Gliding Mechanics

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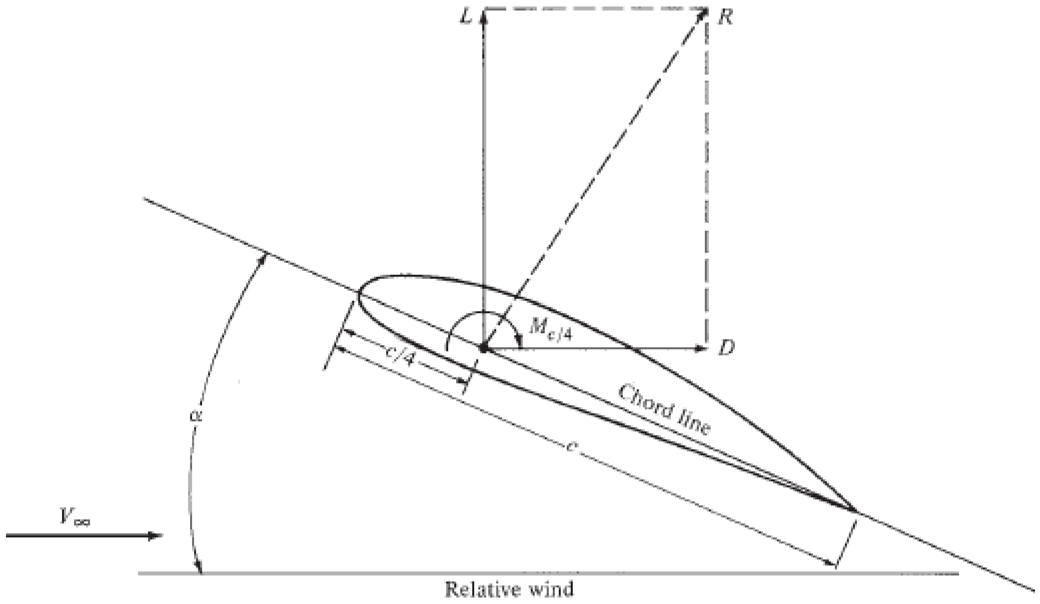
“This isn’t flying. This is falling, with style”

- Buzz Lightyear

Intro and Terminology

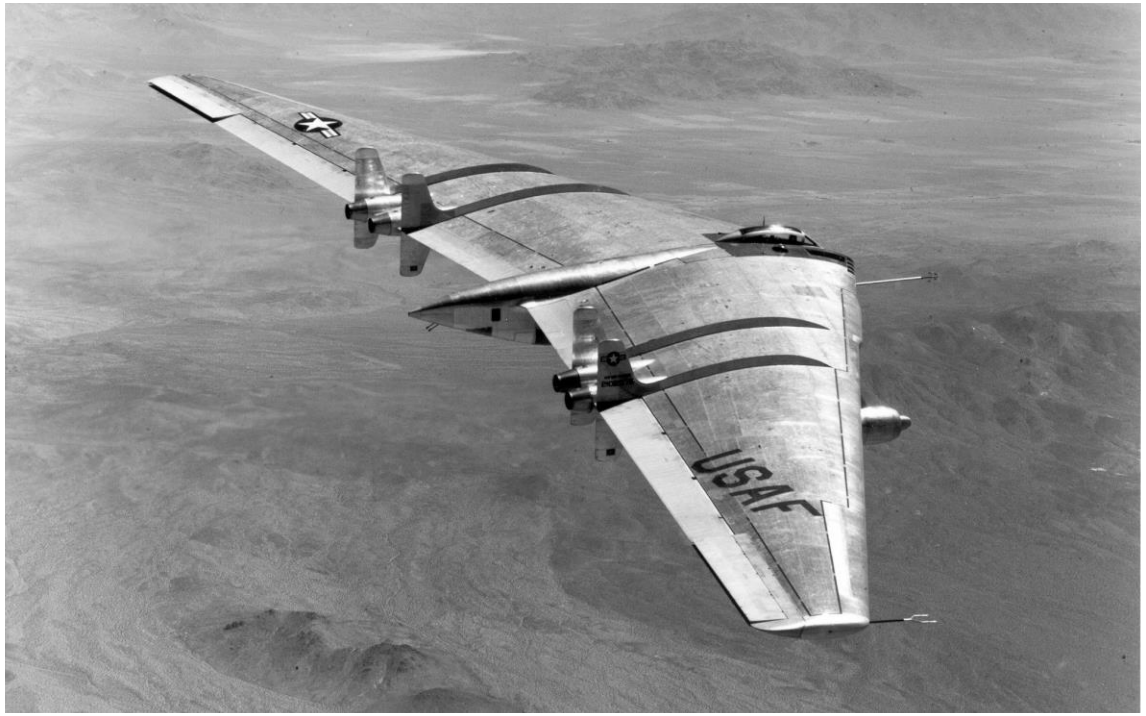
- Wing and airfoil
  - Chord length: c distance from leading to trailing edge
  - Quarter chord: $c_{1/4}$ conventional point to compute L, D, M
  - Size: S area of the wing
  - Wingspan: b length from wingtip to wingtip
  - Aspect ratio: $AR = b^2/S$
- Atmosphere and flow
  - Freestream (flow) velocity: V_∞ *[m/s]*
  - Relative wind: direction of V_∞ *(direction of vehicle travel)*
  - Angle of attack (between chord line and relative wind): α
  - Density of air: ρ_∞ *[kg/m³]*
  - Dynamic viscosity of air: μ_∞ *[kg/(m·s)]*
  - Dynamic pressure: $q_\infty = ½ \rho_\infty V_\infty^2$ *[kg/(m·s²)]*
  - Reynolds Number (x from leading edge): $Re_x = (\rho_\infty \cdot V_\infty \cdot x)/\mu_\infty$



- Aerodynamic force and moment
  - Coefficient of lift: c_l
  - Coefficient of drag: c_d
  - Coefficient of moment: c_m
  - Lift: $L = q_\infty \cdot S \cdot cl$
  - Drag: $D = q_\infty \cdot S \cdot cd$
  - Moment: $M = q_\infty \cdot S \cdot c \cdot cm$

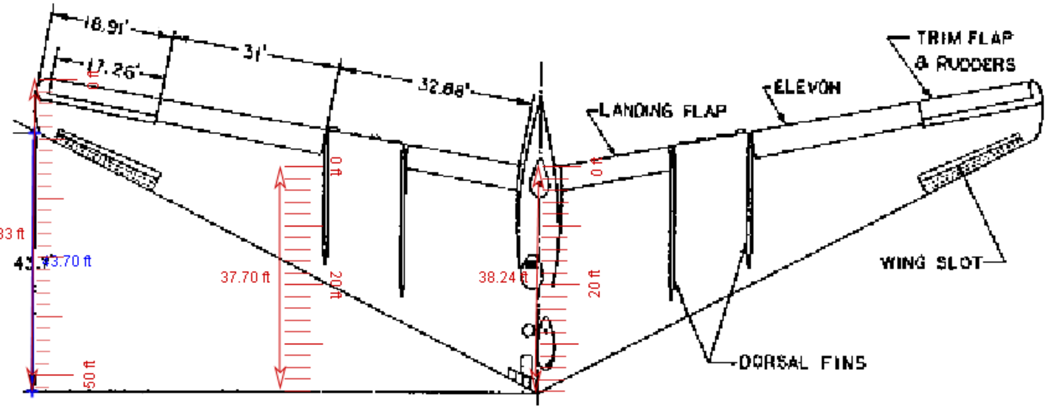
Aircraft Model

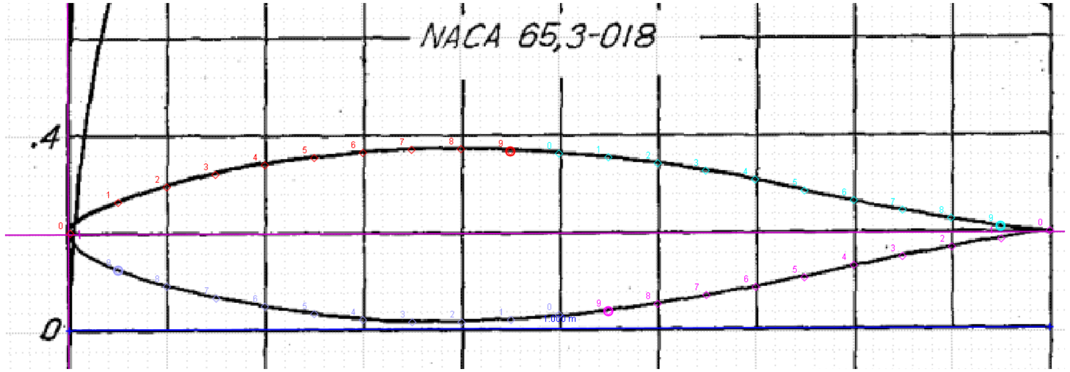
- Northrop YB-49 “flying wing”
- Experimental long-range bomber developed at end of WWII
- Conceptual predecessor of Northrop B-2 Spirit bomber
- Analytical advantages:
    - Easily represented by a single airfoil with no fuselage (no non-lifting surfaces)
    - Declassified airfoil profile (NACA 65_3-018)



Aircraft and airfoil diagrams

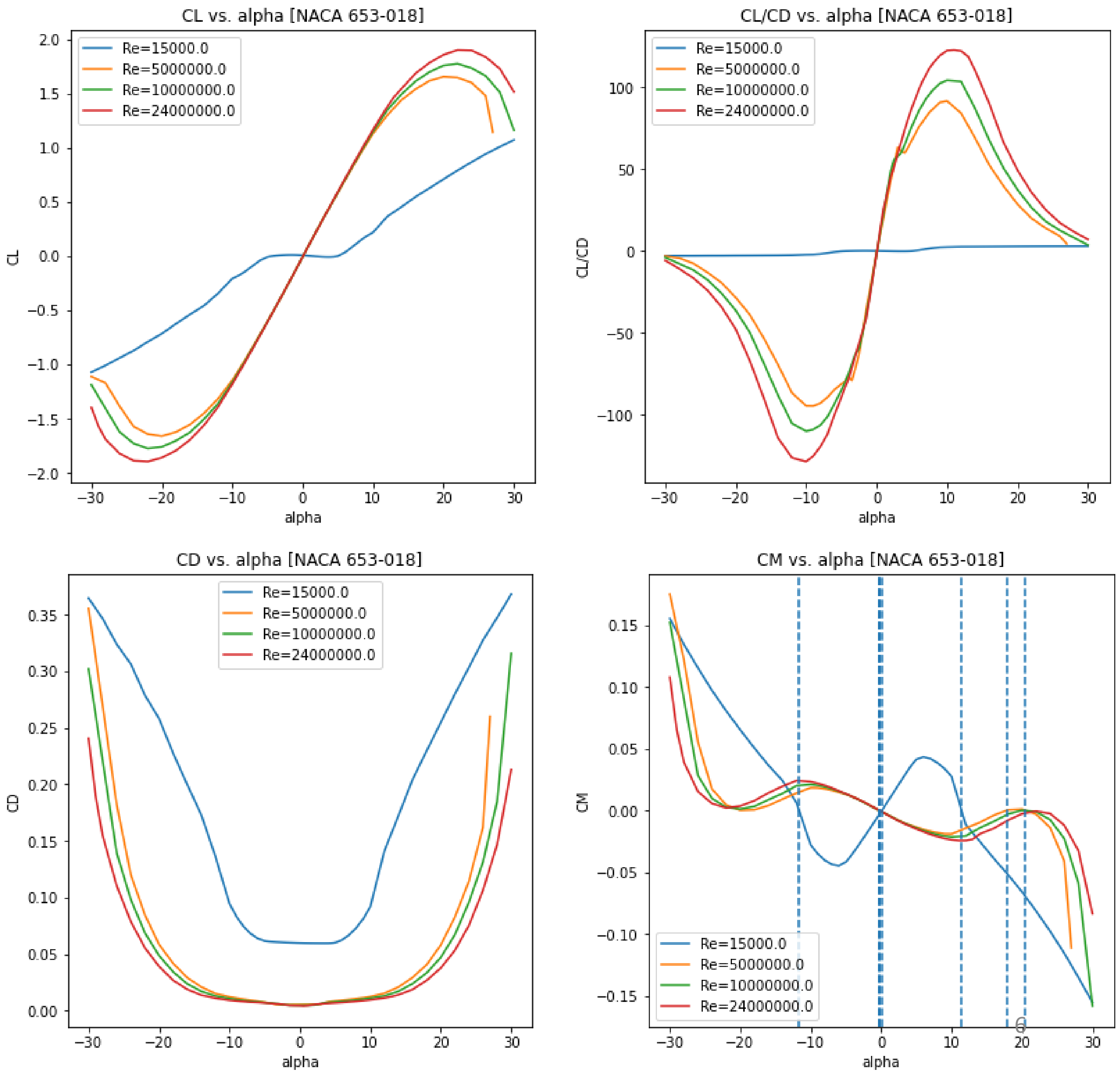
- Used Tracker to overlay planform and airfoil with calibrated grids to obtain measurements and coordinates
  - Chord: 11.66m
  - Wingspan: 52.43m (172ft)
  - Area: 378.47m^2 (4074ft)
  - Aspect ratio: 7.26
  - Center of gravity: 9.36m from the nose (0.8*c*)
  - Mass: 60,500kg (40,000kg empty)
  - Cruising velocity: 587 km/h (163m/s)





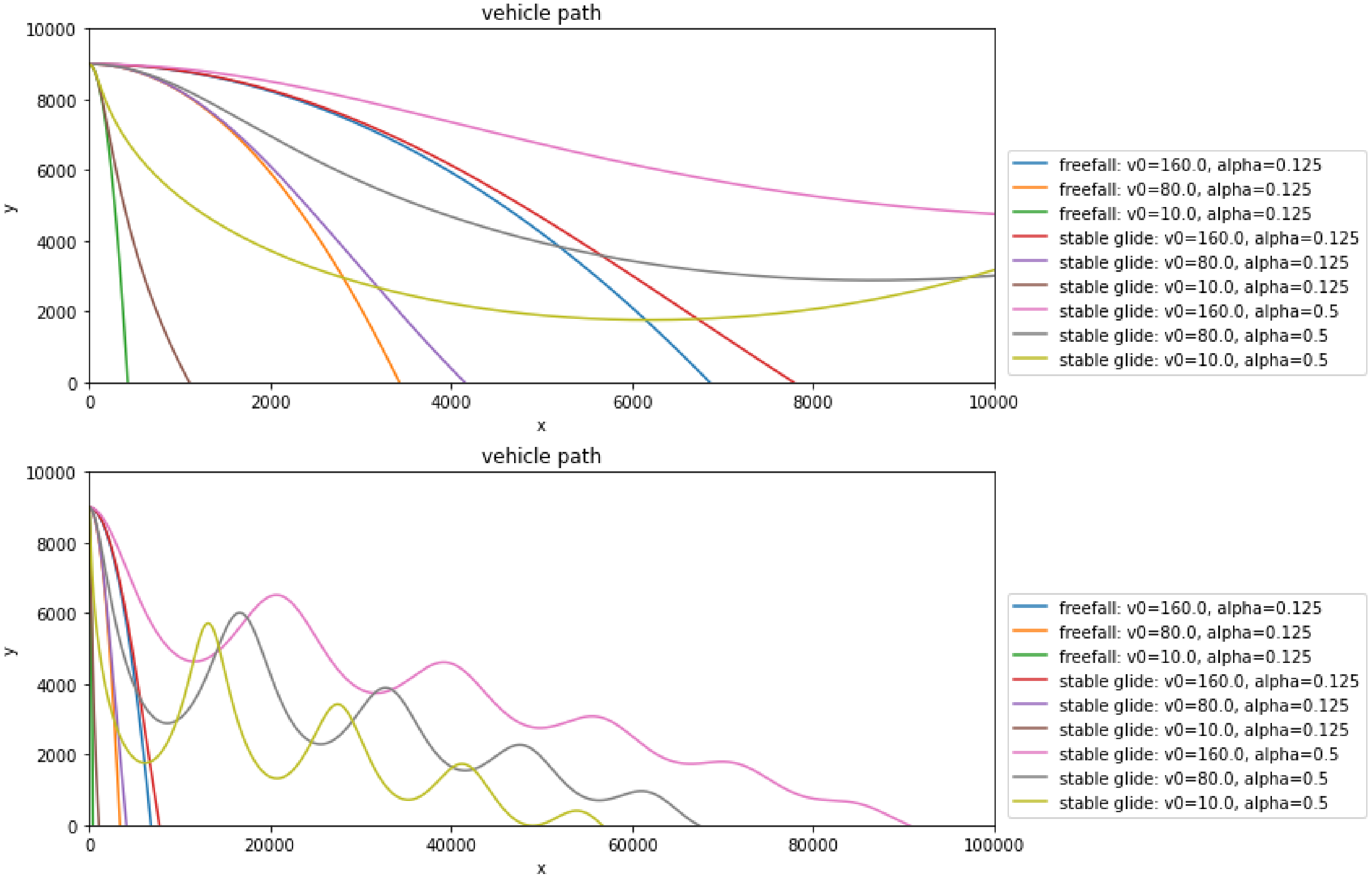
Polars

- Computational fluid dynamics software (XFOIL in this case) can produce lift, drag, and moment coefficients for a given *Re* across a range of angles of attack (*α*)
- The coefficients are consistent for an airfoil of the same shape, regardless of the size (which is why scale wind-tunnel models work)



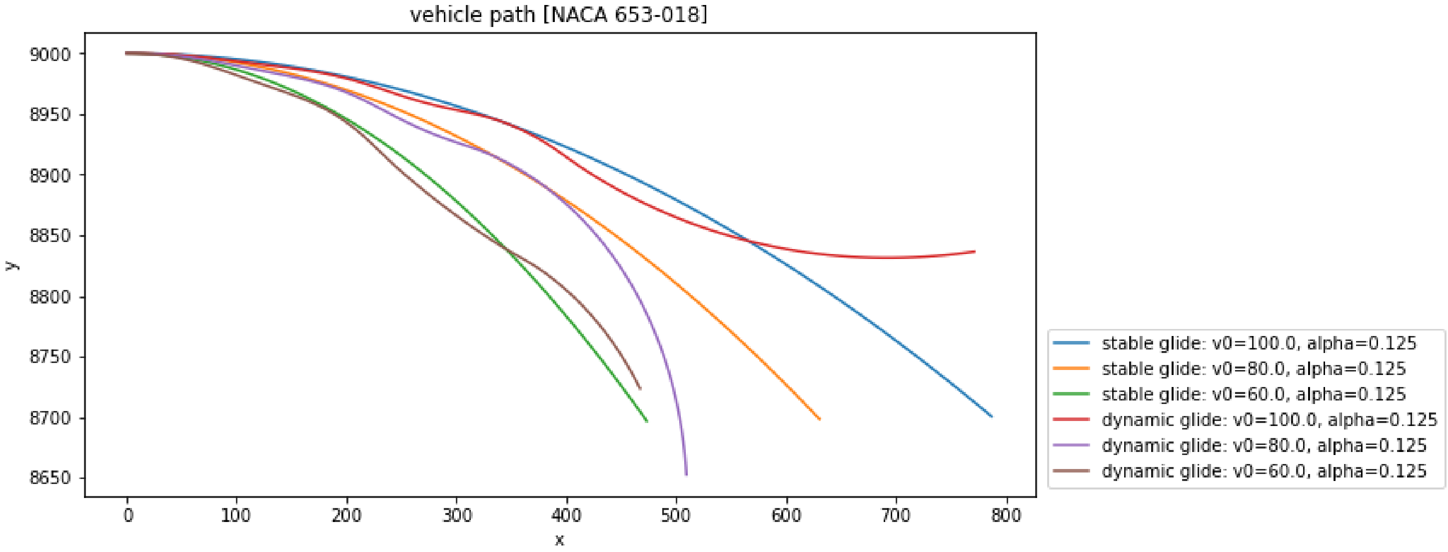
Stable (trimmed) glide with infinite wing

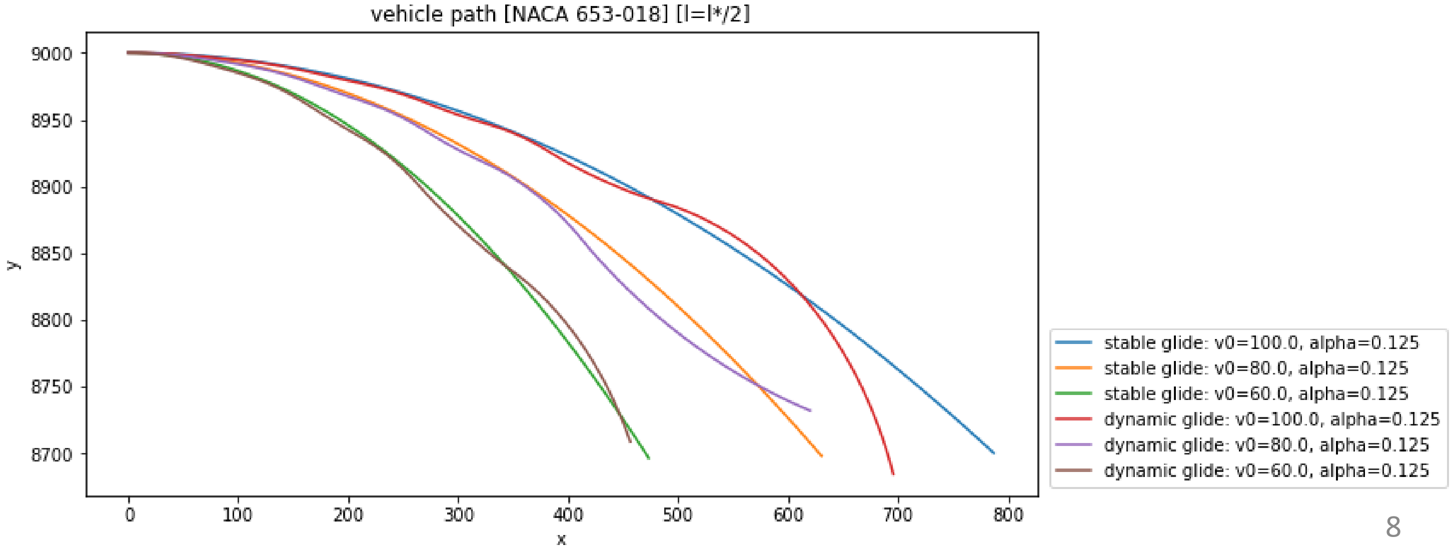
- Assume:
  - Only forces are gravity, lift, and drag on an infinite wing (no downwash/induced drag)
  - Aircraft remains trimmed at a stable angle of attack (c_m=0 and total M_{cg}=0)
- At 9000m initial elevation and 160m/s initial velocity (*Re*=1.46e7) α=0.125 c_l/c_d≈1.60, at α=0.5 c_l/c_d≈11.68
  - α=0.125 is a fixed point for *Re*=1.5e4 but has c_l/c_d≈-48.39 at initial conditions (*Re*=1.46e7) so would not perform well



Dynamic gliding

- In reality, the wing exerts a moment (torque) on the center of gravity, which tends to change the angle of attack through time
  - Longitudinal stability (resistance to pitching) is a function of the airfoil and aircraft properties
- An untrimmed aircraft without a stable fixed point (where c_m=0) at small α may lack longitudinal stability
- The center of gravity also experiences a moment from lift and drag, so a c_m fixed point may not be sufficient
  - $M_{cg}=M_{c/4}+ l \cdot L \cdot \cos(\alpha) - l \cdot D \cdot \sin(\alpha)$ where l = distance between the center of gravity and the quarter chord (approximation of the aerodynamic center) and the wing as mounted at zero inclination angle





Future work

- Interface directly with XFOIL for coefficient computation
- Incorporate finite wing dynamics (downwash and induced drag)
- Incorporate control surfaces
- Incorporate tail and fuselage mechanics
- Expand to 3D

Sources

- Introduction to Flight, John D. Anderson
- Summary of Airfoil Data Report No. 824, NACA
- XFOIL (https://web.mit.edu/drela/Public/web/xfoil/)
- Airfoil Tools (http://airfoiltools.com/)