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Ingenuity flights (If) on Mars (oM)

Part 6[$$]: Scouting and Future Exploration(Safe, If 21-28)

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Dedicated to "J. Applicable Chemistry" during
Start of second decadal(2022-2031) publication era

Conspectus: Ingenuity quadcopter (IQ) weighing 1.8 Kgs was designed and developed by JPL, NASA with a budget of 85 million USD. Hi (Helicopter ingenuity) is a technology demonstration flying robot to accomplish five flights withone-monthfunctional life in the thin atmosphere of MARS. It made its first maiden flight successfully on 19th April, 2021 creating a new record in world science. The intact functional capabilities after first five flights prompted NASA to switch on to operational demonstration, exploration and scout mode phases. By 1st May, 2022, it successfully completed eighty-eight scheduled simple-to-complex flights. And the helicopter is still benign, not showing signal of any signs of even minimum decay of functions/hardware etc. Hi was robust to seasonal changes, dust storms and cold nights. Added to it, the exceptional life-span and functional stability in the harsh environment of Mars is a testimony of hardware/software integrity, although mostly off-the-shelf components were used.

Awards for Ingenuity helicopter team: Helicopter_Ingenuity_on_Mars(Him) team received many National awards for noble achieving(s) viz., outstanding improvement in fundamental helicopter technology, NASA's Pioneering Ingenuity Mars Helicopter, Outstanding Technical Achievement, Current Achievement of Ingenuity Mars Helicopterand Space Exploration. Ingenuity is bestowed with 2022 IEEE Spectrum Emerging Technology Award. Senior software engineer received the award at a ceremony in San Diego in May 2022 on behalf of all involved in the world record research product "Hi" of science and technology.

Keywords: Mars rover-2020; Perseverance; Helicopter Ingenuity; Twenty eight flights;

Single Sentence Summary (SSS): Helicopter Ingenuity (Hi) of JPL-NASA is sturdy to carry out further scouting operations even after 28flights on Mars JEZERO crater during last one year.

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Introduction: The delta areas on earth well preserve the organic carbon molecules (/bio-materials) and thus signs of life. Jezero crater on mars once upon a time (four billion years ago) had a lake and river of warm and shallow water. That was the proper time for upsurge of life and evolution in that region of space. With all available knowledge to human scientists now, it is the most possibilistic location to look for life if at all existed once.

Mars-2020 rover moves slowly and with great care on the surface of red planet. This is to avoid rocks and other obstacles which will damage the Perseverance or even cut short its functional life. Helicopter ingenuity (Hi) detects possible hazards and is instrumental in designing safe driving routes. It also perceives peek of things those are of scientific curiosity. This robot pursues in detail the spots of interest ahead of Perseverance driving to that area for sample collections.

To further enhance the chances of success and minimize failures/stumble blocks of Hi mission (Him), JPL is shrewd and serious in gearing upgrade of software. The focus is on the operational flexibility/expandability/adoptability to unforeseen scenarios and safety of quad-copter. Also, the size of the team of scientists increased to maximisebrain (skills) diversity and intensify successful chores with existing state-of-knowledge-science technology focusing torchon future evolving thought-experiments to real time product machines. The involvement of Hi in Perseverance's second science roadmap is crucial. During last one year, both Hi and MRS explored south and southwest of first landing site on Mats.

In future, Mars thin atmosphere will be filled with a number of fleets of next generation/off-spring of Ingenuity robotic helicopter. Hi will go on testing its capabilities and ways and means to surmount lapses/short comings and inventing solutions for hither to unsolved riddles. These experiences will broaden the design of future hex-copters. All these esoteric/exotic features will bring transition of mind-set within a short time period inrealizing flying robots on Mars (From) which will act as third eye of mars surface rovers (MSR).

Ingenuity flight-Twenty-one(IF.21): Hi bagged success of 21st flighton March 10, 2022. It is the first of three contemplated flights planned to arrive at next leap in the return journey to an ancient river delta in Jezero Crater. The landing site is located in the northwestern area of the planet's

"Séítah" region. NASA opted a route by multi-criteria-optimization of thermal factors, atmospheric parameters, flight time, navigation drift and landing site terrain. Till now, Ingenuity flew 4, 65 kilometers in a total-flight-time of 38.8 minutes.

Twenty-one Ingenuity flight(IF.21)	March10, 2022	22:10	Sol 375
Purpose	✓ Another leap of the helicopter (IF) to return to Wright Brothers Field (its first home on MARS – Mother-in-law abode) ✓ To scout ahead for Perseverance		
Operations			
Takeoff from	Airfield M 18.44 337°N 77.44 859°E		

Reverse path of flight 9(/1/3)
! Rose vertically 33 ft
! Shift northwest 1227 ft
! Flying acrossnorthwestSéítah
! To land near Airfield N

Horizontal Distance	1210 ft
Max Ground speed	8.6 mph
Flight time	129.2sec

Landednear the northern edge of South Séítah	Airfield N	18.44514°N	77.44219°E
Ingenuity flight – 21	**Success**		

Ingenuity flight-Twenty-two (IF.22): The 22nd flight of Ingenuity was successfully completed on March 22 of 2022. It was second of three series of flights to get back nearer to base of the delta. Although only a horizontal distance of 231 feet was covered during this flight, it captured the shot of its own shadow.

Twenty-two Ingenuity flight(IF.22)	March20, 2022	04:06	Sol 384
Purpose	✓ Another leap of the helicopter (IF) to return to Wright Brothers Field (its first home on MARS – Mother-in-law abode) ✓ To scout ahead for Perseverance		
Operations			
Takeoff from	Airfield N		

Reverse flight (/2/3)
! Rose vertically 33 ft
! Shift northwest 231 ft
! Flying acrossnorthwestSéítah
! To land again within Airfield N

Horizontal Distance	231 ft
Max Ground speed	2.2 mph
Flight time	101.4 sec

Landednear the northern edge of South Séítah	Airfield N	18.44610°N	77.44292°E
Ingenuity flight – 22	**Success**		

✓ Helicopter captured shot of its own shadow during its 22nd flight

Ingenuity flight-Twenty-three: If-23 is the third flight on the way back to a position near the base of the delta. It was conducted on 24th March 2022 autonomously (like all other earlier ones). The unit operations were complex, including a sharp turn to avoid a large hill on terrane. Data in this new region is precious and enables NASA-Perseverance team to find potential science targets in the future explorations Mars-2020-rover.

Twenty-three Ingenuity flight(IF.23)	March 24, 2022	6:44	Sol 388
Purpose	✓ Another leap of the helicopter (IF) to return to Wright Brothers Field (its first home on MARS – Mother-in-law abode) ✓ Another flight on the way to a position near base of the delta ✓ To scout ahead for Perseverance		
Takeoff from	Airfield N		

Reverse flight(/3/3)
! Rose vertically 33 ft
! Shift northwest 1229.94 ft
! Flying acrossnorthwestSéítah
! To land near Airfield P

Horizontal Distance	1229.94 ft
Max Ground speed	8.9 mph
Flight time	129.1 sec

Landednear the northern edge of South Séítah	Airfield P	18.44508°N	77.44345°E
Ingenuity flight – 23	**Success**		

✓ Ingenuity completed its 23rd excursion, flying for
✓ 129.1 seconds across 358 meters

Ingenuity flight-Twenty-four (IF.24): The 24th flight of Hi is unique in that it is a short hop and yaw moving only a horizontal distance of 156 feet in 69.8 sec. This flight is fourth among five leaps of the helicopter to cross "Seitah" region to arrive at its first home (delta) on MARS from Airfield P.The rotor speed of 2700 rpm was continued from F-14 onwards. The atmospheric air density was low during summer, but the shift to fall season increased the magnitude. This parameter necessitated reduction of rotor speed to 2537 rpm for safer flight ventures.

The date of F-24 i.e., April 3, 2022 synchronizes with crossing of one year since deployment of helicopter from rover on Mars. The "C" route choice over other two (B and C) for this flight involved a short hop and yaw and in the succeeding F-25 Hi exits Seitah. This multi-flight-short cut keeps Hi ahead of Perseverance rover. The advantages are safety and proper telecommunication. Since, Hi can communicate only with Perseverance and not with control station on earth, the two robots should not be far away for facile signal communication. On the other hand, they should not be even very nearer to avoid the catastrophic consequences in the worst-case scenario.

Twenty-four Ingenuity flight(IF.24)	April 3, 2022	12:49	Sol 398
Purpose	✓ Another leap of the helicopter (IF) to return to Wright Brothers Field (its first home on MARS – Mother-in-law abode) ✓ Another flight on the way to a position near base of the delta ✓ To scout ahead for Perseverance		
Operations			
Takeoff from	Airfield P		

Reverseflight (/4/5)		
!	Rose vertically 33 ft	
!	Shift northwest 156 ft	
!	Flying acrossnorthwestSéítah	
!	To land again within Airfield P	

Horizontal Distance	156 ft
Max Ground speed	3.2mph
Flight time	69.8 sec

☞ Rotors spun at 2,537 rpm,
- Reduction from 2,700 rpm used since flight 14

Landed	Airfield N	18.44 508°N	77.44246°E
Ingenuity flight – 24	**Success**		

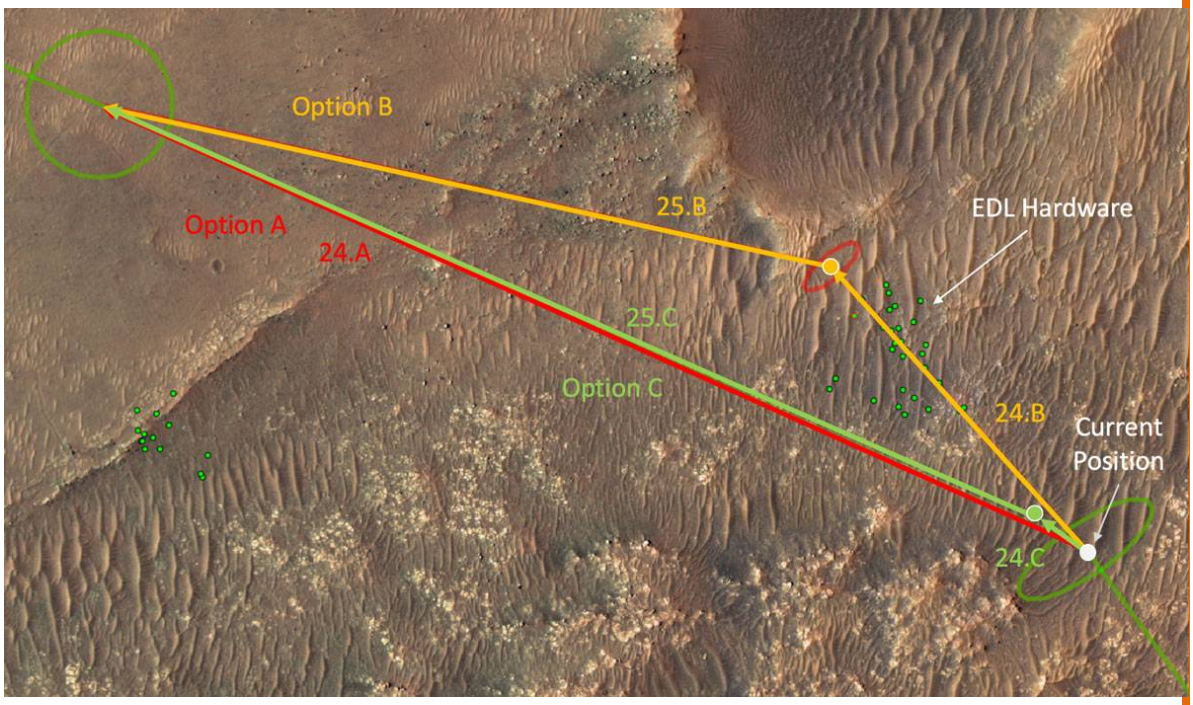
Ingenuity flight- Twenty-five (IF.25): The twenty fifth flight of helicopter Ingenuity is the fastest one (with a maximum speed of 12.3mph)and covered thel ongest horizontal distance of 2,324.2 ft. During the rover's entry-descent-landing (EDL) operation, the backshell, supersonic parachute and hardware were discarded as per the protocol of safe-landing of perseverance. They all fell on the surface of Marsin the way to delta region. The Ingenuity's laser altimeter and visual navigation system may possibly malfunction due to the effect of these materials. The helicopter team avoided a route encompassing that area. This tripof61.3 secbrought the helicopter out of the Séítah region and heads towards base of the delta.

Twenty-five Ingenuity flight(IF.25)	April 8, 2022	16:40	Sol: 403
Purpose	✓ Reverse flight to Jezero Crater		
Operations			
Takeoff from	Airfield N		

Revers flight (/5a/5)	
!	Rose vertically 33 ft
!	Shift northwest 704 meters
!	Flying acrossnorthwestSéítah
!	Crossing the Seìtah region
!	To land at the staging areaat Airfield Q

Horizontal Distance	2,324.2 ft
Max Ground speed	12.3mph
Flight time	61.3sec

Landed	Airfield Q	18.45477°N	77.43 058°E
Ingenuity flight – 25	**Success**		



- ✓ Mars helicopter route options out of 'Séítah'.
- ✓ The labeled "current position" is actually the landing site of flight #23
- ✓ Flight #24 completed; its landing site is the nearby green dot
- ✓ The mission team chose Option C (green) for flight #25

Ingenuity flight-Twenty-six (IF.26): In this successful flight on April 20, 2022, Hi snapped 10 color pictures of the EDL debris, including the spacecraft backshell and parachute. If-26 reached Airfield R which is closer to the delta region in 159 seconds taking off from Airfield Q.

Twenty-six Ingenuity flight(IF.26)	April 20(?19), 2022	01:32	Sol: 414
Purpose	✓ Reverse flight to Jezero Crater		
Operations			
Takeoff from	Airfield Q		

Reverse flight
! Rose vertically 26 ft
! Shift southeast
! Shiftsouthwest
! Shift northwest
! To land at Airfield R

Horizontal Distance	1,283.4ft
Max Ground speed	8.5 mph
Flight time	159.3 sec

! Ingenuity flew closer to the delta

! Color photos of the EDL debris
📖 Includingspacecraft backshell and parachute

Landed	Airfield R	18.45 163°N	77.43 046°E
Ingenuity flight – 26	**Success**		

April19 image from the Mars helicopter Ingenuity

✓ Backshell of Perseverance's landing capsule
✓ Supersonic parachute and debris

✓

Ingenuity flight-Twenty-seven (IF.27): Ingenuity, in its twenty-seven flight, flew for 153.25sec from Airfield R and landed in Airfield S which is closer to the delta. It acquired fullcolor image of ridgeline.

Twenty seven Ingenuity flight(IF.27)	April 24, 2022	04:11	Sol: 418
Purpose	✓ Reverse flight to Jezero Crater		
Operations			
Takeoff from	Airfield R		

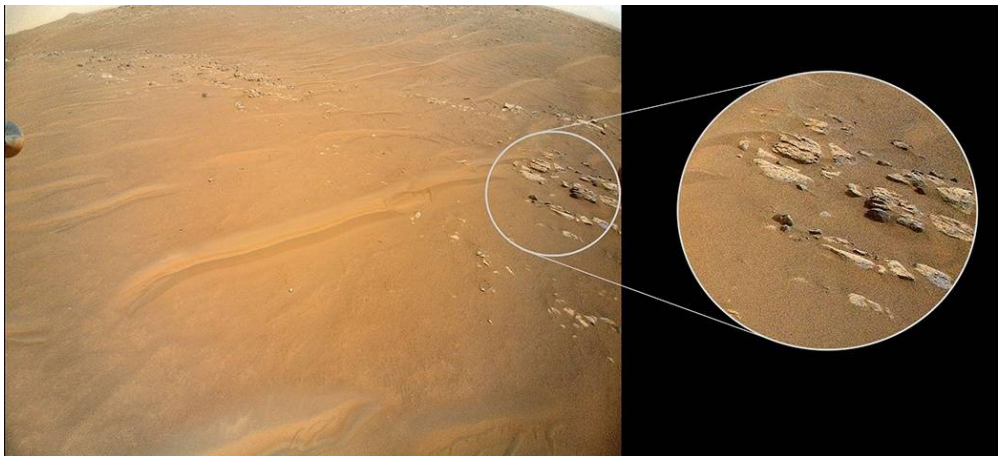
Reverse flight
! Rose vertically 33 ft
! Shift slightly southeast
! Shiftsouthwest
! Shift northwest
! To land at Airfield S

Horizontal Distance	1,000.53 ft
Max Ground speed	6.7 mph
Flight time	153.25sec

o Ingenuity flew closer to the delta.

Landed	Airfield S	18.45 252°N	77.42 636°E
Ingenuity flight – 27	**Success**		

✓ Tracks and locations of Perseverance and Ingenuity as of April 12, 2022



- ✓ Line of rocky outcrops running from the upper left to middle right of the
- ✓ main image “Fortun Ridge.”
- ✓ Right: Enlarged close-up of one of the ridgeline’s rocky outcrops

Ingenuity flight-Twenty-eight (IF.28): The twenty-eight flight of Ingenuity was completed with success on April 29, 2022. It was a flight for 152.86sec moving 1,381.0 ft northwest of takeoff point in Airfield S. It landed very closer to the delta region.

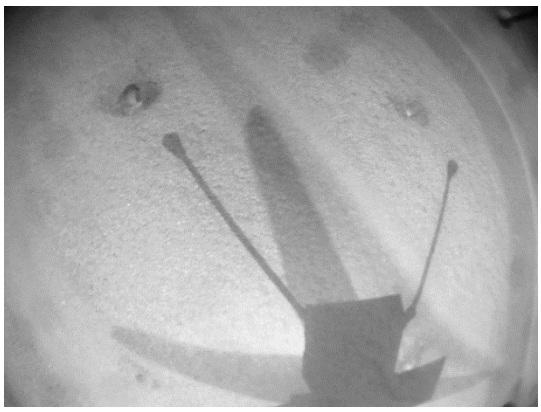
Twenty eight Ingenuity flight(IF.28)	April 29, 2022	07:44	Sol: 423
Purpose	✓ Reverse flight to Jezero Crater		
Operations			
Takeoff from	Airfield S		

Reverse flight (/8)
! Rose vertically 33 ft
! Shift northwest1,381.0 ft
! To land at Airfield T

Horizontal Distance	1,381.0 ft
Max Ground speed	8.1 mph
Flight time	152.86sec

- o Ingenuity flew closer to the delta.

Landed	Airfield S	18.45 714°N	77.42 608°E
Ingenuity flight – 28	**Success**		

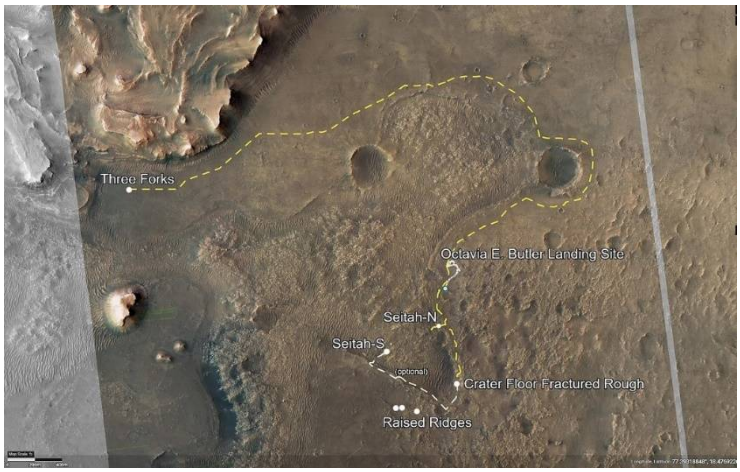


- ✓ MIME image of full_real-time_animation of Ingenuity_flight_28
- ✓ 29 April 2022

Number of flights	Distance flown	Time flown	Sols[$$]
28	6.99 km (4.34 mi)	54.26 min (3,256 sec)	398

[$$]since Detached from roveron mission Sol 43, April , 2021

View of *Perseverance/Ingenuity* exploration area in Jezero Crater



- ✓ Dashed line below Octavia Butler Landing Site: Approximate first route that rover and helicopter explored
- ✓ Dashed line above the site path: Perseverance is driving toward the ancient river delta
- ✓ Ingenuity flies a more direct route, northwest from the landing area to the delta

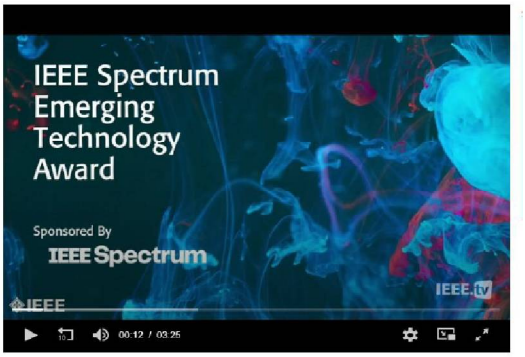
Appendix 1: Awards for Ingenuity helicopter and team

Honors and Awards		
NASA's Pioneering Ingenuity Mars Helicopter	Robert J. Collier Trophy	National Aeronautic Association
Current Achievementof Ingenuity Mars Helicopter	Michael Collins Trophy	Smithsonian's National Air and Space Museum
Outstanding improvement in fundamental helicopter technology,"	Howard Hughes Award	Vertical Flight Society
Space Exploration	John L. "Jack" Swigert, Jr. Award	Space Foundation
Ingenuity	2021 Laureate Award	Aviation Week Network
For Outstanding Technical Achievement	Duke of Edinburgh's Navigation Award	Royal Institute of Navigation

Ingenuity Mars Helicopter	2022 IEEE Spectrum Emerging Technology Award	Senior software engineer of Ingenuity received award at a ceremony in San Diego in May 2022

NASA Jet Propulsion Laboratory: Mars Helicopter - IEEE Spectrum Emerging Technology Award

NASA Jet Propulsion Laboratory: Mars Helicopter - IEEE Spectrum Emerging Technology Award



NASA Jet Propulsion Laboratory: Mars Helicopter - IEEE Spectrum Emerging Technology Award

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Mars Helicopter team members	o Dr. Robert H. Goddard Memorial Trophy Memorial Awards Dinner on March 18, 2022.	NationalSpace Club

Ingenuity lead Teddy Tzanetos

Appendix 2: Web sites and references

https://youtu.be/lX5iVyfF3N0?t=46	NASA's Perseverance Rover Captures Sounds from Mars ✓ Whirring of Ingenuity,Zap ✓ Puffs and pings from a rover tool ✓ Light Martian wind ✓ laser zaps
https://youtu.be/F56UL5iezAw?t=13	NASA's Ingenuity Mars Helicopter Complete 28th Flight on Martian SKY (May 3, 2022; 294 views)

https://youtu.be/-FwGDT2mAP0?t=94	Ingenuity Mars Helicopter completed first flight
https://youtu.be/-B4v49Bxom8?t=46	Ingenuity flies on Mars! flight 21 to 24 imagery 3,427 viewsApr 6, 2022
https://youtu.be/Q75-HetU57A?t=8	NASA's Ingenuity Mars Helicopter Fly in 3D May 12, 2021; 545,856 views
 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 6-9), 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):124-133;
Part 5 ; Exploratory Experimental Learning (EEL, If 19-20) J.Appl.Chem., 2022, 11 (2):302-318;

Appendix 3: Numerical Data

Credit : NASA.Gov

Credit: NASA/JPL-Caltech -

Timeline of Ingenuity flight Schedules (Ifs)

Scouting & Exploratory Experiments (See) Return Flights		
Ingenuity Flight(If)	**Sol**	**Date**
21	375	Mar 10, 2022
22	384	Mar 20, 2022
23	388	Mar 24, 2022
24	398	April 3, 2022
25	403	April 8, 2022
26	414	April 19,2022
27	418	April 24, 2022
28	423	April 29, 2022

Exploratory Experimental Learning (Eel)			
Test@	204	Sep 16,2021	
14	241	Oct 24, 2021	08:13
Return Flights			
15	254	Nov 06, 2021	16:22
16	268	Nov 21, 2021	2:09
17	282	Dec 05, 2021	12:25
18	292	Dec 15, 2021	17:27
19	345	Feb 08, 2022	04:21
20	362	Feb 25, 2022	13:35

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

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 ;

Take off and Landing sites in IF01 to IF28

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	**Dist(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	**Airfield M**

		E	

Flight #	Horizontal Distance(m)	Route of Flight	
		From	To
21	1,228	**Airfield M**	**Airfield N**
22	231	**Airfield N**	**Airfield N**
23	1,229	**Airfield N**	**Airfield P**
24	156.0	Airfield P	Airfield P
25	2,325.8	Airfield P	**Airfield Q**
26	1,283	**Airfield Q**	**Airfield R**
27	1,000.5	**Airfield R**	**Airfield S**
28	1,381.0	**Airfield S**	**Airfield T**

Remember yesterday
Perform today
Fallowtomorrow