Akin's Laws of Spacecraft Design

ELEC399 Lecture

http://spacecraft.ssl.umd.edu/

Law 1

"Engineering is done with numbers. Analysis without numbers is only an opinion."

- This is why engineering students spend so much time learning math.
- Engineering success must usually be quantifiable.
- My system is faster. $\Rightarrow$ How much faster?
- My system is cheaper. $\Rightarrow$ How much does it cost?
- My system is simpler. $\Rightarrow$ How do you measure simplicity?

Law 2

"To design a spacecraft right takes an infinite amount of effort. This is why it's a good idea to design them to operate when some things are wrong ."

- Do not design a system that requires 100% reliability.
  - Examples of failures: Deep Water Horizon, Fukushima
- Aircraft control
  - 3 way logic checking

Law 3

"Design is an iterative process. The necessary number of iterations is one more than the number you have currently done. This is true at any point in time."

- Good designs are never finished.
- See some of the following laws for more insight.

Law 4

"Your best design efforts will inevitably wind up being useless in the final design. Learn to live with the disappointment."

- Bhargava's Law: Only 1 out of 10 research ideas make it into industrial practice.
- The biggest commercial success is not the best technical design.
  - Nokia N95 versus the first generation iPhone

Law 5 (Miller's Law)

"Three points determine a curve."

- You will always find a pattern in any set of data.
- Just make sure that your pattern is due to the underlying phenomena that you are studying and not due to the measurement noise.
  - Academics and graduate students are particularly fond of ignoring this rule.

Law 6 (Mar's Law)

"Everything is linear if plotted log-log with a fat magic marker."

- Bigg's Law: "Don't fall in love with your mathematical tools. They will not love you back"
- Don't over-fit your data.

Law 7

"At the start of any design effort, the person who most wants to be team leader is least likely to be capable of it."

- Dilbert cartoons are based on actual experiences in Engineering firms, only mildly exaggerated.
- Some aspects of leadership may be natural but a good deal of leadership must be learned.
- Sometimes managers fail to 'respect the business.'
  - Ask any industrial engineer about MBAs

Law 8

"In nature, the optimum is almost always in the middle somewhere. Distrust assertions that the optimum is at an extreme point."

- Standard example: Optimal power transfer.
- Worked example: optimal sensor resistance.

Law 9

"Not having all the information you need is never a satisfactory excuse for not starting the analysis."

- Just be sure to know what values you want to give a more complete analysis.

Law 10

"When in doubt, estimate. In an emergency, guess. But be sure to go back and clean up the mess when the real numbers come along."

- You are being trained as engineers not surgeons.
- Quality thinking is more important in this profession than fast thinking.

Law 11

"Sometimes, the fastest way to get to the end is to throw everything out and start over."

- Learning when you need to do this can take years.
- Many industries are full of cases when this should have been done but wasn't
  - Russian manned spy space station: Almaz
    - Brilliant technical design
    - Made obsolete by computer controlled spy satellites the year after it was launched.
- Early 'automobiles'

Law 12

"There is never a single right solution. There are always multiple wrong ones, though."

- Keep an open mind.
- Engineering is not a religion.
  - Technical apostasy is perfectly acceptable.
- Example: Mechanical automatic computation
  - Leading method in World War 2.
  - It took until the 1960s for digital hardware to really take over the field.

Law 13

"Design is based on requirements. There's no justification for designing something one bit "better" than the requirements dictate."

- Clients really don't like paying for capabilities they do not need.
- Find the required reliability for your application and design for that reliability level.
  - Easier said than done.

Law 14 (Edison's Law)

"'Better' is the enemy of 'good'."

- Actually a quote of Voltaire
- You need to recognize when you have achieved a system that is good enough.
  - You can always make a system better since perfection requires infinite resources.
  - See Law 13.

Law 15 (Shea's Law)

"The ability to improve a design occurs primarily at the interfaces. This is also the prime location for screwing it up."

- There are a lot of engineers/technicians who understand one system really well.
- It is rare to find someone who understands two different systems really well.
  - e.g. Systems with complex hardware and software interactions usually go wrong at the interfaces.

Law 16

"The previous people who did a similar analysis did not have a direct pipeline to the wisdom of the ages. There is therefore no reason to believe their analysis over yours. There is especially no reason to present their analysis *as* yours."

Law 17

"The fact that an analysis appears in print has no relationship to the likelihood of its being correct."

- Famous opinion from the 1970s:
  - "1200 baud is probably about as fast as telephone modems can go."
    - Known as the "Coding is dead" talk of 1970.
    - Trellis coded modulation got this rate up to 50 kilobaud by the 1990s

Law 18

"Past experience is excellent for providing a reality check. Too much reality can doom an otherwise worthwhile design, though."

Law 19

“The odds are greatly against you being immensely smarter than everyone else in the field. If your analysis says your terminal velocity is twice the speed of light, you may have invented warp drive, but the chances are a lot better that you've screwed up.”

Law 20

"A bad design with a good presentation is doomed eventually. A good design with a bad presentation is doomed immediately."

The Avro C102 – The world's second commercial Jetliner (by 13 days)
(Cancelled to support development of the Avro Arrow)

Law 21

"Half of everything you hear in a classroom is crap. Education is figuring out which half is which."

- Your professors are not trying to waste 50% of your time.
  - We are guessing what techniques you will need in rapidly changing and evolving fields.
- Example: Quantum computing.
  - Either vital knowledge to work as an Engineer in the next 20 years, or it will be of only academic interest until the 2030s.

Law 22

"When in doubt, document. (Documentation requirements will reach a maximum shortly after the termination of a program.)"

- If you cannot solve a problem, do not hide your ignorance.
  - Document what is causing the problem.
  - Maybe someone else can figure out how to solve the problem.

Law 23

"The schedule you develop will seem like a complete work of fiction up until the time your customer fires you for not meeting it."

Law 24

“It's called a ‘Work Breakdown Structure’ because the Work remaining will grow until you have a Breakdown, unless you enforce some Structure on it.”

Law 25 (Bowden's Law)

"Following a testing failure, it's always possible to refine the analysis to show that you really had negative margins all along."

- Example: Canadian Transportation Accident Investigation and Safety Board and Federal Aviation Administration accident reports.
- Some failures are caused by a lack of imagination (Paraphrasing Frank Borman).
- Engineers are forgiven for making mistakes. They are not forgiven for hiding mistakes.

Law 26 (Montemerlo's Law)

“Don't do nuthin' dumb.”

- A surprisingly hard rule to follow in engineering practice.
- Don’t forget the fundamentals.
- Keep your priorities clear to yourself.

Law 27 (Varsi's Law)

"Schedules only move in one direction."

- Leave yourself room for problems and difficulties.
  - Testing failures.
  - Later in life: family emergencies
- Do not forget that others may be late in delivering the required products to you for no fault of their own.
- Always leave yourself and your team some space in the schedule.

Law 28 (Ranger's Law)

“There ain't no such thing as a free launch.”

Law 29 (von Tiesenhausen's Law of Program Management)

"To get an accurate estimate of final program requirements, multiply the initial time estimates by pi, and slide the decimal point on the cost estimates one place to the right."

Law 30 (von Tiesenhausen's Law of Engineering Design)

"If you want to have a maximum effect on the design of a new engineering system, learn to draw. Engineers always wind up designing the vehicle to look like the initial artist's concept."

Law 31 (Mo's Law of Evolutionary Development)

"You can't get to the moon by climbing successively taller trees."

- It is useful to understand the fundamental limitations of your technology/approach.

Law 32 (Atkin's Law of Demonstrations)

“When the hardware is working perfectly, the really important visitors don't show up.”

Law 33 (Patton's Law of Program Planning)

"A good plan violently executed now is better than a perfect plan next week."

- Errors in the industry: waiting for the 'perfect' technology.
  - While you are waiting, your competition will take the market.

Law 34 (Roosevelt's Law of Task Planning)

"Do what you can, where you are, with what you have."

- There is no point designing for non-existent technology unless you are a science fiction writer.

Law 35 (de Saint-Exupery's Law of Design)

"A designer knows that he has achieved perfection not when there is nothing left to add, but when there is nothing left to take away."

Law 36

- "Any run-of-the-mill engineer can design something which is elegant. A good engineer designs systems to be efficient. A *great* engineer designs them to be effective."
  - Elegant design: Standard city water system.
  - Efficient design: New York water system.
  - Effective design: Indigenous civilizations' irrigation systems in North/South America. (Some still functioning after 1000s of years)

Law 37 (Henshaw's Law)

"One key to success in a mission is establishing clear lines of blame."

- Take responsibility for your actions and decisions.
- Don't trust an engineer (or anyone else for that matter) who refuses to do so.

Law 38

"Capabilities drive requirements, regardless of what the systems engineering textbooks say."

- The key is to recognize what new capabilities are being developed:
  - 1950s: Transistors
  - 1960s: Integrated circuits
  - 1970s: Microprocessors
  - 1980s: Home computers
  - 1990s: Internet
  - 2000s: Wireless/mobile computing

Law 39

The three keys to keeping a new manned space program affordable and on schedule:

1. No new launch vehicles.
2. No new launch vehicles.
3. Whatever you do, don't decide to develop any new launch vehicles.

– Avoid the temptation to believe a completely new product will always be better than an evolution of an old product.

Law 40

"Space is a completely unforgiving environment. If you screw up the engineering, somebody dies (and there's no partial credit because *most* of the analysis was right...)"

- Big engineering control disasters:
  - Fukushima, Cherynobl
  - De Havilland Comet (Why windows have rounded corners on commercial airliners)
  - Eastern Airline Flight 401 (Autopilot guided a commercial jetliner into the Everglades)
  - Therac-25 (Canadian radiation treatment machine)
- Paraphrasing Richard Feynman:
  - "Nature cannot be fooled."