FREE FLIGHT TESTING OF ATMOSPHERIC ENTRY CAPSULES IN LOW SUBSONIC FLOW

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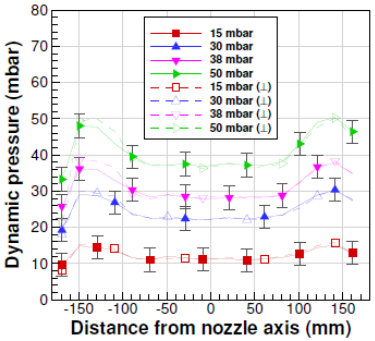
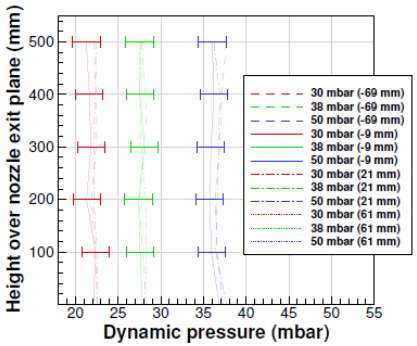
Motivation

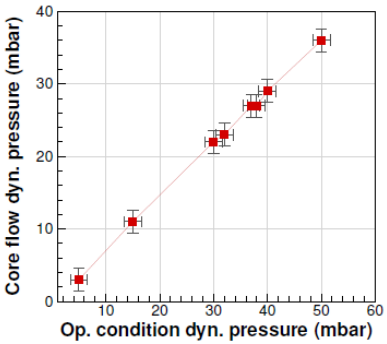
- Several sample return missions are in the planning stage (OSIRIS Rex) or already launched (Hayabusa 2) or proposed (MarcoPolo-R)
- Entry capsules for recording break up process of demised space structures are becoming important
- Alternative for reducing complexity of future missions is omitting parachutes
- Ensuring a certain attitude of capsules during flight or at impact on ground can be a requirement
- Aerodynamic stability of blunt shaped capsules decreases with velocity
- Heavy pitch oscillations jeopardize the success of the mission
- The cause for dynamic instability in the transonic and subsonic regime is not understood fully
- Investigations employing the free flight technique are typically performed in aeroballistic facilities, vertical wind tunnels, and with drop tests

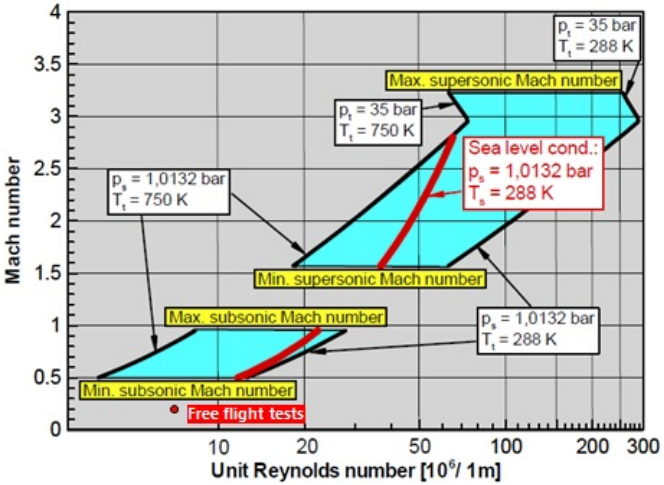
Free Jet Facility (VMK)

- Conventional blowdown wind tunnel
- Sub- and supersonic conditions
- Facility previously not intended for low subsonic flow
- Modifications:
  - o Electro-pneumatic model release system
  - o Free flight duration relatively short
    - – Flow control (pressure drop mesh)
    - – Pronounced dish shape flow profile



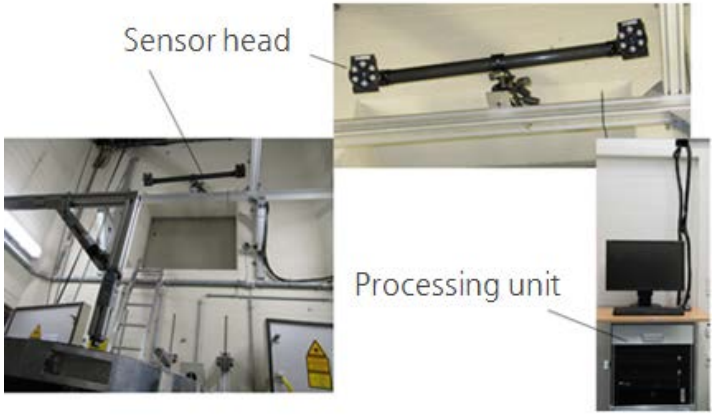


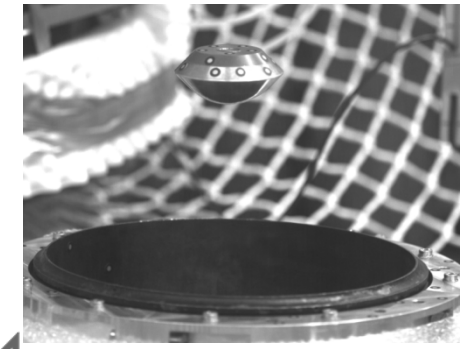


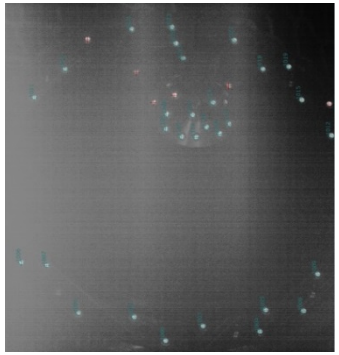


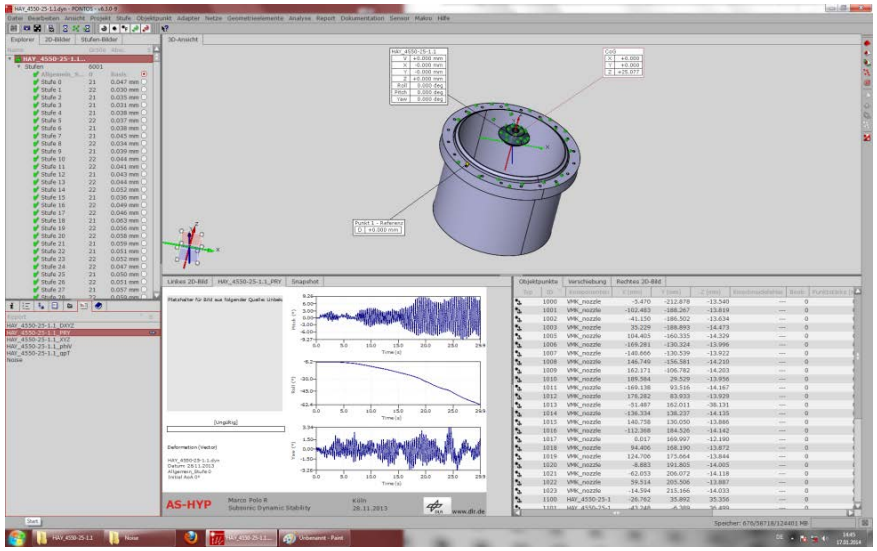
Motion Tracking System

- Optical motion tracking system
- Sensor head (stereo camera) and computer
- Software: PONTOS (GOM mbH, Germany)
- Software tracks position of a point cloud of retro-reflective markers
- 6DoF-analysis with respect to a user defined global coordinate system
- Recording of motion with up to 10 kHz (usually 200 Hz sufficient)

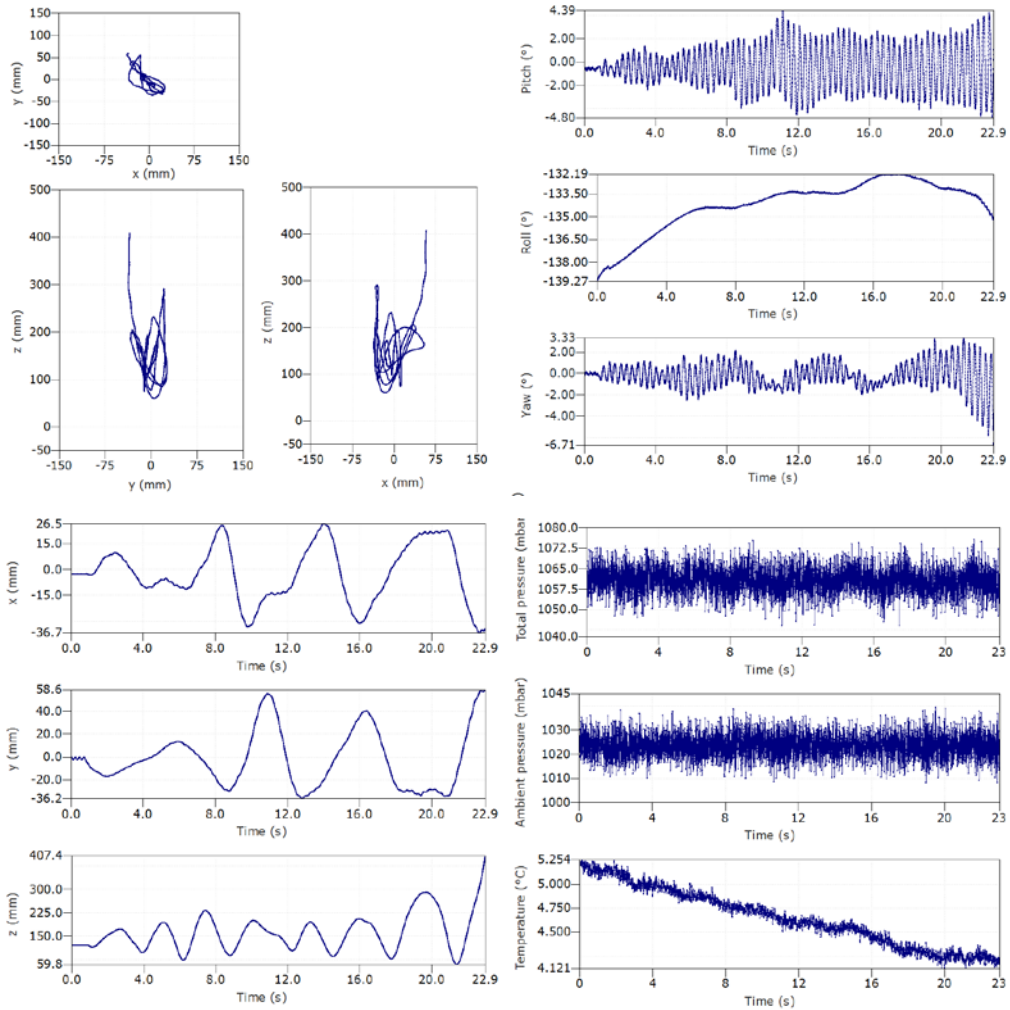




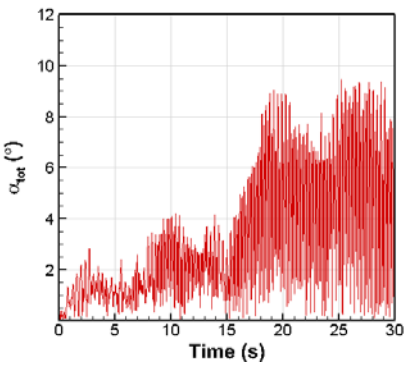




Testing and Measurement Results



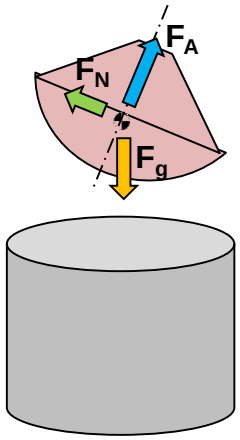
Data Reduction



- Velocity determined from measured data transformed into body frame using rotational matrix

- Total angle of attack determined by standard formulas

$$\alpha_{tot} = \arccos\left(\frac{u}{V_r}\right)$$

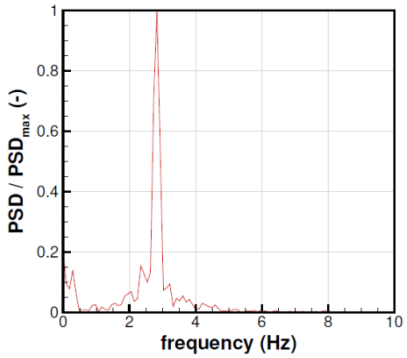


- Axial and normal force coefficients: $C_A = \frac{2mg\cos\alpha}{\rho V_\infty^2 A}$, $C_N = \frac{2mg\sin\alpha}{\rho V_\infty^2 A}$

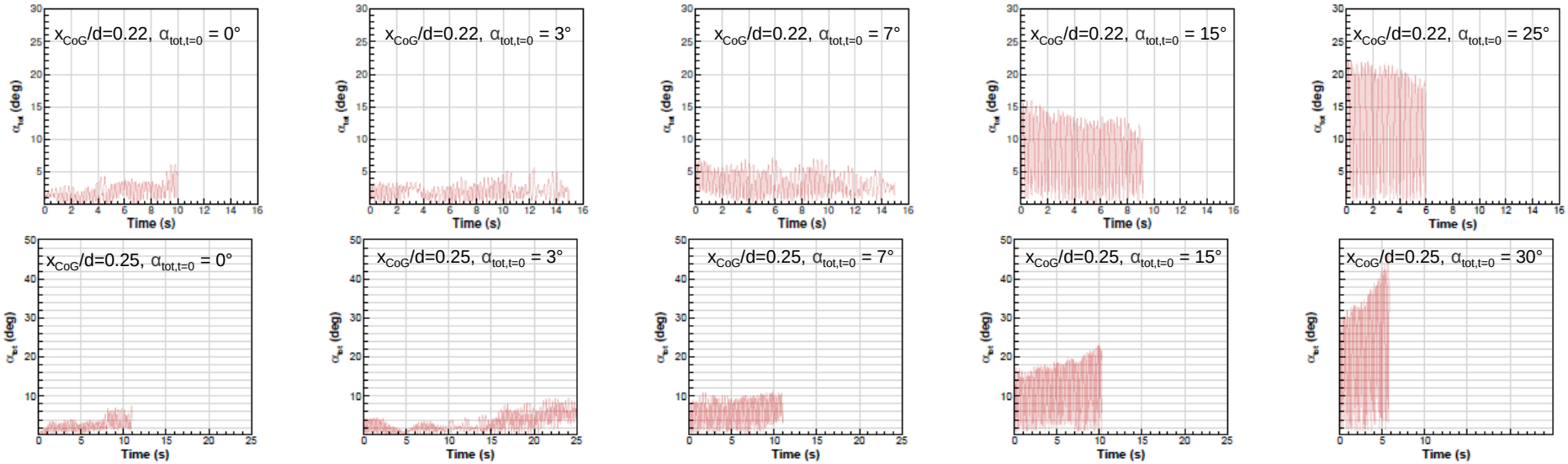
- Slope of the moment coefficient w.r.t. AoA: $C_{m,\alpha} = -\frac{\omega^2 I}{q_\infty A d}$

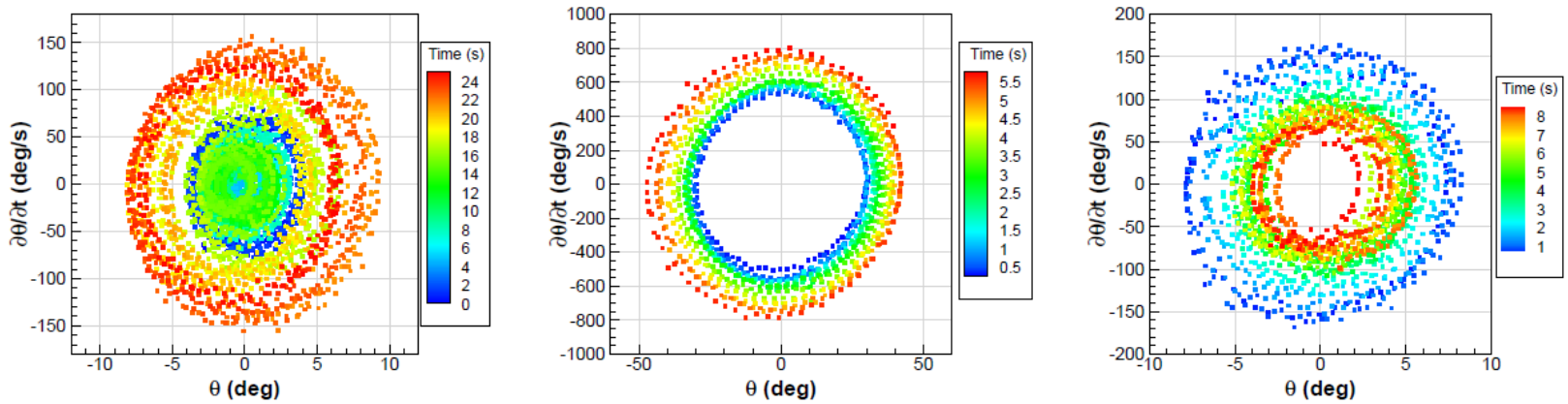
- Pitch damping sum from

$$\ddot{\alpha} - \frac{\rho V A}{2m}\left[-C_{L_\alpha} + \frac{md^2}{2I}\left(c_{m_q} + c_{m_{\dot{\alpha}}}\right)\right]\dot{\alpha} - \frac{\rho V^2 A d}{2I} c_{m_\alpha}\alpha = 0$$



Exemplary Results - Dynamic behavior of capsule models





x_{CoG}/d=0.25, $\alpha_{tot,t=0}$ = 0° x_{CoG}/d=0.25, $\alpha_{tot,t=0}$ = 30° x_{CoG}/d=0.22, $\alpha_{tot,t=0}$ = 15°

Conclusion

- Free jet facility VMK successfully modified for investigating aerodynamic properties of capsules low subsonic flow using the free flight technique
- Motion of the models is recorded optically with high sample rates and accuracy
- The analysis of experiment data shows that the free flight tests in the VMK yield physically reasonable results
- Trends and results compare fairly well to numerical simulation
- Applying simple relations one can determine force and moment coefficients, limit cycle ranges and pitch damping sum
- Analysis indicates that flow control influences the results significantly

- Parameter identification approach will improve accuracy
- Feasibility study for free oscillation technique ongoing
    - Investigation at higher subsonic velocities possible