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Research Activities on Venus Atmosphere  
Balloon Observation Mission

By Tetsuya YAMADA 1), Kazuyuki HIROSE 1), Koji TANAKA 1), Hiroshi TAKEUCHI 1), Naoki IZUTSU 1), Kazuhisa FUJITA 2), Nobuaki ISHII 1)  
Japan Aerospace Exploration Agency  
1) Institute of Space and Astronautical Science  
2) Institute of Aerospace Technology

Be a Dawn of Japanese Planetary Entry !

Reentry Researchers in ISAS have been engaged in...

What’s Next ?  
we would answer  
Planetary Entry !  
Begin with Venus !!

USERS/REV  
dedicated to μG Experiment  
ISAS cooperate with USEF on Research Activities  
Launched Sept/2002  
Recovered May/2003

HAYABUSA  
Asteroid Sample Return  
Launched April/2003  
Arrive at Asteroid Aug/2005  
Return June/2007

DASH  
Launched Mar/2002  
-Hyperbolic Velocity  
-Precursor for M-C

EXPRESS  
Launched Jan/1995  
Reentry Tech. Acquisition
Contents of the Presentation

Research Activities on Venus Atmosphere Balloon Observation Mission

- Brief Introduction of Target Mission Concept
- Recent Status including External Relations
- Brief Outline of the Subsystems with Recent R&D Activities for Critical Issues
- Future Work and Schedule addressed

Planet Venus and Probe Explorations

Venus: Twins of Earth but Mysterious Planet in the Solar System
- 0.72 AU from the Sun
- R=6052 km (95% earth), 0.815 Earth Mass
- Rot. Period = 243 days (reverse)
- T=460°C, P=90 atm (Surface)
- T=200°C (@H=35km)
- Strong Equatorial Wind
- Sulfuric acid Cloud (H47-70km)

#Observations under clouds is Significant from Scientific Point of View

Venus Great Historical Probe Missions

Venera 4-16 (USA,1967-84)
Mariner 2-10 (USA, 1962-78)
Pioneer-Venus, (USA,1978)

historically, lots of probes in USA, USSR
Long-term Observation under the Clouds

**Long-term Observation of Low-Altitude Venus Atmosphere**
by Tracking of water-vapor Balloon

- Target Altitude: H=35km (under the Clouds)
- Mission Period: beyond 2 weeks’ observation

1) Scientific Significance

*Long Term Observation under the Cloud (H70~47km) will reveal...*
- Mechanism of the Strong Equatorial Wind, N-S circulation
  (Internal Gravity Wave, Turbulence, Structure of Vertical Wind)
- Concentration of Aerosol (unknown particle): optional
- Precise Mapping of the Venus Surface (λ~1μm): optional

2) Engineering Significance leading to future Planetary Exploration

*The mission is meant to be ....*
- **Dawn** in Aerothermodynamic Technology on Atmospheric Entry for Future Outer Planets’ Exploration in JAPAN.
- **Demonstration** of the High Temperature Electronics in the Hot Venusian Atmosphere.
- Planetary Long Term Observation by Balloon itself is of significance

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**Recent Status including External Relations**

**Long-term Observation of Low-Altitude Venus Atmosphere**
by Tracking of water-vapor Balloon

1) ISAS / JAXA

Authorized as a pre-phase-A WG for “Future Small Scientific Sat”
- Not Selected to Proceed to Phase-A in 2007FY

2) International Collaboration

Applied to COSMIC Vision 2018 of European Science Academy
- “JAXA low-altitude balloon” : one option of EVE (European Venus Explorer)
- Passed First Selection but not selected as Final 8 Candidates.

Never Give up and Apply again !!
Improving Technical Readiness Levels.
Technical Issues associated with the Mission

1) Venus Entry Capsules
- High Speed Entry to CO2 Atmosphere
  - Flight Environment Prediction
  - Thermal Protection Design
- TPS Development and Facility
  - High Enthalpy CO2 Generation
- Descent System

2) Water-vapor Balloon
- Long-term Observation (2 weeks)
- Multi-Layered Balloon Film
  (Gas Barrier, Lightweight, High Strength)
- Efficient Heat-exchange and Inflation

3) Tracking of the Probe
- Narrow-band VLBI under High Temperature

4) High-Temperature Electronics
- High Temperature Electronics over 180°C
  (Solar Battery Cells, Oscillator/Transmitter,
  Other SOI devices)

Water-vapor Pressure Balloon

Water-Vapor Balloon System makes 2kg Bus+PI float at H=35km.
For Successful Inflation,
Efficient Heat-convection from the atmosphere is Important!

Water-Mass / Surface Ratio is a Key Parameter
Low M/S is desirable

Pumpkin-type
- Hi Buoyancy
- light Weight

Cylindrical-type
- large heated surface
- needs large film
  => weight penalty

Slow Descent by Parachute until Full-Inflation

18 m Long Balloon

Weight Allocation
Bus + PI = 2 kg
Balloon = 3.2 kg
Water = 4.8 kg
**Balloon Deployment Sequence**

- *H* = 55-45 km
- Pilot Chute
- Aft ABL Chute Sack
- Main Chute
- Several Secs. Interval before Lateral Attitude
- Wire Cutter
- Roll Down

$V = 25 m/s$

$V = 9 m/s \quad @ CdS = 2 m^2$

$V = \frac{2 \cdot M \cdot g}{\rho \cdot Cd \cdot S}$

<table>
<thead>
<tr>
<th>$H$ [km]</th>
<th>$\rho$ [kg/m$^3$]</th>
<th>$CdS1$</th>
<th>$CdS2$</th>
</tr>
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<tbody>
<tr>
<td>55</td>
<td>1</td>
<td>12.9</td>
<td>9.1</td>
</tr>
<tr>
<td>35</td>
<td>7.5</td>
<td>4.7</td>
<td>3.3</td>
</tr>
</tbody>
</table>

**Balloon Release Altitude from 55 to 45 km**

**Constraints for Release Altitude**
- Liquid Water must not be freezeed
- avoid Inflation inside Capsule

- BALN is Never Released
  - @H > 55 km (T~ 0°C)
  - so as not to Freeze the BALN Water

- BALN can Inflate (@H=43 km)
  - Vapor Press > Atmos Press
  - BALN released @H=45km

**Table: Venus Atmosphere**

<table>
<thead>
<tr>
<th>Z</th>
<th>T</th>
<th>$\rho$</th>
<th>P</th>
<th>As</th>
</tr>
</thead>
<tbody>
<tr>
<td>[km]</td>
<td>[degC]</td>
<td>[kg/m$^3$]</td>
<td>[Pa]</td>
<td>[m/s]</td>
</tr>
<tr>
<td>59.3</td>
<td>0</td>
<td>0.62</td>
<td>4289</td>
<td>260.2</td>
</tr>
<tr>
<td>47.7</td>
<td>100</td>
<td>2.4</td>
<td>4091</td>
<td>299.6</td>
</tr>
<tr>
<td>37.9</td>
<td>180</td>
<td>5.97</td>
<td>4073</td>
<td>327.8</td>
</tr>
<tr>
<td>35.0</td>
<td>207</td>
<td>7.5</td>
<td>4074</td>
<td>336.7</td>
</tr>
</tbody>
</table>

**Balloon Release Altitude**

55km ~ 45km

- **H=43.4 km**
- **P = 280 kPa**
- **T= 129 [degC]**

**Graph:**

- **Atmos & Vapor Pressure**
- **0°C**
- **Vap>Patm**

- **T_atmos, Water Vapor Press Profiles**

- **watervap.dat**
Trade-off Studies on Balloon Accommodation

How to accommodate 20m-long Balloon

Configuration minimizing the number of Folding Lines

Donuts - Type
Suitable for Flat&Large (Low-β) CPSL
Many Folding Lines Distortion at Deployment

Plate-Type
Easy Extraction
Off-centered PI Crossing (double) Folding

Cylinder-Type
Suitable for Long (Hi-β) CPSL
A Few Folding Lines Distortion at Deployment

Venus Entry Probe (Hi-Ballistic Coeff-type)

For Satisfying Fast Descending Reqirement from Internal Temperature Balloon accommodation => Hi-Ballistic Coeff. Capsule

- Capsule
  Length : 620 mm
  Front Diam. : 350 mm
  Rear Diam. : 500 mm

- Balloon + PI
  250mm×L520mm

- Mortar for Pilot Chute

- Pyrotechnic Device

- Heatshield (Carbon Phenolic)

- Balloon

- PI

Total Weight 35 kg

Ablator (Front) 17 kg
Ablator (Aft) 4.5 kg
Mortar 0.6 kg
P-Parachute 0.3 kg
M-Parachute 0.7 kg
Bus-Electronics 1.9 kg
Balloon & Water 8 kg
B-Electronics 1 kg
Science Inst. 1 kg
**Flight Environment of the Capsule**

Max. Heat Flux expected

- Z : 89.4 km
- V : 10.62 km/s
- Atmos. Pressure : 45.2 Pa
- Atmos. Temperature : 173.8 K

max. qr = 12 MW/m²
max. qc = 16 MW/m²
max. dyn. Press = 180kPa

**Venus Entry and TPS Development**

**TPS Development Scenario**

**Induction-coupled Plasma Generator (ICPG) 10 kW**

- High enthalpy CO₂ heated by 13.56MHz RF
- Acquisition of Thermochemical Aspect of High Enthalpy CO₂

**Arc windtunnel : 1 MW**

- useful in Hi-Enthalpy Air but in CO₂
- due to C deposit to the Electrodes
- Material Thermal Strength Test in High Heat Flux upto 12MW/m²

**Thermochemical Basic Data**

- Reaction Rate Measurement in Hi-Enthalpy CO₂
- Numerical Simulation
- CFD Analysis

utilizes the Ground Simulation Result to predict Flight Environment and Thermal behavior of the Ablator

**Example : Radiative Heat Flux Analysis**
Venus Entry and TPS Development (1/2)

Characterization of ICPG and Material Heating Test are now carried out...

- Preliminary Heating Test Started in CO2
- 40 MJ/kg Enthalpy Accomplished
  => useful for Thermochemical Data of Marial/CO2 Reactions
- Higher Impact Pressure predicted.

Thermochemical Aspect of Venus Entry

Improvement in Flight Environments Assessment

CO thermal relaxation & dissociation has great effect on both $q_c$ & $q_r$.

<table>
<thead>
<tr>
<th>Modification</th>
<th>$m_{W} = 0.3$ kg/m$^2$s$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Uncoupled</td>
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<tr>
<td>CO dissociation rate $\times 0.25$</td>
<td>4.6</td>
</tr>
<tr>
<td>rate of reaction 23) from Ref. 12</td>
<td>4.6</td>
</tr>
<tr>
<td>rate of reactions 22) and 23) from Ref. 12</td>
<td>4.6</td>
</tr>
<tr>
<td>Nominal</td>
<td>4.6</td>
</tr>
</tbody>
</table>

$^{*}T_W = 3,000$ K. $^{*}T_W = 300$ K.

Development of improved models for CO relaxation & dissociation

- MO analysis
- High accuracy PES
- QCT collision analysis
- CFD model
### Inflation Analysis of Balloon Film

#### Analysis of Heat-exchange Process

<table>
<thead>
<tr>
<th>Heat Transfer Rate between Film – “Water sheet” is important</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Heat Transfer Rate</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Low Heat Transfer Rate</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

**Measured: 30-90 [W/m²/K]**

#### Heat-Convection Measurements

Measurement of Gas Permeability and Heat Convection

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### Balloon Expansion Simulation

#### Lessons learned until 2006FY
- Fabrication of Subscale Model (D=0.159m, L=1.88m)
- Expansion Simulation in Hot-Airflow (140°C) Cavity

=> Successful Expansion in 180 sec. within dispersion of prediction
   inflexibility problem of the film was revealed during the experiment!

#### Research Activities in 2007FY
Balloon Film made of Liquid-crystal Polymer (LCP)
- Good Performance in Gas-Barrier Characteristics
- Manufactured in Cylindrical-shape Inflation (desirable for the Balloon!)
- Drawback: Film has hard/poor flexibility, hard to be accommodated

**Change of Resin**
make the film more flexible, easy to treat.
- from PolyPlasitc → Sumitomo Chemicals
  - Strength in High-Temperature (now 103% of Pa)
  - Flexibility
  - Corrosion due to High-Temperature Water
**Tracking of Balloon by delta-VLBI**

*Normal VLBI (Cont. Wave like QUASAR)*

- Sensitivity $\propto (\text{Band Width})^{0.5}$
- Wide Band Detection $\Rightarrow$ Emission Power

**Narrow-band VLBI**

(for spacecraft and probes)

- Sensitivity $\propto (\text{Band Width})^{(-0.5)}$
- because of transmitter power limitation

Integration Time $\sim$ 100sec

(Wind Speed @H35km $\approx$ 30m/s

$\Rightarrow$ Spatial Resolution $\sim$ several km

**Scientific Positioning Request ($\sim$ 2.30km)**

depends on Transmitter Frequency Stability

- Transmit Power $\sim$ Several W $\rightarrow 10^{-8}$ Stability

VEGAは1.7GHz, 6.5MHz離れた2波長, 送信パワー5W, 発生電力20W

**delta-VLBI Lesson by Hayabusa S/C**

- $\Delta$DOR Signal sent from Goldstone (JPL) (±1 MHz), Return at Hayabusa
- Received at Goldston(JPL), Canberra (JPL), Usuda,Kashima.

Canberra 70m - Usuda 64m

**Detected Quasar Flange**

**VLBI Data Acquisition System (ADS-3000)**

for narrow band detection
**High-Temperature Electronics**

**High-Temperature Electronics are Key Technology for Tracking Low-altitude Venus Balloon.**

- Quartz Oscillator: Stability beyond $10^{-8}$ by means of Appropriate Crystal-Cutting and Temperature Control.
- Solar Cells operable in 200 degC environment (Though 200 degC in operation)

![Image of Test Board (IC is centered)]

**Objectives** in Pre-Phase-A (Concept and Feasibility Demonstration Phase) Study

- PLL Functional Demonstration and Characterization in 200°C environment for 3 hours
- First Step Lessons for Stabilization of PLL

**Experimental Setup**

**Thick Film Solar Cells in High-Temp (1)**

Temperature Characteristics of Thin-film Solar Battery Cell were obtained:
- Tandem-type Amorphous-Silicon Solar Battery Cells on Polyimide Film.

![Image of Solar-Ray Flux](chart)

- Temperature: 180°C
- Input Irradiance: 200W/m²

**Test Cells:**
by Fuji Electric Systems Co., Ltd.

**Results:**
- Temperature Characteristic:
  - Voc: -0.46%/°C
  - Pmax: -0.56%/°C
Thin-Film Solar Cells in High-Temp (2)

Spec of a Module (12Cells Series)
- Max Output Power: 2W
- Max Voltage: 13V
- Dimension: 170×240mm
- Conversion Eff.: about 7%
- 1μm Solar Cells on 50μm Polyimide Film

Performance on the Venus
- Operable Temperature: 180°C
- Input Irradiance: 200W/m²
- Generated Power: about 2W/m²

Research Issues
- Surface Protection Film with Anti-Acid Characteristics
- Adhesive bonding

Research and Development Schedule

Schedule
- Feasibility Demonstration of Critical Technologies (3Q / 2008)
  System Description based on the subsystem characteristics obtained until now especially High-Temperature Electronics (Oscillator, Solar Battries in relation to VLBI system)
- Application to “ISAS Small Sat WG” (4Q / 2008FY) (Taking into account of Further Collaboration with European Balloon Community)
Summary

Research Activities on Venus Atmosphere Balloon Observation Mission

- Introduction of Target Mission Concept
- Research Status and External Relations
- Brief Outline of the Subsystems
- Recent R&D Activities for Critical Issues
- Future Work and Schedule