Regenerative Engineering,
a textbook for tomorrow's sustainable engineering
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Dedication: to my daughter Hope, to my wife Grace, and to all the dreamers who refuse to give up.

Contents:

Preface

Years ago (and this dates me obviously), there was a wonderful British TV show called Blake's 7. In that sci-fi, there was a spaceship called Liberator. If not critically damaged, that ship could repair itself (regenerate itself). A really cool idea! Unfortunately, this text is not about regenerating spaceships; it's about a new field of engineering that developed from the union of systems engineering and sustainable leadership (Dr. John Hardman, currently at FAU). Another great TV show from the past was the original Star Trek. In The Empath a character says: "Everything that is truest and best in all species of beings has been revealed by you .. Those are the qualities that make a civilization worthy to survive." But I correct that last word: thrive. Our species ***NEEDS*** to ***thrive*** not just survive.

Question: what is the ***ONE*** thing we can do within our lifetimes that will *enduringly significantly improve* the quality of life for ***ALL*** living things on Earth?

I'm writing this text in Samar, Philippines. It's Hope's and Grace's birth and growing-up place. The village name is Cagmanipis Norte which is about 30 km north of Calbayog, the commercial center of Samar. Historically, this is a fishing and farming community with copra/oil (coconut) being a major export. Copra harvesting is sustainable; dynamite/over-fishing local seas is not. Over-fishing/dynamite has nearly exterminated local fish populations to the point local fisherman cannot feed their families. Hope is now almost eight months old and needs a way out of Samar. I believe if I can inspire her, she can help homo sapiens transform our current exploitative "civilization" into a genuine sustainable one. So this textbook is not just for future engineers; it's also for anybody who wants to improve life on Earth.

Before we can understand regeneration and regenerative engineering, we must understand sustainability. Sustainability is a necessary precursor to regeneration. A good analogy is thriving vs subsistence. By definition, subsistence living is just what you need to get by and nothing more. For example, many of us can live with a bowl of rice and few cups of water each day. We're not considering shelter or any other human need. But, after a few months on rice and water, I doubt many would be healthy even with adequate shelter. Water and rice do not have the vitamins and minerals we need to stay healthy nor recuperate from illness or injury. Subsistence living cannot engender thriving. To thrive, we need more. But not just proteins and vitamins; we need things to inspire us. To thrive is a process like fulfillment. It's like the difference between "summation of parts" and synergy/emergence. Regenerative engineering is to pre-RE – as – synergy is to reductionism. Synergy recognizes something beyond "summation of parts" as RE does.

Regenerative engineering is the engineering analog for global positive transformation.

As implied above, RE can be a part of it. As I compose this text, I'm also recording segments for Hope – hoping to inspire her later on when she can understand and care. God willing, she'll be a great daughter, good student, and caring human being like her father. But I care most about her belief in herself because with that, she can do ***ANY***thing (positive)! Of course, we need cynics and criticism to keep things balanced, in-perspective, and double-checked, but, without optimism at our core, we won't experience a better tomorrow unless by "luck". (I personally don't believe in luck.) We must *forge* a better sustainable *regenerative* tomorrow through faith, understanding, and perseverance.

This text was inspired by John Hardman and our desperate need for it – in engineering and everywhere else. A few years ago, I took a course taught by him entitled Sustainable Leadership at Florida Atlantic University, Boca Raton, Florida, where I believe he still teaches. I did not receive an A-grade for the course even though it was one of three that changed my life: logic and systems science at Michigan State being the other two. To fully integrate concepts taught in Sustainable Leadership absolutely *requires* a change in mind-set which I attempted but obviously did not fully succeed in. Maybe I can make-up for my lacking then with this textbook now?

One of my fundamental childhood prayers was "please help me acquire a unique fulfilling challenging education which will enable me to do Your will God" and His answer was systems science at Michigan State University in E.Lansing, Michigan. Prior to that academically, I studied psychology and statistics and probability also at MSU. I graduated there with a double-major in them. But as implied above, even a double-major was "not enough" for me. I needed something more – something integrative. Systems science seemed to be "the field" for me .. About half a masters later, I still felt that way but the College of Engineering felt something else. Long-story-short, I moved to

California with my best friend and from then on – tried to find an academic home with appropriate mentor. Unfortunately, never found until FAU with mentor Dr. Hanqi Zhuang. Even then, university politics prohibited me finishing a degree so again, I moved on .. Years later, after many ignored articles/booklets published in mathematics, AI, and physics, several published/unpublished screenplays, I find myself writing this in Samar with indescribably beautiful wife and daughter – Grace and Hope.

I almost named her Patience since we seem to need that so much in our daily lives .. In the Bible, “There is faith, hope, and love – and the greatest of these is love.” But for me: “there is hope hope and hope and the greatest of these is Hope”. At this most desperate time in human history, we need Hope (the archetype of hope) more than ***ANY***thing.

It’s true – the word “system” has bee overused. “Farming system” (tractor), “voting system” (ballot), “transportation system” (car),.. These misuses of the word show modern people that it’s a *fad* to name things “systems”. I’m not a PhD – not even an honorary recipient. But there are many instances where individuals have contributed positively and significantly to a field from “outside” that field. In other words, many fields are multidisciplinary such as systems engineering and RE. The historical indicators of engineering disasters from various disciplines calls for S-R and RE. These are not isolated exceptional incidents. They are systemic failures and need to be addressed systemically .. A car is actually a dynamical system for many reasons: the human driver, speeds and conditions which can make steering unstable, being part of a huge complex system of drivers and vehicles,.. these factors actually make the label appropriate. So to label an automobile “a system” is valid but we must be careful about *why*.

Answer: positive global transformation toward a truly sustainable civilization.

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Chapter 1: Systems-Reliability

The traditional systems approach:
For the last seven decades, post-WWII, westerners have referred to the “systems approach” as a four-step ***process***:

1. specifications & boundaries
2. feasibility & scope
3. implementation & stability
4. maintenance & reliability

with steps repeated as necessary throughout design, implementation, and maintenance. A sub-step not mentioned above is brainstorming. That refers to the all-too-human need for exploring alternatives, thinking “outside the box”, and an early identification of fluid-intelligence. Step one is absolutely mandatory for human-made systems; we cannot progress in the process without identifying system specifications and boundaries. Step one directly relates to step two; we cannot even *attempt* step two without completing step one. Once we determine system specifications and boundaries, we can determine system feasibility and scope. All four sub-steps are mandatory, interdependent, and critical in systems design. Feasibility refers to the “yes/no” question of implementability: is the system *physically realizable* - and - can we make it *within budget*? So feasibility is about realism and cost. Scope, though it initially may be unintuitive and difficult to understand, is critical for systems engineering. It refers to the overall objectives or purposes of the system being engineered. Consider the IT development of a software billing-system vs customer bill generator. The latter is simply the computer program required to generate hard-copies of current customer payables – while – the billing-system must maintain a database of all customer accounts and more. This illustration begins to define the critical need for identifying system scope.

We now arrive at step three in our brief overview of the systems approach: stability and implementation. Notice I reversed the sub-steps. This is because *we can't implement an unstable design*. So stability concerns come way before implementation in the design process. In reality, system stability is *always* a concern *throughout* design, implementation, and maintenance. When we generalize this concern, it ***IS*** reliability mentioned in step four: reliability and maintenance. Those two features must be considered from the "get go". A general rule-of-thumb: expect to pay as much for system maintenance as you do for implementation. That means you must budget, *in advance*, 100% extra *exclusively* for system maintenance.

So let's rewrite the steps in dependent order:
1. specifications & boundaries; stability & reliability
2. feasibility & scope
3. implementation & maintenance; goto step 1 as required

Now we see the criticality of stability and reliability concerns: they're *continuous* throughout the *entire* design, implementation, and maintenance process. I'm convinced that this augmented systems approach, if implemented conscientiously, would have averted *both* Shuttle disasters detailed later.

Before we illustrate this augmented approach with a specific example, let's discuss three relevant words: dynamical, robust, and resilient. Dynamical systems can be natural or synthetic. By definition, dynamical systems are those where past inputs affect present outputs. Robustness has been defined almost mathematically – as certain algorithms are more robust than others at solving certain classes of problems. It's safe to say that most algorithms cannot solve certain disparate classes of problems. Robustness is a way to measure efficacy of algorithms. Resilience typically refers to an organism's ability to withstand major environmental changes without reduction in functionality nor adaptability. So resilience is much more than adaptability alone; it's more about about an organism's adaptability after major adaptation. That resilience strongly resembles reliability. So when we design a system to perform sets of functions, we need to make that system resilient as nature has evolved resilient organisms.

A number of years ago, I was working on formalizing reliability theory. Essentially, you use your systems specific expertise to identify major subsystems and two other things: the level of connectedness between all subsystems and the failure rate for each. In this way, you make explicit the failure modes and potential cascade scenarios for the entire system. For organisms such as human beings, we have critical subsystems such as: heart, brain, liver, and kidneys. A major subsystem failure and time without medical attention – that person will die (catastrophic system failure).

Classroom Exercises:
1. ask each student to identify a specific *natural* dynamical system and specifically *why* it's dynamical.
2. ask each student to use failure mode analysis outlined above to illustrate a common cascade catastrophic system failure in detail.

Homework Assignment:
ask each student to do gross-design, using the augmented systems approach above, of a system-of-interest *making explicit* on paper each sub-step as required for the particular system. No more than a few pages. Make sure I understand *you* understand each sub-step.

The systems-reliability approach illustrated – design a rocket-sailplane for space-tourism. Concept: launches like a rocket with wings folded back and lands like a sailplane gliding in. Why the S-R approach is absolutely required: two Shuttle disasters with similar requirements and many independent failed attempts to create similar space-lift infrastructure. S-R approach for a rocket-sailplane:
1. specifications & boundaries; stability & reliability:
    build and test usable prototype with following
     specifications:
      six passengers in spacesuits
      autopilot for all stages: launch, transition, and land

backup human for autopilot and any transition glitches (can go EVA if required)
two engines: solid motor in main-body and rubber -oxygen motor behind passengers
parachute in nose-cone for catastrophic transition failures
lox tank for main compartment (CO_2 venting) and oxidizer for rubber motor
independent air/oxygen tanks for each spacesuit; tanks can last entire flight-plan
test prototype in each stage with ship loaded with equivalent passenger+suit masses
test thrust boundaries
test launch-abort and transition failure features
final pre-passenger test: autopilot backup + passenger masses for entire flight-plan

2. feasibility & scope:
   down-scale prototype appropriately to test entire flight-plan with a smaller RC version possibly using mice as passengers; cost of fabricating RC version should give an estimate of cost of full-scale version; need to estimate other human costs such as insurance; need to address scope for example: this is not an attempt to satisfy all space-tourism needs; it's an experiment to determine feasibility of concept; it's possible the ship could be used to transport small satellites or other cargo to LEO depending on demand.
3. implementation & maintenance:
   need to provide costs estimates with MFEs and project time-line estimate also with margin-for-error

As we see illustrated above, the first step in the S-R approach toward designing a rocket-sailplane for space-tourism is to design and build a scaled-down RC version possibly using mice as passengers. Whether or not that version is actually launched into space is a mission-planning level decision. If actual fuel and engine types are usable in the scaled-down version, it's perhaps best to perform a full flight-plan test using the RC version. In creating this list, I realized a better maiden-voyage should have an $O_2 \rightarrow CO_2$ safe converter equivalent for six people that would better test the air-exchange equipment.

What teamwork is ***NOT***:
Teamwork is ***NOT*** a member taking over and dominating all activity and conversation. Teamwork is ***NOT*** a member going alone and ignoring other members' needs. Teamwork is ***NOT*** all members pretending to work together when they actually ***HATE*** each other – the boss simply said "you're gonna work together or else!". Teamwork is not domination, rogue behavior, nor pretense .. ***Teamwork is genuine care and concern about each role(s) individual members play and empowerment for them – from every member on the team!***

Fluid intelligence:
around half a century ago, human beings were beginning to understand different types of intelligence, fluid being one. It is the special ability to redefine problem solving based on a new class of problems. Imagine a super-race introducing board games to a civilization of humans that had never encountered or developed board games before. You could imagine a "new class of problems" to be associated with board games in general – from chess and checkers to monopoly and dungeons & dragons. As these isolated human beings used their brains to get better at board games, they develop and improve their board gaming skills. Eventually, they invent new board games where they defeat the super-race playing with them. Another analogy relates to quantum mechanics and the Standard Model. For over a century, quantum mechanics and the Standard Model of particle physics have been developed by many individuals with different objectives and frames of reference. But this venue required development of a framework of "new math" including path-integral modeling, Feynman diagrams, and quantum field theory. As the developers of the Standard Model solved problems within this new framework, they were exercising their fluid intelligence. So we can see fluid intelligence is not limited to gaming; we use it when we develop new areas of science and engineering. And it is absolutely crucial to regenerative engineering.

Successive-prototyping is: the set of skills required to create an initial prototype ***as a team***, then – create another that builds on that (or failures of that) – that

improves the system's ability to satisfy requirements. That process is repeated until a satisfactory ***stable reliable*** system is created – one that satisfies ***all*** user requirements .. So whether it's a set of services or products or hybrid set, the system must provide a set of ***reliable functionalities*** the user needs and is paying for.

Chapter 2: John Hardman and Regenerative Leadership

What follows is drawn from two texts by John Hardman:
1. The Regenerative Leadership Handbook, 2017
2. Leading for Regeneration, 2011
We'll reference them as such throughout this chapter.
"Essentially, these exemplary individuals have recognized that much of how and <u>why</u> we do things today is no longer working for us and our planet. As you will see, they have found renewed purpose in themselves and their professional fields, and have translated this purpose into organizational models that challenge the status quo, at times in surprising ways. They also demonstrate that they are humbly, purposefully, and courageously co-creating new, life-affirming, profitable, ***regenerative solutions***, laying new paths through our contemporary challenges." 1, p2, bold italics added.

Before i summarize the regenerative paradigm taken directly from the texts, let me attempt to do that from memory: there are three primary components that create an interdependent tripod such that without one or more, the paradigm collapses and definitively is ***NOT*** Hardman's regenerative framework:
1. is the solution economically viable? Does it give a good product/service (or combination) at a fair price? If there are investors involved, does the price-structure produce decent return? Is the price-structure, cost of implementation and maintenance over the "long haul" sustainable? Does the solution keep and tend to grow the market-share of the provider? All financial concerns need to be addressed in this section.

2. does the solution not only respect but ***enhance*** the environment? It's clear that corporate solutions today must go beyond environmental impact assessments. In the process of designing our regenerative solutions, we must look for ways to repair environmental damage done in the past while renewing associated ecosystems. So our solutions must not only be economically viable, they must nurture the environment.

3. does the solution respect ***all*** human beings involved in ***every part*** of the solution system? Does the solution respect the end-users? The providers (or anybody involved in production)? The investors?

So we can see the three primary components of the regenerative approach ala John Hardman are: economic, environmental, and humanistic viabilities. Let me check the texts to see if i got it right .. "Sustainability is often presented as the Triple Bottom Line (TBL), a term coined by British economist and sustainability expert John Elkington (1998). In Fig. 2, the three 'legs of the stool' of sustainability - the ***natural, social, and economic*** environment – overlap to create a sweet spot of sustainability." 1, p11, bold italics added. Hm .. Well, it appears as if i got sustainability and regeneration confused .. Let's see how he defines regenerative leadership .. "Regenerative leadership is defined as the capacity to ***restore the damage*** caused by human activity on ***natural, social, and economic*** systems, while at the same time ***securing lasting, desirable futures*** for all living beings through the ***design of integrated approaches*** that lead to ***resilient, thriving and life-affirming*** organizations, communities, regions, and the world." (1, p9) Wow, that's kinda wordy .. Let's see if i can minimize that statement while keeping the spirit .. Restore damage in ecosystems, humanity, and economies while enhancing the quality of life for all by ***creating integrated sustainable solutions*** which by doing so makes participating organizations and communities thrive and resilient. The last part makes explicit the desired consequences of regenerative leadership. So i'm getting closer to a definition of what i call ***the regenerative approach: create***

integrated sustainable solutions that restore past damage in three domains, enhance the quality of life for all, and makes participating organizations and communities thrive and resilient. Wow, nice and concise. We’re getting closer to integrating regenerative leadership and the systems approach.

That particular definition of regeneration is too broad and comprehensive to implement in an engineering program. Engineers need objective specifics. So let’s attempt to narrow that broad approach down to a pattern engineers can assimilate and ideally follow.

Let’s take the core elements of regeneration without losing the spirit of it:
paradigm shift
think in global group-advantageous ways
every member must work together for the common gain
bring together expertise from different fields
the solution must (help the)
 end-users be thriving and resilient
 be integrated and sustainable
 and restore past damage to three-sphere systems
Pages 16-33 of 1 itemize the regenerative leadership framework but the details are too numerous to try to list them out and “boil them down” to essentials. We need a different approach: something like back-casting (p29, 1) or logical deduction where we use the conclusion as a guide from the premises working backwards. We know we must end up with ***at least*** the systems approach and our “premises” are all the requirements of regeneration.

From the outline of the RLF:
prepare personal mindset
prepare personal skills relating to regenerative leadership
prepare producer-user mindsets for regenerative solutions
producers work with end-users using quadrant-4 approaches

So using the outline just above and general requirements of regeneration arrived at above, we can attempt to list out the absolute minimal requirements of “regenerative engineering” (here assuming the field exists in the future of engineering – we just need to back-cast it): paradigm shift(s), global three-pronged thinking, authentic teamwork, multidisciplinary approach toward solutions, and producing integrated sustainable solutions by following the RLF outlined above.

The next chapter takes the discussion above to a deeper level. Pretend for a moment you're a new engineer just graduated from an accredited program in regenerative engineering. Your first task is to *design a new discipline using the stuff you just learned in the program*. ***We're going to use regenerative engineering to design itself.***

At MSU, i learned of an optimization technique called the Simplex Method. At that time, it was a tool used to teach techniques to students to help them learn every approach has limitations. There is no foolproof optimization technique. When even used properly, it's quite possible to have "***no*** results" (no solutions arrived at which satisfy problem conditions/criteria). Our professor gave a particular problem which had ambiguous constraints, at best. i believe not a single student presented a viable solution to the class problem. i certainly didn't. That week, i learned the "hard way" there's ***always*** limitations on your approach, regardless of approach .. Fast forward to now and i remember that lesson well .. So many solution techniques present themselves to me like a buffet. As engineers, we can't let our successful techniques and professionalism misguide us to think we're the best engineers in the galaxy. This hubris, like the Biblical Lucifer, would be our eventual downfall if we let it. No, we must add a generous helping of genuine humility to our plate if we're to find this "holy grail" of engineering: regenerative engineering .. At the same time, we must ***never*** lose sight of the augmented systems approach we so dearly paid for in our past collective mistakes .. This leaves us with a hybrid approach: something that takes the best of our past techniques like Simplex and combines them with advanced algorithms like Genetic Programming in order to achieve a kind of dual-optimization technique .. Before we conclude this chapter with that synthesis, we have one more digression about educational longevity .. Some years ago, i studied nuclear engineering at North Carolina State. At that time, i was more interested in nuclear physics than nuclear engineering .. But i tried to make the most of the program while there despite the academic differences between me and the department .. Besides learning that i didn't really want to become a nuclear engineer, i learned something ***very*** important about educational longevity (i use that phrase to describe the *practical utility* of a *particular education* in terms of *years*). Some professors there believed education had an "expiration date" like a bunch of bananas. Frankly, i was appalled to hear this. My primary eduction by that time was my *systems* education from Michigan State. And contrary to those professors at NCSU, that particular education *had* ***no*** *expiration date* (not at least in my lifetime). So it depends on the program. And of course your attitude. If you have an *open mind* about your own particular education, *anything positive* is possible. This optimism guides us to the core of regenerative engineering: the augmented systems approach with sustainable prerequisites:

our "penny pinching" "been there done that" attitudes we ***must*** discard; ***every*** new problem is a ***new*** situation if only with different producers and end-users

we must think differently: humbly, respectfully, and above all – ***collaboratively***

as an ***authentic team***, we must bring together many-times conflicting agendas, criteria, and world-views and find ***sustainable solution-sets*** to choose from ***collectively***

on the production side, we must *acquire the skills* we need to produce those sets if we don't have them already; this could involve training and/or development of new technologies/procedures

that mention of innovation spurs the final prerequisite for regenerative engineering: *the need for* ***successive -prototyping***; entrepreneurs know this; many engineers don't (even packaging engineers must use the systems approach)

i hope by this time you realize above was ***NOT*** wishful thinking on my part but truly inspired wisdom .. As a kid growing up in Michigan, i prayed to the goddess Athena. But over the years i realized she was an illusion or mask at best for God .. And if your prayers are selfless and beautiful, don’t you think She’s ***compelled*** to answer *positively*? .. Just realize regenerative engineering won’t become a legitimate engineering discipline without ***you***. How could something that has sustainability and the future of our children at its ***core*** be wrong?

Chapter 3: Regenerative Engineering

Why did we cover teamwork, successive-prototyping, and fluid intelligence in Chapter 1? For engineering students, the first two should be “given”/understood, right? There’s many misconceptions about teamwork just as many people might not fully/correctly understand fluid intelligence. They were worth reviewing because they’re absolutely mandatory for the 5-4-3 REP as we see below.

5-4-3 Regenerative Engineering Process (REP):

(5 prerequisites)

1. assumptions : *gone*
2. fluid intelligence : *must have*
3. teamwork : *must have*
4. relevant skills : *must have*
5. successive-prototyping: *must have*

(4 requirements)

1. *Access to relevant data*: as a team, if we don't have access to project-relevant data, we'll be operating under incomplete information; this typically can 'make or break' project results.

2. *Access to relevant skill sets*: if we don't have the proper training, at least one individual per team, this is another deal-breaker; in the very least, the team must have access to appropriate training.

3. *Access to solution components*: notice I did not say 'materials' because solution components may be: people, relationships, ideas, media, or any number of non-material things; whatever the nature of the solution, we need access to 'raw materials' required for an adequate solution.

4. *Ability/authority to implement*: perhaps this is the 'most critical' of these four requirements; if we cannot implement a solution, that solution might as well not exist; we need the authority/ability to implement our solutions in order for them to become realized.

<u>(3 steps)</u>
1. specifications & boundaries; stability & reliability
2. feasibility & scope
3. implementation & maintenance; goto step 1 as required

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Skimming the prerequisites, we notice things like “assumptions: gone” which might seem trivial but actually is ***fundamental*** in this new approach. We have to make it ***explicit and mandatory*** because typically, we “cut corners” to save money whenever we design a new system. In order to avoid repeating the same types of design errors we always seem to do, we ***MUST*** adhere religiously to the 5-4-3 REP.

Why 5-4-3 REP? Why not just the three step S-R approach? As you can see by scanning the 5-4-3 REP, most of it is “preparation”. Historically, all great artists, before composition, would be absolutely completely unequivocally unabashedly prepared. Nothing was left to chance nor doubt. When they created their greatest works, they had assistants and backup assistants, materials and backup materials, financiers and backup financiers. What’s the common thread? Backup. They had backups for ***EVERY***thing! What happened with 3-Mile-Island even with redundant systems? It *still* failed (in a messy way). Why? Because they didn’t use the 5-4-3 REP.

Successfully employing the 5-4-3 REP means the difference between an expensive tedious lengthly clean-up like 3-Mile-Island and an overnight clean-up with next-day inspection.

Of course it’s more expensive to implement but the dollars allocated in the ***proper directions*** assure loss of brand-value and company/organization image simply won’t happen.

But as implied above, we’re not just going for market-share security or even sustainability, we’re going for ***permanent*** market-share stability, ***growth***, and thrive-ability.

The 5-4-3 REP is ***not*** a fad/gimmick; it’s a *paradigm* for a new kind of engineering: sustainable design, sustainable growth, sustainable ***future*** for our children and theirs. It’s not only the “holy grail” for engineering; it’s also the authentic holy-grail for marketing and sales. What other discipline can absolutely ***guarantee*** sustainable growth and sales? None .. The 5-4-3 REP is the ***authentic*** holy-grail for a ***new sustainable millennium*** precisely because it grew naturally from the mandatory S-R approach and successful marriage with sustainable leadership ala John Hardman.

Chapter 4: Case Studies of Pre-RE Engineering

Space Shuttle Challenger
“On January 28, 1986, the NASA shuttle orbiter mission STS-51-L and the tenth flight of Space Shuttle Challenger (OV-99) broke apart 73 seconds into its flight, killing all seven crew members, which consisted of five NASA astronauts and two payload specialists. The spacecraft disintegrated over the Atlantic Ocean, off the coast of Cape Canaveral, Florida, at 11:39 EST (16:39 UTC). Disintegration of the vehicle began after an O-ring seal in its right solid rocket booster (SRB) failed at liftoff. ***The O-ring was not designed to fly under unusually cold conditions*** as in this launch. Its failure caused a breach in the SRB joint it sealed, ***allowing pressurized burning gas*** from within the solid rocket motor ***to reach the*** outside and impinge upon the adjacent SRB aft field joint attachment hardware and ***external fuel tank***. This led to the separation of the right-hand SRB's aft field joint attachment and the structural failure of the external tank. Aerodynamic forces broke up the orbiter. The crew compartment and many other vehicle fragments were eventually recovered from the ocean floor after a lengthy search and recovery operation. The exact timing of the death of the crew is unknown; several crew members are known to have survived the initial breakup

of the spacecraft. The shuttle had no escape system, and the impact of the crew compartment with the ocean surface was too violent to be survivable. The disaster resulted in a 32-month hiatus in the shuttle program and the formation of the Rogers Commission, a special commission appointed by United States President Ronald Reagan to investigate the accident. The Rogers Commission found NASA's organizational culture and decision-making processes had been key contributing factors to the accident, *with the agency violating its own safety rules*. ***NASA managers had known since 1977*** that contractor Morton Thiokol's design ***of*** the SRBs contained ***a potentially catastrophic flaw in the O-rings, but they had failed to address this problem properly***. NASA managers also disregarded warnings (an example of "go fever") from engineers about the dangers of launching posed by the low temperatures of that morning, and failed to adequately report these technical concerns to their superiors." Italics and bold added; Wikipedia, https://en.wikipedia.org/wiki/Space_Shuttle_Challenger_disaster

I used to work for BellSouth/at&t. A work friend of mine totaled a work vehicle due to another non-company vehicle hitting him as he was pulling out of a company parking lot. The company later determined that accident was "avoidable" and later punished my friend by terminating him relating to another more technical mishap. Even before reading above, I realized the Challenger disaster was also avoidable. But it's easy to say in retrospect. Could I have *predicted* the Challenger disaster? Perhaps if I were reliability engineer on the design team. To segment a container for violent hot gases is *always* a bad idea. Anyone knows that: more seams invites more potential failure modes.

Using the S-R approach and simulations should have revealed the potentially catastrophic failure mode that actually occurred. The manufacturer of the solid motors could have performed more thorough testing. NASA could have paid attention to the warning signs. In this case, the 5-4-3 REP should have revealed this since the augmented S-R approach is part of it. As stated below referring to the Tacoma

Bridge, this text is making a case for advancing the systems approach toward *regenerative thinking* which goes *beyond* sustainability by *necessity*.

A casual observation of a video of Challenger exploding appears to indicate a bomb being set off. The first set of bolded and italicized text above alludes this. If that simplistic observation is correct, the side-jetting rocket gases impinging on the fuel tank act as fuse to bomb. Engineers designing future solid rocket motors should always keep this in mind. As I understand solid rocket engines, the burn should be even cylindrically outward from core axis. Any cylindrical asymmetry in density/burnable material would create asymmetry in burn and potentially leak exhaust gases in those areas. It's possible the disaster may have been avertable if proper choice of gasket and/or adhesive between fuel cylinders in each solid rocket was performed. This indicates Morton Thiokol and/or NASA did not perform sufficient testing of the solid motors.

Space Shuttle Columbia
"On February 1, 2003, the Space Shuttle Columbia disintegrated upon reentering Earth's atmosphere, killing all seven crew members. The disaster was the second tragedy in the Space Shuttle program after Space Shuttle Challenger in 1986, which broke apart and killed the seven-member crew 73 seconds after liftoff. During the launch of STS-107, Columbia's 28th mission, a piece of foam insulation broke off from the Space Shuttle external tank and struck the left wing of the orbiter. A few previous shuttle launches had seen damage ranging from minor to major from foam shedding, but ***some engineers suspected that the damage to Columbia was more serious***. ***NASA managers limited the investigation, reasoning that the crew could not have fixed the problem [even] if it had been confirmed.*** When Columbia re-entered the atmosphere of Earth, the damage allowed hot atmospheric gases to penetrate and destroy the internal wing structure, which caused the spacecraft to become unstable and break apart."
Italics, bold, and "[even]" added; Wikipedia, https://en.wikipedia.org/wiki/Space_Shuttle_Columbia_disaster

Wow.. This even *more* neglectful than Challenger and this was chronologically *after* Challenger! NASA ignored the warning signs (***again***) and failed to create a remediation method with fairly minimal cost. I have been thinking about this on-and-off for several years and have developed at least two repair methods: astronauts/robots use repair tiles and space-glue to fix the shield holes. The core problem here is the uniqueness of all the tiles in the shield. Impossible to store all, we'd have to find a way to modify general tiles to fit. Or, we could do an inspection and ferry the needed tiles with another Shuttle. Either way, I guarantee you, with the 5-4-3 REP, we'd have a feasible fix for this unique catastrophic problem.

The neglect shown in the Columbia incident is almost unforgivable. The attitude seemed to be: "Well, we know it will likely fail catastrophically, we know we don't have repair mechanisms in-place to fix the problem, our budget is always cut even when human life is at-risk, let's let it fail so the American public knows how badly we've been treated by administration and budgeting!" But if that was the case, didn't they ***know*** Americans would hold ***them*** responsible?! The apathy and sheer ignorance of administration dumbfounds me.

Tacoma Narrows Bridge
"The bridge's collapse had a lasting effect on science and engineering. In many physics textbooks, the event is wrongly presented as an example of elementary forced resonance, with the wind providing an external periodic frequency that matched the bridge's natural structural frequency. In reality, the actual cause of failure was aero-elastic flutter. Its failure also boosted research in the field of bridge aerodynamics-aero-elastics, the study of which has influenced the designs of ***all*** the world's great long-span bridges built since 1940." Italics added; Wikipedia, https://en.wikipedia.org/wiki/Tacoma_Narrows_Bridge_(1940)

So we can see there's still a misunderstanding about the root-cause of the catastrophic failure of the Bridge. Some people erroneously believe it's an example of forced resonance while in actuality, it’s “wing flutter”. But the point of this text is not simply revising long bridge design because both distinctly different Shuttle disasters illustrate the ***systemic incompleteness of engineering design paradigms***.

A link to a video of the Bridge failure:
https://www.youtube.com/watch?v=j-zczJXSxnw
Historically, civil engineering project leaders tended to think they were exempt from systems principles and the systems approach. The video above clearly demonstrates they’re decidedly not. The fact NASA prides itself as an early advocate of S-R engineering further demonstrates even if you do purportedly advocate it..; if you care more about cutting costs than saving lives, over time, it’s gonna “bite you in the ass” (you’re going to have a catastrophic failure likely involving loss of life) .. A casual observation of the video with URL above gives me the following impression: a dynamical system driven by wind shear that went unstable and tore itself apart. The oscillations were known during construction and attempts were made to dampen them. But during finishing, the dampening feature was eliminated out of inattention to detail (explicitly, this is where we pre-clean something so well we lose stability by damaging a critical stability feature of a device). Of course, unless we rebuild an exact replica in the same position as before with the stabilizing feature retained (or simulate it in detail), we can’t know if that particular stabilizing feature would have worked under similar conditions of failure.

“The decision to use such shallow and narrow girders proved to be the original Tacoma Narrows Bridge's undoing. With such minimal girders, the deck of the bridge was insufficiently rigid and was easily moved about by winds; from the start, the bridge became infamous for its movement. A mild to moderate wind could cause alternate halves of the center span to visibly rise and fall several feet over four-to-five second intervals. This flexibility was experienced by the builders and workmen during construction, which led some of the workers to christen the bridge "Galloping Gertie" .. finally, the structure was equipped with hydraulic buffers installed between the towers and the floor system of the deck to damp longitudinal motion of the main span. The effectiveness of the hydraulic dampers was nullified, however, because the seals of the units were damaged when the bridge was sand-blasted before being painted .. The Washington Toll Bridge Authority hired Professor Frederick Burt Farquharson, an engineering professor at the University of Washington, to make wind-tunnel tests and recommend solutions in order to reduce the oscillations of the bridge. Professor Farquharson and his students built a 1:200 scale model of the bridge and a 1:20 scale model of a section of the deck. The first studies concluded on November 2, 1940 - five days before the bridge collapse on November 7. He proposed two solutions: 1. To drill holes in the lateral girders and along the deck so that the air flow could circulate through them (in this way reducing lift forces). 2. To give a more aerodynamic shape to the transverse section of the deck by adding fairings or deflector vanes along the deck, attached to the girder fascia. The first option was not favored because of its irreversible nature. The second option was the chosen one, but it was not carried out, because the bridge collapsed five days after the studies were concluded .. An important source for both the AAPT user’s guide and for Feldman was a 1991 American Journal of Physics article by K. Yusuf Billah and Robert Scanlan. According to the two engineers, the failure of the bridge was related to a wind-driven amplification of the torsional oscillation that, unlike a resonance, increases monotonically with increasing wind speed. The fluid dynamics behind that amplification is complicated, but one key element, as described by physicists Daniel Green and William Unruh, is the creation of large-scale vortices above and below the roadway, or deck, of the bridge. Nowadays, bridges are constructed to be rigid and to have mechanisms that damp oscillations. Sometimes they include a slot in the middle of the deck to alleviate pressure differences above and below the road.”

Apparently, just as with Challenger, cost (or skimping on quality) was a major factor in causing the Bridge collapse. The construction managers obviously thought they could not afford to build the Bridge to avoid catastrophic oscillations. Or perhaps they thought their cheaper design would be “good enough”. This casual attitude toward life and property has always been around. Decision makers who don’t have a clue about engineering safety seem to always pop up as well. “It should be fine” or “we can’t afford that” have always been the excuses before major catastrophies .. You would think in today’s super-fearful atmosphere about liability, we’d invest more in prevention.

However, this text is ***NOT*** about spending more money on less likely catastrophic failure modes! That’s naive reliability engineering. This text ***IS*** about ***smart*** RE: the 5-4-3 regenerative engineering process. In the last example above, *a dog died* and there was considerable embarrassment for the civil engineers involved. We ended this chapter with a chastisement of civil engineers who think they’re exempt from the systems approach: no engineer is! And anything that is subject to the systems approach is subject to regenerative engineering.

Notice I didn’t capitalize just above “regenerative engineering process”. Why? By this point in your reading, you should be convinced of the ***absolute necessity*** of the 5-3 REP. The cases above were ***not*** random isolated unrelated incidents. They are examples of ***systemic problems*** in all-too-human engineering. We “ignore the writing on the wall”, we cut corners even when human lives are at risk, and we make major design changes without considering consequences. All three mistakes violate the systems approach and 5-4-3 REP .. It took me ***years*** to develop and refine that new paradigm. Nothing good happens overnight. So let’s take our time installing the 5-4-3 REP in our educational system; but let’s do it for our children’s children – forever .. In a casual reading of above, one might think I blame NASA administration for both Shuttle disasters and blame Bridge administration for its failure. But I don’t; I blame ***us***; ***we*** are responsible for Challenger, Columbia, and Tacoma Narrows Bridge. We .. Just as ***we*** are responsible for correcting the systemic engineering problems causing them.

Years ago, I tried to stimulate IEEE to consider this new engineering discipline; they ignored me. After years of contemplation and review, I’m convinced regenerative engineering is the “holy grail” engineering has unknowingly been searching for ever since systems engineering was conceived. When I first studied systems science at MSU, I had ***no*** idea there was anything more general or *better* than the systems approach; how naive I was; how naive I was.

Murphy’s Law in a nutshell: given enough time, anything bad that ***can*** happen eventually ***will***. But there’s a ***positive side*** just like the Golden Rule that people neglect: ***when you clean yourself of bad-habits, focus your energies and attention in positive ways, it’s inevitable that GOOD things WILL happen!*** We will fail as a civilization if we don’t take these words to heart.

Chapter 6: Colonizing Mars – Missions Planning

Other than the Shuttle disasters, what was the critical failure of America’s space program? Please pause and think about it .. When we implemented Space Lab, we forgot about one very important thing: freedom. The mission specialists and astronauts had no freedom. Their schedules were packed full of responsibilities with no freedom whatsoever. This failure reminds us that when we finally go to Mars, we need to build-in some freedom into the Martian explorers’ schedules. For example, instead of a time-line, we should create an objective-schedule without strict adherence to planned event times. This will allow variability in process compliance while keeping sequence of events. Some objectives will take less time than anticipated while others may take more; this flexibility in scheduling will give the astronauts necessary freedom due to unpredictability of exactly when they’ll complete a mission objective. We also need to give them freedom when to insert a needed break into their schedule; everyone knows a rested worker is a better worker.

Appendix

For Hope

My eight month old daughter Hope inspired this among other wonderful things.

God’s **functions**:
 create (as in create our universe and life here)
 guide life (as in the evolution of life here)
 inspire us (like for examples: Mozart and Michaelangelo)
 love us (through each other)
 guide us (through Her Son like what are
           meaning and fulfillment)
 and **remind** us that all good things are possible thru Her.

The following was inspired by Her a few years ago then modified recently. Discussion will follow.

Basic Human/Sentient Rights:
mobility: freedom to live and work in ***any*** location
health: free access to ***premium*** health care
education: free education for ***all*** levels
resources: freedom of equitable access to ***all*** world resources
religion: freedom of religion ***except*** when violating others’ rights
slavery & war: freedom from subjugation, exploitation, and conflict
freedom to live without bio-weapons, nukes, military, and money

The title may seem a little strange to some: why not just human? Because dolphins, whales, and future robots may be sentient and we need a broader criteria for rights. Why robot rights before sentient robots are developed? Because if we create a race of sentient slaves, don’t you think they’ll resent that and rebel? The items are listed in order of decreasing importance. Since mobility is disregarded historically, i put it first. Since health seems to be only for those who can afford it and those they pity, that’s next. My father believed education can solve many of the world’s problems so that’s next. Resources is next because that seems to be one of the things we fight a lot over. Same for religion. Historically, our Earth has been plagued by slavery and war so that’s next. Finally, without those weapons and money to fight with and over, we should be able to sustain world peace. How no money? We implement a system i call Work-Units which means ***ANY*** time a person works, whether parenting or elder-care, they receive WUs. Equal time for equal units (nobody gets extra units because of position; so no one will become a doctor or actor or athlete for the money). And finally about no military: i have compassion and believe all military personnel all over the world should be retired simultaneously with full pension.

Finally, what Hope directly inspired was the following plan for enduring world peace: ***every human being on the planet needs to nurture the positives of those around them – and – let go the rest*** .. My father and i used to frequently discuss “how to save the world (from itself)” but never came up with a realistic global solution. This was way before BH/SR was established. What i realized over my 54 years was that if we micro-manage ***ANY***thing, it tends to f-it-up. And that we need to stop focusing on negatives and just freaking let them go. When we obsess about negatives, we waste time, money, our attention, our energies, and our lives. Look at the Middle East – it’s a testament to revenge and “make them pay”; the more we subjugate the Palestinians, the more we become like Nazis.

Hope also inspired a new textbook for a new discipline called regenerative engineering. It takes the best of systems engineering and sustainability and successfully marries them. This text and the outline above about nurturing positives should “do the trick” if conscientiously implemented.

Of course, anything improperly/sloppily implemented will be a failure before it’s finished.

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