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Ingenuity flights (If 6-9) on Mars (oM)

Part 2[$$]: Operations Demonstrations (OD)

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Conspectus: Ingenious helicopter (Hi!) of NASA, (named as Ingenuity), was designed for technology demonstration of autonomous power flight on MARS with a budget of 85 million USD. This robotic drone was carried to MARS in the belly of MARS-2020 rover (Perseverance)targeted to collect rock samples from surface of red planet in JEZERO region. The laser focus of this state-of-knowledge science project (costing 2.7 billion USD) is to explore microbial life that existed (even earlier) and also traces of water now present in locked rock structures. The samples will be brought to Earth aroundthe year2026 for intense chemical analyses.

Technology Demonstrationof Hi (If-1 to If-5): The five flights in the technology demonstration phase of Ingenuitywere designed to carry out a feasibility study of hurdle-free autonomous (with no real time earthly-ground-machine or human control) functioning of Hi. The successful outcome and in-tact functional state of Hi, prompted NASA to go for second phase of exploration i.e.operations demonstration (IF-6 to IF-9 till now).

Operations Demonstrations of Hi (If-6 to If-9,….): Astounding success (save watch-dog-timer, color-image-issues) with stretched limits of height/duration/ maximum speed of flight on slopy/rough/non-flat surfacestructure of ground, there is convincing proof of goodness-of-fit for Hi to take up execution of even more daring new robotic mission operations.

$$: Part I ; J.Appl.Chem., 2021, 10 (3): 409-436

Future Ingenuity helicopter flights (IF>9): Now, Ingenuity flights (If) on Mars (Om) will go on to new (unexplored/treachery) airfields for longer flight-times. The limit is it's survival in harsh environment of MARS and this activity of Hi doesn't interfere with the science work schedule of the Perseverance rover. It is rather a way of "see How it goes" perspective of human-experts and ensemble-of-expert-systems with time and action.

	Layout
1.	Phase I: Technology Demonstrations (If-1 to If-5)
2.	Phase II: Operations Demonstrations (If-6 to If-9,….)
SI	Supplementary Information 1. Image-gallery 2. Numerical Data

Phase I: Technology Demonstrations(If-1 to If-5): NASA designed Ingenuityhelicopter for technology demonstration of flying aroundautonomously in the dusty world of low-density atmosphere of MARS. The budget was around 85 million USD for the tiny 1.8 Kg robot and it is not meant to do any science. It has two imagers, solar panel and planned for five flights on MARS. The life expectancy of this helicopter was 30 days and supposed that it crashes by the end technology demonstration phase. Ingenuity was transported to MARS in the belly of Perseverance, MARS-2020 roverwith advanced state-of-knowledge scientific instruments, cameras and communication modules developed with 23 billion USD. The communication system module of helicopter Ingenuity **(**Hi**!)** was impregnated in Perseverance. Thus, Hi depends on Perseverance for ground contact.

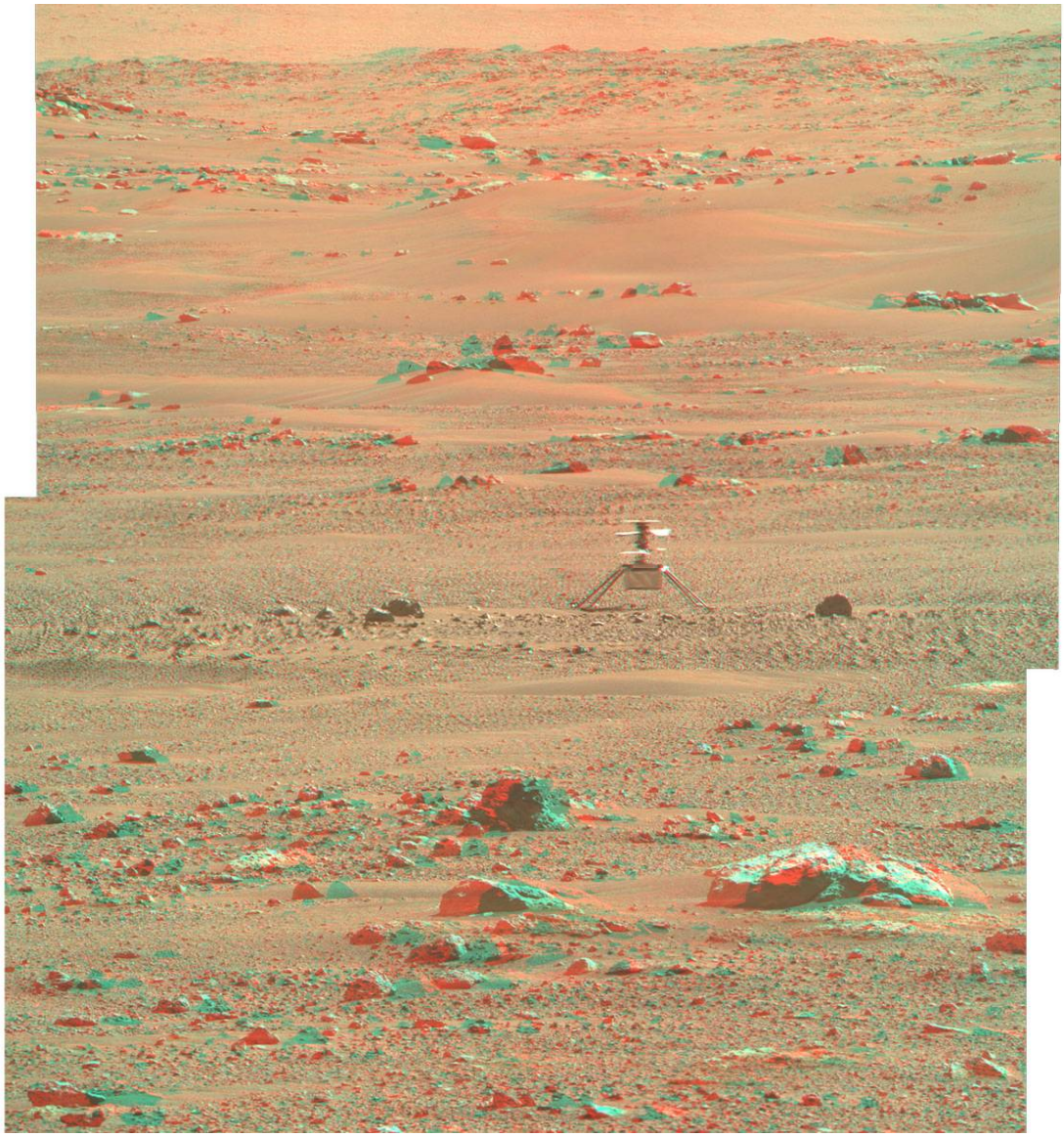
A full scale model of *Ingenuity*
HubschraubermuseumBückeburg (Helicopter Museum of Germany) (17 Feb., 2021)

The five flights (If-1 to If-5) designed were to demonstrate hurdle-free autonomous (with no real time earthly-ground-control) functioning of Hi viz. take-off, vertical-rise, hovering, tilting, horizontal movement (with varying speed) at higher altitude from Martian flat-surface, turning back (180^{o}) retracing to take-off region, and smooth landing. The data acquisition includes HD, 3D- black-and white and color images of ground, horizon with Hi's cameras. The overwhelming success of first five flights (save watch dog timer failure) and intact status of Hi after the first phase, NASA planned second phase for operation demonstration.

Since	IF-1 to IF-5were successful
Then	IngenuityTechnology task (phase) **Successful**

- Photographer: NASA's Ingenuity Mars Helicopter ;navigation camera: black and white.
- camera location: mounted in the helicopter's fuselage ; pointed directly downward
  - ✓ to track the ground during flight
- image acquired Date: May 22, 2021

Credit: NASA/JPL-Caltech



Ingenuity Helicopter in 3D;Date: June 6, 2021,
Photographer: Left and right Mastcam-Z cameras aboard NASA's Perseverance Mars rover.
Credit: NASA/JPL-Caltech/ASU/MSSS.

Phase II: Operations Demonstrations (If-6 to If-9,….): In this operational demonstration (IF-6 to IF-9 till now) phase, judicious design is used to stretch the limits of vertical height (above Martian ground) during take-off, flight duration, maximum speed in horizontal flying, varied (non-flat, slopy, rough with trenches) surface structure of ground in the flight area of Hi. The other target is acquiring sequential colour images/videos of surroundings/ground surface during the course of flights. This is with a foresight for future Martian critical investigations of areas, not reachable by rovers. More intuitive focus is knowledge generation/pooling to learn, face, tackle, surmount and solve glitches, difficulties in these newer ventures with proved (IF-1 to IF-5) technology. It opens up a new window for intelligent/smart science-methods and technology-products in planetary explorative research for good of mankind.

Iff	Hi . F6 success	&
	Hi . F7 success	&
	Hi . F8 success	&
	Hi . F9 success	
Then	Demonstration of Ingenuity Operations task (phase) **Success**	

IFF	If and only if (Mathematical logical Strong condition)

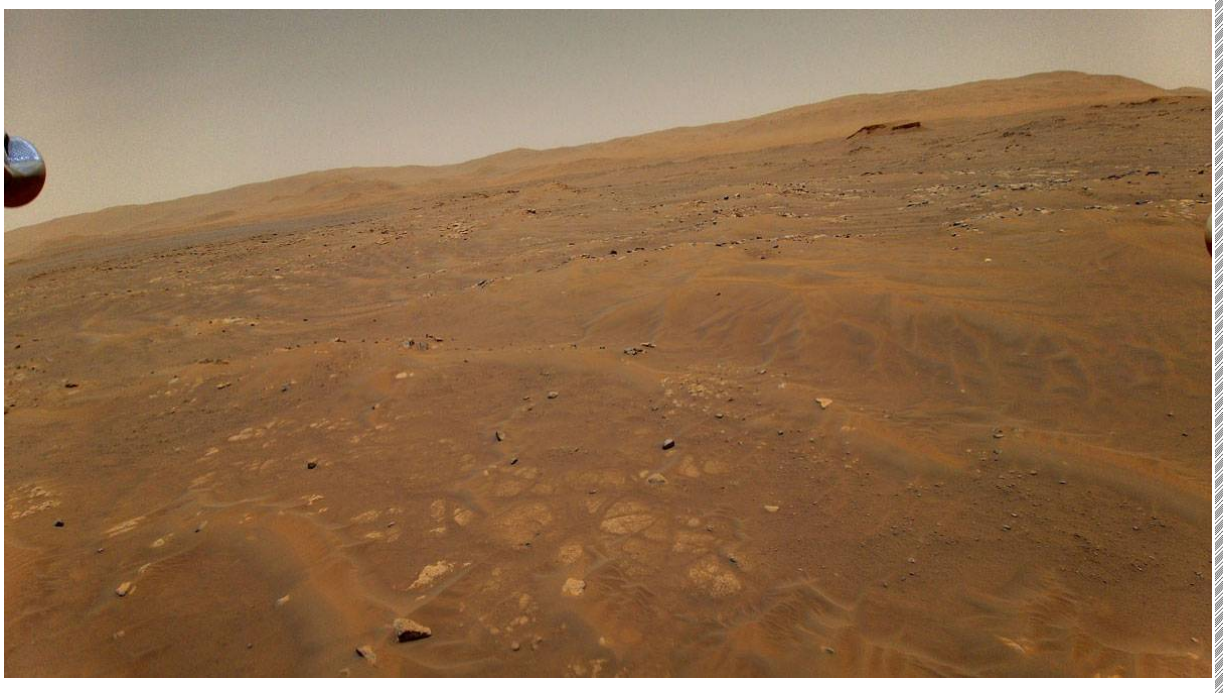
Hi . F	HelicopterIngenuit . Flight

Ingenuity flight-Six: The firsttask in operations demonstration phase was to expand the flight envelope and make a feasibility study of aerial-color imaging capabilities by taking stereo images of a region of interest. Further, moving at higher speeds than previous flights andlonger flying time are other objectives.

Approximately 54 seconds after take-off of sixth flight, a glitch occurred in the pipeline of images which were delivered by the navigation camera. Not only the image was lost, but it also resulted in all subsequent navigation images were delivered with inaccurate timestamps. As a consequence, Ingenuity began adjusting its velocity and tilting back and forth in an oscillating pattern. This behaviour persisted throughout rest of the flight. After wobbling, suffering power spikes, and enduring velocity fluctuations, NASA's Ingenuity helicopter safely landed.

Sixth Ingenuity flight	May 23, 2021 at 5:20
Operations	
Takeoff from	Airfield B
Rose vertically	33 ft
Hovered	For a short while at the same altitude
Shift	➔ Southwest 490 ft ➔ southward 49 ft ➔ northeast 160 ft
Horizontal motion	705 ft
Max speed	9 mph
Flight time	139.9seconds

Landed	Airfield C	18.44166°N 77.44994°E
Error in Landing from scheduled spot	16 ft away from the planned site	
Flight	One way	
Start of	**Operations demonstration phase**	
Achievements		
+ Collected Color images	**+ Landed at an airfield C – ☞ not survey from the air during a previous mission**	
Ingenuity flight - 9	**Success**	



Color image of Marson May 22, 2021

Photographer: NASA's Ingenuity Mars helicopter during its sixth flight taken from the height of 33 feet

Credit: NASA/JPL-Caltech

Ingenuity flight-Seven: The tissue-box-sized drone flew to a new landing site, Airfield C, navigation cameras had never seen before.NASA only had information about the new area from its Mars Reconnaissance Orbiter, which images the red planet from space. The orbiter's pictures indicated that the spot was flat and should be safe for landing. The Ingenuity helicopter hovered above ground, then gently lowered itself and reached to touchdown.

Seventh Ingenuity flight	June 08, 2021 at 15:54		
Operations			
Takeoff from	Airfield C	Flight	One way
Rose vertically	33 ft		
Hovered	For a short while at the same altitude		
Tilt	South	Horizontal motion	348 ft
Max speed	9 mph		
Flight time	62.8 seconds		
Landed	Airfield D	18.43988°N 77.45015°E	
Error in Landing from scheduled spot	Landed 154 ft from the center of the 160 ft radius airfield.		
Continuation of	**Operations demonstration phase**		
Constraint	**Color camera not used**		
Ingenuity flight -7	**Success**		

Ingenuity flight-eight: Flight 8 was the first flight the vehicle executed the new software. All telemetry data indicate that the update was a success.

Eighth Ingenuity flight	June 21, 2021
Operations	
Takeoff from	Airfield D
Rose vertically	33 ft
Hovered	For a short while at the same altitude
Tilt	Southwest
Horizontal motion	520 ft
Max speed	9 mph
Flight time	77.4 seconds

Landed	Airfield E (Séítah) 438ft away from Perseverance	18.43724°N 77.45079°E
Error in Landing from scheduled spot	Landed 154 ft from the center of the 160 ft radius airfield.	
Flight	One way	
Flight software	Flight-Controller New upgradedone	
Continuation of	**Operations demonstration phase**	
Constraint	**Color camera not used**	
Ingenuity flight -8	**Success**	

Ingenuity flight-Nine: Ingenuity landed in a brand-new airfield with a total of nine successful flights under its belt.The operations demonstration phase (IF-6 to IF-9) defied expectations of NASA (JPL) Mars's mission expert scientists. Still robust design and functioning of Ingenuity Helicoptor of NASA's labs is a gem of gems in this century.

Nineth Ingenuity flight	July 5, 2021at 9:03	
Operations		
Takeoff from	Airfield E	
Rose vertically	33 ft	
Hovered	For a short while at the same altitude	
Tilt	Southwest	
Horizontal motion	625 ft	
Max speed	11 mph	
Flight time	166.4seconds	
Landed	Airfield F	18.42809°N 77.44545°E
Error in Landing from scheduled spot		
Flight	One way	
Continuation of	**Operations demonstration phase**	
Constraint	**Color camera not used**	
Ingenuity flight - 9	**Success**	

State-of-health and functionality of Ingenuity helicopter: Hi completed IF-9 successfully. NASA confirms the robot, Hi, is alive andready for executing even more daring new missionoperations. It does not have any issues now even after landing in anew zonesofJezero Crater. It just consumes Perseverance time for communication with ground station before and after every flight.

Future Ingenuity helicopter flights (IF>9): This drone will keep flying to new airfieldsfor longer time, as long as it survives and doesn't interfere with the science work of the Perseverance rover, which carried it to Mars. Now the mission just is "see-how-it-goes phase".

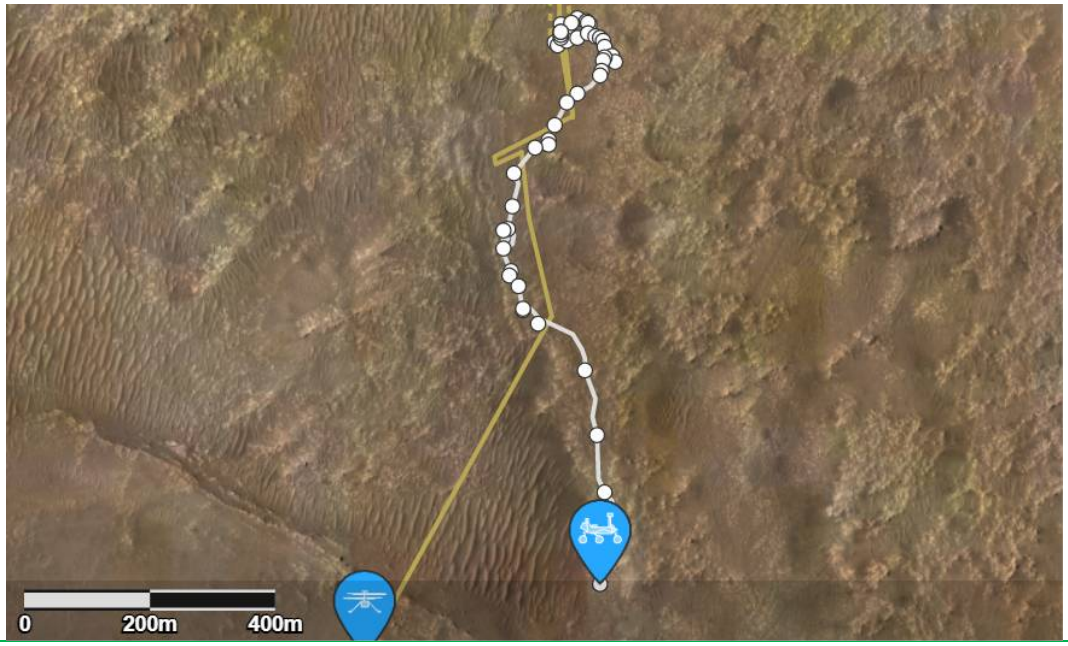
Future space Ingenious helicopters: The far-off goals of NASA in future design and operation of Ingenuity-likereconnaissance helicopterin combination with a rover are

- Scouting and mapping
- Observing interesting features of Mars from air
- Exploring rough terrain that rovers can't access

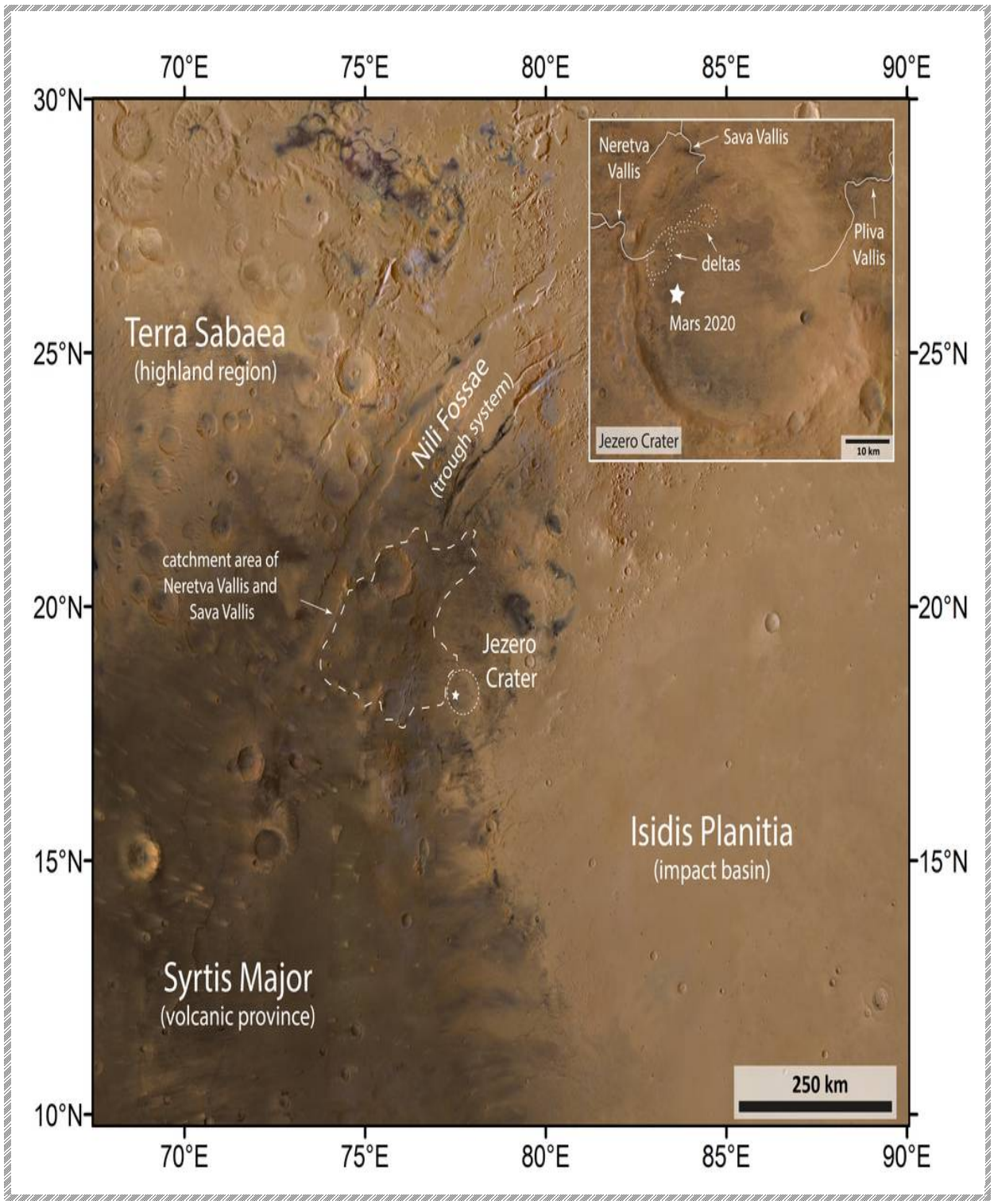
Perseverance Explorations on Mars

Referred as Percy affectionately

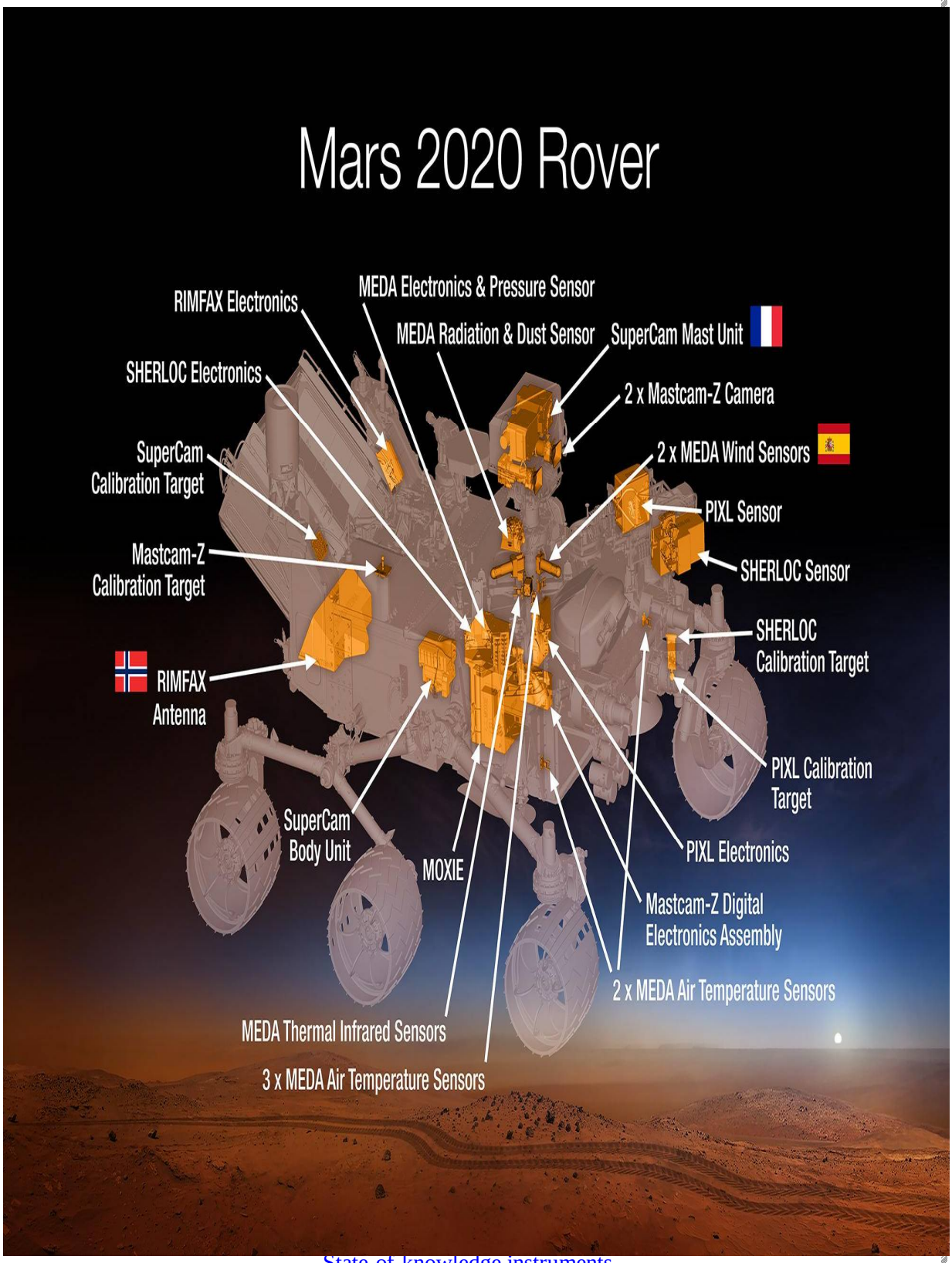
MARS-2020 rover (named as Perseverance) is a six-wheeled Scientist (geologist- Chemist- Physicist- astrobiologist- hydrologist- MARS_knower) with current brain stuff. It is a NASA mission of 2.7 billion USD (US $) unveiling the secrets of Mother-Nature. This decade is a new era for Astro-biology and Planetary Science discoveries. The target area (space) for NASA mission is in a part of Jezero Crater called the “Cratered Floor Fractured Rough”.



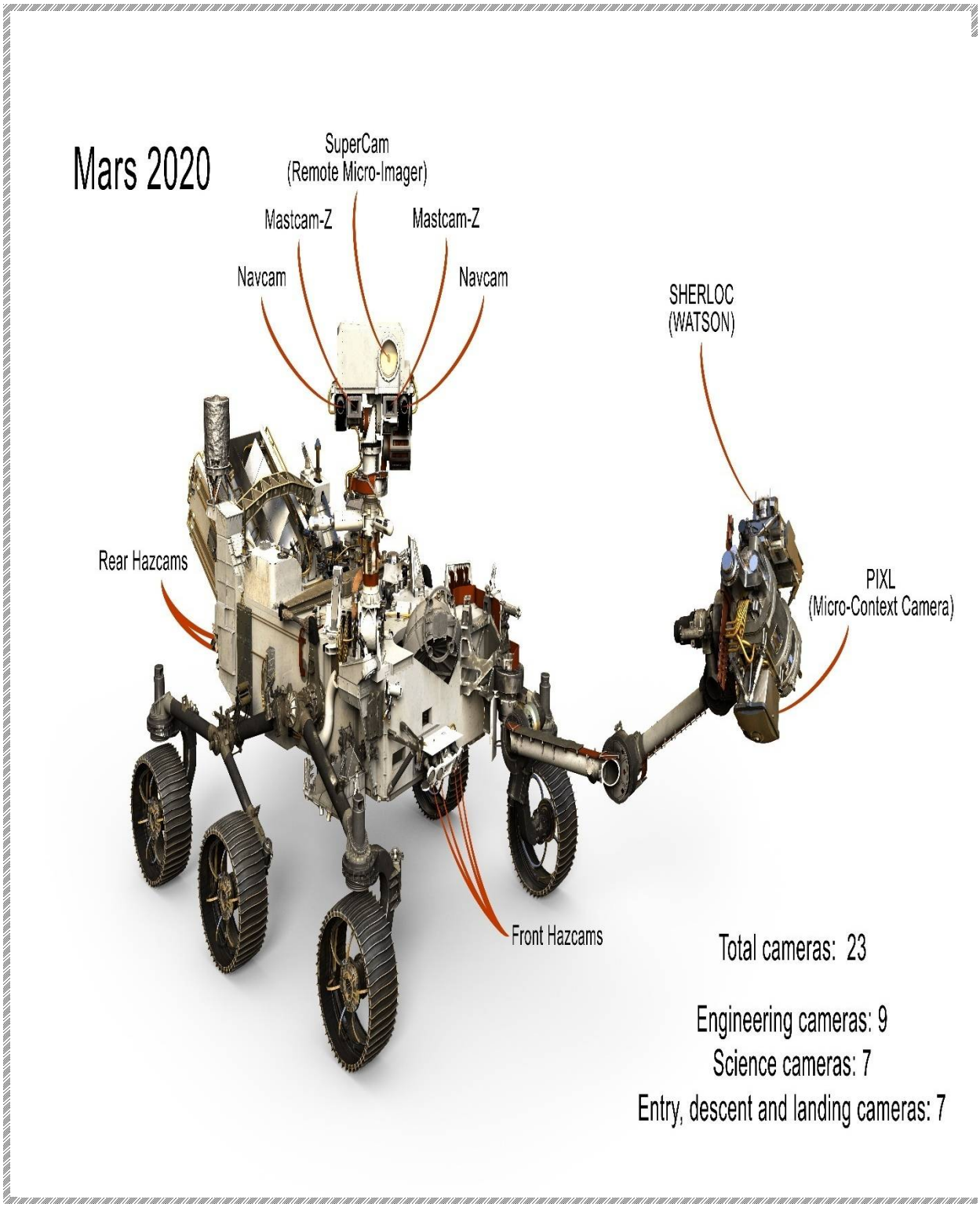
Perseverance rover and Ingenuity helicopter



Perseverance rover is bristling with advanced instruments, long robotic arm,rock drilling tools and cameras all with state-of-knowledge-features. The goals are identifying, collecting, and sealing Martian rock, regolith (broken rock and dust) samples for return to Earth by future spacecraft around year 2026.



State-of-knowledge instruments

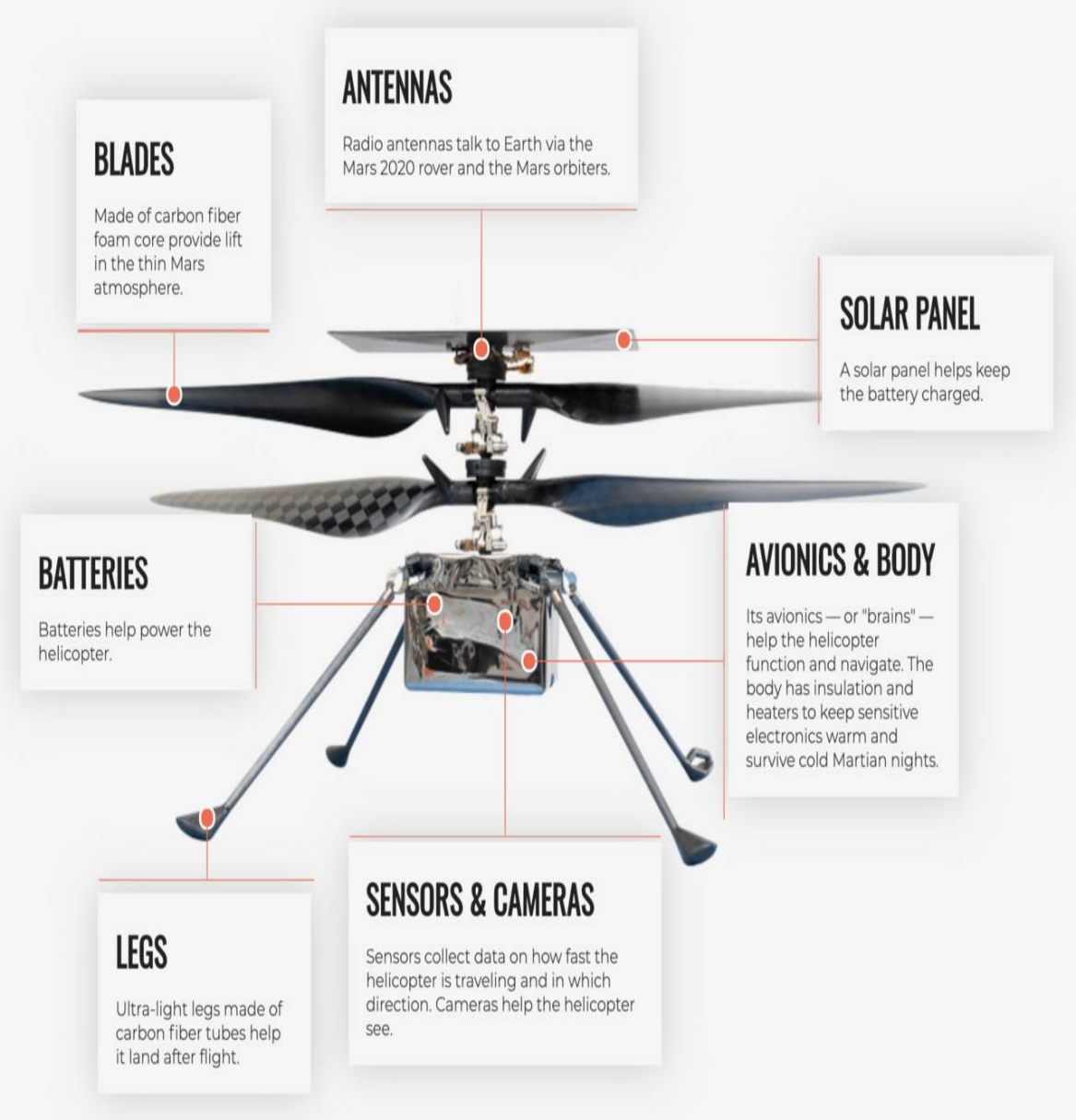


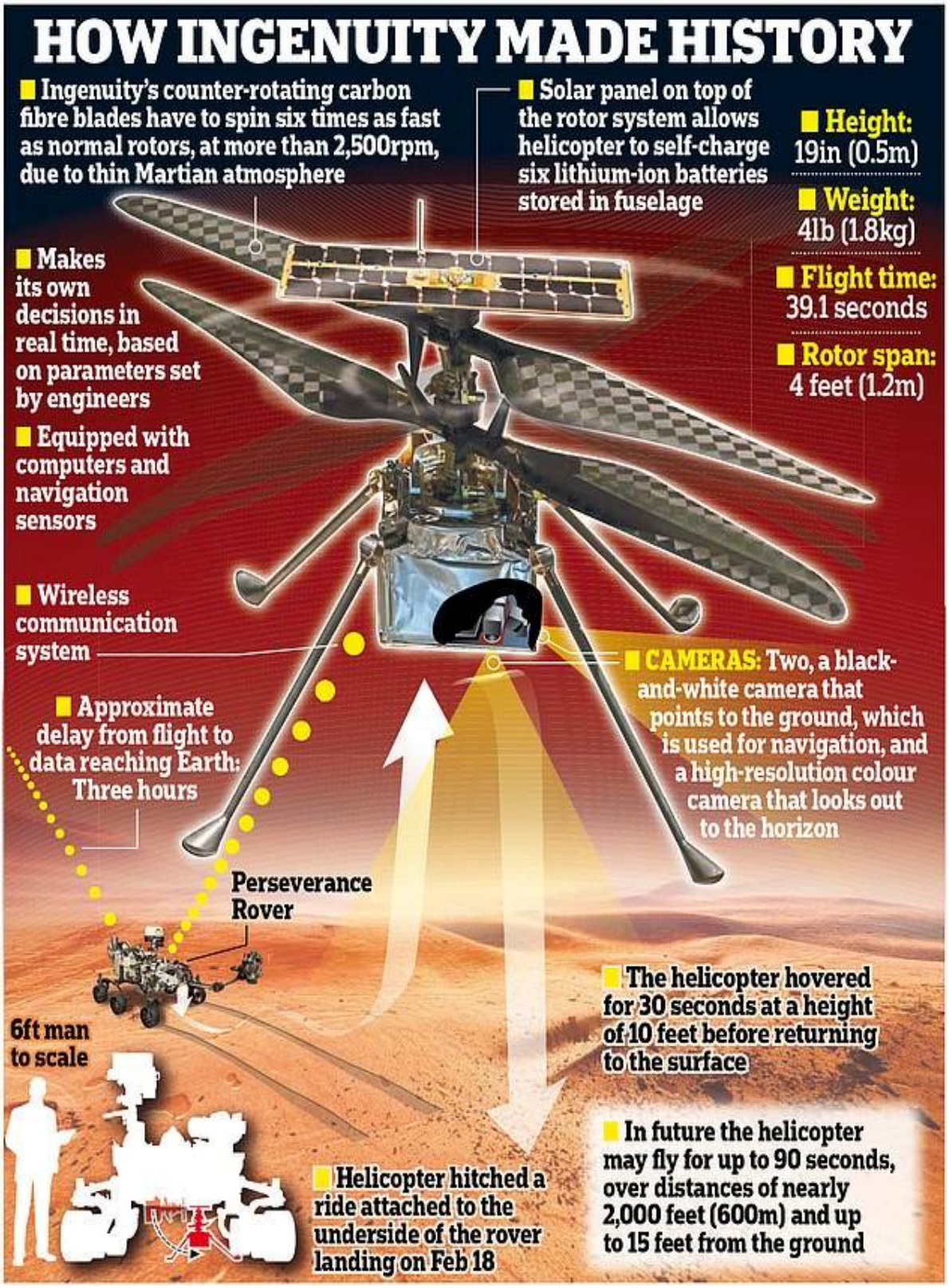
The rover that carried Ingenuity in its belly to Mars has started driving south to the region where it will attempt to take its first sample of Martian soil within a few days. The laser focus at the current instant is on the outcome of in-situ analysis of Martian rocks and soil which possibly find the first evidence of ancient alien microbes - fossils trapped in the bottom of an ancient lake bed.

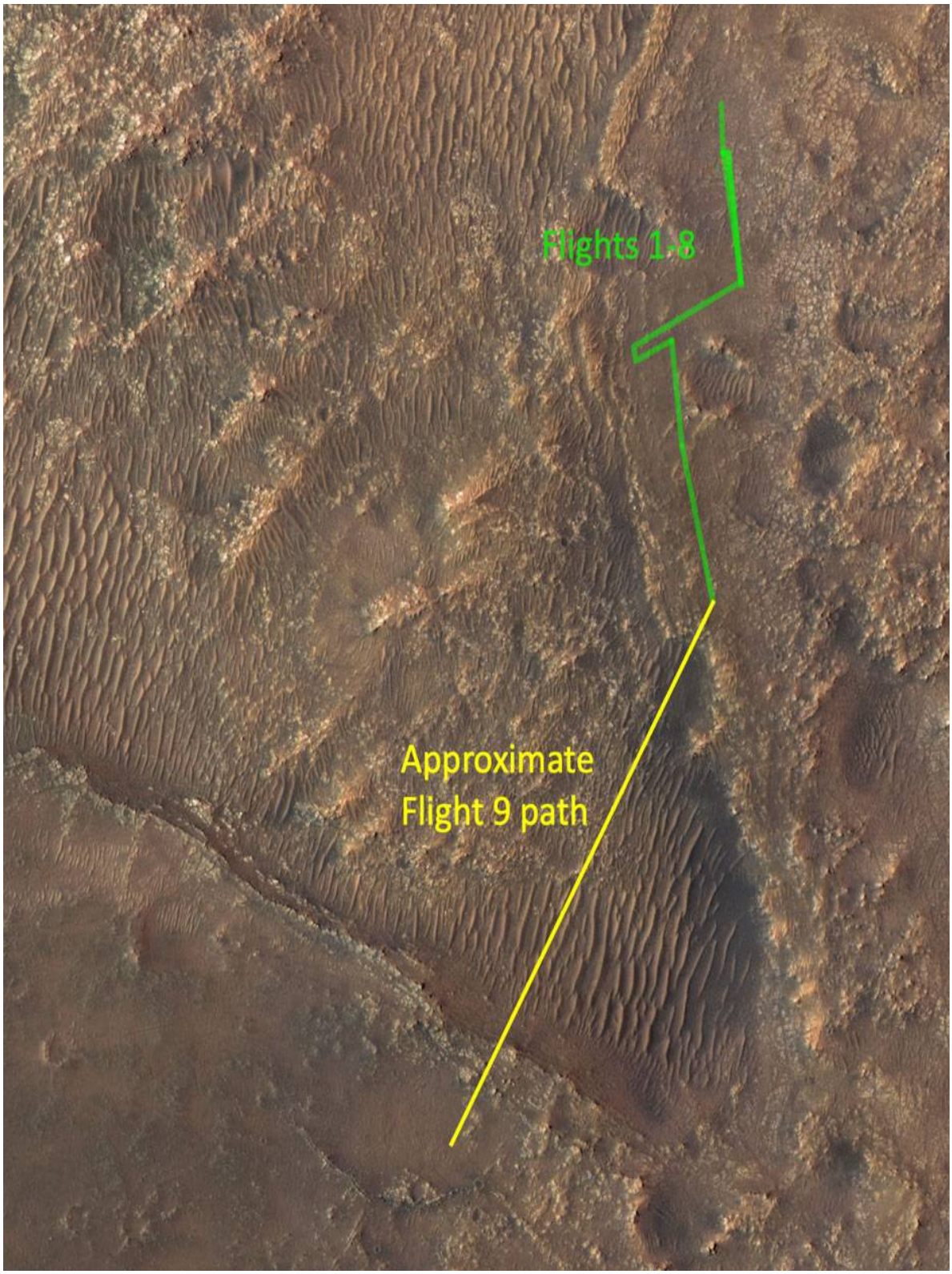
SI: Supplementary Information-1
Image-gallery

Credit : NASA.Gov

Credit: NASA/JPL-Caltech -

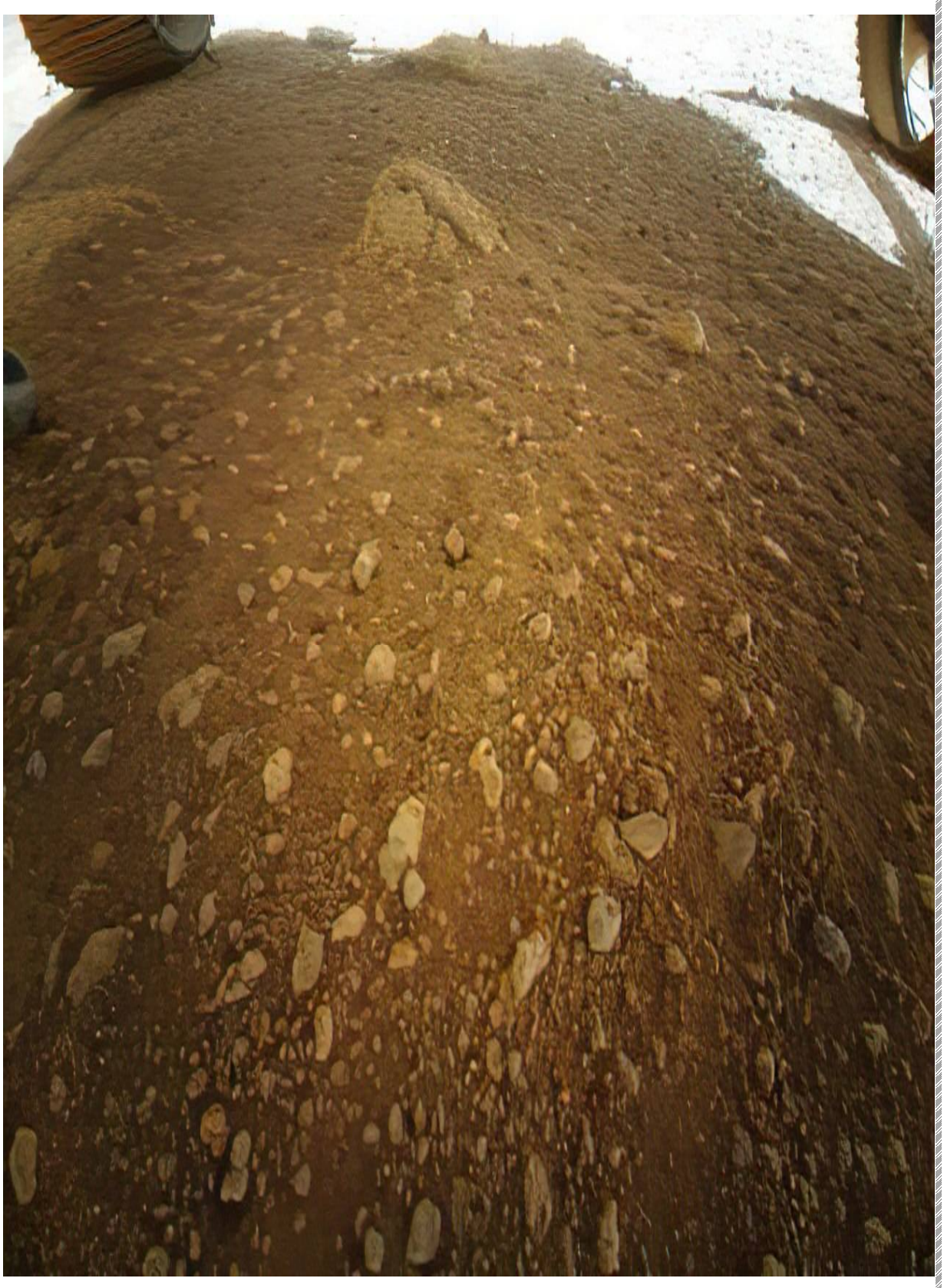



HOW INGENUITY MADE HISTORY
Ingenuity's counter-rotating carbon fibre blades have to spin six times as fast as normal rotors, at more than 2,500rpm, due to thin Martian atmosphere
Solar panel on top of the rotor system allows helicopter to self-charge six lithium-ion batteries stored in fuselage
Height: 19in (0.5m)
Weight: 4lb (1.8kg)
Flight time: 39.1 seconds
Rotor span: 4 feet (1.2m)
Makes its own decisions in real time, based on parameters set by engineers
Equipped with computers and navigation sensors
Wireless communication system
CAMERAS: Two, a black-and-white camera that points to the ground, which is used for navigation, and a high-resolution colour camera that looks out to the horizon
Approximate delay from flight to data reaching Earth: Three hours
Perseverance Rover
6ft man to scale
The helicopter hovered for 30 seconds at a height of 10 feet before returning to the surface
In future the helicopter may fly for up to 90 seconds, over distances of nearly 2,000 feet (600m) and up to 15 feet from the ground
Helicopter hitched a ride attached to the underside of the rover landing on Feb 18

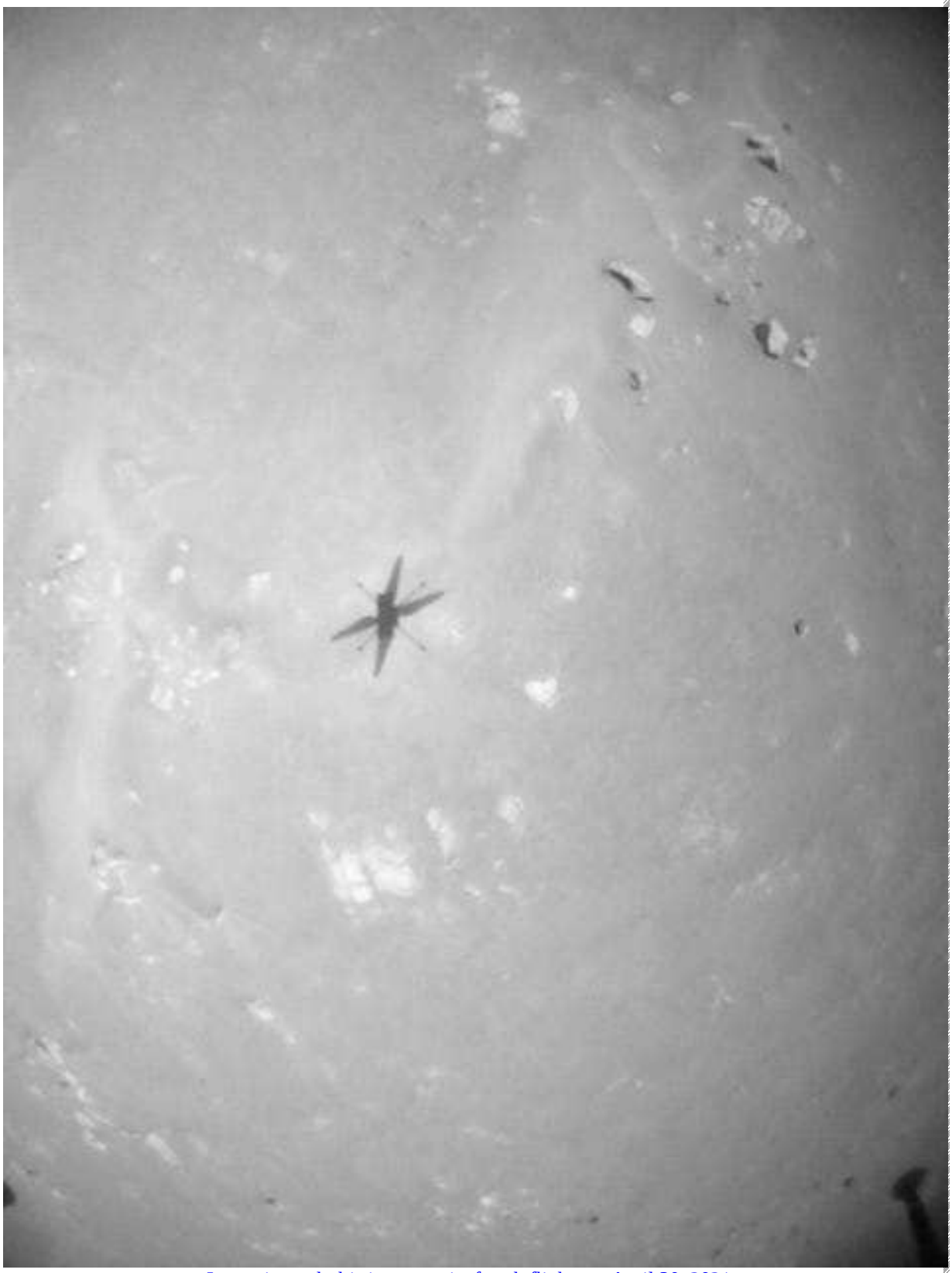


Approximate Ingenuity-ninth-flight-path on July 5.

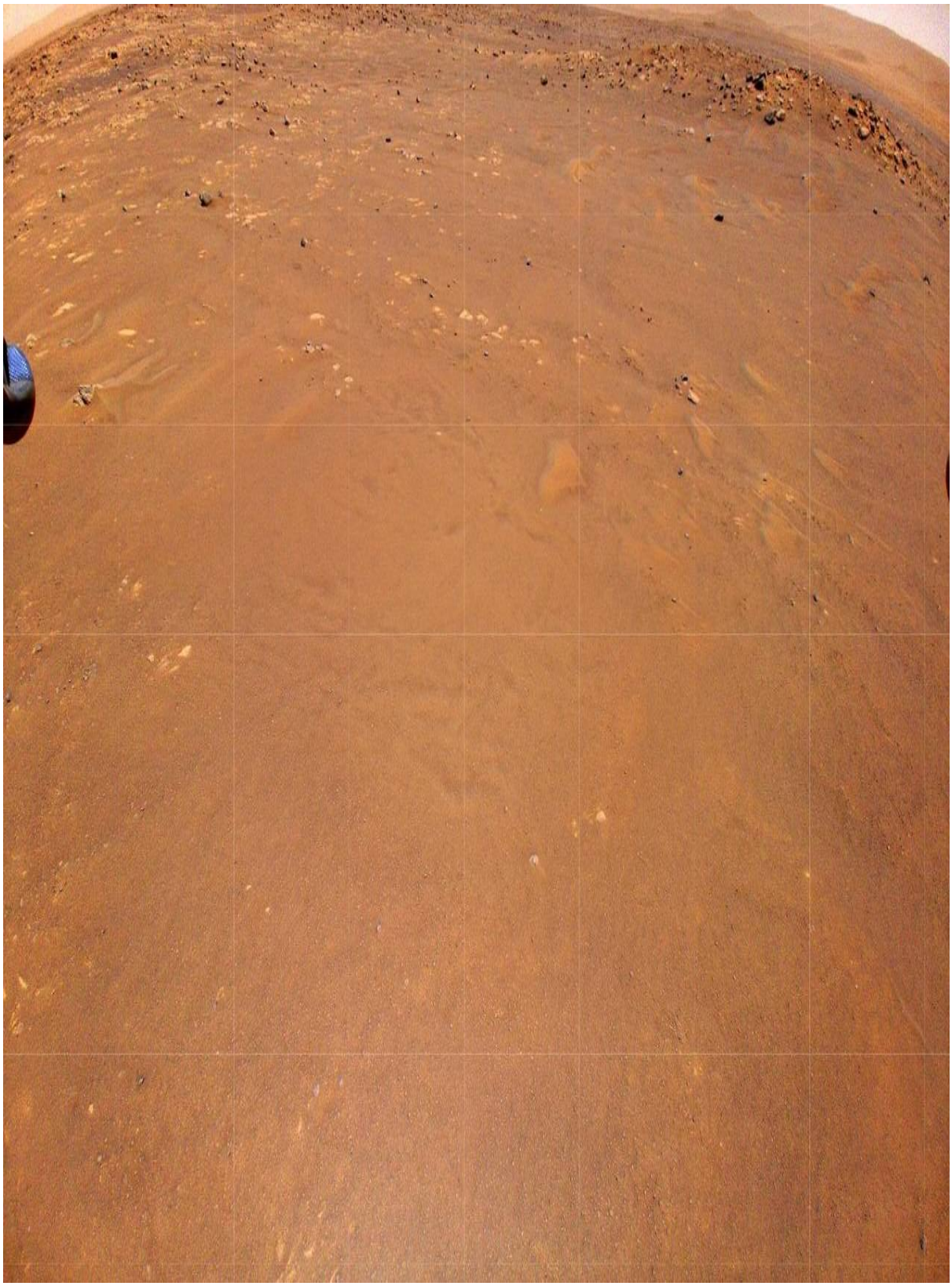
Credits: NASA/JPL-Caltech



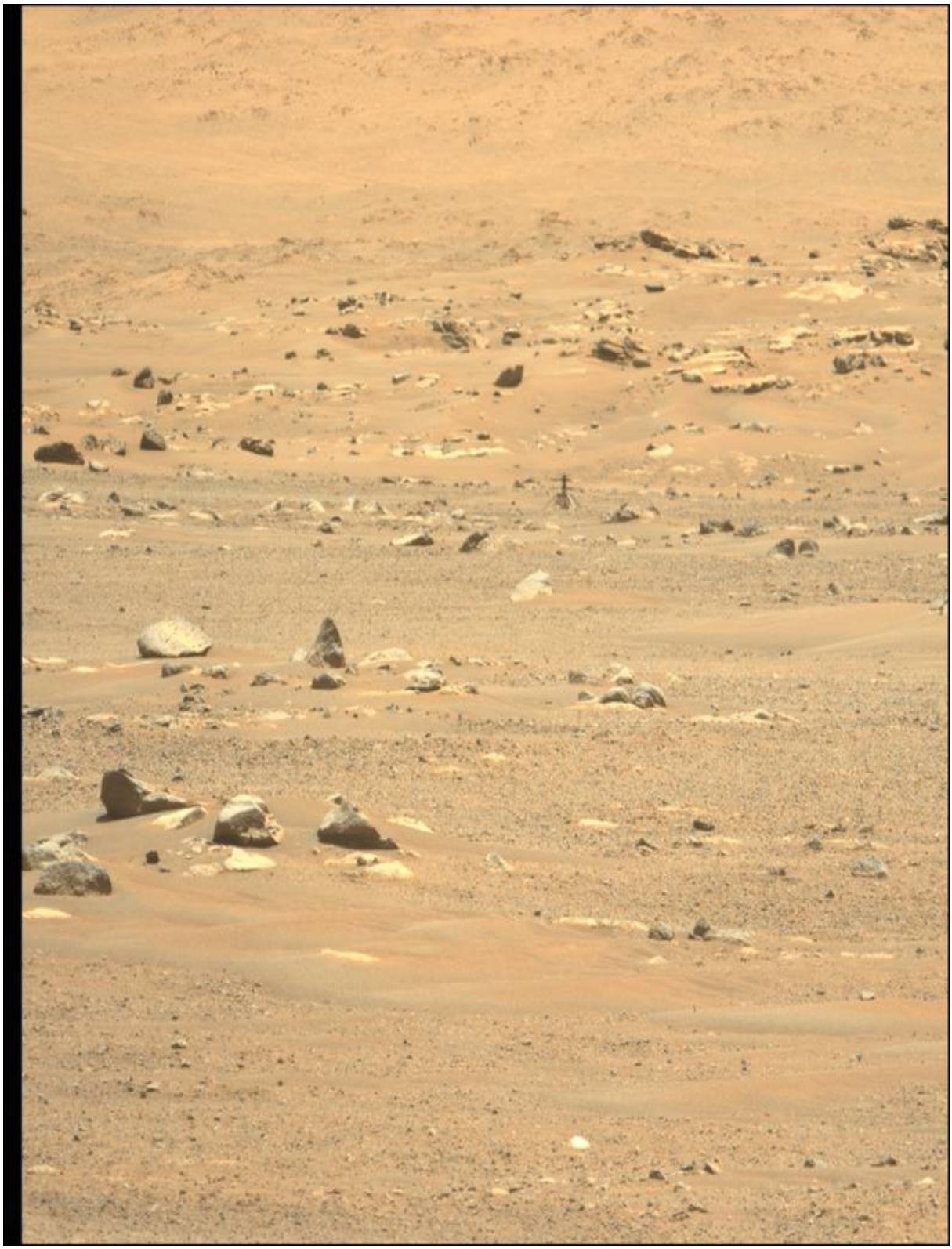
Ingenuity's first color image



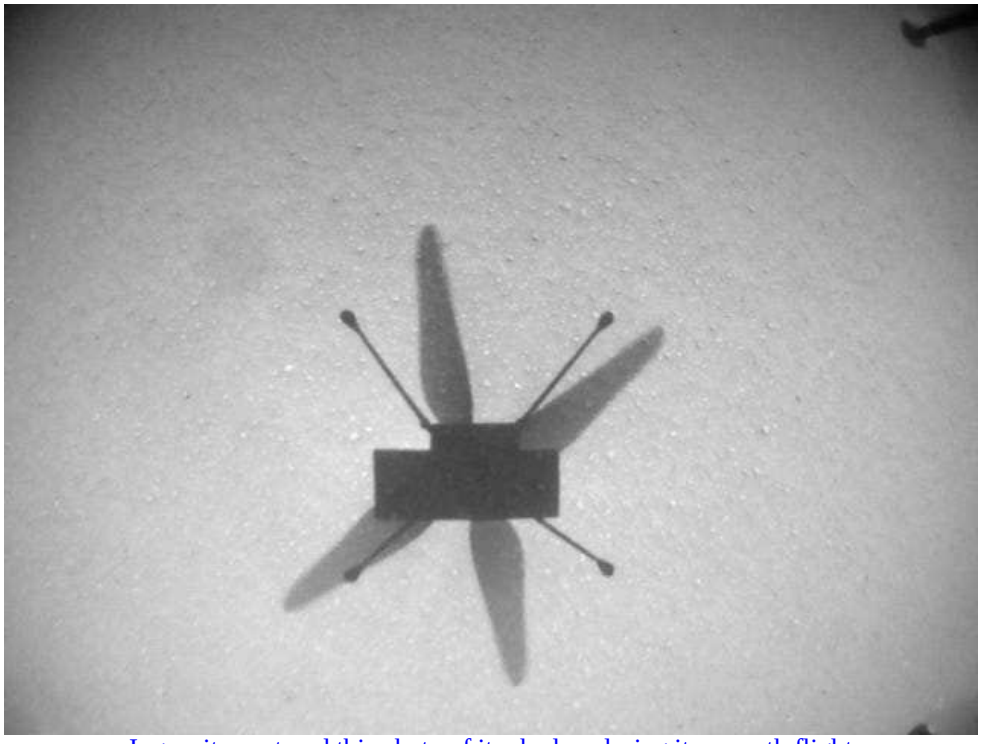
Ingenuity took this image on its fourth flight, on April 30, 2021



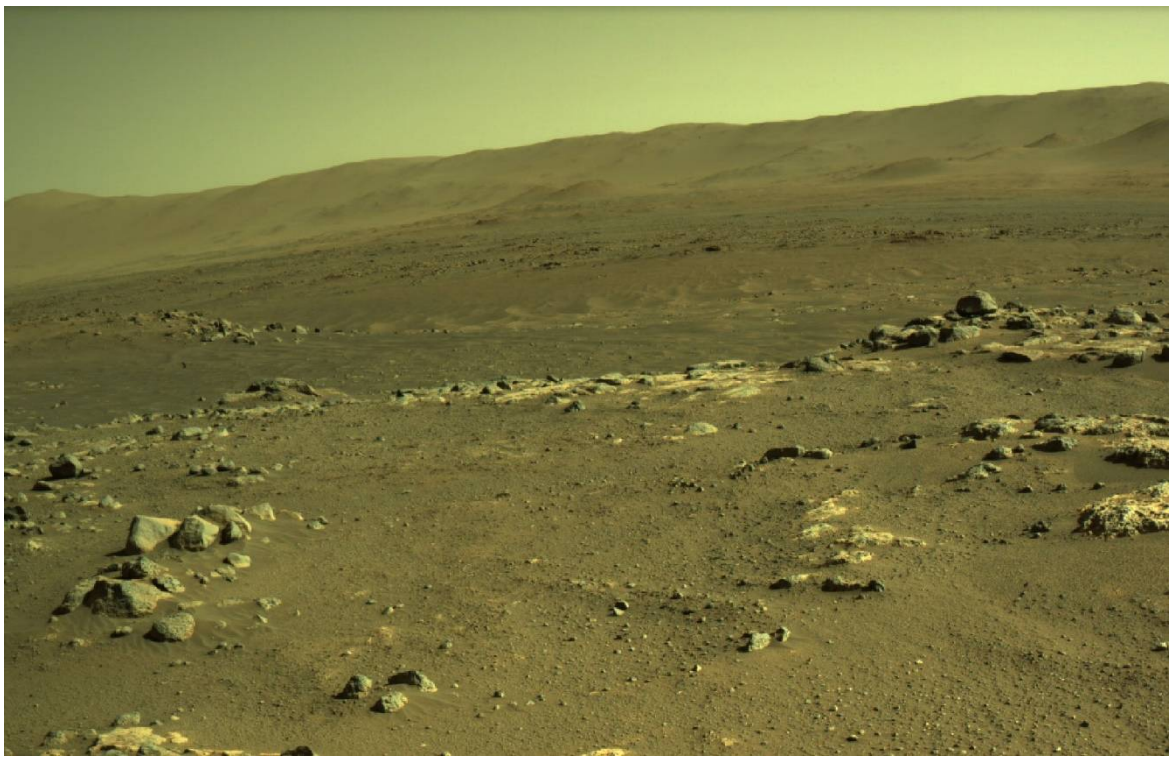
Ingenuity finds new Airfield B on fourth flight (30 April 2021)



Ingenuity one day after its sixth flight



Ingenuity captured this photo of its shadow during its seventh flight



Flight 9 Was a Nail-Biter, but Ingenuity Came Through With Flying Colors

SI: Supplementary Information-2
Numerical Data

Credit : NASA.Gov

Credit: NASA/JPL-Caltech -

Flight	Sol	Date
Demonstration. Technology		
1	58	April 19, 2021
2	61	April 22, 2021
3	64	April 25, 2021
4	69	April 30, 2021
5	76	May 07, 2021
Operations. Demonstration		
6	91	May 22, 2021
7	107	June 08, 2021
8	120	June 21, 2021
9	133	July 5, 2021

Flight	Horizontal Distance	Max. Altitude	Max. Groundspeed	Duration	Route of Flight	
	ft	ft	mph	seconds	From	To
1	0	~10	0	39.1	Wright Brothers Field	
2	~13	~16	~1	51.9		
3	~328	~16	~4.5	80.3		
4	~873	~16	~8	116.9		
5	~423	~33	~4.5	108.2	Wright Brothers Field	Airfield B
Technology demonstration successful in IF-1 to IF-5						
6	~705	~33	~9	139.9	Airfield B	Airfield C
7	~348	~33	~9	62.8	Airfield C	Airfield

						D
8	~525	~33	~9	77.4	Airfield D	Airfield E
9	~2051	~33	~11	166.4	Airfield E	Airfield F
	Horizontal Distance	**Max. Altitude**	**Max. Groundspeed**	**Duration**		

Demonstration of Operations phase successful in IF-6 to IF-9 (….To continue)

"Dare mighty things"
JPL motto
Wish us good luck
Get a chance to live and count on it

Far better is
to dare mighty things
to win glorious triumphs,
even though checkered by failure...
than
to rank with those poor spirits
who neither enjoy nor suffer much
Why?
because they live in a gray twilight
that knows not victory nor defeat.
By Theodore Roosevelt

Nature is the best Scientist/engineer/technologist of all times	KLab rsr.chem1979