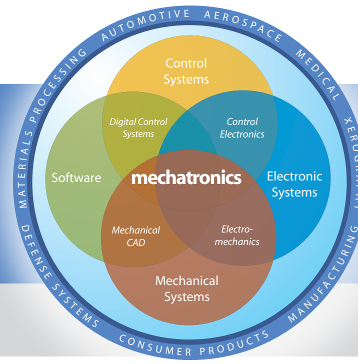

Visualizing Fundamental Design Principles

With practice, these principles become transparent in a design.

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WHEN I WAS WORKING with him, I observed, listened, and always learned. His understanding and insight brought fundamental design principles to light in both what existed and what was yet to be. For me, that person was Vittorio Castelli, Columbia University Professor and Xerox Senior Research Fellow. For over 30 years, Rino, as he was known to all, guided and inspired me and others as a mentor, educator, and inventor with unbounded energy and passion. Mentoring is a key element in fostering innovation. Each one of us can be that mentor for a young engineer or student. What are these fundamental design principles and how can they become ingrained in an individual?

When viewing an existing design or creating a concept to solve a need, fundamental principles as images will guide the designer to achieve what was thought impossible. As breadth of knowledge has been continuously traded for depth of knowledge, awareness of these principles has diminished. Here is a top ten list with brief explanations, many from the works of A. Slocum and J. Skakoon.

1. **Laws of Nature**: Predict before you build! Understanding the basic laws of nature is essential to know the fundamental limitations of a design, to predict how a design will perform, and to know how to improve an existing machine.

2. **Simplicity vs. Complexity**: Create designs that are explicitly simple. Keep complexity intrinsic, buried, and invisible. The less thought and less knowledge a device requires for production, testing, and use, the simpler it is.

3. **Exact-Constraint vs. Elastically Averaged Design**: Use exact constraint when designing precision structures and mechanisms, i.e., apply just enough constraints to define a position or motion, no more, no less. Controlled compliance can make an overconstrained design more stable, however, e.g., a five-caster chair to improve load bearing, a multiple ball bearing to compensate for geometric errors.

4. **Load Paths**: Plan load paths in parts, structures, and assemblies. Keep them short, direct, symmetric, locally closed, and easily analyzed, e.g., the bicycle handbrake, which is squeezed rather than pulled or pushed.

5. **Self-Help**: Forces applied to a structure or mechanism are used to great advantage when they create new, useful forces, transform or redirect themselves, balance themselves or existing loads, and help to distribute loads. Examples are the tubeless tire, left- and right-handed scissors, and a balanced door with an articulated hinge.

6. **Independent Functions**: Keep the functions of a design independent from one another. Of course, everything in design is a compromise. Combining functionality might have benefits.

7. **Accuracy, Precision, and Resolution**: Accuracy, precision, and resolution of a machine's components and the manner in which they are combined are the most important factors affecting the quality of a machine. Always identify the directions in which accuracy and precision are most important, i.e., the sensitive directions.

8. **Stability**: Before performance, there must be stability. Marginally stable designs work only on paper. Designs must have adequate stability margins. Beware of buckling of compression members.

9. **Saint-Venant's Principle**: Several characteristic dimensions away from an effect, the effect is essentially dissipated. And if an effect is to dominate a system, it must be applied over several characteristic dimensions of the system.

10. **Manage Friction**: Friction is always present, that is certain. How much friction, and its consequences, are uncertain. Manage it! Avoid sliding friction and use rolling element bearings whenever possible. **DN**

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