SENSORS AND LIGHTWEIGHT INSTRUMENTS FOR VENUS ATMOSPHERIC INVESTIGATIONS

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BRIEF SCIENCE OVERVIEW

Venus Atmospheric Structure

80 km: Ice Crystal Haze, -93°C
70 km: Sulfuric Acid Cloud Deck, Thin Smog, -43°C
60 km: Slow Convection Circulation, -23°C
50 km: Thick Opaque Clouds, High Sulfuric Acid, 67°C
40 km: Convectively Stable, Global Circulation Patterns Horizontal With Rising Currents at the Equator, Descending at the Poles
30 km: Haze layer - Thin Likely Sulfuric Acid Particles, 142°C
20 km: Atmosphere is Clear Below 30 km, 210°C
10 km: Gloomy Red Murk, 390°C
0 km: Surface, 455°C

10 to 50 km Atmosphere:
- Convectively Stable
- Global Circulation Patterns
- Rising Currents at the Equator
- Descending at the Poles

Sulfuric Acid Cloud Deck:
- Sulfuric Acid Particles

Surface:
- Low Winds

Ice Crystal Haze:
- -93°C

Thin Smog:
- -43°C

67°C:
- High Sulfuric Acid

142°C:
- Haze layer

390°C:
- Gloomy Red Murk

410°C:
- Clear Below 30 km

455°C:
- Surface
Example Proposed Instrumentation for Atmosphere Studies

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Mass (kg)</th>
<th>Power (W)</th>
<th>Source or Proxy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Chromatograph Mass Spectrometer</td>
<td>11</td>
<td>40</td>
<td>Next-gen Huygens, JPL VCAM</td>
</tr>
<tr>
<td>Thermocouple, Anemometer, Pressure Transducer, Accelerometer</td>
<td>2</td>
<td>3.2</td>
<td>MVACS, ATMIS</td>
</tr>
<tr>
<td>Radio Tracking</td>
<td>0</td>
<td>0</td>
<td>–</td>
</tr>
<tr>
<td>Net Flux Radiometer</td>
<td>2.3</td>
<td>4.6</td>
<td>Galileo Probe</td>
</tr>
<tr>
<td>Magnetometer</td>
<td>1</td>
<td>2</td>
<td>JPL internal studies</td>
</tr>
<tr>
<td>Nephelometer</td>
<td>0.5</td>
<td>1.2</td>
<td>Pioneer Venus</td>
</tr>
<tr>
<td>Lighting Detector</td>
<td>0.5</td>
<td>0.5</td>
<td>FAST</td>
</tr>
<tr>
<td>TOTAL</td>
<td>17.3</td>
<td>51.5</td>
<td></td>
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</tbody>
</table>

Venus STDT Section 4.3.2
Scientific Objectives for the Exploration of Venus by Aircraft
Venus STDT Section B2.1

- The determination of atmospheric properties over a region of the atmosphere.
- Direct sampling and analysis of the atmosphere.
- Characterization of trace gases as possible biogenic indicators of life.
- Searching for volcanic emissions in specified regions of the planet.
- Magnetic field mapping over a region of the planet.
- Platform for radar investigations of the surface.
- Magneto-telluric sounding of the interior.
- Correlation of atmospheric motion between different locations by two or more aircraft.
- Communications and command relay for balloons, landers, and possible surface vehicles.
OVERVIEW

• FLIGHT CONDITIONS SIMILAR TO THAT OF EARTH FLIGHT MISSION EXCEPT:
  ➢ HIGH WINDS
  ➢ SULFUR CONTENT

• COMPLEX AND LARGER INSTRUMENTATION EXISTS
  ➢ HIGH CAPABILITY SYSTEMS
  ➢ IMPLEMENTATION MAY BE CHALLENGING DEPENDING ON THE ATMOSPHERIC FLIGHT PLATFORM USED

• SIGNIFICANT AMOUNT OF TERRESTRIAL ATMOSPHERIC SCIENCE EXPLORATION ON-GOING; DECREASE IN SIZE, WEIGHT, AND POWER ON-GOING

• THIS PRESENTATION GIVES A BRIEF OVERVIEW OF SMALLER, LIGHTWEIGHT SYSTEM’S THAT MIGHT BE USED FOR VENUS ATMOSPHERIC INVESTIGATIONS
  ➢ TARGETED TOWARD SCIENCE OBJECTIVES
  ➢ CORE SUGGESTION: SMALLER SYSTEMS MAY ADDRESS ASPECTS OF SCIENTIFIC QUESTIONS WHILE BEING MORE APPROPRIATE FOR SOME AERIAL PLATFORMS
  ➢ IN EACH CASE, MODIFICATION FOR VENUS ENVIRONMENTS NEEDED
MEMS GAS SENSOR ARRAY

- PLACEMENT OF SENSORS SIGNIFICANTLY CLOSER TO THE ENGINE OUTLET THAN TRADITIONAL EQUIPMENT ALLOW REPLACEMENT OF INSTRUMENT RACKS
- PROVIDE MEASUREMENTS IN APPLICATIONS WHERE SYSTEMS SUCH AS MASS SPECTROMETERS WOULD BE PROBLEMATIC
- PRESENT WORK INCLUDE MEASURING ENGINE EMISSIONS FOR DETERMINATION OF ENGINE HEALTH

Sensor Array Engine Data At Rolls-Royce

Rake Sampling System At The Outlet Of The JT-12 Jet Engine.
VENUS APPLICATION DEVELOPMENT
Phase I SBIR

- LEVERAGE MEMS-BASED SENSOR DEVELOPMENT FOR VENUS APPLICATIONS
- OPERATIONAL OVER A BROAD RANGE OF APPLICATION ENVIRONMENTS

- TARGETED TOWARD DROP SONDE APPLICATIONS FOR BOTH ATMOSPHERIC AND SURFACE MEASUREMENTS
  - PROFILING CHEMICAL COMPOSITION OF THE VENUS ATMOSPHERE IN A DROP SONDE
  - PROVIDING GAS COMPOSITION MEASUREMENTS AS PART OF THE LONG LIVED LANDER WITH METEOROLOGICAL MONITORS.

Examples of packaged MEMS based sensors
VENUS SCIENCE APPLICATION

- For application ranges where more complex instruments are challenged by size or weight considerations
- Could be coupled with a drop sonde to combine monitoring of species at higher atmospheres with a profile down to the surface
- A range of species of interest have been indentified
  - Multiple sensor designs tested
  - Most mature systems NO, CO, O2, H2O, H2 and SOx
  - Designs for other species investigated
  - Array aimed towards a smaller footprint than more complex systems

> 8 to 12 sensor array: ~200 gm, 4 cm X 4 cm X 4 cm, ~ 1 W

<table>
<thead>
<tr>
<th>Species</th>
<th>Measurement Range of Interest</th>
<th>Tested in Phase I</th>
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<tbody>
<tr>
<td>CO</td>
<td>0-50</td>
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<tr>
<td>SOx</td>
<td>0-200</td>
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<tr>
<td>OCS</td>
<td>0-50</td>
<td>Yes</td>
</tr>
<tr>
<td>H2</td>
<td>0-30</td>
<td>Yes</td>
</tr>
<tr>
<td>HF</td>
<td>0-50</td>
<td>No</td>
</tr>
<tr>
<td>HCl</td>
<td>0-5</td>
<td>No</td>
</tr>
<tr>
<td>NO</td>
<td>0-30</td>
<td>Yes</td>
</tr>
<tr>
<td>O2</td>
<td>0-50</td>
<td>Yes</td>
</tr>
<tr>
<td>H2O</td>
<td>0-100</td>
<td>Yes</td>
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</tbody>
</table>
MINIATURIZED PARTICULATE SENSOR

- PRINCIPAL ELEMENT: MONOBLOC OPTICAL ASSEMBLY HOUSING TRANSMITTING AND RECEIVING OPTICS
- APPROACH HERE UTILIZES MULTIPLE, FIXED-ANGLE SCATTERING MEASUREMENTS
  - ALLOW DETERMINATION OF MULTIPLE DISTRIBUTION PARAMETERS
  - FLIGHT QUALIFIED/FLOWN ON ISS
  - TOOLKIT OF TECHNOLOGIES FOR A WIDE RANGE OF PARTICULATE SIZES/SHAPES
  - MOVING TOWARDS UAV IMPLEMENTATION

VENUS SCIENCE APPLICATIONS
DIRECT SAMPLING AND ANALYSIS OF THE ATMOSPHERE INCLUDING MEASURING, CHARACTERIZING, AND MONITORING ATMOSPHERIC PARTICULATES IN REAL TIME. RECOGNIZES THE SPECIFIC PROPERTIES OF AN UNKNOWN AEROSOL AND MEASURES THE TOTAL MASS AND SURFACE AREA OF A GIVEN AEROSOL CLOUD.
Airborne Hyperspectral Imager
Designated for Aircraft Implementation

- Great Lakes Ecology: Monitoring Harmful Algal Blooms (HABs) in fresh water ecosystems – Great Lakes Environmental Research Lab
- Ecological change: Monitoring change of dry forest and coral reef ecosystems – University of Puerto Rico at Mayaguez
- Invasive Species: Measure the spread of invasive plant species in the Detroit River International Refuge – Eastern Michigan University

Fundamental Research: 2006 - 2011

GRC and GLERL have demonstrated HSI capable of detecting HABs in low concentrations - key capability for bloom prediction

Venus Science Application:
When included with an upward looking irradiance sensor, it is possible to determine localized atmospheric constituents by measuring spectral reflection and absorption of atmospheric and surface features

Processed HSI data of Microcystis Bloom with higher concentrations indicated by red and sediment is in blue (0.8 km x 1.4 km)

The Great Lakes contain 18% of the world’s fresh surface water and 90% of the U.S. supply

http://www.glerl.noaa.gov/res/Centers/HumanHealth/
Cloud and Earth’s Radiant Energy System (CERES)

- Researchers from GRC and LaRC are working together on CERES follow-on sensors
- Multiple new technologies are being developed and tested for future missions, with a focus towards high yield sensor technologies
- Sensor is measuring total radiance in a band from 400 nm to 100 microns.
- Additional sensors could be included for measuring specific wavelength bands.

VENUS SCIENCE APPLICATIONS

- Instruments very similar to those presently flown to measure the Earth’s Radiation budget could be included in a Venus high altitude platform to determine radiant energy contributions from the lower atmosphere and surface. This would also allow for the study of the upper atmosphere contributions when studied concurrently with an orbiter.
- Sensors would be tailored to operation in the Venus upper atmosphere