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Enroute *Wake Vortex Flight Data Acoustic Signature Characteristics*

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Acknowledgements:

- NAVCANADA
  - NRC T33 HAARC team
    - Camile Lebrun, Design Manager, FRL
    - Matthew Bastian, S&FTE

Overview:

- data from the NRC WVE flight research project
  - review recent flights, 20th/23rd Oct & 14th Dec 2009
  - P_S analysis (ADS static pressures transducer)
    - 600 Hz sampling, ≈1 Pa resolution
      - simulation of acoustic pressure, $\overline{\Delta p} = P_S' = (P_S - P_S)$ by P_S filtering & differencing
  - compare
    - Kirchhoff vortex elliptic instability
      - recent work of Zheng & Wang (runway approach WV)
  - *raison d'être*, against the premise of detect for avoidance

Canada – *enroute* wake turbulence issues:

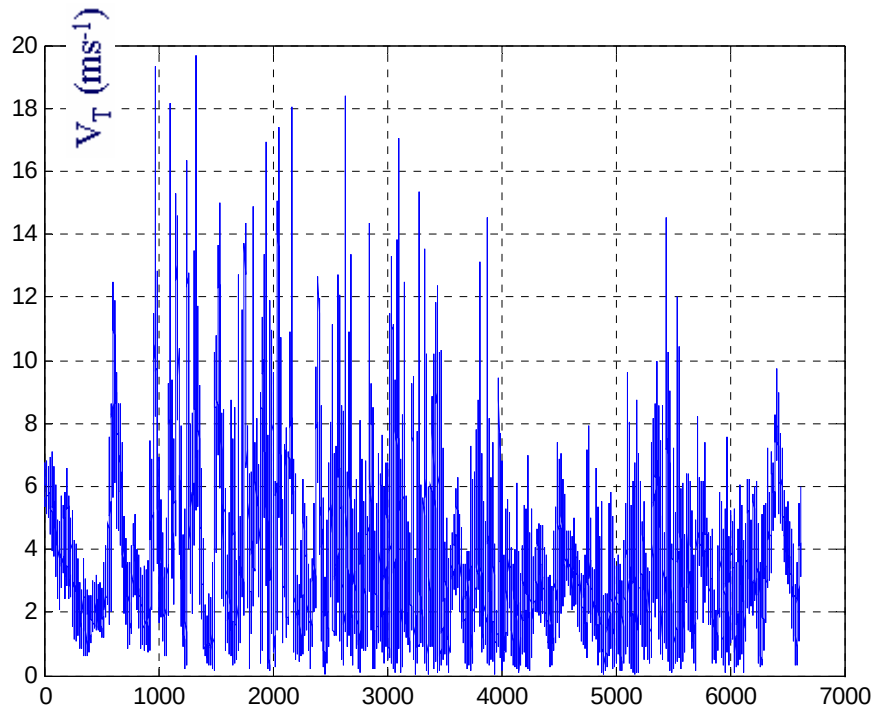
- Canadian airlines (Air Canada's internal reporting scheme)
  - *enroute* & RVSM WVE occurrences, on-going
    - climb/descent track-crossing OR level, same airway
    - response (dependent upon crew SA)
      - human injuries & aircraft damage
      - RVSM violations
        - severe WVE at 1,000 ft separation (opposing track)
        - loss of altitude, sometimes close to 1000 ft (*e.g.* 850 ft recently)

NRC recent research flight activity summary:

- T33 post-depot maintenance (ejection seat ballistics):-
  - 20th October, non-turbulent/non-startified atmosphere
    - B744 (LH440)
      - 6nm-28nm
      - first B744 (for NRC) where vortex funnel form of instability not present
      - rather, 'sausage-type' of axial-direction core instability, meander plus mutual long-wave
      - V_T peaks 16-20 ms^{-1}
  - 23rd October. similar atmosphere
    - same B744 (LH440)
    - also A332
    - also B772 (vortex funnels evidenr)
  - 14th, December similar atmosphere
    - A380
      - V_T peaks, 21-29 ms^{-1}

20th October 2009:

- Wake generator:-
  - B744
  - Non-turbulent/non-stratified
    - 6-25 nm (40 sec to 3 min), or 170-700b
    - Included a patch of vortex-linking

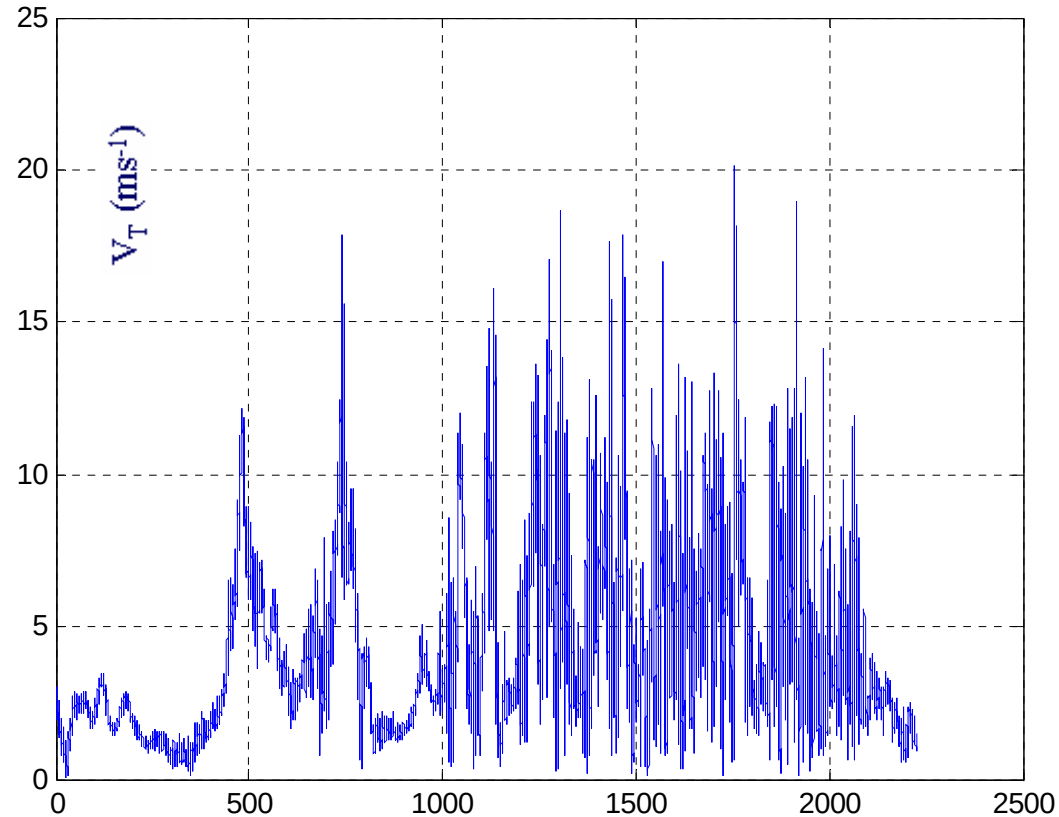


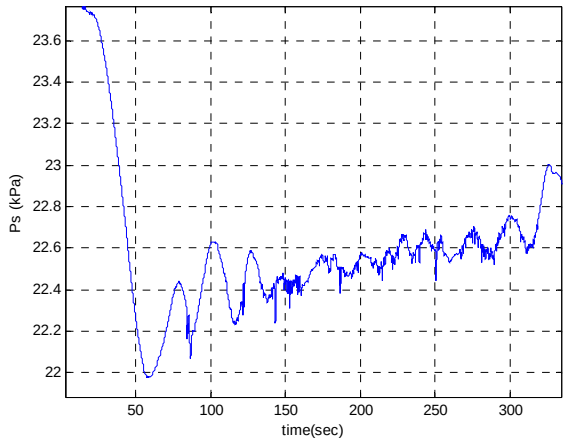
23rd October 2009:

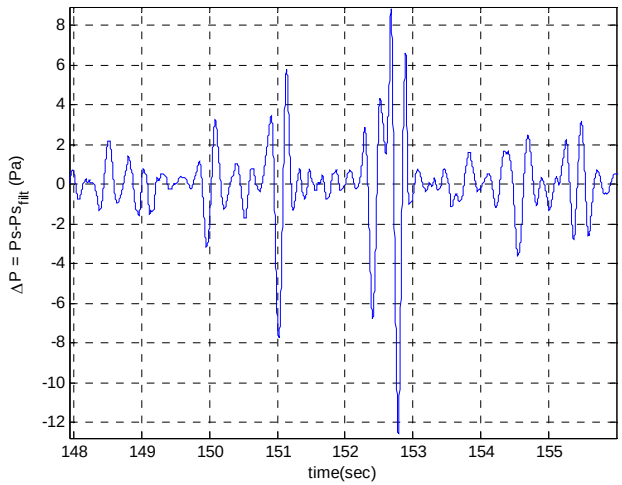
– B744 & A332 & B772:-

23rd October 2009:

- B744:-
  - Γ_{gen} 552 m^2/s; assuming b_O of 80% span
  - intercept climb @ 5 nm, so that over 6-8nm, measured Γ by closed-path integral, 478 m^2/s, 87% Γ_{gen}

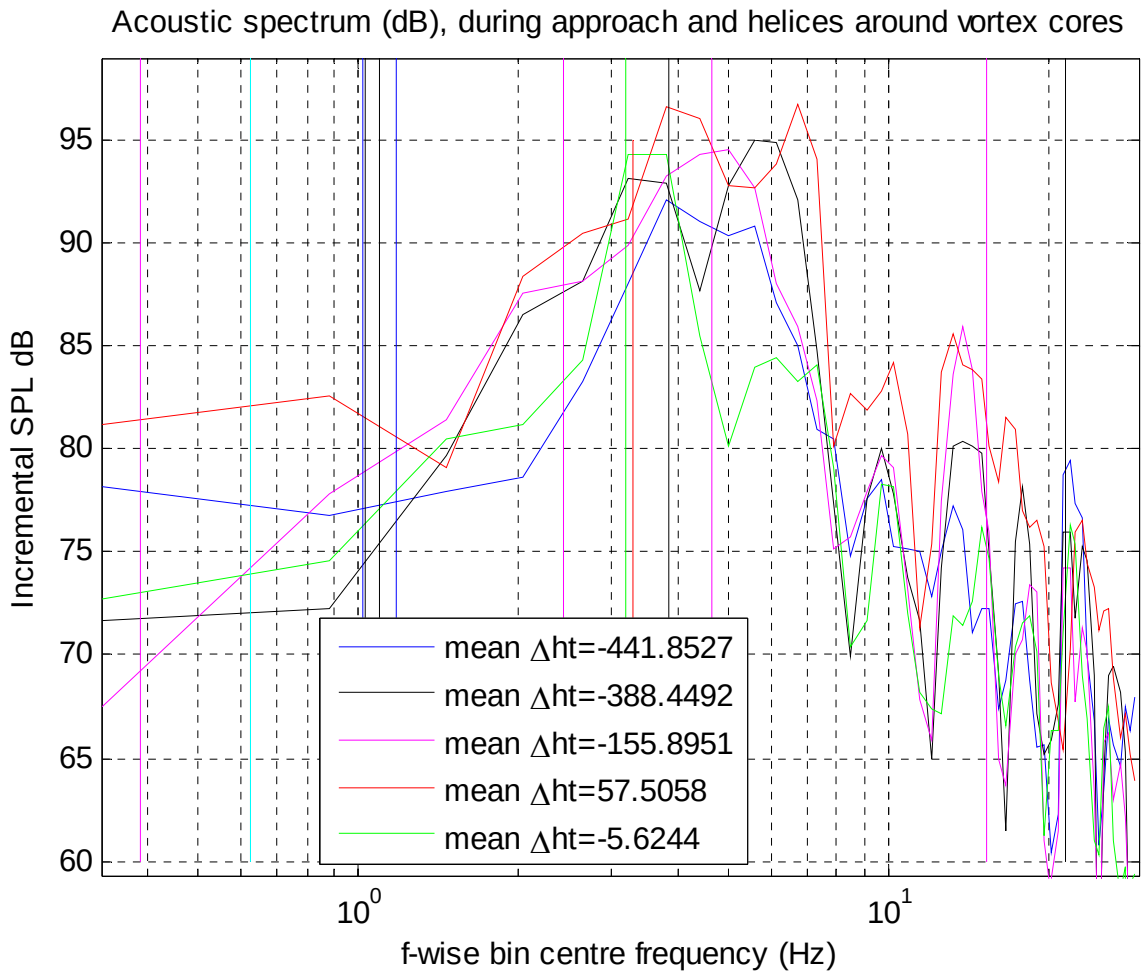






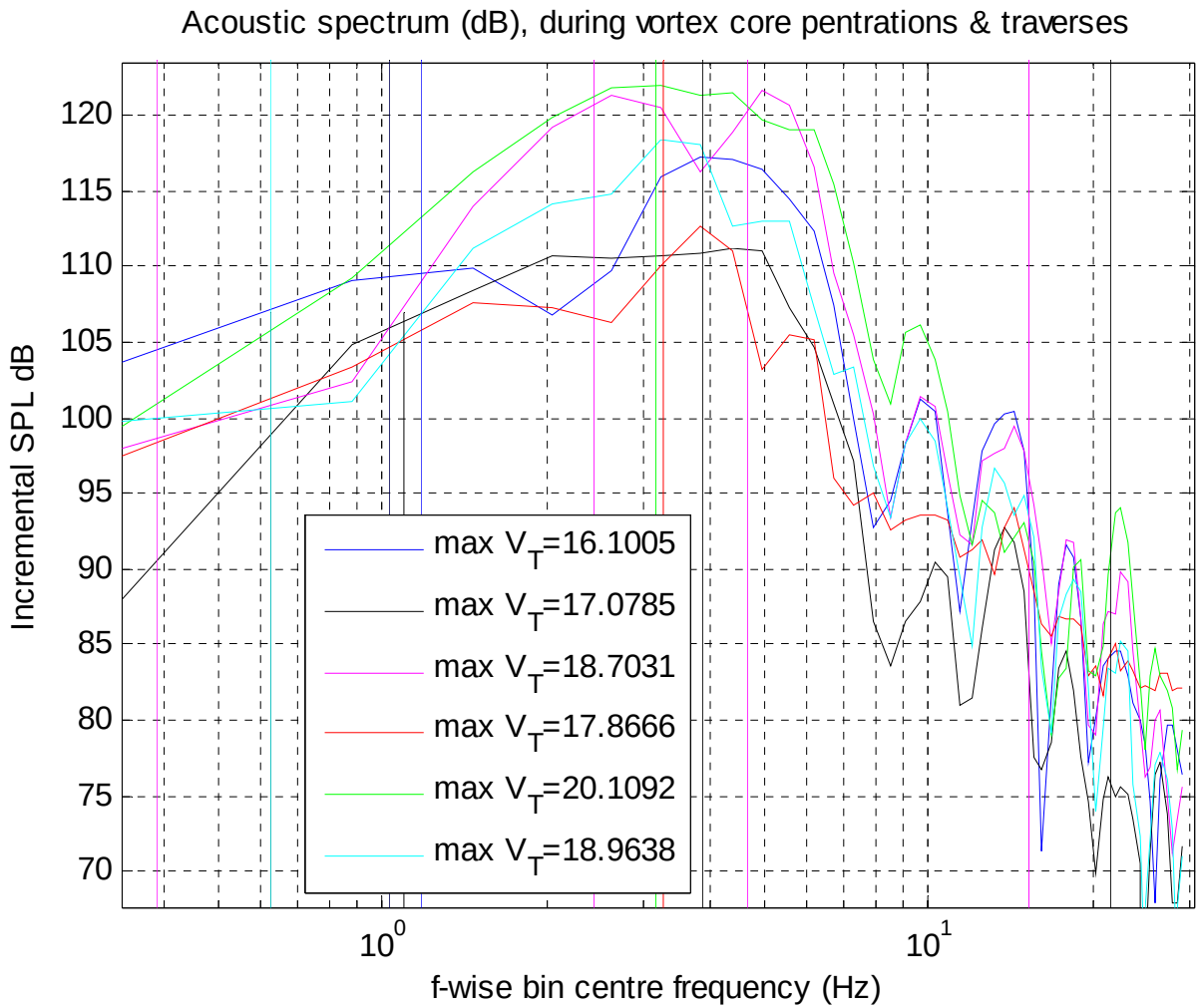
23rd October 2009:

– B744:-



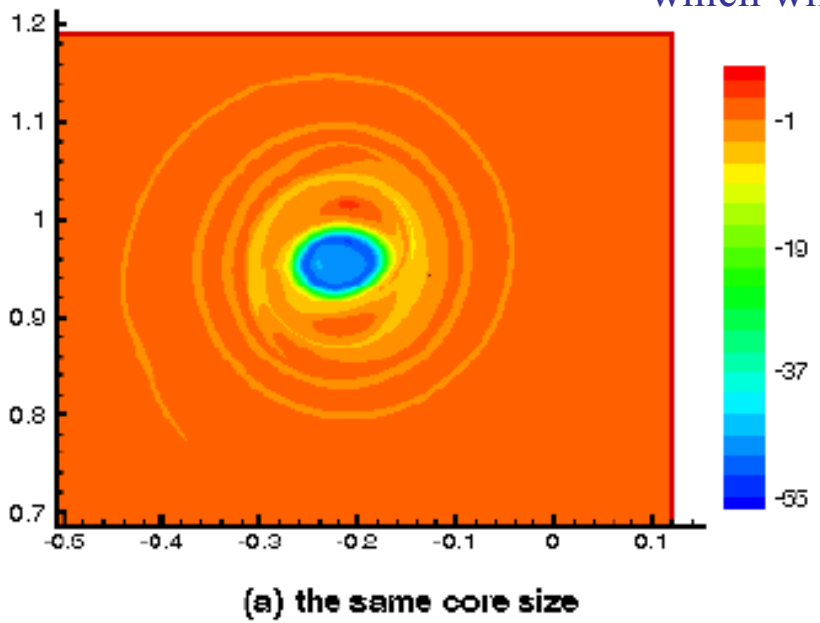
23rd October 2009:

– B744:-



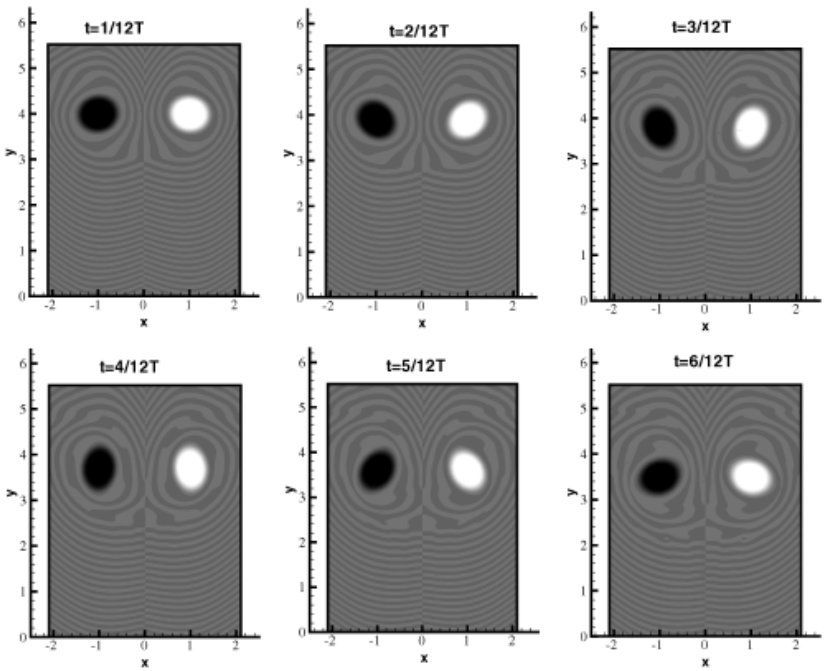
Kirchhoff vortex elliptic instability:

- analysis included in Lamb, history summarised in Saffman
  - Kirchhoff vortex, 2D, core of constant ω ($\Gamma/\pi r^2$) will self-induce rotation at angular rate of $\Omega=\omega ab/(a+b)^2$, with ar_C & br_C being the major/minor axes upon perturbation, respectively; in the limit, $\lim\Omega=\omega ab/(a+b)^2 = \omega/4$; thus model ω to estimate Ω, which will result in Δp at a non-dim freq of 2Ω.



(a) the same core size

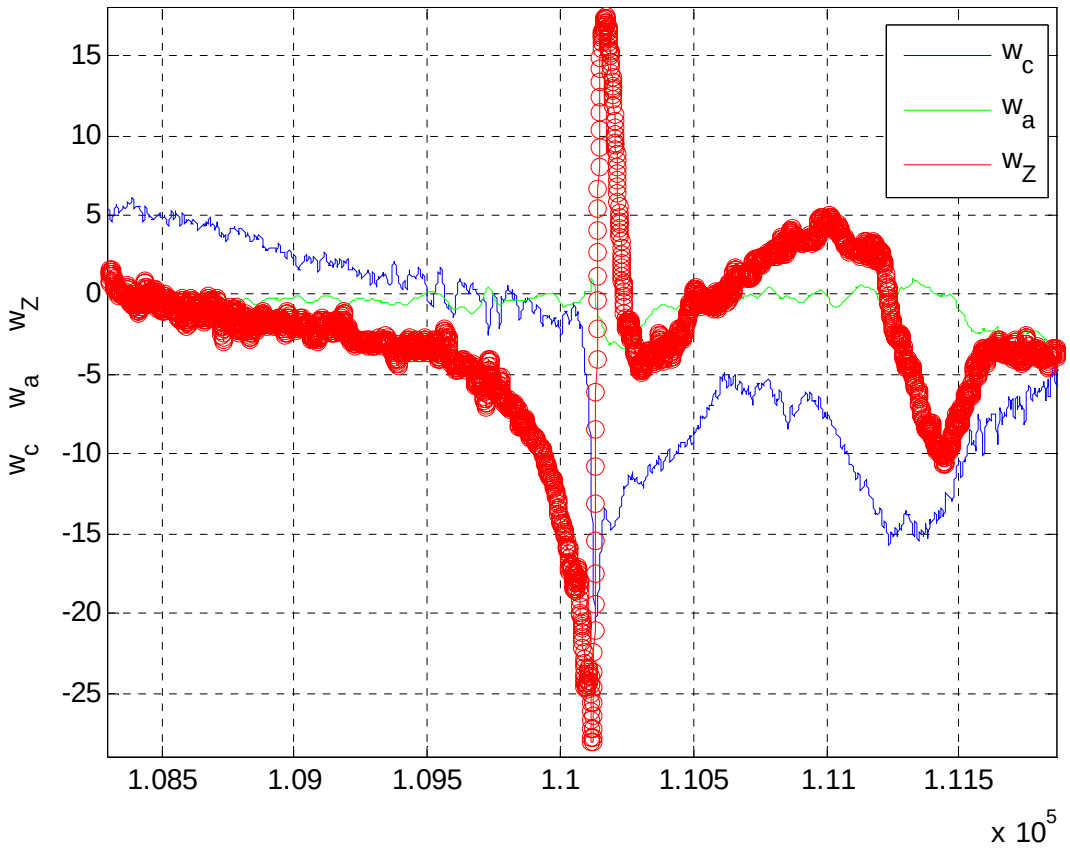
- Zheng & Li, Aero.J, Vol113,No1142, pp233-242



- Zheng & Wang, JofA, V44/4, Jul-Aug 2007, pp.1369-1377

Vortex Γ (based upon V_T) and r_C identification:

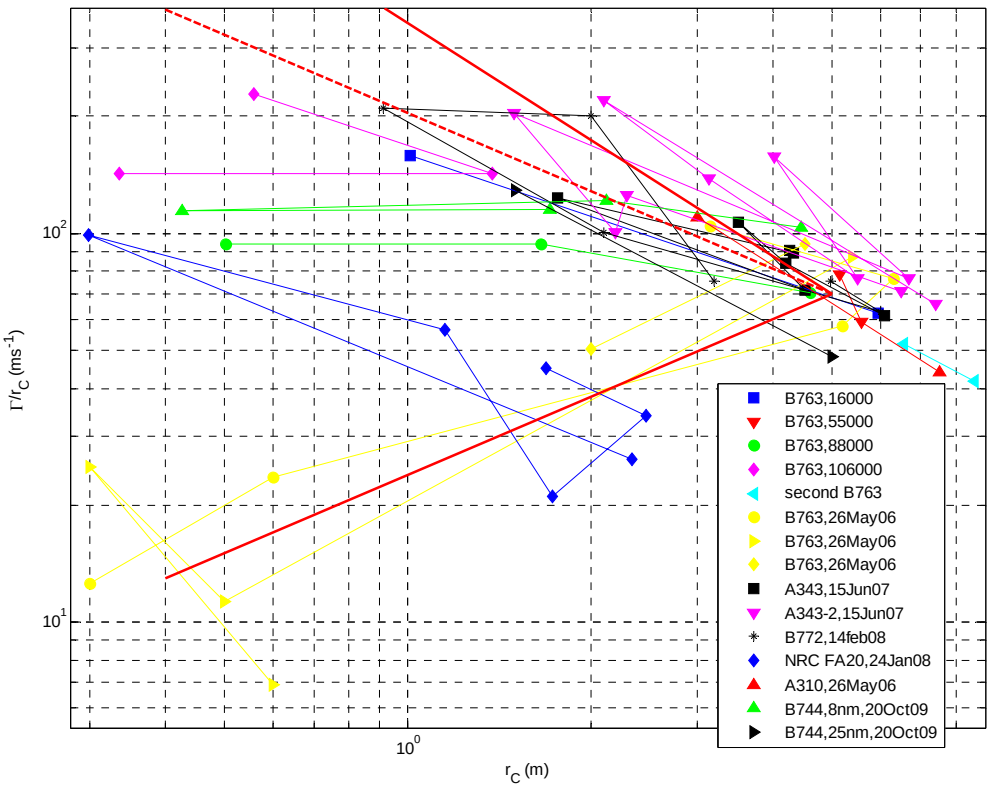
- Time-marching inspection of V_C, V_Z & V_A
  - Cross-referred to $V_T=\sqrt{(V_C^2+V_Z^2+V_A^2)}$ time-traces ('M' signatures)

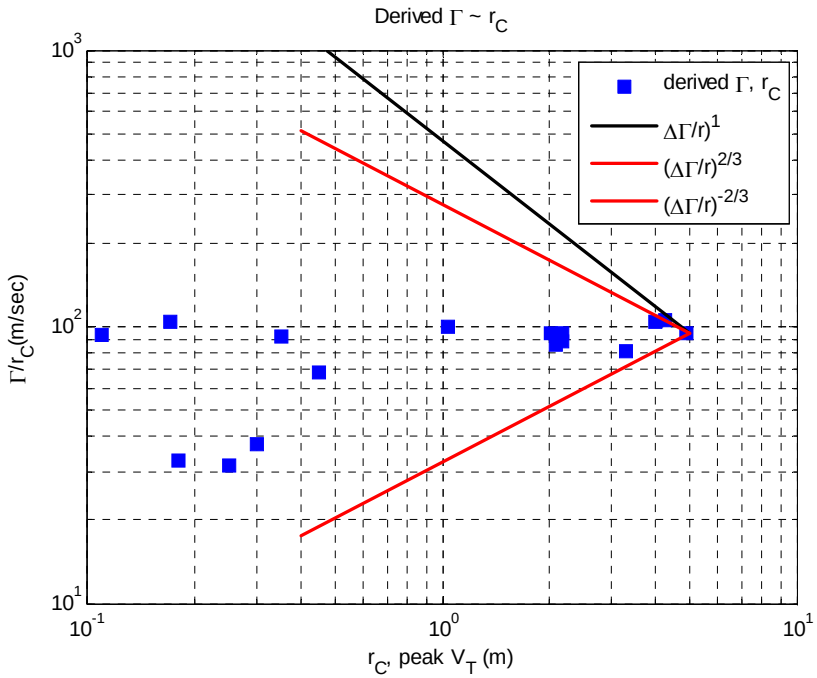


Trace, B777-200, 23rd Oct 09)

23rd October 2009:

- B744:-
  - Vortex circulation (V_T) ~ core radius identifications, by the method on previous slide:-





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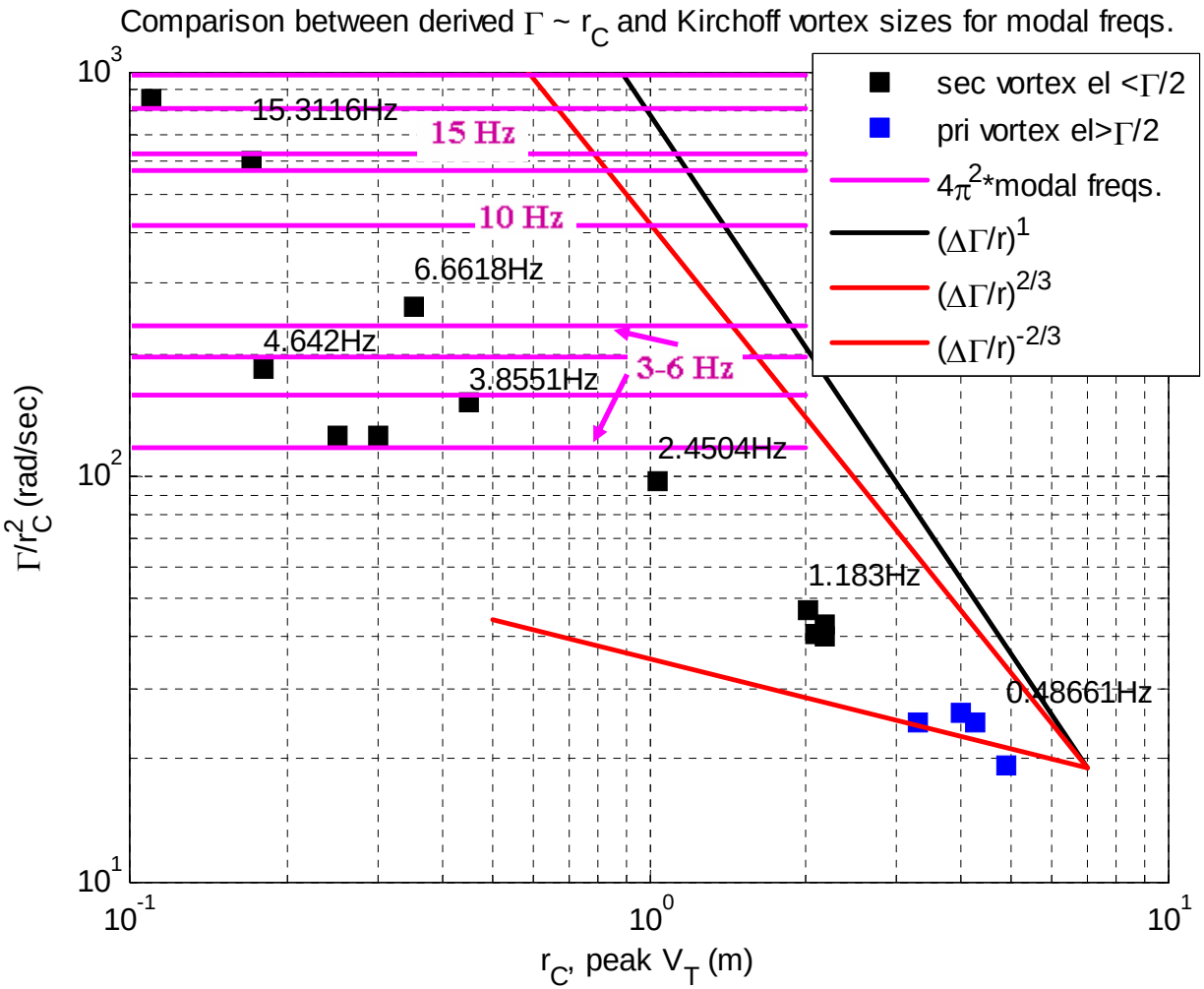

14th December 2009:

– A380:-

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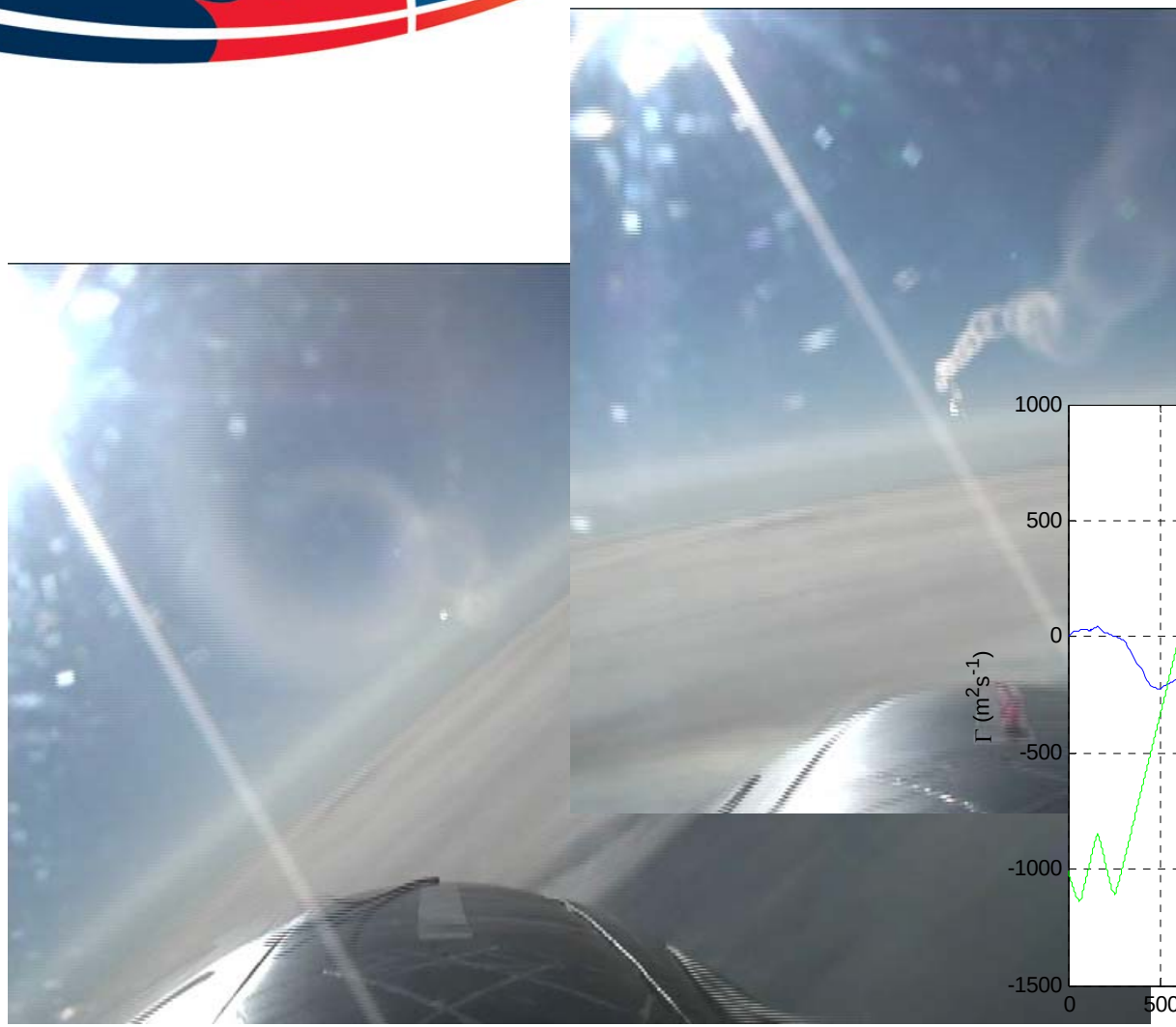
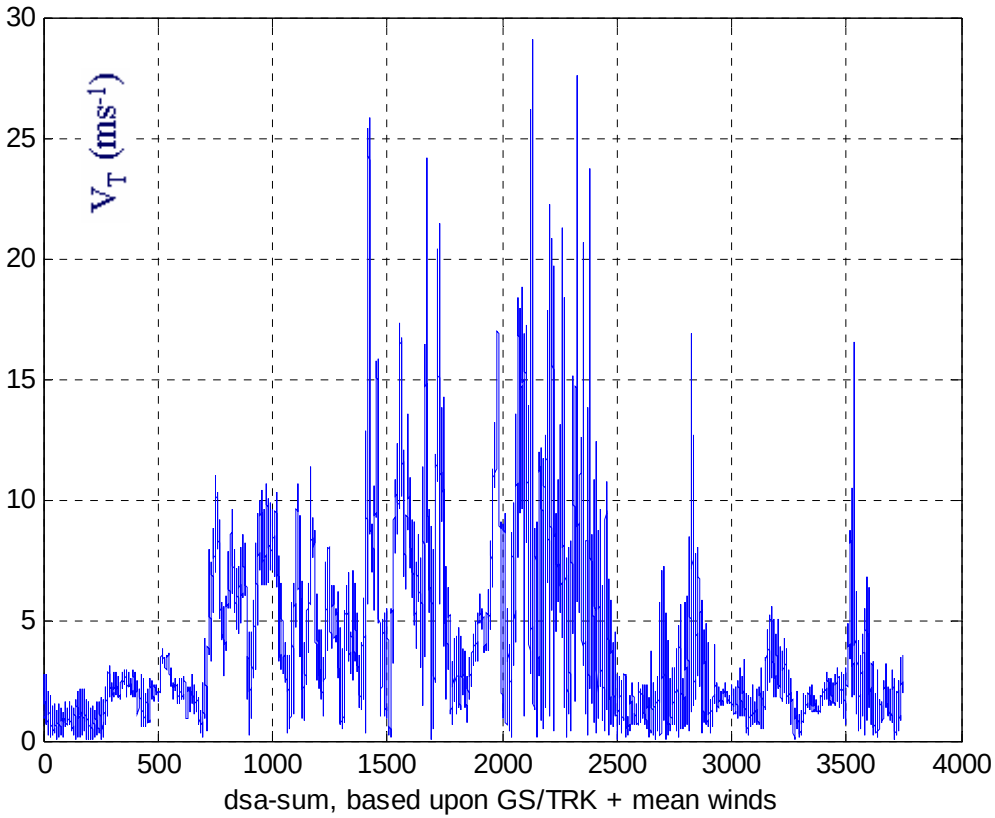


14th December 2009:

- A380:-
  - Γ_{gen} 735 m^2/s, assuming b_O of 80% span
  - intercept climb commenced @ 5 nm
    - Over 6-8nm, Γ measured by closed-path integral, 629 m^2/s, or 86% generated circulation
      - $\Gamma_{A380} / \Gamma_{B744}$ approx. = 1.31, and
      - mean of peak tangential velocities during core traverses V_{TA380} / V_{TB744} =24/18=1.33.



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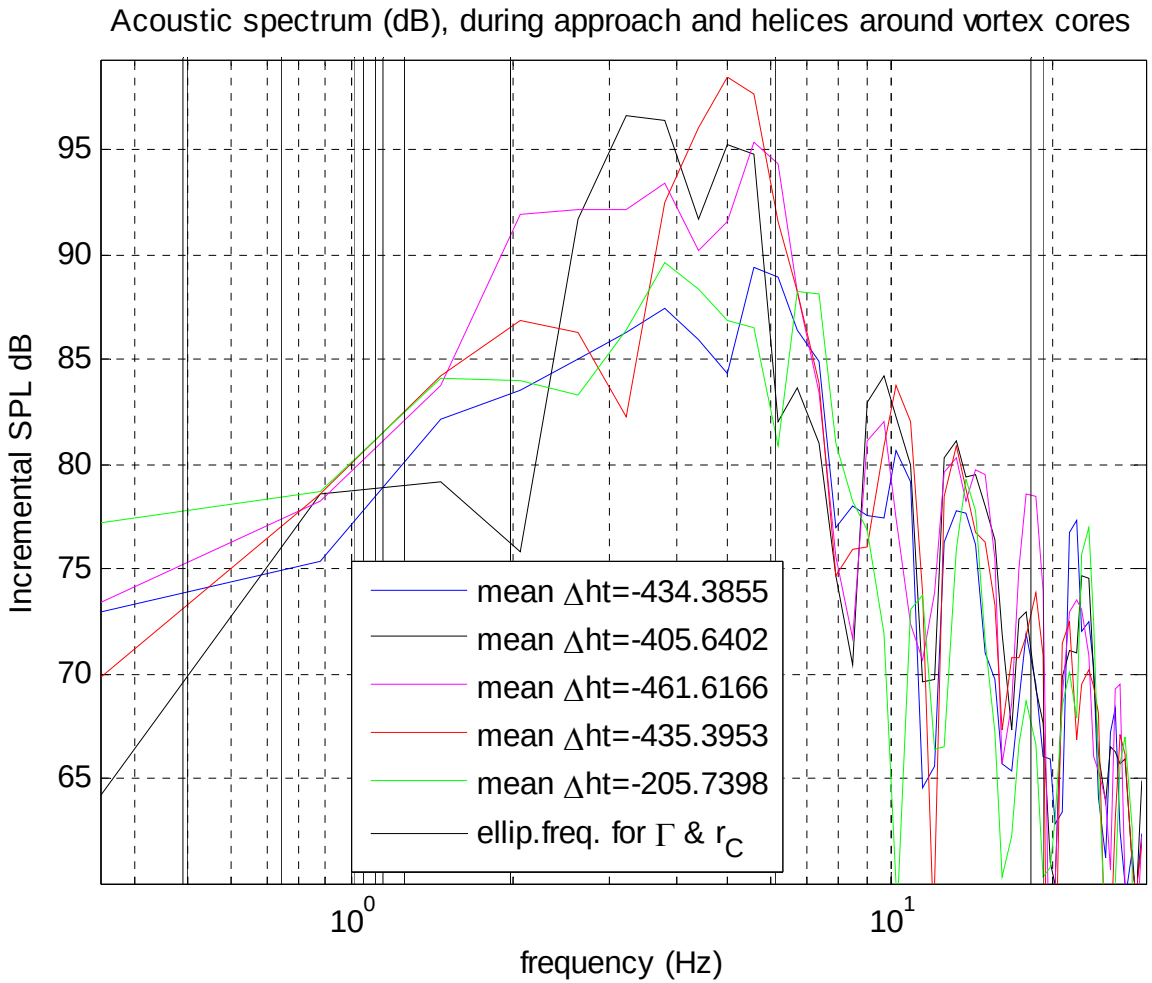

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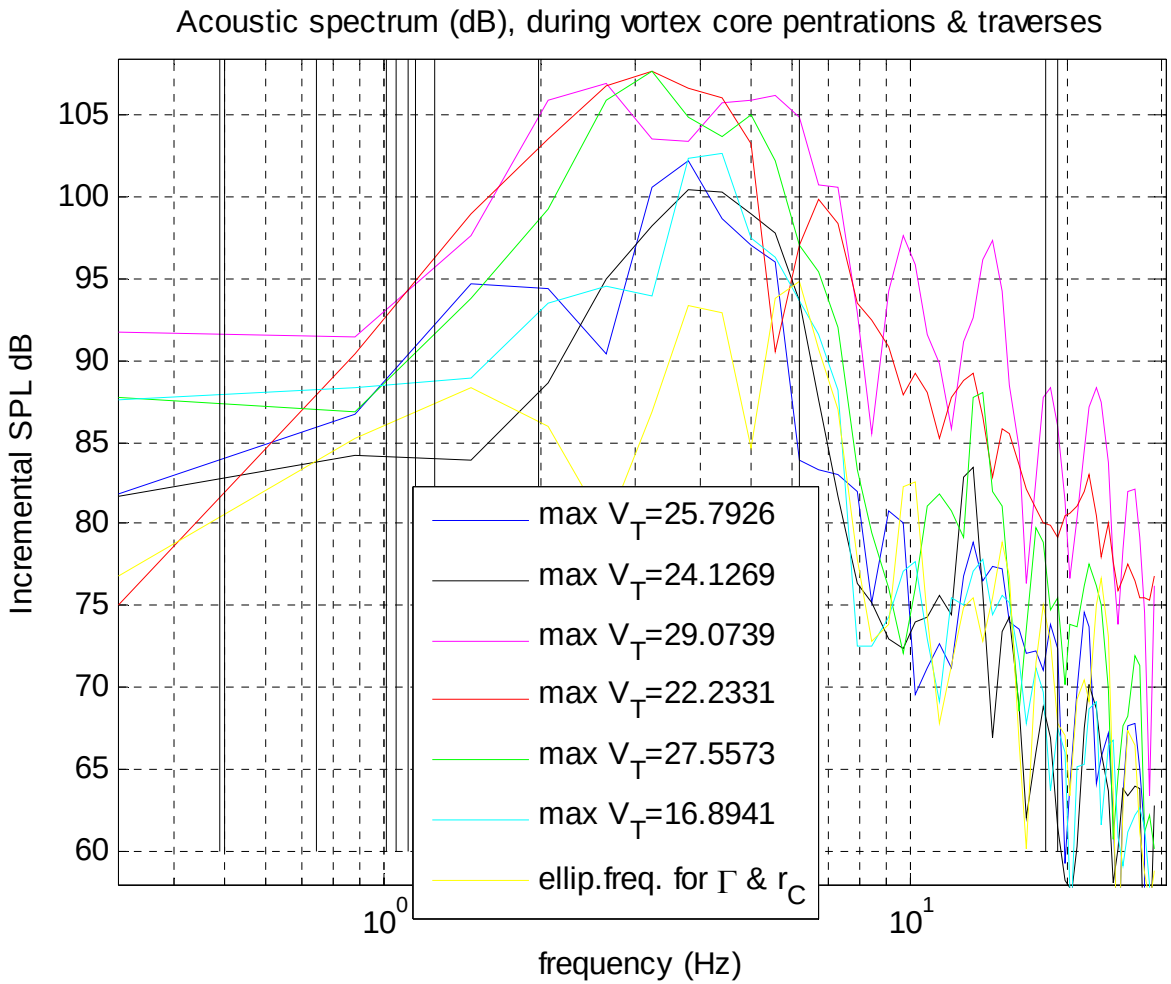
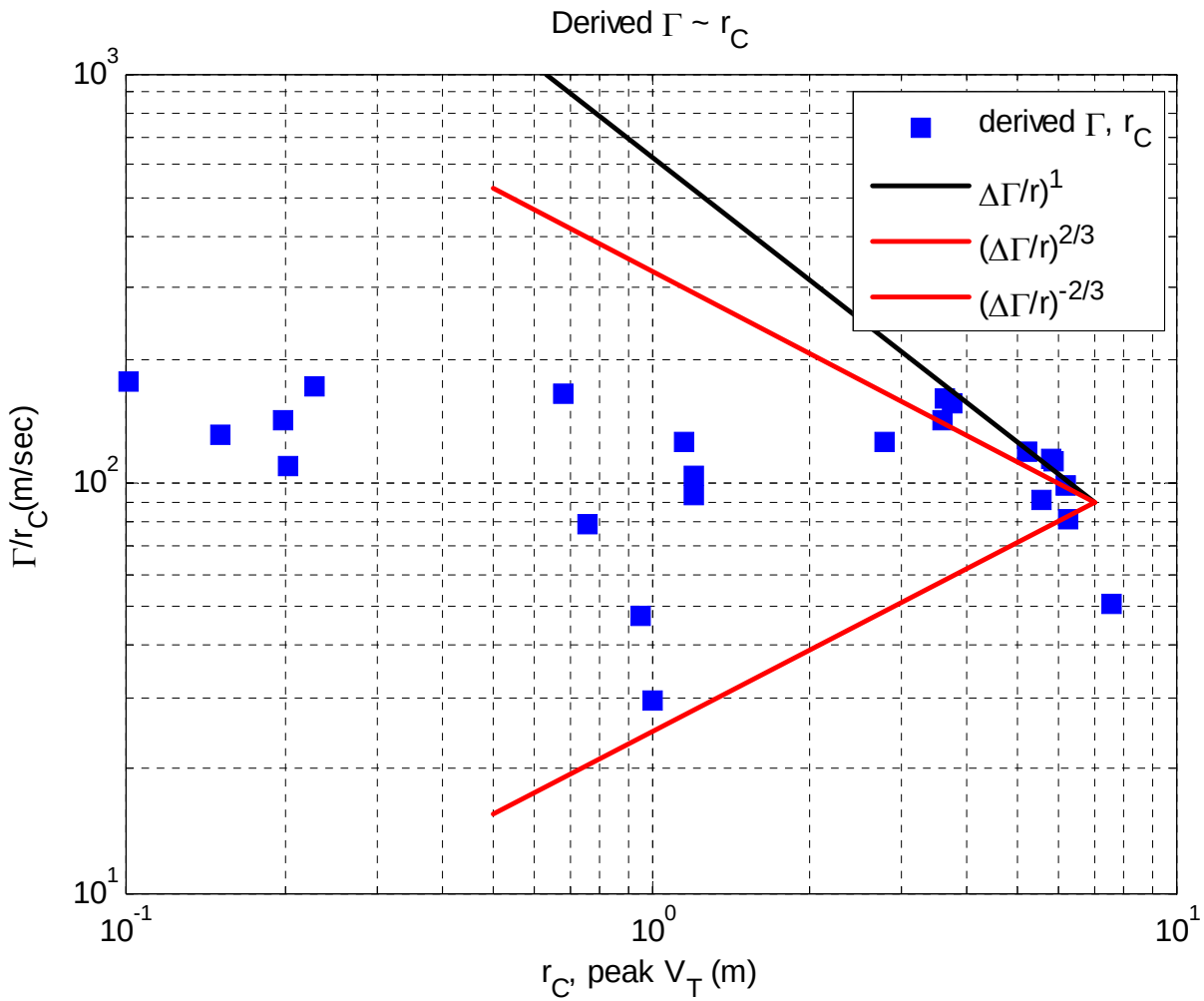


A380 – an example of vortex Γ (based upon V_T) and r_C identification:

- Right vortex core entry
  - V_T, 25.3 m/s, arc dist 1419.8 m
- Vortex core exit
  - V_T, 25.8 m/s, arc dist 1425.6 m
- V_T 25.6 m/s, core radius 3.5 m

14th December 2009:

– A380:-



14th December 2009:

– A380:-