Approach Stabilization: an energy management problem

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- Stable Approach Criteria – Interdependencies
- Stable Approach in terms of Energy
- Descent and Approach as an Energy Management Problem
- The Energy Dissipation Boundary
- Energy Dissipation Margin
- Results
- Un-Stable Approach Assessment

- **Stable Approach Purpose:**

Consistent initiation and performance of flare and landing

  - Aircraft with **reference behaviour** prior to flare and landing
  - **Sufficient duration**
  - **Suitable** for intended flight crew population and anticipated conditions

- **Stable Approach Criteria:**

  - Target Speed
  - Target Rate of Descent (ROD)
  - Target Flight Path Angle (FPA)
  - Target Thrust Setting
  - Target Track
  - Landing Configuration

  - Reference (Gate)- Height

- **Stable Apprach criteria and reference are not independent:**

  - When ***speed*** and ***FPA*** are fixed (say Vapp & -3°)

    Then *ROD, thrust, landing configuration* are implied

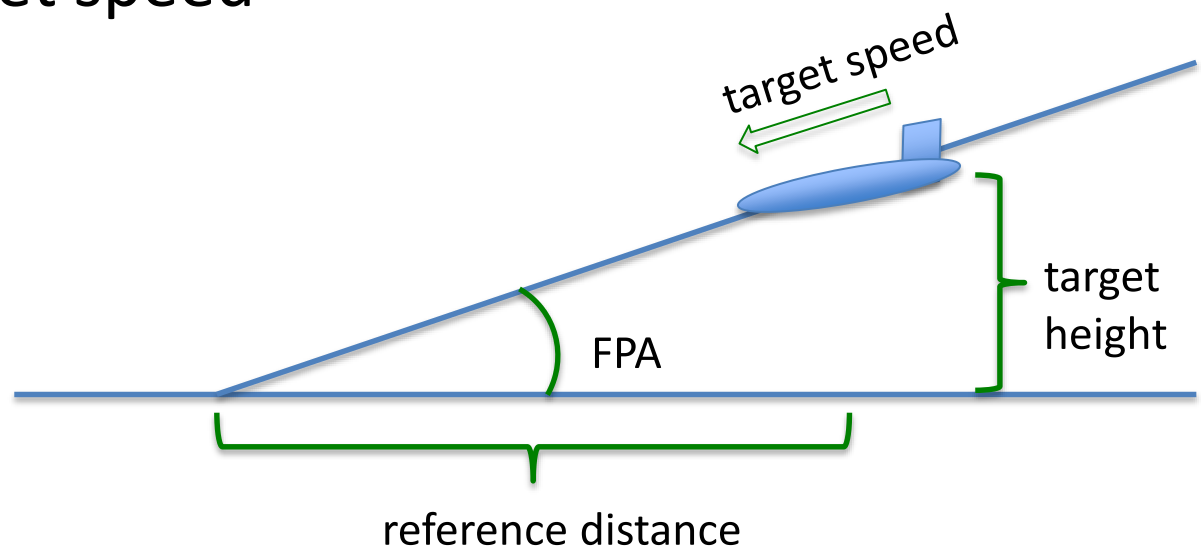
- The point at which the reference height is reached moves with the actual FPA flown

$\Rightarrow$ not fixed, not a reference

Replace with ***reference distance*** corresponding to the intended *reference height, now a target height* when *on target FPA*

- Approach Stabilization captured by 3 parameters:

1. Reference distance
2. Target height
3. Target speed

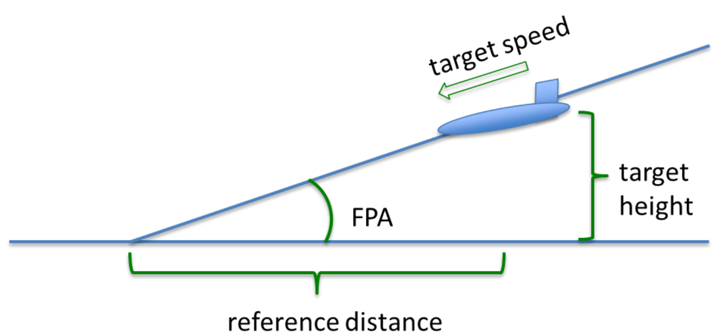


- 3 parameters relate directly to energy:

$$E_{tot} = E_{pot} + E_{kin}$$

$$E_{tot} = m\ g\ h + \tfrac{1}{2}\ m\ v^2$$

target height	target speed
@ reference distance	



- Introduce the concept of
  Specific Energy or *Energy Height* as:

  $E_s = E/mg$

so that

  $E_{s,tot} = h + 1/2g.v^2$

  Allows comparison of flights with different aircraft masses.

- We can now formulate a requirement for stable approach:

@ 1.54 nm before threshold:

$$E_{s,tot,\ stable} = 500\text{ft ARL} + 1/2g.V_{app}^2$$

- Remarks

- *Lateral deviation*:

This method covers only vertical plane – does not detect lateral deviation

-*Thrust*:

V_{app} can not be maintained on a 3° FPA at idle thrust => so to ensure thrust is above idle at 500ft ARL, look for the requirement slightly earlier: 1.88nm/600ft ARL

- Re-formulation of the requirement for stable approach:

@ 1.88 nm before threshold:

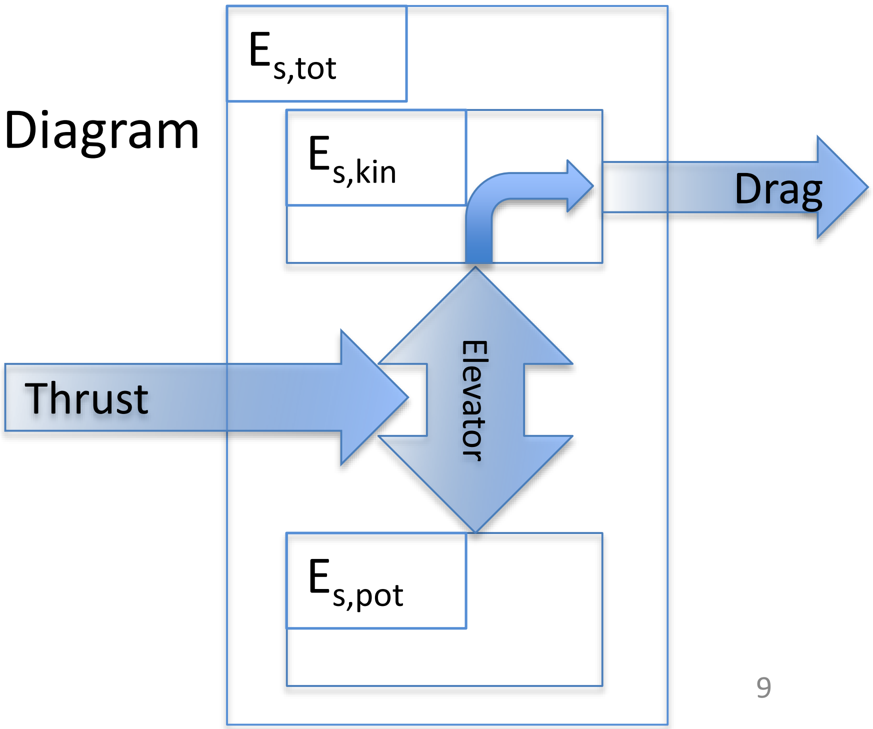
$$E_{s,tot,\ stable} = 600\text{ft ARL} + 1/2g.V_{app}^2$$

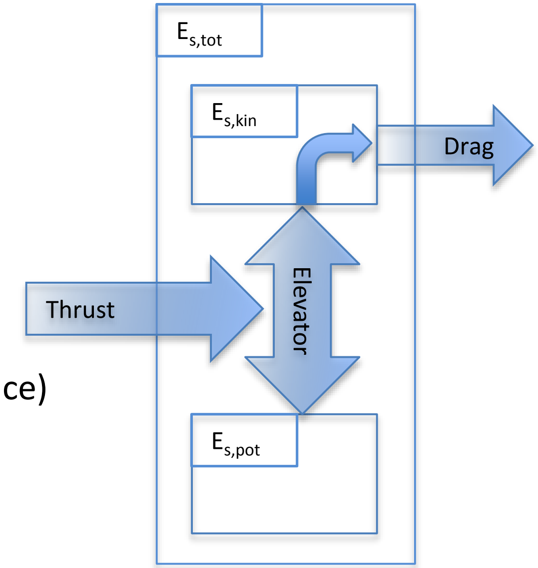
- $E_{s,tot}$ target represents approach stabilization

=> descent and approach planning = *energy management problem*

in a given distance dissipate the difference in energy from cruising conditions, high & fast, to final approach conditions, low & slow, in preparation for landing

- Energy Management - Aircraft Energy Diagram
    - *supply*: fuel burn -> thrust
    - *dissipation*: drag
    - *distribution*: elevator





- Energy dissipation → Drag > Thrust

  - Constraint: distance to gate

  - Quantity of interest: ($\Delta E_{s,tot}/\Delta GD$) (**GD**: Ground Distance)

$$\frac{\Delta E_{s,tot}}{\Delta GD} = \tan\gamma_0\, WCF + \frac{1}{g}\frac{\Delta(CAS + WC)}{\Delta t}$$

With :

γ_o the zero-wind FPA

WCF the wind correction factor, CAS/GS

WC the wind component

- $(\Delta E_{s,tot}/\Delta GD)_{max}$ when $(\text{Drag} - \text{Thrust})_{maximum}$
  - minimise Thrust => **idle**

  - maximise Drag => **max allowable CAS** for given configuration

  - optimize distribution for CAS_{max}

- $(\Delta E_{s,tot}/\Delta GD)_{max}$ -> integration -> $E_{s,tot} = f(GD)$ = maximum $E_{s,tot}$ at any given GD from the reference distance or gate, which allows just to meet the stablization criteria at the gate.

  This function is the energy dissipation boundary…

- IF
  an aircraft arrives **at the**
  reference distance with excess $E_{s,tot}$
  THEN
  somewhere during the descent and approach, the aircraft must have **crossed the energy dissipation boundary**…

- ...and

  By comparing the actually flown $E_{s,tot}$ profile with the $E_{s,tot}$ boundary it can be established when the flight became irrecoverably unstable.

$$\boxed{E_{s,tot} = h + 1/2g.v^2}$$

- Manufacturer's performance data:
  -> γ_0 = f (*CAS* (i), config. (*n*), Alt.) at idle thrust + wind data from recorded data, the maximum energy dissipation gradient, can be calculated using:

$$\frac{\Delta E_{s,tot}}{\Delta GD}_{n,i} = \tan\gamma_{n,i,0}\, WCF_i + \frac{1}{g}\frac{\Delta WC}{\Delta t}$$ and

$$\frac{\Delta E_{s,tot}}{\Delta GD}_{n,i} = \tan\gamma_{n,i,0}\, WCF_i + \frac{1}{g}\frac{\Delta(CAS_i + WC)}{\Delta t}$$

  - Cruise = high, fast clean, Landing = low, slow, landing configuration and
    γ = f(CAS, Altitude, configuration)

    => approximations for γ used

- The Boundary

1. 10000ft -> 4000ft @ idle thrust, 250 KCAS, LDG DN, Airbrake Extended: avg $\gamma_0 = -10^o$, ROD +/- 5000fpm

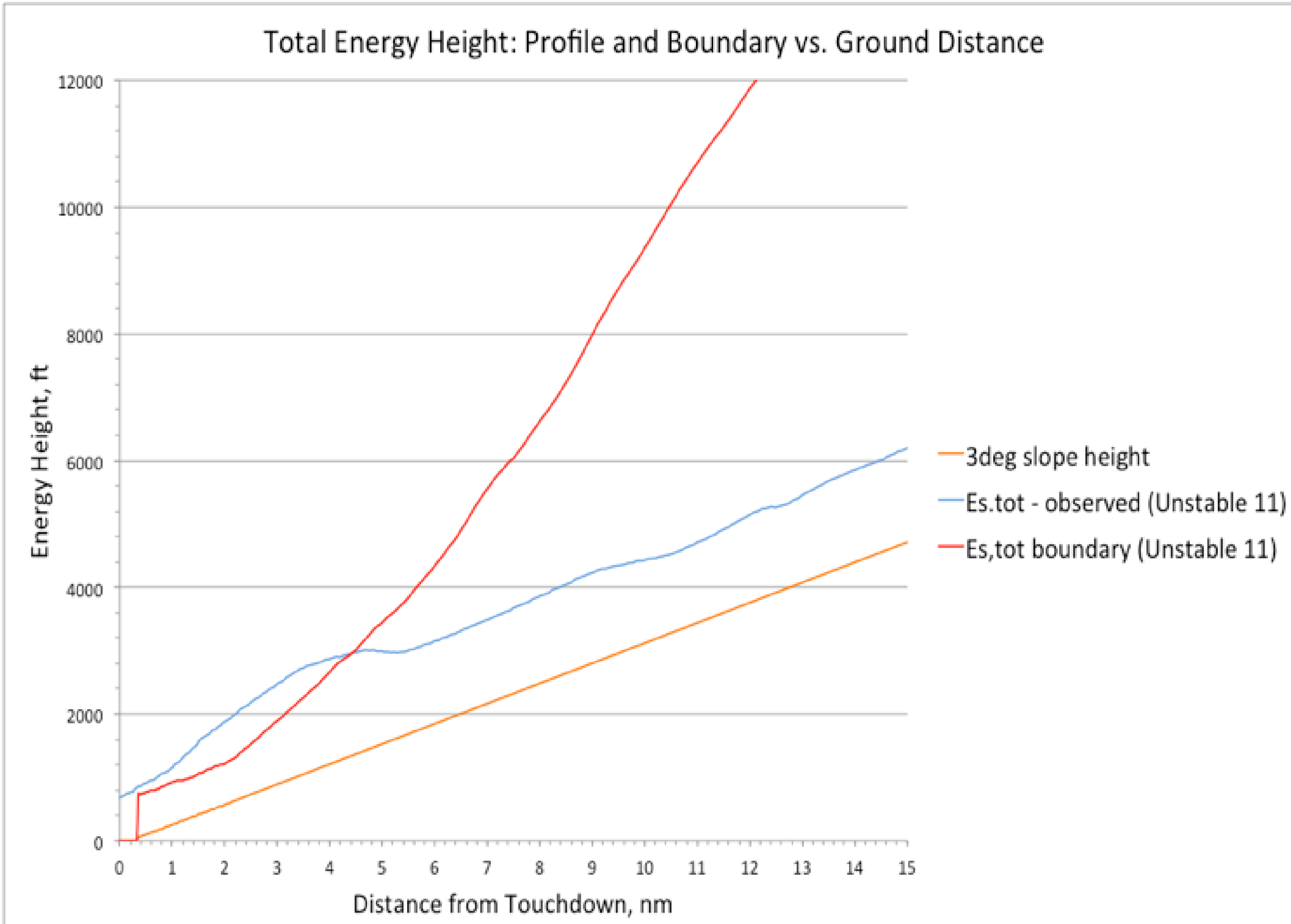
2. 4000ft level idle thrust deceleration to 220 KCAS, LDG DN, Airbrakes Extended

3. 4000ft -> 3^o GS, idle thrust,
   interception from above @ 220 KCAS
   LDG DN, Airbrake Extended: avg $\gamma_0 = -8.5^o$, ROD +/- 3000fpm

4. 3^o descent, idle thrust decelration to V_{app} and
   configuration to landing configuration,
   to reach by 600ft.

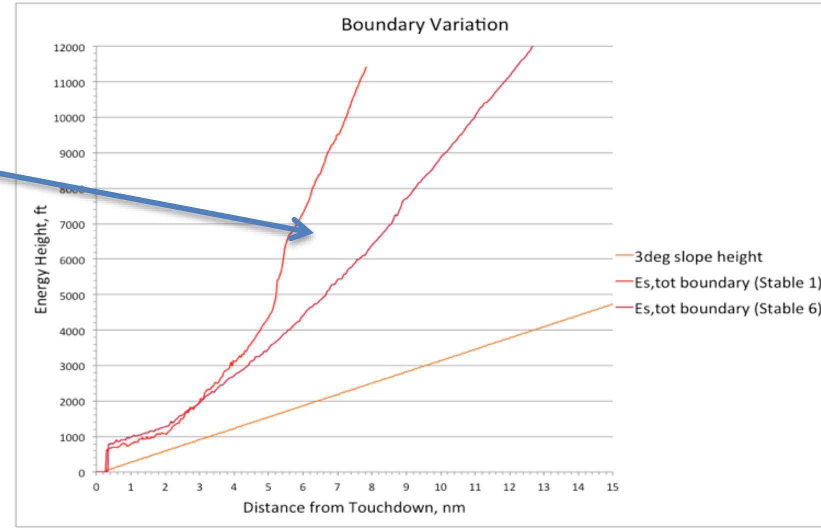
5. 600ft -> 50ft, @ V_{app} on a 3^o FPA.

- Example



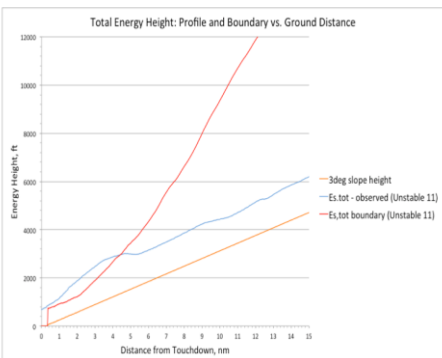
Total Energy Height: Profile and Boundary vs. Ground Distance
Energy Height, ft
12000
10000
8000
6000
4000
2000
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Distance from Touchdown, nm
3deg slope height
Es.tot - observed (Unstable 11)
Es,tot boundary (Unstable 11)

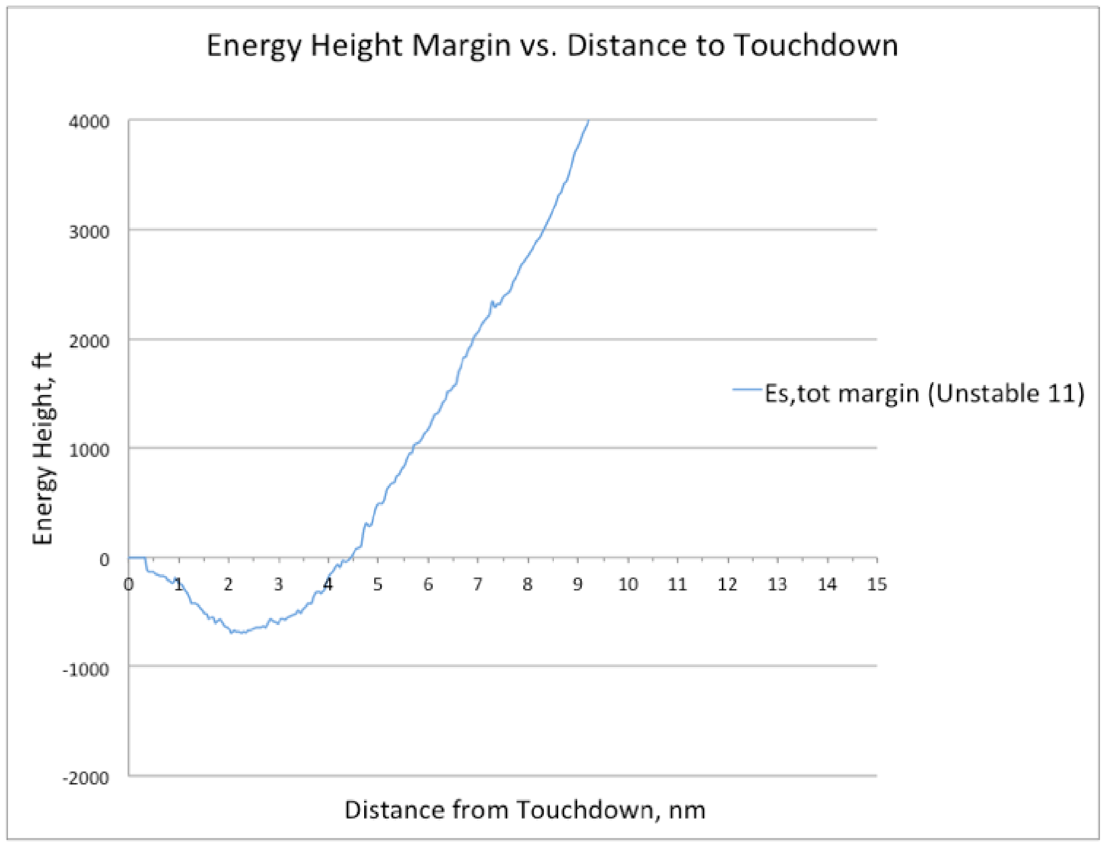
Different flights
-->different conditions
-->different boundaries…



… introduce the $E_{s,tot}$ margin:

$E_{s,tot,boundary} - E_{s,tot,observed}$



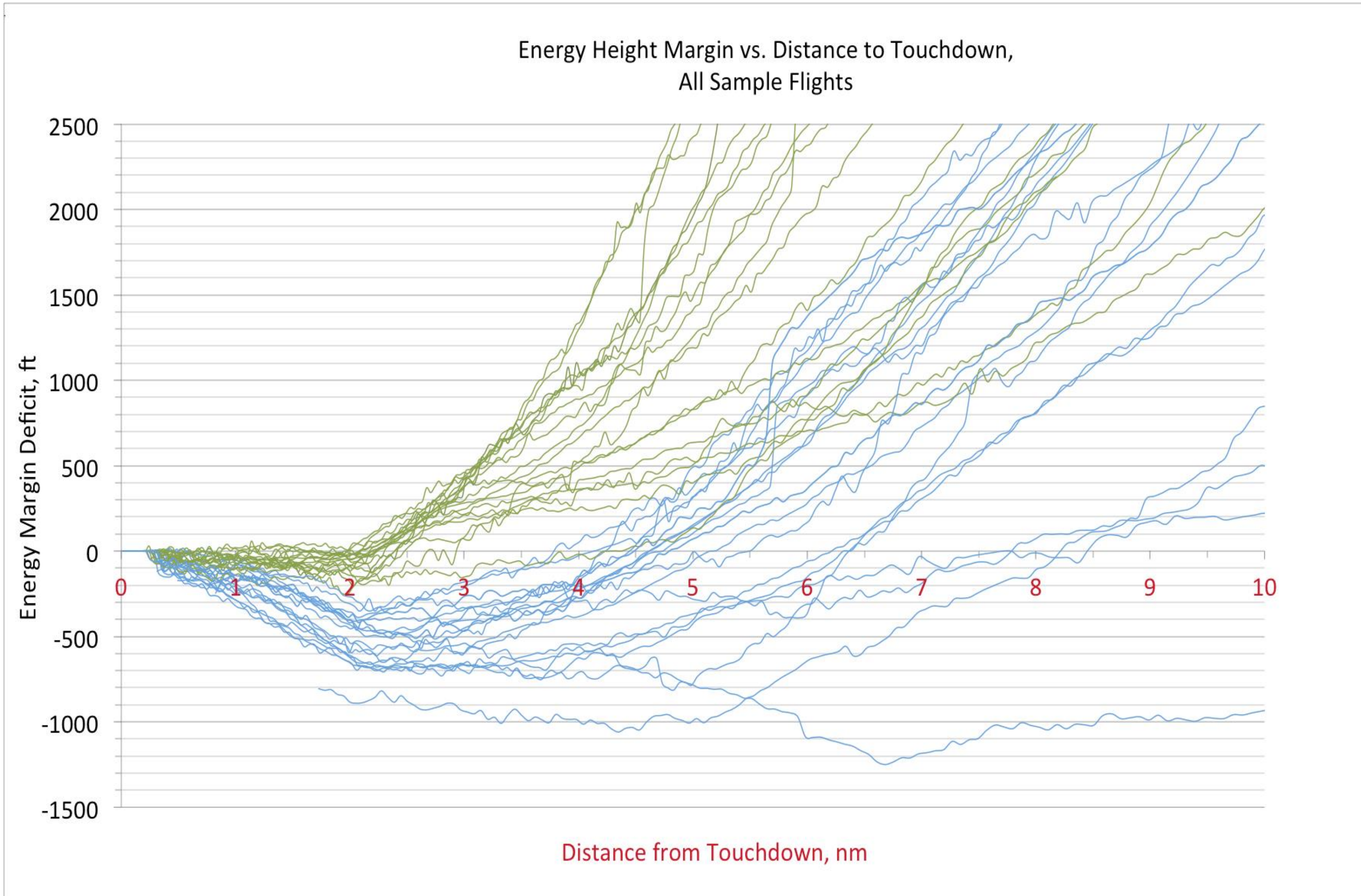


Sample flights:

- All A319
- 20 flights identified by Pilot Investgators as meriting further investigation, *<u>based on FDM Events</u>*
  - 2 forwarded for reasons other than unstable approach
- 16 flights not forwarded by Pilot Investigators
  - 1 showing events meriting classification un-stable

Resulting in 19 un-stable flights and 17 stable flights…

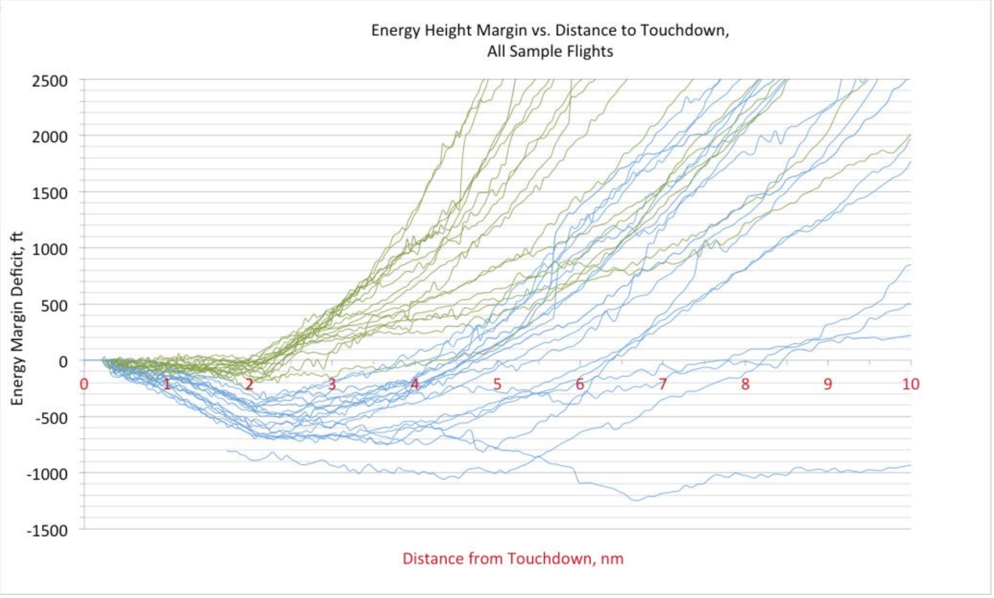
The $E_{s,tot}$ Margin - Results



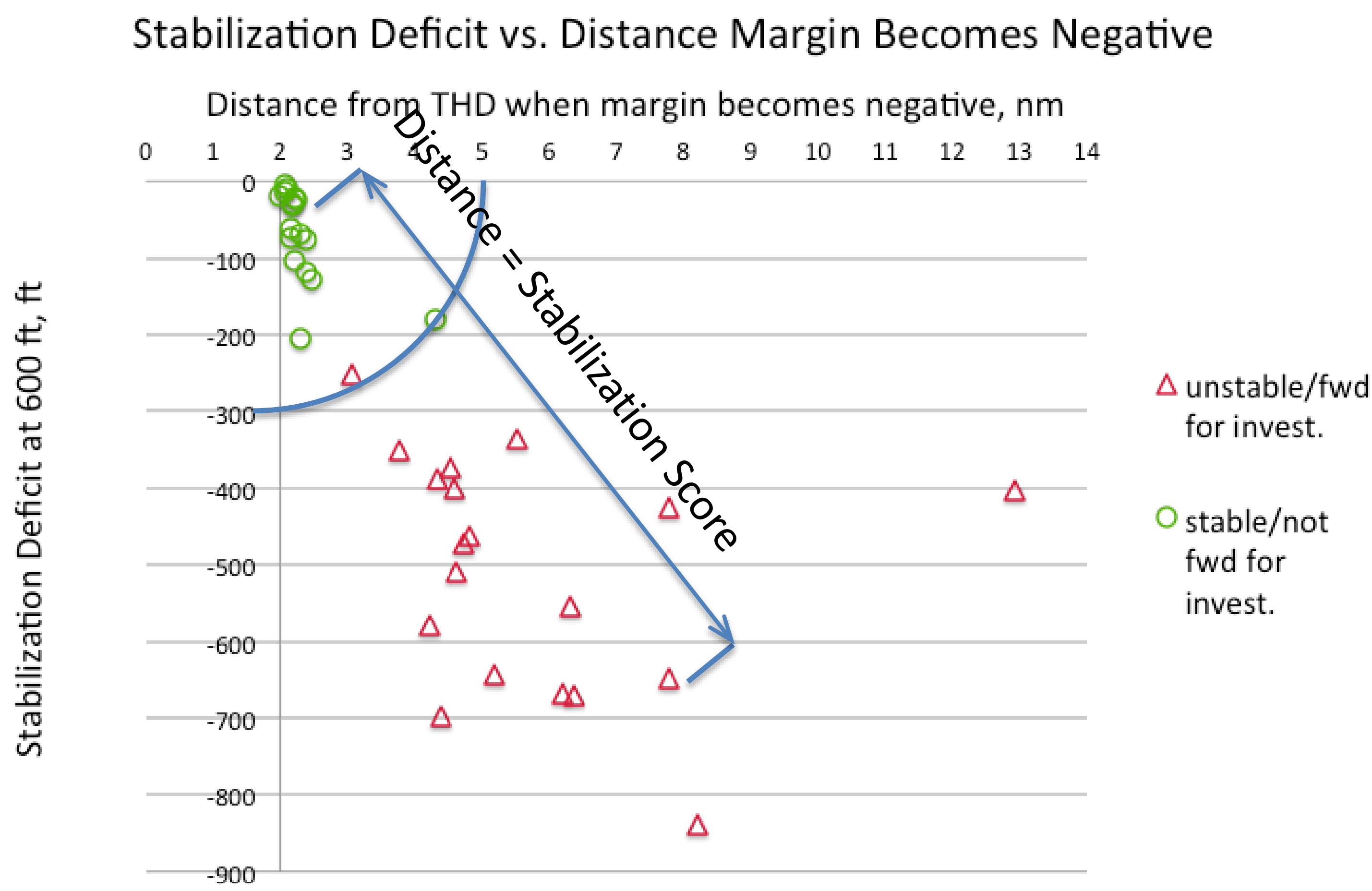
The $E_{s,tot}$ Margin - Results

Observations:

- Tight cluster of stable flights with close to but not exactly 0 margin deficit at around 2nm/600ft
- Clear separation between stable and un-stable flights around 2nm/600ft
- Flights with a large margin deficit at 2nm/600ft in general become unstable early

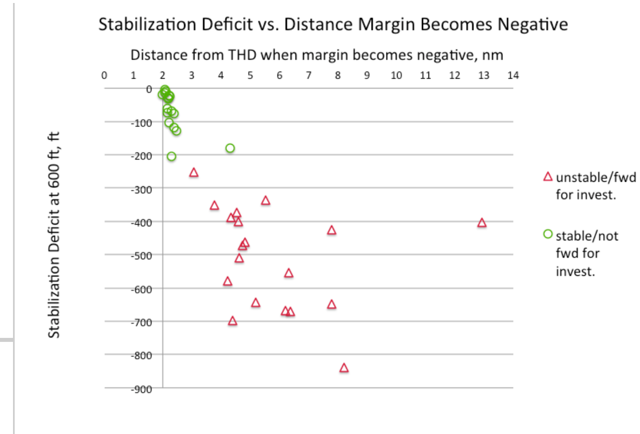


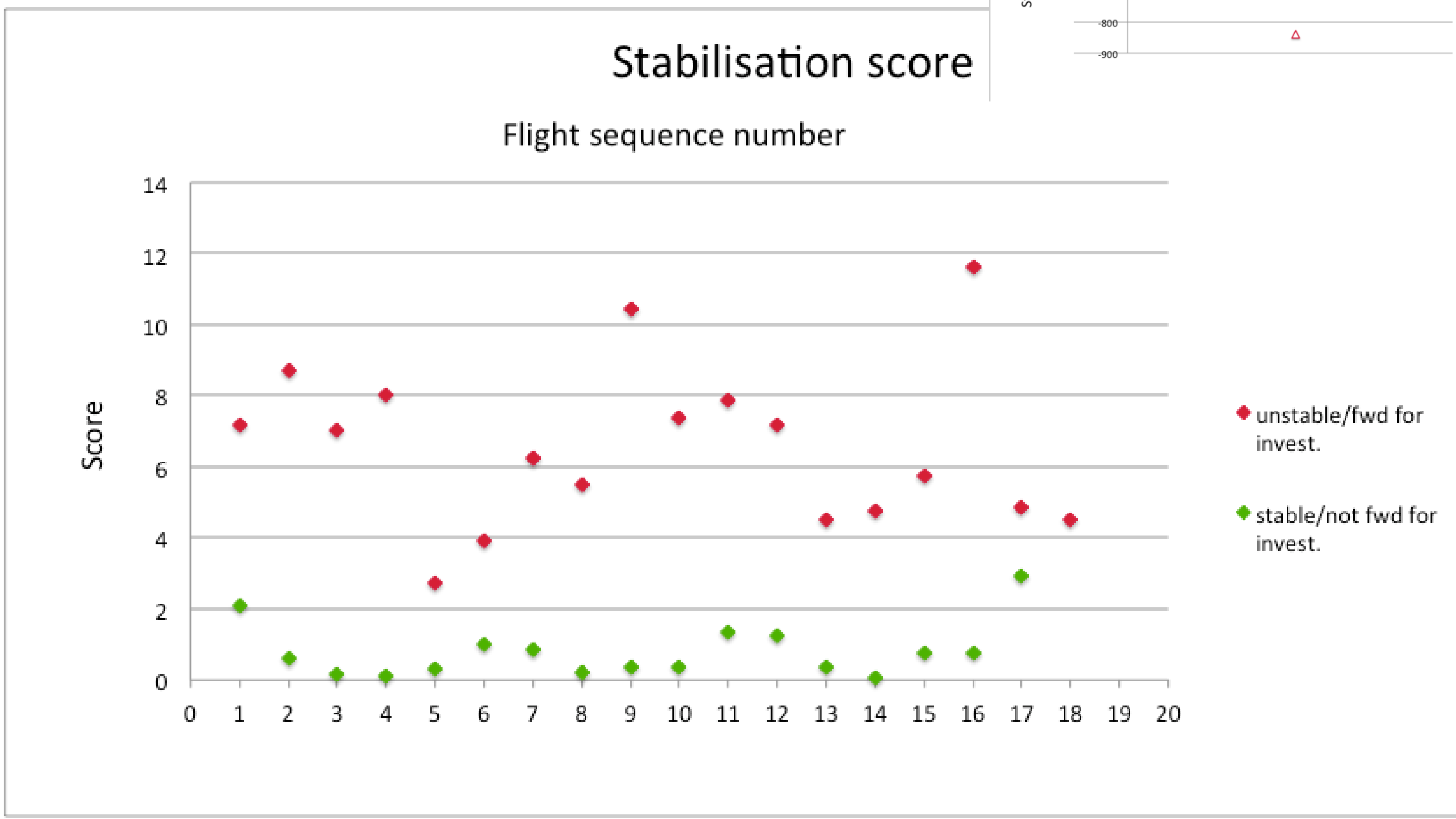
Stabilization Score



Stabilization Score

Perfect stability corresponds to score = 0



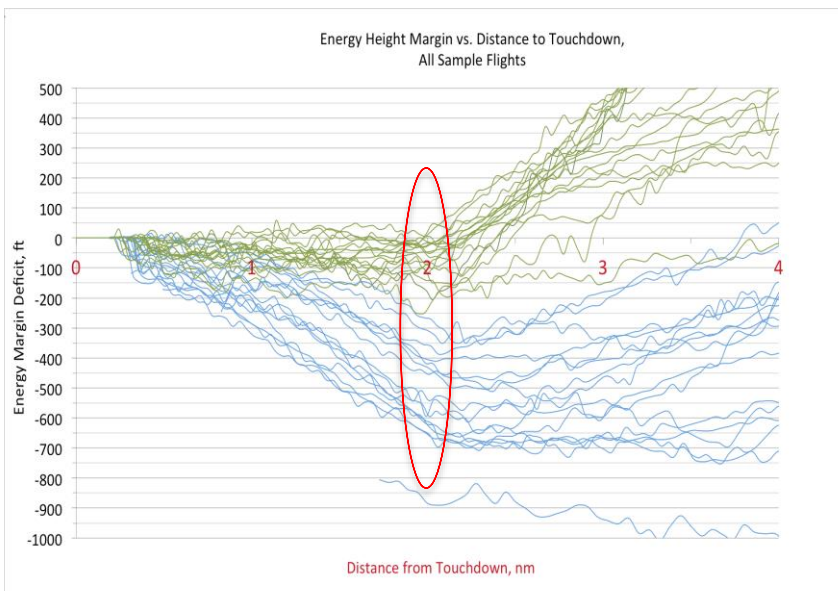


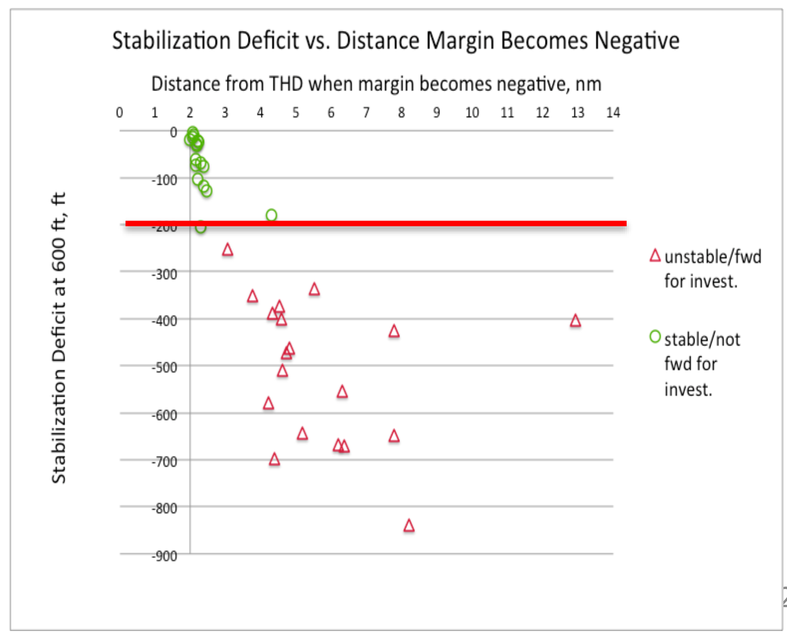
Stabilization Score

$E_{s,tot,target}$: @ 1.88 nm before threshold:

$E_{s,tot,\ stable}$ = 600ft ARL + $1/2g.V_{app}^{2}$

- Boundary construction is laborious
- Consider simplified score: $E_{s,tot,observed} - E_{s,tot,target}$
  - required parameters: V_{app}, height, distance
  - available in/easily derived from recorded data – no performance data required



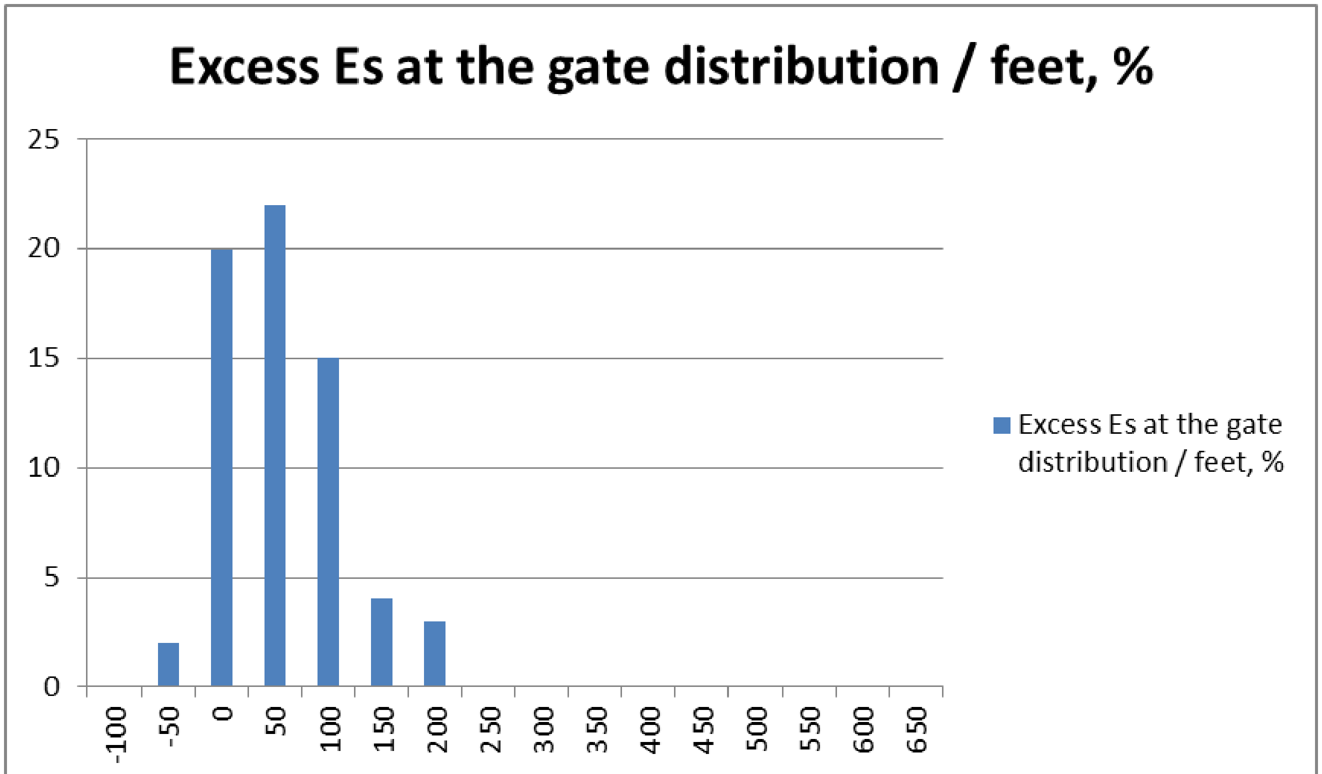


Simplified Stabilization Score: Excess E_s at the gate

$E_{s,tot,observed} - E_{s,tot,target}$

Sample: 68 flights

Bin Width: 50 ft



- Conclusions
  - $E_{s,tot}$ margin is a promising candidate to score approach stabilization
  - Further development required:
    - sensitivity to ISA deviation, airfield elevation, approximations made
    - smoothing? – based on aircraft aerodynamic model?
    - boundary definition best representing crew limit behaviour
    - implementation in commercial software

Thank You

Reference: Wilfried Van Laer, 2014, MSc Thesis,
(Human Factors and Safety Assessment in Aeronautics):
'Developing a Method to Use Energy Parameters Derived from Recorded Flight Data to Study Approach Stabilization',
(Cranfield University, School of Engineering)