Similarity

The principle of similarity underlies the entire subject of dimensional analysis. There are three necessary conditions for complete similarity between a model and a prototype.

- Geometric similarity: the model must be the same shape as the prototype, but may be scaled by some constant factor.
- Kinematic similarity: the velocity at any point in the model flow must be proportional by a constant scale factor to the velocity at the homologous point in the prototype flow. (That is, the flow streamlines must have the same shape.)
- Dynamic similarity: all forces in the model flow must scale by a constant factor to the corresponding forces in the prototype flow. In other words, the relative importance of different types of forces (e.g., viscous and inertial forces) must be the same for the model and prototype. This requires that the model and prototype have the same dimensionless parameters (e.g., the same Reynolds number), although they may (and usually do) have different dimensional variables. Mathematically, for all *p* pi groups that can be defined for two different flow situations, dynamic similarity requires that

$$\Pi_{k,\text{model}} = \Pi_{k,\text{prototype}}, \quad k = 1 \ldots p.$$

Thus, geometric and kinematic similarity are *necessary but insufficient* conditions for dynamic similarity. That is, it is possible to have geometric and kinematic similarity, but not dynamic similarity.

Further reading

Çengel, Y.A. and Cimbala, J.M. *Fluid Mechanics: Fundamentals and Applications*. Boston: McGraw Hill, 2010, pp. 291-292.

Panton, R. *Incompressible Flow*. Wiley, 2013, p. 170.

Sonin, A.A. “The Physical Basis of Dimensional Analysis.”