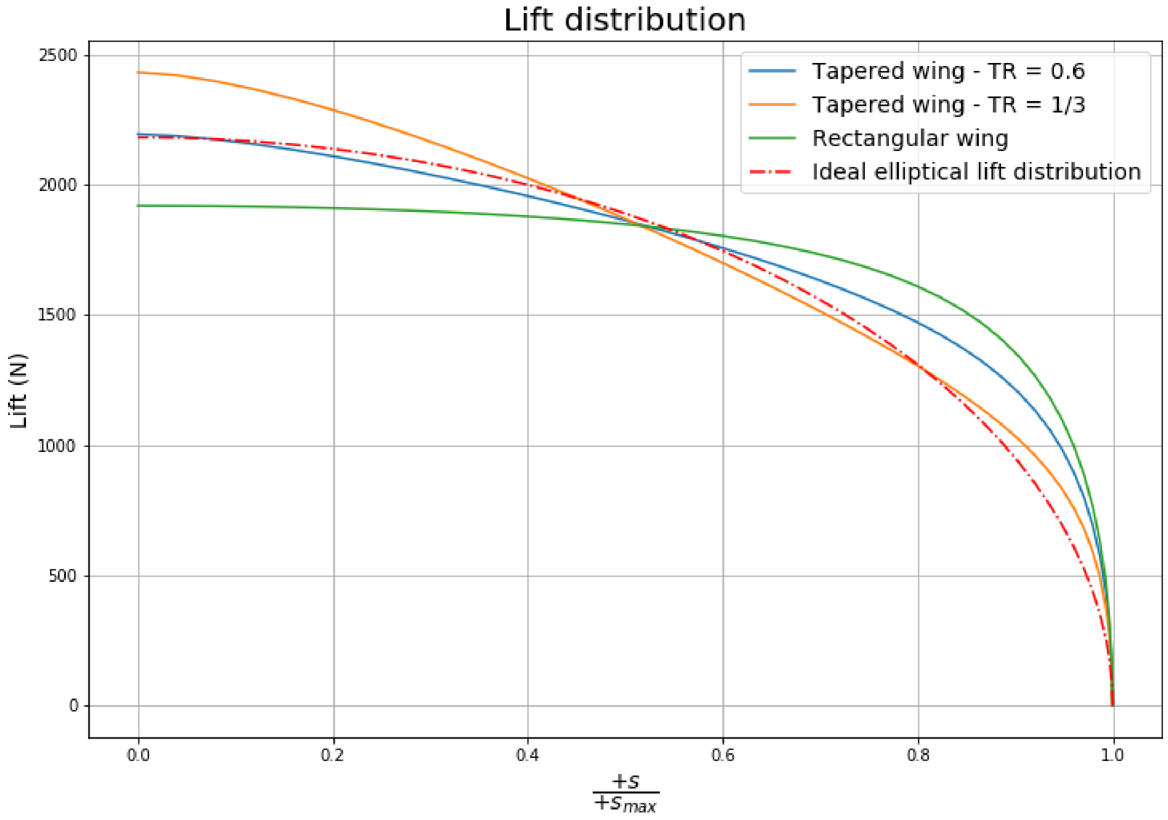
Wing design – General guidelines

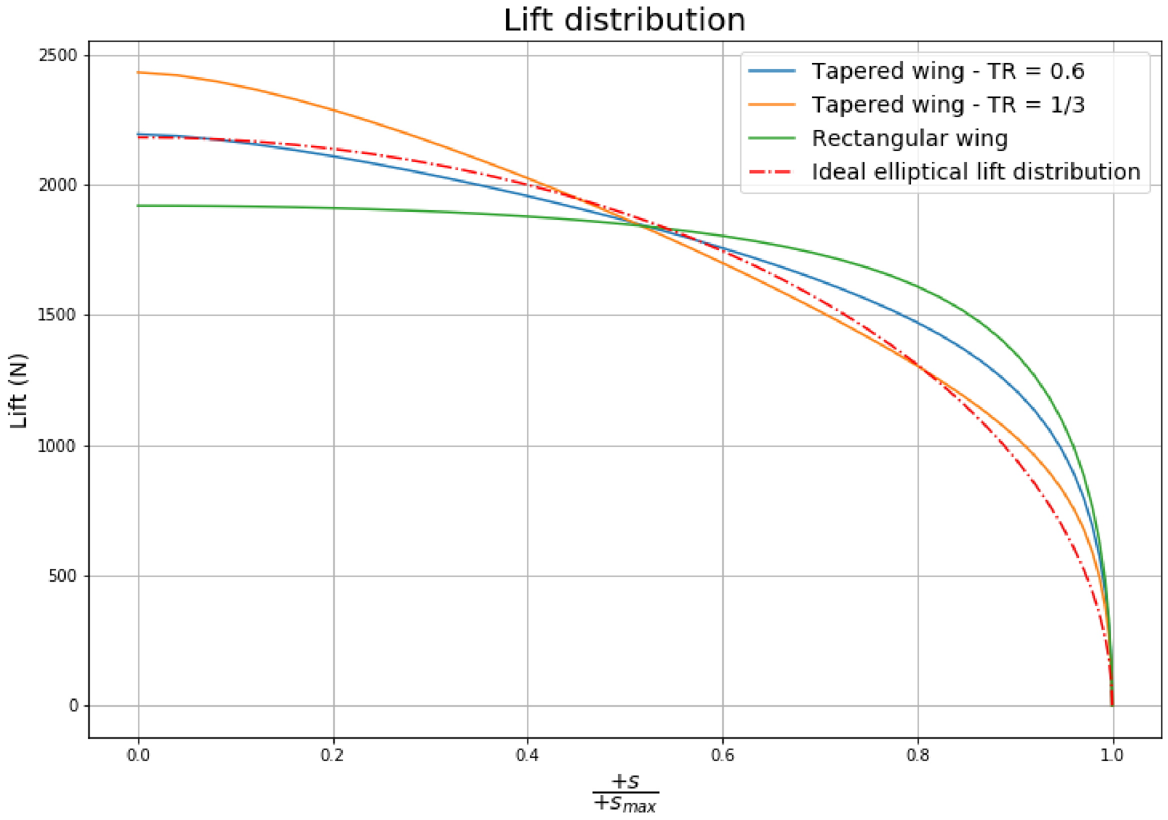
Wing design – General guidelines

- From a purely aerodynamic point of view, when designing a wing the **span lift distribution** curve should be elliptical in shape.
  - As we have seen in the theory, this guarantees the minimum induced drag.
- We also want a wing with low viscous drag, and this requirement strongly depends on the airfoil selection.
- Satisfying the previous two requirements is not an easy task.
- If your wing generates the required lift, this is not a problem.



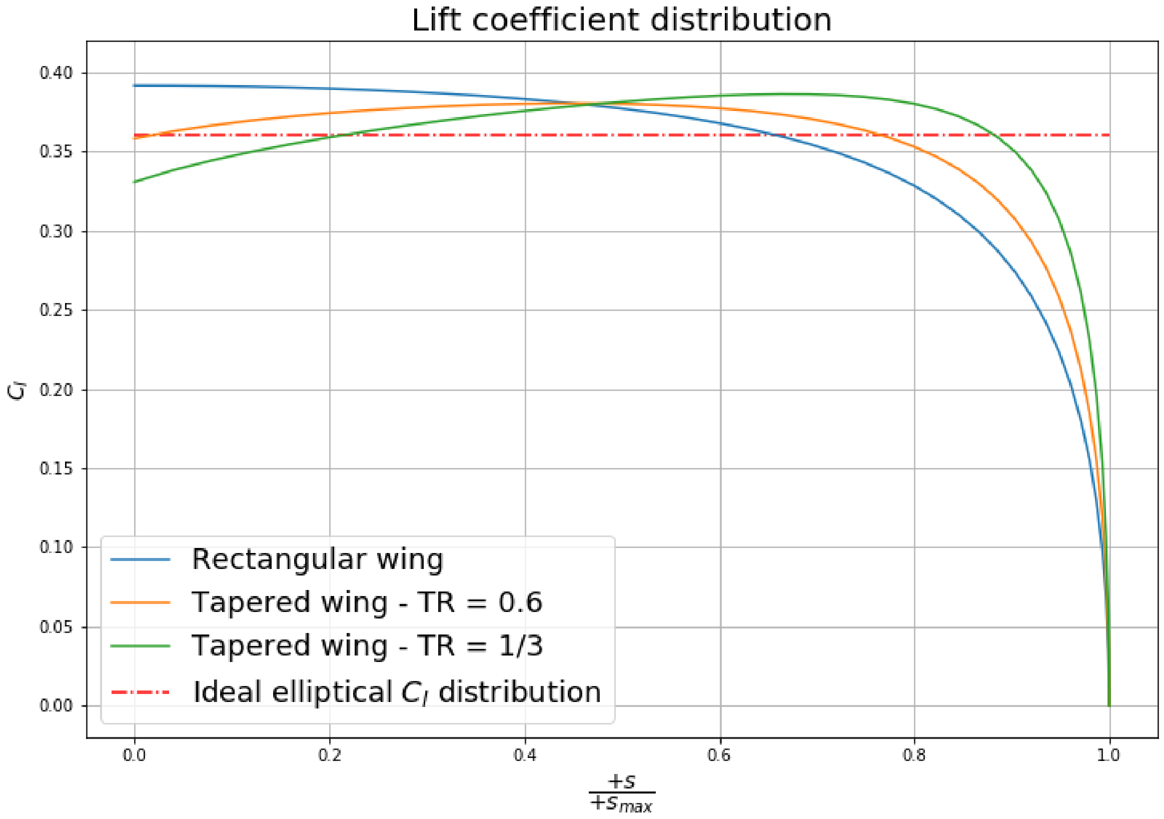
Wing design – General guidelines

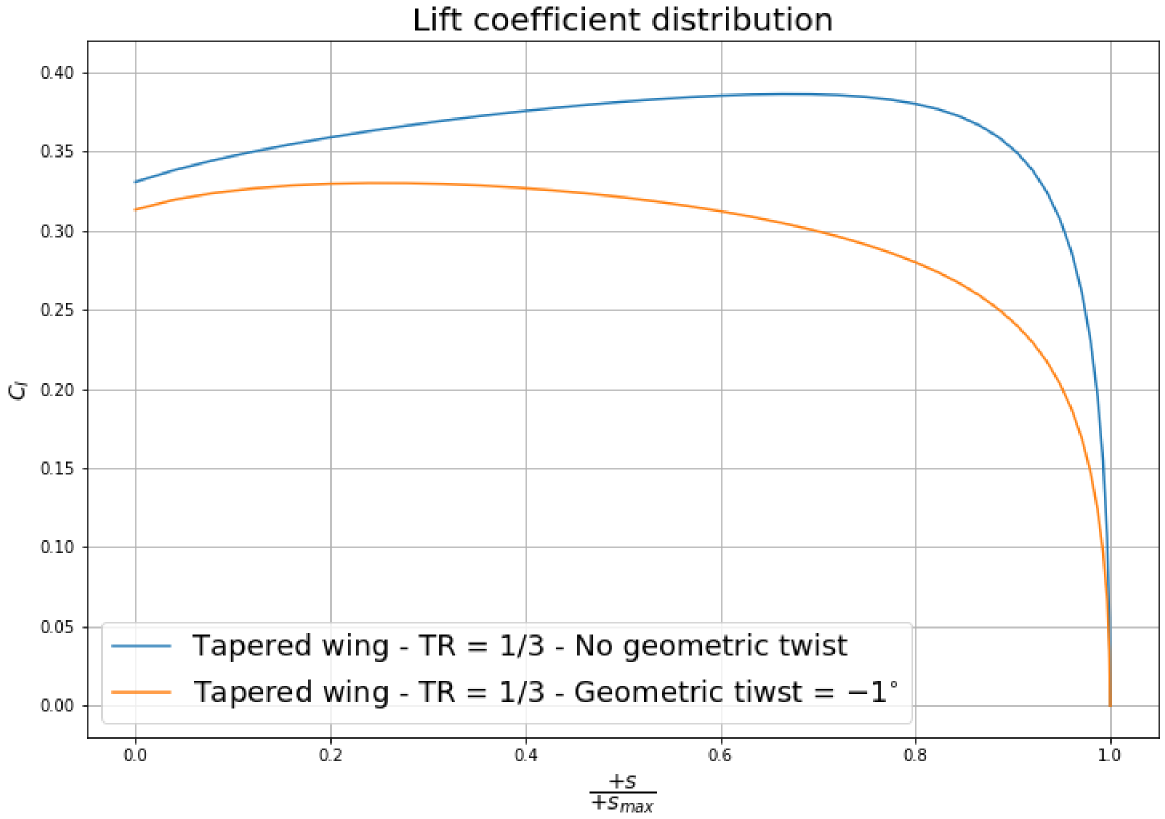
- Satisfying the requirement of elliptical lift distribution without resorting to an elliptical wing planform can be tricky.
- A properly tapered wing with small washout will approximate very well the elliptical lift distribution in the outer part.
- Whereas, in the inner part, the lift distribution deviates a little bit from the ideal distribution, this is not a problem.



Wing design – General guidelines

- Another important factor to consider when designing a wing is stall progression.
- The wing must be designed in such a way that it does not stall first at the tips, this is in order to avoid losing roll control.
- Wing stall progression can be controlled by adding twist, either geometric or aerodynamic, or a combination of both.
- Note that an elliptical lift distribution not necessarily translate into an uniform C_l distribution.





Wing design – General guidelines

- An elliptical lift distribution can be obtained by using an elliptical wing planform with no twist.
  - However, this wing is hard to manufacture.
  - Also, the stall progression characteristics of this wing planform are not very good.
  - In theory, elliptical wings should stall at the same time along the span
  - But in practice they tend to stall first at the tips due to smaller chord at the tips.
    - That is, the Reynolds number is smaller at the tips. Therefore, the maximum lift coefficient of the local section is lower.
- An elliptical lift distribution can also be obtained by properly twisting the wing.
  - We can use either aerodynamic or geometric twist.
  - We can also use a combination of aerodynamic and geometric twist.
  - The twist can be applied to any planform type, namely, rectangular, tapered, compound tapered, and so on.

Wing design – General guidelines

- A close approximation to an elliptic curve may be obtained through the use of a taper ratio equal to 0.4 with no twist.
- Then, by adding a little bit of twist, we can control the stall progression.
- Also, we should focus in getting the elliptical lift distribution in the outer part of the wing (towards the tips), where the wingtip vortices generates.
- Wing setting angle can also be used to control the lift curve distribution and wing lift coefficient.
- Rectangular wing planforms stall first at the root, which is desirably.
    - However, they have a strong downwash.
        - They produce a lot induced drag.
    - A properly twisted rectangular wing will have and elliptical lift distribution (related to induced drag) and elliptical lift coefficient distribution (related to stall progression).
    - In fact, a rectangular wing is the only wing planform that can have an elliptical lift distribution, an elliptical circulation distribution, and elliptical lift coefficient distribution.

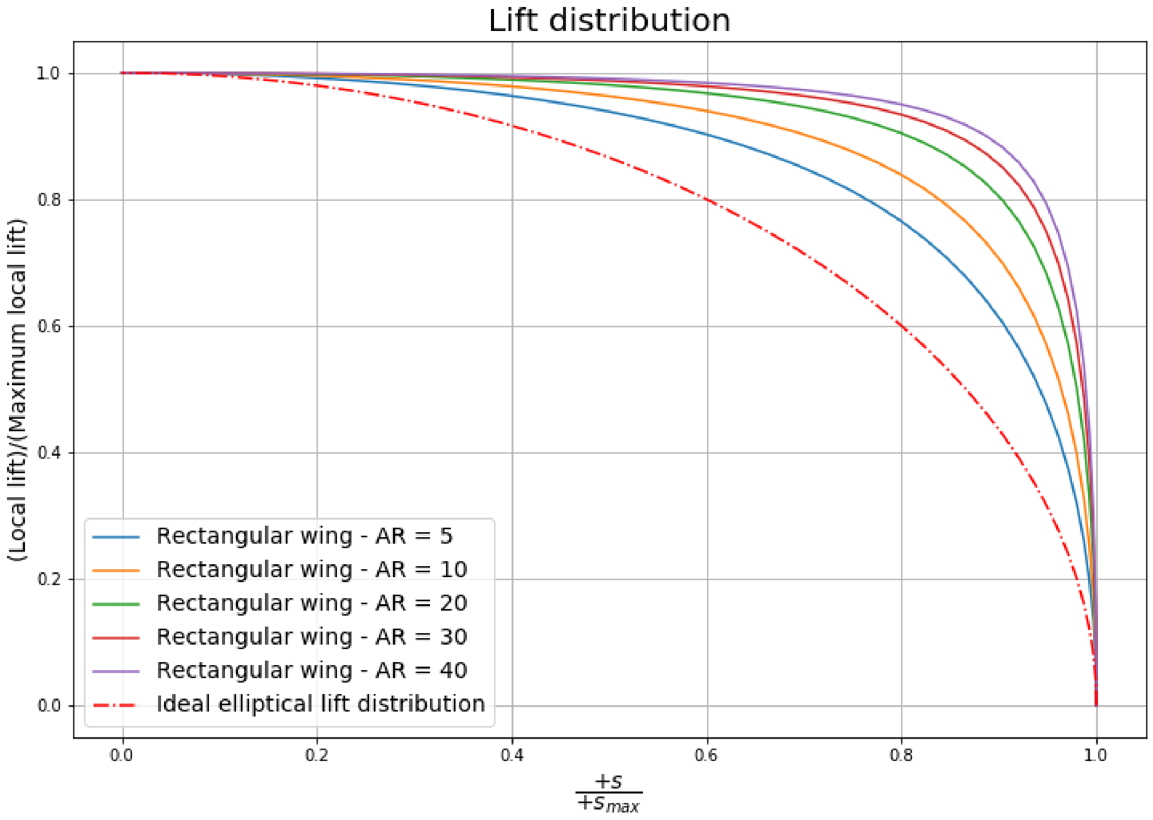
Wing design – General guidelines

- The minimum induced drag for a given span occurs with elliptic loading (lift force).
- Larger reduction of induced drag can be obtained by increasing the span.
    - Of course, until the wing weight becomes excessive or due to ground operational requirements.
- Larger spans, that is, larger aspect ratios, are in general preferable.
- Try to avoid low taper ratios.

$$C_{D_{ind}} = \frac{C_L^2}{\pi AR}(1+\delta)$$

Aspect ratio	Induced drag coefficient	Lift curve slope (per deg)
5	0.00149	0.07529
10	0.00107	0.08807
20	0.00069	0.09675
30	0.00051	0.10026
40	0.00042	0.10219

Thin airfoil theory = 0.10966 per deg.



Wing design – General guidelines

- We have talked a lot about induce drag in wing design.
- However, other factors may be more important to a particular design than minimum induced drag.
- Among these we find:
    - Cost of construction.
    - Weight.
    - Maneuverability.
    - Critical Mach number and divergence Mach number.
    - Wing volume for fuel storage.
    - Low bending and low twisting moments.
    - Aeroelasticity and flutter.
    - Airport operational wingspan.
    - And so on.

Wing design – General guidelines

- From an aerodynamic point of view, when designing a wing you must follow these general recommendations:
  - Lift = Weight.
  - Large L/D ratio. The maximum value should be as close as possible to the AOA in cruise conditions.
    - Very important for aircraft performance.
    - Many optimal metrics of airplane performance are obtained in flight at L/D maximum. For example,
      - Maximum range of propeller-driven airplanes.
      - Maximum climb angle for jet-powered airplanes.
      - Maximum power-off glide ratio (for jet-powered or for propeller-driven airplanes).
      - Maximum endurance for jet-powered airplanes.
    - Just take a look to Breguet equation (for range or endurance) to see the influence of L/D on aircraft performance.

Propulsion

Performance ← $$R = \frac{L}{D} \times \eta \times ln\left(\frac{W_{Initial}}{W_{Final}}\right)$$ → Structures + Materials

Aerodynamics

Wing design – General guidelines

- From an aerodynamic point of view, when designing a wing you must follow these general recommendations:
    - Low cruise AOA (as close as possible to zero).
    - Low drag contributions in the drag polar (skin friction drag, lift induced drag, and wave drag),

$$C_D = C_{D_{min}} + k(C_L - C_{L_{mindrag}})^2 + \Delta C_{D_M}$$

Skin friction drag — Lift induced drag — Wave drag

- Then things get multidisciplinary.