15 Rules of Engineering Design

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1. Consider the system to be designed as a field of requirements, characteristics, and criteria. It is easy for a design engineer, and all too common, to jump right into a specific design before thoroughly understanding all of the requirements that relate the subject system to its environment. To make genuine progress, the designer must take the time to study the problem for which an engineering solution is desired in a broad interdisciplinary context. This demands understanding and documenting all of the desired performance, environmental, social, and economic requirements. By the "field of characteristics" I mean all of the alternative system characteristics possible. For example, a vehicle requires suspension and that could be by wheels, air cushions, magnetic fields, or sled runners. Detailed study of the requirements must lead to a set of criteria that will guide the design.

2. Identify all trade-off issues. One trade-off issue in transit design, for example, is the means to be used for suspension, and four possibilities are given above. We found 45 trade-off issues for transit design, certainly not an exhaustive list, but each issue must be considered carefully in any new design. By treating such issues explicitly with the criteria firmly in mind, the task of design is clarified and organized.

3. Develop all reasonable alternatives within each trade-off issue. By rushing into details too quickly, which is tempting, practical alternatives are often overlooked; someone else finds a better one and develops a superior design. Perhaps more important is that the designer who has not examined alternatives carefully before committing to a design cannot defend the design rationally and becomes emotionally "locked in" to one approach as others point out superior alternatives. All too often such a designer causes more harm than good in advancing a design.

4. Study each alternative until the choice is clear, rational and optimal. This is hard work, but if not done rationally the design may have fatal flaws. Such a process creates designs that are difficult or impossible to better, which is the objective of a good designer.

5. Seek and listen *humbly* to comments on your design from anyone. By explaining ideas and listening to comments, you clarify them. A difficulty many engineers have is failing to listen humbly, particularly to an outsider. Arrogance is disastrous to good design. A good designer must be humble − a rare attribute.

6. Seek advice from the best experts available in every specialty area. It should be obvious that none of us can know the details of every specialty required, yet there is an innate desire to try to develop the design ourselves. The best design will take advantage of the best information available anywhere, from anyone. A large portion of an engineer's work involves searching for information developed by others. In the age of the Internet, this is much easier than it was in former times.

7. Consult with manufacturing engineers at every stage of the design. In the United States, particularly, all too many design offices have left manufacturing considerations to the end of the design process. By grading manufacturing engineers lower than design

engineers, the able engineer has been informed where to concentrate. The Japanese practice of including the manufacturing engineer in every stage of the design process led to superior products that often took most of the market share.

8. Recognize that while emotion is a fundamental driving force in human behavior, emotion must not select alternatives. Emotional commitment is vital for any human being to commit fully to a task, but it must be set aside when making design decisions. A good design engineer must be free of emotional "hang-ups" that inhibit making use of all information available, calmly sorting through the pros and cons of each approach before recommending a solution, and being willing to accept someone else's idea when objective analysis shows it to be superior. Too few engineers have a deep understanding of the subconscious factors that motivate and direct thinking. Yet it is necessary for the engineer to put the ego in the background when making design decisions. The following verse from The Bhagavad Gita, written over 5000 years ago, hits the nail on the head.

"Therefore unattached ever
Perform action that must be done;
For performing action without
attachment
Man attains the highest."

Attachment to a favored component or technology and then trying to design a system around it without seriously examining alternatives has led to the demise of more than one system.

9. Recognize and avoid NIH (Not Invented Here). I worked for seven years in the Honeywell Aeronautical Division's Research Department in Minneapolis. Honeywell management established a design and production group in Clearwater, Florida, partly for the purpose of commercializing systems and components developed in the Research Department. It was found time and again that after designs management wanted commercialized were sent to Clearwater they were changed for the worse. As a result, management implemented a policy that required that whenever a project went from Minneapolis to Clearwater, the engineers that developed it went with it to supervise the detail-design process through production. NIH is joked about, but it can destroy the profitability of a design office. The motivating drives that produce it must be understood and controlled. The human emotion that says "we can do it better than you can" is okay if it is controlled, but when it prevents an engineering office from making good use of ideas developed elsewhere, as all too often happens, it can be destructive.

10. Consider the overall economic implications of each design decision. This requires good market and economic analysis to parallel design analysis. A design is good if it can win in a highly competitive market, and it can do so only by taking economics into account at every step. Unfortunately, cost and economic analysis are not part of most engineering curricula so too many graduate engineers are unprepared and must learn these subjects after graduation.

11. Minimize the number of moving parts. Some engineers become fascinated with extremely complex designs, but they all too often are subject to more failures and end up with higher life-cycle cost. Examine carefully the function of each part.

12. Consider the consequences of failure in every design decision. It is easy to design something if failures are not considered. A good design requires that the best engineers perform careful failure-modes-and-effects analysis as a fundamental part of the design process. FMEA cannot just be tacked on at the end, as too often happens.

13. Use commercially available components wherever practical. I have mentioned that the temptation to "design it yourself" is strong, but it is expensive and does not take into account that a design engineer cannot be a specialist in very many areas of engineering. There are of course times when a commercially available component will just not do, but such a decision should be made only after commercially available components are considered very carefully.

14. Design for function. Sounds obvious, but is all too often overlooked. A Japanese engineer reduced the cost of a magnetron for an infrared oven from over $500 as developed by an American engineering firm to under $5 by asking himself what the magnetron was really supposed to do. I reduced the design of an instrument from 90 parts to 19 simply by asking about the functions of each of the parts. The new design passed a much tougher vibration specification than the former and dominated its market.

15. Analyze thoroughly. It is much cheaper to correct designs through analysis than after hardware is built. Analysis is hard, exacting work. Most engineers do not have sufficient mathematical background to do such work well and therefore blunder along from one inadequate design to another. This "garage-shop" approach has initiated many designs, for example the bicycle and the automobile, but modern aircraft and automotive design requires a great deal of analysis corroborated by experiment. Design of a truly cost-effective, high-performance system requires the best of modern engineering analysis.