Scaling Fallacy

A tendency to assume that a system that works at one scale will also work at a smaller or larger scale.[1]

Much is made of the relative strength of small insects as compared to that of humans. For example, a leafcutter ant can carry about 50 times its weight; whereas an average human can only carry about half its weight. The standard reasoning goes that an ant scaled to the size of a human would retain this strength-weight advantage, giving a 200-pound ant the ability to lift 10,000 pounds. In actuality, however, an ant scaled to this size would only be able to lift about 50 pounds, assuming it could move at all. The effect of gravity at small scales is miniscule, but the effect increases dramatically with the size of an object. This underscores the basic lesson of the scaling fallacy—systems act differently at different scales. There are two basic kinds of scaling assumptions to avoid when *growing* or *shrinking* a design: load assumptions, and interaction assumptions.[2]

Load assumptions occur when designers scale a design by some factor, and assume that the working stresses on the design scale by that same factor. For example, initial designs of the Trident 2 missile, designed to be launched from submarines, underestimated the effects of water pressure and turbulence during launch. The anticipated estimates for pressure and turbulence were based largely on the Trident 1 missile, which was much shorter and roughly half the weight of the Trident 2. When the specifications for the Trident 1 were scaled to meet the specifications for the Trident 2, the working stresses on the missile did not scale by the same factor as its physical specification. The result was multiple catastrophic failures in early tests, and a major redesign of the missile.[3]

Interaction assumptions occur when designers scale a design, and assume that the way people and other systems interact with the design will be the same at other levels of scale. For example, the design of very tall buildings involves many possible interactions that do not exist for buildings of lesser size—problems of evacuation in the case of fire, people seeking to commit suicide or base-jump off of the roof, symbolic target for terrorist attacks, to name a few. These kinds of interaction effects are usually an indirect consequence of the design, and therefore can be difficult to anticipate and manage.

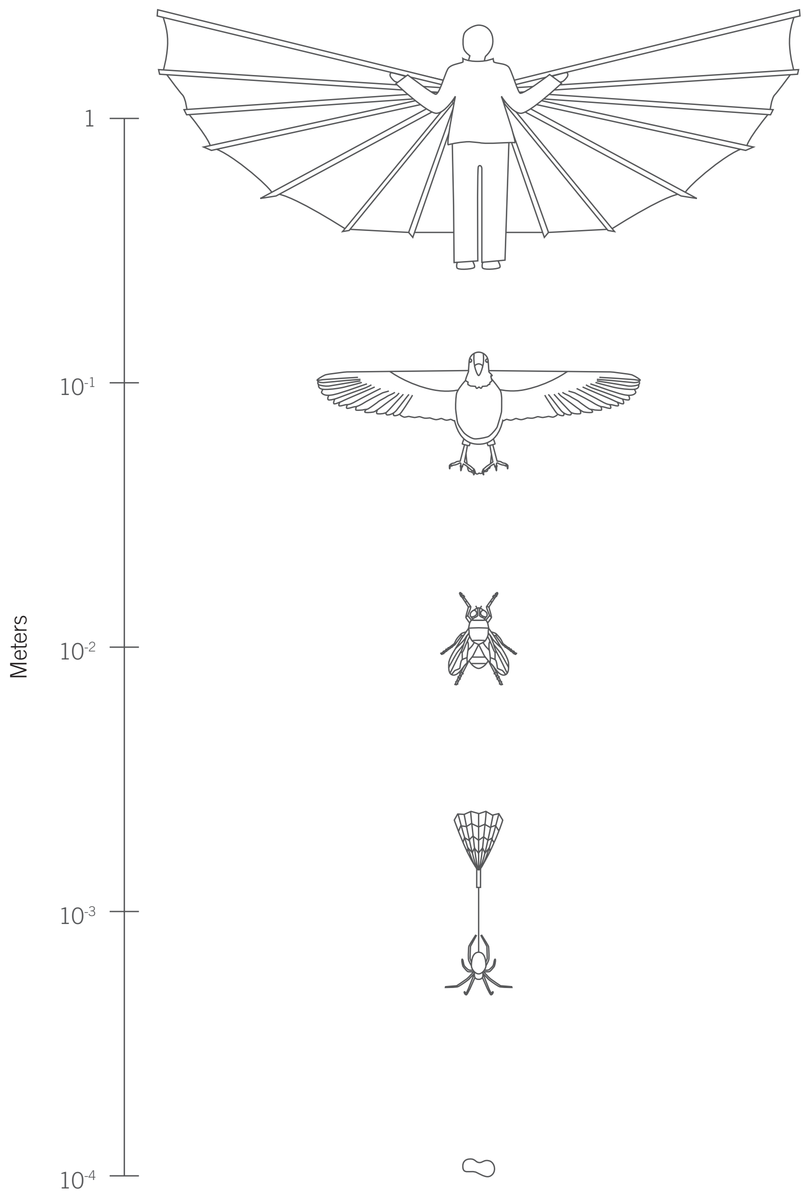
The best way to avoid the scaling fallacy is to be aware of the tendency to make scaling assumptions. Therefore, raise awareness of load and interaction assumptions in the design process. Verify load assumptions through the use of careful calculations, systematic testing, and appropriate factors of safety. Minimize incorrect interaction assumptions through careful research of analogous designs, and monitoring of how the design is used once implemented.

See also Factor of Safety, Feedback Loop, Modularity, and Structural Forms.

[1] Also known as *cube law* and *law of sizes*.

[2] The seminal work on scaling is *Dialogues Concerning Two New Sciences* by Galileo Galilei, Prometheus Books [reprint], 1991.

[3] "Design Flaw Seen as Failure Cause in Trident 2 Tests" by Andrew Rosenthal, *New York Times*, August 17, 1989, p. 1.



The scaling fallacy is nowhere more apparent than with flight. For example, at very small and very large scales, flapping to fly is not a viable strategy. At very small scales, wings are too small to effectively displace air molecules. At very large scales, the effects of gravity are too great for flapping to work—a painful lesson learned by many early pioneers of human flight. The lesson is that designs can be effective at one scale, and completely ineffective at another.

The images from small to large: aeroplankton simply float about in air; baby spiders use tiny web sails to parachute; insects flap to fly; birds flap to fly; humans flap but do not fly.