written.

### Elevator Wars ADV---1AC

#### Advantage three is ELEVATOR WARS

#### Global elevator investments are inevitable---AND, elevator physics will channel all development to the Galapagos, creating a choke point that triggers escalatory security dilemmas. Formalizing a cooperative approach is key.

Bryan P. Long 18. Civilian, Department of the Navy, M.S. in Systems Engineering Management @ Naval Postgraduate School. June 2018. “A COMPARATIVE ANALYSIS OF FUTURE SPACE ORBITAL TRANSPORTATION SYSTEMS.” https://apps.dtic.mil/dtic/tr/fulltext/u2/1059988.pdf

C. GEOPOLITICAL IMPACTS OF A SPACE ELEVATOR

If constructed, a space elevator system would be one of the most audacious construction projects in the history of mankind, on par with the pyramids of Egypt. Such a major human endeavor will no doubt have major geopolitical challenges along with the already discussed technical challenges.

The main geopolitical challenges of the development of a space elevator directly relate to the physical location of the space elevator and the security dilemma inherent with an unfettered physical line of transportation and communication to space. To support the geostationary orbit of a space station atop the space elevator, the associated ground station must be located on, or very near, the equator (Laubscher 2004; Swan 2004). Equatorial circumference of Earth is 40,074 kilometers, with a linear landmass of approximately 8,545 kilometers. The vast majority of land mass passes through 51 politically challenged developing nations, not necessarily aligned, politically or economically, with spacefaring nations (Google Earth n.d.). Brazil, an emerging space power, provides the best option for land-based space elevator (Harvey, Smid, and Pirard 2010). The remaining 50,446 kilometers of Equatorial Ocean provide ample unclaimed surface area. Study of climatology and human behavior suggests an area of the Pacific Ocean located approximately 200–800 kilometers west of Galapagos is suitable for seabased space elevator (Laubscher 2004; Swan 2004).

Adapting principles of maritime strategy to space strategy, the space elevator represents an area where terrestrial and space vehicles will converge and interface, potentially becoming a choke point in the space lines of passage and communication (Klein 2006; Grove 1988). A potentially conflict scenario of controlling an evolutionary “gate” to space, points to an eventual arrangement of the conditions for conflict over protection and control of the space elevator choke point, and the access it provides. In order to maintain peace, four treaties provide the basis for the current international space regime, widely known by their common names: The Outer Space Treaty (OST), UN Resolution 34 and 68, and the Conventions on Liability and Registration, with four additional agreements that specifically address military affairs (Dolman 2006). While these treaties have succeeded in preserving peace for the better part of four decades, they are merely cooperative agreements among participating nations united in the common good of space exploration.

As one of the dominant powers in space, the U.S. National Military Strategy both outlines the importance of, and declares U.S. commitment to, preserving access to space and security of space (Dolman 2006; Joint Chiefs of Staff 2015). Given the current dominance of the U.S. as a space power, the idea of U.S. leadership in establishing, managing, and controlling a space elevator is rational. Applying the political realist model, Realpolitik, in conjunction with U.S. dominance in space, points to Everett Dolman’s Astropolitik as valid model for U.S. controlled space access via a space elevator. U.S. Astropolitik includes three steps:

1. Withdraw from the current international space regime and establish free-market sovereignty in space; 52

2. Exploit current and near-term U.S. space superiority to construct and establish control of the space elevator choke point; and

3. Establish an agency to define, separate, and coordinate commercial, military, and civilian space and space access requirements (Dolman 2006).

The combination of U.S. space power capabilities coupled with American willingness to maintain control of an international system would establish a benign hegemony for the construction of the space elevator and control of space access (Dolman 2006). Unfortunately, as Mike Moore argues, an American attempt at unilateral space-dominance will alienate nations and people who might otherwise be allies and friends (Moore 2008).

The challenge for U.S. political and military leaders will be to preserve access and provide security, while preventing the appearance of hubris and upholding American exceptionalism (Moore 2008). The development of such a major evolutionary transportation system, such as the space elevator, would provide not only one of the greatest technical challenges (as described above) in the history of mankind, but also provide the greatest geopolitical challenge for control and protection of such a system.

The next chapter will summarize the conclusions and recommendations of this effort, as well as provide recommendations for further research.

53 VI. CONCLUSIONS, RECOMMENDATIONS, AND FURTHER RESEARCH

This final chapter of this thesis will summarize conclusions made during the research of this exciting topic, offer recommendations and areas for further research on topics that are important to consider when studying Orbital Transportation Systems (OTS).

A. CONCLUSIONS

Recent new entrants into the space rocket industry have forced innovations to happen faster than the traditional government and large corporation controlled industry has been accustomed to in the past. Additionally, a revitalized interest in the human population becoming a space-faring species, travelling to near future locations like the Moon and Mars, have helped focus more attention on getting larger human capable space systems into orbit. This revitalized focus has helped continue to increase payload capacities of rocket-based systems and continued to drive down the cost per kg to orbit. This in turn, makes the likelihood that humans will travel to and establish extra-planetary outposts and later on habitations more possible in this century.

This thesis has conducted a comparative analysis of near future, rocket-based capabilities with the space elevator transportation system. The results of this analysis are as follows:

1. Utilizing a systems engineering process, MOPs were developed to compare two OTS: near future rockets to a leading non-rocket OTS, the space elevator. Near future rockets have the competitive advantage over the space elevator in five of the seven MOPs identified. However, both systems have unique characteristics and capabilities and depending on the requirements of a mission, one system could be preferred over the other.

2. New major entrants into the rocket industry will continue to push an increase in payload capacity and decrease the cost per kg to orbit of near future rockets systems. The increase in payload capacity and cost per kg to orbit will impact the way space systems engineers and scientists design their systems in the future, to take advantage of these improvements. The Satellite Communications (SATCOM) community will benefit in the following ways:

i) SATCOM engineers will design satellite structures to support the systems necessary to meet mission requirements, rather than optimize and adapt satellite systems to fit a structure compatible with the size of a launch vehicle and the rigors of a launch sequence.

ii) Larger satellites, delivered by a large payload capacity rocket or space elevator, would provide increased physical structure to mount a greater number of antennas, providing maximum gain for numerous individual frequencies or narrower frequency bands. Additionally, large aperture optical and radar systems would benefit greatly from increased payload capacity.

iii) Larger satellite vehicle structures also provide space for larger power generation, power storage, and power management systems, to include power amplifiers. This increased power capacity would provide the capability to generate signals well above the 10 to 100 Watt range typical of a traditional satellite that is limited by mass and available power. The increased power of the satellite will provide increased flexibility for uplink and downlink signals, facilitating effective communication for potentially disadvantaged ground stations with low power signals, small antennas, or both.

iv) Capitalizing on the array of antennas and available power, and similar to the Advanced Extra High Frequency (AEHF) payload on the Military Strategic and Tactical Relay (MILSTAR), these new satellites could incorporate advanced on-board digital processing hardware, firmware, and software, to facilitate on-orbit processing, ensure secure, high-speed communications, and provide flexibility in communication systems via on-orbit network management.

v) The SATCOM industry would benefit from the democratization of satellite communication, satellites with capability and capacity similar to ground stations.

vi) Larger payload capacities will allow systems that are currently stuck on the drawing board or in laboratory experiments, like space-based solar power, to begin to make sense economically and from a space construction standpoint.

vii) Interplanetary ships could now be conceived to be built or assembled in orbit, with higher payload capabilities and lower costs per kg to orbit.

3. The space elevator, a non-rocket OTS alternative, appears to be technically feasible, with the assumption that tensile strength in materials, such as carbon nanotubes (CNTs) continued development.

4. Technical advantages of non-rocket OTSs like the space elevator make it quite an appealing system to continue to develop. It has advantages, such as: 55

i) A comparison of payload capacity “throughput” to orbit would indicate a space elevator system would be able to transport more payload to orbit then traditional rockets, unless significantly more launch infrastructure was developed. Most recent estimates on a single space elevator system indicate a tether climber could reach GEO on a daily basis, which would far outweigh rocket systems total annual throughput.

ii) A space elevator would offer the unique capability to be able to transport systems back from space to the earth. This characteristic was one of the benefits of the space shuttle, that a space elevator could reintroduce to the space community;

iii) The unique capability space elevator could offer is the ability to work on systems in space, at one of the space gates. Systems would begin to be designed in a completely different way, to take advantage of this fact.

5. Geopolitical challenges are being overcome in the USA to allow major new entrants into the rocket industry, which will continue to drive up rocket capability and drive down costs per kg to orbit.

6. Geopolitical challenges with developing a space elevator system will be quite daunting, as the major challenge will come with locating the Earth port of the system and facing the challenges associated with operating and protecting an evolutionary gateway to space.

The future for rocket-based systems looks very bright for the near term as multiple new-entrants continue to develop larger payload capacity rockets and continue to “compete” for (mainly SATCOM) business, thus driving down the cost per kg to orbit. This could have an adverse effect on continuing to develop alternate OTS, such as the space elevator, as R&D capitol that could be available for those systems gets swallowed up by new missions that can be accomplished now w/ the larger payload/lower cost. However, from a physics perspective, the rocket-based system is tied to the limitations of the rocket-Equation; one cannot simply ignore the rules and laws of Newtonian Physics. This disadvantage of rockets, plus the potential major advantages of having a consistent, daily to-orbit, very large payload capacity, at extremely cheap costs, makes the space elevator system (and other alternatives to rockets) worth the R&D dollars needed to invest in such alternative OTS systems. 56

#### Existing legal frameworks are insufficient---it causes extinction.

Kelly Weinersmith 17. Kelly Weinersmith is an American scientist, New York Times best selling writer, and podcaster, member of the faculty at Rice University, and an alumni collaborator with the Parasite Ecology Group at the University of California Santa Barbara; Zach Weinersmith is an American cartoonist. 2017. “2. CHEAP ACCESS TO SPACE: The Final Frontier Is Too Damn Expensive.” Soonish: Ten Emerging Technologies That’ll Improve and/or Ruin Everything, Penguin Press.

The laws that’ll govern a space elevator are actually pretty important. It was our sense that most scientists who work on this stuff would like the space elevator, if it’s ever built, to be something that no single nation controls. If one nation alone has cheap space access, that’s a pretty big power asymmetry. So, from a let’s-not-all-kill-each-other perspective, having joint ownership of the means of cheap launch might be good.

Once this system is operational, researchers estimate that cargo could go to space for under $250 per pound, very fast and very safe.

As a bonus, once you build one, building another is a lot cheaper. After all, the big initial expense is going to be launching all that cable by conventional means.

Most likely, we will also have base stations along the way up. These can serve as fuel and maintenance depots, as well as launch points for satellites and spacecraft. One of the best features of this design is that you can reach different altitudes just by climbing up and down the cable. Once you reach 300 miles up, you’re in Low Earth Orbit, like most satellites. Go a lot higher and you get to geostationary orbit, which is great for communications satellites, but right now costs a fortune to reach. Beyond that, you get to where Earth has very little gravitational pull. So you’re like a rock at the tip of a sling. If you want to get fired into space, just hop out of the station.

This last point is especially exciting for those of us who watched a lot of Star Trek. If you can get anywhere you want simply by climbing (instead of carrying fuel onboard), not only is satellite launch cheap, launching very large spacecraft is cheap too. More than any other method that seems feasible this century, the space elevator would open up the solar system to human exploration.

So why not do it?

Well, there are a lot of technical challenges, but the greatest of all is what the hell do we make the cable out of?

The unit of specific strength is the Yuri, named for Yuri Artsutanov, a pioneer of the space elevator concept, whose last name was apparently too hard to pronounce. Depending on who you ask, an ideal cable material should be 30 million to 80 million Yuris. For reference, titanium is about 300,000 Yuris and Kevlar is about 2.5 million Yuris. Regular materials will not do.

The most promising candidate material is called carbon nanotube. Imagine a molecule made entirely of carbon atoms, but shaped like a straw, with its width a small fraction of the thickness of a human hair.

It turns out that if you have pure carbon nanotubes with no imperfections,\* they can get into the 50- or 60-million-Yuri range, meaning they might work as a space cable. The problem is that carbon nanotubes are a relatively recent discovery, and we’re still pretty bad at making them. The longest nanotube ever created was made in 2013, and made headlines all over the place, and . . . it was about a foot and a half long.

You can, of course, weave these fibers together, but the smaller the pieces of the weave, the worse your specific strength becomes and the more imperfections there are likely to be. A long, taut cable is only as good as its weakest part, and if your cable breaks at any point, someone in a cable car is gonna have a real bad afternoon.

The long-term question is whether a market exists to make better and better materials. According to NIAC’s Dr. Ron Turner, “Theoretically, and materials-wise, the carbon nanotube could become plenty strong enough . . . for a space elevator. Terrestrially, there wasn’t much of a market after a certain point, so the carbon nanotube fibers have not continued to grow as strong as the space elevator would need.”

Even supposing we could get the fibers long enough, Mr. Derleth points out an issue for carbon nanotubes: “The material is very sensitive to electricity, and so if it ends up having a lightning strike happen, it will disintegrate a large portion of the ribbon. . . . Thankfully, there’s a solution to this; unfortunately, it’s not a very satisfactory one, intellectually. There is an area of the Pacific Ocean that has never had a recorded lightning strike. So you’d place your space elevator there. That’s the solution. Now if a storm came through, you would have a lot of worry.”

If you could keep cable rope away from lightning strikes, you would still need to worry about debris. There’s a lot of stuff zooming through space, so even if you can dodge the big stuff, little things might wear out the cable over time. According to Dr. Turner, “This concept of continuing to have to refurbish the elevator remains one of its biggest challenges, in my mind, and it’s one that they don’t have a good answer for, yet.”

Plus, the space elevator might make for a particularly good target for terrorists. Dr. Phil Plait (astronomer and author of the blog Bad Astronomy) points out that someone coming along to snip it might not be such a remote possibility. “It’s a pretty ripe target for people to want to destroy, and not everybody is nice. We have enemies.”

We’re guessing a lot of you would like to know what happens if you have a cable to space, and then somebody comes along and snips it. Among the people we interviewed, there was some disagreement on how bad this might be. Dr. Turner and Mr. van Pelt thought that a break in the space elevator tether might not be so catastrophic. They point out that groups have tried modeling what would happen by simulating the results that follow snips at different points. Roughly speaking, it’s something like this:

Anywhere you cut, the stuff above the cut will go into a higher orbit and the stuff below the cut will fall toward earth. The stuff in higher orbit will need to be collected, since it represents some serious space trash.

If you snip high, then a lot of the cable falls in toward Earth. Once that happens, there are a number of complex interactions between gravity, the atmosphere, the motion of the Earth, and possibly some electric charge picked up from the solar wind.\*

The mechanics get a bit complex, but in short, the cable will start to whiplash back and forth, heating up in the atmosphere, until it breaks apart. Because the material is necessarily lightweight, the individual pieces probably won’t hurt anyone down on the surface. And you could minimize the risk even more if the cable were made into a mesh comprised of thinner strands.

Dr. Plait agrees with some of these particulars, but is a little less optimistic about the implications. “Sure, stuff hundreds of kilometers up might burn up as it falls (not that thousands or millions of tons of material burning up over one area is a great thing to have happen), but what about stuff from lower down? That’ll just fall. And then there’s the space debris. Most of the tower is below orbital speed, so it’ll all fall down to Earth, but 35,000 kilometers of it will fall through the orbital space of Low Earth satellites. I have NOT done the math or physics here, but until someone can tell me how that won’t destroy hundreds or thousands of assets in space I’m not inclined to think a space elevator is a great idea.”

Concerns

Cheap access to space means our relationship to space will change forever. It will be possible to create large space stations or even settlements in orbit. We see this as a good thing, but it could potentially put power in the hands of bad actors. One idea that originated in the Cold War was the so-called rod from God. Basically, you get a heavy hunk of metal and throw it from space at an enemy. Given its weight, height, and whatever speed bump you can give it, a simple metal rod could do as much damage as a nuclear bomb. Right now, the only people who go to space are ultraqualified supernerds—the sort of people who pass psychological tests and are willing to spend decades training for a chance to get a few months in space. If space becomes more generally populated, we could be putting ourselves in a dangerous position.

Setting aside terrorists, another scary possibility is how we might deal with the ambitions of powerful nations. Outside of the Soviet breakup, the national borders on Earth have been relatively stable since the costliest war in human history ended in 1945. The laws of space that are legally agreed upon essentially say that no nation can claim anything out there. We find it hard to believe that a nation with a space elevator would abide by this. In fact, as we’ll see in the next chapter, the United States is already making a few moves in this direction.

We tend to think of the universe as divided between space and “down here.” But this is sort of like an ant thinking Earth consists of “space” and “inside the anthill.” It’s true, but perhaps a bit chauvinistic on the part of the ant. “Space,” as we use it, refers to everything in the entire cosmos outside one planet in one solar system in one of many billions of galaxies.

If humanity gets cheap access to space, it’s hard to imagine there will be no conflict over claims. And, as seems likely, if only one (or a few) nations have that access first, it may create conflicts on Earth. In other words, if humanity gets cheap space access, it means there may be a sudden political squabble at the same moment a single nation gains the most powerful weapon system in history.

#### Specifically---it’ll cause an elevator race to monopolize lunar helium

Irina Slav 19. Writer for Oilprice.com with over a decade of experience writing on the oil and gas industry. 09-24-19. "World’s Longest Elevator Could Trigger New Commodity Race." Oil Price. https://oilprice.com/Energy/Energy-General/Worlds-Longest-Elevator-Could-Trigger-New-Commodity-Race.html

Rare earth elements and helium are just some of the resources scientists believe are abundant on the Moon. The problem is how to get them here. Rockets are not cost-efficient, otherwise we would have already colonized our natural satellite. Yet there is an alternative to rockets and it might have just got doable: a lunar elevator.

Two astronomy students from the University of Cambridge and Columbia University recently published a paper on an invention dubbed Spaceline—a space elevator they say could be built with existing technology and would cost only about $1 billion. And it would be easy to build.

“By extending a line, anchored on the moon, to deep within Earth’s gravity well, we can construct a stable, traversable cable allowing free movement from the vicinity of Earth to the Moon’s surface. With current materials, it is feasible to build a cable extending to close to the height of geostationary orbit, allowing easy traversal and construction between the Earth and the Moon,” Zephyr Penoyre and Emily Sandford write in the abstract of their paper.

A cable to the Moon may sound like something out of a cartoon, but Penoyre and Sandford are not joking. According to their idea, travellers to the Moon would fly to the end of the cable on spacecraft and then transfer to solar-powered autonomous vehicles that would climb the cable to the Moon. The cable itself could be no thicker than the lead of a pencil and made from Kevlar, which is much cheaper than other materials considered for a space elevator.

Of course, the question everyone would ask is, why bother building a space elevator to the Moon. True, there are potentially valuable minerals on the Moon, but we have yet to determine if their mining is commercially viable. But there is another reason a cheap enough space elevator could make sense: helium-3.

Helium-3, many believe, is the solution to the nuclear fusion problem, that is, how to make it work. The element is scarce on Earth but thought to be abundant on the Moon, with several governments eyeing lunar mining to get their hands on it. The reason is helium-3 is a potentially much more efficient fuel for nuclear fusion reactors than what researchers currently have access to on Earth. Combined with deuterium—already used in nuclear fusion reactors—it turns into regular helium with a single proton as a by-product, meaning a lot less energy waste than other elements. What’s more, a deuterium-helium-3 fusion reaction would be much easier to contain.

#### World war 3

Benjamin D. Hatch 10. Executive Notes and Comments Editor, Emory International Law Review. 2010. “Dividing the Pie in the Sky: The Need for a New Lunar Resources Regime.” Emory International Law Review, vol. 24, p. 229.

 [\*263] The DO-NOTHING strategy does exactly what it says. The commons managed under DO-NOTHING remains unregulated and open to all who seek to exploit the commons resource. 224Link to the text of the note Inevitably, a DO-NOTHING strategy will lead to a tragedy of the commons. 225Link to the text of the note

KEEPOUT is a regulatory scheme that follows the DO-NOTHING approach until a point in time where further participation by newcomers would harm the interests of the first participants. 226Link to the text of the note At that point, newcomers will not be permitted to access the commons - only those already present may continue to use its resources. 227Link to the text of the note In a pure KEEPOUT regime, the regulation applies to the participants in commons exploitation, not to the conduct of those participants. 228Link to the text of the note

RIGHTWAY is the flip side of the KEEPOUT coin. 229Link to the text of the note The regulation in a RIGHTWAY system applies only to participants' conduct, not to their identity. 230Link to the text of the note A strict RIGHTWAY system makes no attempt to limit participation. 231Link to the text of the note Instead, the regulatory scheme will ensure that the rights of all users will be protected as much, and for as long, as possible. 232Link to the text of the note

The final scheme Rose discusses in her article is termed PROP. In a PROP system, users are vested with "individualized property rights." 233Link to the text of the note Rose's example of a PROP system is a regulatory scheme for fishing that would allow the regulatory agent to limit individuals' abilities to fish in a given location and then auction off available fishing rights. 234Link to the text of the note Rose continues, "in a sophisticated version, the fishers could trade these rights among themselves." 235Link to the text of the note By implication, the common holding of the resource does not cease to exist. In Rose's PROP system, the regulatory agent acts as a trustee for the commons, allowing some users to participate while (1) regulating their conduct and (2) receiving compensation for the right to appropriate commons resources. 236Link to the text of the note

 [\*264] Rose's PROP scheme is an institutional method to confer limited property rights on commons users. While this scheme is useful for its applicability to scenarios in which commons users are individuals and where the regulatory agent is a third party, it is not directly applicable to the present lunar situation. Lunar commons users will presumably be state actors rather than individuals. 237Link to the text of the note State policy is driven by the outcomes of compromises between policymakers working together, not by a single individual's rational analysis. Additionally, no third-party regulatory agent exists to govern activities on the Moon, or in outer space, that would bind state actors. 238Link to the text of the note

There are three general ways that property rights could be acquired over the Moon. First, state actors could construct a regime that parallels Rose's idea of a PROP system: Property rights could be sold or auctioned (or otherwise pre-determined through some alternative form) through an agreed-upon mechanism to spacefaring states. (This type of system will be referred to as PROP-A.) This type of scheme has been found in environmental regulations through which polluters essentially pay for the right to pollute. 239Link to the text of the note

A second scheme is the creation and vesting of property rights in one actor, a trustee, who would then become the agent to exploit the property rights. In other words, the trustee becomes the only commons user and acts in the name of some group of interested parties (e.g. states seeking use of commons resources, all humanity, etc.). (This type of system will be referred to as [\*265] PROP-B.) This is the approach taken by the controversial Part XI of the United Nations Convention on the Law of the Sea, described infra. 240Link to the text of the note

The third type of imaginable property scheme does not use a trustee either as a source of rights or as a rights bearer. Instead, this third type of regime vests proprietary rights in commons users from the moment of the regime's instantiation, not by relying on any other actors to carry or apportion the rights. It is up to commons users to work together and regulate the commons among themselves based on their mutual consent. (This system will be referred to as PROP-C.) PROP-C is essentially a partition strategy and, as with any other kind of partition, comes in two varieties.

The first type of PROP-C would be akin to a partition-in-kind. 241Link to the text of the note Essentially, lines would be drawn on the subject of the appropriation (in this case, the Moon), and each property holder would have total dominion over its sector. While this has been successfully implemented in other contexts, 242Link to the text of the note it would not be an efficient approach to regulating the Moon. Certain countries could be slotted into sectors with harsher geographic features, making landings nearly impossible. Moreover, too little is known about the quantities and geographic distribution of lunar resources; therefore, certain states could randomly inherit vast deposits of sought-after materials while others are left with nothing. This in itself could prove to be a cause for military conflict. Furthermore, a full partition of the Moon would deny to states that are not yet spacefaring, but that could be at some point in the future, a tract of lunar real estate to develop.

A second way for PROP-C to be implemented would be an approach similar to a partition-by-sale. 243Link to the text of the note The main object of property rights in this form would be the sale or use of the commons resources rather than any mastery over a pre-designated lunar colony or territory. To avoid conflicts, states in such a system should create a regime to manage their own conduct and disputes, but actual rights-bearing would be vested in autonomous states rather than in the newly created regime. Examples of such state-oriented approaches to resource distribution can be seen in resource cartels like the Organization of [\*266] the Petroleum Exporting Countries ("OPEC"), which regulates extraction and sale of petroleum. 244Link to the text of the note

In order to fully appreciate the differences in these varying approaches to commons management, the next section will provide brief overviews of actual implementations of these theoretical models. By looking at certain commons agreements and describing their political structures, the rights vested in member states, the agreement's recognition of the proprietary status of the commons resource, and the political reception of each agreement, certain trends should appear that will effectively dictate what a properly-functioning lunar resources regime should look like.

B. Learning by Analogy: Examining Other Commons Resource Regimes

This section will briefly evaluate the contents, structures, and impacts of five other resource management regimes, ordered by the theoretical model that informed its operations (DO-NOTHING, KEEPOUT, RIGHTWAY, PROP-A, etc.). It will also sketch what a lunar system premised on that theoretical approach might resemble. It must be noted that key differences exist between any terrestrial commons management model and the Moon, because the Moon already is naturally subjected to a form of the KEEPOUT system. 245Link to the text of the note Only one state has ever actually been able to place its citizens on the Moon, 246Link to the text of the note and for the foreseeable future, at most six spacefaring actors appear to be in position to do so. 247Link to the text of the note

Before turning to the five case studies, a discussion of the impacts of a true DO-NOTHING approach to the Moon will be offered as a comparison to the case studies that will follow.

1. DO-NOTHING: The Wild West

DO-NOTHING systems impose no restrictions on commons users. n248 Rather, they permit free use (and abuse) of the system. A DO-NOTHING [\*267] system would effectively be imposed on the Moon if the OST and Moon Agreement were repealed with no substituted agreement in their place. In combination with the natural KEEPOUT system governing the Moon, n249 the only factor preventing the Moon from being subjected to a tragedy of the commons would be the small number of actors dividing the vast expanse of the lunar surface. n250

On the other hand, with no legal regime for the Moon at all, the tragedy of the commons should be the least of humanity's worries. The total repeal of the OST and Moon Agreements would cause the Moon to cease being an object of international law, leaving it utterly free and open for the uses of the first claimants. Rather than create a regime to govern state interests over the Moon, this policy would cause the Moon to become the international equivalent of the Wild West. Rights to the Moon would be defined only to the degree that those rights could be protected.

The total repeal of the OST would almost certainly solve the Moon's economic problems generated by the tragedy of the commons. With no regulation or convoluted proprietary schemes and no legal mandate to provide for free riders, the disincentives that have suppressed lunar development would vanish. However, this total lack of lunar law would likely heighten the comparison to the Wild West - with no regulation, states would have an incentive to militarize the Moon and to engage inprolonged conflicts with other would-be users to gain monopolies and exclusive uses over valuable lunar resources. While a scheme rejecting all lunar regulation might lead to an era of free and open use of the Moon, it also may lead to World War III.

#### Engagement now is key AND solves

Vernon Nase 06. BA, MA, LLB (Hons), PhD (Law), Dip. Ed., Grad. Dip. Lib. is a senior lecturer in air and space law at Murdoch University, Western Australia. 2006. “Questionable Legality of the US Space Elevator Concept, The / Zur Rechtmassigkeit Des US Amerikanischen Space Elevator Konzeptes / La Legalite Du Concept Americain Space Elevator.” Zeitschrift Fur Luft- Und Weltraumrecht - German Journal of Air and Space Law, vol. 55, no. 1, pp. 118–136.

Conclusions

There is no doubt that NASA sees value in the space elevator concept. It provides an allocation in its annual budget to support research into the space elevator and it also has provided financial support to the Spaceward Foundation and the 2005 Climber Competition.

In a presentation to the 2 nd Annual International Space Elevator Conference70 Dr. Brad Edwards and Dr. Marjorie Darrah suggest that there is a need for a champion to take up the legal and regulatory issues and work through all the details and identify universities and law schools who may have an interest in using these issues as thesis or dissertation topics. James Gardner, in a presentation at the same conference disagrees suggesting the use of 'unknown "everyman" spokespersons representing appealing political stereotypes'7 1 . However, Gardner's emphasis on 'framing' the debate suggests a greater concern with politics and marketing than with legitimacy and legality. Gardner suggests that the 'right frame' to achieve public acceptability is that the Space Elevator will improve 'the intelligence-gathering capacity of America and its allies', that it will facilitate the acquisition of an 'enhanced defence capability against emerg ing military and terrorist threats', that it will enhance long-term prospects 'for new and more secure energy supplies' and that all of these will be achieved 'better, faster [and] cheaper'72 . Despite current international concerns about terrorism it is highly doubtful if this security based approach to establishing a space elevator and creating its role would garner broad international support. 73 The view that "under the right circumstances the U.S. is legally justified in using force against the territorial integrity of the neutral State74" should sound warning bells to the international community. It is doubtful if either the current space legal regime or international customary law would support this interpretation. However, the realities are that the strategic use of navigation and imaging satellites make such satellites targets where they supply information of battlefield significance.

At the 2004 Space Elevator Conference Robert Munck in a presentation entitled 'Educating the Public About the Space Elevator" acknowledges the difficulties associated with marketing the Space Elevator to its various audiences which he identifies as (i) the general population (ii) politicians (iii) lawyers (iv) venture capitalists and (v) the science (and science fiction) savvy public15.

That the campaign to win over the public has in small measure already begun is evidenced by the Spaceward Foundation's U.S. $400,000 sponsorship by NASA and the conducting of the Elevator 2010 competition.76 The race to capture public approval and imagination is most certainly on with Ben Shelef, speaking at the Space Exploration Conference in 2005, declaring that 'Elevator 2010 wants to do what air-shows did for airplanes with climber competitions each year.'77

Supporters of U.S. based research and development of the space elevator need to look more broadly than only to the U.S. and its closest allies. If there is a need to amend the multilateral Space treaties there will be an accompanying need to garner international support for the concept. In this context it should perhaps be borne in mind that cooperation and sharing are legal requirements under the Space Conventions.7 8

Acting unilaterally ought not to be the first legal option considered. A diplomatic response to the need to create legal legitimacy for the space elevator is to seek international agreement either by virtue of a discreet multilateral treaty on the Space Elevator or through amendment of the Chicago Convention, the Law of the Sea, the OST and/or the Liability Convention. The legal obligation is to negotiate and not to act unilaterally. Dupuy states the legal obligations on states in the following words:

"It obliges them, of course, where cooperation and negotiation structures have been opened to them through treaties and the creation of international institutions, to have recourse to these norms and these institutions, on pain of incurring, if they are ignored, international liability vis a vis the states concerned."

The general obligation upon states to cooperate and to seek accord is founded on the United Nations (UN) Charter and that organization's three fundamental purposes, which are:

- to maintain peace and security;

- to develop friendly relations based on respect for the principle of equal rights of peoples; and,

- to achieve international cooperation in solving international problems. 79

Dupuy suggests that to these one should add 'the principle of the sovereign equality of states' and that 'the principle of cooperation is one of the three constitutive pillars of the UN Charter.' 0

Early on in this study it was acknowledged that the space elevator in its entirety may be categorized as a 'space object' and so subjected to the space regime provided by the Outer Space Treaty and the Liability Convention. However, at the same time it was indicated that the semi-permanent nature of this structure and its relative permanence in air space and the need to declare a defensive or exclusion zone around the sea anchor and the cable do create a need to reform those multilateral treaties and to include provisions that allow a more substantial defensive zone and that attend to 'due care obligations'. The alternative of establishing the space elevator in sovereign territory of a state does not involve the need to deal with such big picture issues of multilateral reform. Although there are legal impediments as outlined to establishing a space elevator there is time to seek such amendments to the various liability regimes. The process of reform might be tortuous but it is necessary for the elevator to assume the cloak of legal legitimacy.

The Space regime works well for damage in space and damage to the ground caused by the space object. However, this is an unprecedented structure in air space and the exclusion zones needed are illegal under both international air and sea law as they currently stand. If it proceeds unilaterally the first nation to establish the space elevator is likely to do so against the backdrop of consistent and sustained objections from other states which would serve to rob the space elevator of legal legitimacy at international law. 81 Further, there is the prospect of challenge under the Chicago Convention dispute resolution provisions which could see the matter headed in the direction of the Council of the International Civil Aviation82 and ultimately to the International Court of Justice. 83

Whatever course of action is ultimately adopted the temptation to act unilaterally should be resisted. Adherence to the notion that he who builds the first space elevator effectively owns space ought to be resisted by all states. If the US were to proceed under this proposition how long would it be before another state (perhaps even China) challenges this dominance by building its own elevator?

The model provided by the international space station with multi-state partnerships is worth considering. Under this model each participating state has a form of jurisdiction over the parts of the station under its control. Each party retains jurisdiction and control over personnel in or on the space station who are its nationals.84 Such jurisdiction can potentially be the product of either bilateral or multi-lateral negotiations among participating states. Article 2 of the Registration Convention, for example, permits states to enter into separate agreements with respect to jurisdiction and control. While state responsibility for the actions of their nationals, be they corporations or individuals, is the 'norm' for outer space the no sovereignty principle remains in place for this domain.

Tobias raises the issue of whether sovereignty and property rights ought to exist in outer space.85 He suggest that 'without sovereignty jurisdiction cannot be imposed, laws cannot be applied, and investments cannot be secured'. 86

Where the space elevator promises to herald a revolution in space development and use by creating easy access to space, the temptation, for the state and corporations who have interests in it, is to regard outer space in a proprietary manner, even without reform of the legal regime. And where corporations are, for example, mining near earth asteroids it is all too convenient for the state and its corporations to ignore the sharing aspects of the current legal regime or even terrestrial safeguards and safety systems. It seems that the space elevator debate will rapidly become a commercialization of space debate. A number of commentators have already called for a roll out of real property rights in outer space and for recognition of sovereignty for those registered under their own national regimes as developers in outer space. 87

Where issues associated with commercial exploitation of outer space will not go away the need is for the international community either to develop a new treaty or to amend the existing treaties. This can be accomplished by adding new sections to explicitly address mining rights in outer space and to provide legitimacy to the space elevator through developing, for example, an appropriate exclusion zone.88

The more rapid development of commercial interests in outer space that would inevitably follow the establishment of a 'legally legitimate' space elevator also makes it paramount for the international community to take a proactive stance. Where history suggests that competition for territorial claims leads to armed conflict and European states, Japan, India, Russia and China, in addition to the United States, are currently active in outer space it is desirable to seek international accord. The alternative is for a single state to deploy an elevator and to develop outer space in an exclusive manner. Under no circumstances should domestic commercialization and regulating legislation be seen as conferring endless legal legitimacy on unilateral action. While such legislation and regulation of a state's corporations is often legitimate89 and necessary it occurs against the backdrop of an international legal regime. The orderly development of commercial opportunities would be best facilitated by an international organization registering and controlling interests and resources exploited in outer space. As previously observed history suggests that open slather development would inevitably lead to conflict and arms race possibilities. Amendment of the existing regime is the answer. While it may not be desirable to recognize sovereignty in outer space it may still be possible to create a system of licensing and registration of commercial activity that is both orderly and international in character.

One possibility is to create a UN authority to perform a regulatory function in outer space much as the International Civil Aviation Organization performs for air space or the International Sea-Bed Authority 90 performs for those states who are signatories to the United Nations Convention on the Law of the Sea (1982). Some commentators may even argue for this role to be grafted on to the roles already performed by the International Civil Aviation Organization.

Whatever one's reservations about the space elevator concept its creation is likely to hasten reform of the outer space legal regime. It is far better that a debate should start now than that a process of stealth should see a space elevator established and operating without a meaningful debate having occurred.

#### Involving Russia is vital AND opens broader channels of trust

--“Russia” added in brackets for readability

--English language diagram is obviously not quite identical to the original but very similar and translates all the labels – from here: Ezekiel Nygren 15. 02/28/2015. “Space Elevator.” Hypothetical Spacecraft and Interstellar Travel, Lulu.com. pp 179.

--Russian diagram says, from top to bottom: “Counterweight, geostationary orbit, elevator center of mass, cable, climber, Earth, Fig. 1. Space Elevator”

Pavel Evgenievich Zakharev 14. Павел Евгеньевич Захарьев, engineer and researcher studying space transportation control systems, candidate for M.A. equivalent, city of Mirnii, Arkhangelsk Region. 2014. “Возможности Сотрудничества в Космосе,” or, “Opportunities for Cooperation in Space.” Российский Научный Журнал, vol. 41, no. 3, pp. 282–285. Translated by Truf.

\*\*\*ORIGINAL\*\*\*

Рукопожатие в космосе стало символом программы «Союз-Аполлон», первой советско-американской космической миссии. Символом того, что великие свершения в космосе – это плод совместных усилий многих наций [1].

В наши дни наиболее значимый совместный международный проект, в котором участвуют 15 стран: Бельгия, Бразилия, Германия, Дания, Испания, Италия, Канада, Нидерланды, Норвегия, Россия, США, Франция, Швейцария, Швеция, Япония – Международная космическая станция [2].

Однако не всегда всё идёт так гладко. По мнению Дэвида Саусвуда, бывшего руководителя департамента научных и роботизированных исследований ЕКА, можно выделить пять основных уроков из международных проектов, реализация которых не пошла как должно [3].

Во-первых, каждая сторона должна понимать мотивацию других участников проекта. Во-вторых, все участники должны быть готовы отказаться от каких-то аспектов проекта, если бюджет начнет выходить из-под контроля. Отсюда следует третий вывод: аппарат должен иметь модульную структуру, так, чтобы весь проект мог быть реализован, если несколько его составных частей просто-напросто удалены. В-четвертых, надо помнить, что любые международные соглашения не являются железной гарантией. Наконец, пятый, и последний урок: если планируется серьезная международная миссия, необходимо придумать сильные полити- ческие причины для сотрудничества. Политики не будут держаться за проект, какой бы научной ценности он не имел, но будут сражаться за то, что принесет другую выгоду.

В ряде источников высказывается мнение, что оптимальным сценарием развития космической деятельности и человеческого общества было бы создание и реализация общих «правил игры», единой стратегии и систем управления всей сферой космической деятельности на национальном и международном уровнях [4].

Сотрудничество выходит за чисто экономические рамки. Оно разрушает культурные преграды, повышает уровень общего доверия, открывает новые возможности в научном сотрудничестве и вызывает глобальный интерес общества, что в конце концов полезно для всего человечества. Ущерб, нанесенный разрывом договора, пусть даже формально безупречным, по всем этим причинам должен избегаться [3].

На сегодняшний день ни одна страна в мире не в состоянии самостоятельно отправить человека на Марс и обеспечить ему там безопасные условия работы [5]. Для организации такой масштабной миссии необходимо создать новые технологии, новые средства, прежде всего, новые двигатели, эффективные средства защиты от радиации и других факторов воздействия агрессивной космической среды. Необходимо создать высокоэффективную систему жизнеобеспечения экипажа, научиться готовить людей к подобного рода работе.

Подготовка к такой миссии займет несколько десятилетий и потребует как огромных финансовых вложений, так и развития новых технологий. Это очень ресурсоемкий и капиталоемкий проект и он может быть реализован только посредством международной кооперации.

Один из будущих проектов международного сотрудничества – Космический лифт (концепция инженерного сооружения для безракетного запуска грузов в космос). Данная гипотетическая конструкция основана на применении троса, протянутого от поверхности планеты к орбитальной станции, находящейся на ГСО. Впервые подобную мысль высказал Константин Циолковский в 1895 году, детальную разработку идея получила в трудах Юрия Арцутанова [6].



Космический лифт, будучи построенным, может обеспечить простой и дешевый способ доступа в космос [7]. Однако задача создания лифта представляет собой комплекс проблем:

– недостаточная прочность существующих материалов;

– доставка строительных материалов на геостационарную орбиту;

– космический мусор, угрожающий разрушить лифт.

Новое исследование, поддержанное Международной академией астронавтики и вобравшее в себя мнения специалистов в разных областях, приводит к оптимистичным выводам. Идея космического лифта представляется осуществимой, если принять во внимание предполагаемый прогресс в технической области, и ограничена лишь коммерческой целесообразностью. При этом инфраструктура космического лифта в любом случае потребует активного международного сотрудничества, как в случае с Международной космической станцией.

Так 21 марта 2014 г. НАСА объявило, что ищет предложения для исследований технологий, которые помогли бы существенно снизить затраты при реализации миссии по захвату астероида [8]. Космическое агентство ищет идеи в пяти направлениях: система захвата астероидов; система сближения; вторичная полезная нагрузка; адаптация коммерческих платформ космических аппаратов, а также международное и коммерческое партнерство.

План НАСА, включенный в бюджет на 2014 год, состоит в отправке автоматического космического аппарата для захвата астероида и транспортирования его на орбиту Луны для изучения. Одна из заявленных целей НАСА – посетить астероид к 2025 году [9].

[[PICTURE 2 OMITTED]]

Миссия захвата астероида должны играть ключевую роль в доставке людей на Марс и другие места по всей Солнечной системе. Очевидно, астероид также может служить сырьём для производства лифта, либо противовесом.

По убеждению сотрудников Центра Хруничева, развитие технологий, неизбежно приведет к созданию гиперзвуковых самолетов-носителей «космических» ступеней [10]. В дальнейшем же такие самолеты будут оснащены эффективными комбинированными двигателями и преобразованы в полноценные одноступенчатые аэрокосмические самолеты, например проект Скайлон [11].

В данном направлении идут исследования в США, Англии и Австралии. Что, однако, ещё не говорит об окончательном выборе. Это как бы «розовая мечта». Возможны создания аэрокосмических самолётов на ядерной энергии или на какихто ещё неизвестных принципах.

Возможно, в недалёком будущем мы увидим строительство космического лифта или полёт космического самолёта. Что- [[PICTURE 3 OMITTED]] бы не задаваться вопросом: чьи это технологии? – необходимо принимать участие в их разработке, в том числе, делая упор на международное сотрудничество.

\*\*\*TRANSLATION\*\*\*

The Soyuz-Apollo program, which encompassed the first joint US-Soviet space mission, came to be symbolized by a handshake in space – an acknowledgement that great accomplishments in space are produced by the collective efforts of many nations [1].

Today’s most significant international space project, the ISS, includes 15 countries: Belgium, Brazil, Germany, Denmark, Spain, Italy, Canada, the Netherlands, Norway, Russia, the US, France, Switzerland, Sweden, and Japan [2].

But things do not always go so smoothly. According to David Southwood, former Director of Science and Robotic Exploration at the European Space Agency, there are five key lessons to be learned from international projects whose implementation did not go as planned [3].

First, each side must reach an accurate understanding of the other participants’ motivations. Second, all participants must be ready to reject some aspects of the project if the budget begins to spiral out of control. This leads to the third conclusion: any project must be structured in a modular fashion so that the project can still succeed even if several elements are removed. Fourth, it is important to remember that international agreements are not immutable pacts. Fifth, and finally: if a serious international mission is being planned, it is important to highlight strong political reasons for cooperation. Politicians will not cling to any project, regardless of its scientific merit, unless it brings some other benefit.

A variety of sources have expressed the opinion that the optimal scenario for expanding space activities and human society would entail the formulation of “rules of the game”; a single strategy and regulatory system for the entire sphere of space activities at both national and international levels [4].

Cooperation exceeds purely economic frames. It tears down cultural barriers, increases general trust between partners, opens new opportunities for scientific collaboration, and draws global interest in projects, which is ultimately beneficial for all of humanity. For all these reasons, the damage inflicted by the abrogation of agreements, even if such abrogation is legally unimpeachable, should be avoided [3].

Today, no country is capable of unilaterally sending a human to Mars and providing for safe working conditions upon their arrival [5]. Such a massive mission will require new technologies, new resources, and, most importantly, new engines, effective technologies to shield humans from radiation and other hostile forces in the space environment. It is necessary to build a hyperefficient life support system for the crew, and to prepare the crew for work under those conditions.

The preparation for such a mission will take decades and require massive financial investments, as well as the development of new technologies. This is a very resource and capital intensive project, and can only be realized through international cooperation.

One future project that will require international cooperation is the space elevator (a concept for an engineering project for space launch without the use of a rocket). This hypothetical structure is based on the use of a tether stretching from the planet’s surface to a station in geostationary orbit. Such a concept was first proposed by Konstantin Tsiolkovsky in 1895, and was further developed in the works of Yuri Artsutanov [6].



The space elevator, once built, can provide a simple and cheap mechanism to access space [7]. However, the task of building such an elevator faces a variety of problems:

– insufficiently strong materials;

– delivery of construction materials to geostationary orbit;

– space debris, which threatens to destroy the elevator.

A new study sponsored by the International Academy of Astronautics and spearheaded by experts from a variety of fields, however, reached optimistic conclusions. The idea of a space elevator is, assuming continued technological progress, feasible; the only limit is commercial viability. However, the infrastructure for a space elevator will unavoidably require active international cooperation, as with the International Space Station.

NASA’s plan, which is spelled out in its 2014 budget, includes the capture of an asteroid for transportation into Lunar orbit and subsequent study. One of NASA’s declared goals is to visit an asteroid by 2025.

[[PICTURE 2 OMITTED]]

The asteroid redirect mission will likely play a key role in delivering people to Mars and other places across the Solar System. The asteroid can also serve as a source of raw materials for the space elevator, or as the counterweight.

Researchers at the Khrunichev Center are convinced that technological development will unavoidably lead to the creation of hypersonic planes designed to carry rocket stages [10]. In the future, these same planes will be equipped with effective combined engines and transformed into self-contained, single-stage aerospace planes, as seen in project Skylon [11].

Research in this direction is being conducted in the US, England, and Australia. This does not necessarily mean that this technology will be chosen. At this point, this is merely a dream. Aerospace planes may be powered by atomic energy, or by some as-yet unknown energy source.

In the near future, we may see the construction of a space elevator, or the flight of a space plane. [[PICTURE 3 OMITTED]] In order to avoid getting hung up on the question of who these technologies should belong to, it is necessary for us [Russia] to participate in their development, including through international cooperation.

#### Prevents short-term nuke war---physical infrastructure for dialogue exists, BUT underlying trust is key.

George Beebe 19. Vice President and Director of Studies at the Center for the National Interest, Former Chief of the Russia Analysis Group at the Central Intelligence Agency. 2019. “6 Absorbing Shocks.” The Russia Trap: How Our Shadow War with Russia Could Spiral into Nuclear Catastrophe, First edition, Thomas Dunne Books.

But technology has evolved since the post–Cold War period in ways that make escalation from conventional to nuclear conflict more likely once fighting starts, even if the combatants try to avoid crossing that threshold. James Acton, a physicist working on deterrence and nuclear policy issues at the Carnegie Endowment for International Peace, has been sounding the alarms about what he calls “nuclear entanglement,” the intermixing of the command, control, communications, and intelligence warning systems that oversee nuclear and conventional weapons systems in the militaries of the world’s great powers, coupled with new nonnuclear capabilities that can threaten an opponent’s nuclear retaliatory force. The bright line separating nuclear and conventional conflict is in reality not bright at all, he argues, and national command authorities in Russia and the United States probably have less control than they think over whether any conventional military clash turns into a catastrophic nuclear conflict.10

During the Cold War, the only viable means of countering an opponent’s strategic nuclear forces was a nuclear strike against the weapons themselves or against their hardened command and control systems. Each country’s satellites—used both to communicate with nuclear weapons systems and for early warning of an adversary’s nuclear launches—were largely safe from ground-based attacks. Unless one of the superpowers detected the other preparing or launching any of its nuclear forces, it could rest assured that its strategic retaliatory force was safe, able to serve as a reliable nuclear deterrent.

Today, that is no longer the case. The world’s great powers have grown more and more dependent on satellite-based systems to detect launches of nuclear and nonnuclear missiles, to guide ever more accurate weaponry through global-positioning systems, and to communicate with both nuclear and nonnuclear weapons systems. But these satellites have also grown more vulnerable than ever to nonnuclear anti-satellite (ASAT) weapons.11 And highly accurate long-range conventional weapons, not to mention cyberweapons and ballistic missile defense systems, hold the potential to undermine an opponent’s nuclear capability without resort to nuclear strikes.

As a result of these new capabilities and vulnerabilities, both Washington and Moscow have officially announced that they might launch a nuclear attack in response to conventional threats. The United States has lapped the field of global competitors in developing and using long-range sea-launched and air-launched conventional cruise missiles, with an inventory of several thousand. Russia’s concerns about these conventional capabilities had years ago prompted it to announce that it might use nuclear weapons to counter a conventional threat. But Russia has recently deployed a smaller number of similar weapons, most notably the Kalibr cruise missile that it has employed in the Syrian war. As Russian and Chinese conventional weapons, anti-satellite technology, and cybercapabilities have evolved, the United States has grown more concerned about nonnuclear threats to its nuclear arsenal. Its 2018 Nuclear Posture Review declares that in the event of “significant nonnuclear strategic attacks … on US or allied nuclear forces, their command and control, or warning and attack assessment capabilities,” the United States would consider the use of nuclear strikes.12

Even more alarming, according to Acton, is the fact that such nonnuclear threats to nuclear capabilities might be inadvertent, flowing from activities not meant to be escalatory.13 Today, a significant number of weapons systems are dual-use, capable of delivering either nuclear or conventional warheads. Thus, whereas the command, control, communications, and intelligence surveillance and reconnaissance systems (C3ISR) that govern the nuclear arsenal were once largely separate from those of conventional weaponry, those systems today are increasingly networked and overlap. As a result, if Moscow were to grow concerned in a crisis situation that the United States might target its forces with conventionally armed Tomahawk cruise missiles, it would have strong incentives to counter those weapons preemptively by crippling the American C3ISR satellites controlling them through anti-satellite weapons or cyberattacks or some combination thereof. Washington might interpret an attack on dual-purpose satellites, however, as a threat to American nuclear capabilities—causing US authorities to believe they must choose between launching nuclear weapons immediately or losing their ability to use them altogether. This would constitute a highly escalatory situation driven by misunderstanding and fear rather than by any desire to initiate a nuclear exchange. Some Russian experts share Acton’s concerns, cautioning that “entanglement erodes the traditional delineation between nuclear and nonnuclear arms, as well as between offensive and defensive systems, and creates the threat of a swift and unintended escalation of a local conventional armed collision between the great powers into a nuclear war.”14

TWO SCENARIOS FOR WAR

Dry tinder does not produce a fire absent a spark of some kind, and sparks do not always result in a conflagration. Conditions that are ripe for an escalatory spiral—deep mistrust between adversaries, ongoing cybersparring, a mutual belief that the other side is intent on one’s own destruction, and deteriorating organizational and procedural frameworks that might normally contain conflicts and manage crises—do not necessarily lead to disaster, as the encounter in February 2018 between Russian mercenaries and American special forces in Syria demonstrated. Still, an examination of two hypothetical conflict scenarios, an exercise in imagination based on actual conditions that are ripe for escalation, illustrates how easy it would be for Washington and Moscow to find themselves in a nuclear confrontation neither wants.

RELIGIOUS VIOLENCE IN UKRAINE

The 2014 Russia-Ukraine crisis has precipitated one of the largest schisms in Orthodox Christian history. Millions of worshippers are caught in the middle of a struggle for political control between Moscow and Kiev. The present conflict has its roots in 1686, when the Ecumenical Patriarch of Constantinople granted the Russian Orthodox Church (ROC) conditional jurisdiction over the Kiev Metropolis. This arrangement has remained unchanged for over three centuries, but the Soviet collapse and Ukraine’s subsequent attainment of statehood have elicited a host of difficult political questions dividing Ukrainian public opinion: How does nationality intersect with religious identity in an overwhelmingly Orthodox state? Does fealty to the Moscow Patriarchate compromise Ukrainian national sovereignty?

The majority of Ukraine’s Orthodox parishes currently belong to the Ukrainian Orthodox Church under the Moscow Patriarchate (UOC-MP), subordinate to the ROC. In 1992, a faction led by the newly proclaimed “Patriarch of Kiev,” Filaret Denysenko, broke off from the UOC-MP to assert its autonomy from Moscow. This spiritual project has proved popular with Ukrainian nationalists, who have long expressed displeasure at the political messaging scattered throughout some Russian Orthodox liturgies; most strikingly, these include prayers for the health and safety of the Russian armed forces. The schism came to a head with the annexation of Crimea, when Ukrainian president Petro Poroshenko took up the cause of the Kiev Patriarchate (UOC-KP) as an assertion of Ukrainian “spiritual independence” from Russia.

But over the span of its existence, the UOC-KP has not been recognized by any other Orthodox church; the Russian-aligned UOC-MP remained the sole Orthodox authority in Ukraine. In a bid to secure international legitimacy, Ukraine lobbied the Constantinople Patriarch for a certification of autocephaly, or full self-government. It was granted this document, a Tomos in Orthodox terminology, in January 2019. Shortly afterward, the UOC-KP and smaller Ukrainian Autocephalous Orthodox Church (UAOC) were merged into the new Ukrainian Orthodox Church.

The UOC-MP, with its twelve thousand parishes across Ukraine, is regarded by Ukrainian nationalists as a national security threat and stands on the verge of being branded as an illegitimate sect within Ukraine. Around seventy parishes have opted to join the Ukrainian Orthodox Church, but what will become of the less willing? Several UOC-MP priests have unequivocally stated their resolve to die in defense of their churches and monasteries. Meanwhile, the Russian Orthodox Church is accusing Ukrainian authorities of seizing and vandalizing UOC-MP property with increasing frequency. The Ukrainian Rada has already passed an unprecedented law allowing church allegiance to be switched by majority vote, further increasing the likelihood of conflict within UOCMP communities.

From this point, it is easy to imagine how events might begin to spiral out of control. Ukraine’s president is unlikely to seek outright physical confrontation with the UOC-MP, but Ukrainian nationalists to his right have proved themselves less restrained. Right Sector, a prominent nationalist coalition, sees the UOC-MP leadership structure as wartime traitors, hostile foreign agents who cynically undermine Ukrainian national sovereignty under the cover of religion. Over the past year, Right Sector has staged several large street confrontations outside of UOC-MP churches to disrupt ongoing religious services. These ongoing efforts are likely to intensify and become more frequent, as the granting of autocephaly has cast the dispute over UOC-MP church property in a new political light.

Imagine, then, that a large group of Ukrainian nationalists blockades yet another UOC-MP church, as they have recently done in the Volyn Oblast of northwestern Ukraine. The priest arrives shortly thereafter, accompanied by a small congregation. Against a cacophony of jeers and threats of violence, he insists on entering his church to hold regularly scheduled services. As he pushes his way through the crowd, someone throws a stone at the back of his head. He collapses at the footsteps of his church. An ambulance is called, and responders pronounce him dead on the spot from a fatal concussion.

The religious cold war in Ukraine begins to turn hot. Tens of thousands of Russian Orthodox believers march in protest against the violence in Ukraine. Hundreds of private Russian citizens cross the border armed with pistols, rifles, and other small arms, intent on preventing further Ukrainian attacks and defending what is seen as Russian Orthodox property. The US State Department attempts to defuse tensions with a statement condemning violence, affirming the importance of religious freedom, and supporting Ukraine’s right to handle its own internal affairs in accordance with democratic principles.

The Russian response does not prove nearly as restrained. Since the presidential election of 2012, Russian president Putin has had to contend with growing Communist and nationalist movements on his political right flank. They accuse Putin of not doing enough to defend Russian interests with military force and complain that he naïvely seeks compromise with the West when he should instead be taking aggressive measures to roll back NATO influence in Russia’s legitimate sphere of interest. According to one particularly popular Communist critique, Putin has failed to protect the predominantly Russian-speaking people of Donbass from what is portrayed as a Ukrainian ethnic-cleansing campaign.15

The Communists charge, with overwhelming popular support, that this killing of a priest demonstrates the need to act immediately and decisively to protect Russian compatriots in Ukraine. They use this opportunity to again demand formal Russian recognition of the Donetsk People’s Republic (DPR) and the Luhansk People’s Republic (LPR), something that they have sought since 2015. Putin has to this point resisted calls for open and direct Russian military involvement in Donbass, a move that would invite serious international repercussions. But doing nothing in the face of the Ukrainian religious violence would play into the hands of his detractors, whose hawkish calls to action reflect the country’s mood better than Putin’s caution. Actively preventing Russian mercenaries from defending their co-religionists would be seen as an act of betrayal. The Kremlin settles for a response that stops just short of recognizing the Donbass: Russian emergency ministry units, supported by the Russian national guard, will cross into Donbass to establish a safe zone around the Luhansk area, replete with field hospitals to treat Ukrainians wounded over the course of the civil conflict.

Kiev calls this move not merely an invasion but an act of war, and it appeals to Washington for immediate military aid. Poland supports this call and offers to host additional American military forces to respond to Russia’s aggression. With Congress and influential segments of American public opinion demanding a forceful response, the White House has neither the political capital nor the diplomatic tools to de-escalate with Moscow. American tactical missile defense systems, air assets, artillery, and heavy armor pour into western Poland over the next several weeks. The US president announces that he has ordered US military personnel that had been rotating through Poland on temporary assignments to be increased in number and stationed along the border with Ukraine, ready for action should Russian military forces move toward the western portions of Ukraine. He explains that this show of force is not to help Kiev retake Donbass but to be ready to defend the rest of Ukraine against Russia. Moscow views the US announcement with alarm. Despite Washington’s denials, Russian military leaders conclude that Washington and Kiev are preparing for joint military action against Donbass.

From here, both sides become constrained by an increasingly narrow field of policy options. Moscow officially recognizes Donetsk and Luhansk as independent of Ukraine in a desperate last bid to deter what it sees as an imminent invasion. To protect what it has now acknowledged as two sovereign states, Russia establishes and enforces a no-fly zone across Donbass while stationing military forces across the border from Kievcontrolled territory. The United States, in turn, has no choice but to support a Ukrainian military buildup on the other side of the Donbass border, putting the two sides within a hair’s breadth of kinetic conflict.

A single shot across the unofficial border serves as the spark to war. It was not ordered in Moscow, Kiev, or Washington, however. Rather, it comes from the many “volunteer” forces active in and around the Donbass region, including the Kuban Cossack Host, which had long threatened to “come to the defense of our homeland and mother church” in response to acts of persecution against Russian Orthodox believers, and from ultranationalist paramilitary groups within Right Sector that had long been convinced that the Ukrainian government is unable or unwilling to take the steps necessary to retake Donetsk and Luhansk. As limited conventional skirmishing between Russian and Ukrainian forces begins, the United States does its best to avoid being drawn directly into the fighting, providing intelligence, arms, and advice to Ukrainian forces while keeping its own forces far from the line of contact, ready to defend against a Russian offensive. But a Ukrainian-operated antiaircraft unit shoots down a Russian fighter plane on combat air patrol over the Donbass, and Russian aircraft and artillery retaliate against several sites where US advisers were assisting Ukrainians, killing four American military personnel. A direct US-Russian military conflict starts climbing the ladder of escalation.

THE FOG OF CYBERWAR

The highly sophisticated, Russia-generated NotPetya malware attacks in Ukraine in 2017 quickly spilled out of control beyond Ukrainian borders and into networks across the world, inflicting more than $10 billion worth of damage and constituting the most destructive malware attack in history. The American response—indicting some named Russian individuals and adding new economic sanctions to those already in force against Russia, struck many cyberprofessionals as incommensurate to the severity of the damage. “The lack of a proper response has been almost an invitation to escalate more,” commented one.16 The next time Russia launched an attack, many advised, the United States should actively disrupt Russian cybercapabilities and impose much higher costs for such reckless aggression.

Imagine, then, a scenario in which a new cyberweapon is unleashed on Ukraine that targets gas pipeline control systems. Its effect is nearly instantaneous, shutting down valve control systems and pumping stations and bringing the flow of gas through Ukrainian pipelines to a halt. Because the halt is brief, and because the attack occurs in summer, the impact on European gas supplies is not nearly as severe as it would be in cold weather, but the intended message seems clear.

Ukrainian, European, and American governments issue immediate condemnation of the attacks and all but officially accuse Russia of responsibility. Moscow denies any involvement. Russia’s foreign ministry spokesperson suggests that Ukrainian hackers had launched the attack themselves in what she calls a “provocation.” Russian cybersecurity experts say Ukrainian criminal hackers who had been part of a transnational cybercrime group had initiated the crisis using Russian botnets and imitating Russian techniques. Their aim had been nothing more than extortion against Ukrainian government officials. US and European audiences find the Russian counteraccusation risible.

The perception of bald-faced Russian lying only reinforces American determination to act. Leaders at US Cyber Command urge the White House to draw a firm line. Issuing toothless legal indictments that have little chance of putting any Russian hackers behind bars would only underscore American powerlessness in the face of such attacks, they counsel. They ask for authorization to mount a reciprocal and proportionate attack on Russian infrastructure, reverse engineering the Russian malware and redirecting it against valve control systems and pumping stations in Russia. The White House agrees. Within weeks, Russia experiences a brief disruption of gas flows. The economic impact is minimal, but the psychological effect is significant. The United States, it seems, has removed the gloves on offensive cyberoperations.

Events soon begin to accelerate. As markets open on Wall Street several weeks later, traders experience a series of short “flash” outages of their online systems that result in the loss of several trillion dollars. Intermittent trading outages continue over the course of the few days, and trading is halted as stock and bond markets begin to plunge. FBI investigators strongly suspect that Russia is behind the attacks. The US Treasury secretary warns that sustained Wall Street losses could have a devastating domino effect on the American economy, producing a collapse of confidence from which it might be difficult to recover. If investors lose faith in the stability of the American economy, the foreign credits on which the financing of America’s massive national debt depends could grow dangerously more expensive.

In response, the American president draws a firm redline. He telephones the Russian president and states that cyberinterference with the US financial system constitutes an attack on critical American infrastructure that poses an existential threat to US national security. US policy allows for a kinetic response to such cyberattacks. He has no desire to attack Russia, he says, but unless Russia’s cyberattacks stop immediately, he will be forced to take military action, which he insists will be narrowly targeted and proportional. He counsels his counterpart to remove personnel from the Internet Research Agency building in Saint Petersburg as a precaution to minimize the chances of civilian deaths.

In Moscow, the Russian Security Council convenes a meeting on the growing crisis. One official recalls the critical role that an informal back channel between Bobby Kennedy and the Soviet ambassador had played resolving in the 1962 Caribbean crisis, but others point out that Russia’s current ambassador has long been frozen out of contact with anyone who matters in the US administration. Russian military officials, fearing the possibility of conventionally armed Tomahawk or drone attacks on key cyberunits, urge the Kremlin to authorize a “demonstration” event to discourage American aggression. Since many of America’s precisiontargeted munitions depend on satellite-guidance systems, they argue, Russia should use ground-based weapons to temporarily disable a US global positioning system (GPS) satellite. By “escalating to de-escalate,” the action would show Washington that Russia can and will defend itself against attacks and bring US decision-makers to their senses. The Russian president approves the operation.

But the “temporary” disabling of a single GPS satellite proves to be more damaging and more enduring than the Russians had expected. The satellite remains out of service for three days, and its outage has a cascading effect on the twenty-three other satellites in the US GPS constellation. Synchronization failures disrupt the entire system. Though it is popularly regarded as a mapping system, GPS in fact is an enormous space-based timing device vital to a wide range of government and commercial functions. Telecommunication networks rely on GPS clocks to allow cell towers to transfer calls. Electrical power grids use GPS to balance current flows. ATMs and credit cards cannot function without GPS time-stamping. Even computer network synchronization depends on GPS clocks.17 And much to Moscow’s surprise, its disabling of a single satellite brings all of this activity and more to a grinding halt. Americans are shocked to learn that the US government has no effective backup system in place.

Outrage over the Russian satellite attack quickly mounts. Congress demands that the White House respond, and it passes an immediate authorization for the president to use any and all means he deems necessary to end the Russian aggression. Pentagon officials tell the president that under the circumstances, they cannot be confident that Russia will not target even more critical C3ISR satellites next, which might cripple the United States’ ability to receive early warning of a Russian missile attack or to communicate with its conventional or nuclear forces. Piggybacking on the Pentagon warning, the NSA and CIA report that they have detected what they believe is a Russian cyberpenetration of a C3ISR communications network, and they cannot determine whether the intrusion is meant to monitor or disable the system. All concur that unless the president strikes back against the Russians immediately, he might lose the ability to defend the United States altogether. They urge an immediate retaliatory attack on all Russian ground-based ASAT facilities, in addition to targeting Russia’s cyberunits and its GLONASS counterpart to the US GPS system.

The march up the ladder of military escalation begins skipping rungs.

These hypothetical scenarios are far from inevitable. At each rung in their particular notional escalatory ladder, American and Russian leaders had options they failed to exercise that could have reduced tensions, cooled off emotions, and mitigated the dangers of spiraling into a disastrous confrontation. Individuals matter in the affairs of state, in addition to national interests, perceptions, technologies, alliances, behavioral norms, and the balance of power. Wiser leaders could have taken more responsible decisions that might have produced a much less alarming outcome. The fog of war and the “slings and arrows of outrageous fortune” could have shaped developments in substantially different ways.

But neither are the scenarios far-fetched. To one degree or another, each of the elements in the scenarios are based on current trends, actual recent events, the tendencies of leaders now in power, and genuine military capabilities. Nor are they the only set of events that could trigger an escalatory spiral. Unrest in the Baltic states, a clash in Syria, and a US-China confrontation in the South China Sea that Russia seeks to exploit are among a wide range of realistic situations that could produce unsought catastrophe.

No matter its origins, any escalation scenario is likely to have some features in common with the events illustrated in this chapter. The adversaries show themselves willing to run risks in the interest of gaining a competitive advantage, but they prove unwilling to take risks in the interest of peace. Both sides in the scenario fall into the same cognitive trap, the unexamined assumption that incremental escalation at each stage of the dispute will cause the other to reconsider its actions and back down, that “escalating to de-escalate” will prove to be a winning strategy. Both eventually discover that they are not dealing with what international relations scholar Robert Jervis has labeled a “deterrence model,” where a tough response to an ambitious aggressor state ends its aggression, but rather with a “spiral model,” in which coercive steps against a state that already sees itself as threatened wind up magnifying perceptions of vulnerability and triggering a dangerous escalatory reaction.

But both reach that discovery too late to change course.

PART II

Synthesis: Managing the Problem

Everything simple is false. Everything complex is unusable.

—Paul Valéry 5

Escaping the Simplicity Trap

How does one handle what management experts call a wicked problem— one that is not rooted in a primary cause but rather results from dynamic interactions between a multiplicity of vexing technological, psychological, political, societal, institutional, and international factors, few of which individually are prone to solutions?1 There is no universal recipe for success. Like Tolstoy’s observation that every unhappy family is unhappy in its own way, every wicked problem exhibits its own peculiar qualities that require particular approaches. But failures in dealing with such systems problems tend to have some important common features. One way to begin grappling with the complexities of the current US-Russian dynamic and mitigate the dangers of escalatory spirals is to examine past failures in dealing with other complex systems problems, to understand what not to do. And looking outside the realm of statecraft, toward such fields as ecology, is a good place to start.

PROBLEMS IN MANAGING SYSTEMS

The path toward wisdom in managing our Russia problem begins in Yellowstone National Park. Created by an act of Congress in 1872 as the first formal nature preserve in the world, the park encompasses more than two million acres of the American West, an area larger than the states of Delaware and Rhode Island combined. At the time of its establishment, Yellowstone teemed with wildlife. One naturalist characterized the early park as “an unfenced zoological garden for the enjoyment and enrichment of visitors who rarely saw such animals elsewhere.”2 Visiting the park in 1903, President Teddy Roosevelt observed many thousand elk, hundreds of antelope, and numerous cougar, mountain sheep, deer, and coyotes. Overwhelmed by the abundance and natural beauty, he wrote, “Our people should see to it that this rich heritage is preserved for their children and their children’s children forever, with its majestic beauty all unmarred.” And for more than a century, American law has required the US government to do exactly that, protecting the park against damage to its geological and botanical wonders and preventing “wanton destruction of fish and game found within.” Yet within a few decades of Roosevelt’s visit, Yellowstone was in steep decline. In 1934, an official US government publication announced that “white-tailed deer, cougar, lynx, wolf, and possibly wolverine and fisher are gone from the Yellowstone.” In the mid-1980s, one of the park’s foremost chroniclers declared, “As a wildlife refuge, Yellowstone is dying.”3 The tale of what produced this decline is not one of neglect or corruption or ill intentions. Rather, it is the story of a complex systems problem.

When the park’s new rangers set to thinking about how they would preserve its wonders, they quickly realized that they had been handed an enormous challenge. The park’s elk and bison populations were becoming endangered. At their peak, millions of bison and elk had roamed the American West. But for decades, Native American tribes and Euro- American settlers and game hunters had aggressively hunted the herds. In the years following the Civil War, the proliferation of modern rifles had greatly improved the efficiency of hunters, while new tanning technologies had generated huge markets for wildlife hides around the world.4 This combination devastated the bison and elk populations throughout the West. The Yellowstone herds were no exception. Hunting in Yellowstone was still legal through the 1870s, although the ill-defined “wanton destruction” of wildlife was banned. Hunters killed some four thousand elk in the park in the spring of 1875 alone, and they had reduced the Yellowstone bison herd to a mere twenty-five by 1894.5

To arrest the herds’ decline, the United States government banned the hunting of game in the park and literally called in the cavalry. Beginning in 1886, US Army personnel took over management of the park and invested considerable resources in feeding its elk and bison, driving out their poachers, and killing their natural predators. “Buffalo” Jones, appointed as the park’s first game warden, oversaw what effectively became a dedicated bison ranch within the park, devoted to the herd’s breeding, feeding, and care. These efforts were strikingly successful. By the late 1880s, Yellowstone’s elk population had started to rebound. Within a few more decades, the Yellowstone elk herd had grown to some thirty-five thousand, and bison had once again become a significant tourist attraction for the park.6 Moose began to establish themselves in Yellowstone for the first time, and the bear population increased. By early in the twentieth century, nearly everyone associated with Yellowstone, in and out of government, viewed the park as a grand success. More and more visitors were coming, and the park was regarded as a true national treasure.7

Just as old problems were being solved, however, new problems emerged. By the 1920s, it was becoming clear that something was going very wrong with park wildlife. Elk and bison continued to thrive, but the park’s antelope, deer, and bighorn sheep populations went into steep decline. White-tailed deer were gone altogether by 1924. Most alarmingly, beaver grew scarce:

Perhaps no animal was more important in Yellowstone than the beaver. By building his dams, he slowed spring runoff in the streams, discouraging erosion and siltation, keeping the water clean for the spawning trout. By building ponds, the beaver raised the surrounding water table, adding moisture that promoted vegetation—willow and aspen, forbs (broad-leaved plants such as aster, yarrow, and clover), berries and lush grass—that were essential foods for other animals. The ponds themselves provided habitat for waterfowl, mink, and otter.8

The National Park Service, which had been established in 1916 and had taken over management of Yellowstone from the US Cavalry, was convinced that it knew what was causing the problems: predators. Beavers were the primary staple of wolves, and cougar and coyotes preyed on deer, antelope, and bighorn sheep. Rangers redoubled their antipredator efforts, declaring “open war” on mountain lions, wolves, and other predatory animals.9 They eliminated the wolves and cougar altogether from the park. But instead of helping the deer, sheep, beaver, and antelope, these corrective steps only made the situation worse. “The more predators they killed, the greater the decline of the game; and the greater the decline of the game, the more predators they killed.”10

Perplexed, the park service called in experts to study the problem. The biologist Adolph Murie reached his conclusion after a two-year study in 1939. Predators, he said, were not the cause of the declining herds. Rather, the elk population “is unquestionably too large.” Hungry elk herds had devastated the park’s once abundant aspen and willow trees, which in turn left little for deer and antelope to eat. With the aspen in decline, beavers had fewer and fewer trees with which to build dams, and the beaver population declined. Without beaver dams, meadows lost a critical factor in their water management, and vast areas of the park that were once a source of native grasses, waterfowl, and small mammals dried up. This cascading effect was devastating the ecosystem.

As the origin and scale of the problem became increasingly evident, the National Park Service began to grasp the damage that well-intentioned but ill-informed park management had caused. They hired range specialists to study the park and invited more research by independent biologists. They followed elk movements, measured spring runoff and soil erosion, and carefully monitored tree and vegetation growth to gauge the impact of grazing. The more they learned, the worse things looked. Not only were the large herds overgrazing, but they were trampling vast areas of the park, compacting the soil and diminishing its porosity. When it rained, the water ran off the surface of the soil rather than soaking in. The soil dried out, and the water table dropped, decreasing plant growth. This, in turn, contributed to soil erosion, which exacerbated the other problems. Range decline had become a vicious cycle.

To break out of this cycle of devastation, park rangers embarked on a new program to contain the size of the elk and bison herds by trapping and transferring them to other parts of the country. They launched an ambitious reseeding effort to restore vegetation and native grasses. They encouraged the hunting of elk outside the confines of the park. But they made only limited progress; the elk population still remained too high. Trapping and transferring could only go so far in containing the herd, as demand for elk in other parts of the country was saturated. So rangers reintroduced cougar and wolves into the park and began to view coyote as allies rather than enemies. Elk would be “naturally controlled” by a combination of native predators and periodic harsh winters. But the addition of natural predation still failed to control the herd.

Absent alternatives, the National Park Service ultimately determined that it would have to kill a large number of elk annually in Yellowstone. A little over a century after the park’s dedication, its management approach had come full circle. The hunters and predators once thought to be the primary threat to the park’s wildlife were determined to be critical parts of its survival. Park managers had gone from regarding Yellowstone as the sum of its individual parts, each posing problems to be addressed segmentally, to viewing the park as an integrated ecosystem, a superorganism whose parts are interrelated and must be managed as such.

Through trial and a lot of error, the National Park Service had discovered in Yellowstone one of the main tenets of dealing with complex adaptive systems: you can never do merely one thing.11 In a complex system, multiple individual elements are connected to and interact with one another in ways that change over time. Relationships in such a system are not arithmetic, and good intentions do not necessarily bring success. Combining two and two seldom produces four; sometimes it produces twenty-seven or negative eight. Every individual step that you take inevitably has effects on other parts of the system, some of which may be damaging. And recognizing in advance what those cascading effects will be is immensely difficult.

RUSSIAN REFORMS: GOOD INTENTIONS GO BAD

Around the time that the National Park Service was coming to grips with failed efforts to fix the problems in Yellowstone, government officials in Russia and experts from the United States were embarking on an ambitious new effort half a world away: to build a free-market democracy in Russia on the ruins of the Soviet Union’s failed communist system. Their intentions were noble. Both Russian and American reformers wanted those who had suffered under the Soviet system to have better, freer, more prosperous lives. Each side believed that successful reforms would enable Russia to be “at peace with itself and with the world.”12 But while there were many free-market democracies in the world at the start of the 1990s, nearly all of them had evolved gradually over time, growing out of the rich soil of a substantial middle class and long experience with private enterprise and rule of law that the Soviet Union lacked. And when the recipe that the reformers devised for Russia’s rapid transformation produced an unanticipated cascade of negative effects—a handful of crooked insiders owning billions of dollars of former state assets, an unprecedented 40 percent decline in gross domestic product, a shocking plunge in male life expectancy to some fifty-seven years—each side pointed fingers at the “predators” they deemed culpable rather than admitting misplaced confidence in their ability to reengineer a complex societal system. Learning lessons from what went so wrong with reforms in the 1990s is a critical part of taming the vicious cycles of US-Russian hostility that threaten to spin out of control today.

Russia’s new leaders faced a daunting task as they surveyed the wreckage of the Soviet Union on its last day of existence, December 25, 1991. The newly independent Russian Federation had almost none of the attributes of a viable state, let alone a free-market democracy. First, the Soviet economy had collapsed. Store shelves had emptied, budget deficits had ballooned, and hard currency reserves had dwindled. The ruble was nearing worthlessness. Starvation threatened. Second, the levers of government that a normal state might employ to deal with this crisis barely functioned. Key government operations had been in the hands of the highly centralized but dysfunctional Soviet state, and Russia lacked the ability to collect taxes, coordinate monetary policy, control borders, regulate trade, enforce laws, or oversee military activity on its own. Directives were given but not carried out. Third, although the state had imploded, civil society was all but nonexistent. People were bewildered, demoralized, and spiritually exhausted. There was next to no private property or private enterprise. Genuine political parties and nongovernment civic organizations did not exist. Religious life had long been hollowed out. Decades of KGB informant networks had bred deep mistrust among Russians toward both the government and each other. The Russian republic had held its first legislative elections in 1990, but the newly created Russian Congress of People’s Deputies had little experience with the business of passing actual legislation or representing the views and interests of its constituents. Under the circumstances, how were Russia’s leaders to pull the country out of its rapidly worsening crisis?

A small team of young Russian economists, led by Yegor Gaidar and Anatoly Chubais, insisted that they had the answer. Russia’s crisis, they argued, had its roots in Soviet leader Gorbachev’s refusal to adopt true market-based reforms. Gorbachev had hoped to preserve some elements of the Soviet state-owned and state-run economic system, but his timid half measures had only made matters worse. The Soviet economy could not be tweaked, they argued, only destroyed and replaced. Putting the old system out of its misery would be painful, but “shock therapy”—Harvard economist Jeffrey Sachs’s term for the immediate elimination of price controls, rapid privatization of state-owned enterprises, extreme tightening of the money supply, and radical reduction of government spending— would minimize the duration of that pain. Classical capitalism would restock Russia’s empty shelves, reduce budget deficits, stabilize the currency, and begin to restore growth and prosperity within as little as a year.13

American experts largely agreed. There was a broad consensus in Washington at the time of the Soviet collapse that the fate of liberal reform in Russia would be a critical factor determining whether Moscow would make a decisive break with its old imperial ways. Senior officials strongly believed that the United States had a compelling interest in Russia’s liberalization; the only question was how it should liberalize. A few lone voices warned that radical economic disruptions could produce a societal backlash and endanger the survival of Russia’s fragile democracy, and they cautioned that the post-Soviet transition to capitalism should proceed carefully in accordance with local Russian traditions.14 But the vast majority of American experts, including several Harvard economists who advised the Russians and later joined the Clinton administration, regarded Russian traditions as the problem, not the solution. A gradual transformation of the Soviet command economy would only allow benighted revanchists to choke reform in its cradle. Rapid market reforms, on the other hand, would produce a growing Russian middle class that would become the foundation for an enduring capitalist democracy.

President Yeltsin was no economist, but he liked the approach Gaidar and Chubais advocated. It not only promised an economic turnaround relatively soon, but it also contrasted nicely with Gorbachev’s indecisiveness and resonated with the world’s wealthiest and most powerful nation. And Yeltsin was not a patient man. As he put it in his memoirs, “I couldn’t force people to wait once again, to drag out the main events and processes for years. If our minds were made up, we had to get going!”15 He put Gaidar and Chubais in charge of economic stabilization and privatization, and they launched “shock therapy” on January 2, 1992. Overnight, most state-controlled prices were freed.16 Then, in rapid succession, old import barriers were lifted, and private retail trade was legalized.

Much as the shock therapists anticipated, the pain was immediate: prices skyrocketed almost instantly. But they soon reached unexpectedly high hyperinflationary levels of 2,500 percent annually. Russians had only recently lost their empire and then their country, and now inflation caused them to lose their savings. “A scientist, whose salary in Soviet times may have been two hundred rubles a month, who may have saved five thousand rubles over a career, saw the value of his entire life savings shrink to a loaf of bread.”17 Consumer goods eventually returned to shelves, but by the time they did, no one could afford them. Stores became, as one observer put it, “museums,” where Russians came to look but not buy. Protests spread across Russian cities, and people resorted to bartering and selling personal possessions on the streets to get by. By April, Gaidar had become Russia’s most unpopular figure, and by year-end, he was forced to resign from his post as acting prime minister and play a less public role on Yeltsin’s team.

The problem was not that Gaidar was a bad economist. He understood the workings of a classical market economy well, probably better than any other economist in Russia. But he failed to grasp the limits imposed by the complexities of the broader social and political system in which he was operating,18 so he was surprised when his narrowly focused technocratic prescriptions produced unintentional cascading effects. Ending state price controls was necessary, but freeing prices without first breaking up the Soviet economy’s numerous monopolies to create market competition had invited an uncontrollable inflationary spiral. Monopolists, not markets, started dictating prices. Tightening Russia’s money supplies made sense, but it was impossible to do when the other newly independent former Soviet republics also had the ability to print rubles and when the chairman of Russia’s own central bank was not on board with the reform team. As one humorist put it, Russia was like a man who had fourteen bitter exwives, each of whom still had a credit card billed to his account.19 And imposing radical market reforms from above without erecting a social safety net or building political support from below created the impression that the Yeltsin team was indifferent to popular suffering. Reformers who were attempting to save Russia quickly came to be seen as wreckers who were trying to destroy it.

Yeltsin’s team adjusted tack amid the storm. They launched an ambitious privatization effort to break up state monopolies, create market competition, and incentivize investment. They tried to explain their approach to the public and build political support. Yeltsin named an experienced Soviet industrial manager, Viktor Chernomyrdin, as prime minister. And Yeltsin’s team worked even more closely with American advisers and government officials to think through their next steps, win large infusions of credit from the World Bank and International Monetary Fund, and cushion the blows of reform.

But while each of the steps they adopted helped to ease some problems, they created others in the process. Establishing new privately owned banks to replace the Soviet state bank, for example, was an important step toward building a functioning financial sector supporting genuine markets. But where would the banks get their capital? In a country where the state owned nearly everything, only the state had money. So several new banks convinced government ministries to deposit their money in special accounts within specific “authorized banks.” And once the banks had state funds on hand, they quickly found lucrative ways to make easy money off of it. Rather than lending money to new entrepreneurs or to old enterprises that needed to retool, the banks made big money off currency speculation.20 And by delaying disbursements, they could keep funds available to invest in high-yield government bonds and reap huge profits.21 But that meant that “coal miners, pensioners, teachers, and nurses [among others] went without pay” because the banks would not release the funds to pay them in a timely fashion.22 Enterprises could not pay their suppliers and went into arrears. That had a domino effect on other enterprises, creating a massive inter-enterprise debt problem.

So an economy that had been running on fumes for the waning years of Soviet rule did the only thing it could under the circumstances: it demonetized. People dumped their rubles and turned to dollars, gold, silver, and barter. Transactions increasingly went off books and underground. “Authorized banks” making huge profits off government deposits shipped their earnings to secret accounts in offshore tax havens denominated in dollars, safe from the reach of the state. With enterprises conducting fewer and fewer transactions officially, and accumulating more and more of their income off-book, the Russian government collected even fewer taxes. The less it collected, the weaker the state grew, and the less it was able to provide the basic services of government. Citizens lost any remaining respect for state officials, and the country’s ethnic republics— including Chechnya—spun increasingly out of Moscow’s control. Corruption and lawlessness spread. Organized crime exploded. Countless Russians desperate to escape poverty fell prey to cynical get-rich-quick scammers.

The Yeltsin reformers sought two ways out of this vicious circle. The first was to lean even more heavily on American help. Borrowing from the World Bank, International Monetary Fund, and other lending institutions became Russia’s primary means to cover its massive budget deficits. Cultivating close relations with official and unofficial Washington heavyweights, in turn, became the Yeltsin team’s best way to convince those institutions to keep lending money. America formed “a strategic alliance with Russian reform,” as President Clinton put it. And the more money the West lent, the more political pressures mounted to show success for its effort. Washington leveraged Russia’s need for debt relief and infusions of capital to push for policies aimed at “transforming almost every aspect of Russian economic, political, and social life.”23 A top Russian diplomat commented at the time that “among ourselves, we call Talbott [the top American official overseeing Russia policy] ‘Proconsul Strobe.’ He has all the answers and rarely hesitates to tell us what to do, as if we were small children in need of instruction.”24

Yeltsin’s second approach was to consolidate power to overcome political resistance. As Russia’s living standards plummeted and popular opposition to “shock therapy” exploded, the Yeltsin team sought a renewed popular mandate by holding a national referendum in April 1993 asking four questions: whether Russians had confidence in Yeltsin, whether they supported his reforms, whether Russia should hold an early presidential election, and whether early legislative elections should be held. American advisers created a high-profile, Western-funded public relations campaign for the referendum, urging Russians to vote “Da, Da, Nyet, Da” on the four questions.25 Yeltsin prevailed narrowly in the referendum, but Russians would not forget such overt American involvement in Russia’s politics.26

Despite the temporary political boost provided to Yeltsin by the referendum, it had become clear by the fall of 1993 that the tension between economic reform and democratic governance had reached a breaking point. Russia could not continue radical market reforms without dissolving the democratically elected Russian legislature, which had openly rebelled against Yeltsin’s rule. In October 1993, he ordered tanks to shell the legislative building, killing more than one hundred of its occupants. In the aftermath of the violence, the Kremlin engineered the approval of a new constitution that dramatically increased Yeltsin’s executive power and diminished that of the new parliament, the State Duma. When the Clinton administration backed Yeltsin’s moves against what it termed “reactionaries,” many Russians concluded that Washington cared little for their economic plight and even less for genuine democratic governance. According to gradualist reformer Grigory Yavlinsky, “The Russian people expected to hear something like this: ‘We Americans understand the difficulties you are facing. America has been through the Depression, has dealt with crime and corruption. Please do not think that crime and corruption are normal attributes of democracy.’ Instead, all they heard was unstinting praise for the [Russian] government.”27

Russian voters made their unhappiness clear in the December 1993 elections to the new State Duma. Gaidar led a pro-Yeltsin reform party called Russia’s Choice, but the “shock therapists” garnered a disappointing 15 percent of the vote. The anti-reform nationalist party of the bombastic Vladimir Zhirinovsky took first place with nearly a quarter of the vote, and the Communists and other anti-reform parties won another 20 percent, with a sprinkling of votes for gradualist-reform and special-interest parties accounting for much of the remainder. Washington was stunned. Almost no one had seen Yeltsin’s popular rebuke coming.28 In a press conference following the vote, Strobe Talbott suggested that the results reflected the need for “less shock and more therapy for the Russian people.”

But many of the shocks had already been administered, and backing off reforms could stall Russia’s transformation in a catastrophic no-man’sland between capitalism and socialism where nothing functioned at all. In the face of a hostile legislature, Yeltsin increasingly resorted to imposing reforms by executive decree, and Chubais pressed the accelerator on his privatization program, worrying that Russia had to make privatization irreversible before revanchists recaptured the reins of power. To get a vital piece of legislation through the Duma, he reluctantly agreed to a provision that would allow workers and managers in state enterprises to buy 51 percent of the shares of their new privatized companies at a nominal price.29 Chubais reasoned that it was the best he could do under the circumstances and that market forces would eventually force the privatized companies to retool and restructure no matter who ran them. But in practice, this meant not only that the government failed to earn much revenue selling ownership shares but also that the old Soviet factory managers under communism became the new Russian managers under capitalism. They pressured workers to sell their shares to management for a pittance and had none of their own skin in the game. Rather than rebuild their companies into efficient producers, many of these “red directors” simply stripped them of assets and embezzled funds. A program aimed at progress produced regression.

The reformers’ most fateful compromise came in 1995 and 1996, as legislative and presidential elections approached. By that time, Yeltsin’s once robust popularity had cratered, his approval ratings consistently registering well below 10 percent. The Communist Party was clearly Russia’s strongest political organization, and Communist presidential candidate Gennady Zyuganov’s polling numbers dwarfed those of Yeltsin. Unless Yeltsin somehow pulled some election magic out of his hat, the reformers looked to be on the way out. To conjure up that magic, Chubais struck a backroom deal with a handful of Russia’s leading bankers and media moguls. In return for lending their financial and media support to the Yeltsin campaign, the moguls would be granted large shares in the crown jewels of the Russian economy, the prized state-owned enterprises in the oil and gas and extractive industries worth billions of dollars. It was a win-win deal for the bankers. The “loans for shares” deal would make them instant billionaires while minimizing the chances that a Communist government might seize their ill-gotten gains and jail them. Chubais recognized that he was making a Faustian bargain, selling the state’s most valuable assets for a tiny fraction of their worth, but he saw no viable alternative.

The deal worked as both sides had hoped. The bankers poured millions of dollars into the Yeltsin campaign to produce television advertising that blanketed the airwaves. American political experts advised the campaign on tactics and messaging. And the Russian media moguls provided the campaign with the equivalent of many more millions in unpaid advertising by focusing network news coverage relentlessly on Yeltsin, lavishly praising his accomplishments and virtues. On the few occasions when television did devote airtime to Zyuganov, news coverage lambasted him. Yeltsin won reelection, Washington breathed a sigh of relief, and the moguls won both instant billions and instant power.

Afterward, some moguls officially joined the new Yeltsin government as ministers and presidential administration members. Others exercised their political power unofficially in what became known as the semibankirshchina, or “reign of the seven bankers.” Some were part of a shadowy group of Yeltsin relatives and close aides that became known as the “Family,” which served as a substitute presidency to compensate for the fact that Yeltsin could no longer govern, having suffered an unpublicized heart attack during the presidential campaign and undergone bypass surgery thereafter, while increasingly succumbing to alcoholism. Russia had privatized and staved off the communist threat. But it had not become a free-market democracy. It had become an oligarchy, with a handful of obscenely wealthy businessmen presiding over a government that could not function, underpinned by a corrupt, semi-criminal economy.

When an ailing Yeltsin resigned the presidency in 1999, apologizing to the Russian people for his failures and turning his administration over to his prime minister, Vladimir Putin, two questions loomed large: Who was to blame for the mess Russia found itself in? And what should be done about it? A few Russians, and many Americans, felt that the Yeltsin team had backed off reforms too soon, watering them down quickly when they met popular resistance, not paying enough attention to democratic reforms, and never completely following through on the reform agenda. The reforms that they did implement accomplished a lot, according to this school of thought, and a stronger reform team would have done a better job of explaining its approach to the public and building support in Russian society. For these die-hard believers in shock therapy, the villains in this tale were those ignorant of market economics and democratic principles who stood in the way of history’s inevitable progress. This only prolonged the pain that Russia would sooner or later have to endure. Getting reform back on track was the only viable path to success in post- Yeltsin Russia.

Others viewed the 1990s not as a narrative of disrupted reforms but as a story of the decline and destruction of the Russian state, a process that had started in the Soviet period, and which accelerated under reforms designed, as Ronald Reagan might have put it, to get the state off the people’s backs.30 Absent that state, however, no private enterprises or civic institutions existed in Russia that could encourage virtuous behavior and respect for the law. In an anything-goes atmosphere, anything went. Democratic and market reforms were both possible and desirable, according to this school of thought, but they should be advanced slowly and carefully over time in accord with Russian history and long-standing traditions, and they could not take place without restoring the state’s authority and capacity for governance. Putin and other gosudarstvenniki— loosely translated as statists—strongly advocated such an approach.

Still others adopted a different diagnosis. Like the Yellowstone park managers who blamed decline on predators, some pointed fingers at Yeltsin’s reformers, at the “oligarchs,” and at the Americans thought to be their allies. Ousting these malefactors was the key to progress. Gaidar came to be regarded suspiciously as a foreign agent. Chubais became the most unpopular man in Russia. The oligarchs were seen as robber barons, stripping the motherland of its riches while ostentatiously flaunting their stolen wealth and frequenting luxury resorts in the West. And because American officials had played such a public and intrusive role in Russian policies, many Russians assumed that the United States, the world’s most powerful nation, had “lured us into a trap, that this was done intentionally. They wanted us weakened.”31 The “fundamental attribution error”—the assumption that bad outcomes are the result of bad intentions or bad character, not difficult circumstances—was evident in Russian perceptions.

Viewed through the prism of Yellowstone National Park’s complex mix of interacting problems a century ago, however, Russia’s catastrophic experiences in the 1990s look more like good intentions gone bad than malfeasance on the part of key individual actors. Attempting to reengineer such a complex and delicate social organism was an enormously ambitious undertaking, prone to precipitating a wide range of knock-on effects difficult to anticipate. The shock therapists of the 1990s may have been guilty of overconfidence, but not of bad intentions. Their failures showed that creating a free-market democracy from scratch is neither a linear process nor a mere matter of will and perseverance. The legacy that decade left behind, however, is an important part of another set of complex system dynamics, one that today threatens to pull the United States and Russia into an unwanted, disastrous spiral of confrontation.

These brief overviews of Yellowstone’s travails in the late nineteenth and early twentieth centuries and Russia’s collapse in the 1990s provide a key lesson in what not to do when faced with a complex systems problem: do not treat it as if it were a linear problem, rooted in a single or primary cause that can be resolved through a determined effort. The Yellowstone managers initially believed the park was suffering primarily from predation—the more predation, the fewer elk, bison, and other game. Thus, they reasoned, reducing predation should solve the problem. But it did not; it caused even greater problems. Their diagnosis failed to consider the dynamics of the broader ecological system encompassing the park. The shock therapists in Russia encountered similar surprises for similar reasons, zeroing in on the economy as the primary cause of Russia’s problems, which they attempted to address with a Herculean campaign. But pressing the accelerator of economic reform did not hasten Russia’s journey toward greater prosperity and better governance, and in some ways diverted it.

This has important implications for the ways the United States has attempted to deal with Russia since the Cold War’s end. We have tended to look for primary causes of what we believe are essentially linear problems, recently attributing the growing dangers in the US-Russian relationship to the nature of Putinism and Russia’s endemic expansionism, believing resolute counterpressure will quell Russian appetites for aggression. We have attempted to seek progress through incremental steps, in the hope that making headway on some discrete problems can build momentum toward larger success. We have habitually sought to compartmentalize issues, preferring to focus on those driven by domestic politics or those that we think hold the best hopes for progress.

This incremental and compartmentalized approach makes abundant sense intuitively. Why complicate things, when one can break the problem down into its component parts and focus on what is most salient or easily achievable? It is also driven by the bureaucratic silo effect, which encourages narrow specialization while discouraging cross-organizational integration. But it has not worked in practice.32 For example, we have attempted to tackle complex issues such as Ukraine in isolation of broader factors, only to find that putting off such thorny subjects as how to structure Europe’s security architecture and how to deal with the controversies over interfering in internal governance renders progress on Ukraine all but impossible. We have hoped that US-Russian cooperation against terrorism or joint efforts to deal with the Iranian nuclear problem might build momentum in other areas, only to find in frustration that success has not proved contagious. We have largely treated Russian cyberintrusions as a technical security issue, and Russia’s subversive influence operations as an aggression challenge, only to find that cybersecurity measures cannot keep pace with the offense and that our punishments of aggression are not resolving the problem and may be making it worse. Meanwhile, our attempts to isolate and pressure Russia have had unexpected secondary effects, reinforcing Russian incentives to deepen security cooperation with China and subvert NATO and the EU. As planning expert Russell Ackoff has observed about “messes,” his term for complex systems problems, “if we do the usual thing and break up a mess into its component problems and then try to solve each one separately, we will not solve the mess.” The fundamental dictum of complex systems, that one “can never merely do one thing,” means not only that our actions will always have secondary effects but also that in order to bring about desired change, we must do several things at once.33

A more holistic approach to dealing with our complex set of problems with Russia would make for a greater challenge in managing the US interagency process, necessitating a larger number of players and deeper integration of regional and functional issues, but without one, we are likely to find ourselves continually slipping backward as we struggle for progress. The simple recognition that we are dealing not with a linear Russia problem but rather with the dangers posed by a complex system may by itself have a salutary effect on our approach. Awareness that we must change course could stimulate creative efforts to find new (albeit less direct) paths to success.34

Recognition that our problems with Russia are not linear has other implications as well. It suggests that we should approach our ambitions with a good deal more humility, acknowledging the limits of our knowledge and our capabilities, while remaining alert to the risks of unintended knock-on effects from our policies. This has particular relevance to the question of promoting democratization, an issue that has plagued the US-Russian relationship for nearly the entire post–Cold War period. George F. Kennan, the father of America’s Cold War containment policy and among the most insightful experts on Russia that our country has produced, warned against ambitious attempts to reshape foreign societies some four decades prior to the disastrous Russian reforms of the 1990s: “The ways by which peoples advance toward dignity and enlightenment in government are things that constitute the deepest and most intimate processes of national life. There is nothing less understandable to foreigners, nothing in which foreign interference can do less good.”35 His advice was premised not on disputation of the virtues that enlightened governance abroad might bring but rather on the recognition of our own limitations in diagnosing and treating the ailments of other countries. “This whole tendency to see ourselves as the center of political enlightenment and as teachers to a great part of the rest of the world strikes me as unthought-through, vainglorious and undesirable,” he later cautioned.36 Realist scholar John Mearsheimer recently put it even more plainly: “Social engineering in any country, even one’s own, is difficult. The problems are multifaceted and complex, resistance is inevitable, and there are always unintended consequences, some of them bad.”37 To this, one might add that good intentions and high ideals are not the only yardsticks by which to assess virtue; implicitly promising the attainment of outcomes that America lacks the power to effect is a moral hazard in its own right.

Reconsidering how we have approached democratization does not and should not require the United States to abandon its ideals or change its nature. Advancing the causes of liberty and justice in the world is an inherent part of what America is and what it represents. But how we advance these ideals matters immensely. If liberalization is not a linear process but one shaped within the contours of a complex, interacting set of factors, most of which we do not and cannot control, then a more humble approach is warranted. Identifying those factors in which the United States can play the most beneficial part, while attempting to minimize the prospects of counterproductive actions, might improve our dismal results in encouraging liberalization abroad. Serving as a powerful example, the “shining city on the hill” that attracts the world’s respect and emulation can be an effective way to advance democratic ideals, and it is a factor that the United States most directly controls. Attempting to impose liberal governance through pressure or coercion, however, in the belief that democratization is a linear process that follows a universal recipe for success, can lead to failures that provoke opposition abroad and prompt doubts at home about our system of governance.

Washington’s foreign policy culture is biased toward action. When problems arise, our first impulse is to “do something,” which at times can foster the impression that we regard any action as better than none. By contrast, this chapter has focused on what not to do, acknowledging the vast potential for unintentionally compounding problems in the context of complex systems dynamics. Avoiding such errors will not by itself restore US-Russian relations to health or eliminate the dangers of escalatory spirals. It will not settle genuine conflicts of interest over Europe’s security architecture, resolve fundamental differences in US-Russian values, or address the problems flowing from cybertechnology. But in a relationship woefully short on trust, a focus on learning from the common threads running through our past mistakes is something each side can do independently, without need of the other reciprocating or making concessions. The old dictum, “When you find yourself in a hole, stop digging,” contains valuable wisdom. Once we have stopped, we can begin to lay the foundation for new rules of the shadow war game and new mechanisms for absorbing future shocks to the system.

6 Absorbing Shocks

Shock absorbers are the pessimists of the automotive world. Their very existence is premised on the belief that roads and highways will inevitably include some bumps and potholes and debris of various kinds, no matter how hard our road designers and construction engineers and maintenance crews work to avoid them. Their purpose is not to correct these defects but to make them less damaging to vehicles and less painful to drivers and passengers. They reflect a recognition that imperfect roads are a chronic condition of transportation, one that we can minimize but not eliminate.

Our interwoven and dynamic world makes shocks—surprise developments that diverge sharply and suddenly from the trends preceding them, sometimes producing disastrous outcomes, sometimes not—all but inevitable. In recent decades, these shocks have included the disintegration of the Soviet Union, the 2008 financial crisis, and the Arab Spring, all discontinuous “black swan” events resulting from complex systems dynamics. The exact form and timing of these shocks are nearly impossible to predict, but their impact can be cushioned, their effects managed. If the first order of dealing with complex systems problems is to avoid treating them as if they were linear problems, susceptible to piecemeal resolution, the second is to build resilience into the system, rendering shocks, when they come, less damaging than they would otherwise be.

A focus on resilience differs in significant ways from efforts to promote stability. Stability is, all things being equal, usually a desirable thing. But in some contexts, the search for stability can be counterproductive. Buildings that are too rigid will crumble under the stress of an earthquake. Similarly, stability strategies that emphasize preventing danger and eliminating risk in the realm of foreign affairs can become too rigid to withstand shocks, too unimaginative to adapt to challenges, too protective of the status quo to adjust to change.

When stability strategies fail, as in the prelude to World War I, their failure can be catastrophic.

In the second half of the nineteenth century, the European system grew increasingly rigid, unable to adjust incrementally to new geopolitical challenges and changing domestic politics. Europe devolved into a system of rival alliances focused on reinforcing the bonds within each camp rather than maintaining broader equilibrium on the continent. Diplomacy lost touch with new technologies and their implications for warfare, and proved unable to cope with the imperatives that were driven by the advent of the railroad and the advantages that would flow from preemptive attack. As a result, the system amplified rather than buffered disturbances and became highly susceptible to shocks generated by relatively minor disputes.1

Resilience strategies, by contrast, acknowledge the inevitability of change and the probability of shocks, and they focus on more general capabilities to respond to hazards when they occur, regardless of what they are.2 California’s Loma Prieta earthquake in 1989, for example, caused the iconic fifty-two-story Transamerica building in San Francisco to sway wildly but produced no lasting damage to the flexible structure, while more rigid buildings not far away collapsed altogether. The early nineteenth-century Concert of Europe featured similar resilience. Prior to the shocks of the Crimean War in 1853 and German unification in 1871, it had been an adaptable and flexible system, able to make incremental adjustments as needed to manage disturbances. It was aimed not at preventing conflicts altogether but at limiting their impact and containing their dangers. How might we build such resilience into the system that is both shaping and shaped by US-Russian relations, improving its ability to bend but not break under stress?

COMMUNICATIONS RESILIENCE

The successful management of any crisis begins with communications. In the wake of the Cuban missile crisis, the United States and Soviet Union established the so-called hotline linking leaders in Washington and Moscow, because it was evident that direct and timely communications were vital to managing crises in ways that minimized prospects for escalation. A similar recognition about the need for American and Russian military commanders in Syria to avoid accidental clashes between their forces led them to establish an official deconfliction channel there in 2016. Extending this narrow channel into broader US-Russian discussions of how we might handle possible security crises in Europe and beyond would be an important preparatory step toward better crisis management. There is much potential danger to discuss in Ukraine, North Korea, Iran, and elsewhere, in our parallel efforts to battle terrorists, and in how we handle the thorny issue of cyberoperations, including false-flag cyberattacks designed to deflect blame or even spark US-Russian conflict.

Communications are not only useful in avoiding accidents and misunderstandings; they are also the best means available for contending with two unavoidable problems that flow from twenty-first-century technology: time and ambiguity. Time played a critical role in the tragedy of World War I, as military leaders pressed to mobilize forces quickly to outflank the enemy rather than be outflanked, and diplomacy relying on the slow transmission of letters and telegrams could not keep pace.3 Time is even more problematic today. News and information flow at light speed across the globe, and the demand for almost instantaneous commentary on cable television and in social media and other digital forums puts enormous pressures on governments to issue statements and adopt policy positions well before the facts of an emerging conflict situation—or their meaning in larger context—are evident. The rapidity with which highprecision weapons systems can strike targets half a world away could force national leaders to make fateful military launch decisions in minutes, rather than hours or days. Moreover, the inherent ambiguity of the cyberworld, coupled with the entanglement of nuclear and conventional weapons systems and the vulnerability of satellite networks, means that they might have to make such decisions with little clarity about the origin or intention of devastating digital attacks. The combination of shrinking time, increasing ambiguity, and burgeoning streams of data is driving increased reliance on artificial intelligence and automation to assess and respond to threats. This can potentially reduce the role of human decision-makers, increase the chances of accidents, and narrow the opportunities for compromise. The time for discussing how to handle such dangers is now, not in the suffocating heat of a crisis.

For maximum resilience, formal lines of communication are not enough. In high-stakes crises, emotions can run hot and the mooting of compromises can be a most delicate matter. Lower-level representatives engaging in off-the-record discussions have greater freedom to explore possible off-ramps and convey the limits of flexibility than do heads of state. In the Cuban missile crisis, the “confidential channel” between US Attorney General Robert Kennedy and Soviet ambassador Anatoly Dobrynin played a crucial role in averting disaster. In fact, the ultimate resolution to the crisis—a secret understanding that Kennedy would remove American nuclear missiles stationed in Turkey after the Soviets dismantled missile sites in Cuba, an understanding that would not be put in writing or acknowledged publicly—was brokered between Kennedy and Dobrynin.4

The fact of a confidential channel is less important, however, than the quality of the communication within it. That quality, in turn, depends both on the skills and wisdom of the specific personnel involved and on the recognition by leaders in both Washington and Moscow that they must invest in building and safeguarding the relationships that the channel requires for effectiveness. Dobrynin observed in his memoirs that a channel that ensured “possibilities for a candid if not always pleasant dialogue between the leaders of both countries … appeared to be the only way of preventing the Cold War from turning into a hot one.” But to work, he added,

[the confidential channel] has to be permanently available, and its immediate participants must possess a certain level of diplomatic and political experience and knowledge. Above all, the channel should never be used by any government for the purpose of misinformation. Of course, a diplomatic game is always being played, but deliberate misinformation is inadmissible, for sooner or later it is going to be disclosed and the channel will lose all its value.5

#### AND, boosts Russian science diplomacy---caps all impacts

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It is almost impossible to discuss science diplomacy without referring to some episodes of Russian and Soviet history. Pierre-Bruno Ruffini, from Le Havre University, begins his book on science diplomacy by discussing the symbolic meaning of the scientific cooperation initiated by the leaders of the Soviet Union and the United States, Mikhail Gorbachev and Ronald Reagan, in 1985. (Ruffini, 2017, p. 1). The influential report ‘New Frontiers in science diplomacy’ by the American Association for the Advancement of Science (AAAS, United States) and the Royal Society (United Kingdom) starts with a brief history of science diplomacy that highlights East-West negotiations on nuclear non-proliferation, arms control and other peace and security issues, where the influence of scientific communities was essential (Royal Society, 2010, p. V). Scientists have been playing a prominent role in Soviet and Russian foreign policy in formal and informal ways, be it by supporting government policy or by challenging it. Their impact ranges from the promotion of the advantages of socialism and to the negotiation of milestone treaties and of international peace initiatives. Scientific achievements such as space exploration, or discoveries of new elements in the periodic table, were an important part of Soviet identity both within the country and abroad.

Today, in the age of globalization, countries aspiring to benefit from the new world stratification and secure favorable strategic prospects must integrate themselves in the global economy and its infrastructure. When developing science and technology domestically, there is a need to build links with the international scientific community becomes a crucial foundation for this endeavor.

The assessment of Russian science diplomacy resources is a complex task. Russia is the last of the top ten countries in the world ranked by gross domestic spending on R&D, measured in purchasing power parities (PPPs). In 2016, Russia’s R&D spending reached US$39.9 billion. The number of researchers and professionals engaged in science in the country is high: it is ranked fourth in the world with almost 429,000 people employed in the sector. And the same time the country ranks only 34th by gross domestic spending on R&D measured as a percentage of GDP (1.1%) and by number of researchers (in full-time equivalent) per 10,000 employed in the economy. It is 47th in terms of spending per researcher, substantially behind the leading nations. The number of publications and citations of Russian scientists indexed in Web of Science and Scopus is steadily growing, as well as the number of patent filings from Russia. There is a substantial share of publications co-authored with researchers from other countries—in 2016 around 25% of all publications. The wages in science organizations have substantially increased recently, by more than 50% from 2017 to 2018. At the same time, the Russian share in global publications output is still relatively low. In 2016, the proportion of Russian articles in peer-reviewed publications indexed by Web of Science or Scopus was 2.56% of all publications indexed that year, by which Russia ranked 14th in the world (Gorodnikova, Gokhberg, & Ditkovskij, 2018, pp. 268–271, 285–288).

Today the term ‘science diplomacy’ is increasingly often used in Russia, especially among the academic community. In 2017, during the election campaign for the president of the Russian Academy of Sciences (RAS), science diplomacy was mentioned in the manifesto of two out of five candidates.1 The same year a prominent think tank, ‘Russian International Affairs Council’, organized an expert discussion on science diplomacy and Russian-American cooperation in the Arctic.2 In addition, the country’s leading foreign affairs university, MGIMO, hosted a round table on science diplomacy organized by the Royal Society and the Russian Foundation for Basic Research (RFBR).3 In September of the same year, Andrei Fursenko, aide to the president of Russia, gave an interview where he stated that the importance of science diplomacy in growing.4 In late 2017, the Russian Academy of Sciences held a special session on science diplomacy and international science cooperation5 and in January 2018 the newly elected president of the Academy presented a plan on the future of RAS to the president of Russia, highlighting the importance of science diplomacy.6 Further, science diplomacy was the major topic of the Seventh Annual Meeting of the Global Research Council held in May 2018 in Moscow.7

But what exactly is science diplomacy and how can Russia benefit from using it in the twenty-first century? The widely accepted description put together by AAAS and the Royal Society encompasses three interrelated dimensions of science diplomacy: science in diplomacy (providing scientific, expert and analytical support to foreign policymakers), diplomacy for science (facilitating international scientific cooperation) and, finally, science for diplomacy (using scientific cooperation to improve relations between countries, including the so-called track 2 or track 1.5 diplomacy, in which think tanks play an important role) (Royal Society, 2010). Many activities can qualify as ‘science diplomacy’ under this broad definition. Ruffin from the WZB Berlin Social Science Centre argues that contexts in which the term ‘science diplomacy’ emerges are just as diverse as the actors:

Science diplomacy thus is first and foremost a new umbrella term to characterize the role of science and technology in numerous policy fields that have an international, boundary-spanning, component. […] The idea of science diplomacy, then, provides a new, more strategic and—more or less—coherent framework to integrate existing instruments in international S&T policymaking. (Ruffin, 2018)

By influencing the international agenda, participating in diplomatic missions and establishing new contact networks, scientists create a new environment for international relations, in which politicians and diplomats need to take into account the opinions and interests of national and international scientific communities.

Science diplomacy in major countries is to some extent bound to economic interests, while international interaction related to the humanities and social sciences seems to be put aside. In many cases, science diplomacy efforts are mainly focused on implementing national science, technology and innovation policies, on supporting national businesses and on engaging the scientific community in R&D. Further, there is often a focus on providing solutions to the most important global problems. At the same time science diplomacy can be regarded as a form public diplomacy or as an instrument for increasing a country’s soft power. It can also play a substantial role in global governance as a way to manage global risks and to look for solutions to problems affecting the majority of peoples and states. When experts become negotiators, and contribute to mending relations between countries, science diplomacy contributes to conflict resolution. These areas overlap: for instance, the country’s role in global governance and in solving global issues can positively affect its attractiveness abroad.

The recent increase of attention to science diplomacy in Russia can be explained through each of these lenses, but it seems that the soft power and conflict resolution considerations slightly prevail over the global governance theme and economic considerations. While some other countries highlight the role of science diplomacy in ‘bringing countries together to work on shared challenges, from responding to emergencies to implementing the sustainable development goals’,8 Russian policymakers and experts often focus on the communicative potential of science diplomacy, on its role in improving relations with other countries as well as on science as a way to position the country as one of the leading global powers.

The distinction between science diplomacy and international science cooperation is not always obvious. It is clear that science is international in its nature and researchers from different countries inevitably interact and influence each other. Yet not every international scientific contact contributes to science diplomacy. Western experts argue that science diplomacy is always connected with national interests:

Science diplomacy’s direct relationship with national interests and objectives distinguishes it from other forms of international scientific co-operation, which are sometimes commercially oriented and often occur without direct state participation. (Turekian et al., 2015, p. 5)

Science diplomacy can sometimes be a by-product of international science cooperation, when contacts between researchers aimed at solving scientific problems provide an opportunity to improve a country’s image, overcome stereotypes, come up with a constructive international agenda and pave a way for cooperation between states. At the same time, there is always a risk of politicizing science and turning it into a propaganda tool rather than a science diplomacy instrument. There is also the question of the independence, objectivity and impartiality of the scientific community as an actor in politics and international relations, as well as the issue of the relative autonomy of science institutions as non-state actors of world politics.

As for Russia, science diplomacy can be considered as one of the ways to mitigate the conflict between Russia and the West and overcome the lack of trust between them. There are allegations of misinformation, propaganda wars, undermined democratic processes and manipulation from both sides. Usually scientists are considered to be less easily manipulated and influenced by propaganda than others and at the same time are not as limited in their public activities and speeches as diplomats. Polls show that people in different countries trust scientists more than politicians, journalists and representatives of many other professional groups. In the United States people tend to trust scientists more than media or elected officials.9 A total of 79% of British people would generally trust scientists to tell the truth, while only 25% say the same about journalists and 22% about government ministers.10 Russia has one of the highest rates of trust in science (89%) and at the same time one of the lowest rates of awareness of new scientific and technological achievements (18%) (Gorodnikova et al., 2018, pp. 263–266). A higher level of trust in scientists provides a possibility to rebuild trust between nations and overcome some of the myths and misconceptions about ‘the other’. Can science diplomacy make a difference and change negative stereotypes about the country? Can scientists help policymakers reach a better understanding? And can scientists become better diplomats and ambassadors?

Science diplomacy in Russia can also be regarded in the context of Eurasian integration and processes in the post-Soviet space. In the Soviet period science and technology developed rapidly. After the collapse of the USSR, many of its industrial, technological and scientific networks suffered heavily, yet some continued to function. In Russia, scientific centers in Moscow, Saint Petersburg, Novosibirsk and other cities as well as in smaller scientific towns (naukograds) experienced major problems with financial, infrastructural and human resources. The links with scientific communities in former Soviet Republics weakened, as these countries developed their own trajectories. Increased attention to science and innovation in the 2010s in Russia and growing interest toward science diplomacy can also be discussed in relation to the post-Soviet space. Can links between scientists, the use of the Russian language for research and publications and the former experience of collaboration become a part of a broader agenda and improve relations between Russia and its neighbors in the long term?

Mechanisms and Instruments of Emerging Russian Science Diplomacy

Unlike, for example, in the United States, United Kingdom, Switzerland or France, in Russia, science diplomacy as a distinctive research field is still emerging. It is also not fully formed as a relatively independent foreign policy area. But the preconditions for science diplomacy are nevertheless present. In 2010, the president of Russia approved a policy document on the main directions of international cultural and humanitarian cooperation. The document envisages such cooperation both in bilateral and in multilateral formats, including in science and education. Contacts in these areas are becoming increasingly important in the context of the country’s modernization.11 The publication was an addendum to the Concept of Russian Foreign Policy. The new Foreign Policy Concept approved in 2016 also mentions science and research in different contexts. It speaks of the need to deliver unbiased information about the country to the international community and highlight Russian cultural and science achievements. The concept also entails responding to many global challenges, including economic development, global disparities, environmental issues and terrorism, using research-based approaches.12

In 2016, a presidential executive order introduced a new long-term Scientific and Technological Development Strategy of the Russian Federation. According to the document, science is an instrument required to respond to several ‘grand challenges’. These challenges create substantial risks for society, economy and governance but at the same time provide new opportunities and prospects for the country’s scientific and technological development.13 The publication of this strategy can be regarded as the result of the country’s political class becoming aware of a new international political reality. It can also be seen as a demonstration of Russia’s commitment to respond to the ongoing competition for global leadership. Approaches to training academic personnel are being revisited. Attitudes to science, its role in global affairs and its place in politics and diplomacy are changing.

The 2016 Strategy puts science and technology at the heart of responding to many global and national issues. The role of science is to forecast global changes, to consider new trends, expectations and needs of the Russian society, to detect new ‘grand challenges’ in good time and to provide an effective response. One of the priorities is to create a model for international scientific and technological development, as well as for international integration, that could allow mutually beneficial interaction while at the same time protect the identity of the Russian scientific sphere and Russia’s national interests. This is particularly relevant in the era of globalization and internationalization of science.

There are a number of publicly funded governmental and nongovernmental organizations involved in Russian science diplomacy. The most prominent of them are the Ministry of Foreign Affairs (MFA), the Ministry of Science and Higher Education, the Ministry of Economic Development, the Ministry of Health, the Ministry of Industry and Trade, the Federal Agency for the Commonwealth of Independent States Affairs, Compatriots Living Abroad and International Humanitarian Cooperation (Rossotrudnichestvo), the Russian Academy of Sciences, the Russian Foundation for Basic Research (RFBR) and the Analytical Centre for the Government of the Russian Federation. There are also prominent think tanks, first of all, Primakov National Research Institute of World Economy and International Relations (IMEMO) and MGIMO University, ranking 34 and 90 in the 2017 Global Go To Think Tank Index Report, respectively.14 There is also the international Valdai Discussion Club established in 2004 and the Russian International Affairs Council created at the initiative of Ministry of Foreign Affairs (MFA) and the Ministry of Education in 2010.

The Russian Academy of Sciences has traditionally played an important role in the country’s science policy and in international scientific cooperation. Established as the Russian Academy of Sciences and Arts by Peter the Great in 1724, its development relied greatly on the results of the Tsar’s innovations, including facilitated access to foreign specialists. Among the first honorary members of the Academy were the famous mathematician Leonhard Euler, the brothers Daniel and Nicolaus Bernoulli, the French writer and philosopher Voltaire, the Swedish biologist Carl Linnaeus, the German philosopher Immanuel Kant and other great. The main reason for bringing foreign specialists into Russia was to develop Russian science to close the gap with Europe. However, a diplomatic dimension was always present.

After the Russian Revolution, the Academy transformed into the Academy of Sciences of the USSR and then in 1991 back to the Russian Academy of Sciences. The history of the Academy in the USSR includes outstanding achievements but also human tragedies. During the Cold War, science and technology was in the center of competition between the two superpowers. This made the Academy powerful but at the same time vulnerable. Science cooperation with Western countries was extremely limited.

Economic and political disarray of the 1990s left the Academy and its institutions in a dire state, the effect of which is still felt today. Although the end of Cold War opened many doors for scientific cooperation and science diplomacy, the poor state of the Academy and of the scientific field in general led to a major brain drain and a human resources crisis, as well as to the decay of infrastructure. Many promising scientists either left the country or changed their occupation. The former reputation of Soviet and Russian science was significantly undermined. In the early 2000s the economic situation improved, but nevertheless the financing of the RAS remained insufficient, and science diplomacy potential remained low.

The new push for reforms started in 2013 with a number of administrative measures, including the creation of the Federal Agency for Scientific Organizations (FASOs), Russia. The Academy’s institutions were originally placed under its authority. The reform was widely criticized by the scientific community. Following negotiations, an agreement was reached on the principle of shared responsibility between the RAS and FASO. In 2018, FASO became a part of the newly established Ministry of Science and Higher Education that emerged after the Ministry of Education and Science split into two agencies. Today, the management problems still exist, and the Academy struggles to re-establish its status as the most respected and influential scientific institution in Russia.

According to the abovementioned Strategy for Scientific and Technological Development of Russia, the government’s road map prepared in 2017 envisions a special role for the Academy in creating a modern system of management in science, technology and innovation and securing a higher investment appeal for the R&D sphere.15 In July 2018, the president of Russia signed a legal act on amendments to the federal law on ‘Russian Academy of Sciences’,16 enhancing the authority of the Academy.

The Academy’s experience and its science diplomacy potential received legal foundation in terms of science in diplomacy and science for diplomacy. The Academy became responsible for providing expert support and advice to Russian authorities including foreign policy bodies. It also gained a formal role in forecasting the main trends of scientific, technological, social and economic development of the country, as well as in guiding and supervising the activities of scientific organizations and higher education institutions. The Academy’s power to implement international science and technology cooperation has increased.

The Russian Foundation for Basic Research (RFBR) is another major player in science diplomacy. It was established in 1992 as a federal organization controlled by the government. It runs competitions and provides grants for scientific research, including funding for projects and events involving foreign partners. The foundation has contacts with many of these.17 In the last ten years the funding of the foundation increased several-fold18 and its international reach continues to expand. The fund recently supported a 2016–2018 project entitled ‘Practices of science diplomacy: natural sciences in international social and political context’ led by MGIMO professor A.V. Shestopal. RFBR has taken part in and/or initiated many of the abovementioned public events and discussions on science diplomacy. The organization positions itself as one of the ‘flagship platforms’ for science diplomacy.19

The governmental and non-governmental organizations responsible for improving Russia’s image abroad, facilitating public diplomacy and overseeing international development, are also involved in science diplomacy. Rossotrudnichestvo was established in 2008 and replaced former agencies responsible for promoting Russian culture abroad. It works under the authority of the Ministry of Foreign Affairs and is represented in around 80 countries through ‘Russian centers for science and culture’. However, science is not central to the activities of Rossotrudnichestvo. The organization’s latest annual report for 2017 lists many cultural and educational activities and programs promoting Russian and just a few sciencerelated projects: ‘days of Russian science’ in three of its offices; a ‘Russian scientific humanitarian expedition’ in Tajikistan, the Kyrgyz Republic and Vietnam; and an International Humanitarian Science Forum in the United Kingdom.20 The organization plans to increase the effectiveness of its science-related activities.21

The Alexander Gorchakov Public Diplomacy Fund was established in 2010 by a decree of the president of Russia. Science diplomacy as a form of public diplomacy is a major part of its activities. It funds projects and organizes events involving foreign policy experts and researchers from different countries. It also facilitates discussions on foreign policy issues. The organization’s priority areas for the 2019 funding cycle include international cooperation to tackle new challenges and threats, such as the development of the Arctic, security issues in the Middle East and many others.22

### Plan---1AC

#### The United States federal government should increase its cooperation with the government of Russia on the creation of a loaded sectioned space elevator for deep space exploration, including the creation of a space elevator exclusion zone.

### Solvency---1AC

#### SOLVENCY

#### The AFF solves---it employs a new design that overcomes technical barriers---BUT, international coop is key.

Yu. A. Sadov & A. B. Nuralieva 15. Keldysh Institute of Applied Mathematics, Russian Academy of Sciences. 05/2015. “Loaded Sectioned Space Elevator.” Cosmic Research, vol. 53, no. 3, pp. 230–236.

GENERAL SCHEME AND MAIN COMPONENTS OF THE SPACE ELEVATOR CONSTRUCTION

It is impossible to construct the SE with materials available nowadays. Maybe because of this until a certain moment the number of papers considering its dynamics and details of construction was small. But in 1991 carbon nanotubes (CNT) were discovered [8–10], whose breaking length theoretically can reach about 10000 km, which readily satisfies the requirements to the space elevator tether. Though nobody so far has succeeded in producing a material from them, the space elevator construction has attracted more attention. One can find reviews of papers in [11, 12]. The NASA’s Institute of Advanced Concepts (NIAC NASA) placed an order with B. Edwards to investigate SE construction possibility. The concept developed by him [13–15] has formed a basis for other works on SE. The Spaceward Foundation company with a financial support of NASA organized a cycle of competitions on manufacturing the super strong material and lift device. More attention is attracted by the SE topic at large space conferences including IAC.

As a result, rather well-developed concepts of SE have appeared [13, 16]. Virtually all of them include the following components.

(1) Super strong suspension tether of variable cross section. It is a common suggestion to manufacture it in the form of a ribbon.

(2) A counterbalance mass on the tether end. It can also be used for other purposes, for example, to func tion as a station.

(3) Transport system in the form of cabins moving along the suspension tether.

(4) Wireless or local power supply system.

(5) Ground-based segments.

Let us consider some issues of this list in more detail.

The tether is a bearing element of the entire con struction and a carrying element for moving cabins loaded by motors, and devices for power supply and coupling with the tether.

In spite of the great potential profit of the space ele vator, energy consumption for delivery of cargo would still remain high. For freight traffic of 1000 kg per day a power of at least 0.5 MW is required. To transmit such a power by wires over tens of thousands kilometers would lead to enormous energy losses, mainly in the form of heat (hence, the problem of its removal arises). There fore, it is usually proposed to transmit power wirelessly (with the help of laser or microwave emissions) and to use solar batteries or even nuclear power plants.

It is often suggested to place the groundbased seg ment on a movable sea platform. This would allow one to change the elevator position (within certain limits). There are also suggestions to locate the lower segment as high as possible, thus reducing the tension in the lower tether section, which should lead to a reduced total mass.

The concept is quite solid, but in our opinion some changes could further improve it. Its main restrictions are as follows.

(1) Transporting cabins move along the tether, i.e., the tether combines bearing and carrying functions. Dynamic loads produced by the nonuniformly moving cabin and mechanical contact with it deteriorate the thin ribbon. In addition, twoway traffic is almost impossible. There are suggestions to use two tethers, but they may tangle or collide with each other. Finally, there is a problem of heat removal, since the moving cabin releases heat.

(2) There are some doubts concerning the wireless transmission of power. Of course, wire conductors from modern materials are too heavy, while solar bat teries cannot provide the necessary power supply. However, by the time of SE construction these tech nologies may be far ahead of their modern level. In our opinion, the main drawback of wireless power supply is its onesided character; in this case any recuperation is practically impossible.

(3) The issues of checking the state of equipment and controlling the elevator motion have almost not been discussed, though they ensure the operability of the construction. Exceptions are represented by sug gestions to place the lower end of the tether on a mov able platform in ocean or to distribute rocket engines along the tether [17].

(4) It is impossible to install additional equipment (scientific and/or industrial) on such a construction.

The concept of a loaded space elevator put forward below is more realistic from the authors’ viewpoint, though they do not expect a quick implementation.

LOADED SPACE ELEVATOR

The SE design suggested here possesses extended capabilities, reliability, and controllability. For this purpose, one should change the tether construction and deploy additional equipment. This will increase SE mass, since in the original conception the tether and lift devices were almost the only essential compo nents.

Bearing construction. The construction suggested here represents a sequence of sections whose shape is formed by circular frames. Superstrong intersecting filaments are tightened between the frames so that the filaments form a hyperboloid lateral surface. The structure resembles the Shukhov tower, but with equal diameters of the sections. Cabins and tethers along which they move are arranged within the sections. Let us enumerate some advantages of such a construction.

(1) There is no need for super strong filaments of cosmic dimensions. The construction is assembled from relatively short filaments, their length being about 100 m.

(2) The problem of preparing a super long tether from short elements without loss of strength is removed from the agenda. The mechanical strength of a construction does not differ from the strength of sep arate filaments substantially, while the strength of glued or woven material from these filaments is essen tially lower.

(3) The task of making the tether section variable with length is solved easily: for this prpose one changes the number of filaments in sections.

(4) The sections have a similar structure, which facilitates their assembly and replacement.

(5) The lateral surface is similar to a two-dimensional one, the anti-meteoritic advantages of a ribbon being kept.

Conveying system. The sectioned loaded construc tion allows one to separate the bearing and carrying functions. The lift devices move along a system of car rying cables fixed to the bearing tower at nodal points, so that the bearing construction is not subjected to dynamical loads and mechanical erosion. The cabin can be fixed to the carrying cable and move together with it, as in the ordinary elevator. The engines and power supply can be placed not on the cabin but at nodal points of the construction. At a sufficient width of the construction (several meters) one can arrange inside it several cables and organize twoway traffic.

Power supply system. Energy can be transmitted by wires. Even if this transmission does not proceed over the entire construction, but locally (within the limits of 1000 km) it can improve efficiency due to recuper ation and more rational deployment of sources and receivers of energy. With movable cables the engines and power receivers are fixed and not limited by cabin dimensions, in this case mechanical recuperation is also possible (when a cabin on its passive motion seg ment pulls another cabin). In addition, if film solar panels are distributed along the construction, they can ensure power supply for transport of freight even at minimal efficiency. Probably light nonmetallic con ductors will be created, based, for example, on graphene, whose conductivity according to some data can approach that of superconductors. This would allow one not only to supply the elevator with power (exchanging it between separate parts of the elevator), but also to transmit to the Earth the energy generated in space.

Control and checking. The advantage of this con struction is that basic elements are open for observation and access. This gives a possibility to monitor its state. Probably, it is also possible (though more com plicated) to replace damaged elements. One can also imagine a sophisticated system of control over the ten sion of separate filaments, which would allow one to control local motions of the tether. Such a system could be useful for many purposes, including avoid ance of collisions.

Geostationary platforms. Rigid frames allow one to deploy research and industrial equipment.

Thus, the SE gains new capabilities. It will be able to ensure sufficiently high two-way freight traffic without the use of propellant and concomitant pollution of environment. It will give places for scientific and industrial bases in space. More distant prospects include creation on the same basis of conditions for habitation of people in space.

SOME ISSUES OF IMPLEMENTATION OF A LOADED SPACE ELEVATOR

Because of its enormous tether length and due to difficulties of linking remote parts of the elevator it is assumed that its basic functions are more or less iden tical at such parts so that the masses connected with them are rather uniformly distributed over length. This assumption leads to a concept of uniformly loaded space elevator, below we will follow it. For the sake of brevity we refer to the uniformly loaded tether as loaded.

Minimization of the elevator total mass. Thus, in addition to a bearing tether with linear density at point s there is an extra mass distributed with a constant linear density σ*a*. Then, the total linear density of the construction is where .

 is the condition of uniformly strained tether. It follows from this condition and (1) that

,

therefore,

where

. (12)

The length distribution of the total linear density has for the uniformly loaded elevator the same form, as for unloaded one (8). But this is already not so for tension

.

The tension at point s is not proportional to tension at the initial point, it includes also a summand proportional to σa.

Let us prove that, similar to an unloaded elevator, the total mass of the loaded elevator monotonously decreases with increasing tether length L.

Accounting for the additional load the total mass of the tether is

.

Adding Mk from (11) and taking (12) into account we get the total mass of the elevator

,

where Fext(s) is the gravity–centrifugal force acting upon unit mass tether element (2).

MT increases with increasing tether length L, while Mk decreases with increasing L at L>hgs. In order to find extreme values of ML(L) = Mk(L) + MT(L) we take the derivative

, (14)

.(15)

Here, .

Summing (14) and (15), and taking into account that , we find .

Since at and , then . is equal to zero, if Mk = 0, i.e. the following equality is satisfied

. (16)

In this case the tether is called self-balancing (i.e., it balances itself, and no end counterbalance is required). It is seen from (12) that > 0 and decreases at . The solution with the smallest L takes place at . In this case , which occurs at where km is the distance at which the potential is equal to that of the Earth’s surface. This is the smallest length of a self-balancing tether.

The minimum of the system’s mass ML is reached always at tether length L is determined from (16), and the total mass of the elevator

.(17)

If the elevator is not loaded, i.e., , аnd then , then from (16), which corresponds to . Thus, the mass of an offload system decreases monotonously with increasing tether length beyond the geosynchronous orbit.

Estimated characteristics. In order to imagine the construction dimension let us make approximate esti mations. The theoretically calculated breaking length of CNT is Lb = 10000 km. Taking into account the margin of safety and the fact that being made into fil aments the material most probably will lose some strength, let us take Lp = 3000 km. Accordingly, 30 km2/s2. We designate as the ratio of the maximum (that is, at the geostationary height) total linear density to the total linear density at the initial point. For the breaking length selected above From (13) we have

. (18)

The tensile force T0 should ensure elevation of a cabin with a mass of at least 1 t, therefore, we assume

[[TABLE OMITTED]]

 N. We set , assuming that σa < 1 g/m is small to guarantee operation of the elevator, while σa > 1 kg/m makes the elevator too heavy. Let us introduce the parameter , which reflects the distribution of mass between the bearing part and additional load. For above σa values 3 < A < 3000. We classify elevators with A = 3, A = 100, and A = 3000 as light, middle, and heavy elevators. Formula (18) takes on the form .

For assumed values of A we have 17 < Tmax/T0 < 12000, therefore, the maximum tensile load of the tether for a heavy elevator is ≅1.2 ⋅ 108 N.

Above we present an example of possible mass distri bution for a heavy elevator with a length of 100000 km (see table).

The obtained values are enormous, but one should take into account cosmic dimensions of the construc tion and the fact that the large additional mass means wide capabilities of the SE. Besides, no optimization was made in the estimating calculations.

Construction and exploitation of the loaded SE. The characteristics tabulated above seem to be unreal izable. But the SE scale is quite comparable to that of groundbased constructions. Giant oceangoing ves sels (aircraft carriers and supertankers) have masses of about 100000 t. The mass of the Great (Cheops’) Pyr amid of Giza is about 5 million tons, and all this mass was elevated almost without technical facilities to a height of a 150 m in 20 years. Many analogies can be found with construction of the TransSiberian Rail way. Its length exceeds 5000 km. It was constructed for 20 years under conditions of lack of roads and bad communication between builders. Of course, these analogies to the SE construction are rather remote. But all foreseeable problems can be solved on the basis of technologies which are either available or at the stage of commercial introduction. The only exception is the key problem of manufacturing the super strong filament.

Several countries are conducting investigations, most actively the USA, China, and Japan. There is some progress, though rather slow. There are communications about already made CNT filaments whose length is many meters [18]. In Japan filaments Zylon and Torayca have been produced, which are among the strongest, and a method is suggested to manufacture long filaments from ordered bundles of CNT. The Japan Space Elevator Association has been estab lished. Unique electric and thermal properties of CNT are revealed, and this gives some hope for wire power transmission.

However, still remains the problem of financial support for this project. Construction of the SE requires enormous funds and a long time (reckoned in decades). Therefore, it is reasonable to implement the project gradually and as a part of a wide program of space exploration, most likely, international [19].

A station in the geosynchronous orbits can be used as a first stage. In addition to its basic tasks, this station will gradually deploy the elevator’s tether. In doing this one should not even wait for manufacture of super strong fil aments. Currently available materials are suitable to be used for the first thousands of kilometers. The deployed sections of the tether can serve as an orbital transporta tion system. They also give an additional (with respect to geostationary orbit) place for instrumentation that should be immobile relative to the Earth.

CONCLUSIONS

The project described here is vast and difficult to realize. It requires the development of new technolo gies, to create new branches of productive industry, and to solve major scientific problems. Such a task can be performed only as a part of a largescale program of space exploration. The space elevator will be one focus of this program, and it will stimulate research in science and technology. Accomplishment of its construc tion will significantly widen the scope of human activ ity beyond the limits of our planet.

\*\*\*DON’T READ\*\*\*

#### FYI---this is what a “loaded sectioned space elevator” looks like

Yu. A. Sadov & A. B. Nuralieva 11. Keldysh Institute of Applied Mathematics, Russian Academy of Sciences. 2011. “О Концепции Нагруженного Секционированного Космического Лифта,” or “The Loaded Sectioned Space Elevator Concept.” M. V. Keldish Institute of Applied Mathematics, vol. 39, pp. 1–25.



\*\*\*START READING AGAIN\*\*\*

#### All physics barriers have been overcome---prefer recent evidence.

Peter Swan & Michael Fitzgerald 19. Swan is President of ISEC; Fitzgerald is Chief Architect at ISEC. October 2019. “Today's Space Elevator. Space Elevator Matures into the Galactic Harbour: A Primer for Progress in Space Elevator Development.” International Space Elevator Consortium. ISEC Position Paper # 2019-1. https://isec.org/wp-content/uploads/2019/10/Todays-Space-Elevator-23-Sep-2019.pdf

5.1 Current Imperative!

Because of the availability of a new material as a potential solution for the Space Elevator tether material, the community strongly believes that a Space Elevator will be initiated in the near term. Indeed:

The Space Elevator and Galactic Harbour Concepts are ready for Prime Time

5.2 Summer of 2019 Space Elevator Themes

The summer of 2019 was a turning point in the visibility of Space Elevator development and the future of movement off-Earth towards the Moon and the planets. As such, ISEC and other members of the Space Elevator community are active at the major conferences in Washington DC: National Space Society's International Space Development Conference (June 2019) and the International Astronautical Congress, sponsored by the International Astronautical Federation, International Academy of Astronautics, and International Institute of Space Law (Oct 2019).

This book is being developed to help in efforts to approach significant players in the space arena who are expected to be at the conferences and accessible to the ISEC team. The four themes to be presented are:

• Theme One: Space Elevators are closer than you think!

• Theme Two: Galactic Harbour is a part of this global and interplanetary transportation infrastructure

• Theme Three: Space elevator development has gone beyond a preliminary technology readiness assessment and is ready to enter initial engineering validation testing -- leading to establishment of needed capabilities.

• Theme Four: The magnitude of the Space Elevator Architecture demands that it be understood and supported by many.

The following sections of this chapter illustrate each of the themes and provides background supporting information.

5.2.1 Theme One: Space Elevators are closer than you think

There are two major factors that have encouraged the Space Elevator community and have lad to this theme. The ISEC leadership believes that we will see a Space Elevator earlier than expected.

• Single Crystal Graphene is being developed and will be applicable for the Space Elevator tether. In the laboratory a 0.5x0.1 m sheet with 130 GPa tensile strength has been proven.

• The International Academy of Astronautics Study states:

o The Earth Port, Headquarters & Operations Center, and Tether Climbers are all buildable with today’s available technologies and engineering expertise

o The GEO Node - GEO Region and Apex Anchor technologies are understandable and not an issue for development.

Recent investigations explored the possibility for making single crystal graphene by a continuous process using liquid metal. It seems highly possible that continuous single crystal graphene will be manufactured in the coming years and this material should be considered going forward for Space Elevator tethers.

5.2.2 Theme Two: Galactic Harbour is part of this global and interplanetary transportation infrastructure

With the latest revelations at the National Space Society's International Space Development Conference there are some remarkable aspects that are common across transportation infrastructures.

• The Space Elevator’s Earth Port is the transportation nexus between Earth and the Solar System. Cargo and Payloads arriving by container destined for:

– Geosynchronous enterprises

– Interplanetary deliveries

• The Obayashi Corporation study (2015)25 designed a Space Elevator with:

– People traveling to GEO, and

– Space based solar power satellites for Japanese energy needs

• Release from the Apex Anchor enables interplanetary mission support in a robust manner. Recent studies at Arizona State University have shown that Apex Anchor releases could arrive at Mars in as little as 77 days with weekly “bus schedules” traveling in non-traditional Lambert method ellipses.

5.2.3 Theme Three: Space elevator development has gone beyond a preliminary technology readiness assessment and is ready to enter initial engineering validation testing -- leading to establishment of needed capabilities.

In the last six years, ISEC’s technology maturation approach has melded with a better definition of Space Elevator engineering solutions. The 2014 publication of ISEC’s “Architecture and Roadmap” report removed the shroud of mystery and myth from the elevator’s scope and complexity. The Space Elevator was no longer a mystery. “Design Consideration” documents published between 2013 and 2017 delineated an engineering approach for Tether Climber, Earth Port, GEO Region, and Apex Anchor. An architectural simulation tool was selected. The last technology hurdle - strong material for the tether – will be overcome. Based upon this technological maturity, and its engineering momentum, we expect that before the middle of this century an operational Space Elevator Transportation System will be built and operating.

[[FIGURE 9 OMITTED]]

Figure 9, Technological Maturity as of Fall of 2019

Further, the engineering substance of a Space Elevator has solidified and become more organized -- most notably as the Galactic Harbour. The Galactic Harbour will support enterprise activities along the GEO belt, factories and solar power generation near GEO and efficient interplanetary departures from the Apex and arrivals at GEO.

The Technology Momentum of the Galactic Harbour is real; and, it underwrites the interplanetary vision of transportation, enterprise, and exploration

In the last year, the International Space Elevator Consortium assessed that basic technological needs are available, and each segment of the Space Elevator Transportation System is ready for engineering validation. The ISEC position:

1. The Galactic Harbour Earth Port è ready for an engineering validation program

2. Space Elevator Headquarters / Primary Operations Center è ready to start an engineering validation program

3. Tether Climber è Engineering model assemblies needed -- then start an engineering validation program

4. GEO Node èEngineering discussions and demonstrations with key members of industry are needed along with collaboration / outreach with certain government offices.

5. Apex Anchor è Engineering discussions and various simulations are needed. Near term collaboration with engineering organizations and academia should begin follow-on outreach to key members of industry and government. Engineering validation follows.

6. Tether material è Prime material candidate is identified; and, production demonstrations are needed.

7. Collision avoidance è Architectural engineering definition is being finalized. Candidate concepts are identified. On orbit performance demonstrations are needed.

With all these thoughts, the preliminary technological readiness assessment is a process that the Space Elevator community, and especially ISEC, has embraced. As such the Space Elevator is ready to move into the validation testing Phase. The infrastructure is Ready to Proceed.

[[FIGURE 10 OMITTED]]

5.2.4 Theme Four: The magnitude of the Space Elevator Architecture demands that it be understood and supported by many.

There are several reasons why the Space Elevator Architecture needs to be included in broader discussions around the world because of the following two discussions:

Safe and reliable access to space is the foundation for humanity’s travel within our solar system. The Space Elevator provides that access and enables:

• Routine [daily], Space Access

• Revolutionarily inexpensive [<$100 per kg] orbit transport

• Commercial development similar to bridge building [Public/Private]

• Financial Numbers that are infrastructure enabling

• Permanent infrastructure [24/7/365/50 years]

• Multiple paths when infrastructure matures

• Massively re-usable, no consumption of fuels

• Environmentally sound/sustainable - will make Earth "greener"

• Safe and reliable [no shake, rattle and roll of rocket liftoff]

• Low risk lifting

• Low probability of creating orbital debris

• Redundant paths as multiple sets of Space Elevators become operational

• Massive loads per day [starts at 14 metric tons cargo loads]

• Opens up tremendous design opportunities for users

• Optimized for geostationary orbit altitude and beyond

• Does not leave debris in LEO

• Co-orbits with GEO systems for easy integration

The Space Elevator is an invaluable addition enabling remarkable support of interplanetary missions because it not only supports Earth oriented satellites and missions, but it enables robust off-planet movement:

• Daily trips towards the Moon with roughly 14 hour transits

• Daily launches towards Mars with short transit times [as short as 77 days]

• High velocity releases from the Apex Anchor that can go to the outer planets with planetary gravity assists

5.3 Conclusion

The four "themes" chosen from the 2019 ISDC should be supported. Each of the four themes will have tremendous impact within the global transportation arena. The Space Elevator is ready for prime time. One constant realization is that ISEC needs to be invited, by space leaders, into discussions of significance. In addition, as discussed early in this report, the Space Elevator Institute should be created to provide more investigative power on issues of importance. The engineering refinements and the tie to business enterprises must be understood and executed.

#### Solving legal issues proves the concept, unlocking global investment.

Peter A. Swan & Cathy W. Swan 07. Ph. D. 2007. “Space Elevator Systems Architecture.” https://space.nss.org/media/Space-Elevator-Systems-Architecture.pdf

2.3.2 Engineering Aspects

Space Elevator Survival: One of the early questions by investors and stakeholders alike will be elevator survival. This should be addressed early and progress shown to illustrate a “Zero Cut” policy and continued survival of the family of systems. This is expanded upon in a full chapter to initiate this discussion early within the program.

Base Anchor Architecture: Many major risk issues of a space elevator are inherent in the first 2000 km of altitude. Multiple approaches must be initiated to ensure survival of this massive endeavor, to include the options of movable base anchor and ribbon dynamics control.

Environmental Threats: The design of space systems has matured over 55 years and a good understanding of the environment has developed. However, there is a slight difference with this project in that a space elevator will not be moving at high velocity though the space environment to stay in orbit. Satellite vehicle designers must realize that the environment is similar, yet unique.

Materials: Materials for the vehicles that will be traveling in space along a space elevator will parallel the current spacecraft systems’ materials. This will ensure that the past history of success can be transferred. However, the material for the ribbon must be developed and is the pacing item on a space elevator project.

Dynamics of Location: The dynamics of a long space tether will be unique and must be fully understood prior to placing climbers on the ribbon. This is not a significant problem with the computing tools available. However, the impact of solar or lunar gravitation on the movement of the ribbon will need to be understood. In addition, the dynamics of moving 20 ton climbers, at 200 km/hr, will need to be studied and simulated extensively.

Size of Ribbon: The size of the ribbon will be a major trade item for many years to come. It must be robust enough to handle multiple climbers. In addition, it must support itself and ensure that a “Zero cut” policy is maintained. How wide does the ribbon have to be to handle the climbers? How thick? How strong and how resilient?

Climber Designs (people, logistics, repair/replace, etc.): The design of the climbers must be based upon an open standard such as the distance between the rails of a train. This open standard would then allow several manufacturers to supply equipment for a standard ribbon. Each of the designs must be very efficient, extremely reliable and essential expendable. The difficulty will be in setting the open standards.

2.3.3 Testing and Deployment Dynamic predictions, environmental impacts, climber interactions and safety/survival aspects all must be included in a test program. Ribbon material survival in the environment could be tested in chambers or in space. The dynamics of a space elevator will have to be simulated on the ground until the first space elevator is constructed. As the program goes forward, testing and incremental deployment will be critical to its success. Along with the development of a space elevator is a mandatory cleaning up of items such as dead satellites and rocket bodies. This deployment phase activity will have to be orchestrated within the rules of space faring nations to ensure compliance toward non-interference of a space elevator corridor [a column of space going from the anchor to the counterweight where a “keep out” zone must be mandated].