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

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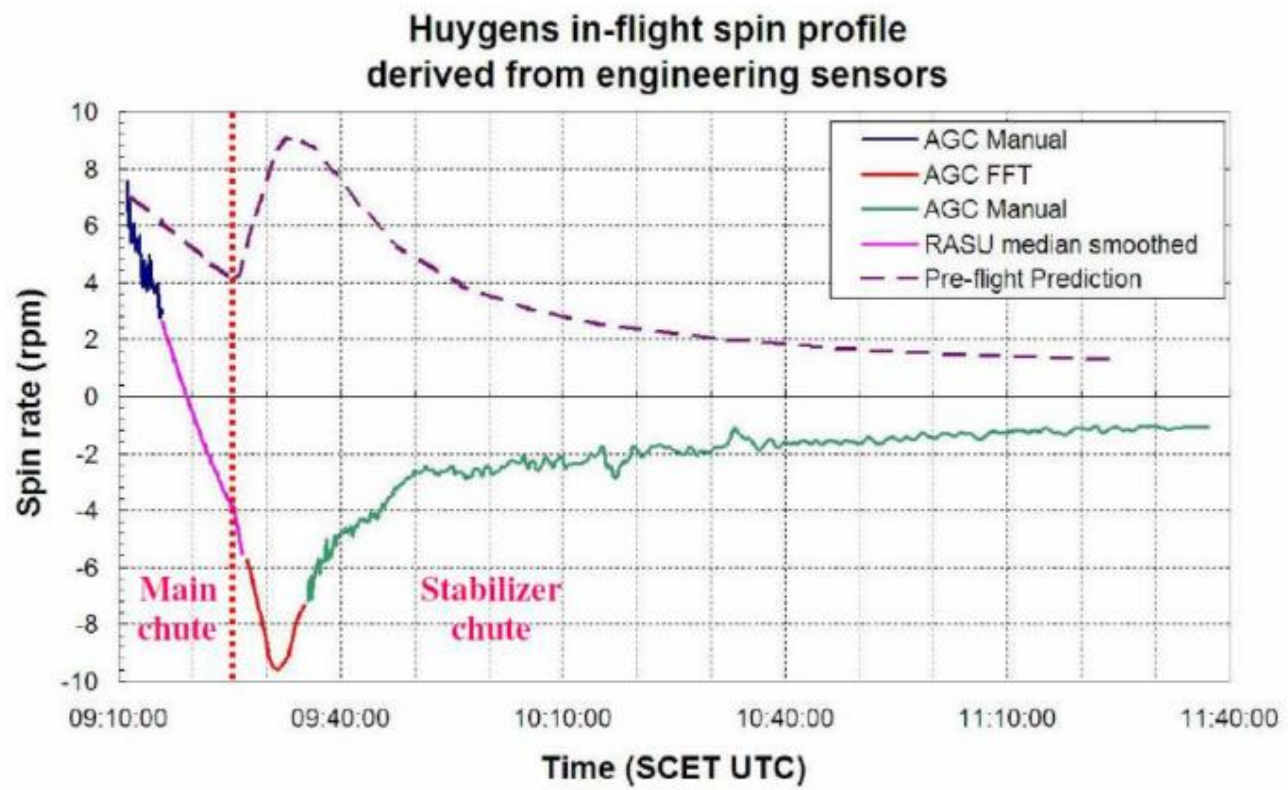
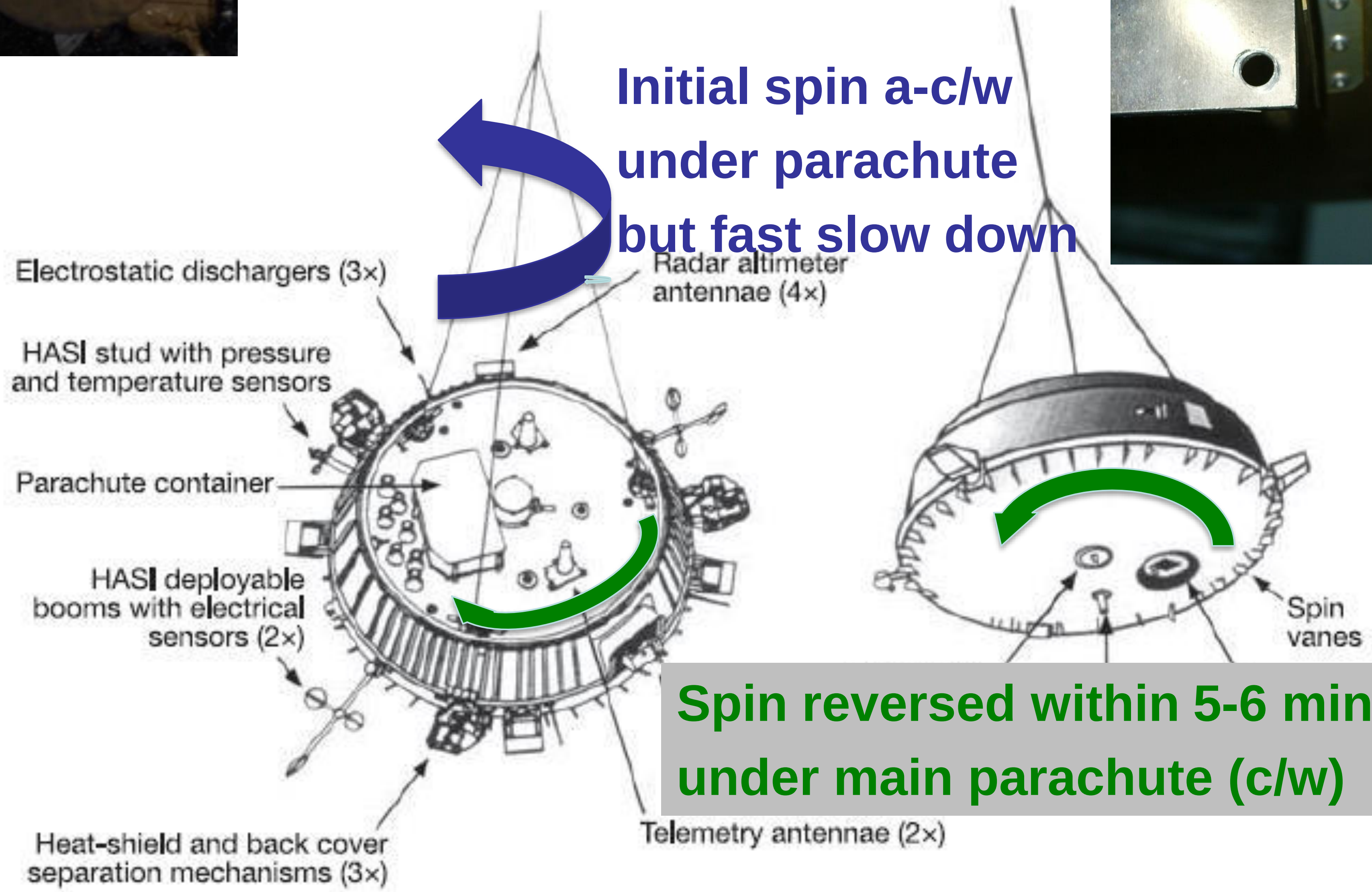
Huygens in-flight spin profile



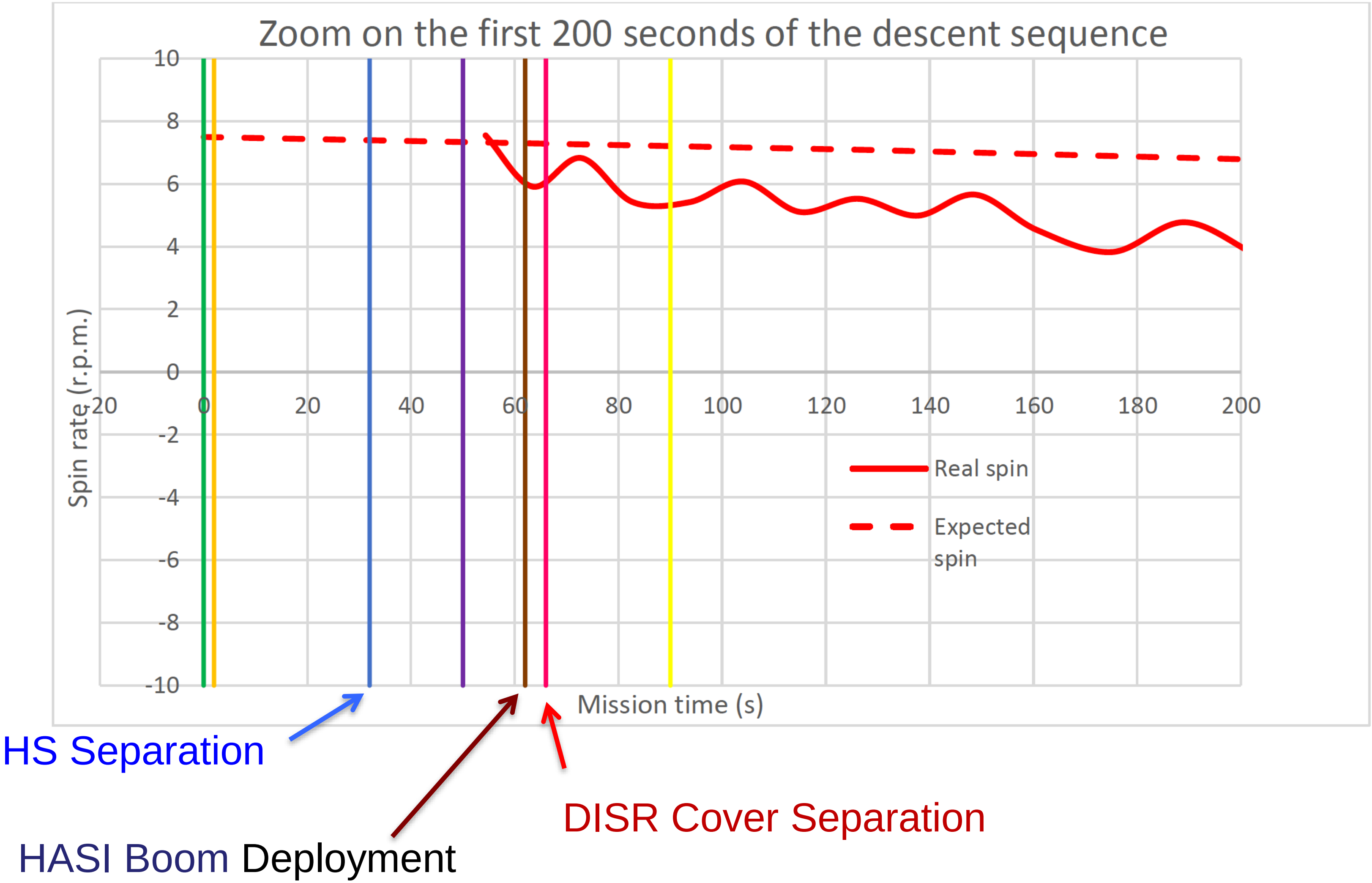
Spin under parachute



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



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: $Re = \frac{\rho V D}{\mu}$

ρ : Density ; V : Flow velocity ; D : Diameter
μ : Viscosity (local pressure and temperature)

PROBE ROTATION AND WIND-TUNNEL SPEED IN FUNCTION OF MISSION TIME

The *Malavard* subsonic wind tunnel

Aerodynamics for buildings

Wind turbine wakes

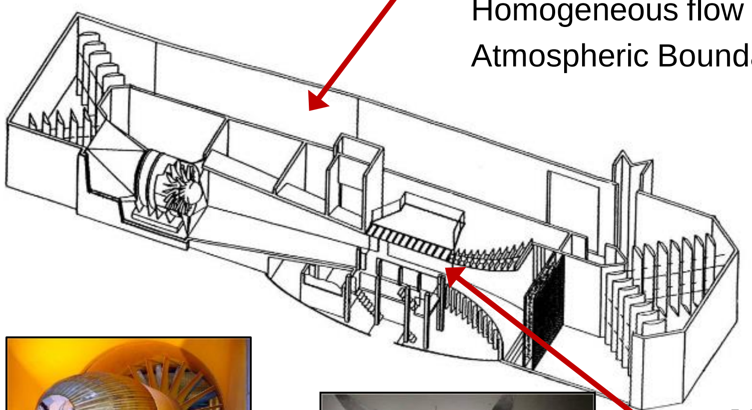
Wind turbine model

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 %

2-year (2018-2019) project involving students in short internships with strong educational objectives

Huygens model and configuration in wind tunnel

Simplified CAD model

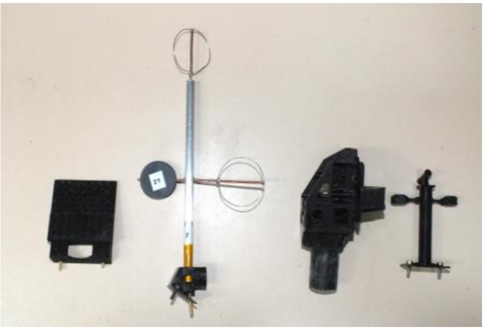
1:3 mock up (diameter 452 mm)

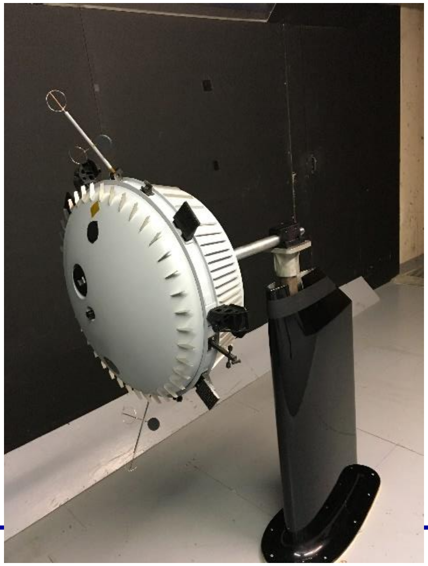
Spin vane angle of 6,8° instead of 2,9° (SM2 :2,2°)

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*





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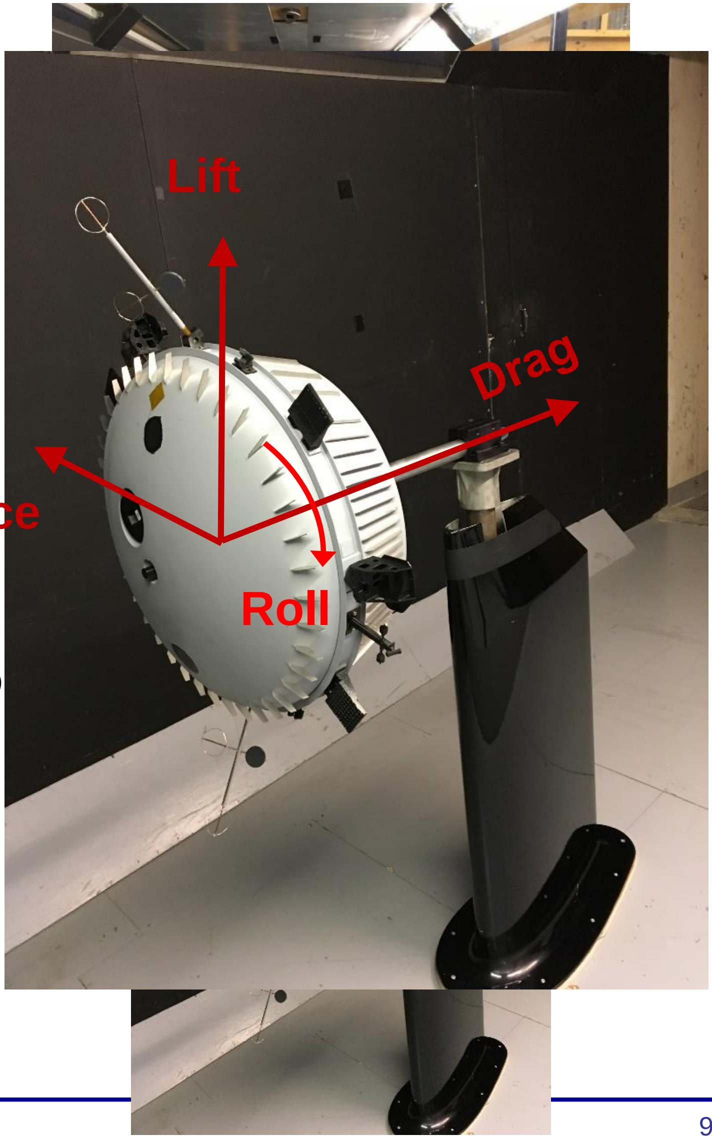

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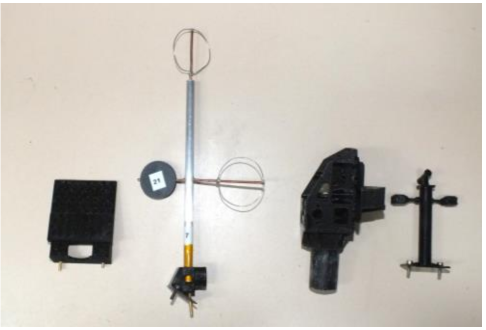


Wind tunnel testing

- First campain : static tests

  Spin rate effect on flow << 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

Balance sensitivity : torque > 0.3 N.m and wind velocity > 5 m/s

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

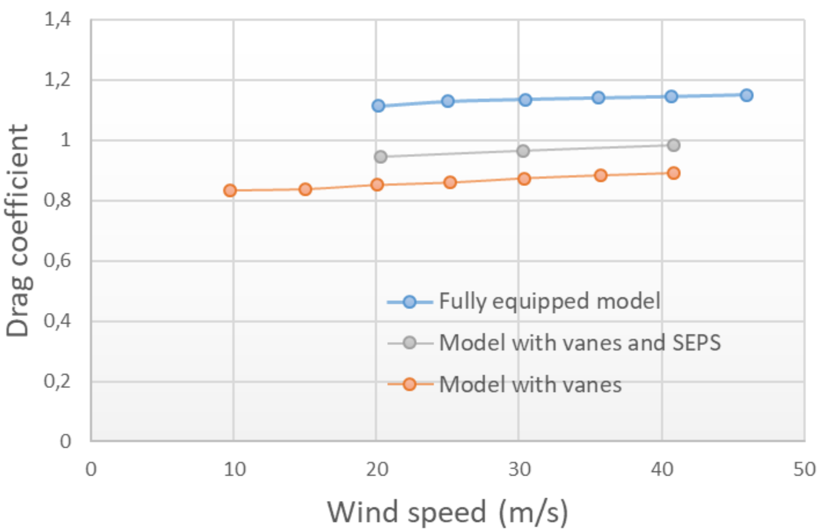
- Numerous configurations tested :

  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…

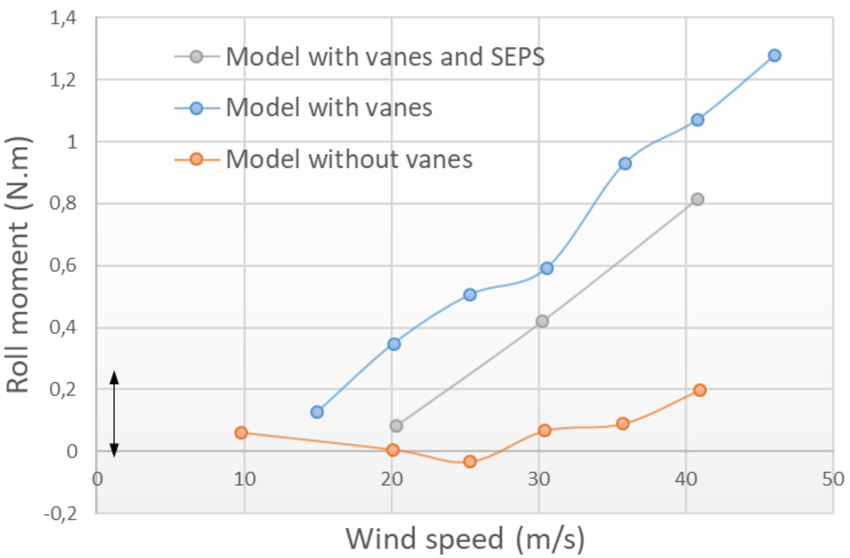
Preliminary results

Drag coefficient versus wind speed

$$C_D = \frac{Drag\ force}{0.5\,\rho\,V^2 S_{ref}}$$



Roll moment versus wind speed



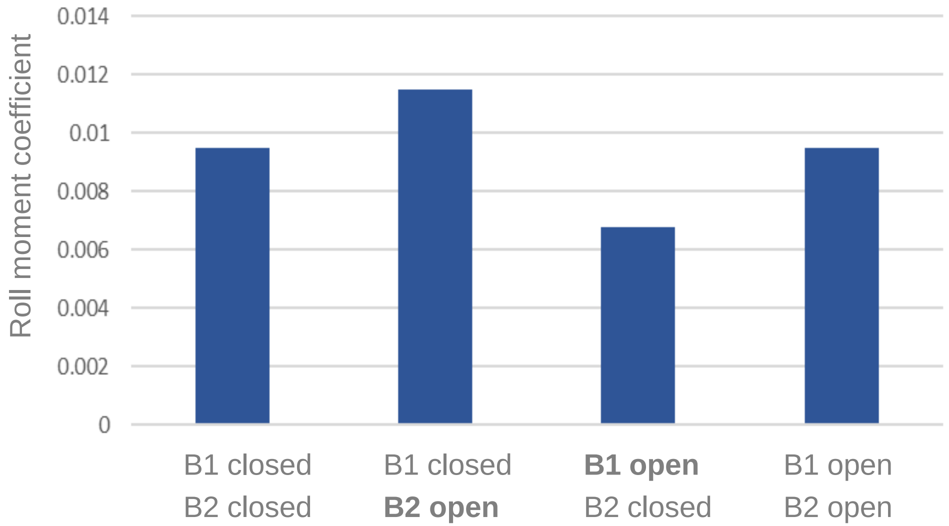
- ✓ No significant Reynolds effects
- ✓ Drag is increased by appendages

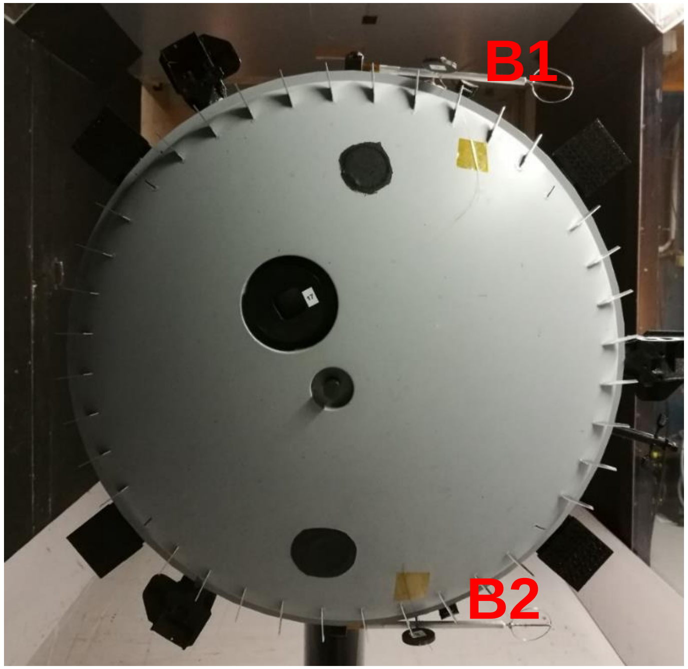
- ✓ Spin vanes induce the correct roll moment (as designed)
- ✓ SEPS tend to attenuate vane effects

Preliminary results

Effects of HASI booms deployement (Boom 1 – Boom 2) on the roll moment coefficient

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

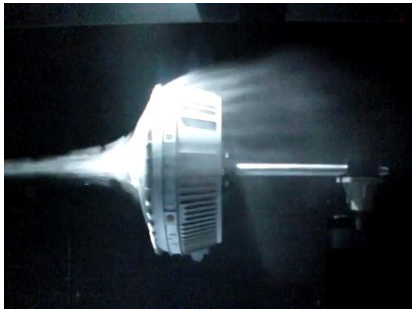




- ✓ Both open or closed booms induce similar roll moment (neutral effects with deployed booms)
- ✓ B2 open roll moment and B1 open roll moment are opposite

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)