Ingenuity Mars Helicopter Technology Demonstration

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- The Mars Helicopter Technology Demonstration is now in final preparation for launch to Mars with JPL's Mars 2020 Rover in July 2020. The helicopter plans to execute the first heavier-than-air flight on another planet in April-May 2021. This presentation will overview the helicopter mission and requirements; the design and special circumstances of flight in the thin, cold air of Mars; and some of the commercial off the shelf technologies used.
  - With an emphasis on the telecom connection to the *Perseverance* Rover
- JPL URS292031 clearance number CL#20-1956

Why Do Planetary Helicopters?

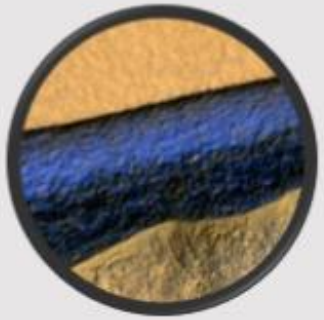
Enabled Science Themes

From https://mepag.jpl.nasa.gov/

Sedimentology and Stratigraphy

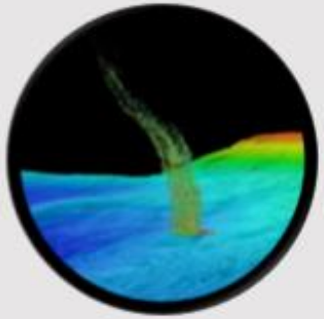
- ✓ High-resolution mapping
- ✓ Traverse potential of 100+ km in relatively short time
- ✓ Access steep slopes, cliffs and avoid obstacles

Polar and Mid-Latitude Volatiles



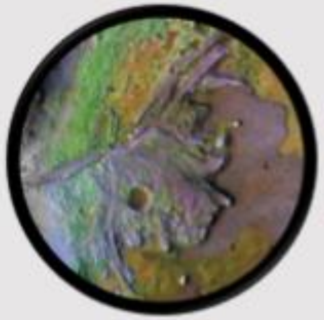
- ✓ Characterize exposed layers comprising ice deposits
- ✓ Fluxes of volatiles and dust
- ✓ Recorded climate history
- ✓ Near-surface ground ice distribution

Atmospheric Science



- ✓ Wind, P, T, dust, and chemical species (e.g., H_2O, CH_4) in boundary layer
- ✓ Vertical and horizontal profiles
- ✓ Active aeolian environments

Astrobiology



- ✓ Exploring distal sites (good for spatially-limited detections and/or exposures)
- ✓ Fast identification and delivery of astrobiological-relevant samples

Geophysics

- ✓ Crustal magnetic field measurements
- ✓ Regolith properties (e.g., Phoenix TECP)
- ✓ Near-surface volatiles (e.g., neutron spectrometer)
- ✓ Subsurface imaging (e.g., SAR)
- ✓ Instrument placement

Special Regions

- ✓ Explore sensitive regions without risk of potential contamination
- ✓ I.e., closely study RSL on steep slopes without contact

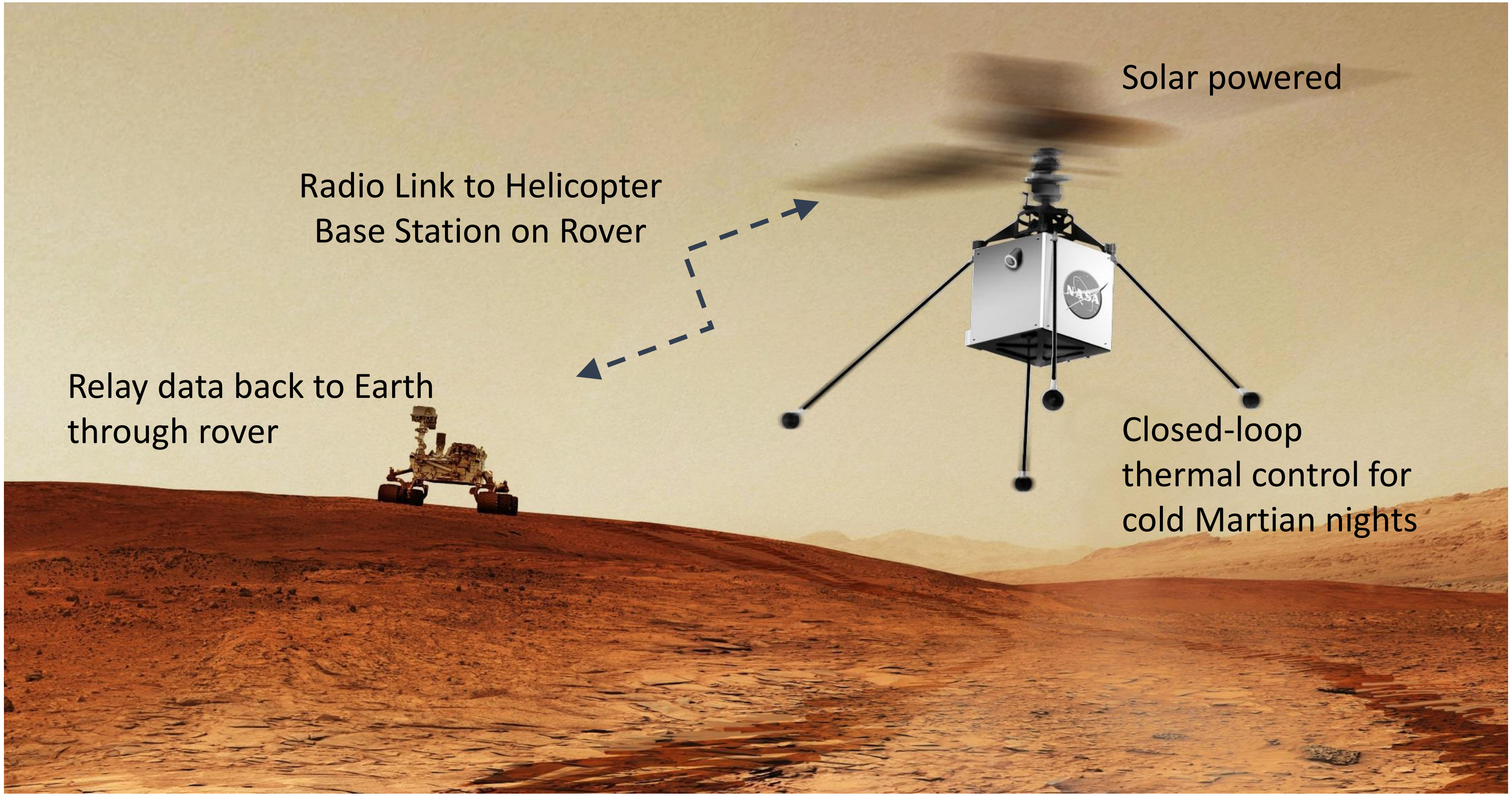
Mars Helicopter Technology Demonstration on Mars 2020

- Capable of flight in thin Mars atmosphere (~1% of Earth, equiv. 30 km)
- "Co-axial" Helicopter
- Blades 1.2-meter tip-to-tip
- Mass ~1.7 Kg
- Solar powered – up to 90-second flight per sol
- Flight distances up to 300 m
- Heights up to 10 m
- Autonomous flight & landing
- Up to 5 flights
- Telecommunication to Base Station on Rover
- Self-sufficient thermal control (nights < -100C)

AeroVironment – Major Industrial Partner

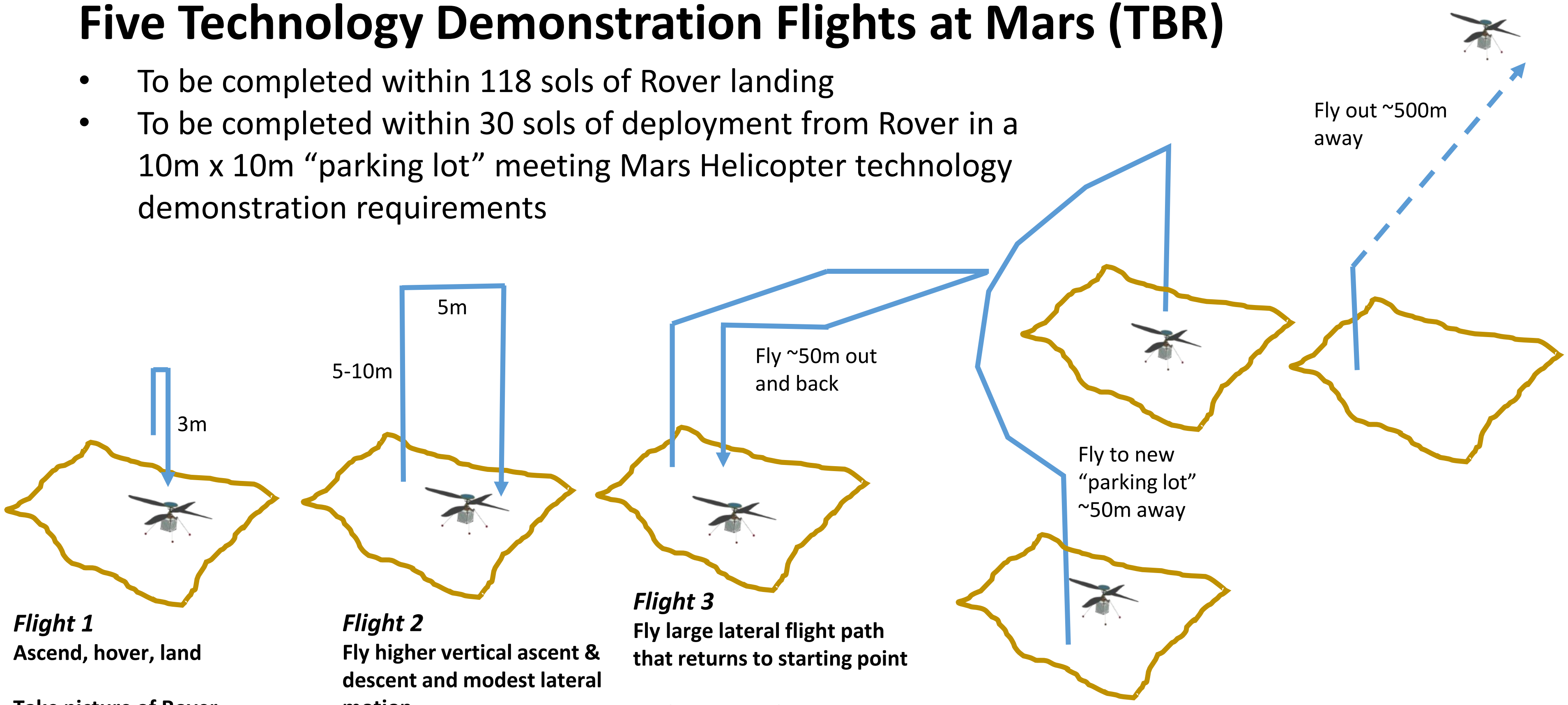
- Founded by Paul MacReady
  - Designer of the human-powered Gossamer Condor that won the Kremer Prize
  - And the Gossamer Albatross that crossed the English Channel
    - Piloted by Bryan Allen, now at JPL
- Simi Valley, CA
  - Unmanned electric aerial vehicles, drones
  - Experience with unusual designs and environments
  - Military systems, precision agriculture, etc.
- Mars Helicopter rotors, motors, servos, mast & wiring, landing gear

After Deployment from Rover, *Ingenuity* Operates in Stand-Alone Fashion, with Radio Link to Base Station on Perseverance



Five Technology Demonstration Flights at Mars (TBR)

- To be completed within 118 sols of Rover landing
- To be completed within 30 sols of deployment from Rover in a 10m x 10m “parking lot” meeting Mars Helicopter technology demonstration requirements



Flight 1
Ascend, hover, land

Take picture of Rover

Rover takes picture of Helicopter in flight

Minimum Mission Success

Flight 2
Fly higher vertical ascent & descent and modest lateral motion

Flight 3
Fly large lateral flight path that returns to starting point

Perform scout function to image terrain far ahead of “parking lot”

Certify new “parking lot” (on Earth)

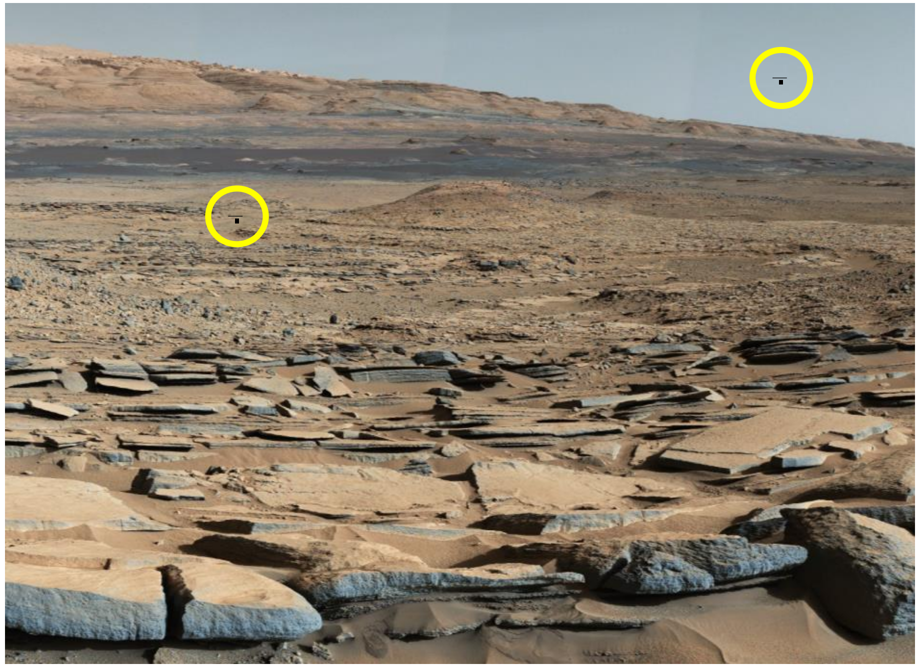
Flight 4-5
Contingency for Flights 1-3

If contingency flights are not needed, then consider the following options:

Fly to new “parking lot”

Fly away to maximum distance that the vehicle can fly (~500m). Note: destination landing site will not have been surveyed.

Potential Images From Rover



- NavCams at 100m:< 3.5 cm/pixel
- At highest resolution:
  - Blade length = 36/5120 pixels
  - Body cube = 3.6/5120 pixels
- NavCam Imaging Plan Proposal:
  - 2x2 & 2x2 tile exposed and read out every ~ 6 seconds
  - 7 cm/pixel

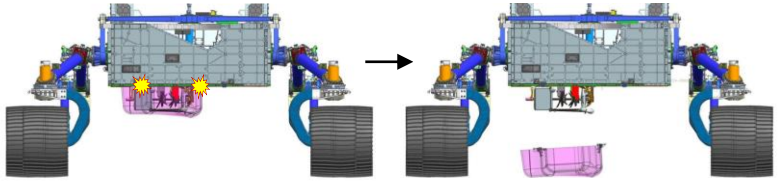
Mastcam-Z
(Full Res) w/ some noise)

Blades are ~ 145 pixels at full zoom
Body Cube ~ 19 pixels at full zoom

Deployment….

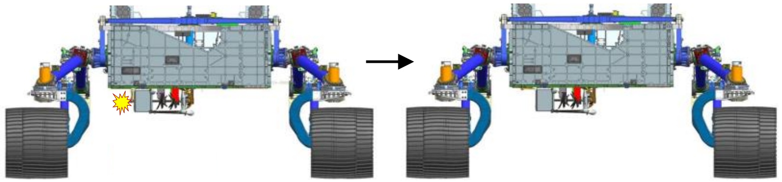
A: Jettison Debris Shield

¼” Cable Cutter Pyros fired severing restraint cables that allows the Debris Shield to drop from the Rover. After drop Rover executes forward drive to prepare for rest of deployment activities



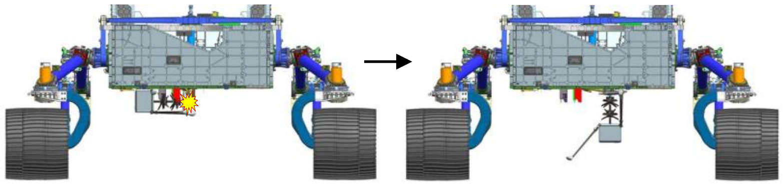
B: Heli Launch Lock Release

Frangibolt energized releasing lower Heli Launch Lock Restraint. Egress Arm / Heli Assy held in place by Egress Arm Restraint



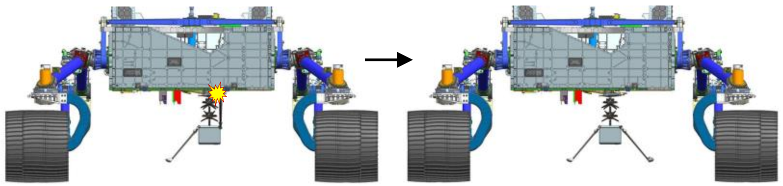
C: Egress Arm Restraint Release and Egress Arm Deploy

Cable Cutter Pyro fired releasing MHDS Egress Arm. Egress Arm Release initiates rotation of Egress Arm & Heli with actuator in dynamic braking mode. Near the end of the deploy motion the actuator completes the arm deploy motion by driving to the hardstop and latching.



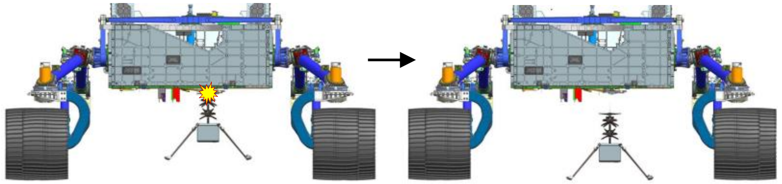
D: Leg Restraint Release

Cable Cutter Pyro fired releasing Helicopter Leading Legs allowing them to spring into their fully deployed state. Helicopter is fully configured for drop after this event.



E: Primary Heli Restraint Release & Heli Drop

Frangibolt energized releasing Helicopter from Rover & Egress Assy. Helicopter drops to Martian Surface below Rover. After nominal drop is confirmed via telemetry and imagery review Rover executes forward drive to allow Heli Solar Arrays to resume charging



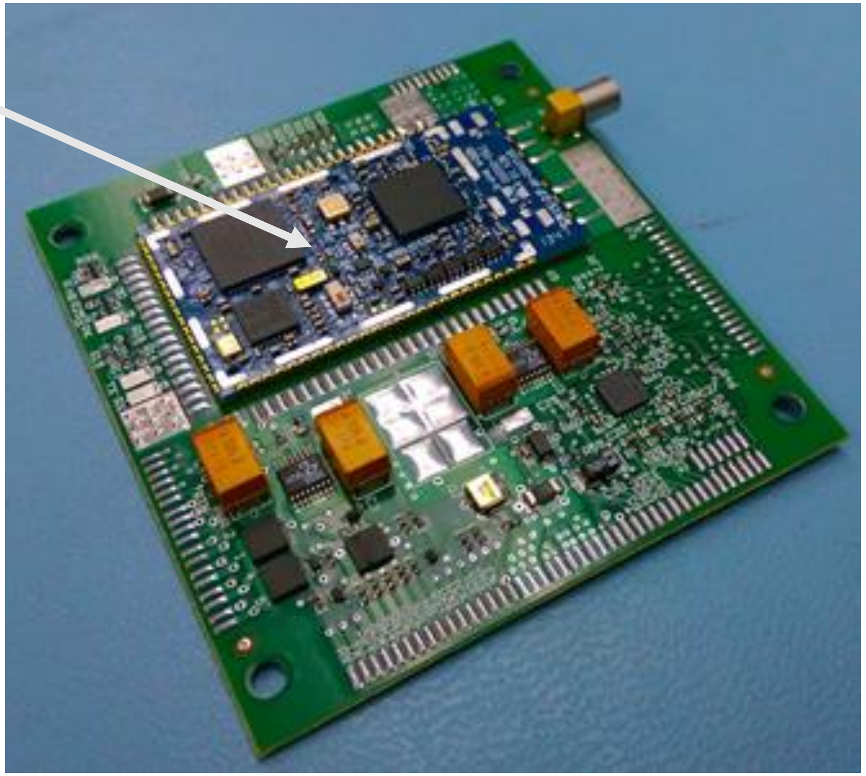
Ingenuity Telecom Specifications

- 10 gram mass
  - Includes antennas and cables
  - 13.3 grams achieved (helicopter side)
- Rover side (HBE) uses the same electronics boards
- Telecom up to 1000 m., two-way
  - NFZ is 100 m. radius
  - no radio-navigation
- Over-the-air rates 20 kbps, 250 kbps
- DC power: TX < 3 W, RX < 0.2 W
- Temperature -40 to +85 C, -50 C non-op
- Protocol modified from ZigBee (IEEE 802.15.4)
- UART connection to SnapDragon “NAV” computer

- COTS Part Selection Criteria
  - Very Low Mass suggests COTS ISM
  - Low frequency for lowest omni to omni path loss, 900 MHz is lowest ISM band
  - “High Power” – most ISM parts run a few 10s of mW, want closer to a watt
  - Diversity – possibility of > 1 antenna

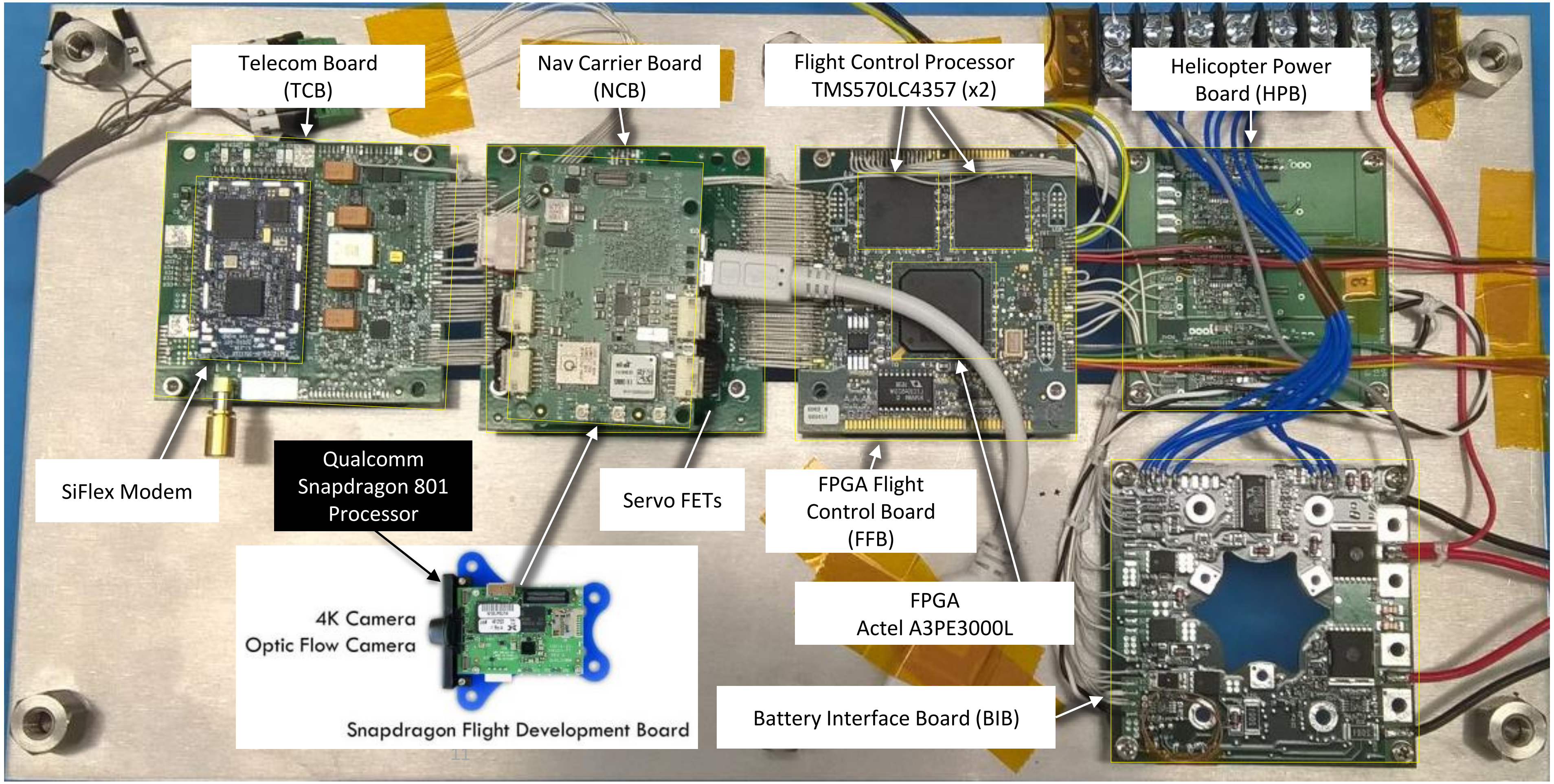
Cost: $60 per unit
Mass prepped: ~3.5g
Power Out: 29 dBm (0.8 W)
Band: 906-924 MHz (10 ch.)
Antennas: 1 or 2

SiFlex COTS Radio



Helicopter FlatSet

Electronics Core Module (ECM)

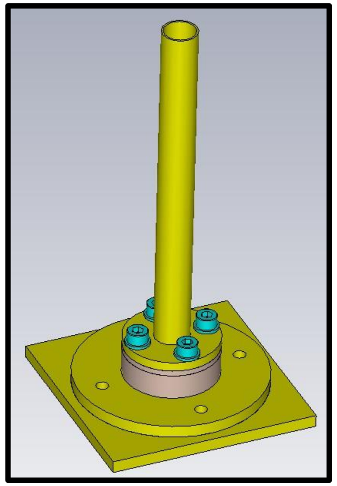


"cube" style in helicopter

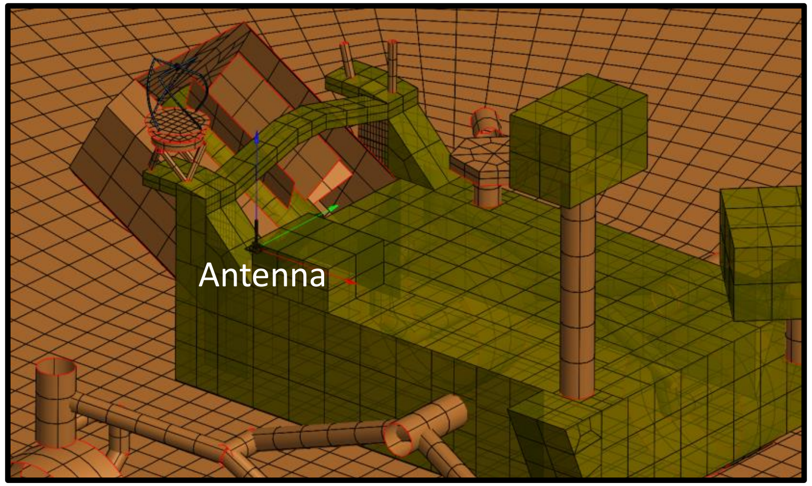
"wallet" style in base station

MHS Flatset 001

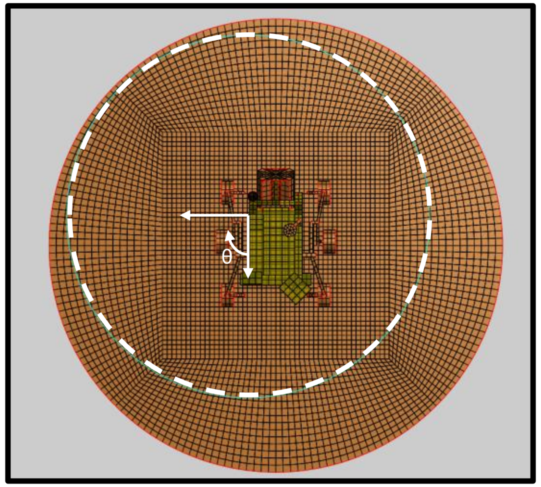
HBS Antenna performance on Mars2020 rover



Antenna design

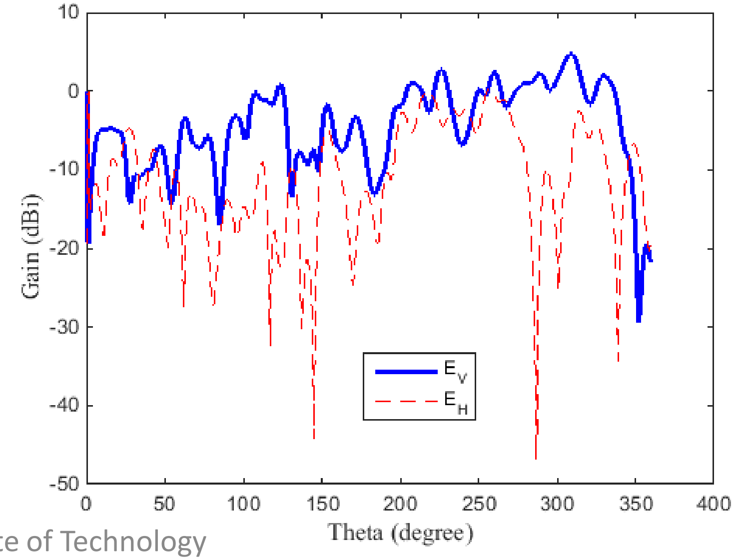


Antenna on M2020 Rover



Coordinate system

Helicopter Base Station Antenna (HBA) radiation pattern



Interpretation of results:

- Shadowing effects
- Multipath (reflections)
- Suffers from a very small ground plane
- Larger ground plane and/or location would improve the result

Map Coverage Around M2020 Rover on the Surface

Map coverage assuming min, mean, max polarization loss with blade rotating.
The math is done for all azimuth angles around the helicopter.
These results were obtained using **Bullington** with $\boldsymbol{h_t}$**=0.48m** and h_r=1.23m.

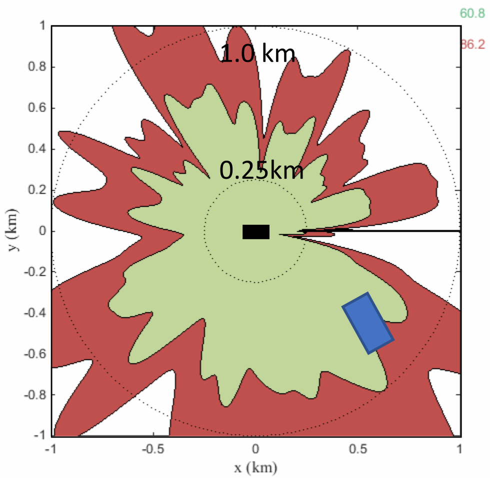
Note: For best results, park the Rover in a "for comm" orientation.

Received power of >-94dBm ⇔ 250kbps

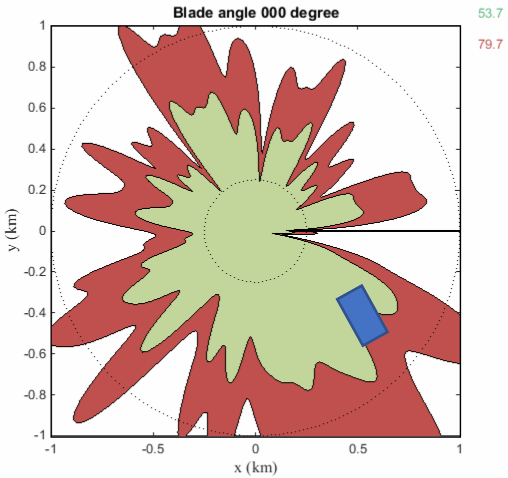
Received power of [-102, -94] dBm ⇔ 40kbps

No link

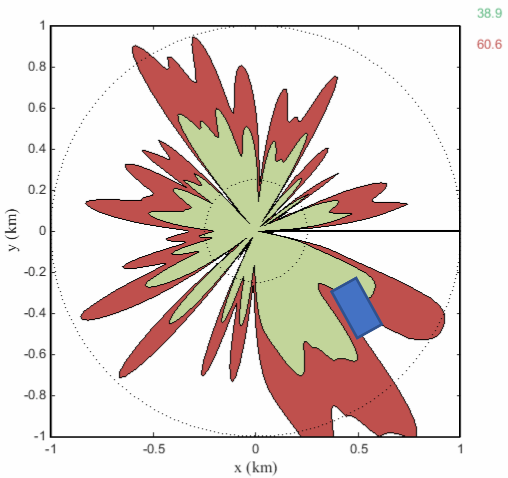
5%



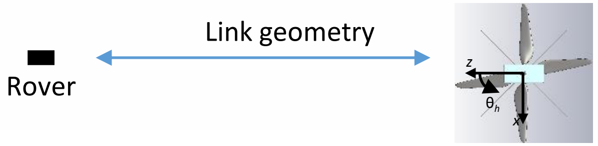
Min polarization loss



Mean polarization loss



Max polarization loss



Azimuth angle θ_h = [0°-359°]

Map Coverage Around M2020 Rover Flying

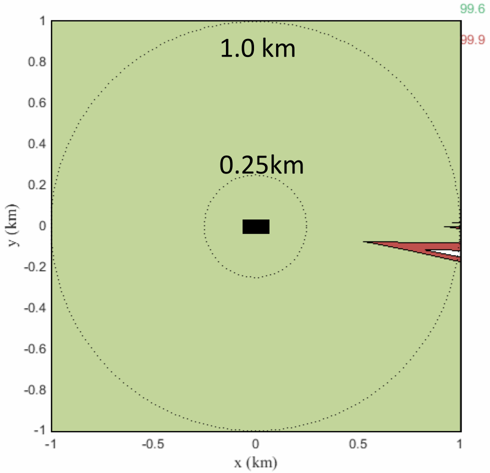
Map coverage assuming min, mean, max polarization loss with blade rotating.
The math is done for all azimuth angles around the helicopter.
These results were obtained using **Bullington** with ***h*$_t$=10m**, h_r=1.23m, and Req = [0.25 - 1] km.

Received power of >-94dBm ⇔ 250kbps

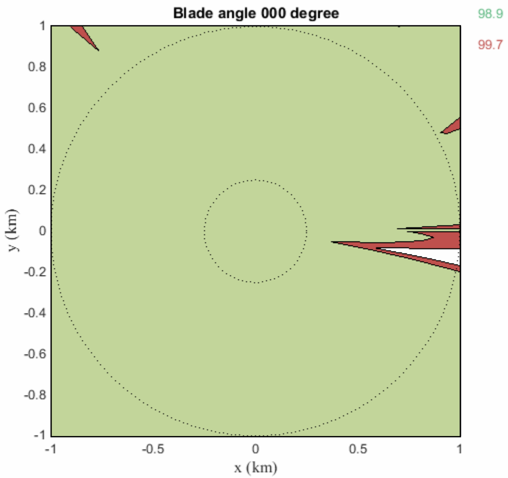
Received power of [-102, -94] dBm ⇔ 40kbps

No link

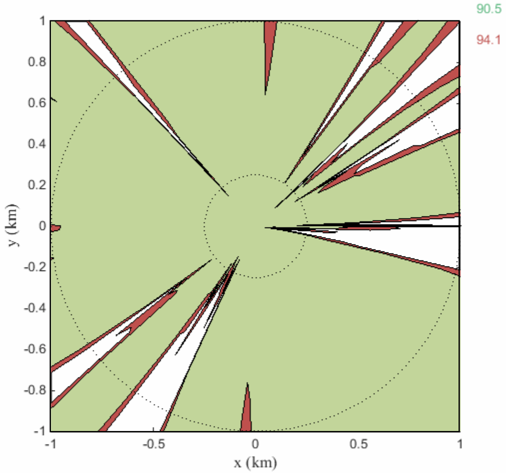
5%



Min polarization loss



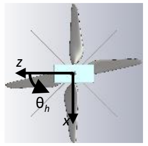
Mean polarization loss



Max polarization loss

Rover

Link geometry



Azimuth angle θ_h = [0°-359°]

Operating Modes

Name	OTA* Rate	Throughput	Modulation	Bandwidth	Direction	Default H/B	Bit Size	Packet Size	Note
Silent	NA	0	NA	NA	NA	NA			No TX
Default	20 kbps	9 kbps	BPSK	600 KHz**	Both	50/50	50 $usec$	50 msec	Boot Up
Data	250 kbps	80 kbps	OQPSK	2 MHz ***	Both	90/10	4 $usec$	4 msec	With OTA acks
TCOW ****	250 kbps	204 kbps	OQPSK	2 MHz	Heli->HBS	100/0	4 $usec$	4 msec	Without OTA acks

"Silent" under HBS 'beacon' control (two node "Mesh" under modified 802.15.4)
* OTA: Over the Air
** Due to 15 chip spreading code
*** Due to Mcps signaling scheme
**** TCOW (Time Critical One Way); VOMIT (Vulnerable, One-way, MHS Information Transfer)

Field Test (JPL Arroyo)

Helicopter Mockup with Antenna

Rover Mockup

View from Rover Mockup antenna to Helicopter Mockup

Questions?

Jet Propulsion Laboratory
California Institute of Technology

jpl.nasa.gov