Level Flight

Calculation of Trim Conditions

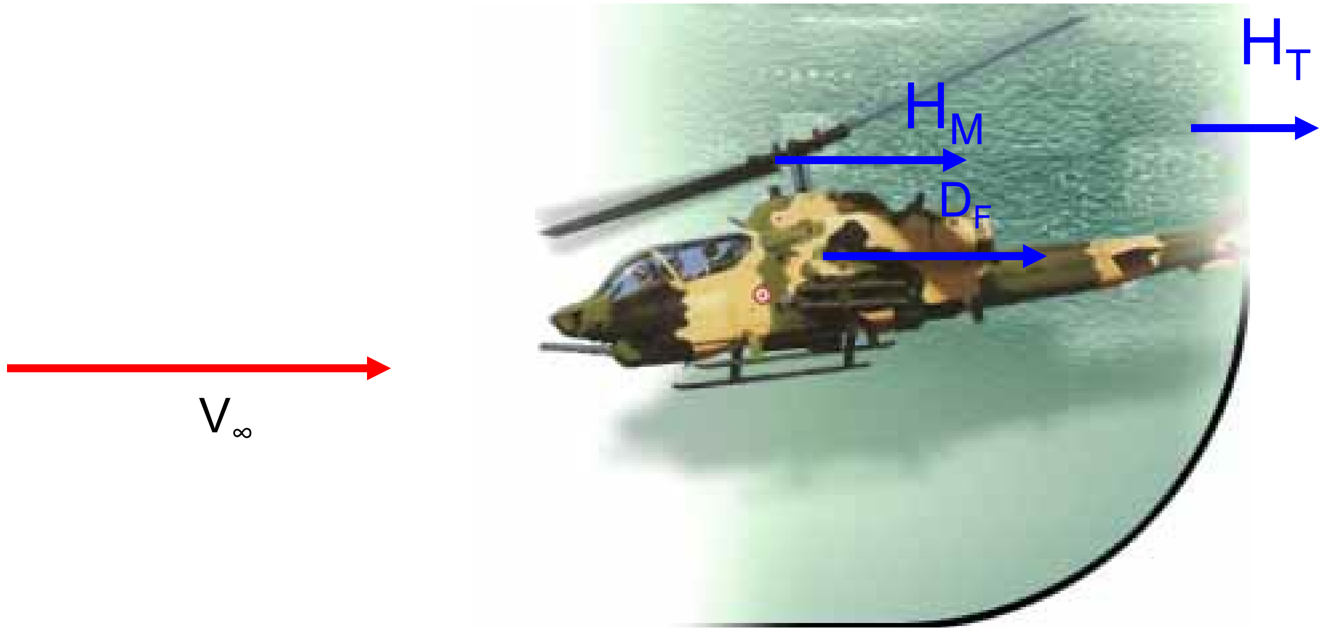
Including

Fuselage Aerodynamics

Background

- By trim conditions we mean the operating conditions of the entire vehicle, including the main rotor, tail rotor, and the fuselage, needed to maintain steady level flight.
- The equations are all non-linear, algebraic, and coupled.
- An iterative procedure is therefore needed.

Horizontal Force Balance

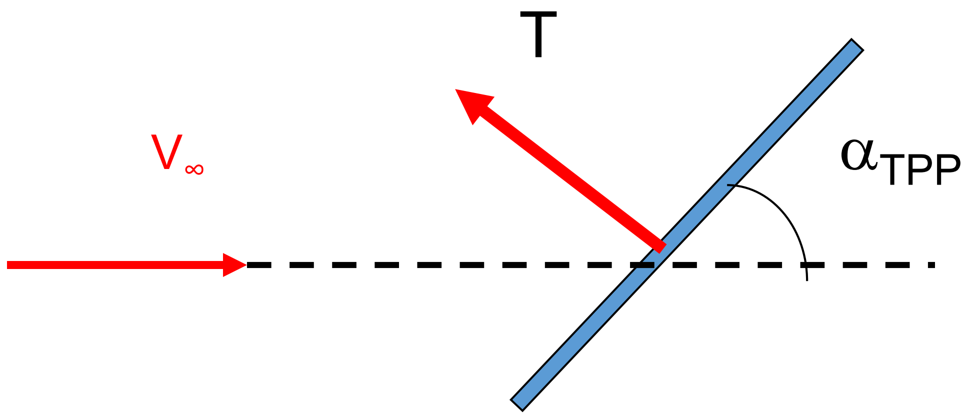


Total Drag= Fuselage Drag (D_F) + H-force on main rotor (H_M) + H-force on the tail rotor (H_T)

Vertical Force Balance

Vertical Force = GW- Lift generated by the fuselage, L_F

Tip Path Plane Angle



$$T\cos\alpha_{TPP} = GW - L_F$$

$$T\sin\alpha_{TPP} = D_F + H_M + H_T$$

$$\alpha_{TPP} = \tan^{-1}\left[\frac{D_F + H_M + H_T}{GW - L_F}\right]$$

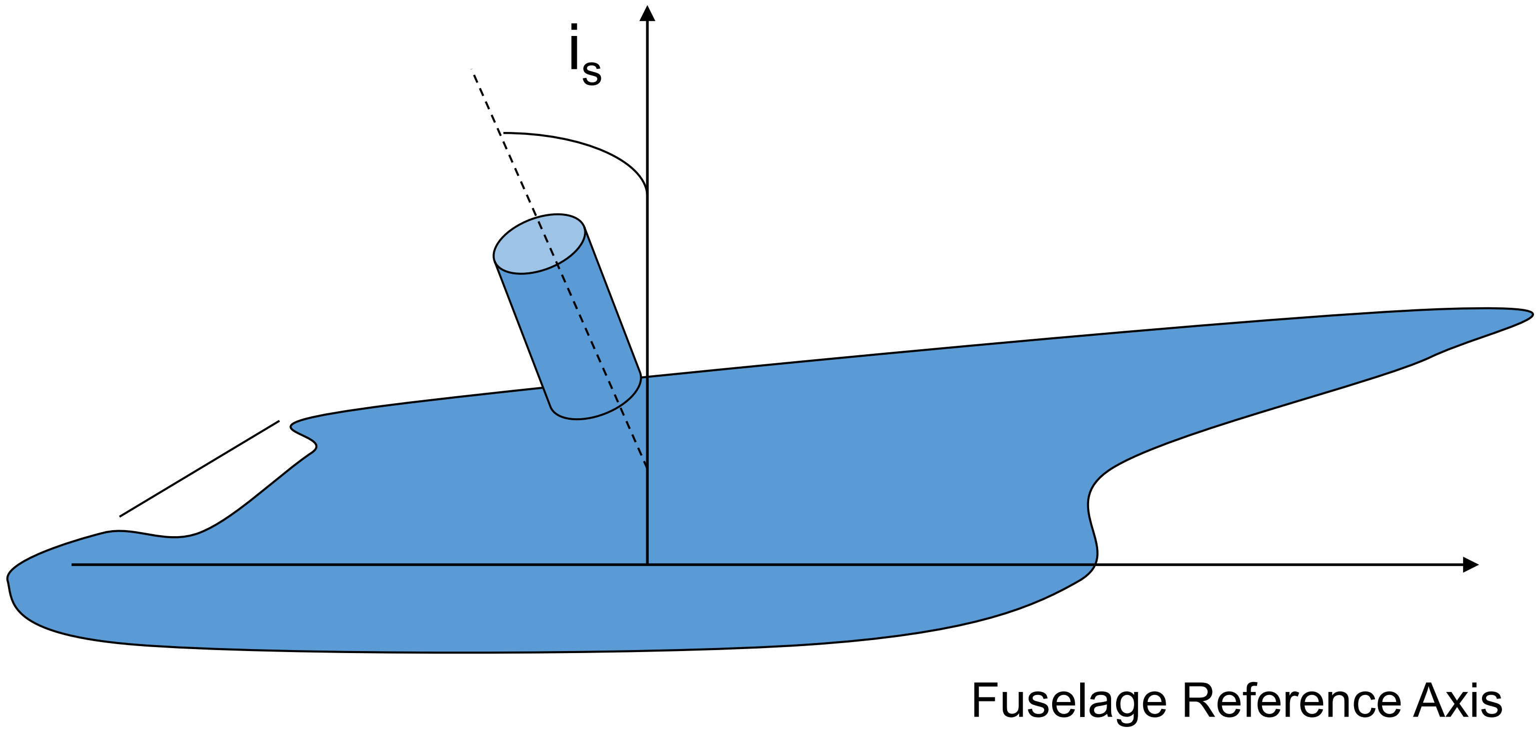
Fuselage Lift and Drag

- These are functions of the fuselage geometry, and its attitude (or angle of attack).
- This information is currently obtained from wind tunnel studies or CFD (for new designs), and stored as a data-base in computer codes.

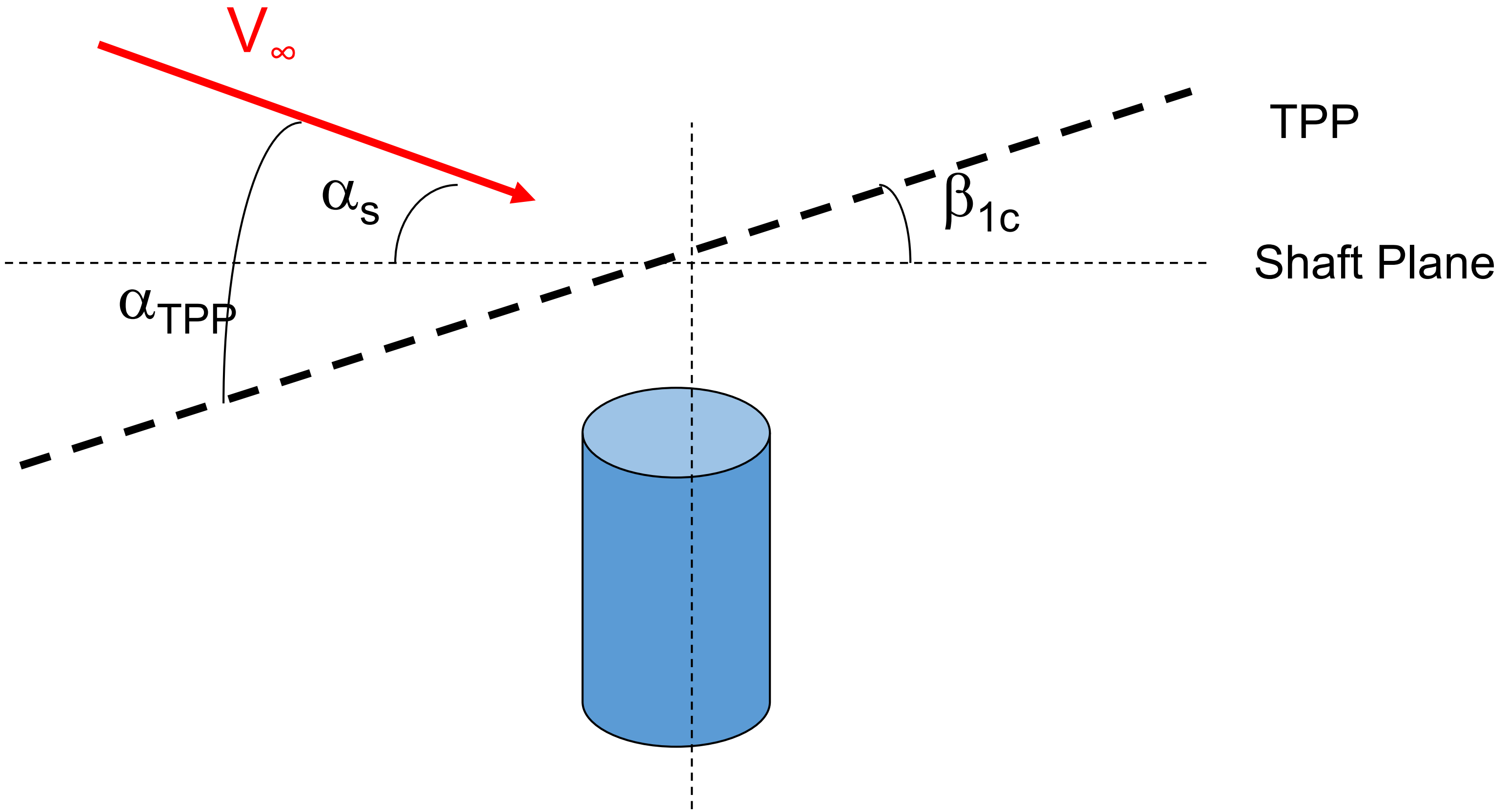
Fuselage Angle of Attack

- Extracted from
  - Tip path angle
  - Blade flapping dynamics
  - Downwash felt by the fuselage from the main rotor
  - Shaft inclination angle.

Shaft Inclination Angle



Relationship between Tip Path Plane Angle of Attack and Shaft Angle of Attack



$$\alpha_{TPP} = \alpha_s + \beta_{1c}$$

Angle of Attack of the Fuselage

- Start with tip path plane angle of attack.
- Subtract β_{1c} to get shaft angle of attack
- Subtract the inclination of the shaft
- Subtract angle of attack reduction associated with the downwash from the rotor

$$\alpha_F = \alpha_{TPP} - \beta_{1c} - i_s + \frac{v}{V_\infty}$$

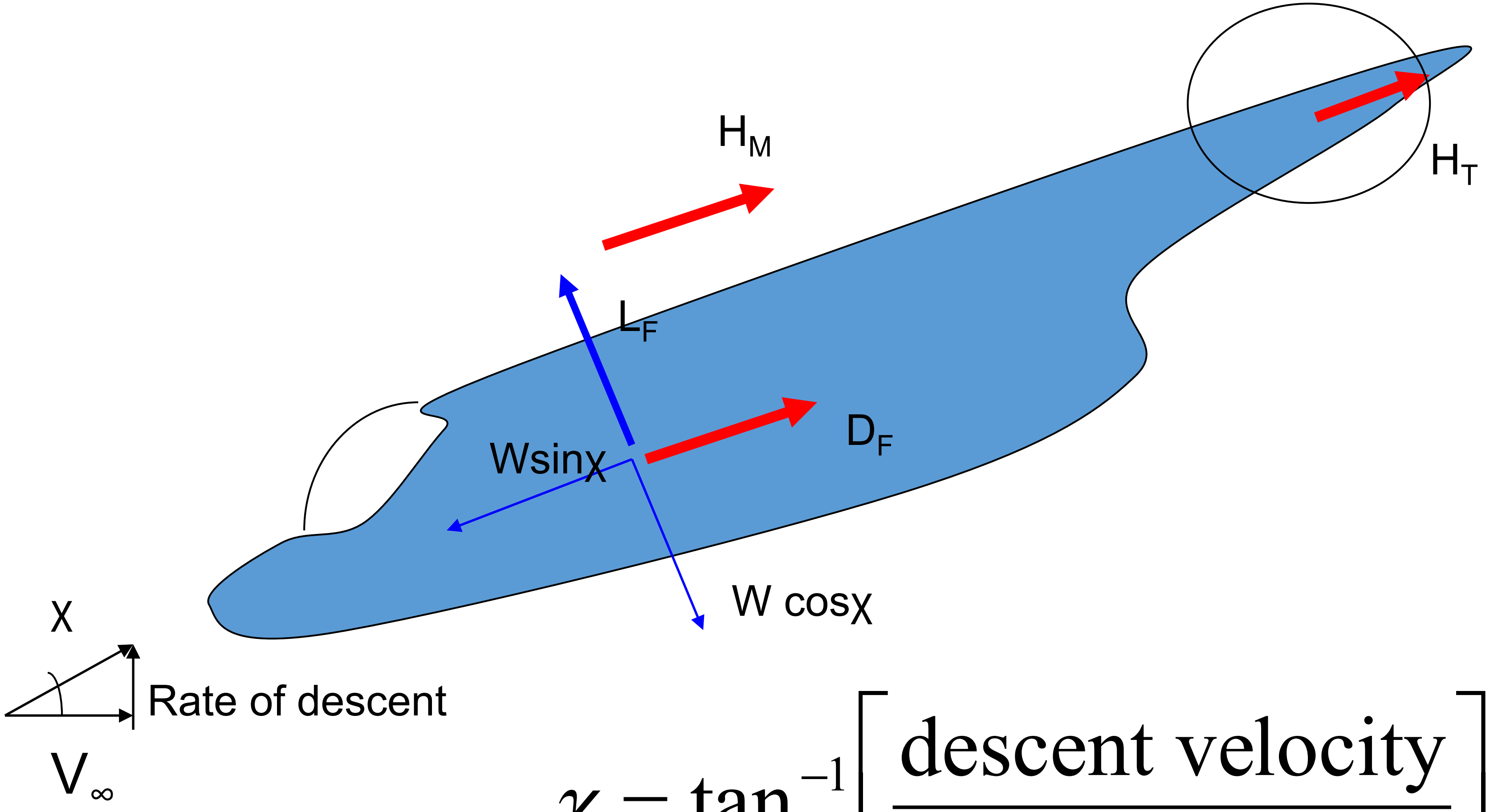
Iterative process

- Assume angle of attack for fuselage (zero deg).
  - Find L_F and D_F from wind tunnel tables.
  - Compute needed T. during the first iteration, T is approximately GW-$L_{F.}$ Use this info. to find main rotor torque, main rotor H-force, tail rotor thrust needed to counteract main rotor torque, and tail rotor H- force.
  - From blade trim equations, find β_{1c}.
  - Find tip path plane angle of attack.
- Recompute fuselage angle of attack.
- When iterations have converged, find main and tail rotor power. Add them up. Add transmission losses to get total power needed.

Autorotation in Forward Flight

- The calculations described for steady level flight can be modified to handle autorotative descent in forward flight.
- Power needed is supplied by the time rate of loss in potential energy.

Descent



$$\chi = \tan^{-1}\left[\frac{\text{descent velocity}}{V_\infty}\right]$$

Tip Path Plane Angle in Descent

$$T\cos\alpha_{TPP} = GW\cos\chi - L_F$$

$$T\sin\alpha_{TPP} = D_F + H_M + H_T - GW\sin\chi$$

$$\alpha_{TPP} = \tan^{-1}\left[\frac{D_F + H_M + H_T - GW\sin\chi}{GW\cos\chi - L_F}\right]$$

Iterative Procedure

- The iterative procedure involves
  - assume a rate of descent
  - Iterate on fuselage angle of attack to achieve forces to balance, as done previously in steady level flight.
  - Compute the power needed to operate= main rotor+ tail rotor+ transmission losses.
  - Equate this power needed with the power available from loss of potential energy= GW * Rate of descent.
  - Iterate until power needed = power available