Why Aeolus?

Previous and ongoing missions to Mars have provided a partial definition of the present climate system, but have not \textit{and cannot} illuminate the nature of the \textit{processes} involved.

They lack two fundamental observations:

1. Direct measurements of winds
2. Full characterization of the diurnal cycle

- Winds are responsible for the movement of dust, water vapor, CO2, and trace gases around the planet
- Winds determine the distribution of their sources and sinks at the surface
- Winds have a large unmeasured diurnal variation that strongly controls transport
Current Derivation of Winds

The gradient approximation can result in significant errors

- Winds calculated using the gradient method and temperatures from the NASA Ames Mars GCM
- These approximate winds differenced from the “truth” (the model winds)
- Areas in white indicate errors beyond contour levels
- *Errors frequently exceed 100%*
Diurnal Significance

Strong diurnal variability in Mars temperatures and winds

- Missions to date have been generally sun-synchronous, thus only observing two times a day (e.g., 2am/pm)
- The observed energy budget (TOA solar and IR) will be a strong function of local time of observation
Energy and angular momentum budgets drive the dynamics of the Mars climate system

- Energy in/out at surface
- Energy distributed through the atmosphere (dust and clouds)
- The balancing of energy (temperature) and momentum results in the winds/transport
- A “full set” of observations would be the product (winds) plus the forcing agents (energy at surface and in atmosphere and aerosols)
Science Baseline

**Planetary Science Decadal Survey Questions**

- What is the four-dimensional wind structure of the Martian atmosphere from the surface boundary layer to the upper atmosphere?
- What are the processes controlling the variability of the present-day climate?
- What are the processes coupling the carbon dioxide, dust, and water cycles?

**Aeolus Science Objectives**

- Characterize Mars global circulation processes, including seasonal and diurnal changes.
- Determine the global energy balance at Mars by measuring incoming solar radiation, reflected radiation, and thermal emission from the Martian surface and atmosphere.
- Measure Martian atmospheric aerosol (H₂O clouds and dust) content.

**Science Themes**

- Winds
- Energy Balance
- Radiative Drivers
**The Aeolus Payload**

**SHS:** Stack of four near-infrared spatial heterodyne spectrometers (SHS) fed by two orthogonal telescopes; instrument from Draper Laboratories.

**TLS:** Thermal Limb Sounder; COTS instrument with custom on-sensor applied filters; instrument from ARC.

**SuRSeP:** Surface Radiometric Sensor Package; instrument from ARC.
Payload Fields of View

SHS Orthogonal FOVs provide wind vector

- TLS and SHS total FOV (at limb) is 100km with <5km vertical resolution
- SuRSep nadir footprint is 100km
Mission Design

- Launch with NeMO
- Quiescent for 25 month NeMO cruise and orbit insertion
- After Aeolus deployment transfers to 383km, 73deg inclined orbit
- 24 months of science observations
Science Orbit

• 383-km average orbit altitude
• 73-deg inclination
• Orbit precession moves local time 2-hours in 10 day
• Measurements every 3 minutes

SHS 10-days of observations with yaw in day 5
Spacecraft Design and Analysis

Key Spacecraft Elements
- UHF Rx/Tx Antenna
- ADCS
- Propulsion System
- Solar Arrays [x2]
- X-band Radio
- C&DH System
- X-band Reflectarray & LGA Antennas [x4]
- SuRSeP
- SHS Stack & Telescopes

Key Spacecraft Specs
<table>
<thead>
<tr>
<th>Resource</th>
<th>CBE</th>
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<tbody>
<tr>
<td>Volume</td>
<td>45 x 35 x 52 cm</td>
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<tr>
<td>Total Launch Mass</td>
<td>37.6 kg</td>
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<tr>
<td>Total Power</td>
<td>53 W</td>
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<tr>
<td>SC Delta V</td>
<td>237.5 m/s</td>
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<tr>
<td>SS Data Storage (Vol)</td>
<td>8 Gb</td>
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<tr>
<td>Data Throughput (UHF DL)</td>
<td>1 Mbps</td>
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</table>

Power System Modeling
- Battery Charge (Wh)
- Cycle: Charge: 5-20 min, Discharge: 1 min, Discharge-50 min, Idling
- 30% DOD
- Daily S/C Activities: Science Orbits
Full grass-roots estimate

- Based on resource loaded WBS and IMS
- 30% reserves on Phase B-D, and 10% on Phase E-F (25.6% overall)

Notes:

- Currently traditional cost estimation tools are incomplete or not applicable for SmallSats
- Cost models do not adequately address existing SmallSat technologies and may underestimate maturation costs

<table>
<thead>
<tr>
<th>WBS Element</th>
<th>Total (Phase A-E)</th>
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<tbody>
<tr>
<td>01 PM</td>
<td>$6,952</td>
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<tr>
<td>02 SE</td>
<td>$4,942</td>
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<td>03 MA</td>
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<td>09 Ground Systems</td>
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<td>Reserves</td>
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<tr>
<td>Grand Total</td>
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1. Establish clear ground rules / expectations for interface mechanisms (ICDs) and level of in-Project development of key systems

2. Telecomm systems represent a major hurdle for deep-space SmallSats

3. SmallSat operations can be as (or more) demanding as their larger counterparts

4. Assuming cost-capped SmallSat programs with limited vehicle resources, missions may be expected to have very few science descope options

5. SmallSat missions are well suited for Class D classification, however, well defined and stable program requirements are required to keep risks and costs down

6. Due to the immaturity in a number of systems higher than normal margins were maintained (for example, >40% wet mass, >50% power, >35% SC ΔV); this margin provides “commodity” (e.g., mass) used to mitigate risks
Aeolus is a low-cost, small spacecraft, but delivers big science!

- Development via the Planetary Deep Space SmallSat Studies Program (Thank you!)
  - Included trade analysis, costing and scheduling to bring the concept to CML 4/5
- Completely novel observations of winds, day and night
- Observations across all times of day
- First dedicated energy balance observations
- Simultaneous observations of the key circulation drivers, including temperature and aerosols
Thank you!
1. To prevent seasonal aliasing in Aeolus, the orbit needs to precess over all local times \textit{at least} once every two months.

2. The inclination of the orbit must be 70-75° to sufficiently measure polar regions.

3. Science requires 10 orbits per day to achieve sufficient mapping resolution.

4. Planetary Protection: the orbit must be stable for at least 50 years.