Rotorcrafts for Mars Exploration

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Rotorcrafts Bridge the Information Gap

- Fly where rovers can’t drive
- Provide higher resolution surface images than now possible from orbit
- See much greater area than possible with Rover-mounted cameras
### Mars Rotorcraft Mission Categories

#### Science

- **Wide-Area Imaging**
  - e.g. rocks, terrain

- **Atmospheric Science**
  - e.g. gas plumes, dust

- **Surface Science**
  - e.g. spectroscopy, sampling

#### Scout

- **Terrain Assessment**
  - e.g. for traversability

- **Inspection**
  - e.g. of rover, instruments

- **Science Target Reconnaissance**
  - e.g. to revise mission sequence

- **Rover Path Reconnaissance**
  - e.g. to revise planned path

#### All-Terrain Imaging

- e.g. seeps, flows, stratigraphy

#### Other

- **Technology**
  - Demonstrator
  - e.g. verification of aerodynamics

- **Outreach**
  - e.g. landing video

- **Sample Cache Retriever**
  - e.g. transport 2 kg cache to a MAV
Scout - Flight Requirements

HELIQUOPTER FUNCTIONAL REQUIREMENTS

Mobility Functions
• Take-off
• Climb
• Hover
• Rotate
• Translate
• Descend
• Land

Autonomously execute flight sequence

Autonomous safe landing

Imaging functions
• Acquire, Store, Transmit images
• Acquire, Store, Transmit Heli TLM

Maintain health & safety of Heli post deployment

Maintain No Fly Zone around Rover

HELIQUOPTER PERFORMANCE REQUIREMENTS

<table>
<thead>
<tr>
<th>Functional Requirement</th>
<th>Projected Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min. atmospheric density</td>
<td>0.012 (kg/m³)</td>
</tr>
<tr>
<td>Flight altitude</td>
<td>3 – 40 m</td>
</tr>
<tr>
<td>Flight range per sol</td>
<td>400 m</td>
</tr>
<tr>
<td>Position error at range reqt</td>
<td>10 m</td>
</tr>
<tr>
<td>Yaw error at range reqt</td>
<td>9°</td>
</tr>
<tr>
<td>Line of sight com range</td>
<td>400 m</td>
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</tbody>
</table>

Heli Subsystem Requirement

Propulsion & Airframe. Provide: (i) forward air-speed of 10 m/s; (ii) vertical speed of 2 m/s; (iii) operation at atm. densities as low as 0.012 kg/m³, (iv) control authority for wind gusts of up to 5 m/s, and (v) landing gear for touchdown.

Flight Control. (i) propagate on-board state to within 2% of distance traveled and deliver the Heli to within 2 m of the estimated state; (ii) implement control for takeoff, lateral flights at altitude of up to 40 m, hovering, & autonomous landing; (iii) determine on-board safe landing sites.

Avionic Processing. Provide fault-tolerant compute elements for vision-based navigation and safe landing, sensor data processing, ScoutCam image acquisition, C&DH functions, and telemetry processing.

Communications & Radiometrics. (i) Provide Rover-to-Heli commands at 2 kbps up to 400m. Provide Heli-to-Rover data transmission (ii) while airborne at 256 kbps up to 400m, (iii) while on the ground in line of sight (LOS) at 128 kbps up to 175 m and at 2 kbps up to 400 m, and (iv) while on the ground in moderate non-LOS (NLOS) locations at 2 kbps up to 140 m. (iv) Provide received signal strength indication on the Heli up to 400 m.

Power & Energy. (i) Provide and store energy for daily 3 minutes of flight or ~ 90 minutes of data transmission.

Thermal. (i) Keep the batteries above the survival temperature at night, and (ii) prevent overheating of Heli battery and electronics during the day.

Warm Electronics Box. (i) Host sensors, computing, power/energy, comm. & camera elements in an integrated multi-function structure.

Hangar. Provide: (i) mechanical restraints/support, electrical & data interfaces to the Rover during launch, cruise, and EDL; (ii) debris protection during Rover landing. (iii) After deployment provide mechanisms to raise the Heli into its vertical flight configuration.
Scout - Test Flight
Scout - Point Design

Rotors are designed for low Reynolds number flows in the thin Martian atmosphere. The rotor tip velocities stay comfortably subsonic.

Flies on Mars

A high-resolution camera is used to take images at a variety of locations and altitudes within 0.6km of the Rover.

Images wide areas

Energy from solar cells is used to recharge the battery.

Operates daily

Aerogel insulation and a heater keeps the batteries warm overnight.

Survives the night

Lightweight flexible legs, active vision, and an altimeter for safe landing on terrain.

Lands on terrain

Rotors are designed for low Reynolds number flows in the thin Martian atmosphere. The rotor tip velocities stay comfortably subsonic.

Safe to the Rover

A radiometric beacon signal allows the Heli to stay away from the Rover.

Commands & data

A camera and other sensors together with a fault-tolerant computer provides a high level of autonomy.

Autonomous mobility

Communicates to the Rover Electra ultra-high frequency (UHF) radio.

Commands & data

6 June 2014

Rotorcrafts For Mars Exploration

11th IPP Workshop
It will make the first flight this great bird

filling the universe with awe

filling all writings with its fame

and eternal glory to the next where it was born.
Scout Point Design - Autonomous Mobility
Scout Point Design - Imaging

Test Images from Camera in JPL Mars Yard

GoPro Camera
Scout Point Design - Aerodynamics

A surrogate rotor (0.7m) designed and fabricated by AV to operate at similar Mach (0.5) and Reynolds numbers (5700) as the proposed scout design.

In order to bracket the expected rotor performance as a function of Reynolds number, tests at two additional chamber pressures (~527 Pa and ~1055 Pa) were also conducted.

<table>
<thead>
<tr>
<th>Tip Mach</th>
<th>RPM</th>
<th>Blade Pitch Angle Delta (degrees)</th>
<th>Pressure Pa (torr)</th>
<th>Tip Rn @M=0.5</th>
<th>Equivalent Mars Altitude (m)</th>
</tr>
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<tbody>
<tr>
<td>0.45</td>
<td>3285</td>
<td>-4</td>
<td>527 (3.95)</td>
<td>4000</td>
<td>6900</td>
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<td>0.5</td>
<td>3650</td>
<td>-2</td>
<td>751 (5.63)</td>
<td>5695</td>
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<td>0.55</td>
<td>4015</td>
<td>0</td>
<td>1055 (7.91)</td>
<td>8000</td>
<td>-1400</td>
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<td>0.6</td>
<td>4380</td>
<td>2</td>
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<td>0.65</td>
<td>4745</td>
<td>4</td>
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Scout Point Design – Autonomous Landing