Direct Aerial Robot Explorers (DARE) For Planetary Exploration

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TOPICS

• Concept Description
• Analysis and Applications:
  - Study of Venus’ general atmospheric circulation
  - Applications for Titan, Jupiter and Mars
• Summary
DARE CONCEPT OVERVIEW

- Phase I NIAC conceptual study of new system architecture for planetary exploration

- **Key elements:**
  - Long-duration planetary balloon
  - Balloon trajectory control
  - Lightweight and efficient power generation and energy storage
  - Deployable micro probes (MIPs)
  - Communications relay orbiter

- Loosely based on previous planetary balloon concepts
ADVANTAGES OF DARE

- Bridge the gap between orbital and surface observations
- Combine advantages of orbital and in situ platforms:
  - Nearly global spatial coverage
  - Long duration
  - Targeted observations on global scale
  - In situ atmospheric profiling on global scale
  - Diurnal coverage
PLANE
TARY SCIENCE WITH
Balloons

- Venera-VEGA (USSR, France, USA, 1984) – 2 floating stations successfully operated in atmosphere of Venus for 2 days
- Mars-94 balloon (USSR, France) – designed, tested, cancelled
- Numerous concepts for Venus, Mars, Titan and Gas Giants
- Balloon technology is there
- No trajectory control
STRATOSAIL® TRAJECTORY CONTROL SYSTEM (TCS)

First Generation TCS

- Wing on a tether several km below the balloon
- Variation of wind and density with altitude result in lateral lifting force
- Rudder controls angle of attack
- Corresponding control velocity 1-2 m/s

Advanced TCS
MICROPROBES

- Single DARE platform can carry hundreds of small probes or several large probes
- DARE platform can serve as a launching and refueling floating station

Biomorphic flight system examples (JPL NASA)

Entomopter for flight on Mars (A. Colozza, Ohio Aerospace Institute)

Mars Hexabot (JPL NASA)
PLANETS TO DEPLOY DARE

TITAN
- high degree of trajectory control
- no balloon technology (cold atmosphere)
- too far away

MARS
- high scientific priority
- low density atmosphere requires large balloons
- balloon flight altitude dangerously close to surface topography
- strong chaotic winds make targeting difficult

JUPITER
- hydrogen atmosphere makes balloons difficult to deploy
- requires large and heavy TCS

VENUS
- high scientific priority
- tested balloon technology
- high degree of trajectory control
  - Selected for more focused study
DARE AT VENUS
VENUS ENVIRONMENT

- Hot and dense CO₂ atmosphere
  \( T_{\text{surface}} = 733 \text{ K}, \ P_{\text{surface}} = 92 \text{ bar} \)
  \( T_{55\text{km}} = 300 \text{ K}, \ P_{\text{surface}} = 0.5 \text{ bar} \)
- Main H₂SO₄ cloud deck from 40 to 75 km
- Strong zonal winds (superrotation)
- Nature of the meridional circulation is debated (Hadley or solar tides dominated)

Venus zonal winds from Venera probes measurements
GUIDED VENUS BALLOON SYSTEM

- Balloon and gondola designs based on Venus Balloon Discovery design (NASA JPL, 1997)
- General circulation study mission:
  - What maintains the superrotation of the atmosphere?
  - What is the nature of the meridional circulation?
- Soundings of the lower atmosphere (0-15 km) at multiple locations
- 100 day flight at 55 km
- 100 light (<1 kg) dropsondes
- Floating mass ~208 kg
- Superpressure Teflon balloon, D=7.6 m
DARE VENUS GONDOLA

- Design based on Venus Balloon Discovery design
- 2 solar panels (0.5 m²) + batteries
- Earth com X-Band and dropsonde relay S-band antennas
- 100 dropsonde magazine
- Gondola science suite
- TCS deployment mechanism
**EXAMPLE VENUS DROPSONDE DESIGN**

- Must survive the descent through hot atmosphere
- Advanced Dewar insulation (Lorenz, 1997)
- Descent time about 1 hour
- Internal temperature at impact ~360 K
- Mass=0.7 kg, D=12.4 cm
- P, T, V, imaging, radiometry, spectrometry
DARE VENUS TCS

- 10 kg 1 m² wing
- 10 km 10 kg PBO tether (d=1 mm)
- Control velocity 1–2 m/s limited by wing weight
- Advanced TCS would provide higher control velocity
**TCS FOLDING OPTIONS**

- **Frame style** – “wraps around” the gondola
- **Box style** – stored below the gondola
DARE MOBILITY AT VENUS

Venus balloons at the end of 100 day flight at 55 km

- Uncontrolled balloon
- Controlled balloon, 1 m/s control velocity

- Start at 55ºN latitude
- Atmospheric model assumes that meridional winds are dominated by solar tides
A VENUS DARE CAN:

- Capitalize on past Venus balloon mission
- Enable global coverage
- Enable targeted observations
- Provide opportunities for in situ atmospheric profiling
- Enable surface imaging (VIS/IR)
- Resolve questions about the nature of meridional circulation and atmospheric superrotation
DARE AT MARS
MARS ENVIRONMENT

- Low density cold atmosphere (like Earth’s stratosphere)
- Southern highlands (2 km above reference level), Northern lowlands (4 km below)
- Tharsis ridge obstacle (8 km above the reference level)
- Ever present atmospheric dust
- Turbulent lower atmosphere (dust devils)
- Strong zonal winds develop during summer and winter seasons
GUIDED BALLOONS AT MARS

- Balloon and gondola design derived from MAP (ASU, NASA JPL, 1994) and MABS designs (JPL&GSFC NASA, 1997)
- Winds, imaging, spectroscopy, surface probes
- Superpressure balloon D=30 m
- TCS – 10 kg 1 m² wing, 3 to 6 km tether
- Gondola science payload 5 kg
- Floating mass 111 kg
- Control velocity 0.1-1 m/s
DARE AT JUPITER
JUPITER ENVIRONMENT

- Hydrogen atmosphere makes balloon operation difficult
- Only Solar Infrared Montgolfier (SIRMA) balloons are practical
- Balloon H₂ is heated by the Sun and IR radiation from Jupiter’s interior
- Strong “banded” zonal winds + large vortices (Great Red Spot)

SIRMA Balloon in Jupiter’s atmosphere (JPL NASA)
TARGETED SCIENCE AT JUPITER

- D=72 m SIRMA balloon (JPL NASA, 1997) at 0.1-0.2 bar
- Sample with probes distinct regions of the atmosphere (GRS, belt/zone)
- TCS – 50 kg 10 m² wing, 10 km tether
- Floating mass 208 kg
- Control velocity 0.9 m/s

DARE 100 day trajectories at 0.1 bar, control velocity 0.9 m/s

NASA
DARE AT TITAN
- Cold N\textsubscript{2} atmosphere (T\textsubscript{50\,km}=72 K)
- Dense haze of organic material above 80 km
- Strong zonal winds
- Weak meridional winds (1 m/s) arising from Saturn tides
GLOBAL COVERAGE OF TITAN

- Superpressure balloon above 50 km, e.g. D=11.2 m at 60 km, 19.8 m at 80 km
- Winds, gas abundances, surface organics/chemistry probes
- TCS – 10 kg 1 m² wing, 10 km tether
- Payload mass 100 kg
- Floating mass 136 kg at 60 km, 195 kg at 80 km
- Control velocity 0.9 m/s at 60 km, 0.5 m/s at 80 km

DARE trajectory for a 100 day mission at 60 km
SUMMARY

- Relatively small (1 m²) and light (10 kg) StratoSail® TCS can significantly modify trajectories of planetary balloons on Venus, Titan and Mars.

- Useful Balloon trajectory control on Jupiter requires larger wing (10 m², 50 kg).

- A guided Venus balloon can enable global sampling of the surface and atmosphere with microprobes.

- DARE platforms offer exciting new approach to the in situ atmospheric and surface planetary science.