

# Sensor System Development for Long-Lived Venus Surface Lander Applications

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Space Administration



G. W. Hunter, T. Kremic, J. D. Wrbanek, M. C. Scardelletti, P. G. Neudeck,  
NASA Glenn Research Center

D.B. Makel  
Makel Engineering, Inc.  
Chico, CA



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# Long-lived lander In situ Solar System Explorer (LLISSE)

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- LLISSE is a small long-duration lander for Venus
  - Designed to be an independent platform with all the needed subsystems (power, communication, sensors, etc..).
- ~ 10 kg, < 20 cm/side at the base
- Operates for 60 days or more on Venus (> Solar day)
- Enable compelling science by returning first ever temporal In situ data: Meteorology (temp, pressure, radiance, winds) as well as atmospheric specie abundances and their variability
- Transmits measurements to a supporting orbiter, which is needed to relay the data to Earth
- LLISSE is a platform that can be expanded to achieve more or other targeted science (E.g. SAEVe, VBOSS)



# Surface Technology Development Overview

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- Technologies relevant for Venus surface applications may often have their origin in other harsh environment applications e.g., aeronautics or industrial processing
- Material systems and engineering approaches standardly used for even harsh environment terrestrial applications may not be viable for Venus missions
- A major challenge is operation in Venus surface conditions without significant degradation and for extended periods of time
- Testing of proposed technologies in first at high temperature leading up to Venus simulated conditions include relevant chemistry, is core to technology advancement
- The status of Venus technology development is in some cases at the level of 1970's to 1980's technology; at these levels significant science can be accomplished.
- A mission needs a complete compliment of relevant technologies for success

GEER: 92 atm, 465 °C +  
chemical composition  
found at the surface of  
Venus (CO<sub>2</sub>, N<sub>2</sub>, SO<sub>2</sub>, H<sub>2</sub>O,  
CO, OCS, HCl, HF, and H<sub>2</sub>S)



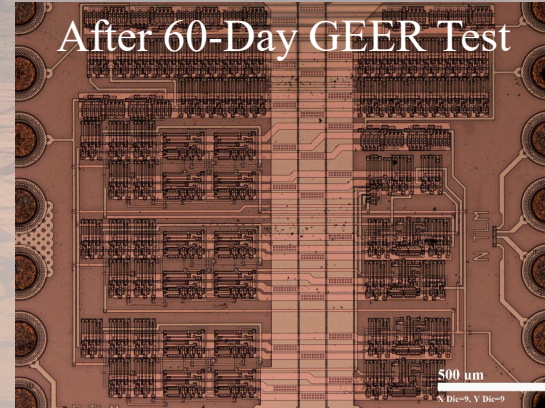
**GLENN EXTREME  
ENVIRONMENT RIG**

# Material Choice (and GEER Testing) Matters

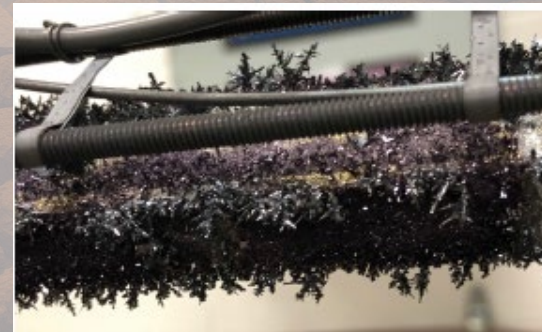
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## SiC Clock IC Chip Optical Microscope Photos (These IC Materials Work - Chip operated for 60 days)



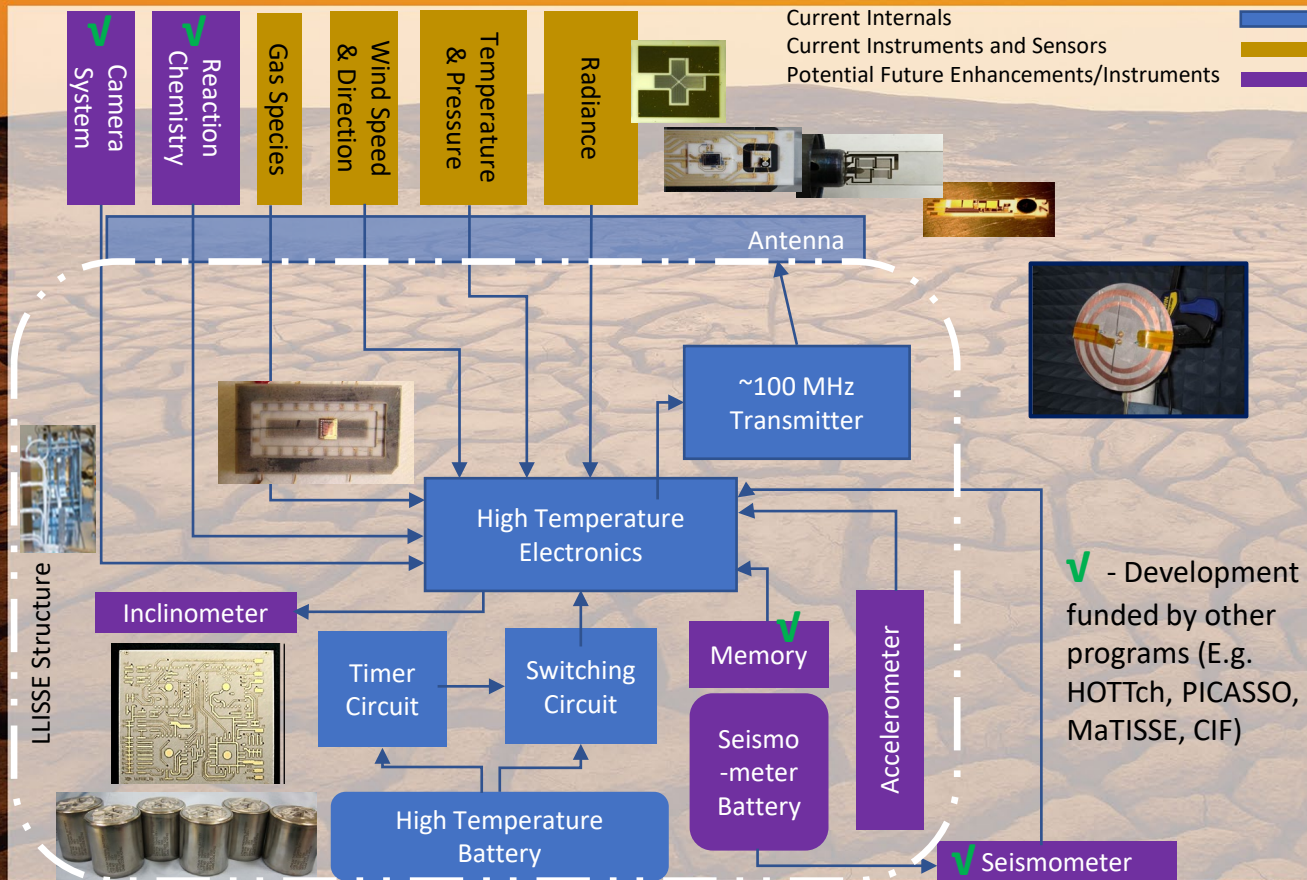
## Wave Guide Before and After 60 Days of GEER Testing (These materials react – grow crystals – will NOT work)



# LLISSE Block Diagram

## Legend

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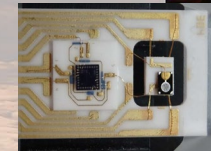
✓ - Development funded by other programs (E.g. HOTTch, PICASSO, MaTISSE, CIF)

## Broad Array Of Sensor Technology For Venus Applications Leveraged From Aeronautics Development

- Long History Of Active Development of Harsh Environment Smart Sensors Systems For Engine Test Stand, Health Management, and Intelligent Engines
- Multiple Demonstrations/Applications e.g., Including On-wing Engine Testing

## Development Approach

- Miniaturized Sensor Systems Produced By Microfabrication Techniques and High Temperature Compatible Materials
- Parallel Development Of Multiple Sensor Types
  - Multiple Chemical Species
  - Wind (2 Directions)
  - Temperature
  - Pressure
  - Radiance
- Each Sensor is at a Different Level of Maturity



Courtesy of D. Makel,  
Makel Engineering, Inc.

**SiC Electronics  
Combined With  
Chemical Sensor for  
GEER Testing**



**High Temperature  
Pressure Sensor**

# LLISSE Sensors Background

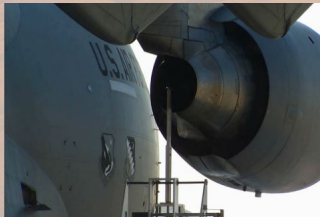
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- Significant History Of MicroSensor Development For Aeronautic Applications Including Demonstration of a Multiparameter Sensor Array On An On-wing Engine of a C-17 Aircraft
- Building from this base, LLISSE Sensor Development Targeted Toward Venus Specific Applications and Measurement Targets

## LLISSE Measurement Targets: Notional

Sensor	Description	Number	Sensor Input	Sensor Output	Draft Requirements				
					Target Min	Target Max	Target Accuracy (+/-)	Success Criteria Min/Max	Success Criteria Resolution
Wind Sensor	Cantilever with strain gage	3 perpendicular	voltage	voltage	0.25 m/s	2.5 m/s	0.1 m/s	0.5-2.5 m/s	0.25 m/s
Temperature Sensor	RTD in electronics	1	current	voltage	450°C	490°C	0.2°C	450-470°C	0.2°C
Pressure	Resistive or Capacitive	1	voltage	voltage	80 bar	95 bar	1 % full scale	80-90 bar	5% full scale
			capacitance	voltage					
Radiometer	Thermopile	1	voltage	voltage	4 W/m <sup>2</sup>	25 W/m <sup>2</sup>	2 W/m <sup>2</sup>	4-25 W/m <sup>2</sup>	2 W/m <sup>2</sup>
Chemical Species	SOx	1	voltage	voltage	0	400 ppm	0.3 ppm	3-400 ppm	1.6 ppm
	H2O	1	voltage	voltage	0	100 ppm	1 ppm	5-100 ppm	0.4 ppm
	OCS	1	voltage	resistance	0	50 ppm	1 ppm	5-50 ppm	0.2 ppm
	CO	1	voltage	resistance	0	50 ppm	1 ppm	5-50 ppm	0.2 ppm
	HF	1	voltage	voltage	0	5 ppm	0.5 ppm	1-5 ppm	20 ppb
	NO	1	voltage	voltage	0	10 ppm	2 ppm	4-10 ppm	39 ppb
	N2	1	voltage	voltage	0	5%	0.10%	0-5%	0.02%



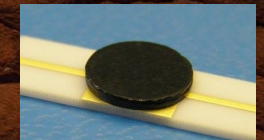
Sensor Array Testing on an On-Wind C-17 Engine



Chemical Sensor Probe



Wind Sensor Cantilever



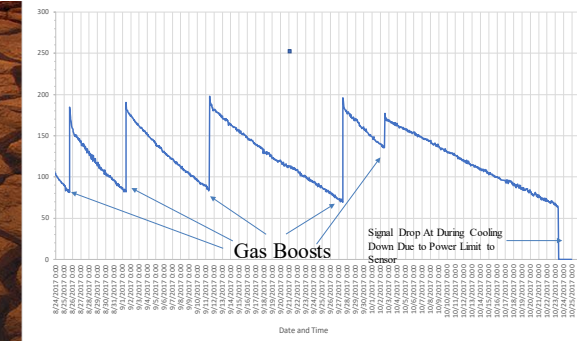
Capacitive pressure sensor

# LLISSE Chemical Sensors Summary

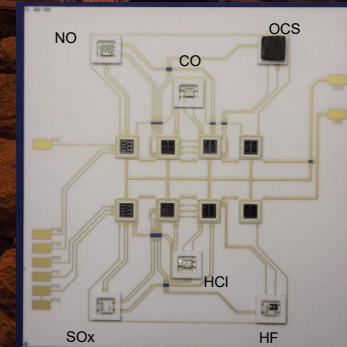
SO<sub>2</sub> Sensor Operation in GEER for 60 Days in Venus Simulated Conditions

- **Background: Sensor Array Developed Under Completed NASA Phase I and Phase II SBIR**
  - Demonstrated Measurement of Key Species Including SO<sub>2</sub>, H<sub>2</sub>O, OCS, CO, HCl, and HF Under Relevant Conditions
  - Sensors are selective to targeted species with minimal cross sensitivity to other species in Venus atmosphere
- **Status: Development of Chemical Sensors (including GRC sensors)**
- **Integrated with NASA GRC SiC Electronics On-Going in HOTTech project** Four Chemical Microsensors (SO<sub>2</sub>, CO, OCS, HF) Tested for 60 days in Venus Simulated Conditions in GEER
  - All 4 Sensors Operated Nominally During 60 Day Test
  - First Demonstration of In-Situ SO<sub>2</sub> Tracking in GEER for Extended Periods
    - HF Sensor Integrated With Signal Transduction/Amplification SiC Electronics Monitored HF Boosts in GEER 10 Day Test
- **TRL Summary:** Four chemical sensors successfully tested in Venus conditions for 60 days with SO<sub>2</sub> sensor tracking concentration changes and consistent with gas chromatograph readings. HF sensor with SiC electronics responded to concentration changes in 12 day testing. Near term permanent installation in GEER planned

Type	Date	GEER GAS ANALYSIS	SENSOR	Δ ppm
Pre-boost	8/25/2017	89.4	84.7	4.7
Post-boost	8/28/2017	132.2	126.9	5.3
Pre-boost	9/1/2017	82.6	83.3	-0.7
Post-boost	9/1/2017	178.0	180.9	-2.9
Pre-boost	9/11/2017	76.7	83.5	-6.8
Post-boost	9/11/2017	186.0	186.8	-0.8
Pre-boost	9/27/2017	64.8	71.4	-6.6
Post-boost	9/27/2017	177.2	183.2	-6.0
Pre-boost	10/2/2017	139.8	135.6	4.2
Post-boost	10/4/2017	161.6	159.5	2.1
Post-boost	10/18/2017	80.0	88.8	-8.8
Post-boost	10/20/2017	70.0	80.9	-10.9



Multiparameter Sensors Board



# LLISSE Wind Sensor Summary

- **Background: Drag-Force Anemometer (Cantilever) Baseline Approach with Significant History of Demonstrations in Engine Environments**
  - Full Bridge Strain Gage Approach Allows Flow Measurements with Minimal Power Consumption
  - Force of Wind Bends Cantilever; Deformation Measured Using Strain Gages.
  - Wind Speed/Direction Determined Using 3 Perpendicular Cantilevers
- **Status: Wind Sensor Tested in Wind Tunnel and Multiple Times In GEER Environment Showing Viability of Approach**
  - Core Material Compatibility Demonstrated
  - Wind Sensor Integrated with Electronic Amplification Has Shown Ability to Track Gas Flow in GEER Simulated Venus Conditions
  - CFD Models Suggest LLISSE Structure Would Not Inhibit Wind Measurement
- **TRL Summary:** Prototype versions with high temperature electronics designed and tested in Venus conditions. Tracking measurement of environmental changes in Venus conditions demonstrated. Improvements to sensor and driving electronics towards meeting LLISSE specs designed and in fabrication. Integration and testing in a multiaxis system needed.

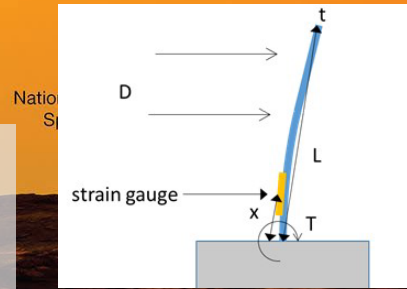
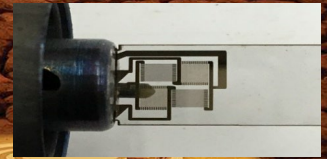


Diagram of drag-force anemometer cantilever



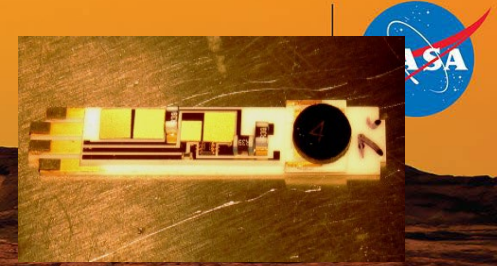
Wind Sensor Strain Gage Full Bridge assembly





# Pressure Sensor Summary

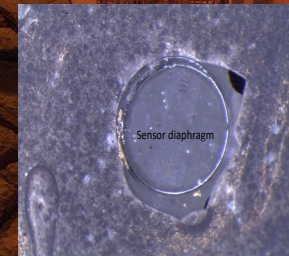
- **Background: Significant History In Development Of Pressure Sensor Systems, Including On-engine Testing And Commercialization. Two Major Sensor Types:**
  - Resistive Pressure Sensors: Mature, Commercialized, and Demonstrated in Engine Environments
  - Capacitive Pressure Sensors: Simpler Measurement System/Electronics and in Development
  - Aeronautics and SBIR Funds Support Development
- **Status: Parallel Path Development Approach Until Operational Sensor Demonstrated**
  - Both Sensor Types Viable For Venus Surface Applications
  - Multiple GEER Tests Conducted, including Pressure Sensors With Electronics.
  - Pressure Sensors Yet To Provide Relevant Durability/Dynamic Range In GEER Conditions
- **TRL Summary:** Two wide pressure range sensor designs demonstrated in harsh conditions. Demonstrated integration with electronics, and 12 days of operation/ 60-day survival of sensor element in Venus conditions. Meeting LLISSE measurements specifications is next focus.



Capacitive Pressure Composed Of Silicon Carbon Nitride (SiCN) With Electronics



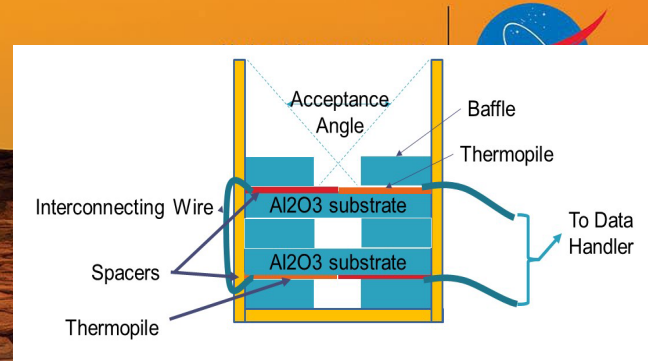
Resistive SiC pressure sensor in preparation for evaluation in GEER.



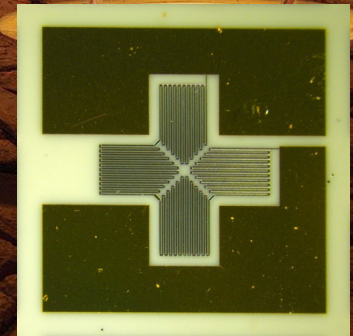
Optical Images Of Resistive Pressure Sensor Face After GEER Testing: Structure Maintains Integrity

# Radiometer Sensor Summary

- **Background: History of Radiometer Measurements Including on Pioneer Venus. Objective is to measure both Upward and Downward Looking Net Flux Rates From the Venus Surface**
  - Overall Net Flux Rates Are Bounded By These and Other Measurements with Modeling
  - Bolometer is the Sensor in a Radiometer Instrument That Measures the Temperature Change From Absorbing Radiant Power and Can Be Based on Thermopiles
  - Notable History of High Temperature Thermopile Development
- **Status: Approach Toward Radiometer Design Established Based on Past Development and Initial Bolometers Fabricated**
  - Activity Initiated Later in the Project; Earlier State of Development
  - Baseline Radiometer Design Identified Based on High Temperature Thermopile Approach
  - Initial Thermopile Materials Identified and Prototype Fabricated
- **TRL Summary:** Baseline design approach established and prototype bolometer sensors fabricated. Relevant materials tested in Venus conditions



**Schematic of Baseline Radiometer Approach**

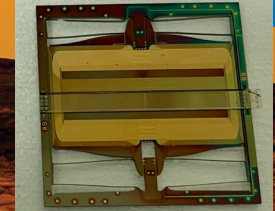


**Microbolometer based on High Temperature Materials Thermopile**

# Summary: Venus Surface Instruments / Sensors

- LLISSE Instruments and Sensors Overview Provided:
  - Chemical Species
  - Wind
  - Temperature
  - Pressure
  - Radiance
- At different levels of maturity but all sensors have demonstrated basic viability
- Other work under PICASSO, MaTISSE, SBIR and HOTTech-2 for Venus surface suitable conditions includes:
  - Seismometer
  - Mineral Reaction Sensor
  - Venus Imager
- Recent successful demonstration of chemical species sensors with SiC electronics in terrestrial volcanic field
  - Field testing near Icelandic volcano;
  - Real-time species detection from 540°C source achieved
- *Coupled with other development in Venus compatible systems including electronics, communications, power, and structures*

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Prototype  
Microseismometer Design



Chemical  
Sensors  
SO<sub>x</sub> and SiC  
Electronics



Chemical Sensor  
Probe Suspended  
in Lava Surface  
Crack

Field testing in Iceland of  
microchemical sensors  
array with electronics

# Potential Opportunities

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- Belief is next Venus mission to be selected will be in situ.
- Studies conducted on various versions on long durations landers – basic technology demonstration, to multiple landers / orbiter missions.
  - Multiple science teams
- Hardware exists for sub-systems and various levels of testing have been completed
- A significant science enabling instrument, a MEMS based seismometer, is also in development under HOTech-2, low power memory as well, although that is not required to conduct a mission
- Future New Frontiers, Discovery, SIMPLEX, MOOs as ride along missions, are all options

