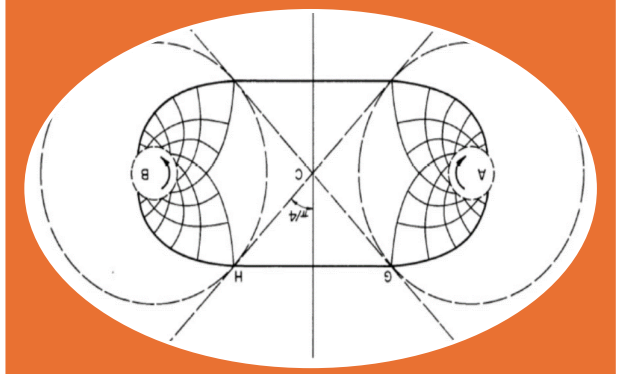
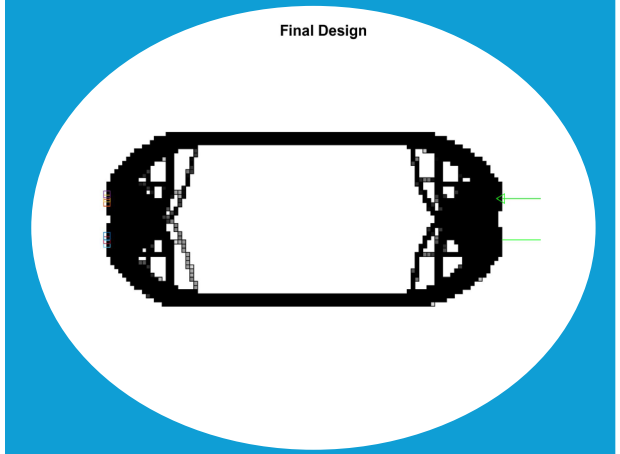




SO-1.0

SO-2.0

SO-3.0

SO-4.0

1860 to early 20th century

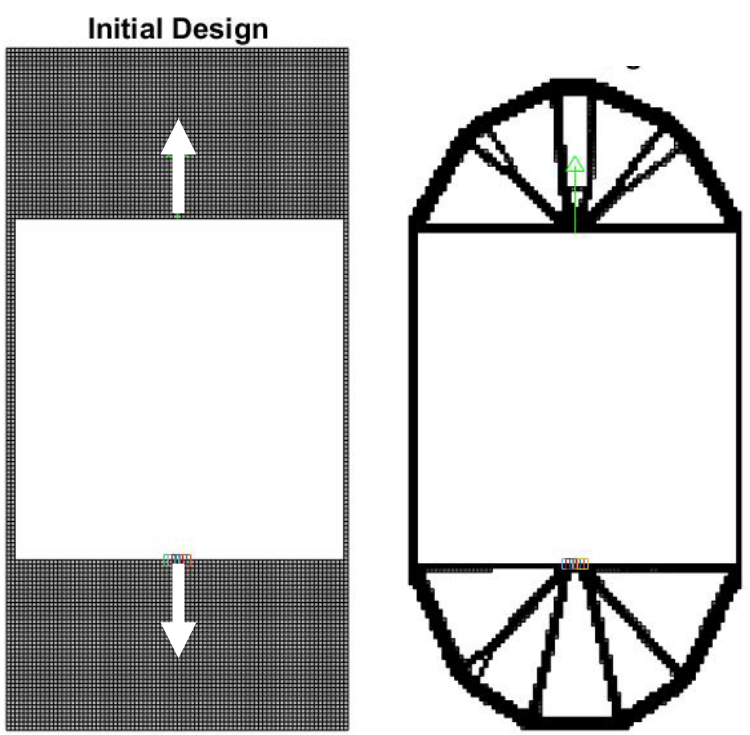
1950s to 1980s

1980 to early 21st century

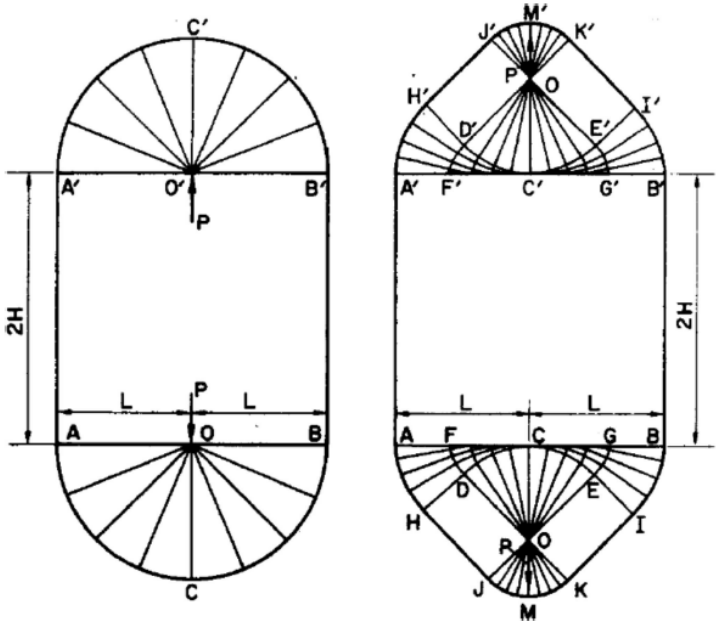
2010 onwards

SO 1.0	SO 2.0	SO 3.0	SO 4.0
Structural Engineers Physicists Rankine, Maxwell, Airy, Michell, Cremona, Cullman, Cox, …	Aerospace engineers Structural engineers Mechanicians Prager, Haftka, Taylor, Haug, …	Mechanicians Applied mathematicians Bendsøe, Kikuchi, Kohn, Rozvany, Sigmund, …	More engineers Physicists Material scientists Industry!
Focus on structures	Focus on aircraft structures and automotive components	Focus spread from structures to compliant mechanisms and *multiphysics* problems	Focus on *designing the interior*; meta- and *architected materials*
Graphics statics method; reciprocal form and force diagrams	Constrained minimization, optimality criteria method, sensitivity analysis	Homogenization method; SIMP; filters; level-set method;	Multi-objective; data-driven; fundamental physics

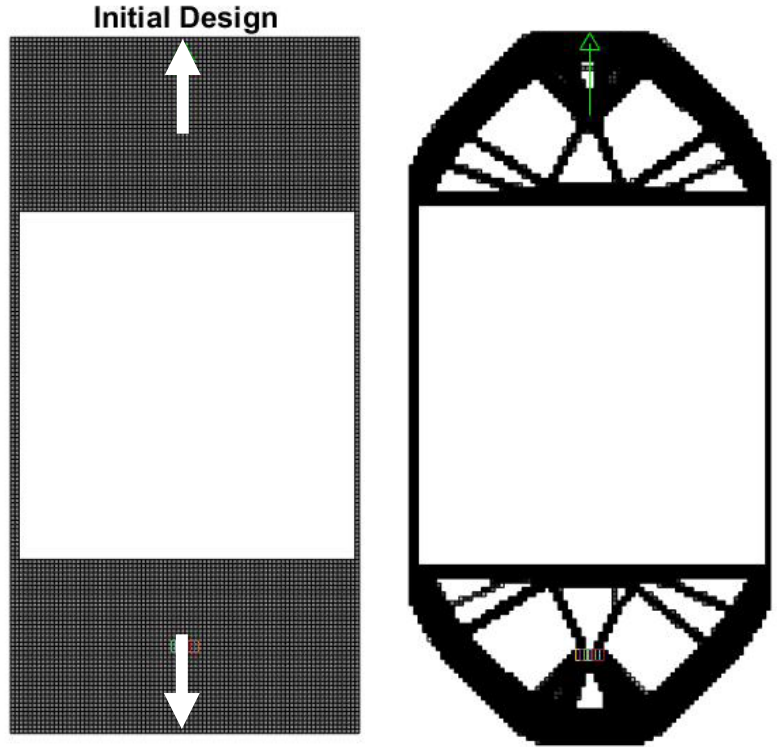
Then (19th century) and now (21st century)



YinSyn (our SIMP code)

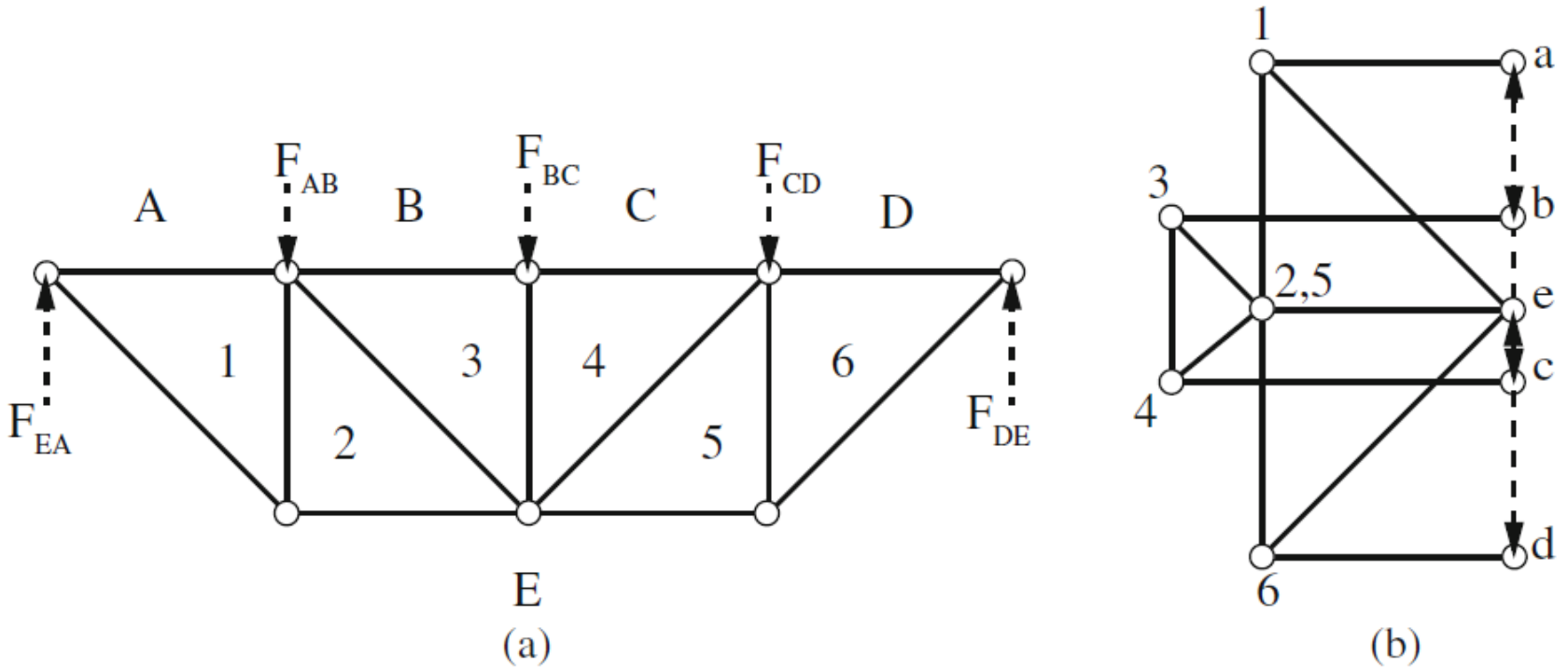


H. L. Cox



YinSyn (our SIMP code)

Maxwell reciprocal force diagrams



Baker et al. 2013, Struc. Mult. Disc. Opt.

SIMP: Simple Isotropic Material with Penalty

Optimal material distribution

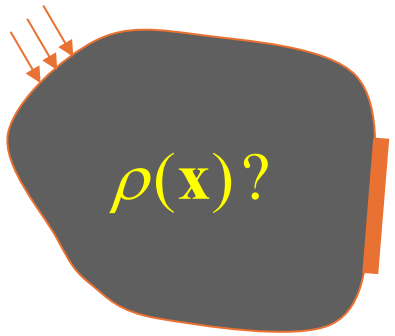
$$\underset{\rho(\mathbf{x})}{\text{Minimize}} \int_{\Omega} \mathbf{f}\cdot\mathbf{u}d\Omega + \int_{\partial\Omega} \mathbf{t}\cdot\mathbf{u}d\partial\Omega$$

Subject to

$$\nabla\cdot\boldsymbol{\sigma} + \mathbf{f} = \mathbf{0}$$

$$\int_{\Omega} \rho \mathrm{d}\Omega - V^{*} \le 0$$

Rozvany, Sigmund…



$$\boldsymbol{\sigma} = \mathbf{D}(\rho) : \boldsymbol{\varepsilon}$$

$$\boldsymbol{\varepsilon} = \frac{1}{2}\left(\nabla\mathbf{u} + \nabla^{T}\mathbf{u}\right)$$

$$E(\rho) = E_0\rho^{\eta} + E_{\min}$$

$$\upsilon(\rho) = \upsilon_0\rho^{\eta} + \upsilon_{\min}$$

$$0 \le \rho \le 1$$