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EOFDM Conference, 12 January 2012

Characterising hard landings

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Summary

I. What is a "hard landing"?
II. What are the relevant parameters to characterise a hard landing?
III. How to assess these parameters?

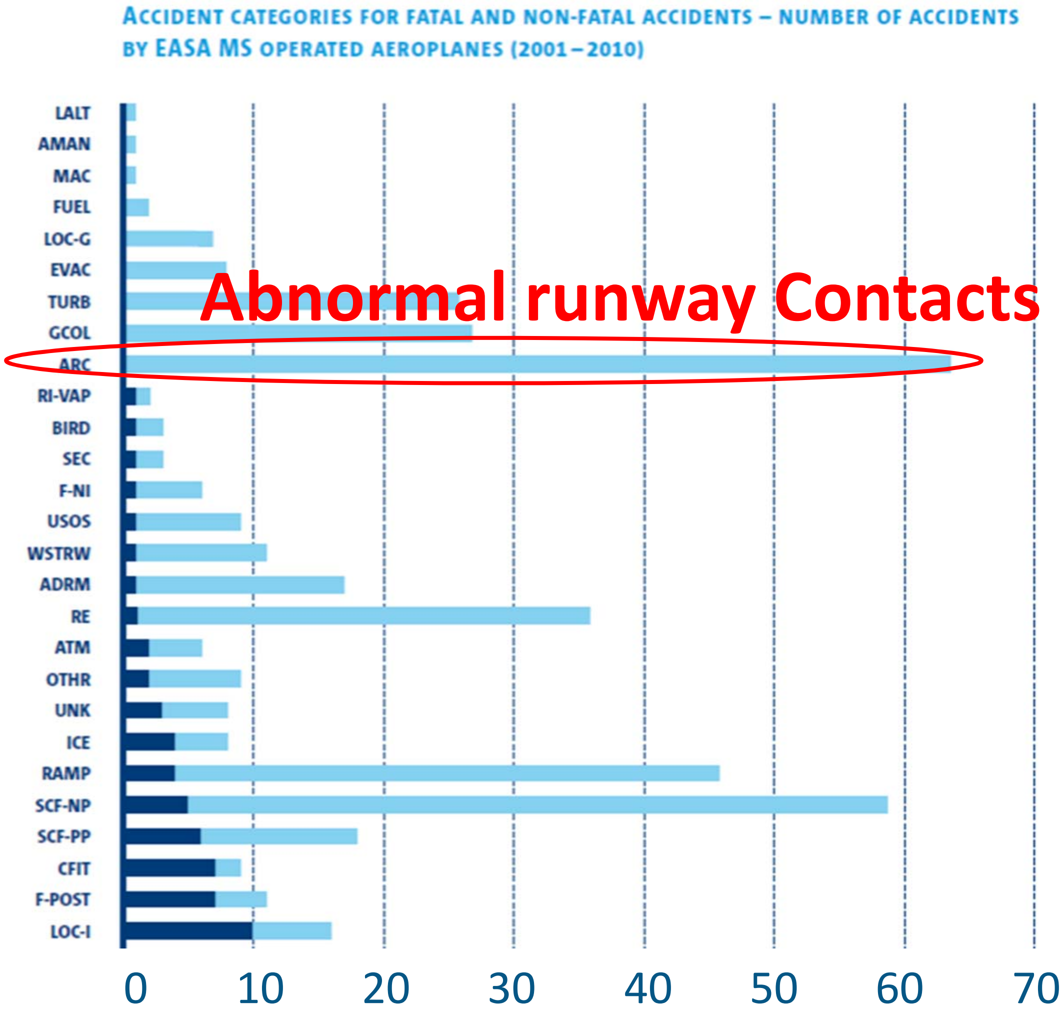
Disclaimer

- **Disclaimer**
  - The following slides contain ideas to pre-screen potentially hard landings in FDM data
  - Pilot reports are another valuable source of info
  - OEMs should be involved if an in-depth assessment of the touchdown severity is needed

What is a “hard landing”?

- Abnormal Runway Contacts (ARC):
  - hard/heavy landings,
  - long/fast landings,
  - off center landings,
  - crabbed landings,
  - nose wheel first touchdown,
  - tail strikes,
  - wingtip/nacelle strikes,
  - etc

What is a "hard landing"?



EASA MS registered aeroplanes operated for Commercial Air Transport - fatal and non-fatal accidents

(2001-2010)

Source: EASA Annual Safety Review 2010

What is a “hard landing”?

- Study case:
  - a **symmetrical** and **conventional** touchdown
    - Roll angle small,
    - lateral load factor ≈0
    - Pitch angle>0

- Risk considered:
  - **high loads** in the main landing gears and aircraft structure

Looking for the relevant parameters

- The « ***vertical acceleration*** » parameter
- is **neither vertical nor an acceleration**…
  - It is the normal load factor in the aircraft reference frame
- is **not** sufficient for assessing contact severity!

Looking for the relevant parameters

- Relevant parameters for assessing landing severity:
  - The **aircraft mass**
  - The **vertical speed** right before contact
  - The ***true* vertical acceleration** right before contact

Certification Specifications 25, §473 « Landing load conditions and assumptions »:

- 10 ft/sec (600 ft/min) at MLW
- 6 ft/sec (360 ft/min) at MTOW
- Steady vertical speed prior to touchdown

Looking for the relevant parameters

AIA
AEROSPACE INDUSTRIES ASSOCIATION

AIA Publication 05-01

Best Practices Guide

Inspection Processes following High Load Events

Computing the aircraft mass

- Relevant parameters for landing severity:
  - The **aircraft mass**
  - The **vertical speed** right before contact
  - The **true vertical acceleration** right before contact

Computing the aircraft mass

- A/c mass may be not recorded
  - To be reconstructed using fuel flow
- Even if recorded, it is not measured
  - Computed from data entered before the flight

Computing the <u>true</u> vertical acceleration

- Relevant parameters for landing severity:
  - The **aircraft mass**
  - The **vertical speed** right before contact
  - The **<u>true</u> vertical acceleration** right before contact

Computing the true vertical acceleration

- Based on load factors and aircraft attitude angles:

$$\boxed{a^{z} = g \cdot \left(1 + \sin(\theta) \cdot n^{x1} - \cos(\theta) \cdot \sin(\varphi) \cdot n^{y1} - \cos(\theta) \cdot \cos(\varphi) \cdot n^{z1}\right)}$$

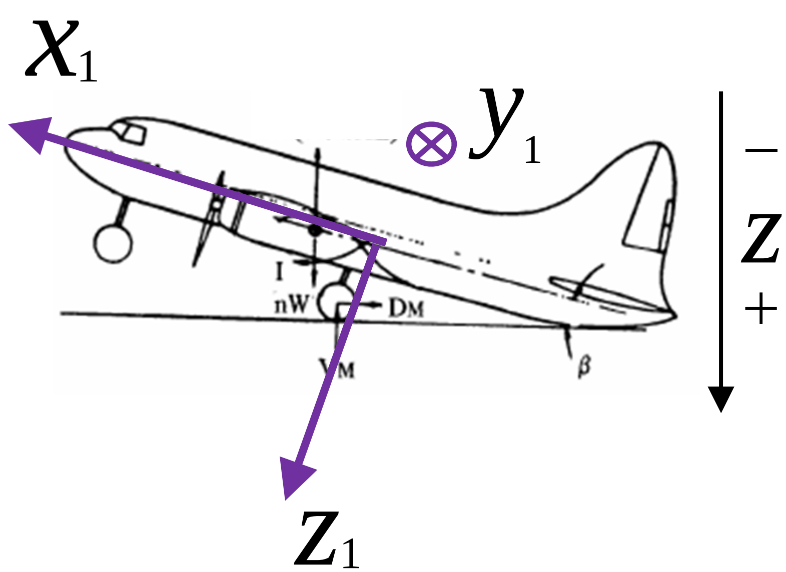
θ : *pitch angle*; φ : *roll angle*

a^{z} : *vertical acceleration*

n^{x1} : *longitudinal load factor*

n^{y1} : *lateral load factor*

n^{z1} : *normal load factor*



Computing the vertical speed

- Relevant parameters for landing severity:
  - The **aircraft mass**
  - The **vertical speed** right before contact
  - The **true vertical acceleration** right before contact

Computing the vertical speed

- If vertical speed is not recorded
- how to compute it?

Computing the vertical speed

- 1st method: derive pressure altitude

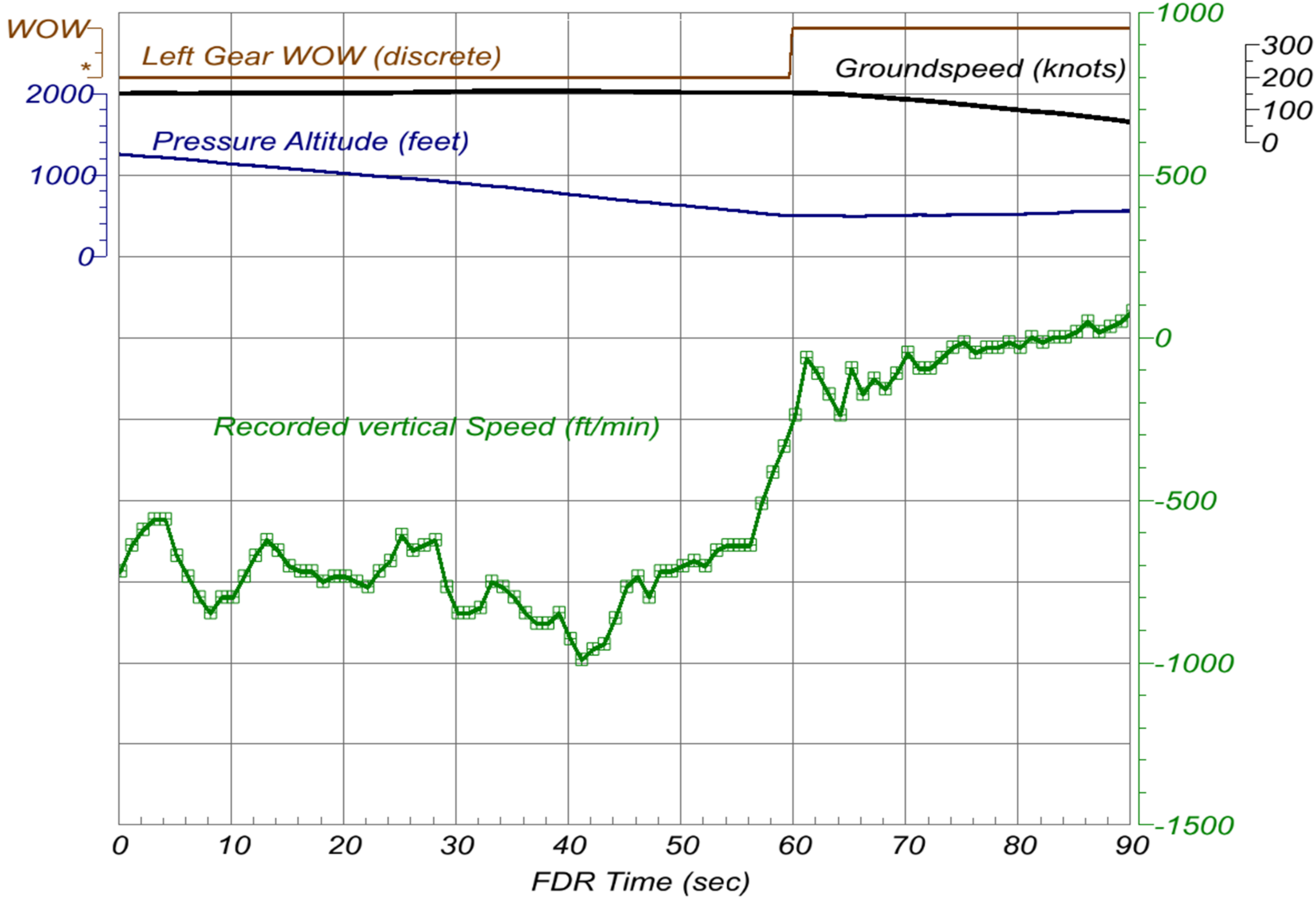
$$v^z = \frac{dz}{dt}$$

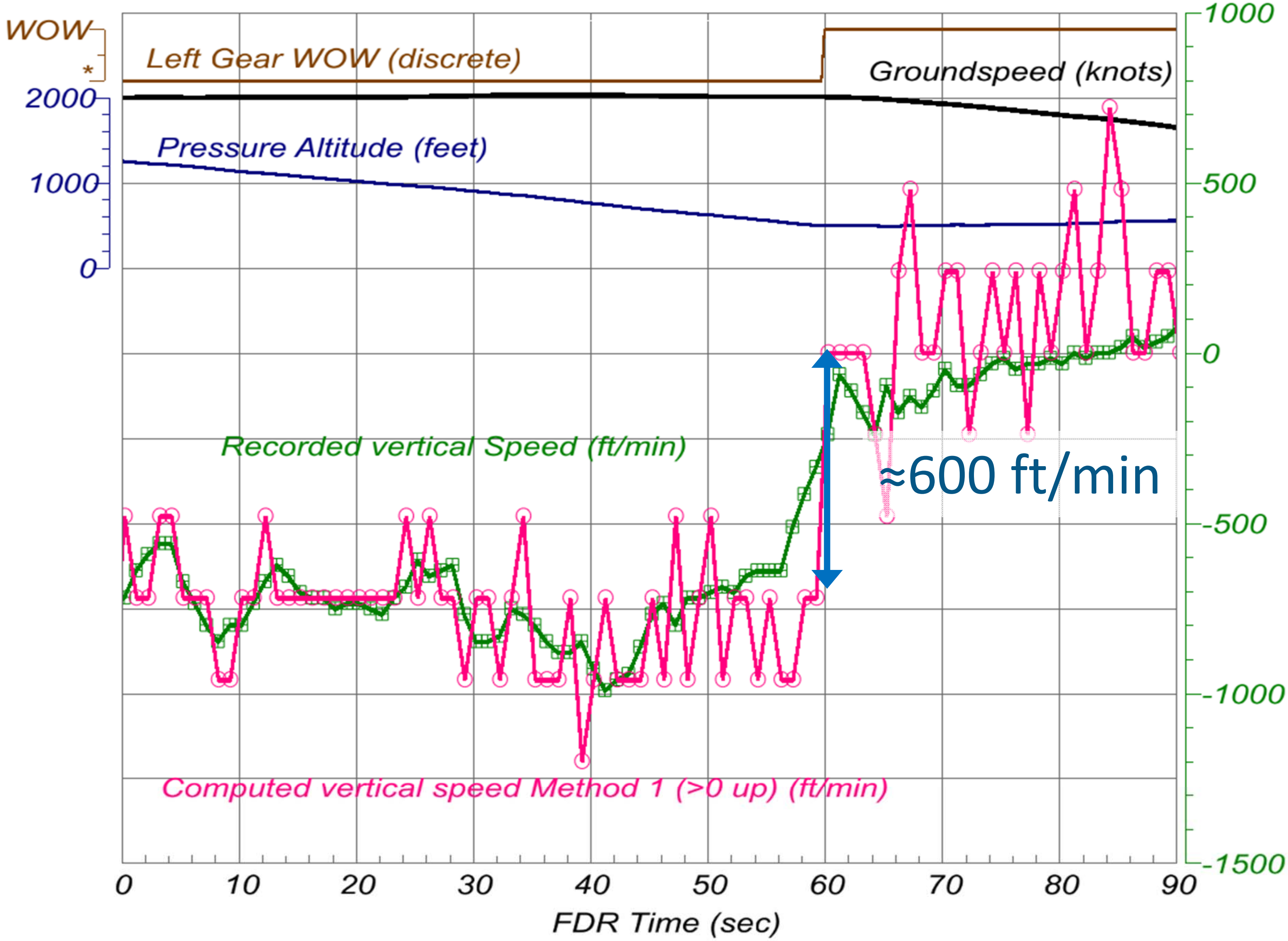
$$\boxed{v_n^z \approx \frac{z_n - z_{n-1}}{T}}$$

v_n^z : vertical speed at time t_n

z_n : pressure altitude at time t_n

T : sampling period


WOW
*
Left Gear WOW (discrete)
Groundspeed (knots)
300
200
100
0
2000
1000
0
Pressure Altitude (feet)
1000
500
0
-500
-1000
-1500
Recorded vertical Speed (ft/min)
0
10
20
30
40
50
60
70
80
90
FDR Time (sec)


WOW
*
2000
1000
0
Left Gear WOW (discrete)
Groundspeed (knots)
Pressure Altitude (feet)
Recorded vertical Speed (ft/min)
≈600 ft/min
Computed vertical speed Method 1 (>0 up) (ft/min)
1000
500
0
-500
-1000
-1500
300
200
100
0
0
10
20
30
40
50
60
70
80
90
FDR Time (sec)

Computing the vertical speed

- 2nd method: integrate true vertical acceleration

$$v^z(t) - v^z(0) = \int_0^t a^z(t)\,dt$$

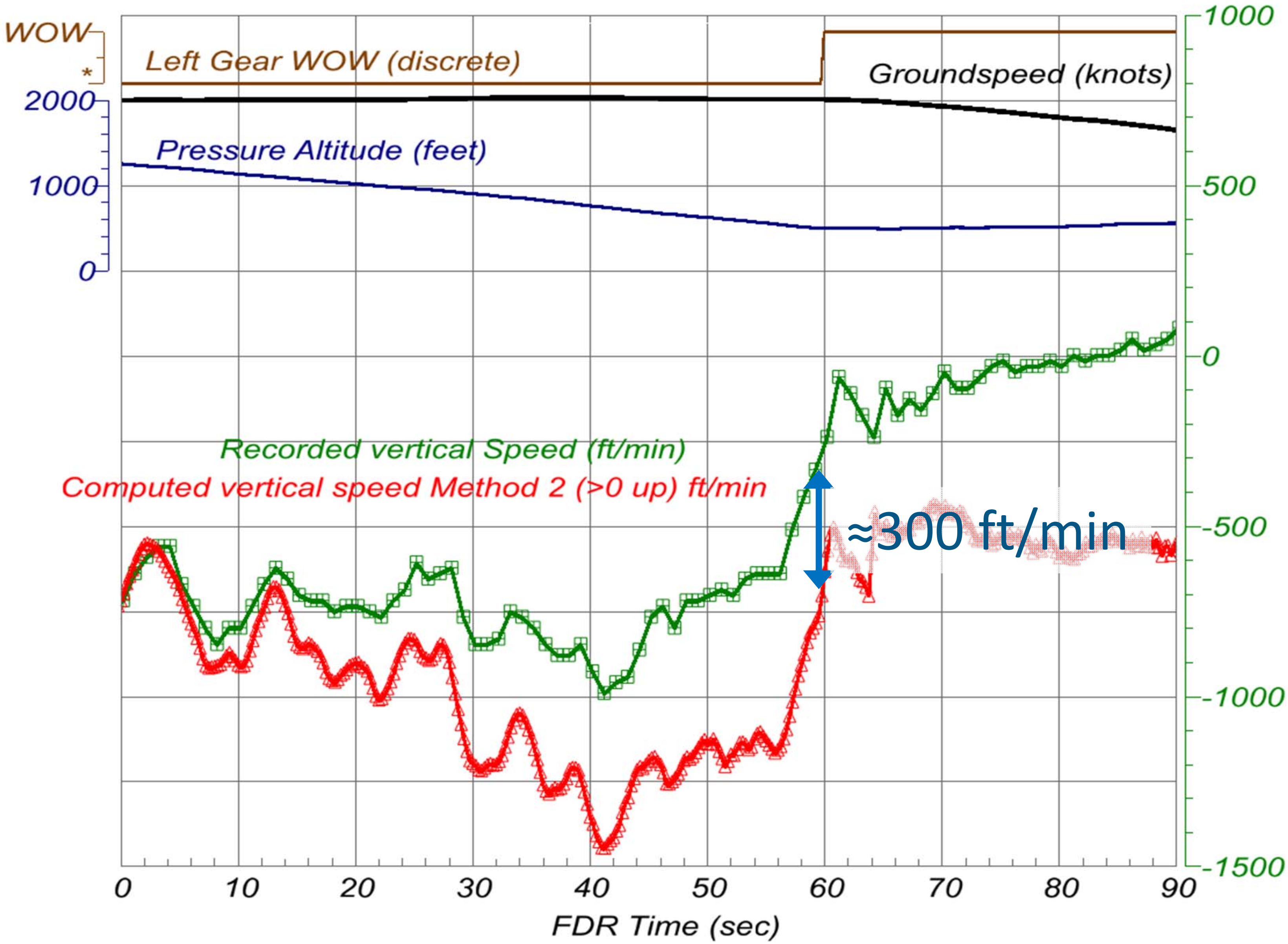
$$\Downarrow$$

$$\begin{cases} v_0^z : \textit{initial condition} \\ v_n^z = v_{n-1}^z + a_n^z \cdot T \end{cases}$$

v_n^z : vertical speed at time t_n

a_n^z : true vert. acceleration at time t_n

T : sampling period


WOW
*
2000
1000
0
Left Gear WOW (discrete)
Groundspeed (knots)
300
200
100
0
Pressure Altitude (feet)
1000
500
0
-500
-1000
-1500
Recorded vertical Speed (ft/min)
Computed vertical speed Method 2 (>0 up) ft/min
≈300 ft/min
0
10
20
30
40
50
60
70
80
90
FDR Time (sec)

“right before contact”?

- Vertical speed and true vertical acceleration to be measured « *right before contact* »
  - i.e. in the second the precedes ground contact
- Need to determine accurately the time of first contact
  - sampling rate of « Weight-on-wheels » parameters should be once per second (1 Hz) or higher

Conclusion on hard landings

- Relevant for assessing the severity of a symmetrical landing :
  1. True vertical acceleration right before contact
  2. Vertical speed right before contact
  3. Aircraft mass at time of contact
- Easier assessment with new-generation flight data frames:
  - Mass recorded,
  - Vertical speed recorded,
  - Higher sampling rates.

Thank you for your attention

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