Detailed investigations of the Huygens spin anomaly in a subsonic wind tunnel

A. Leroy\textsuperscript{1}, J.-P. Lebreton\textsuperscript{2}, P. Devinant\textsuperscript{1}, S. Loyer\textsuperscript{1}, G. Thébault\textsuperscript{1}, J. Simier\textsuperscript{1}, O. Witasse\textsuperscript{3}, R. Lorenz\textsuperscript{4}, M. Perez Ayucar\textsuperscript{5}

\textsuperscript{1} PRISME Laboratory, UPRES 4229, Université d’Orléans, Polytech Orléans, Orleans, France,
\textsuperscript{2} LPC2E, CNRS-Université d’Orléans, Orleans, France,
\textsuperscript{3} Science Support Office, ESA/ESTEC, Noordwijk, The Netherlands,
\textsuperscript{4} JHU/APL, USA,
\textsuperscript{5} ESAC/ESA, Madrid, Spain.
Huygens in-flight spin profile

Huygens in-flight spin profile derived from engineering sensors

Spin rate (rpm)

Main chute
Stabilizer chute

Time (SCET UTC)
Spin under parachute

Initial spin a-c/w under parachute but fast slow down

Spin reversed within 5-6 min under main parachute (c/w)
Zoom on Huygens in-flight spin profile

Zoom on the first 200 seconds of the descent sequence

- Real spin
- Expected spin

Mission time (s)

Spin rate (r.p.m.)

- HS Separation
- HASI Boom Deployment
- DISR Cover Separation
Context and motivation for this work

- Huygens spin profile anomalous (fast slow down and then reverse direction) under parachute; reversed spin also for drop test on Earth (SM2, was not noticed during post-test data analysis).
- It took 9 years to put a study in place
- Study led by Vorticity Ltd under ESA contract in 2013-2015 (SM2 wind tunnel tests) provided lots of insight into the individual effects of the spin vanes and all appendages.
  - Effect of SEPS evidenced (no rotation if SEPS removed)
  - Effect of HASI boom neutral if both stowed or deployed, but opposite effect by each boom (by design)
  - Study suggests that one HASI boom did not deploy during the whole descent. Not in agreement with analysis made, and conclusions reached by HASI team (Hamelin, et al.; Béghin et al); It would invalidate some of the HASI findings:
    - One boom did not deploy under main parachute, but full deployment under drogue chute
- This work: 1:3 mock-up wind tunnel tests with removable appendages (any combination testable) to explore further remaining
Why subsonic wind tunnel testing?

- It is possible to take into account laws of viscosity similarity for flight conditions in Titan’s atmosphere:
  - Reynolds number: $Re = \frac{\rho vD}{\mu}$
    - $\rho$ : Density ; $V$ : Flow velocity ; $D$ : Diameter
    - $\mu$ : Viscosity (local pressure and temperature)
The Malavard subsonic wind tunnel

Return test section 2.5×2.5 m² to 4×4 m²
Homogeneous flow and adjustable section
Atmospheric Boundary layer test section 3m × 5m × 16m
Vmax = 15m/s

Main test section: 2×2 m² - 5 m
Homogeneous flow, Vmax = 55 m/s
Turbulence level < 0.4 %

Aerodynamics for buildings
Wind turbine wakes
Wind turbine model

2-year (2018-2019) project involving students in short internships with strong educational objectives
Huygens model and configuration in wind tunnel

Simplified CAD model

1:3 mock up (diameter 452 mm)

Spin vane angle of 6.8° instead of 2.9° (SM2 :2.2°)

Mock-up mounted on a mast linked to a 6-axis aerodynamic load balance (located under the test section)

3D-printed appendages (RAA-HASI Boom – SEPS – TPP)

- Radar altimeter antennae – x 4
- HASI (Huygens Atmospheric Structure Instrument) deployable booms – x 2
- Heat-shield and back-cover separation mechanisms, or separation subsystems (SEPS) – x 3
- HASI study with pressure and temperature sensors
Huygens model and configuration in wind tunnel

Simplified CAD model

1:3 mock up (diameter 452 mm)

Spin vane angle of 6.8° instead of 2.9° (SM2 :2.2°)

3D-printed appendages (RAA-HASI Boom –SEPS – TPP)

- Radar altimeter antennae – x 4
- HASI (Huygens Atmospheric Structure Instrument) deployable booms – x 2
- Heat-shield and back-cover separation mechanisms, or separation subsystems (SEPS)
- HASI study with pressure and temperature sensors
Wind tunnel testing

- **First campaign: static tests**
  
  Spin rate effect on flow vs descent velocity

- **Measurement protocol:**
  
  - Balance reset before every different testing configurations
  
  - 6 components of aerodynamic loads and moments with simultaneous acquisition of test section temperature and pressure (density, wind velocity)
  
  - 30 second time series at a sampling frequency of 1 kHz
  
  - Mean value computation

\[
\text{Balance sensitivity: torque} > 0.3 \text{ N.m and wind velocity} > 5 \text{ m/s}
\]

Repeatability of the tests has been verified (at least 3 tests per configuration)

- **Numerous configurations tested:**
  
  Bare mock-up, model with spin vanes alone, model with spin vanes and each of the appendages separately and combination of appendages, HASI booms in closed or open configuration, fully equipped mock-up…
Preliminary results

Drag coefficient versus wind speed

\[ C_D = \frac{\text{Drag force}}{0.5 \rho V^2 S_{ref}} \]

- No significant Reynolds effects
- Drag is increased by appendages

Roll moment versus wind speed

- Spin vanes induce the correct roll moment (as designed)
- SEPS tend to attenuate vane effects
Effects of HASI booms deployement (Boom 1 – Boom 2) on the roll moment coefficient

\[ C_l = \frac{\text{Roll moment}}{0.5 \rho V^2 S_{ref} L_{ref}} \]

- Both open or closed booms induce similar roll moment (neutral effects with deployed booms)
- B2 open roll moment and B1 open roll moment are opposite
Conclusion and perspectives

- **Data processing in progress**
  - Spin behavior depends on spin vanes and appendages
  - Some qualitative results are consistent with previous results obtained by Vorticity Ltd
    - SEPS attenuate spin vane effects
    - HASI boom deployment effects on spin

- **Future work with the same testing conditions**:
  - SEPS effects have to be more deeply investigated
  - Comparison with Vorticity findings on deployed boom effects
  - Characterization of the flow close to the appendages
  - Effect of sideslip (yaw) angle in the wind direction

- **Further tests will be designed and conducted in order to investigate spin under dynamic conditions (2019)**