Returning to Titan

- New discoveries of surface features
- To further explore, need:
  - longer observation time and range than Huygens probe
  - closer proximity than Cassini to see through haze
Current Status
## Current Status

<table>
<thead>
<tr>
<th>Mode</th>
<th>Atmospheric Science - Constant Altitude</th>
<th>Atmospheric Science - Variable Altitude</th>
<th>Surface Imaging Capability</th>
<th>Surface Sample Acquisition</th>
<th>Site Selection Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-propelled airship</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Drifting light gas balloon</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Drifting RTG Montgolfiere balloon</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Maybe</td>
<td>No</td>
</tr>
</tbody>
</table>
Montolfièrè Balloon

- Satisfies long range, long duration and low altitude
- Variable altitude between 1 km to 20 km
- Independent enough for autonomy
Three Navigation Goals

- Wind assisted site-selection
  - stable longitude
  - stable altitude
  - recovery

- Ground collision avoidance

- Optimization of flight path
Three Navigation Goals

- Wind assisted **site-selection**
  - stable longitude
  - stable altitude
  - recovery
- Ground **collision avoidance**
- **Optimization** of flight path
## Two Wind Models

<table>
<thead>
<tr>
<th></th>
<th>LMD</th>
<th>Tokano</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accuracy Range</strong></td>
<td>&gt; 40 km</td>
<td>&lt; 40 km</td>
</tr>
<tr>
<td><strong>Predominant Winds</strong></td>
<td>Westerly</td>
<td>Westerly</td>
</tr>
<tr>
<td><strong>Low Altitude Retrograde Wind</strong></td>
<td>Sparse</td>
<td>Prevalent</td>
</tr>
</tbody>
</table>
Tokano Model

- Movie of latitudinal contour plot in Huygens season
- Wind speeds shown at different longitudes (x) and time (t)
- Prograde / Retrograde
Utilization of Wind

- “Free” prograde ride at 10 km
- Descend by decreasing buoyancy
- Backtrack in retrograde wind to selected sites
Utilization of Wind: Demonstration

- Prograde
- Descent
- Retrograde
- Ascent
Utilization of Wind: Demonstration
Prograde Altitude

- Icing above 20 km
- Maximum prograde wind between 5 and 15 km
- Optimum prograde altitude is 10 km
Descent

- Realistic altitude control from 10 km to 1.5 km
- Max. vertical supplied velocity is 0.5 m/s
- PID controller - combination of proportional, integral and derivative controls
- Halts descent at 1.5 km
Descent

Before PID Controller

After PID Controller
Retrograde Altitude

- Gradual topography, less than 1 km
- Retrograde wind reaches 2 km
- Optimum retrograde altitude is 1.5 km
Three Navigation Goals

• Wind assisted site-selection
  -stable longitude
  -stable altitude
  -recovery

• Ground collision avoidance

• Optimization of flight path
Ground Collision Avoidance

- Downward gusts into ground
- Sense altitude AGL with radar
- Compute vertical change in velocity
- Implement 0.5 m/s escape climb
Ground Collision Avoidance

- Sustained flight at 1.5 km
- Error +/- 0.3 km
- No lower than 1.2 km
Three Navigation Goals

- Wind assisted site-selection
  - stable longitude
  - stable altitude
  - recovery
- Ground collision avoidance
- Optimization of flight path
Optimization

- SQP method - only in x, z coordinate plane
- Know longitude, altitude of target
- Begin with rough path
Optimization

- Minimize $\mathbf{z}_c^T \mathbf{z}_c$, or vertical control
- Wind data given
- **Results in vector $\mathbf{z}_c$, most efficient trajectory**
- Only theoretical
Summary

- Started with Titan wind data model
- Vertical control enables site selection
- Safeguards avoid ground collision
- Optimized path to selected site
Further Research Ideas

• Latitudinal control
• Find launch time to optimize retrograde wind
• Complete autonomy controls
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Questions?