Landing Energy Analysis

Energy Dissipation throughout the Landing Phase

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Landing Energy Analysis

Energy Dissipation throughout the landing phase

- How is energy dissipation distributed?
  - Rolling Resistance
  - Aerodynamic Drag
  - Brakes
  - Slope
- Which factors have the most effect on landing distance?
- Why do we care?
  - ~20% of US runways are less than 3,000’
  - Getting on the ground and off the runway helps traffic flow
  - Knowledge of energy dissipation provides more options

Landing Energy Analysis

Energy Dissipation throughout the Landing Phase

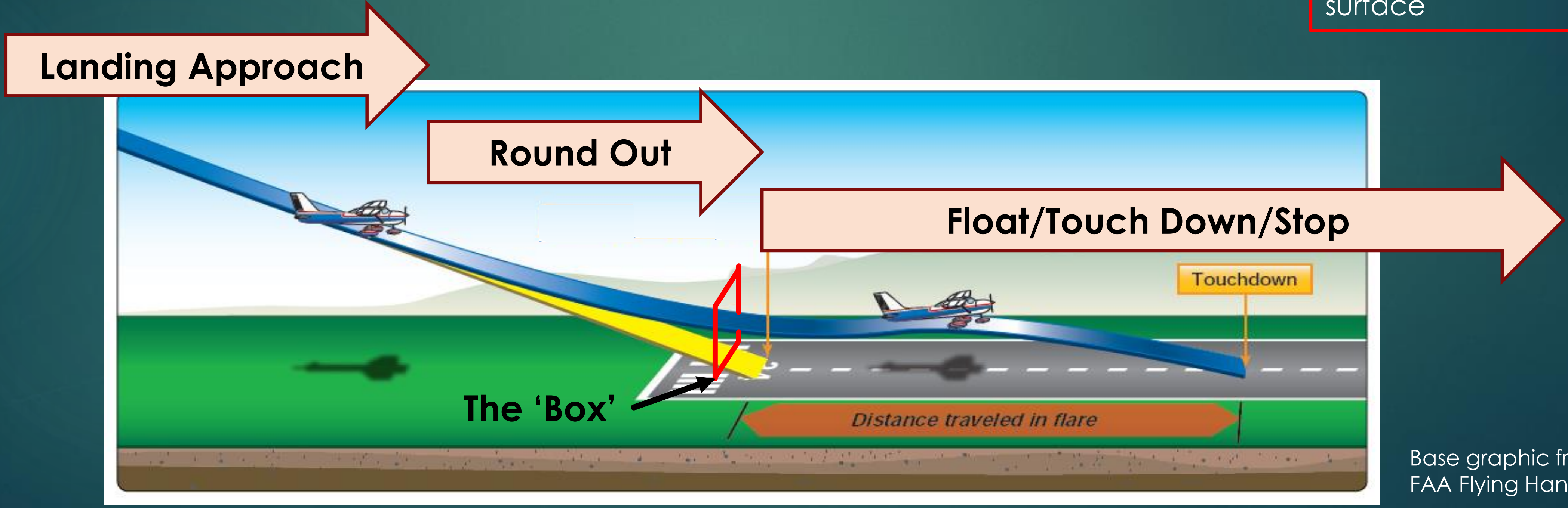
- Assumptions:
  - General Aircraft Characteristics:
    - Straight Wing
    - Simple Flaps (CL_{max} <2.0) – not multi-segment
    - Piston/Prop – not turbine
    - No spoilers
    - No thrust reversing
  - Procedural:
    - Power pulled to idle in the Round-Out
    - Normal Landings – no short field techniques

Landing Energy Analysis

Three Segments

- Approach, Round Out, Float/Touch Down/Roll Out)
  - Independent of each other
  - Common point: the 'box'

The Red Box indicates point at which aircraft has completed the round-out and is flying parallel to runway surface



Base graphic from FAA Flying Handbook

Landing Energy Analysis
Float/Touch Down/Roll Out

- Flare to Stop
  - Minimum Runway Required is set at the threshold – via height/speed
  - Energy Dissipation Options limited:
    - Aerodynamics
    - Brakes – Maximum effectiveness is set by weight on wheels and torque rating

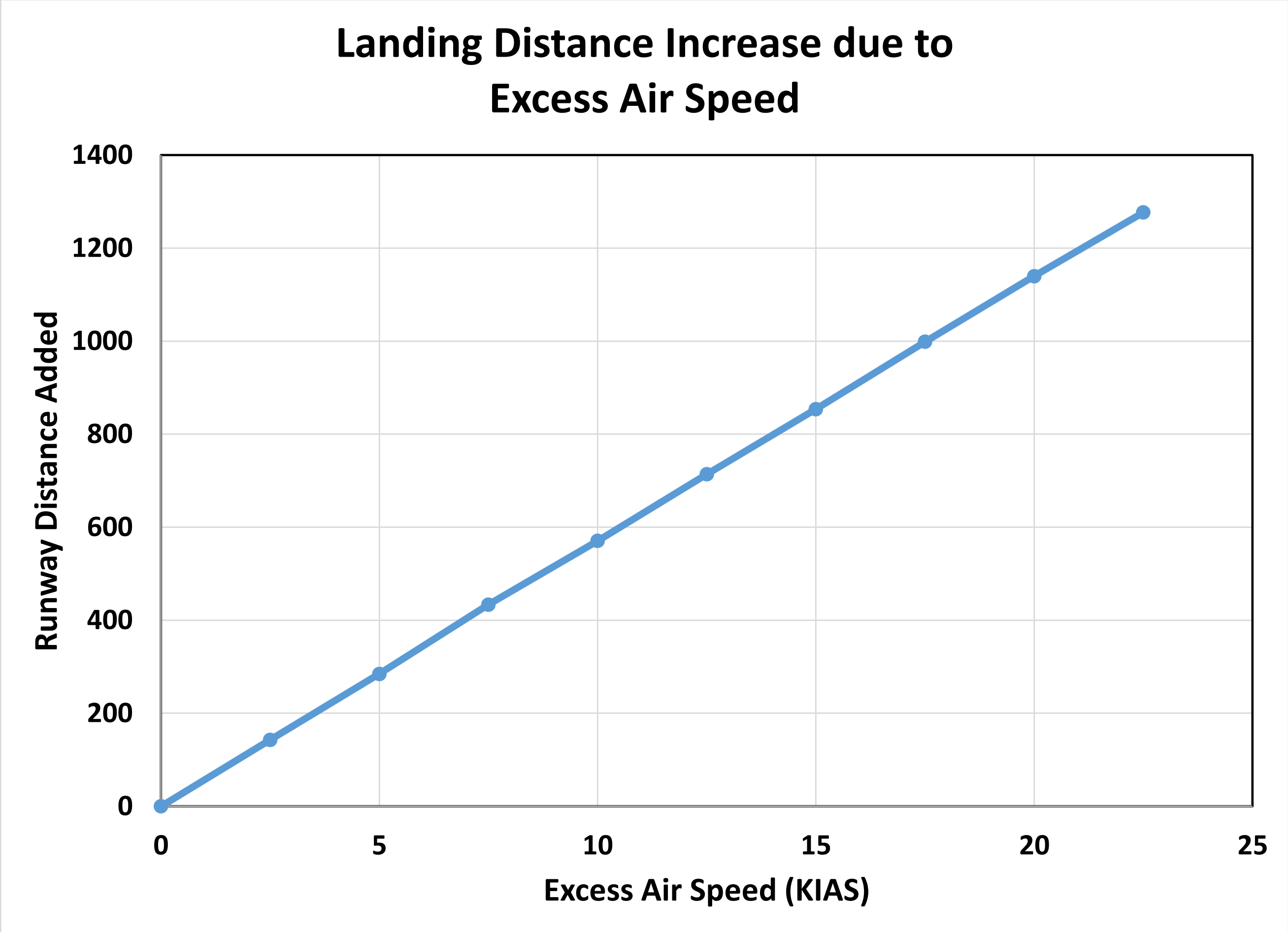
Sample Break-down
-Lancair 360, 1600 lb
-Stock Matco brakes/Outback Gear
-No wind
-No slope

Distance	1,584	ft	% total
Brake Energy	158,000	ft-lb	42
Aero Energy	191,000	ft-lb	51
Rolling Resistance Energy	25,600	ft-lb	7
Total Energy	374,600	ft-lb	100

Landing Energy Analysis
Sensitivity to Airspeed

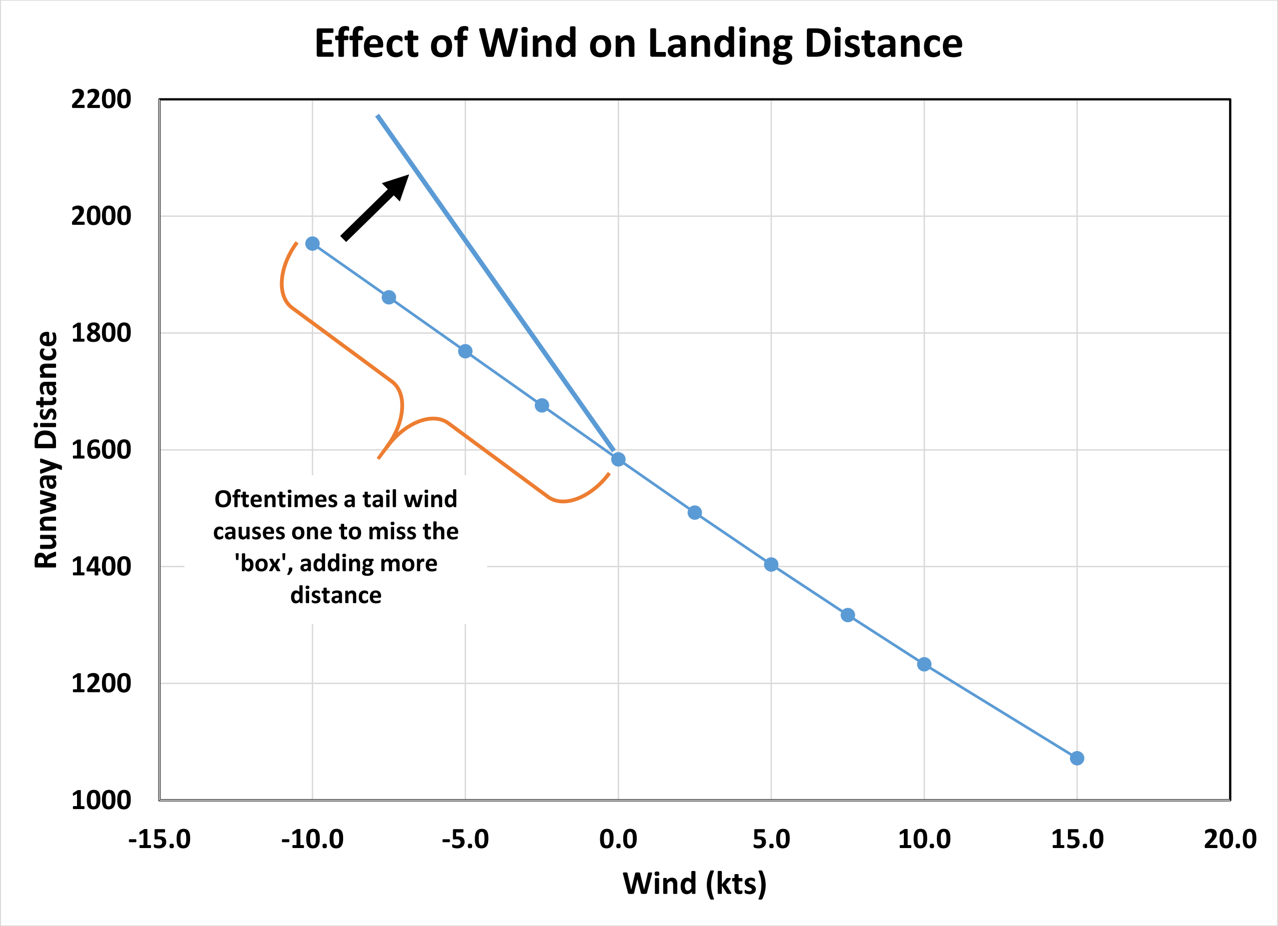
- Excess Airspeed
  - Excess Speed ➔ longer float/rollout
  - ~57'/ kt ➔ 10 kts = 600'
  - 13% more speed = 40% more runway

Assumptions:
- Nominal Approach Speed = Vref = 1.3 V_{SO}
- Full flaps



Landing Energy Analysis
Sensitivity to Wind

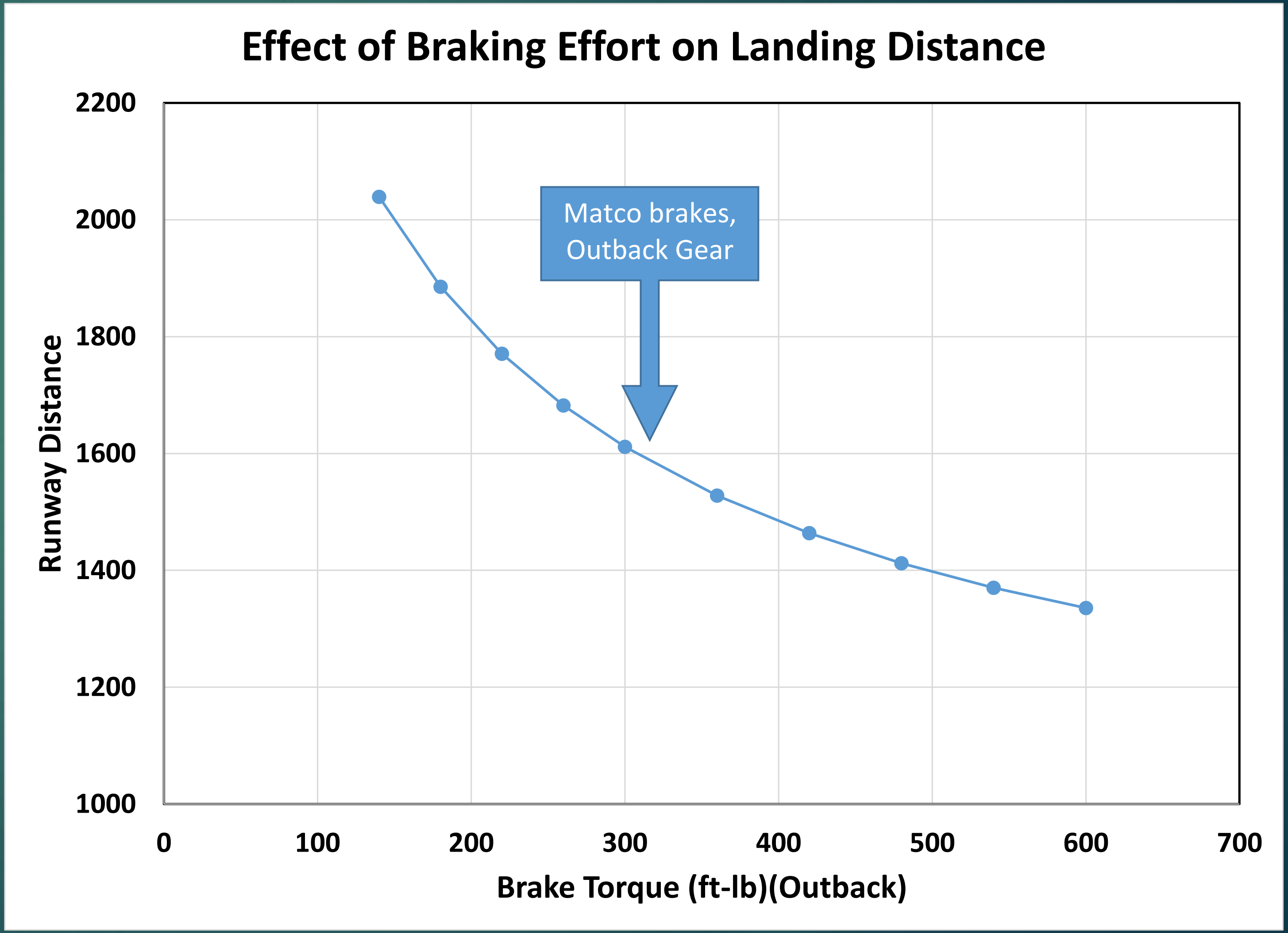
- Headwind
  - Dramatically shortens ground roll
  - Energy Dissipation required is based on ground speed
  - Just a little wind adds lots of margin on short runways
  - Huge penalty for landing with tailwind as opposed to headwind



Landing Energy Analysis

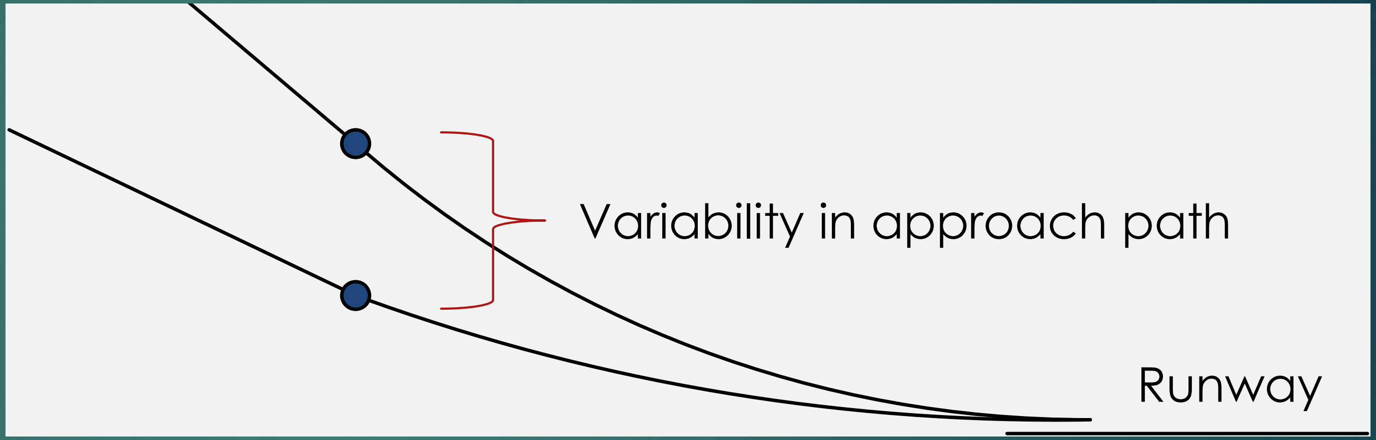
Sensitivity to Braking

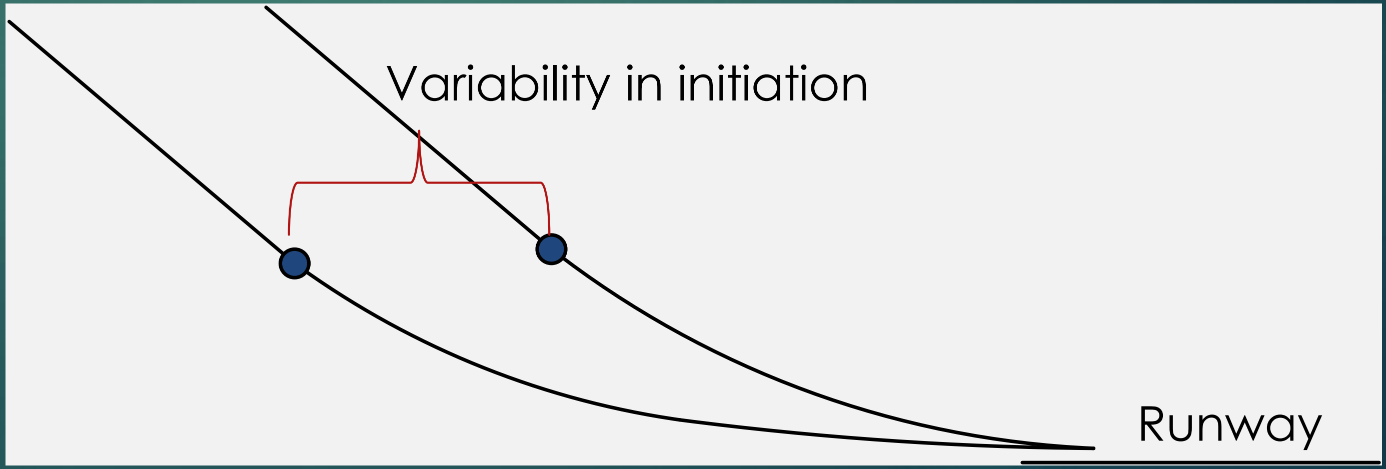
- Braking Effort
  - Max braking effort has weight on wheel requirement
    - Aircraft still produces lift below stall speed
    - The more torque that is available, the more weight required



Landing Energy Analysis
Energy Dissipation in the Round Out

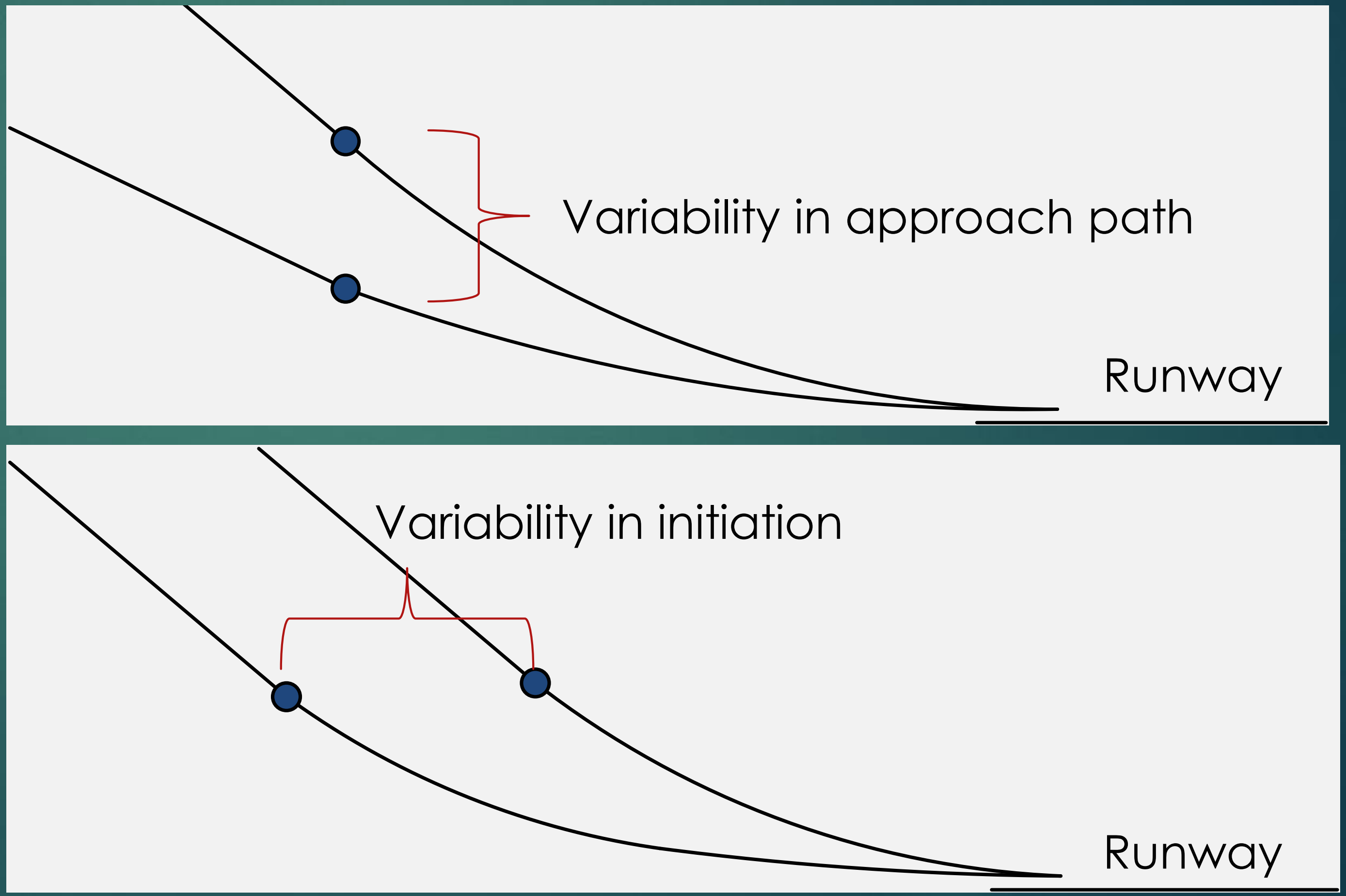
- This segment has variability due to timing elements
  - Round-Out can be shorter or longer in duration
  - How quickly is power reduced to idle
- Primary Energy Loss is due to aerodynamic drag – maintaining flight without out propulsion (prop & gravity)
- Secondary contribution in arresting descent





Landing Energy Analysis
Energy Dissipation in the Round Out

- Extreme Short
  - 1.7 G pull , 0.2 s
- Extreme Long
  - Complete Round out right at stall, ~10 sec
- Typical
  - 1-2 seconds for shallow approach
  - 3-4 seconds for steep approach



Landing Energy Analysis

Energy Dissipation in the Round Out

- How much energy is needed to arrest sing rate?
- Round Out should a deliberate and well defined departure from approach segment – it should not be long and drawn out
- Maintain 1.3Vso until round out to maintain energy

Kinetic Energy Summary		
Kinetic Energy entering Round-Out, 1.3 Vso	496,000	ft-lb
Kinetic energy at touch down, Vso + 5	328,000	ft-lb
Kinetic energy to be dissipated	169,000	ft-lb

Energy Required to Arrest Sink		
500 fpm	1,800	ft-lb
1000 fpm	7,500	ft-lb
1500 fpm	17,000	ft-lb

Values for Lancair 360, 1750 lb

Landing Energy Analysis

Energy in the Approach Phase

Sink Rate Energy at 1.3 Vso

Kinetic Energy Summary		
Kinetic Energy entering Round-Out, 1.3 Vso	496,000	ft-lb
Kinetic energy at touch down, Vso + 5	328,000	ft-lb
Kinetic energy to be dissipated	169,000	ft-lb

Energy Required to Arrest Sink		
500 fpm	1,800	ft-lb
1000 fpm	7,500	ft-lb
1500 fpm	17,000	ft-lb

Sink Rate Energy at max flap extension speed

Kinetic Energy Summary		
KE entering Round-Out, max Flap speed	775,000	ft-lb
Kinetic energy at touch down, Vso + 5	328,000	ft-lb
Kinetic energy to be dissipated	448,000	ft-lb

Energy Required to Arrest Sink		
2000 fpm	30,287	ft-lb

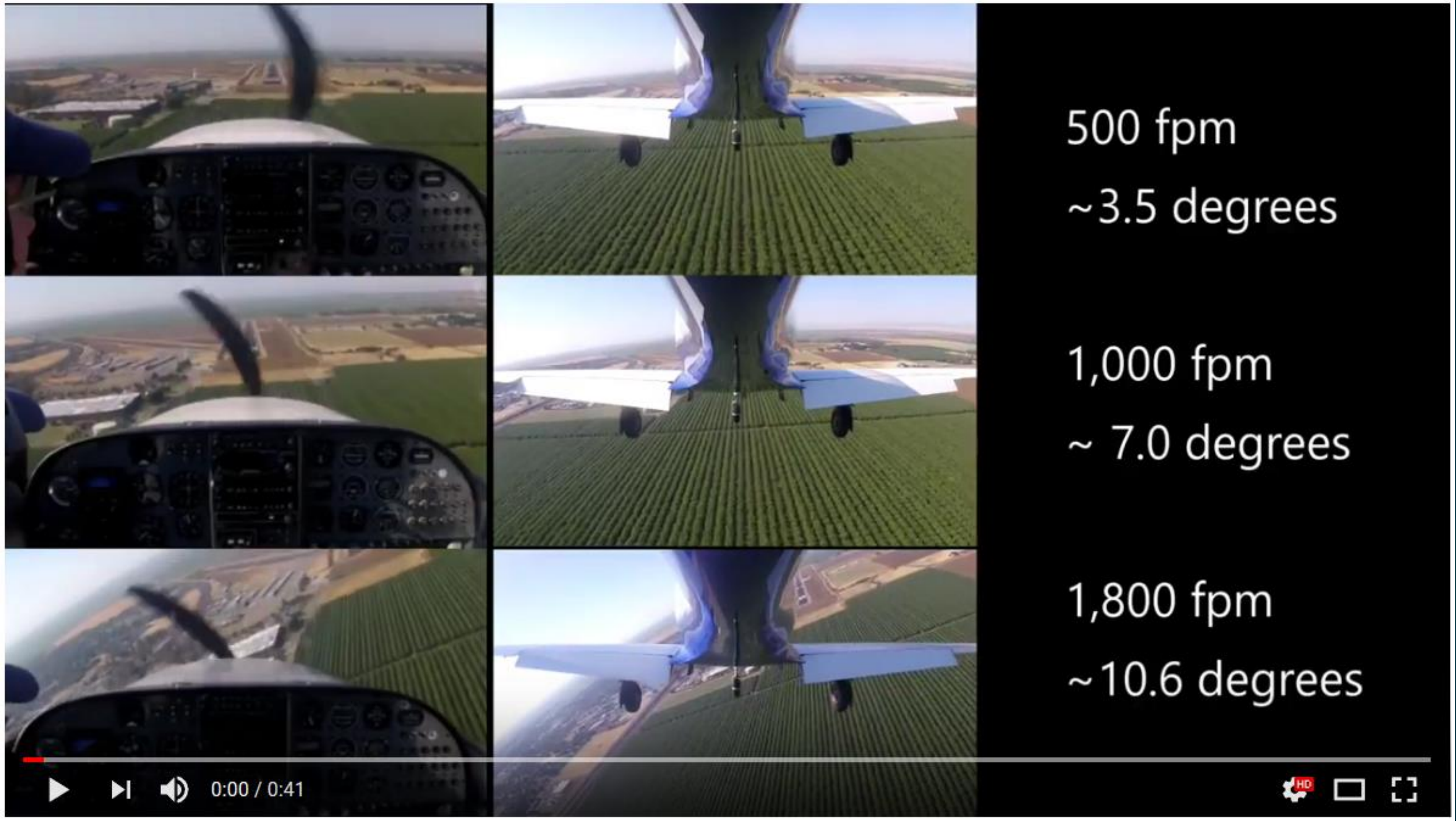
A maximum of 10% of energy available is required to arrest sink

Landing Energy Analysis
Final Approach Phase

- Approach phase is a stable steady state segment prior reaching the round out
- Goal is to arrive at round out at Vref (sets energy state) and then fly through the 'box' (sets position)

Landing Energy Analysis
Final Approach Phase

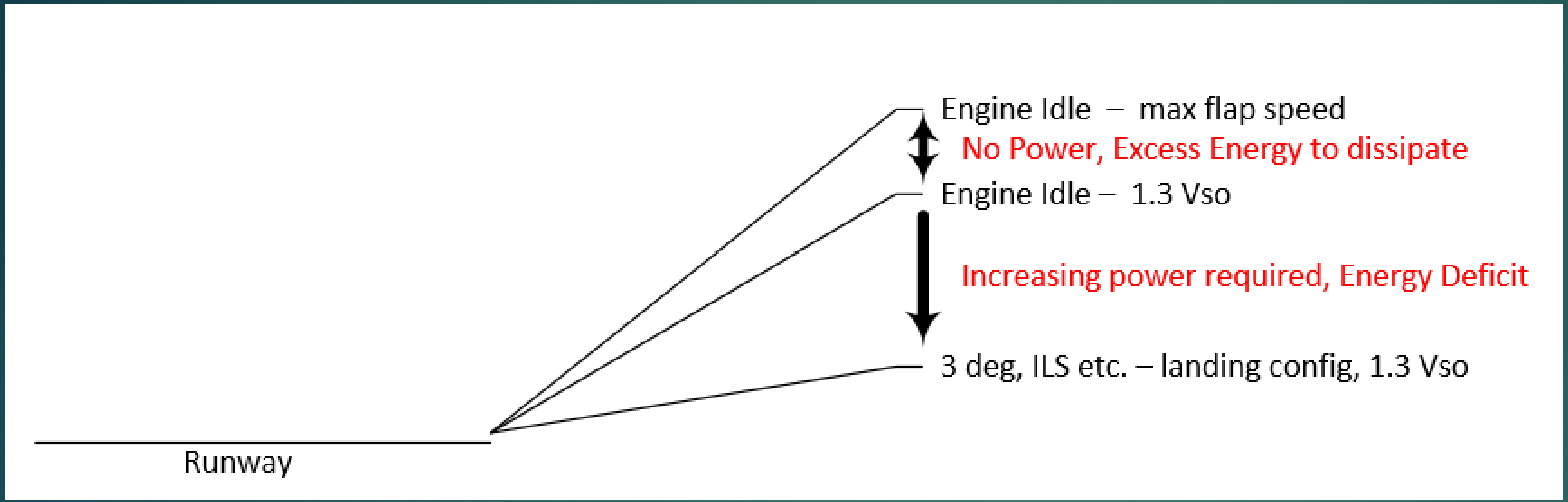
Three consecutive landings demonstrate that the energy state crossing the threshold is completely independent of angle of the approach and the descent rate



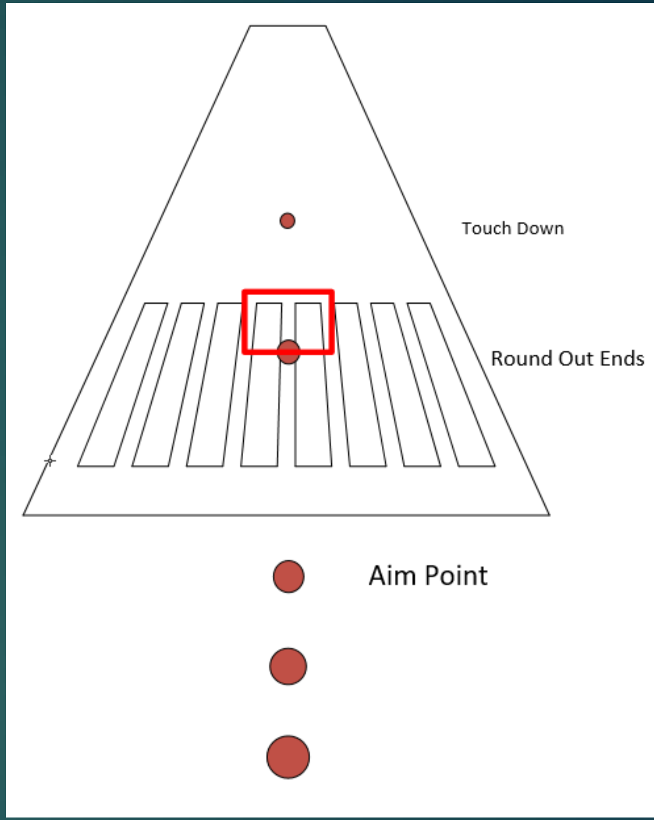
Video Link: 3 approaches

Landing Energy Analysis

Energy in the Approach Phase



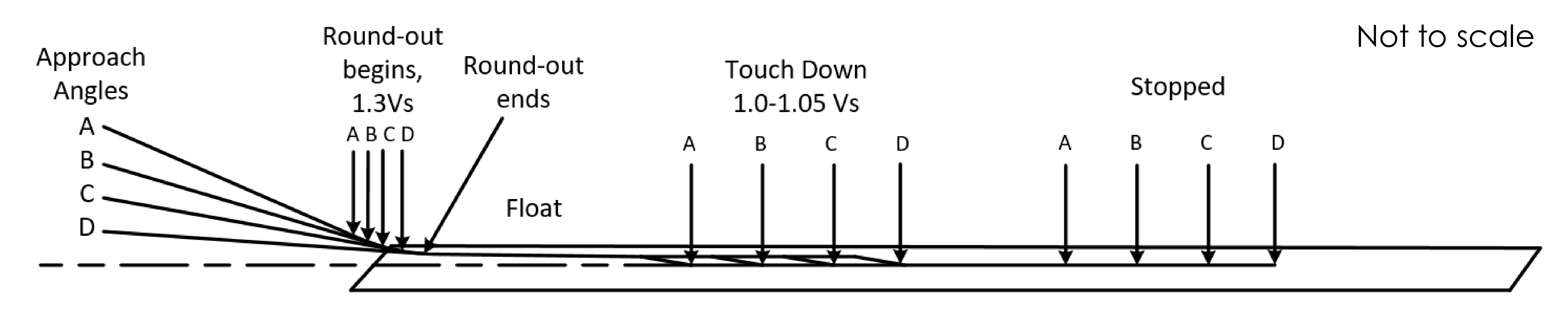
- Excess energy (altitude) can be dissipated by raising the airspeed from 1.3 Vso up to max flap extension speed
  - Aim point must be moved back as approach speed is increased to arrive at the 'box' at same speed
  - Round Out starts earlier, but ends at the 'box' at the same speed as shallower approach angles



Aim Point is adjusted for:

- Desired touch down point
- Angle of approach

Landing Energy Analysis
Final Approach Phase



If the round out could be flown with perfect precision and repeatability, the steeper the approach, the shorter the landing.

Due to:

1. More time spent in the roundout
2. More energy absorbed in arresting sink rate