The Huygens Radio Link Anomaly

Dr. Claudio Sollazzo, newly appointed ESA Operations Manager to the Columbus Control Center (Col-CC) at DLR Oberpfaffenhofen gave a seminar-lecture about his very interesting operations experiences about the Huygens Probe radio anomaly recovery as part of the Cassini Project. If not counteracted operationally this anomaly would have put the mission success of the probe in severe jeopardy.

SpaceOps News (SoN) had the opportunity to conduct an interview on the subject with Dr. Sollazzo expanding on the operational aspects.

SoN: Dr. Sollazzo could you give a brief summary of the Cassini mission?

Dr. Sollazzo: The Cassini-Huygens mission was conceived and implemented by a joint co-operation between NASA, ESA and ASI, to explore the Saturn system. The Huygens Probe (ESA) was transported from Earth by the Cassini Orbiter (NASA-JPL, launched in October 1997) on a 7-year voyage to an orbit around Saturn. On 25th December 2004 it was released by Cassini onto a course to encounter Titan, the largest moon of Saturn and the only planetary moon in our Solar system having a substantial atmosphere. The mission of the Huygens Probe was to enter the atmosphere and descend by parachute to the surface of Titan, sending back direct measurements of physical and chemical properties of the atmosphere and surface, as well as information about the Titan landscape.

SoN: What were the main operations principles for the Huygens Probe?
Dr. Sollazzo: The Huygens Probe was designed and built with redundancy in mind, it actually comprised two "Probes" each one performing its mission in parallel and independent of the other acting as redundant chains with few exceptions: commanding in cruise as well as during the actual mission was sent to both chains, chain B telemetry was delayed w.r.t. chain A by 6 seconds. The on-board instruments listened by default to the chain A computer, unless it became invalid. However there were some exceptions to this rule: science data telemetry was supposed to be channeled redundantly, engineering data from each chain was transmitted via that same chain i.e. essentially no cross-strapping between A & B chains existed.

SoN: How did you find out about the anomaly and how did it manifest itself?

Dr. Sollazzo: We found out during a planned in-flight Probe Relay Link Test performed on 3/4 February 2000 to characterize the Huygens receiver behavior with particular emphasis on signal and data detection thresholds. To our surprise unexpected behavior was observed at sub-carrier and data-stream level: although the Cassini Orbiter receiver performed nominally at zero-Doppler it showed anomalous behavior including loss of data when simulated mission Doppler (~5.6 km/s) was applied to carrier, sub-carrier and data. In addition an unexpected loss of data was observed at high values of link power. So, the end-to-end test uncovered this anomalous behavior on both Huygens receivers, which, if not being detected would have caused inability of the Huygens data receivers to track the Huygens Probe data stream during the entire Probe decent phase.

SoN: Following the established procedures warranted in cases like that a joint ESA-NASA task force was established. What were the findings and recommendations?

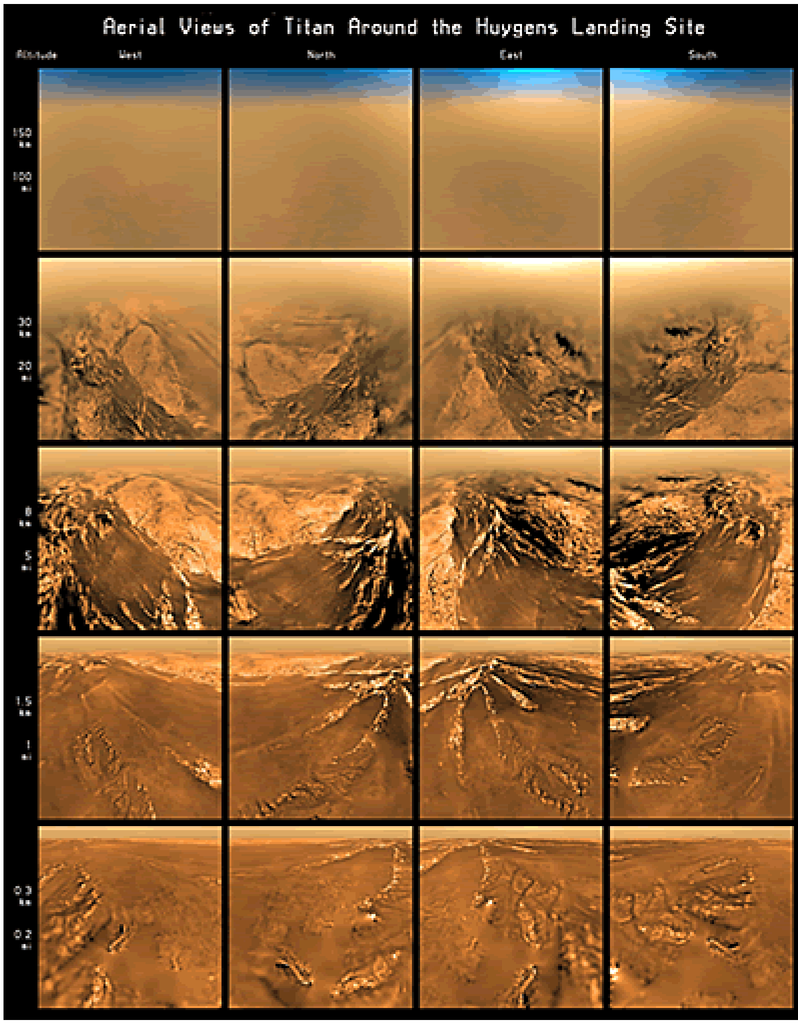
Dr. Sollazzo: The source of the unexpected behavior was the bit synchronizer in the Huygens receivers: its bandwidth being too small to accommodate the actual mission Doppler shift of +5.6 km/s of the data stream: At certain combinations of Frequency Offset, Signal to Noise Ratio and Data Transition Density the bit synchronizer loses lock on the data stream and a cycle slip occurs. These cycle slips cause data corruption, on-board sync detection failures and on-ground decoding failures. The consequence is a mixture of the following: a number of data frames after this event are directly rejected by the receiver; a number of data frames after this event, if accepted by the receiver, are rejected on-ground because they are corrupted beyond the recovery capability of the on-ground Reed Salomon-decoding mechanism implementation. The predicted data loss during the mission amounted to a scary 70-80 %, consequently the Task Force recommended to initiate a mission recovery plan.

SoN: What were the changes to the mission?

Dr. Sollazzo: A very thorough investigation into the design of the receivers enabled us to create a performance model allowing us to relate mission characteristics like geometry, to the overall frequency shift of the data stream. To implement the new Huygens mission, the old Cassini tour at Saturn had to be partly modified to produce an opportunity to appropriately reduce the Doppler shift between the Orbiter and the Probe. The necessary trajectory modifications have been concentrated in the first part of the tour: the first orbit period was reduced; the first Titan fly-by was moved to an earlier date, a second Titan fly-by (~2300 km) was newly introduced. The actual mission happening on the third fly-by (~60000 km) as a retrograde fly-by of the Orbiter, i.e the Orbiter is looking backwards during probe touchdown contrary to the original planned prograde Probe entry coverage by the Orbiter.

SoN: What operational changes were necessary due to the new mission design?

Dr. Sollazzo: The re-design of the Cassini Tour was primarily driven by two demands: first to introduce as little as possible additional delta-V and secondly a return to the original tour design as early as possible. The new tour incurred a propellant spending estimated to an End-of-Mission delta-v (99%) of about +75 m/s, however this was well covered within the propulsion margin.



The second part of the Huygens receiver anomaly recovery solution introduced the implementation of a 4-hour pre-heating strategy: this required to warm-up the Probe by turning it on 4 hours prior to entry in the atmosphere of Titan.

The Huygens PSA receivers on Cassini were designed to revert to a Doppler-shift mode in absence of carrier lock. As the new mission had a much lower Doppler shift than the original, the PSAs would fail to detect the carrier therefore the PSA was commanded every 12 seconds for the whole duration of the mission, to zero-Doppler-shift mode. As this would have corresponded to an unmanageable number of commands to be stored on-board Cassini for release to the PSAs, the Orbiter CDS software had to be modified to implement this mode as well.

SoN: Could you describe the actual system performance for the Huygens Probe entry?

Dr. Sollazzo: As can be seen from the returned images during the actual descent of the Probe the entry phase was not unproblematic at all. During the decent no data could be received on chain A due to the fact that the Huygens receiver USO accidentally was not powered however continuous data could be received via chain B throughout the descent and for 50 min on Titan surface. Minor data losses occurred -as expected- during the following 20 min before the Cassini Orbiter passed beyond the Probe's horizon. Probe RF carrier continued for > 122 min after LOS at Cassini Orbiter, as detected by Earth-based monitoring of the Probe carrier as part of the VLBI experiment. All equipment measuring deceleration behaved nominally detecting the entry, as well as the chute deployment and surface impact. The G-Switches also functioned nominally detecting the entry into the Titan atmosphere. All the 47 commands automatically issued by the Probe on-board software mission time tables have been verified. No problems in the Probe were identified but the internal temperatures were between 8-12 °C higher than predicted.

SoN: Were additional cost incurred for recovering the mission as explained?

Dr. Sollazzo: The re-design of the mission, the establishing of new procedures and the onboard software changes were basically covered in the operations budget, however additional industrial aid had to be requested above the original planned mission support.

SoN: Could you give us some summary conclusions on the overall mission results?

Dr. Sollazzo: After successful implementation of the mission recovery plan the Huygens mission was a great success in many respects. Huygens unveiled an unknown world by descending through a hazy, windy and turbulent atmosphere, floating down and drifting eastward for about 160 km taking in-situ measurements of the composition of the atmosphere and of aerosols. After landing Huygens determined the surface structure and composition of material at the landing site. Clear images of the surface obtained below around 50 km (see figure) revealed an extraordinary world resembling Earth in many respects: icy landscape with evidence of fluvial activity. In addition the Probe provided ground reference data for Cassini Orbiter remote sensing measurements like composition, structure and surface geomorphology. Science data return enabled a quantum-leap in understanding Titan, its evolution and current state. The combination of remote measurements by the Cassini Orbiter with in-situ measurements by the Huygens Probe proofed to be very beneficial. In conclusion I would say that International cooperation is mandatory for missions of breath and challenges that were -and still are- successfully coped with in the case of Cassini-Huygens. It took 25 years of work from hundreds of dedicated professionals from many countries to achieve the dream of landing on Titan and the dream lives on with the spectacular success of Cassini and its on-going tour of Saturn: the nominal Cassini mission will end in 2008; a two year extension is in planning.

Dr. Sollazzo, thank you very much for the interesting interview.

Interview by Joachim J. Kehr, SpaceNews Editor

For more information please refer to the "The Huygens Probe Mission to Titan: Engineering the Operational Success"
by C. Sollazzo, J. Wheaton, as presented during the SpaceOps Symposium Roma, 2006