National Aeronautics and Space Administration

MAHD: Mid-Air Helicopter Delivery system for Mars

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Program: FY21 R&TD Strategic Initiative **Strategic Focus Area: Mars Science Helicopter**

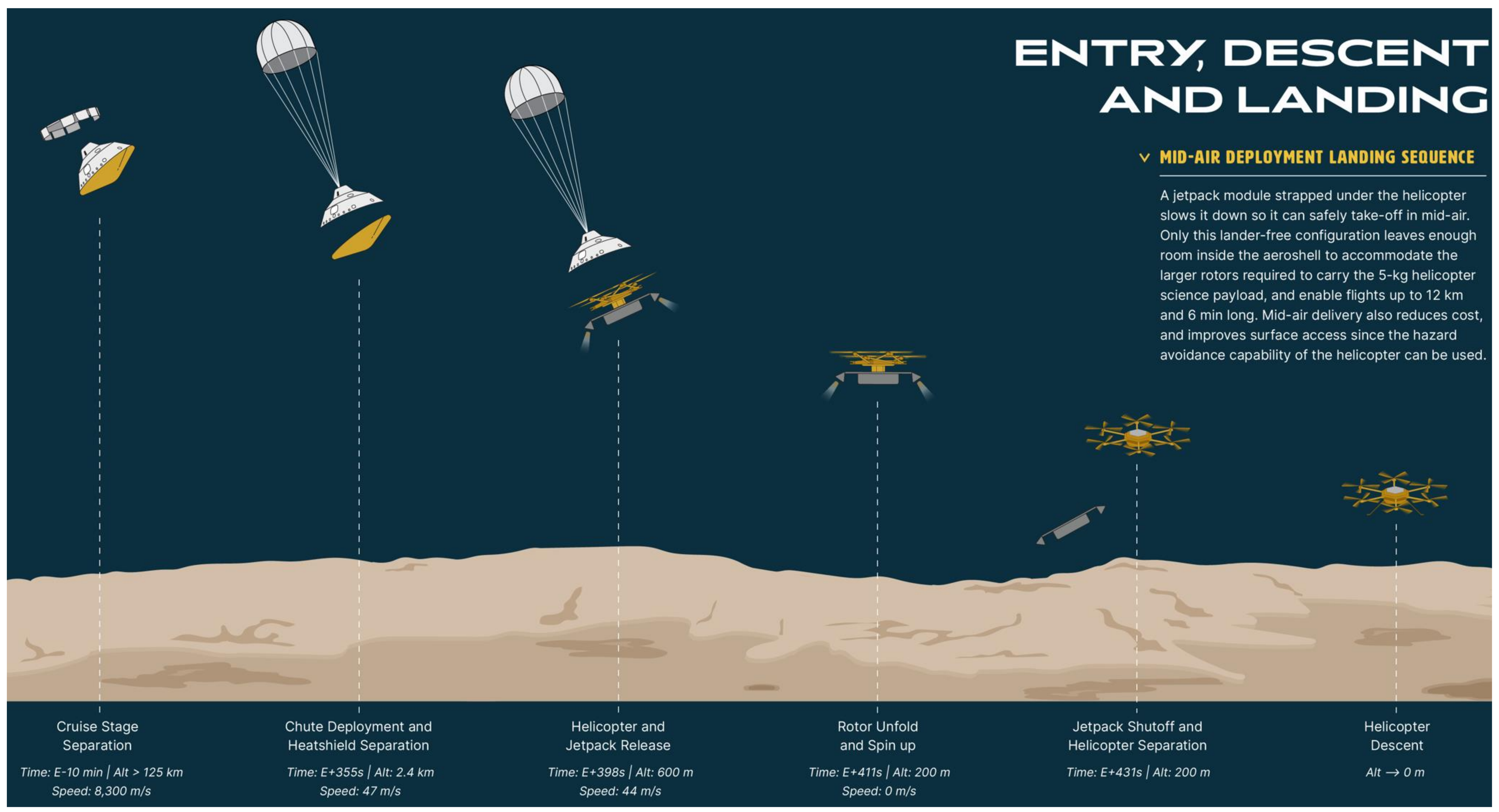

Figure 1 - MAHD concept of operations (Illustration credit: JPL Web Design & Development Team)

Objectives:

1) **Design a jetpack delivery system** to enable safe take-off of the Mars Science Helicopter (MSH) in mid-air at the 200-m nominal cruise altitude, after separation from the backshell.

2) **Characterize end-to-end MAHD performance** for the combined {aeroshell+jetpack+MSH} with closed-loop controls in high-fidelity simulation.

3) **Design a navigation sensor and software architecture** for MAHD leveraging MSH capabilities.

4) **Design mechanical interfaces** between the jetpack, the aeroshell and the helicopter compatible with the 2.65-m aeroshell.

5) **Design and plan follow-up effort**: FY22-22 risk reduction V&V experimental test campaign.

Background:

- Ingenuity demonstrated impressive planetary rotorcraft technology, but was delivered on the ground by the Perseverance rover.
- Next helicopter mission will likely be based on the MSH architecture:
    - Helicopter-only mission
    - 3.6-m diameter hexacopter (2.4-m folded)
    - 31kg total mass, including 5-kg science payload
    - 12-km range / 6-min hover flight capability
- **Volume, mass, risk, and cost constraints associated with planetary lander are unacceptable for MSH**

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Publications:

Delaune, et al. "Mid-Air Helicopter Delivery at Mars Using a Jetpack". Abstract pre-selected for IEEE Aerospace Conference, 2022.

Veismann, et al. "Axial Descent of Variable-Pitch Quadrotors: An Exp. and Comp. Study for Mars Deployment Applications". Vertical Flight Society's Forum, 2021.

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Approach and Results:

- Designed a 47-kg jetpack architecture (wet mass with margins) => Obj. 1
    - Using PHX/Insight heritage pulsed hydrazine thrusters and diaphragm tanks (see Figure 2).
    - Mechanical interface allow the jetpack and 31-kg MSH to fit within the 2.65-m Pathfinder heritage aeroshell, along with Viking-Heritage Disk Gap Band chute (see Figure 3) => Obj. 4
    - High heritage helps reduce mission development cost.
    - MSH avionics and vision-based navigation system controls the jetpack powered descent => Obj. 3
- Developed concept of operation for the jetpack to deliver MSH in mid-air, after separation from the backshell (see Figure 1)
    - Force-torque sensing at the MSH / jetpack interface measures the pitching moment imposed by the wind on the spinning rotors
    - Moment measurement is used to trim the collective angles of each individual to allow safe take-off from the jetpack at 200 m.
- End-to-end performance analyses in 500 Monte Carlo runs through 4 consecutive simulation framework => Obj. 2
    - Entry and descent simulation using the MAHD aeroshell and chute in DARTS/DSENDS
    - New jetpack dynamics, guidance, navigation and control simulator.
    - Navigation errors from MSH high-fidelity terrain-relative simulation at jetpack altitude.
    - New linearized helicopter dynamic and control simulator for take-off from the jetpack
- Proposed a 2-year risk reduction effort, using experiments in Caltech / CAST's wind tunnel facility. Selected for FY22-23 SRTD => Obj. 5

Significance/Benefits to JPL and NASA:

MAHD enables in situ mobility for Mars science in a Discovery budget

- Larger rotors can fit in aeroshell ➔ Improved performance

	w/o MAHD	w/ MAHD	Gain
Helicopter Payload Mass	2 kg	**5 kg**	+60%
Max Flight Range	10 km	**12 km**	+20%
Max Hover Time	5 min	**6 min**	+20%

- Lander-free
    - Cheaper, simpler, safer
- Uses helicopter advanced navigation system
    - Improved surface access w/ hazard avoidance
- 50% entry ballistic coefficient reduction
    - Opens access to Martian Highlands (the other half of Mars)

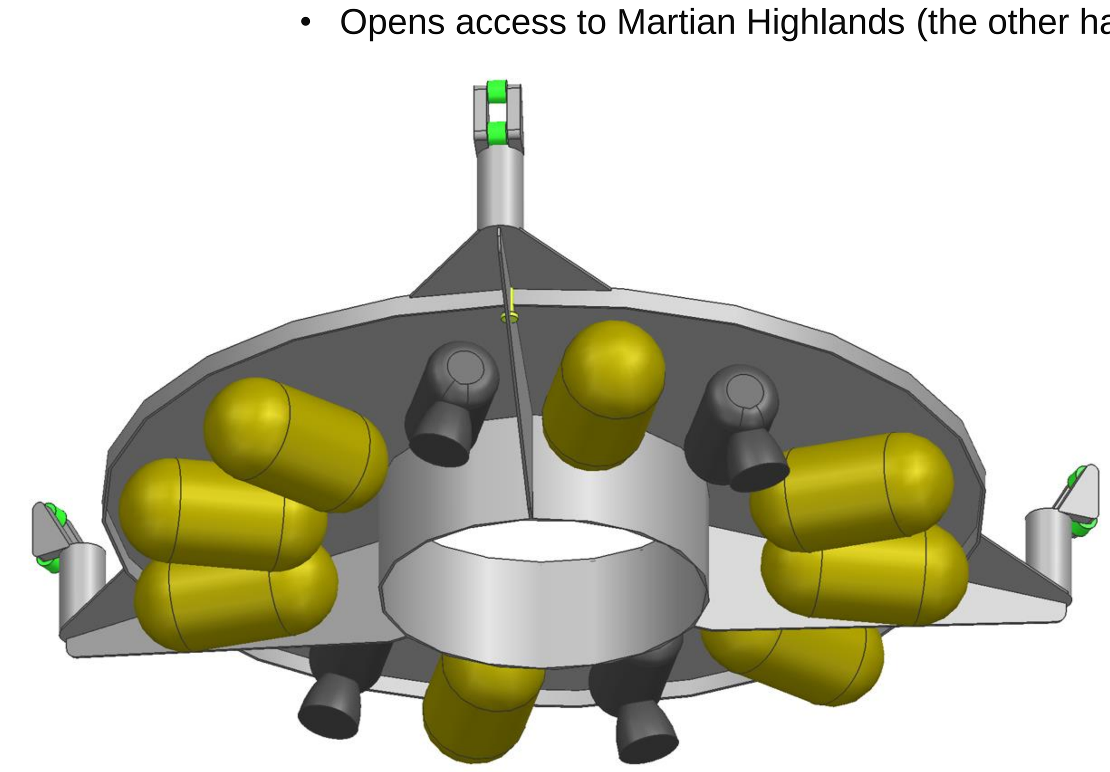

Figure 2 - 3D view of the jetpack assembly without the helicopter. On the bottom panel, the four hydrazine thrusters are shown in dark grey and they diaphragm tanks are shown in yellow.

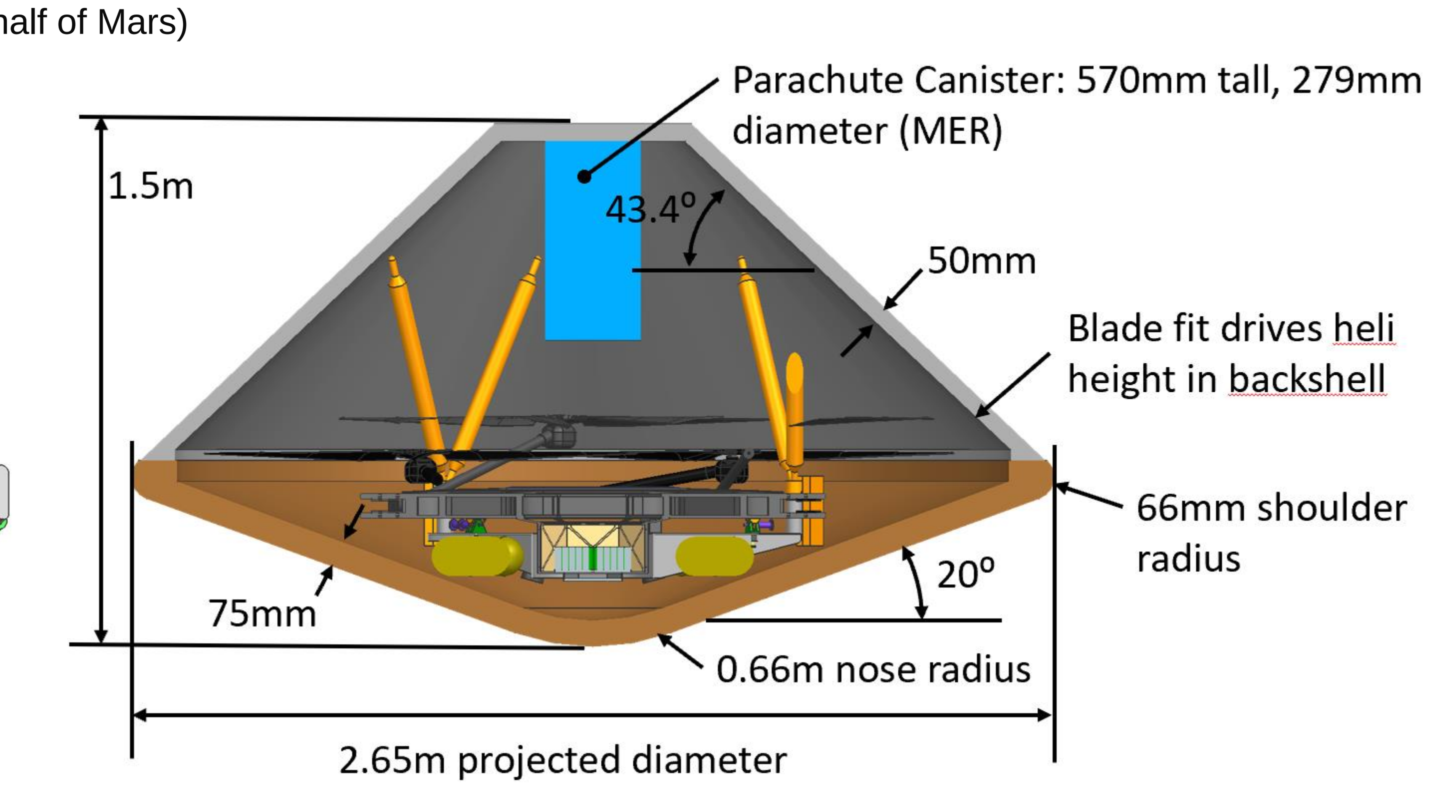

Figure 3 - The 31-kg Mars Science Helicopter and the 47-kg MAHD jetpack can fit within the 2.65-m Pathfinder heritage aeroshell.

Clearance Number:
RPC/JPL Task Number: R21015