"Test-as-you-fly" environments for planetary missions

(Adv. In Space Research, in review)

Ralph Lorenz

'A custom more honoured in the breach than in the observance'. Hamlet

Ralph.lorenz@jhuapl.edu
http://www.lpl.arizona.edu/~rlorenz
http://civspace.jhuapl.edu/our_staff/
http://www.imdb.com/name/nm1985744/

APL
JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

NASA Technology Readiness Levels (TRL) based on testing in ‘relevant environment’.

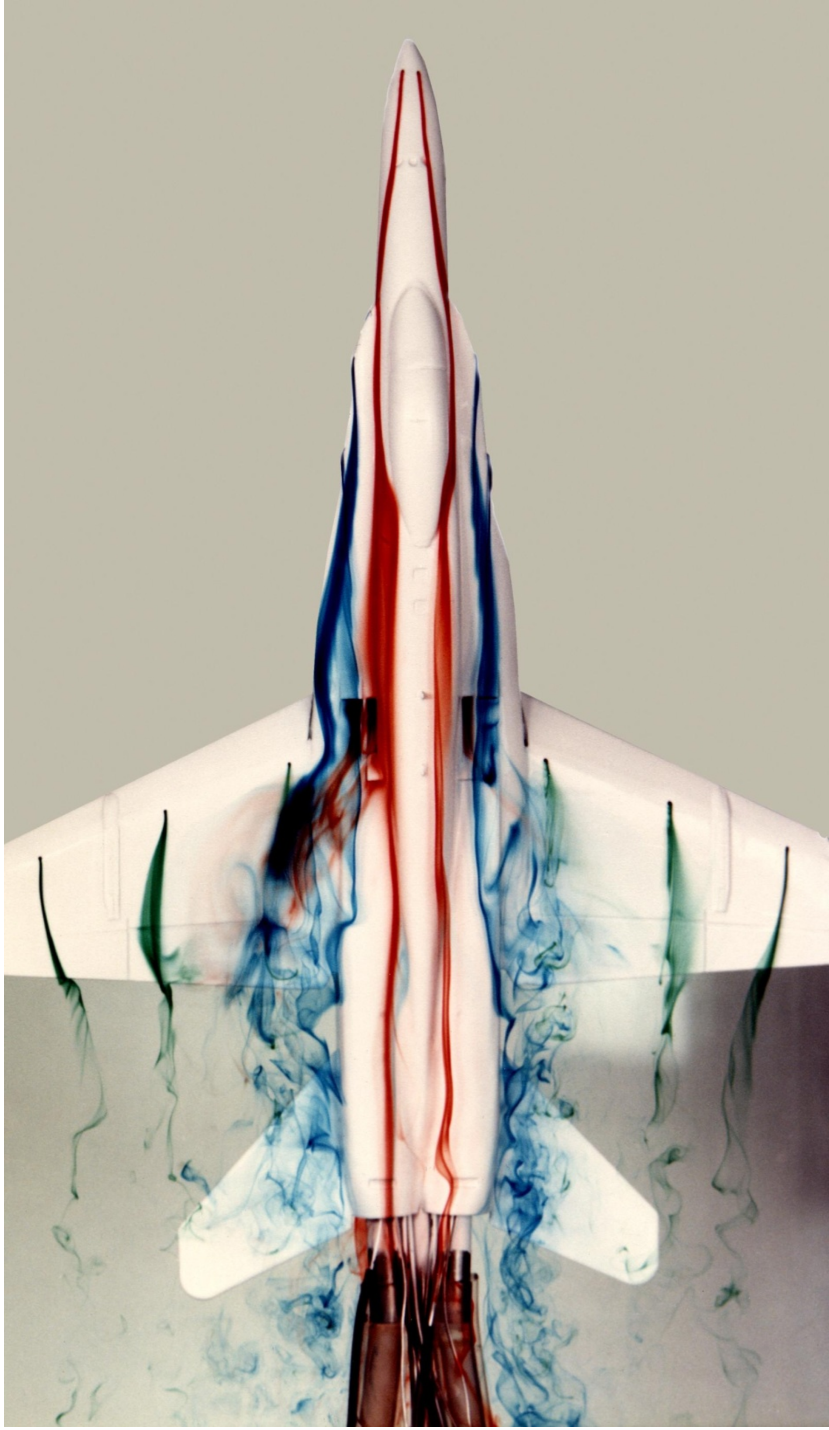
What does this mean ?

Perfect replication of environment for e.g. Titan Mare Explorer implies a 1.5bar 94K test chamber, filled with liquid methane, put inside the ‘Vomit Comet’ aircraft on parabolic flights to simulate 1/7g.

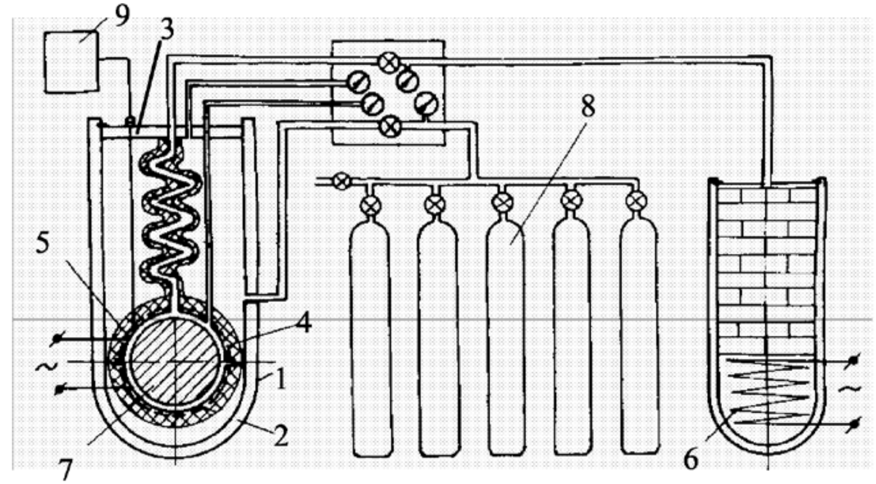
This is neither practicable, nor necessary. Nor, as this talk will show, has this level of fidelity ever been applied to complex full-scale planetary vehicles.

Is a cold nitrogen atmosphere at 1 bar good enough for Titan tests, or must it be 1.47 bar, with 5% methane, and 0.1% hydrogen, and 50 ppm argon, and……?

In aerodynamics, flow similarity (Mach, Reynolds numbers) has long been recognized as adequate – qv water tunnels.



Development Aspect	Similarity Desired (secondary criteria in parentheses)	Implementation & Limitations
Solid-body aerodynamics	Mach & Reynolds Number (sometimes Knudsen number for hypersonics; sometimes Strouhal number for vortex-shedding	Scale model wind tunnel tests; ballistic range tests; occasional full-scale drop test
Parachute characteristics (esp. inflation)	Dynamic Pressure and Mach Number (Reynolds Number; area loading/stiffness)	Wind tunnel test ; drop test (usually full-scale)
Aerothermo-dynamics	Heat Flux, Shear (Mach, Reynolds Number)	Arcjet testing (usually coupon testing to assess material response , rather than to predict loads at different locations on a vehicle)
Thermal Balance	Convective Heat Transfer Coefficient	Chamber tests at full scale. Gas density altered to compensate for effect of gravity on free convection. Wind rarely simulated.
Landing Dynamics and Ground Interaction	Froude Number (Splashdown)	Drop test (scale model or full scale). Sandbox tests at full scale



Early Veneras (4-8) had ‘cold’ structure, with external insulation. Insulation performance depends on gas, so CO2 at high pressure was used in some tests on full-scale vehicle.

Only subassemblies were tested on later (larger) Venera and VEGA landers !

Viking Lander

Thermal balance tests used CO_2 atmosphere for nominal, hot cases (insulation performance). Cold case test used 20 mbar Argon atmosphere, as CO_2 would have frozen on the chamber walls! Tests lasted several days.

Project had a Proof Test Capsule – even drop-tested from 1m.

Sandblasting tests were made on coupons of exposed materials (slightly soft silicone paint proved more abrasion-resistant than less compliant materials.)

Pioneer Venus CO_2

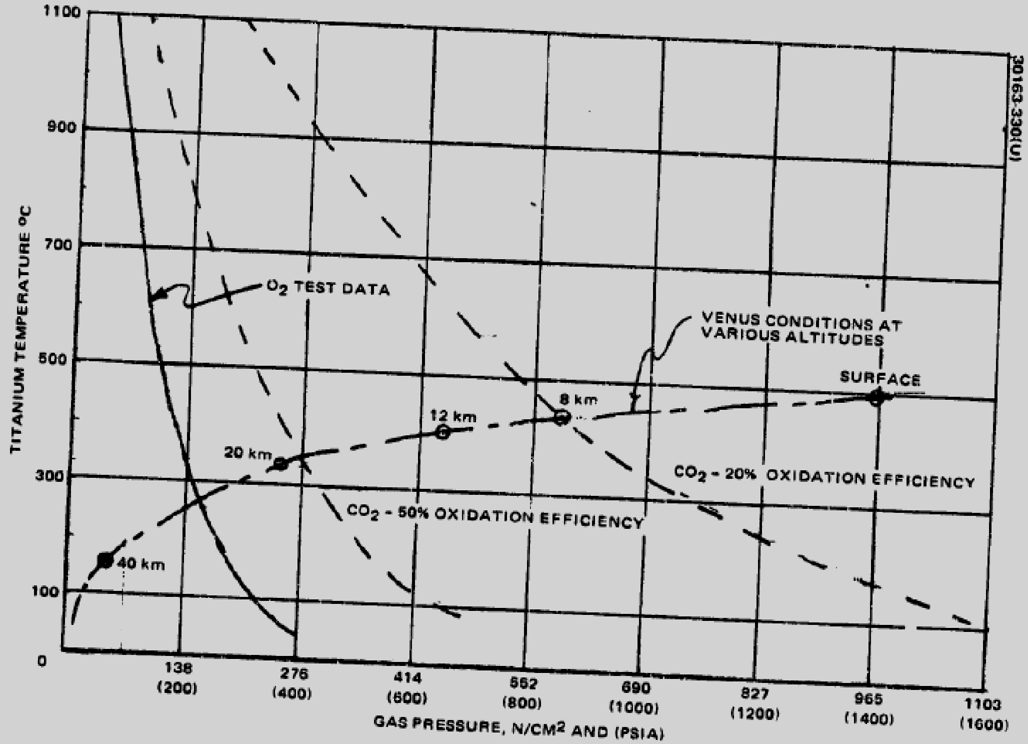
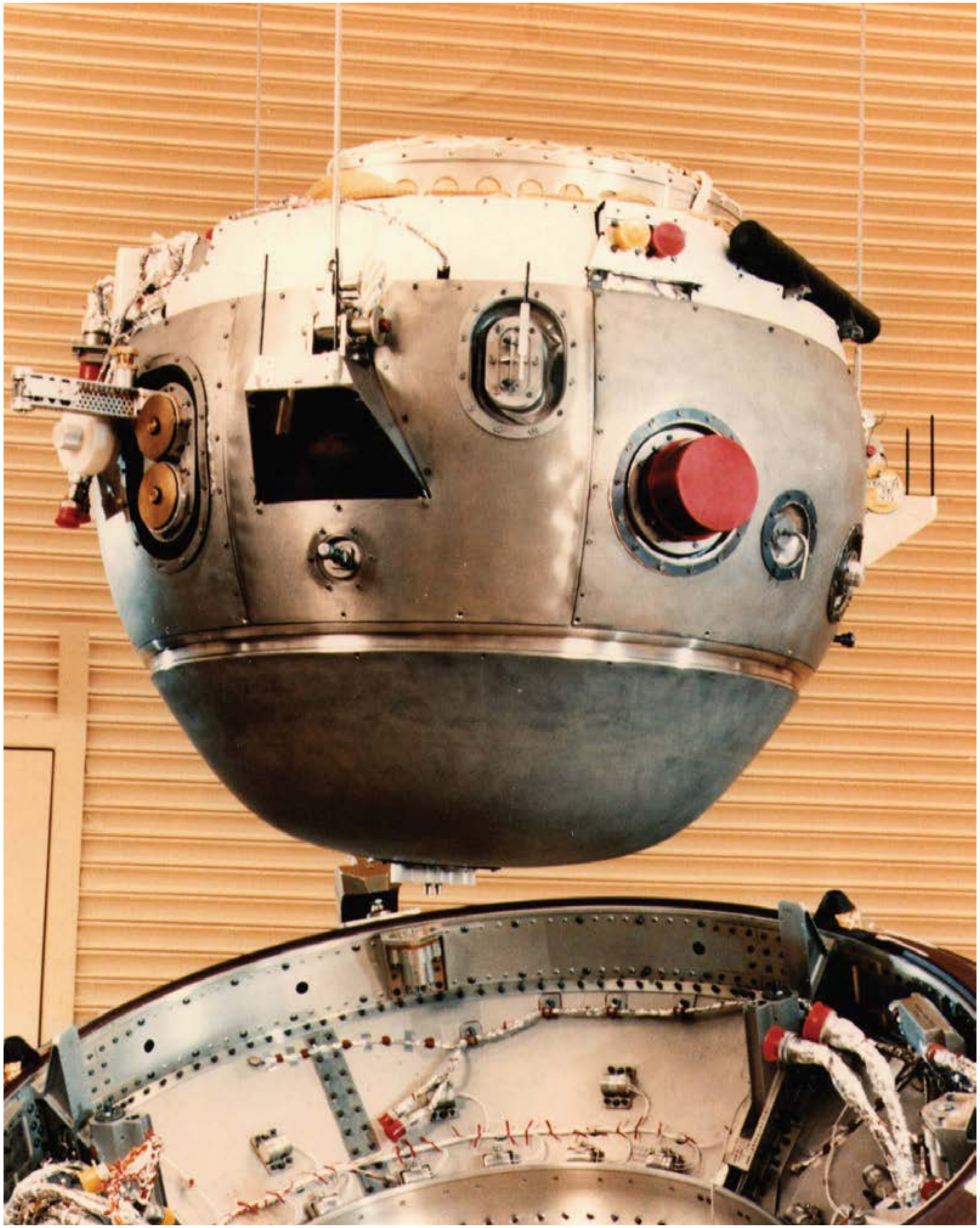


FIGURE 4.3-1. PRESSURE/TEMPERATURE CONDITIONS FOR AUTOIGNITION AND COMBUSTION OF SOLID OXIDE-FREE TITANIUM

Nolte and Stephenson (1973) present about 6 pages of discussion, backed with experimental data from several references, to determine that *'ignition and combustion of a titanium descent probe, with the resulting premature termination of the mission, is thought to be a very serious possibility'.* Embrittlement by mercury was another hazard considered.

Yet, "An extensive test program was conducted in December 1974 and it was concluded that there was no problem with the Venusian environment" and in January 1975 the design for both large and small probes was changed from maraging steel to 6Al-4V titanium alloy, with a significant mass saving. Pioneer Venus thermal/pressure tests made with nitrogen atmosphere. Some limited materials compatability testing (e.g. parachute fabric).

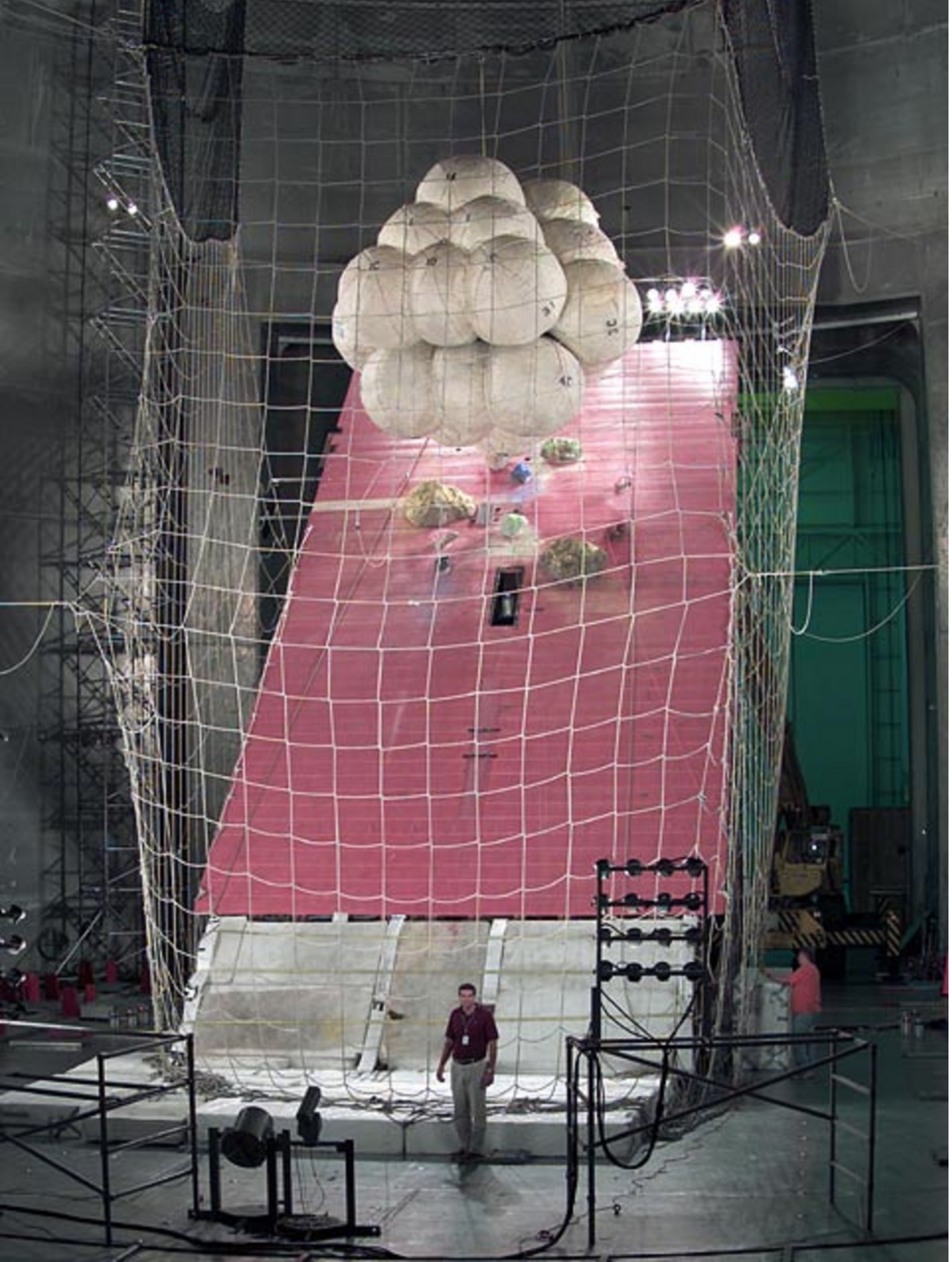


Galileo

Thermal balance tests done in Helium atmosphere (not H_2)

Significant deviation from predicted thermal behaviour observed in flight : believed to be enhanced internal convection due to rocking and spin of the probe.

Parachute fabric permeability test in He noted change in effective porosity.



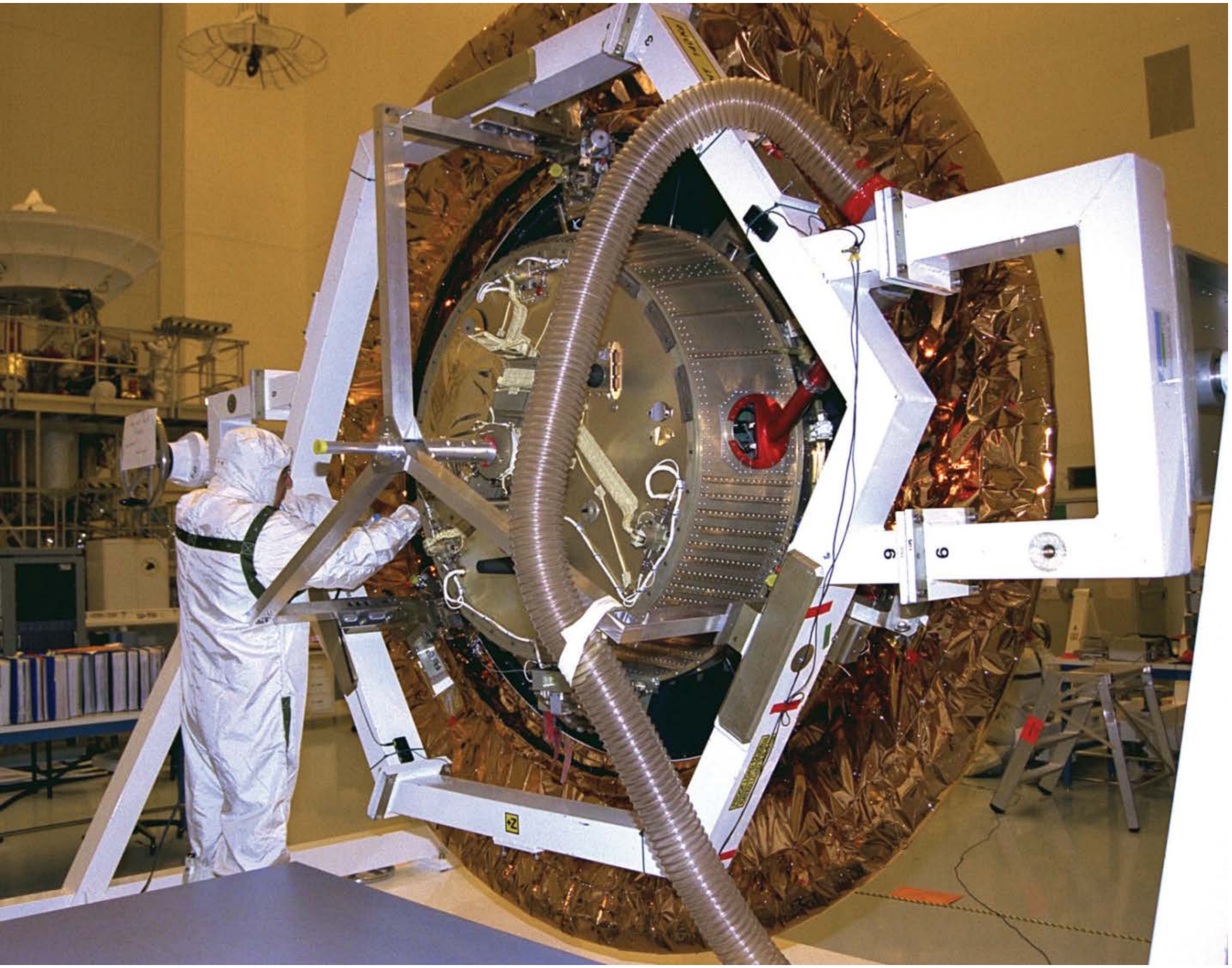
Mars Pathfinder

Early thermal tests in CO_2 atmosphere at JPL observed formation of CO_2 ice in chamber, most subsequent tests used N_2 atmosphere only.

Attempts to use fan to simulate wind were abandoned after motor burned out twice.

Impressive airbag dynamics tests at full-scale in 10mbar (air) atmosphere at Space Power Facility at NASA Glenn.

(Inflation tests at low temperature etc. done in smaller chamber)

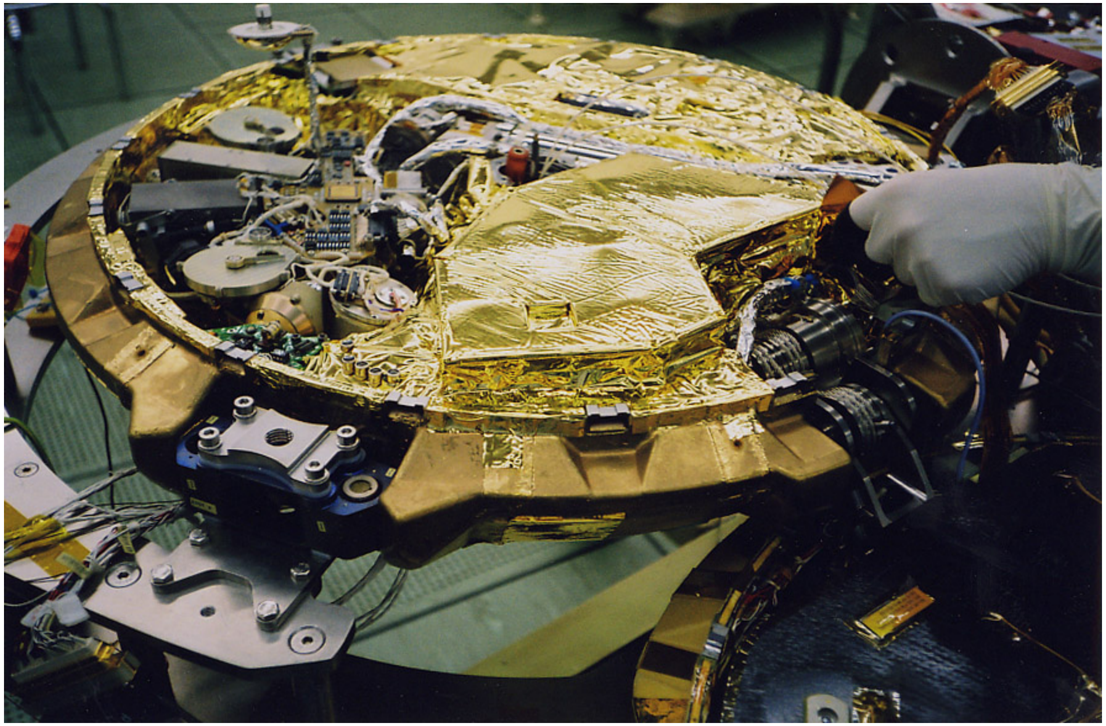


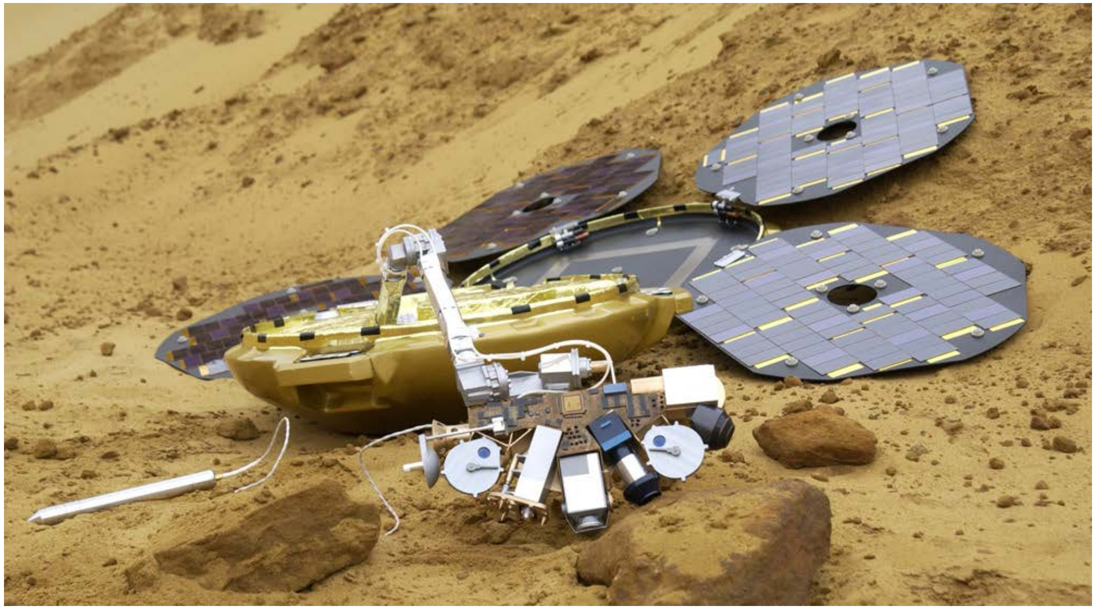
Huygens

Descent thermal balance test made in 600 mbar nitrogen (no methane).

Assumption that convective heat transfer in 600mb in 1g would be similar to that in 1.5 bar in 1/7g.

Note that even though surface pressure is 1.5 bar, descent started at ~mbar levels. GCMS instrument had pressure housing, gas-filled to inhibit arcing. (Must consider transitional environments too!)





Beagle 2

Small vehicle with limited power budget – thermal balance absolutely critical.

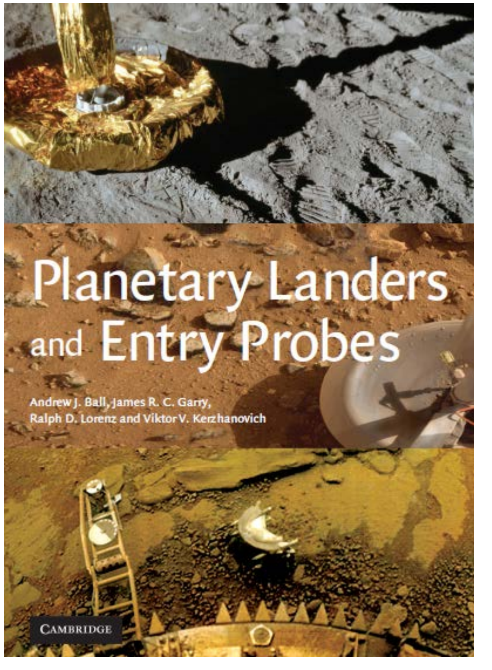
High-fidelity test chamber built allowing 6mbar CO_2 operation, including fan to blow air.

Lesson – limited value in investing in tests where environmental risks are small compared with other risks (e.g. launch)

Almost all unanticipated non aerothermodynamic effects attributable to atmosphere constituents are instrument-related. One example is Alpha particle scattering – the scattering effects of the Mars CO2 atmosphere appear not to have been fully recognized in the Mars Pathfinder APXS development.

Another interesting example (albeit one that had no impact on Huygens operations) is the surprising observation (J. Garry, MSc. Thesis) during testing of the Surface Science Package speed-of-sound sensor, that attenuation increased when the test chamber was being purged (i.e. certain nitrogen-methane mixtures absorbed more strongly than either pure methane or pure nitrogen..)

It is thus prudent to evaluate in detail (preferably experimentally) any genuinely new process-environment combination.



A. J. Ball, J. R. C. Garry, R. D. Lorenz and V. V. Kerzhanovich, Planetary Landers and Entry Probes, Cambridge University Press , 2007

Conclusions

The history of planetary probe development shows that even on flagship missions, the compositions of test atmospheres have been a compromise between fidelity and affordability – most Mars and Venus testing has been made in nitrogen atmospheres (not CO_2), Jupiter testing in helium (not H_2). *System-level* test atmospheres with minor constituents (e.g. CO_2+N_2 on Venus, or N_2+CH_4 on Titan) have **never** been performed in the history of spaceflight.

Deviations from predicted performance have usually been due to dynamic effects, not the fidelity of test atmosphere.

Better to do many imperfect tests early and understand, than to attempt a 'perfect' test, as it never actually will be so.

'Test as you fly' is a worthy goal. But if not quite a myth, it is at least 'a custom more honoured in the breach…'

This work supported by APL. Paper in review at Adv. Space Res.