

Status of Long-Duration Lander Capabilities Developed Under the LLISSE project. T. Kremic¹, G. Hunter¹, and C. Tolbert¹, ¹NASA Glenn Research Center, 21000 Brookpark Rd, Cleveland, Ohio 44135, ti-bor.kremic@nasa.gov

Introduction: Venus possesses unique challenges to scientists and spacecraft designers that are targeting in situ surface science. The cloud layers and dense atmosphere make standard remote sensing practices challenging and surface conditions are extremely challenging for landers, none of which have survived for more than ~2 hours. NASA has been tackling these challenges by investing in relevant technologies through programs like HOTTech and the Long-Lived In Situ Solar System Explorer (LLISSE) project. Investments have focused on a variety of technologies such as electronics, which were one of the topics for the HOTTECH-1 call. The LLISSE project was supported over several years until 2022 and this project uniquely focused on developing a full lander system including power source, avionics/electronics, communications system, sensors and instruments, the structure, as well as the fundamental aspects for all these areas such as material capability. This presentation will focus on the technical progress and expected state of the technologies developed under the LLISSE project.

Objectives of the LLISSE project: The objectives of the LLISSE project were to develop technology to enable a small and innovative long-duration lander for the Venus surface which would operate for 60 or more Earth days on Venus returning the first ever temporal science data. The science objectives are traced to the decadal survey and include understanding planetary atmospheres, climate, surface atmosphere interactions and weathering processes, energy deposition and balance and more. This data would be relayed through a Venus orbiter. Details on the LLISSE lander (physical characteristics, science objective, instruments and concept of operations) can be found in a white paper submitted during the planetary science decadal review process [1].

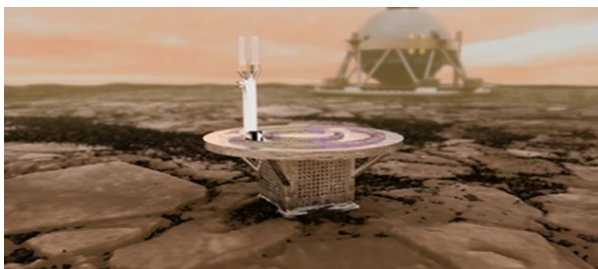


Figure 1. LLISSE Concept Model

Development by Major Subsystems: The major subsystems for a long-duration Venus lander, and therefore LLISSE, are Power, Electronics, Communications, Instruments and Sensors, and Structure/Mechanisms. A brief status is provided for each major subsystem.

Power is arguable the most difficult technical challenge on the surface of Venus. The first generation LLISSE will be powered by a high-temperature primary battery. The battery is an evolution off thermal batteries that have been used for many years but tailored for the specific needs at the Venus surface and long lived mission requirements. LLISSE funded development has produced a battery system that has achieved ~2x the required life of 60 days (120 days) at Venus temperatures under simulated loads that are representative of what the actual lander would experience. The battery development effort has shifted to packaging to minimize opportunities for early failure and account for potential anomalous conditions such as off-angle operations.

Through LLISSE development efforts, the needed high-temperature electronics (operating at 460°C or higher) has increased in complexity (devices per integrated circuit (IC)) by ~2 orders of magnitude. Many of these ICs and devices have operated successfully in Venus simulated conditions (temperature, pressure and chemistry) unpackaged for up to 60 days. Current activities are to address potential failure points, increase yield rates, further increase complexity, and reduce overall power requirements. At the time of this writing, fabrication is occurring on a set of devices that, if successful through the fabrication process, will be able to demonstrate LLISSE capability on Venus for 60 days.

The communications subsystem is perhaps the most complex and highest risk area for a long-duration Venus lander. This is because this subsystem must process the most power and at a high frequency relative to other LLISSE elements. In fact, the communication subsystem requires that LLISSE develop robust Bipolar Junction Transistor (BJT) devices in addition to the Junction Field Effect Transistor (JFET) devices used elsewhere in the electronics. BJT will not only enable the needed performance but will allow for higher frequency operations and have the additional benefit of providing better performing power switches.

At the time of this writing, all the critical components of a Silicon Carbide BJT have been developed and are in assessment / test phase, with good results to

date. If the remaining assessment and full device fabrication meets expected characteristics, the devices will be incorporated in the overall circuit design and build activities, eliminating the highest risk item in the overall LLISSE system. The other notable challenge with the communication subsystem has been the antenna material and design. Both of aspects have been in work and recent progress has been made. A material has been identified that has the electrical properties required, is compatible with the Venus surface environment, and is manufacturable at the scales needed. This material has passed testing to date and is currently in long duration testing under Venus conditions. Including chemistry. If this final test proves successful as anticipated, risks associated with the antenna system are significantly reduced.

LLISSE's instruments and sensors are at various levels of maturity, most in the TRL 4-5 range. The range of readiness is due to the fact that not all sensors started their development efforts at the same time and because some instruments are more difficult to develop than others.

The temperature sensor is most mature with several examples operating in Venus conditions for 60 days. The Makel Engineering chemical species sensors for 4 gases has also been demonstrated in Venus conditions and successful operated, as has a single axis wind sensor, which captured gas injections in the Glenn Extreme Environment Rig (GEER) during testing. Two approaches to the pressure sensor are in development with competing techniques to address the need to measure small pressure changes in a high absolute pressure environment. The radiance sensor development started a later than other sensors and is the least mature (TRL 3) for that reasons.

The LLISSE structure will hold and protect the other subsystems during deployment and serve to maintain appropriate orientation. A notional bus has been included in an integrated system test that housed electronics boards and cable interconnects. There is one mechanism on LLISSE and that is to lift a mast (that hosts sensors e.g. wind measurement) from horizontal position to vertical. Several approaches have been explored including a novel shaped memory based allow approach that requires no power and will inherently lift the mast to its final position and maintain it there at Venus surface temperatures.

Summary: The LLISSE project has been developing all subsystems necessary for long-duration Venus lander to operate and return data for 60 day or more. Significant progress has been made on all subsystems. The team is working to enable a test of a LLISSE in 2023 that is expected to will demonstrate breadboard level system operations in Venus conditions (GEER).

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References: [1] Kremic, T., et al. 2021, <https://assets.pubpub.org/fhm6bv7l/21617915343249.pdf>.

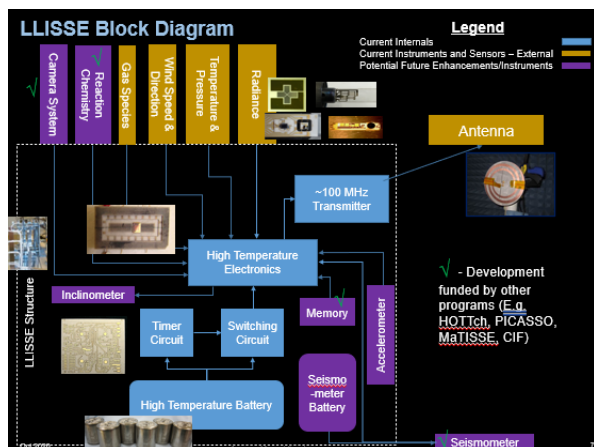


Figure 2. LLISSE Block Diagram and images of hardware for each subsystem