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Ingenuity flights (If) on Mars (oM)

Part 5[$$]: Scouting and Future Exploration(Safe, If 19-20)

KnowLab

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Dedicated to "J. Applicable Chemistry" during
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Conspectus: Dr Balaram, an engineer in JPL (Jet Propulsion Laboratory, CA) invented Helicopter Ingenuity (Hi). NASA delivered the 1.8 Kg. quadcopter with its technical expertise and financial support. This physical drone flew for the first time in Mars' thin atmosphere on April 19,2021. Hi rose 10 feet vertically in air, hovered and landed at the same point on Mars (oM). The duration of flight was for 39.1 seconds. It is the first ever flying instance in the atmosphere of another planet (other than earth) in our solar system. This is the proof-of-concept of technology demonstration to show that aerial flying is feasible in low density, low gravity, extremely low temperatures, thin (carbon dioxide) atmosphere with frequent dust storms. The only other venture on earth in the annals of human scientific history was Wright brother's aeroplane flying for 12 sec in the year1903.

Hi completed twenty trips (If-01 to If-20) in JezeroCrater region of Marsafter first its flight last year. These flights confirm successful demonstration of technology, learning scoutingandflight-operations. Flight 14 was brief (23 sec), but a critical one. It was a test for feasibility and robustness of helicopter for very high (2700 rpm) rotor speed. The success is a passport (work permit) for carrying out flight operations in the forth-coming unfavorable weather seasons. Flight-20 is a risk-to-neck type of operation, as the helicopter has to cross over most unfavorable terrane with cliffs, uneven rocks etc. The safe landing at the scheduled site is a testimony of its fitness for further functional operations. From If-15, Hi started return journey to reach its first landing site on Mars (its' mother-in-law-abode). There, ingenuity quadcopter (IQ) will meet Mr. Perseverance returning from the roving trips. The scientific-activity-schedule (SAS) of Persy, this year is to collect Mars surface rock samples (Ms RS) and transport to sophisticated labs on our earth for state-of-knowledge analysis in 2030s. Hi will scout to design Pareto optimal

plan for path of Perseverance rover (PR-2020).

Keywords: Ingenuity helicopter; Mars weather; Mars rover-2020; Perseverance; Rock Surface Sampling—Samples-to-return-to-earth in 2030s

Layout	
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2.	If-20
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Ingenuity flight-Nineteen(IF.19)

Although nineteenth flight of Helicopter Ingenuity (Hi) on Mars was scheduled in the first week of January, 2022, it was pushed back by one month. The sole reason was unfavorable atmospheric conditions on Mars as a result of change of season, decrease in air density and on-set of wild dust storm.

On February 8, 2022, NASA's Hi completed 19th flight successfully, by covering a horizontal distance of 205 feet in 99.98 seconds.The images taken during Flight 9 by the rotorcraft's high-resolution Return-To-Earth (RTE) camera were used to select a safe landing zonefor Flight 19. If-19 is the third return flight and covered the same ground flown during Flight 9, but in the opposite direction. Thus,this trip can be considered as another leap in the return travel to Wright Brothers Field (its' Mother-in-law abode).The helicopter turned nearly 180 degrees before landing to aim its color camera towards the river delta for photos, as a part of itsscouting operation. Thecolor-mages will be of immense use in planning future flights.Ingenuity is fine after nineteenth flightand stable to go forward in its explorations.

The reasons for slow pace of this flightare due to lack of large landing sites in the area and also low density of atmosphere (summer effect). Now, it happened good that Hi escaped the ill effects of rugged patch of South Séítah (in Jezero's floor), ridges and plateaus. This gave Hian opportunity to perform more noteworthy exploratory feats.

Nineteen Ingenuity flight(IF.19)	Feb08, 2022		Sol 345
Purpose	Another leap of the helicopter (IF) to return to Wright Brothers Field (its first home on MARS – Mother-in-law abode)		
Operations			
Takeoff from	South Séítah basin, across a dividing ridge and up to the main plateau, near the landing site of Flight 8		

Reverse path of flight 8		Horizontal Distance	203 ft
!	Rose vertically 33 ft	Max Ground speed	2.2 mph
!	Shift northeast 203 ft	Flight time	99.98sec
!	To land near Airfield E		

Landednear the northern edge of South Séítah	Airfield E	18.43700°N	77.45080°E
Ingenuity flight – 19	**Success**		

Ingenuity flight-Twenty (IF.20)

This flight is another leap in the backward journey to NASA-Persevere's landing location i.e.Wright Brothers Field. If-20 covered a horizontal distance of 1,283 feet moving at speed of 9.8 mph in this flight. Hi flew for 130.3 seconds at a vertical height of 33feet.

In the tentative future plan is Hi, itwill take a shortcut to the Jezero Crater river delta, flying northwest across Séítah. The land rover, Perseverance, drives towards the delta to reach that region.

Twenty Ingenuity flight(IF.20)	Feb25, 2022		Sol 362
Purpose	Another leap of the helicopter (IF) to return to Wright Brothers Field (its first home on MARS – Mother-in-law abode)		
Operations			
Takeoff fromAirfield E		18.43700°N	77.45080°E

Reverse path of flight 8		Horizontal Distance	1,283 ft
!	Rose vertically 33 ft	Max Ground speed	9.8 mph
!	Shift north-west 1280 ft	Flight time	130.3 sec
!	To land near Airfield M		

Landednear the northern edge of South Séítah	Airfield M	18.43700°N	77.45080°E
Ingenuity flight – 20	**Success**		

Appendix 1:Atmosphere on Mars –
Annual Seasons andDust storms

Atmosphere on Mars: The diameter of Mars is about half that of Earth. The distance of earth from Sun is 92 million miles, while that of Mars (from Sun) is 128 million miles. The atmospheric volume of Mars is less than 1% that of Earth and the composition is alsosignificantly different. The atmosphere of Mars is much less dense compared to that of earth. The Earth;satmosphere contains about 78 percent nitrogen, 21 percent oxygen, 0.9 percent argon. The remaining 0.1 percent is made up ofcarbon dioxide, methane, water vapor, neon etc. On the other hand, the atmosphere of Mars at the surface has 95% CO2 (by volume), 2.6% molecular nitrogen, 1.9% argon, 0.16% molecular oxygen and 0.06% carbon monoxide.

Annual Seasons and Dust storms: In spite of many differences in atmospheric characteristics, Mars climate shares many similarities with that of Earth like seasons, changing winds, ice (CO2 on Mars) cloudsamong others.

Dust storms on Mars:Big, powerful dust storms occur regularly on Mars. For instance, those of global-scale in the years 2018, 2007, and 2001 are amazing. To cite an exampleof power of devastation, a planet-encircling maelstrom killed off NASA's venerable Opportunity rover.

Weather on Mars (2021-2022):Jezero Crater (which lies about 18 degrees north of the Red Planet's equator)has progressed through spring (April, 2021), and into summer. Now, we are currently approaching the end of summer and the beginning of autumn, which starts in Feb. 2022. The autumn through winter is known as the "dusty season" on Mars.

As Mars transitions into autumn, an increase in the amount of dust in the atmosphere globally is expected; levels will remain heightened through winter. But on New Year's Day (1st Jan) of 2022 itself, a big dust storm kicked up near the 28-mile-wide Jezero Crater. This year, the dust storm came quite early i.e.,even before the dusty season traditionally started. Moreover,a storm of this strength was never seen in the Mars_years before. It took more than a (earthly-calendar-) month for restoring normalcy.

Perseverance rover of Mars-2020 exploratory mission then in the same area observed increased dust lifting within Jezero crater. This was the first signals of the dust storm. In orbit, MRO captured images of this growing regional dust storm, which showed signs of expansion from the southern hemisphere into the northern hemisphere – potentially towards Jezero crater

Forecast systems of Mars weather changes:Coming to Prediction of weather events, as is true for Earth, it is always an uncertain endeavour. Mars Environmental Dynamics Analyzer (MEDA) is an operating weather station aboard the Perseverance rover on Mars surface of Jezero crater. This is the most useful forecasting resource with powerful suite of instruments with state-of-real_time- intelligent_knowledge-based-Science & Technology. The outcome is calculation of the air density, measuring winds throughout the day and tracking their changes with season. The orbital assets, either – both the Mars Color Imager (MARCI) and Mars Climate Sounder (MCS) aboard the Mars Reconnaissance Orbiter (MRO) provide daily updates on the state of the atmosphere. This is useful for understanding activity outside of Jezero crater that could impact future weather. Of course, at the moment, we do not have the advantage of a large number of weather stations or orbiting weather satellites at Mars, as is the case on Earth. Yet, the large number of tools at the disposal of NASA are adequate to ascertain if weather conditions are acceptable for risk-free Mars-Helicopter-flights. The weather forecast team of JPL adhere the protocol to go forward for decision of future

flight operations. Also.

Impact of dust , density and temperature on safety of If on Mara (oM) : The dust in the atmosphere is heated by sunlight and warms the surrounding atmosphere. This results in a reduction of the density air. The visibility ('clear sky' levels) is decreased (a drop of about 18%) with the increase in dust content and the amount of Sun rays reaching the surface also diminished. The energy of batteries charged from Solar panels on Hi is used for the flight and heating purposes during chill nights.

Decision protocols for Hi-flight schedule:Even normally, Mars' air is just 1% as dense as that of Earth at sea level. The further decrease in density in dusty season, deposit of dust on Solar panels and decrease in Sun's rays reaching panels all pose a threat for the safety of If on Mars.

The green signal for every Ingenuity flight sanction comes fromweather forecast team working with an intelligent protocol adhering decision making procedure. The flight is not cleared if density is below the lower threshold of safe flight to circumvent imparted undue risk to the precious (cost/hardware/location wise) helicopter. That is the reason why they inspect strictly and even wait for favourable conditions especially air density, wind speed and dust content.

Appendix 2: JezeroCrater on Mars

Jezero area (on) Mars (Jam): Here on Earth, river deltas are good at preserving carbon-containing organic chemicals and signs of life itself. About 3.5 billion of years ago, the 28-mile-wide Jezero area on Mars hosted a lake filled with water. But now it is dry. The choice of this area for 2020-Mars rover mission was based on educated/intelligent guess that microbial life should have existed in the past.

Mars surface rock samples (to) Return (Ms RSR)

Perseverance (Mars-2020) rover mission 2021-2022: The robotic Astro-Geo-biologist (Mars rover-2020, a surface explorer and Hi.2020 an aerial scout cum explorer)touched down on the Red Planet in 2021 Feb. The duo spent their first (Earth) year on Mars exploring locales to the south and west of their touch-down zone. The mission team members named the area after famous sci-fi author Octavia E. Butler. Perseverance is on a long-term mission to pick up potential samples with signs of ancient life in them. The rover and Hi are now on back toward journey approaching the landing site. Once they are there, the Science program will look at the bottom of the ancient lake for signs of past microbial life. The whole next year activity of Persy will be travel and sample collection through remnants of ancient lake/river deposits within the delta.

Future explorations: NASA and the European Space Agency plan to get the samples back on Earth safely in 2030s for examination in high-powered laboratories, with more advanced equipment. It cannot be easily shipped to Mars to assess the material. These explorations may open window in detecting and confirming of lifeformson planets other than our mother earth. This is the start of mega-events like how rovers, helicopters, or multiple robotic explorers, could roam on other planets. The forth coming helicopters move toward 'ultimate modules' in US Mars-Earth-Moon missions.

Appendix 3: From-Brainwave-to-Brainchild-to-Physical object_functional (Hi)

Brainwave (a sudden clever idea): Dr Balaram attended aconference in 1990 and heard the 'applicationsof "mesicopter(aminiature air vehicle) on Earth'. Immediately, a sparkle of "flying a small vehicle in Mars' atmosphere" splashed in his brain.

Financial Sanctions for the-Brain-child**(**a product of one's creative effort)***project:*** The collaborative project proposed for finances resulted in only blade-rotor test under Mars conditions at JPL. The idea "sat on a shelf" for next 15 years. Charles Elachi, the then director of JPL liked the 'flight-on-Mars'concept and asked Dr Balaram to send a new proposal for payload in Mars 2020 mission. The proposal was rejected as an instrument, but was funded for technology development and risk reduction. NASA decided to fund the helicopter for flight as a technology demonstration.

Design Essential objectives: Ingenuity was designed to fly for 30 days to demonstrate that such a craft could navigate in the thin Martian atmosphere. It was deployed for five flights in one month period.

Design Scope: Hi was a demonstration project of feasibility-of-concept and not meant for doing any science.

Physical object development: Ingenuity, the rotor craft of 1.8 Kgs with four blades, solar panel, two cameras was delivered in JPL, CA (USA). This, non-life robotic system, came into being (physical existence with functional capabilities) because of a small but passionate team of experts (geniuses) in NASA. These active professionals bag discoveries and inventions aimed at only welfare of progeny of humankind and not personal credit. The gestation period was over two decades from flash of idea in Bob's brain to the tiny robot arriving on Mars to make arangetram with its maiden flight.

Functional Assurance: The engineers performed rigorous and many-possible flight tests in a wind tunnel (CalTech labs on Earth) under simulated Martian atmosphere. With the favourable results obtained, they were fairly confident that the light drone will fly successfully in that atmosphere.

Threat of Failure: However, wind gusts, dust storms, low gravity and low density are all increase threat of uncertainty in smooth operations and success of flight.

Deployment to Jezero crater on Mars: Ingenuity Helicopter was kept inside the Perseverance rover bottom shield. Hi landed on the floor of JezeroCrater with NASA's life-hunting, sample-caching Perseverance rover on Feb. 18, 2021. The mode of transport is akin to Kangaroo pouch in nature to carry its baby along with it. Baby Kangaroo leaves the pouch (second womb)after eight to ten months. Kangaroo-mother-(skin-to-skin-touch) care is recent fruitful approach for pre-term or low birth weight babies.

Real time Functioning in Real world: The first flight on 19th April, 2021 was a complete success. It was a day of celebration for JPL, NASA (USA) scientists and for that matter of fact for all humansliving on earth. The solar-powered chopper soon embarked on a five-flight technology-

demonstrating mission designed to show that powered flight is possible in the Red Planet's thin air. It overcame teething problems and excelled in its performance. The mission has surpassed twelve months, witnessed a change of seasons on Mars, survived a near-total blackout of communications during a solar conjunction.

Hi succeeded in technology-demonstration, operations-demonstration, Exploratory-learning and scouting phases. It survived in the harsh climate of Mars and continued to be functional even after twenty flights beyond wise expectations of its designers.

Exceedance of expected performance: The Ingenuity design worked incredibly well and exceeded all expectations in functioning, made autonomous landings, captured airborne imagery of rough terrane, unforgettable land marks in flight characteristics and exhibited intelligence/ adaptability. Hi's flights play arole in finalising safest and most efficient route for Perseverance toward the delta region. It allows the rover's handlers to choose the path in new places. It opened a new type of robotic exploration for next generation planetary aerial investigations.

Appendix 4: Emotional feelings of Scientists in life-cycle of Mega-missions

Emotional feelings of Scientists and life-cycle of Mega-missions: Space missions also, like many other huge- ordered-ventures, bring together large groups of engineers, scientists and technicians. These top-ranked-human-experts work under pressure for years. The closure of such teamwork is but natural after the time of accomplishment of the task many times of realising products/huge machines. Here satisfaction that the "job is well done" brings out positive emotion. But, missing the team and state-of-knowledge-machinery outbursts the individuals.

In NASA, rovers (Spirit, Opportunity, Mars-2020 etc.) and Ingenuity Helicopter (Hi) teams of promotors of truth-seeking personnel grew old and became gray together during one or two decades of time in planning, execution and fabrication. Tears most likely will flow at NASA's Jet Propulsion Laboratory in Pasadena, Calif, at such 'call it a day' closure moments.

Functional Life of rovers, helicopters on other planets: Earlier Mars-missions lasted much longer than NASA anticipated. To cite an example, the Opportunity rover, which had a budget and design for just 90 days of exploration in 2004. It didn't quit until 2019, almost 15 years after landing on Mars.

Hi on Om: Hi is the first to fly on Mars and it's just the beginning of a new era in newer helicopters on other planets in solar system with better pieces. Though, the design was for five flights and one-month active life, Ingenuity Helicopter (Hi) successfully completed twenty flights and is alive even after one-earthly-calendar-year. Still, it is fit and ready for future scouting/ exploration activity. Ingenuity's achievements need not be overstated, and it will be remembered as one of the great pioneering flying vessels of all time.

The experts from the Jet Propulsion Laboratory have very little idea of how long the helicopter (Hi) will last in active mode. Last flight, last transmission or running into goes quiet/unfunctional condition, like last breath of a human being, is certain with 100% probability. This has to happen on a day as no perpetual machine continues ever and ever. The engineers, with all accumulated knowledge, expect eventually something will crack or break down due to wear and tear in extreme temperature fluctuations on the Red Planet. Whatever it be, one day Ingenuity will make its last flight on Mars (place of deployment far away from birth place on earth), an inevitable event.

But, whenever that happens, its creators and we all miss it forever. It is a moment of mixed (happiness for its commendable performance and sadness for death of man-made-intelligent adaptive lifeless-exceptional spacecraft) emotions with an outward expression of tears in the eyes of lively creators. The story remains in achieves with a massive celebration of all the accomplishments and exerts of knowledge bits for scientific progeny.

Appendix 5: Web sites and references

https://youtu.be/-FwGDT2mAP0?t=94	Ingenuity Mars Helicopter completed first flight
https://youtu.be/pblKotm5dRY?t=29	Ingenuity Flight 20 Successful on Martian Surface
https://youtu.be/OQo1W57oL7g?t=39	Mars helicopter's 20th flight in B&W time lapse + color imagery
https://youtu.be/_6GMhGm9DHY	NASA's Curiosity Rover Capture Evidence for Microbial Life on Mars
 If-01 on Mars-.m4v	First Flight on Mars

$$:K. Somasekhara Rao,R. Sambasiva Rao,Ingenuity flights (If) on Mars (oM),
Part 1 ; Ingenuity flew (If 1-5) on Mars (oM), J.Appl.Chem., 2021, 10 (3): 409-436 ;
Part 2 ; Operations Demonstrations (OD, If 5-9),J.Appl.Chem., 2021, 10 (4):569-589;
Part 3 ;Exploratory Experimental Learning (EEL, If 10-13) J.Appl.Chem., 2021, 10 (5):740-754
Part 4 ;Exploratory Experimental Learning (EEL, If 14-18) J.Appl.Chem., 2022, 11 (1):xxx

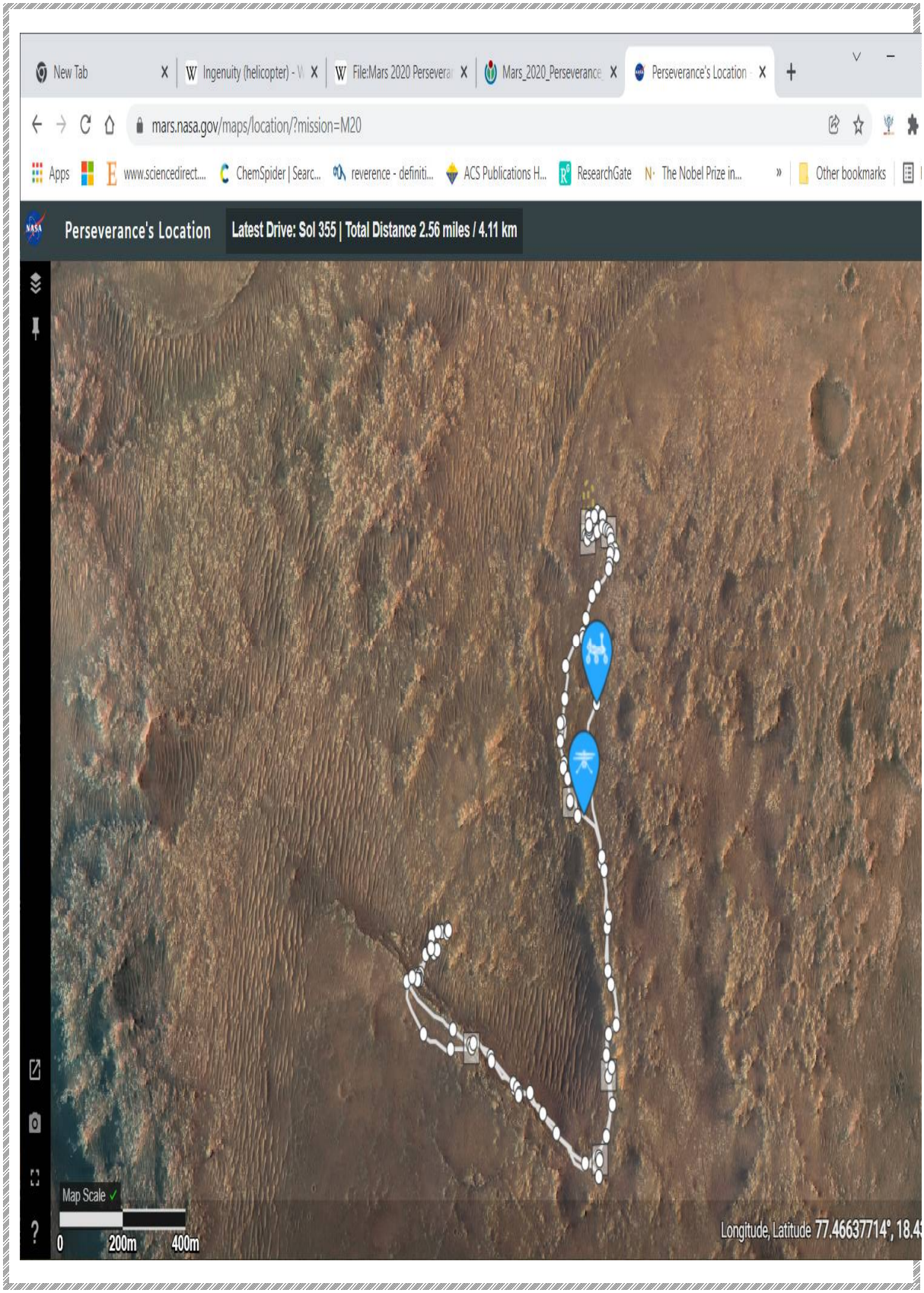
SI: Supplementary Information

Image-gallery

Credit : NASA.Gov

Credit: NASA/JPL-Caltech -

Tracks and locations of Perseverance and Ingenuity as of February 13, 2022[89]
357 :10:46:20Sol:Hrs:Mins Secs; 20-02-2022; 16:31 IST

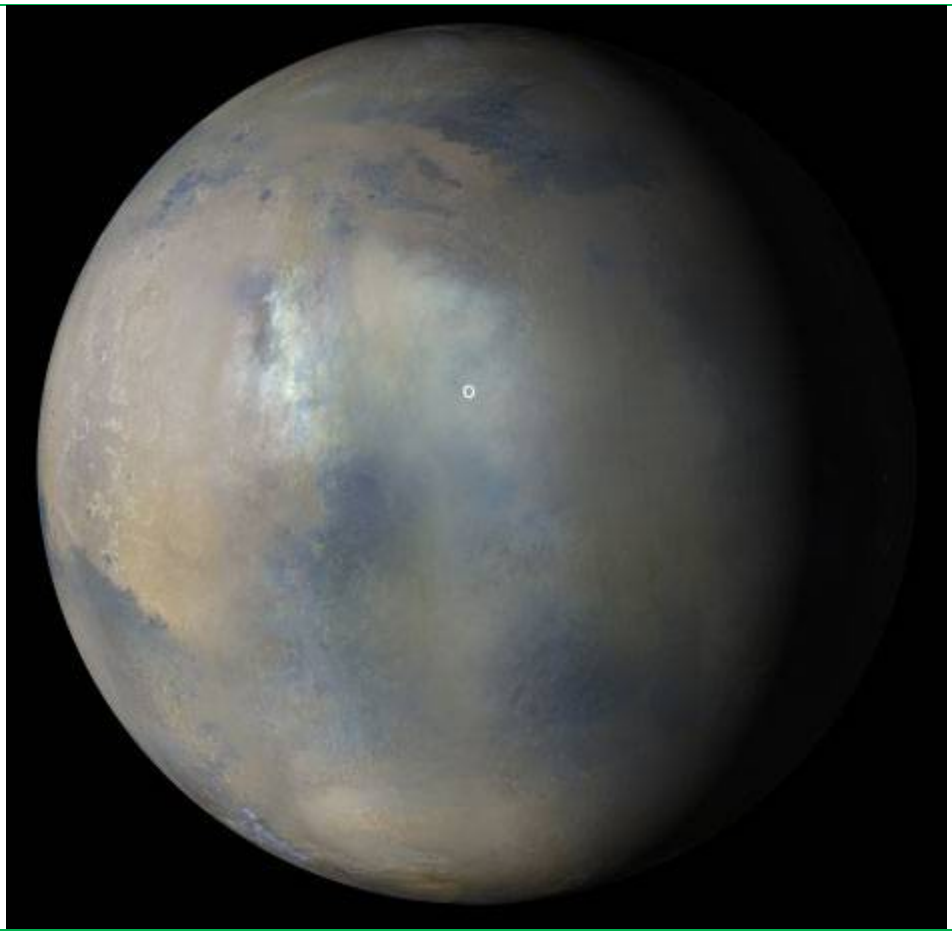

New Tab
Ingenuity (helicopter) - V
File:Mars 2020 Perseverar
Mars_2020_Perseverance
Perseverance's Location
mars.nasa.gov/maps/location/?mission=M20
Apps
www.sciencedirect....
ChemSpider | Searc...
reverence - definiti...
ACS Publications H...
ResearchGate
The Nobel Prize in...
Other bookmarks
Perseverance's Location
Latest Drive: Sol 355 | Total Distance 2.56 miles / 4.11 km
Map Scale
0
200m
400m
Longitude, Latitude 77.46637714°, 18.4


Three Forks
Octavia E. Butler Landing Site
Seitah-N
Seitah-S
(optional)
Crater Floor Fractured Rough
Raised Ridges

- NASA's Mars helicopter Ingenuity captured this image of its own shadow using its navigation camera on Feb. 8, 2022, during the chopper's 19th Red Planet flight. (Image credit: NASA/JPL-Caltech)

Sunset on Mars on Nov. 9, 2021,

Captured by NASA's Perseverance Mars rover using its Mastcam-Z camera system



- Dust Storm and Jezero Crater:Images acquired Jan. 9, 2022

! Location of Perseverance rover and Ingenuity Mars Helicopter (white circle)obscured by presence of a regional dust storm

✓ NASA's Mars helicopter Ingenuity captured this shot of its shadow during its 20th flight

✓ Feb. 25, 2022.

(Image credit: NASA/JPL-Caltech)

SI: Supplementary Information-2

Numerical Data

Credit : NASA.Gov

Credit: NASA/JPL-Caltech -

Flight totals(*IF01 to IF20)*

Flight property	(April 3, 2021/Sol 43) Since deployment	Tech demo phase	operations demo + Eel
Sols achieved	322	31	291
Number of flights	**20**	5	14
Distance flown (km)	4.28	0.50	3.78
Time flown (sec)	2197 (34 min 31 s)	396 (6 min 36 s)	1600 (27 min 55 s)

Timeline of Ingenuity flight Schedules (Ifs)

Scouting & Exploratory Experiments (See)		
Ingenuity Flight(If)	Sol	Date
19	345	Feb 08, 2022
20	362	Feb 25, 2022

Eel (Experimental exploratory learning)			
Flight	Sol	Date	Time
10	152	24th July, 2021	21:07
11	163	5th August, 2021	04:53
12	174	16th August, 2021	12:57
13	193	4th Sep, 2021	12:57

Exploratory Experimental Learning (Eel)			
Test@	204	Sep 16,2021	
14	241	Oct 24, 2021	08:13
15	254	Nov 06, 2021	16:22
16	268	Nov 21, 2021	2:09
17	282	Dec05, 2021	12:25
18	292	Dec 15, 2021	

Flight	Sol	Date
Demonstration. Technology (DT)		
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 (OD)		
6	91	May 22, 2021
7	107	June 08, 2021
8	120	June 21, 2021
9	133	July 5, 2021

Sol: Martian Day starting with Ingenuity landing on MARS

Date: Calender on Earth ; Time:

Take off and Landing sites in IF01 to IF20

Flight	Horizontal Distance(m)	Route of Flight	
		From	To
1	0	Wright Brothers Field	
2	4		
3	100		
4	266		
5	129	Wright Brothers Field	Airfield B
6	215	Airfield B	Airfield C
7	106	Airfield C	Airfield D
8	160	Airfield D	Airfield E
9	625	Airfield E	Airfield F
10	233	Airfield F	Airfield G

Flight	Horizontal Distance(m)	Route of Flight	
		From	To
11	383	Airfield G	Airfield H
12	450	Airfield H	
13	210		
14	2		
15	407	Airfield H	Airfield F
16	116	Airfield F	**Airfield J**

17	187	Airfield J	**Airfield K**
18	230	Airfield K	**Airfield L**
19	63	Airfield L	Airfield E
20	1,283	Airfield E	**Airfield M**

Ingenuity's imagery

Count of stored images from both cameras per each flight[144]				
Flight No.	**Date (UTC) and Mars 2020 mission sol**	**Photographs**		**Comments**
		b/w NAV	**color RTE**	
	Before April 19, 2021 (sol 58)	6	6	Preflight camera tests
1	April 19, 2021 (sol 58)	15	—	
2	April 22, 2021 (sol 61)	17	3	The first color photo session
3	April 25, 2021 (sol 64)	24	4	
4	April 30, 2021 (sol 69)	62	5	
5	May 7, 2021 (sol 76)	128	6	
6	May 23, 2021 (sol 91)	106	8	
7	June 8, 2021 (sol 107)	72	0	RTE was turned off
8	June 22, 2021 (sol 121)	186	0	
9	July 5, 2021 (sol 133)	193	10	
10	July 24, 2021 (sol 152)	190	10	Five pairs of color images of Raised Ridges taken to make anaglyphs
11	August 5, 2021 (sol 164)	194	10	
12	August 16, 2021 (Sol 174)	197	10	Five pairs of color images of Séítah taken to make anaglyphs
13	September 5, 2021 (Sol 193)	191	10	
	September 16, 2021 (Sol 204) to October 23, 2021 (Sol 240)	6	1	Preflight 14 tests
14	October 24, 2021 (Sol 241)	182	—	

15	November 6, 2021 (Sol 254)	191	10	
	November 15, 2021 (Sol 263)	—	1	Ground color photo
16	November 21, 2021 (Sol 268)	103	9	
	November 27, 2021 (Sol 274)	—	1	Ground color photo
17	December 5, 2021 (Sol 282)	5	—	
18	December 15, 2021 (Sol 292)	20	—	
19	February 08, 2022 (Sol 345)	92	----	