BEAGLE 2 DISCOVERED

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Entry Challenges & Philosophy

Small Mass and Low Cost Constraints

- Robust design to minimise testing
  - Ballistic entry with low ballistic coefficient ~70kg/m2
    - Laminar Flow
  - Maximum heritage re-use
    - 60 degree sphere cone, ~Huygens forebody proportions
    - ESA TRP Studies on CO_2
    - ESA feasibility studies, Marsnet and others
    - Open literature (US mainly)
- Minimal ground tests for most uncertain phenomena
  - Dynamic stability
  - CO_2 specific aerodynamic stability features
  - Base heating (base TPS mass)
- Avoidance of worst on worst margin situations
  - Risk balancing
  - Maintain mass target

Dynamic Instability

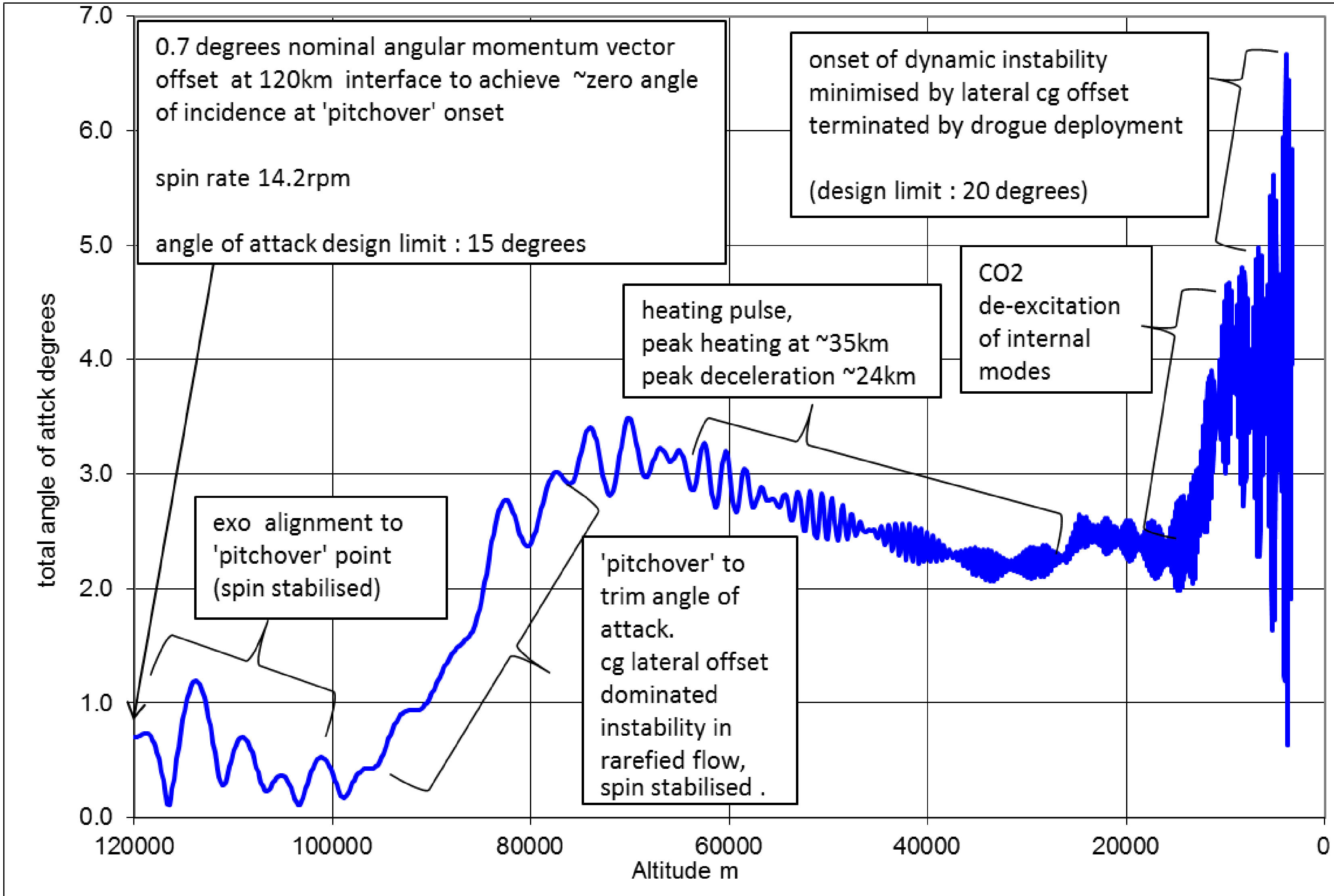
Below Mach 2 leading to parachute deployment, blunt vehicles exhibit dynamic instability. The largest uncertainty for Beagle 2 entry dynamics.

Mitigation

- Far-forward axial centre of gravity
  - The only 'red line' for capsule configuration
  - Literature sources for ground test and limited flight data
- Centre of gravity lateral offset
  - Result of sensitivity analysis with spin rate (multiple Monte Carlo)
  - Selective assembly reduced mass balance requirements to zero.
  - Geometric asymmetry accounted for (in roll moment to ensure sufficient spin rate at parachute deployment)
- High Mach drogue deployment
- Limit cycle testing
  - 1st dynamic stability tests in CO_2,
  - Oxford University ultra quiet 'suck down' tunnel
  - Special Mach 1.5 and Mach 2 nozzles for cool CO_2.

Critical Regions During Entry

(nominal trajectory, March 2009 transitional aerodynamics update, EMCD5.2 June 2015)



High Altitude Aerodynamics

Free-Molecular/Transitional Static Stability

- Blunt vehicles can be statically unstable at ~100km and above on Mars
- Minimal angle of attack excursions are desired through peak heating and as initial condition for onset of dynamic stability
- Lateral cg offset used as mitigation for dynamic stability adds to high altitude instability

Mitigation

- Forward axial centre of gravity (also required for dynamic instability mitigation)
- Optimisation of cg offset and spin with low Mach dynamic instability condition
- Careful targeting of attitude at entry interface (at 120km).
  - ~Zero-angle of attack at ‘tip-over’ altitude
  - Coordinated into Mars Express release attitude.

Low Hypersonic Aerodynamics

CO_2 exhibits vibrational excitation at lower temperature than air.

- Pitching moment and normal force coefficients halve at much lower Mach (6) than in Air or Titan atmospheres (12). Trim angle of attack doubles
- Critical to dynamic instability mitigation

Mitigation

- Validation of CFD computations (FGE & CFDRC) undertaken at Oxford University gun tunnel (Mach 6 in CO_2)

Forward Heatshield Aero-heating

Laminar flow expected (Beagle2 is small)

- TPS minimal gap and step manufacturing specification
- Three different transition criteria tracked
- Fully Catalytic wall condition set (not super-catalytic)

Erosion assessment for dust storm condition

- no additional margin indicated

No additional forebody flux margin

- TPS sizing undertaken by EADS (Norcoat Liege)
  - Cross check by FGE

Base Heatshield Aero Heating

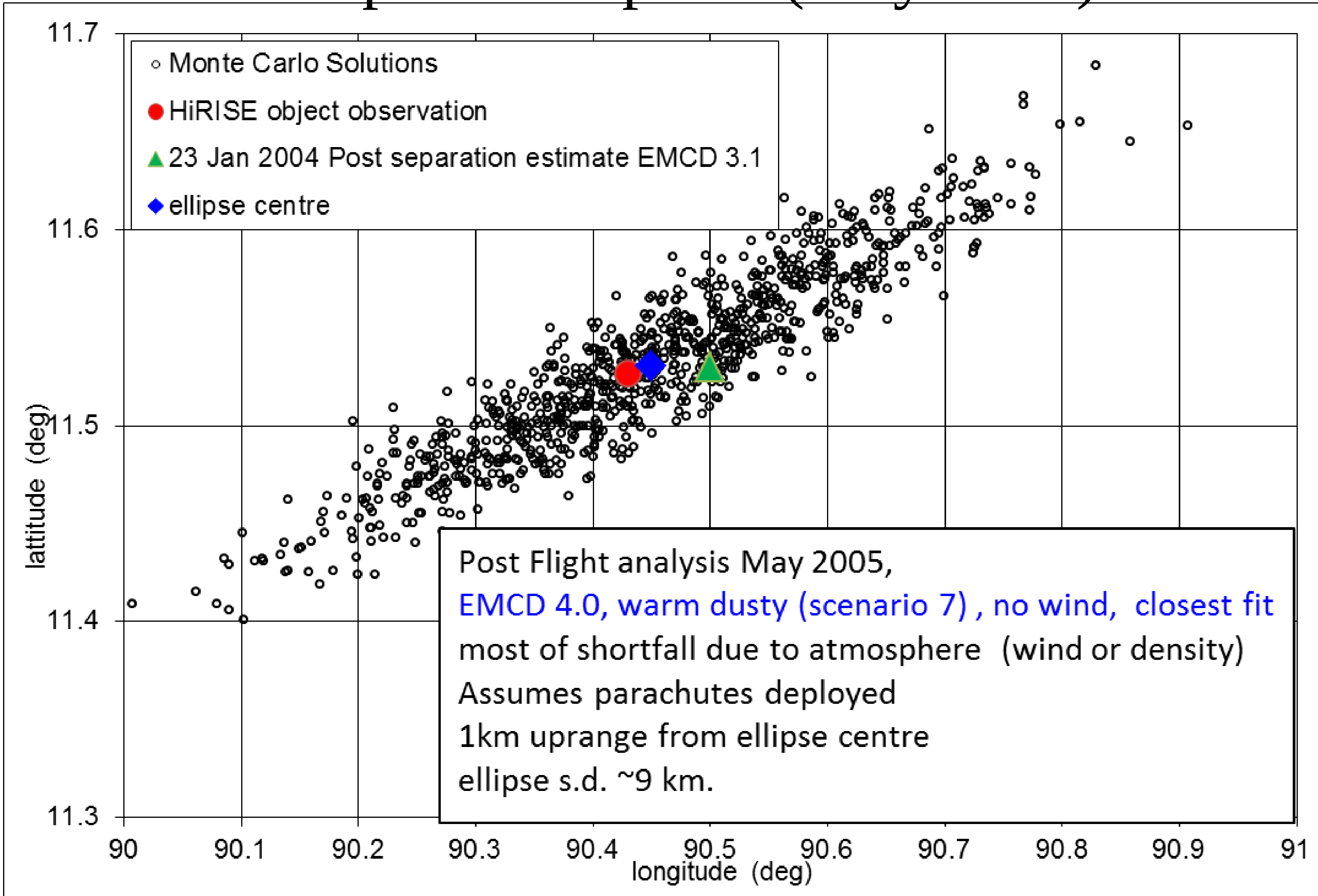
Base heating difficult to compute

- Recirculation and re-attachment highly mesh and geometry dependant

Mitigation

- Shallow rear cone angle (promote flow separation)
- Oxford gun tunnel tests in CO_2 for CFD validation
- Construct ‘double hump’ envelope of maxima from ground tests, computation and available flight correlation (Viking includes radiation, low radiation for Beagle2)
- Maintain freestream enthalpy in hot wall TPS correction as additional margin.

Dispersion Update (May 2005)



Entry Phase Aero-Physics Risks Re-assessment

Risk Phenomena	Consequence	BG2-Pre-Flight	June 2015	Reasoning
Dynamic Stability	Excess aoa at drogue deployment	Acceptable	Acceptable	Re-examination of evidence for ERV's etc. Extensive EXM testing. no change in 'rules'
High altitude static stability and entry dynamics	Tumble	Acceptable	Low	Additional aerodynamic computations in 2009-10
Base Heating	Burn through and/or overheat	Acceptable	Low	Extensive EXM testing, Confirmed low radiation assessment (cf Viking)
Forebody heating including boundary layer transition	Burn through and/or overheat	Acceptable	Acceptable /Low	Still concerns over all ground test interpretation in CO2 but Norcoat Liege better understood.
Dust cloud erosion	Burn through and/or overheat	Acceptable	Low	Low dust loading on entry date (Lewis 2006), EXM experimental 'g'law similar to Beagle2 assumptions