Fracture is the process of one coherent solid piece fragmenting into two or more pieces. We may also use the word fracture to describe a fissure bordering an incipient fragment. Fracture mechanics concerns the ways in which such fissures or cracks grow, under what conditions they grow, and from what initial defects they start. One of the early conundrums faced by aeronautical engineers was how the engineering strength of lightweight, brittle materials scaled with the size of the piece. It was hypothesized that larger pieces start out with more and larger defects than smaller pieces, thus explaining the poorer than expected strength of larger pieces. Understanding how these defects propagate during stress to lead to material failure became important for large-scale engineering.

In this brief reading we will consider three realms and associated theories of fracture mechanics: linear-elastic behavior; elastic-plastic (or, more correctly, nonlinear-elastic) behavior; and fully plastic deformation. Further, we will briefly review how experimental data can be obtained to test such theories and predict fracture behavior. Finally, we will consider some engineering design guidelines that emerge from consideration of fracture mechanics.

You have already studied in subunit 2.3.4 how macroscopic engineering features such as holes, corners, grooves, and edges can raise or concentrate stress in a particular area of a piece. The geometry of those features and orientation with respect to the load, or bulk stress, are important in determining their effects. Those areas are where pieces are under the highest stress and are hence most likely to fail. Likewise, small defects occurring inadvertently as a result of material processing can cause local stress elevation and incipient fracture.

**Linear-Elastic Behavior.** Early work in this area was confounded by the fact that stresses at sharp crack tips approach infinity in the elastic model. Griffith adopted a thermodynamic approach to explain early experiments and obtained an approximate result $\sigma_t = c \sqrt{2E \gamma / \pi a}$, where $\sigma_t$ is the stress at failure, $c$ is a constant, $E$ is the Young’s modulus of the material, $\gamma$ [J/m$^2$] is the surface energy density of the material, and $a$ is a length scale for the defect or crack. For specific model geometries and loading conditions, stresses may be computed using linear elastic modeling. The stress intensity near cracks may then be compared to the bulk stress and represented by a stress intensity factor, $K$, which is a function of defect size, defect shape, region of interest, and loading conditions. The local stress intensity may then be predicted and compared with the known strength of the material. This idea seems to work well for brittle materials. For more ductile materials like steels, small regions of plastic deformation near defects impart resistance to fracture. Accommodation of energy dissipation by plastic deformation permitted Irwin to explain the fracture resistance of such materials with a formalism very similar to that of the linear-elastic model, except with $\gamma$ replaced by $\gamma + g_p/2$, where $g_p$ is an energy dissipation per unit area of crack growth.

**Elastic-Plastic Behavior.** For plastic deformations approaching, or larger than, the crack size, the linear-elastic model fails. Work in this area has proceeded along a variety of
approaches to consider the energy released by crack tip deformation or displacement. The approaches are variously known as R-curve, J-integral, and cohesive zone or crack-tip displacement models.

*Fully Plastic Deformation.* Neither of the above approaches is useful when deformation or crack sizes approach macroscopic part dimensions. Rather, for modeling purposes it is more useful to consider that the part has changed its macroscopic geometry.

In practice, the *stress intensity factor* approach, in which stress amplification due to the presence of defects is computed with linear-elastic models and compared with known failure stresses, has found widespread use. Details of the engineering practice of stress intensity factor formalism for analyzing crack growth and propagation are provided in detail at [this link](https://www.swri.org) from the Southwest Research Institute.