EPFL

Lessons Learned from Space Exploration
- Project -

Minor in Space Technology
Electrical Engineering Department

Marc Toussaint
Retired from ESA

Spring Session 2024 / 2025 at EPFL

Examination / Project Work

- ✓ It is proposed to perform the examination on the conduct of a project lead by teams of students being put into competition. Teams work independently from each others.

- ✓ Subject proposed : Conceptual Design of an Unmanned Moon Lander and its Moon Rover Mission; selection of one end-to-end mission concept using a "Trade-Off Method". Basic requirements for missions and vehicles conceptual design are based on the GLXP initial competition.

- ✓ Set-up of students groups (number and size of group depend upon course attendance) with missions, operations, advertising and/or financing assignment.

- ✓ Based on past experience, group's members size should not be larger than six (7 is the MAX).

- ✓ Semester continuous evaluation through the project (mid-term 14.04, final 30.05.2025 reports).

- ✓ Follow-up and guidance during lectures cycle; dedicated Zoom meetings if requested. Discussion of Mid-Term report through dedicated Team's Zoom or in-person meeting (weeks 17 to 19, tbc).

Project Main Guidelines

✓ Launch strategy options (Soyuz rocket provided, launched from Kourou, with a Fregat upper stage):
- ➡ One shot Fregat (TLI launch), then Fregat is discarded; or
- ➡ Use of Fregat for the mission (Trajectory Dv correction, and/or Moon orbiting Dv, and/or Initial Dv for landing), but more Fregat usage means less useful payload (simplified-lighter Lander / Rover).

✓ Lander / Rover mission strategy options:
- ➡ Shoot and land, then move (hard or soft landing)
- ➡ Shoot / orbit the Moon and land, then move (hard or soft landing)

✓ Landing options:
- ➡ Soft (Solid, or Solid & Liquid, or Liquid, or Hybrid propulsion), or
- ➡ Hard (Airbags, crushing structure or other techniques).

✓ Project steps:
- ➡ Identify technologies building options (for propulsion, power, communications, roving, etc.);
- ➡ Propose funding possibilities based on sponsoring ideas (which will impact Rover's design);
- ➡ Build 3 end-to-end "conceptual" missions (with different technologies / fundings choices);
- ➡ Describe the 3 missions to be traded-off. Define system evaluation criteria;
- ➡ Apply the trade-off method with the objective to select a "best" solution from the group viewpoint.

Google Lunar X-Prize (GLXP)

GLXP Competition Guidelines:

- ✓ *Successfully land a privately funded craft on the lunar surface (you start from scratch, 0 € in pocket)*
- ✓ *Survive long enough to complete the basic mission goals:*
  - ➡ *Rove on the lunar surface for at least 500 meters (you go AWAY from the lander !)*
  - ➡ *Send a defined data package, called a "Mooncast", back to Earth (see next slide).*

Grand Prize: $20 million (1st to land a craft on the Moon, rove for at least 500 meters, and transmit 2 Mooncasts back to Earth).

Second Prize: $5 million (for teams to continue to compete, after fulfilling Grand Prize goals, and to increase the possibility that multiple teams will succeed).

(The Grand Prize and Second place will be available until December 31st 2017, at which point the competition will be terminated unless extended by Google and the X PRIZE Foundation.)

Bonuses: $5 million in bonus prizes (to complete additional mission tasks) Only once, whatever # bonus !

- ✓ *Rove longer distances (> 5,000 meters), and/or*
- ✓ *Image man-made artefacts (e.g. ~~Apollo~~, Luna and/or Chang'e probes hardware, failure impacts), and/or*
- ✓ *Discover water ice, and/or*
- ✓ *Survive through a frigid lunar night (approximately 14.75 Earth days).*

Google Lunar X-Prize (GLXP)

MOONCAST:

The Mooncast consists of digital data that must be collected and transmitted to the Earth composed of:

- ✓ *High-resolution 360º panoramic photographs taken on the surface of the Moon;*
- ✓ *Self-portraits of the rover taken on the surface of the Moon;*
- ✓ *Near-real time videos showing the craft's landing and journey along the lunar surface;*
- ✓ *High Definition (HD) video;*
- ✓ *Transmission of a cached set of data, loaded on the craft before launch (e.g. first email sent from the Moon).*

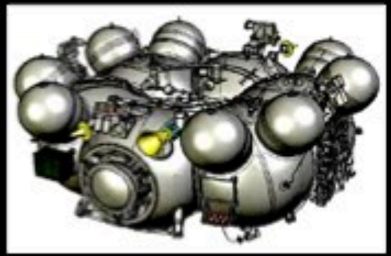
Final Product:

Teams will be required to send a first Mooncast (#1) detailing their arrival on the lunar surface, and a second Mooncast (#2) that provides imagery and video of their completed journey roaming the lunar surface. The Mooncasts will represent approximately a Gigabyte of data returned to the Earth.

Do not forget to provide solutions for those secondary aspects of the project:

- ✓ *How to perform the video of the landing, 360° panoramic HR pictures?*
- ✓ *How to perform the self-portraits?*
- ✓ *How to accommodate and manage the transmissions from the Moon?*
- ✓ *How to take advantage of those equipments to propose advertising campaigns to sponsors?*

End-to-End Mission Analysis (1): To the Moon



Launch

Soyuz Launcher from Kourou
(≈ 2,5 to 3 T. in TLI)

Don't look for other launch options

FREGAT part of the mission or only for TLI?

Earth-Moon Transfer

Are operations needed during TLI transfer (impact on S/C & Pld)?

Don't look at complex injection orbits (e.g. GTO)

Moon Arrival

- Direct landing?
- Orbiting & Landing?
- Keep element in orbit?

Moon Orbit Injection?

Operations or Specific Support in orbit required?

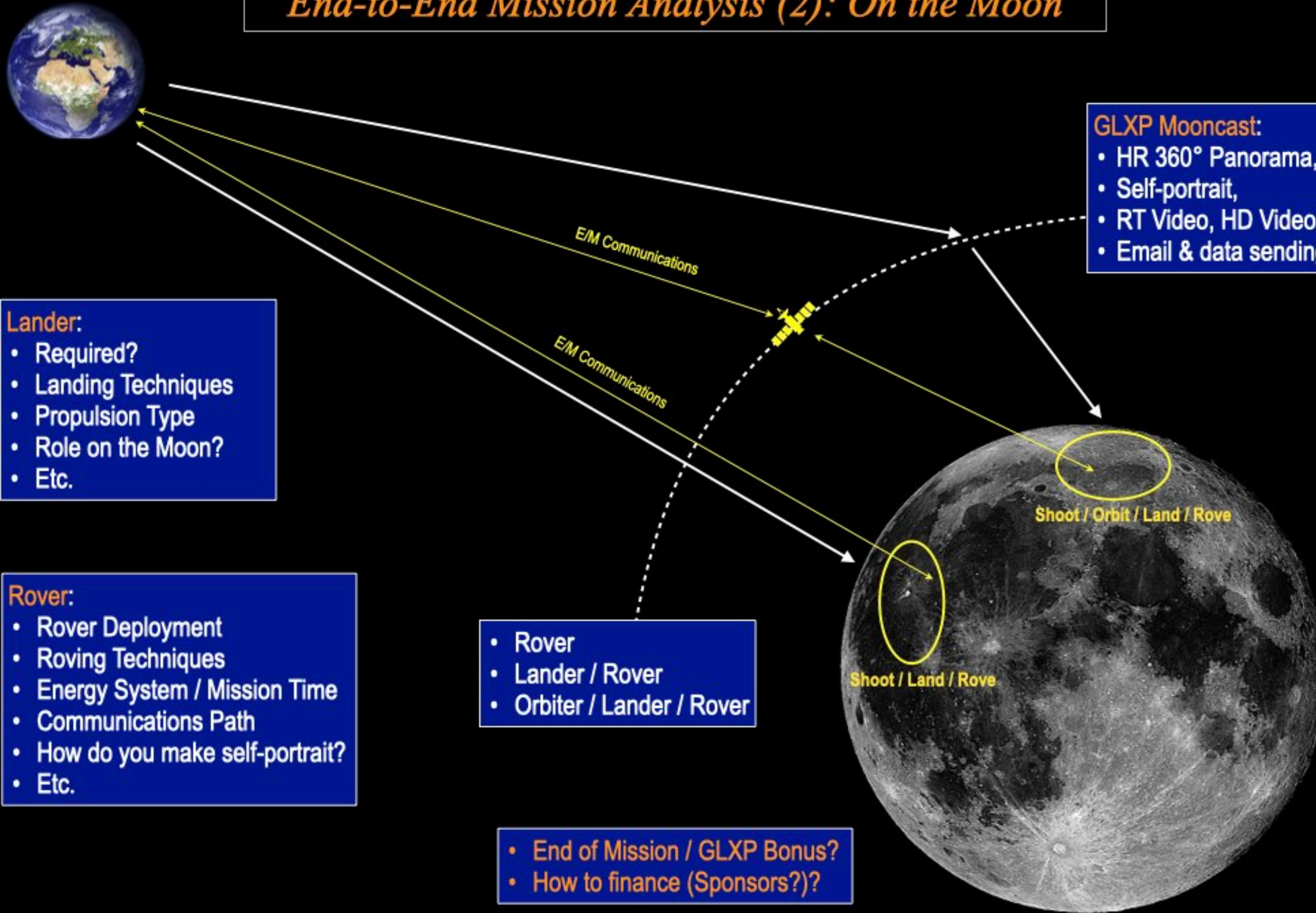
Direct Landing?

Lander Landing Techniques

Moon Landing Precision?

Moon Landing

End-to-End Mission Analysis (2): On the Moon



GLXP Mooncast:

- HR 360° Panorama,
- Self-portrait,
- RT Video, HD Video
- Email & data sending

Lander:

- Required?
- Landing Techniques
- Propulsion Type
- Role on the Moon?
- Etc.

Rover:

- Rover Deployment
- Roving Techniques
- Energy System / Mission Time
- Communications Path
- How do you make self-portrait?
- Etc.

- Rover
- Lander / Rover
- Orbiter / Lander / Rover

- End of Mission / GLXP Bonus?
- How to finance (Sponsors?)?

End-to-End Mission Concepts and Evaluation Criteria

✓ White sheet of paper approach per mission concept: write down ideas, knowledge, identify what has to be done at System level and which technologies to propose for Sub-systems, etc.

- ➡ System: lunar approach, landing options, rover concepts, configurations, accommodations …
- ➡ Subsystems technology options: lander propulsion, power supply, telecommunications system, rover motion techniques, camera systems, …

✓ Elaborate preliminary lander and rover concepts for 3 missions (Moon orbit or not, how to land, how to rove, … any other strategy and/or selected options at system and/or subsystem levels)

✓ Perform a short design of the 3 mission concepts. Write an "end-to-end mission" description for each.

✓ Define mission concept evaluation criteria (min 8, max 12):

- ➡ Identify and Define the evaluation criteria.
- ➡ Weight the evaluation criteria.

✓ Perform System Trade-offs (see method in next slides).

Supporting document to the Trade-Off method: Columbus Resource Module (RM) Reference Configuration - Trade-offs analysis Examples, Dornier System document (1985).

End-to-End Mission Concept Selection (1)

Mission Build-up (with / without options)

- Moon Arrival Strategy *
- Lander Concepts
- Rover Concepts
- Mooncast Solution
- Ideas for Sponsors
- Mission Option(s) ?
- Funding Option(s) **

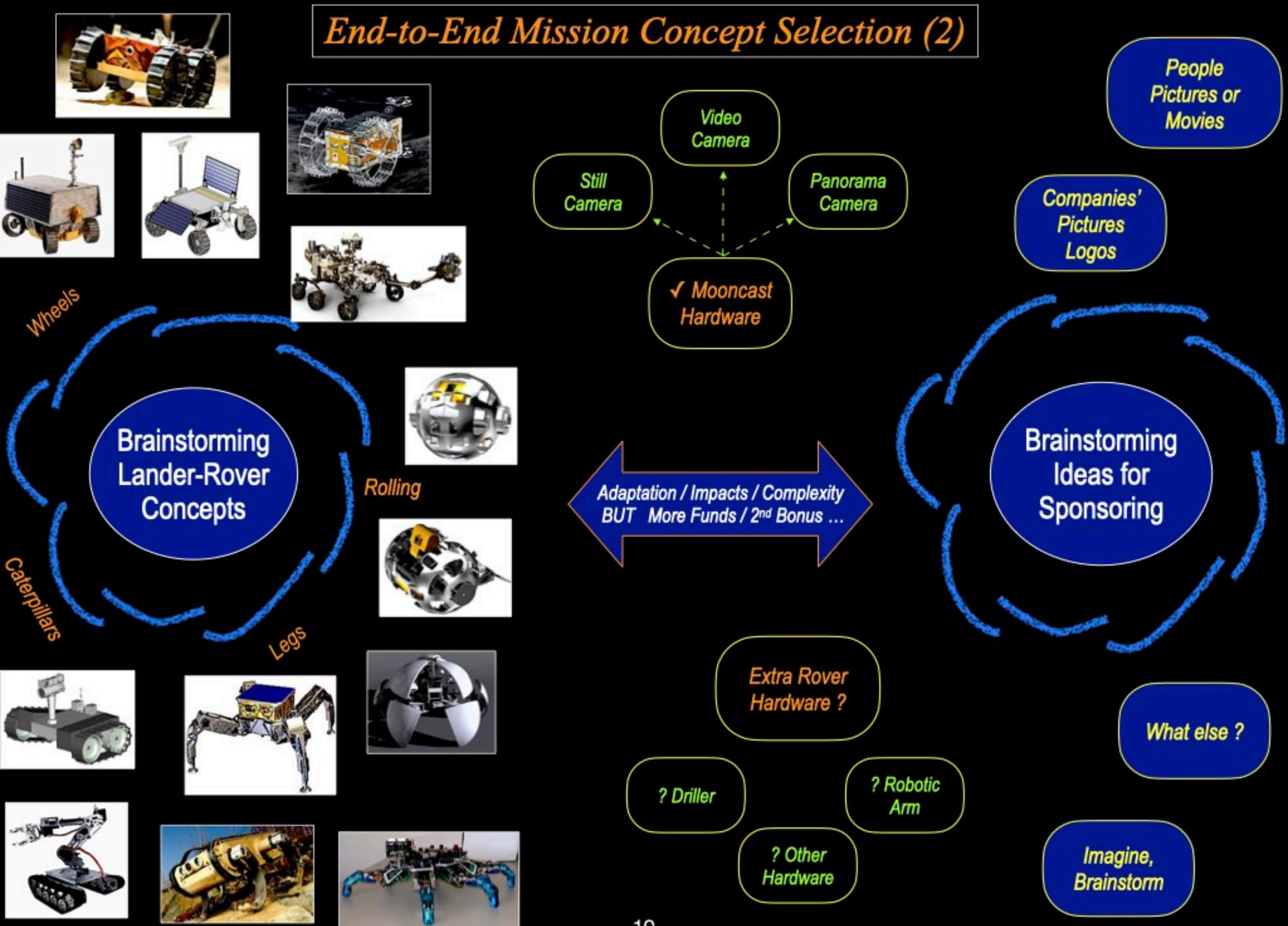
Technology Building-blocks

- Propulsion: Liquid / Solid / Hybrid
- Power supply: Solar C / Fuel C Batteries ***
- Rover prop.: Caterpillar / Wheels / others
- Communication Video Navigation
- Other Techno: Landing ? Roving ?

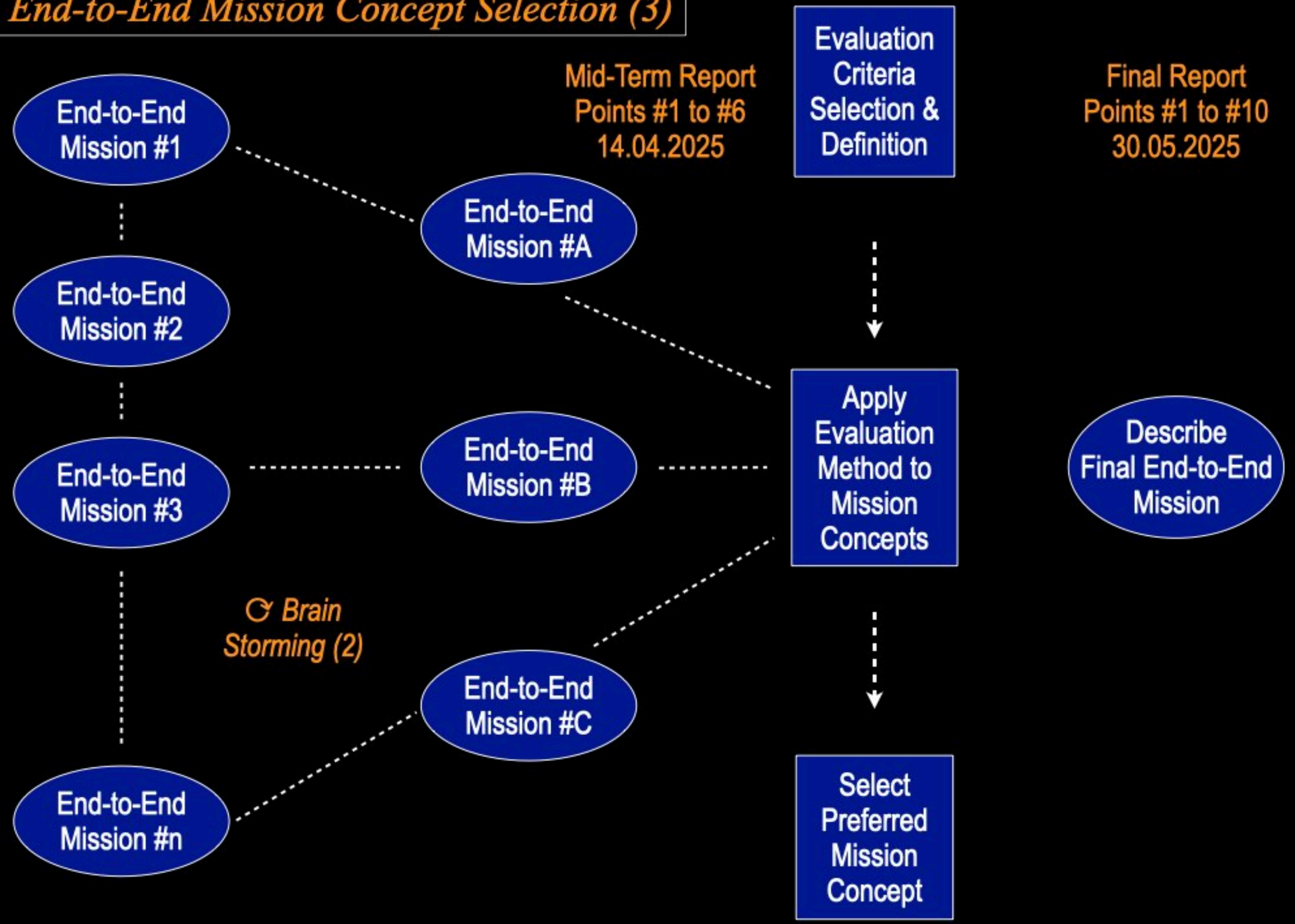
*** No RTG !

* From Trans Lunar Injection (TLI) orbit

** Sarting level: 0,- € ! Sponsoring ?


End-to-End Mission Concept Selection (2)
Video Camera
Still Camera
Panorama Camera
✓ Mooncast Hardware
People Pictures or Movies
Companies' Pictures Logos
Wheels
Brainstorming Lander-Rover Concepts
Rolling
Caterpillars
Legs
Adaptation / Impacts / Complexity
BUT More Funds / 2nd Bonus …
Brainstorming Ideas for Sponsoring
Extra Rover Hardware ?
? Driller
? Robotic Arm
? Other Hardware
What else ?
Imagine, Brainstorm

End-to-End Mission Concept Selection (3)



Project Report - Table of Content

1. Introduction. List of Abbreviations.
2. Team members, responsibility, method of working and list of meetings.
3. Mission concepts build-up: assumption, description (system & subsystems) *
4. Funding / Sponsorships ideas and impact on missions (Rover)
5. Brief summary description of identified end-to-end missions concepts (3).
6. List and definition of evaluation criteria (technical, operational, programmatic).

Draft Report by 14.04.2025 (points #1. to #6.) - 10 to 15 pages max !

7. Weighting of evaluation criteria **
8. Application of evaluation criteria to mission concept options (Excel or Number).
9. Selection and description of team's preferred mission.
10. Conclusions. Lessons learned during the project's process.

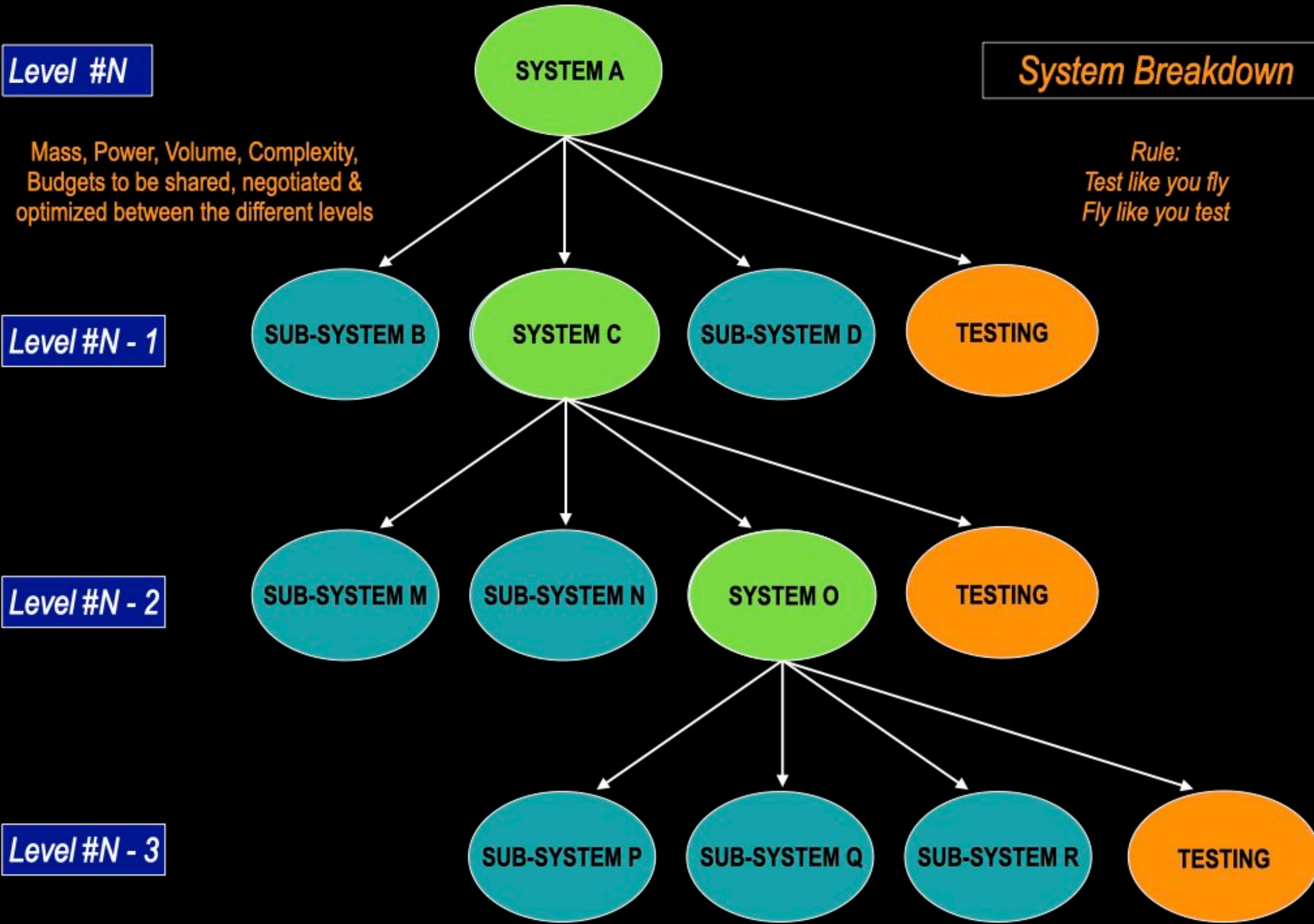
List of references.

Final Report for 30.05.2025 (complete report, including #1. to #10.)

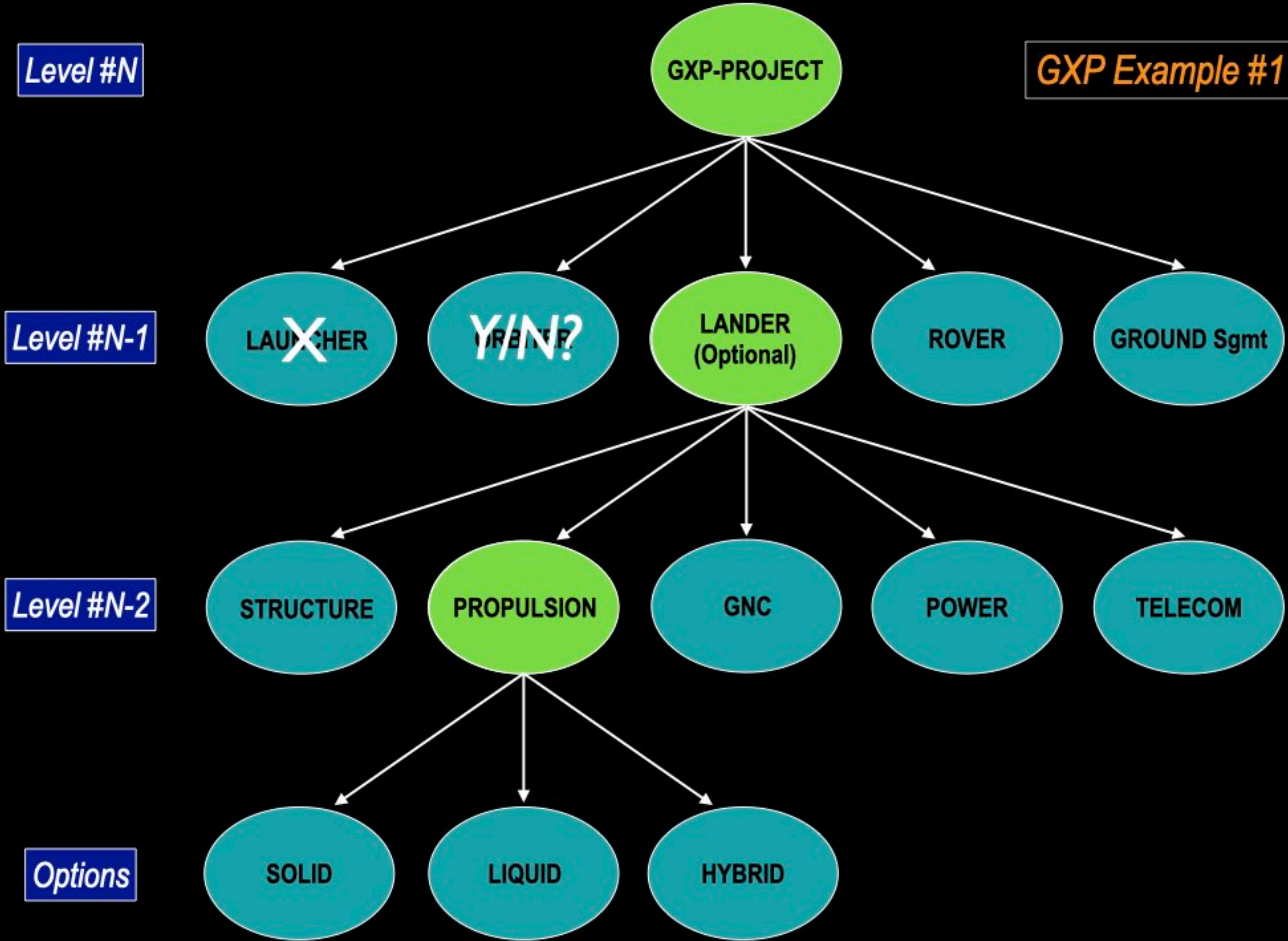
* If drawings / simple sketches are available, include them in the report.
Think about less text and more pictures !

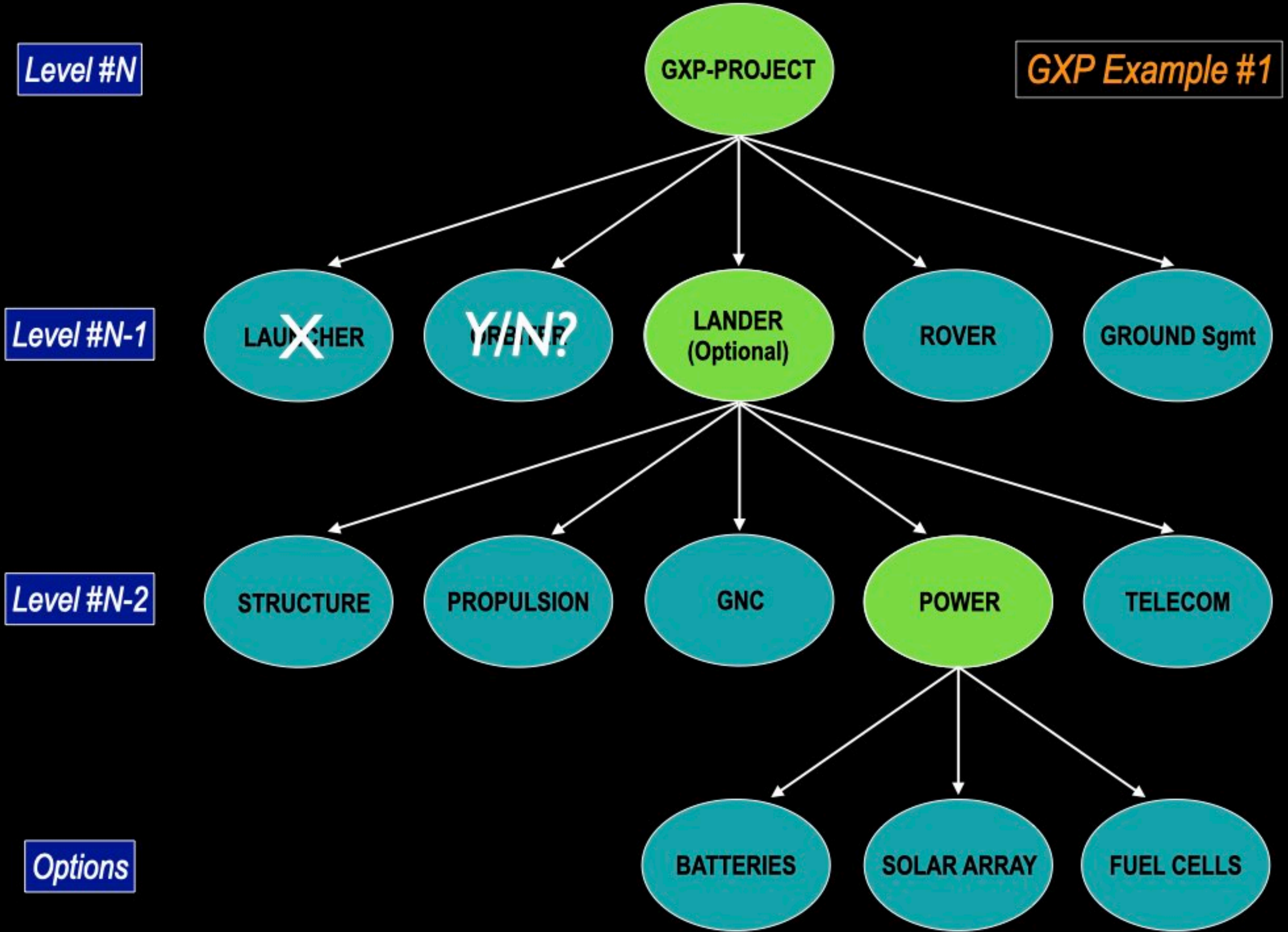
** Keep track of the reasoning and logic followed in the process (see after).

System Breakdown

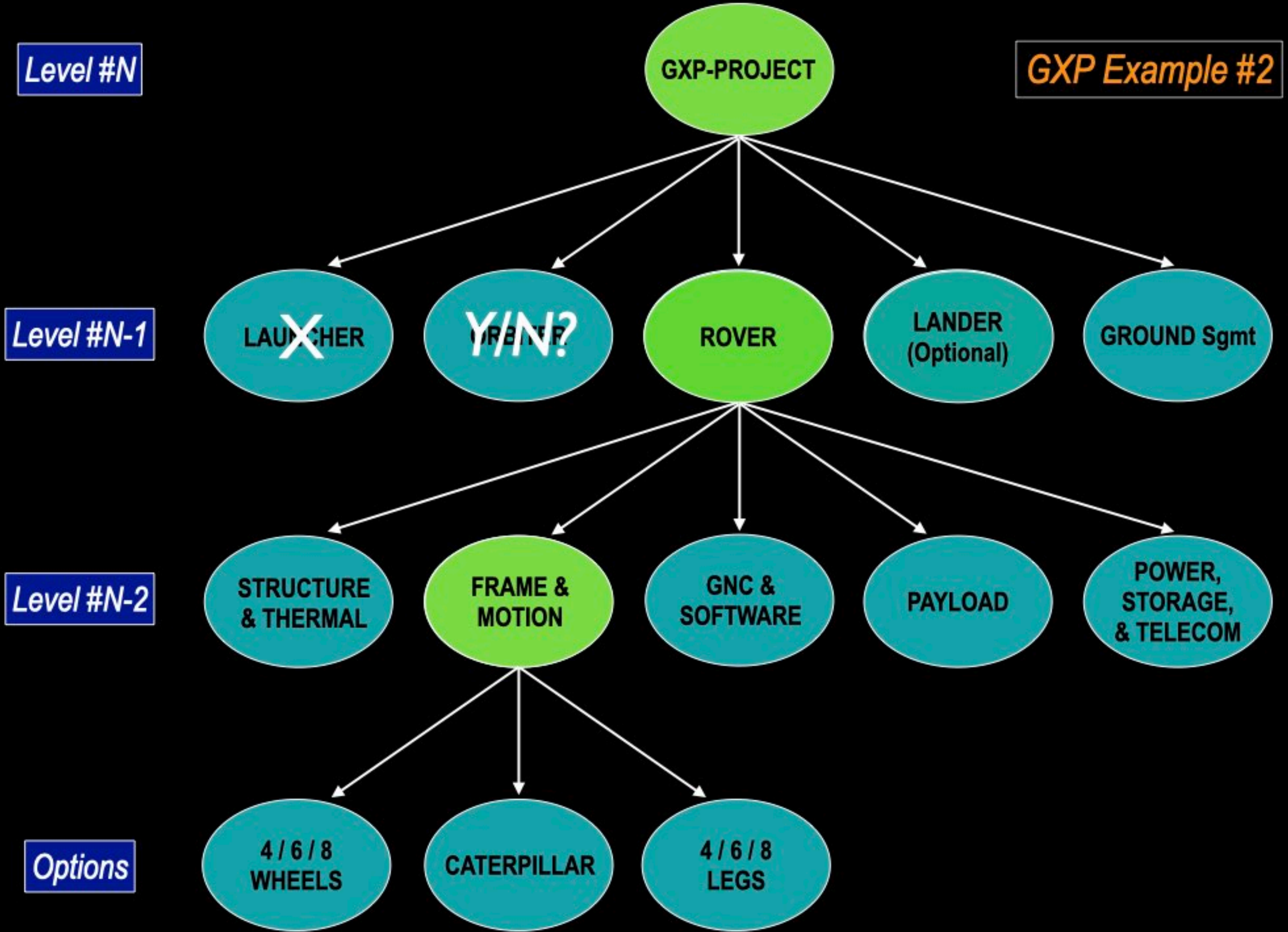


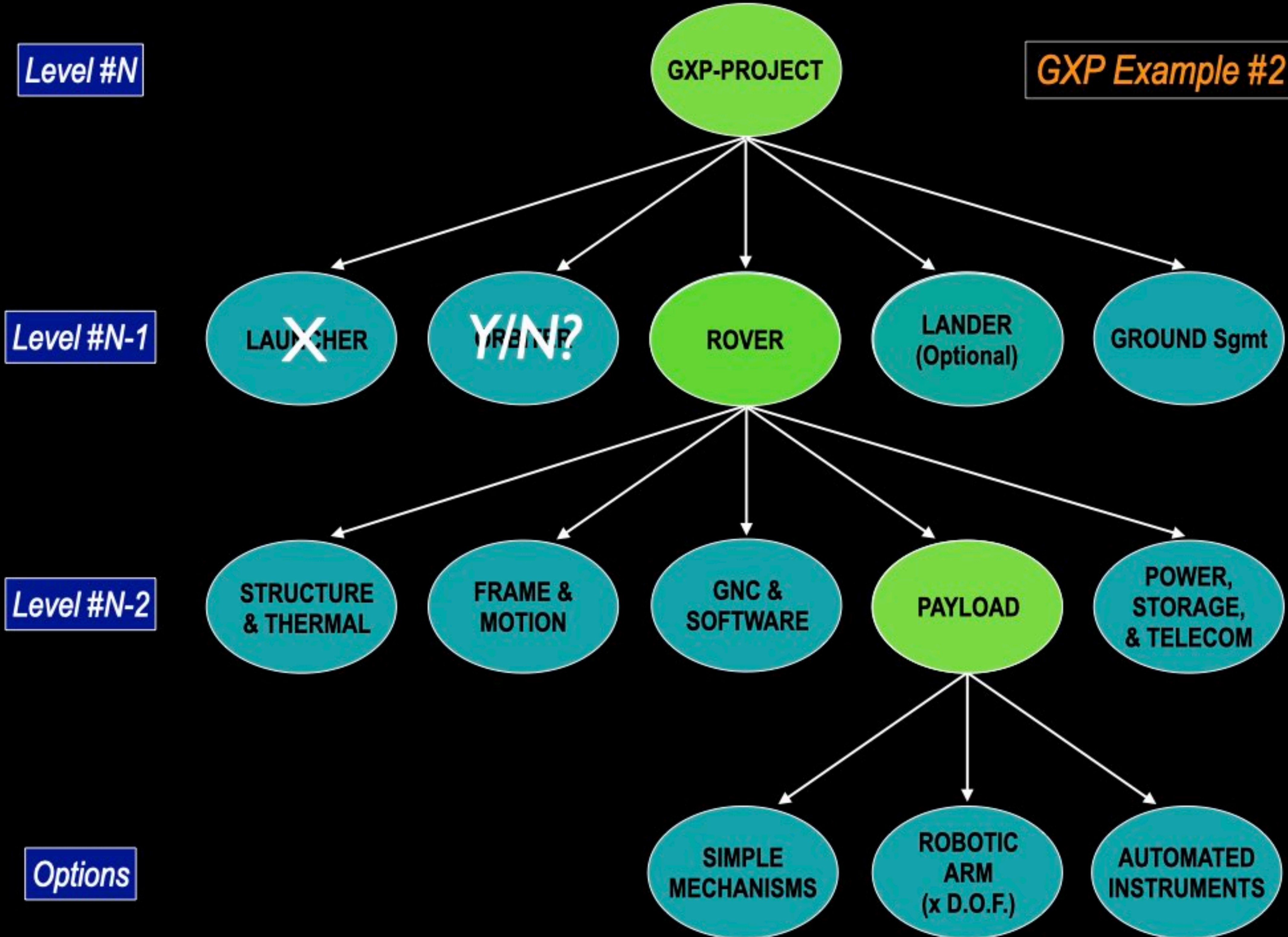
GXP Example #1





Level #N
GXP-PROJECT
GXP Example #1
Level #N-1
LAUNCHER
X
Y/N?
LANDER
(Optional)
ROVER
GROUND Sgmt
Level #N-2
STRUCTURE
PROPULSION
GNC
POWER
TELECOM
Options
BATTERIES
SOLAR ARRAY
FUEL CELLS


Level #N
GXP-PROJECT
GXP Example #2
Level #N-1
X
Y/N?
ROVER
LANDER (Optional)
GROUND Sgmt
Level #N-2
STRUCTURE & THERMAL
FRAME & MOTION
GNC & SOFTWARE
PAYLOAD
POWER, STORAGE, & TELECOM
Options
4 / 6 / 8 WHEELS
CATERPILLAR
4 / 6 / 8 LEGS


Level #N
GXP-PROJECT
GXP Example #2
Level #N-1
X
Y/N?
ROVER
LANDER (Optional)
GROUND Sgmt
Level #N-2
STRUCTURE & THERMAL
FRAME & MOTION
GNC & SOFTWARE
PAYLOAD
POWER, STORAGE, & TELECOM
Options
SIMPLE MECHANISMS
ROBOTIC ARM (x D.O.F.)
AUTOMATED INSTRUMENTS

Trade-Off Method (1)

Based on defined and agreed Evaluation Criteria among Group's members:

List the evaluation criteria: (8 min, 12 max.)

1. *Xi: definition of criteria X i*
2. *Xj: definition of criteria X j*
3. *Xk: definition of criteria X k*
4. *Xl: definition of criteria X l*
5. *Etc.*

Start the evaluation criteria weighting process:

-3 = criteria Xi is much less important than criteria Xj
-2 = criteria Xi is less important than criteria Xj
-1 = criteria Xi is slightly less important than criteria Xj
0 = criteria Xi is as important as criteria Xj
+1 = criteria Xi is slightly more important than criteria Xj
+2 = criteria Xi is more important than criteria Xj
+3 = criteria Xi is much more important than criteria Xj

Trade-Off Method (2)

Build Matrix of criteria correlation with individual weightings (Excel or Numbers)

	X i	X j	X k	X l	Etc.
Xi = criteria		1	3	2	1
Xi = criteria	-1		-2	1	0
Xi = criteria	-3	2		-3	-2
Xi = criteria	-2	-1	3		0
Etc.	-1	0	2	0	

Only one half of the matrix (blue for example) has to be filled up

Sum	a (-7)	b (2)	c (6)	d (0)	e (-1)	Sum = 0

Sum + (N-1)x3	a' (5)	b' (14)	c' (18)	d' (12)	e' (11)	Sum = Z (60)

N = total number of criteria; (N - 1) x 3 = (5 - 1) x 3 = 12

Importance (%)	a" (8,3%)	b" (23,3%)	c" (30,0%)	d" (20,0%)	e" (18,3%)	Sum = Z' (99,9%)

Adjusted %	a"' (8,3%)	b"' (23,3%)	c"' (30,0%)	d"' (20,0%)	e"' (18,4%)	Sum = 100

Rank	5	2	1	3	4

Trade-Off Method (3)

Missions Marking	%		Mission #1			Mission #2			Mission #3		
	I		M	N		M	N		M	N	
Xi = criteria X i	8,3		10	...		5	...		0	...	
Xi = criteria X j	23,3		0	...		5	...		10	...	
Xk = criteria X k	30,0		10	...		0	...		5	...	
Xl = criteria X l	20,0		5	...		0	...		10	...	
Etc.	18,4		10	...		5	...		0	...	

I: Evaluation criteria in adjusted % of importance; M: Marking from 0 to 10 (recommended 0 / 5 / 10); N = (M x I) / 10

	Mission #1	Mission #2	Mission #3
Mission Score	a	b	c
Mission Rank (highest, the best)	3	1	2

M: Marking from 0 to 10

- 10 = alternate mission meets criterion best (at least once per line)
- 0 = alternate mission meets criteria least
- 5 = alternate mission is somewhere between

Special Advices on:

#1 The Final Report
#2 Project & Team Aspects
#3 System and Sub-System Aspects
#4 Moon Environment
#5 Evaluation Criteria

Additional Advices #1: on the Report

- ✓ Try to add some pictures / drawings / sketches, every time you can (it is worth thousand of words), to illustrate your ideas at system or sub-system levels (landing / propulsion techniques, rover locomotion, power supply, and communications), also for showing accommodation on the rover.

- ✓ Be synthetic and concise ! Try to remain between 10 and 15 pages max for the Mid-Term report.

- ✓ Try to have the same level of definition / analysis in each end-to-end mission's description (Orbiter (if used in the scenario) Lander and Rover) to reach a coherent and uniform approach.

- ✓ Try to put in a short synthesis / summary table (when appropriate) the mission concepts proposed, once you have introduced them, and before performing the trade-offs.

- ✓ If you use abbreviations and/or acronyms, please put them all in a separate list / table.

- ✓ Don't forget to have in the report the list of references you are using for your project.

- ✓ As the document is written in English, don't hesitate to use the "grammar" and "spell-check" tools of the text processing software you are using to minimize typo errors.

- ✓ Take some time to go back to the project introduction document (this document) to check advices and recommendations, and to the end-to-end drawings.

Additional Advices #2: on Project & Team Aspects

- ✓ You should see your team as being independent and in competition with all the others.
- ✓ Try to look and think at simple, robust solutions when possible. Avoid proposals with too advanced technologies or not space-qualified yet in Europe (see next slides, "autonomy and nuclear" aspects).
- ✓ Don't forget to explain how you will fulfill and answer to the required GLXP "Mooncast and Final Product" based on the rover(s) and the lander designs, capabilities and equipments (cameras).
- ✓ Time to conceive, develop, qualify and launch your project is short! Availability of funds is not guaranteed and is the major constraints to the GLXP undertaking. You start with 0,- €.
- ✓ You should think about and propose strategies to get some funds for your project (prior to the launch or once on the Moon). Sponsoring, yes, but how to take them on-board, in the design(s).
- ✓ When time pressure is growing up, take advantage of being a team to resolve quickly, together, pending issues in a dedicated meeting (one subject / one consensus / within one time slot).
- ✓ Don't loose too much time, a teamwork is also a good coordination and distribution of tasks among participants, followed by synthesis sessions with all members. Be efficient for the (short) allocated time within the semester!

Additional Advices #3.1: on System & Sub-Systems Aspects

- ✓ The launcher is provided and shall not be part of the analysis. It shall not be considered as cost criteria (launch cost), or for accommodation aspects (i.e. volume under the fairing). It is a dedicated mission, using all the capabilities, characteristics of a "standard" Soyuz vehicle from CSG. The Fregat is providing the escape velocity to reach the TLI (Trans Lunar Injection) orbit.

- ✓ As a dedicated flight, you can consider an injection with the Fregat directly in a TLI trajectory, with or without short ballistic phase(s). Going to LEO and later injecting in TLI adds constraints on orbital operations. It might only be of interest if you have a requirement to reach a specific orbit around the Moon and then a particular target on its surface. It will take time and ressources to perform all those orbital operations and you are in a competition with others. Be pragmatic and go straight towards the Moon.

- ✓ If you want to use the Fregat up to the Moon (for orbiting and/or start landing), the useful payload will be smaller because you will have to operate with the full stage mass. To use Fregat you have also to increase its capabilities, after liberation from Earth orbit, in order to perform additional mission steps (Earth-Moon cruising, or initiate landing retro-firing, etc.). Additional hardware for power supply & storage, antenna, propulsion fuels, might be needed, i.e. less useful payload for the prime mission goal.

- ✓ Orbiter and lander strategy: you don't have to make estimations about fuel consumption, time of flight, etc. as it is mainly a conceptual mission analysis (no computation required ;-).

Additional Advices #3.2: on System & Sub-Systems Aspects

- ✓ *Power supply or Thermal Systems: don't propose to use nuclear energy (RTG - Radioisotope Thermoelectric Generator, or Radioisotope Heater Units, RHU).*

- ✓ *Keep in mind major constraints, such as development time and hardware cost, work, transport and all integration / operations risks, etc. with nuclear materials. It has not been developed nor used by the European space industry, nor flown on European launchers. It is banned Today from CSG.*

- ✓ *Be careful with the meaning of "Autonomy". The development and implementation of sophisticated software providing "a lot" of autonomy to any space vehicle is a very expensive and long process: software development and validation issues; costly associated hardware (computer, sensors, actuators, etc.) which shall be "space qualified" and robust to the space environment.*

- ✓ *Even if we are nowadays working with more and more powerful computers and devices on Earth (iPhones, tablets, computers), we use in general ''older'' electronic equipment generations in space (mainly for reliability purpose, cost or delays in qualifying the latest technology components).*

- ✓ *The usage of an Articulated arm in space (depending on the number of degrees of freedom) might also be quite complex (hardware and software wise). It may have some mass penalty, impact the qualification / validation processes, and therefore cost.*

- ✓ *It is more important that you come with clever, simple ideas on how to perform the missions and the solutions to realize them. After, you will trade the mission concepts, in the follow-on analysis.*

Additional Advices #4: on the Moon Environment

- ✓ *There is no dense atmosphere around the Moon, which could be of use for the landing process: so aero-shell, parachute, etc. shall be excluded (it is not comparable to Mars).*

- ✓ *Temperature range: +130°C (sunny side) and -170°C to -190°C (in shadow, or during the night).*

- ✓ *Lunar day duration is 14.75 Earth days, and Lunar night duration is 14.75 Earth days.*

- ✓ *As you are going to land on the visible side of the Moon (always facing the Earth), during a Lunar day, it shall help for communications aspects (one-way signal: ≈1.3 sec) and power supply (sunny).*

- ✓ *The basic GLXP requirements can not be fulfilled in a short time after landing (i.e. the 500m roving takes time and "Moon-cast" preparation and transmission also). It means that a "minimum" solution (with limited funding) should assume a bare minimum set of resources to fulfill those requirements.*

- ✓ *A Lunar day may provide enough time to perform extra GLXP goals (options) but you could also decide to land closer to the edge of a Lunar day to move quicker in the Lunar night and realize an extra objective.*

- ✓ *Avoid Apollo sites as Man made artefacts: US Congress has voted a law to protect them from being damaged by the GLXP participants, or others.*

Additional Advices #5: on Evaluation Criteria

- ✓ *The most important part of the work is the selection, definition and understanding (what it means) of evaluation criteria and the allocation of their respective "weights". It shall be defined in common agreement by your team, and then applied to your proposed mission concepts options (3). Spend some time to write clearly together for each a short description text. You should not have altogether a number of criteria lower than 8, and higher than 12.*

- ✓ *In the process of weight attribution to the criteria (matrix in Excel or Number) and final weighting of the different options, keep track of the arguments retained for selecting the values. Before the end of the projects, you may have to redo iterations for the weights attribution, and for the mission selection.*

- ✓ *Options to be traded-off are at system level (lunar orbit or not, landing strategy, etc.), not necessarily at subsystems level (options for propulsion, power supply, landing control technique etc.). It shall also address the orbiter, lander and rover concepts associated to a mission.*

- ✓ *Evaluation criteria must not impose a final choice (i.e. looking at autonomy does not mean that the criteria "autonomy" must be very high or low, but how autonomy must be compared to the other criteria such as cost, development time, complexity (required on-board equipments), etc.). Your proposed mission concepts may have different degree of autonomy and a choice has to be made.*

- ✓ *After comes the justification of your final mission choice, which could be different from what the trade-off method proposes. Your team makes the choice (and justifies it).*

Review of Past and Recent Lunar Missions

USSR: Luna 9, 13 and Luna 16, 17, 20, 21 & 24

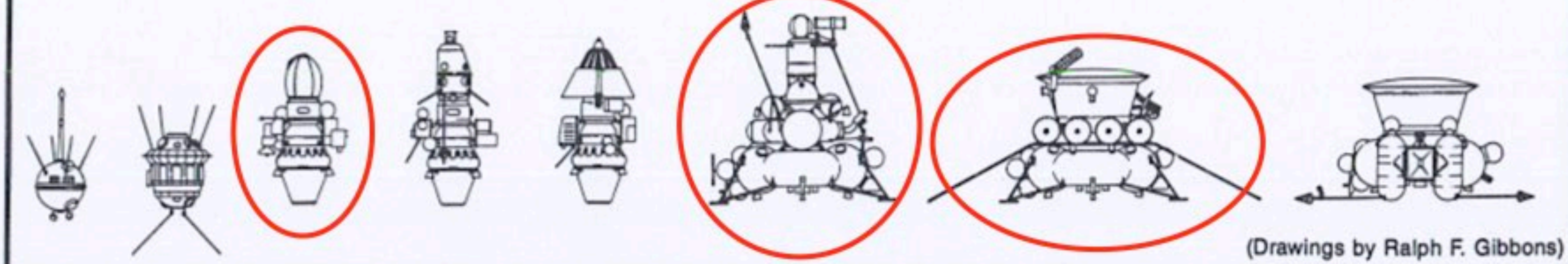
USA: Surveyor 1 to 7

China: Chang'E-3 to 6 / India: Chandrayaan-3

7 Failures in the last 5 years !

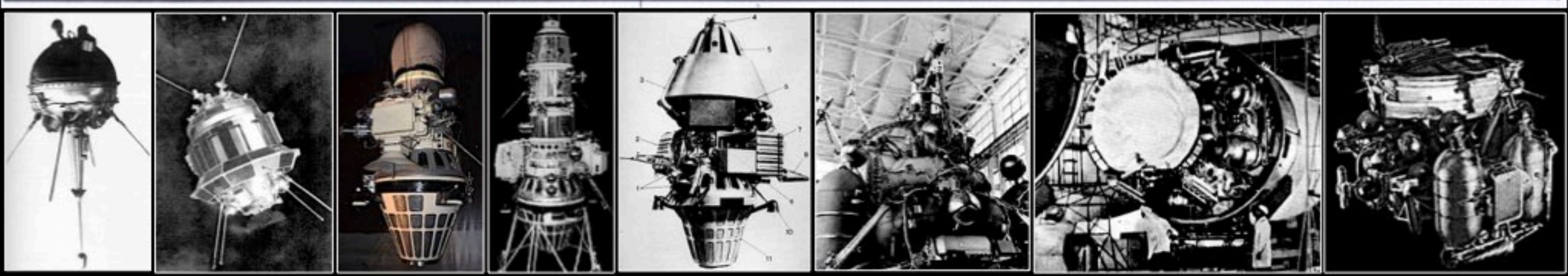
Soviet Moon Exploration Programme

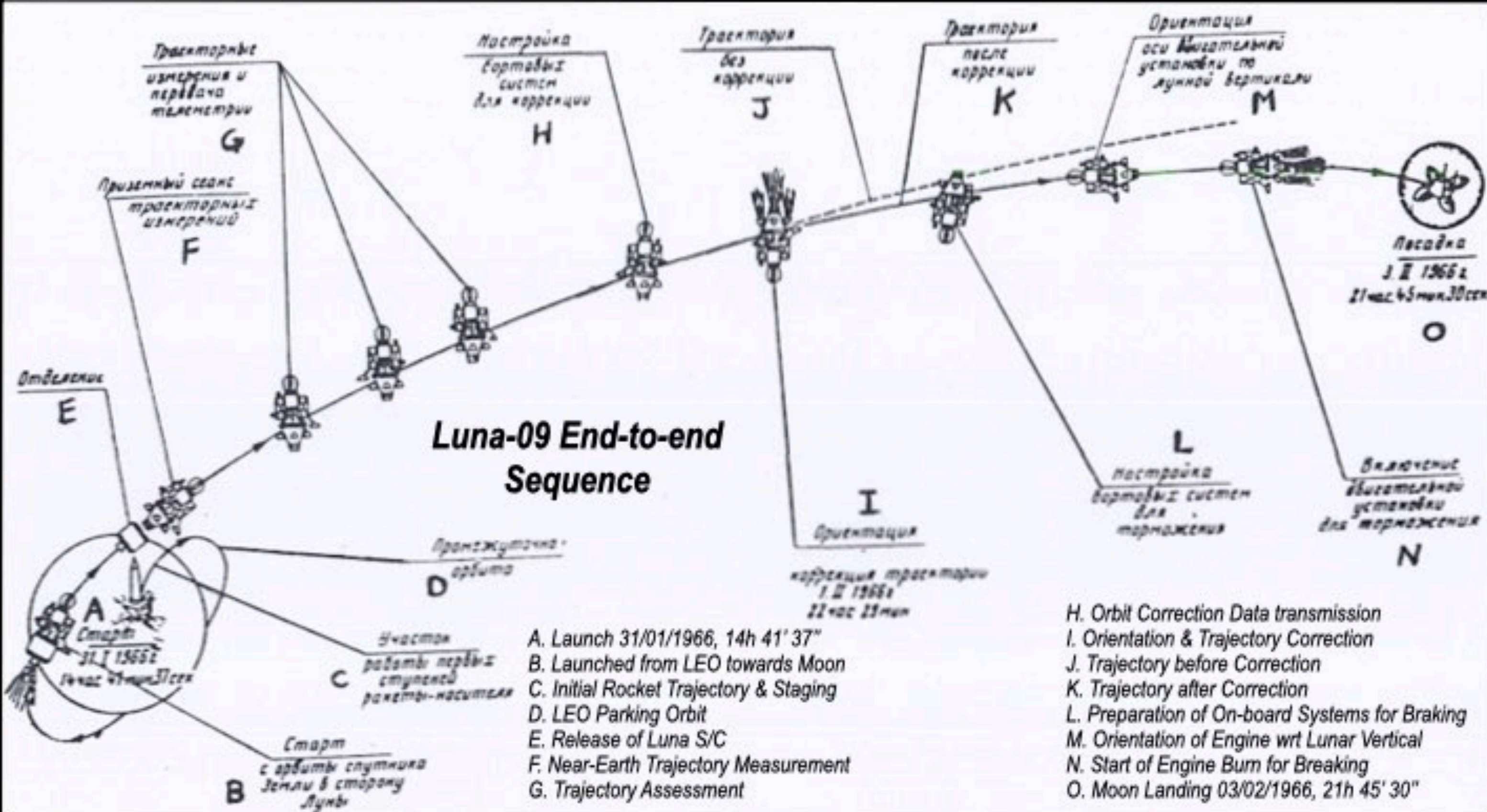
Luna S/C Generations:
#1 (1959)
#2 (1963)
#3 (1969)

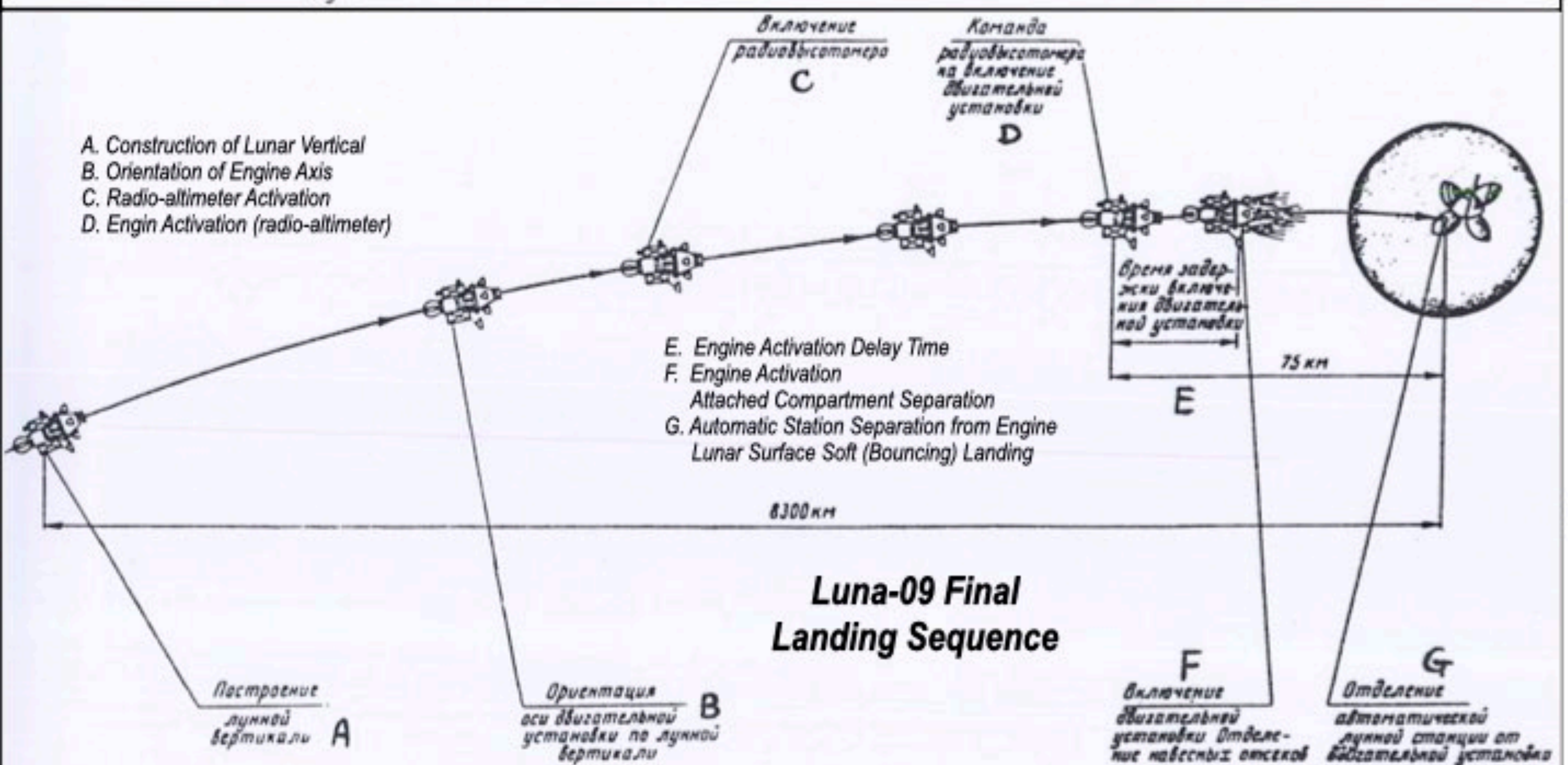


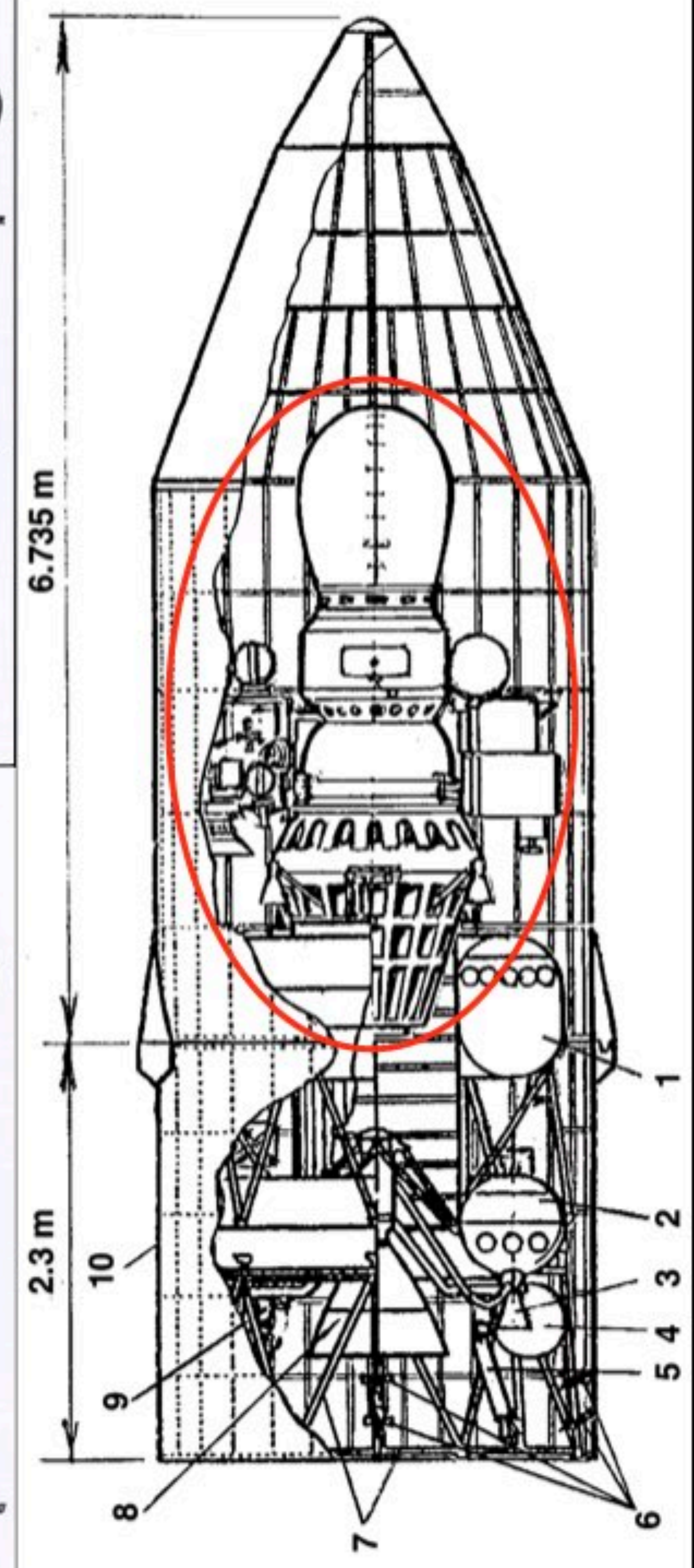
(Drawings by Ralph F. Gibbons)

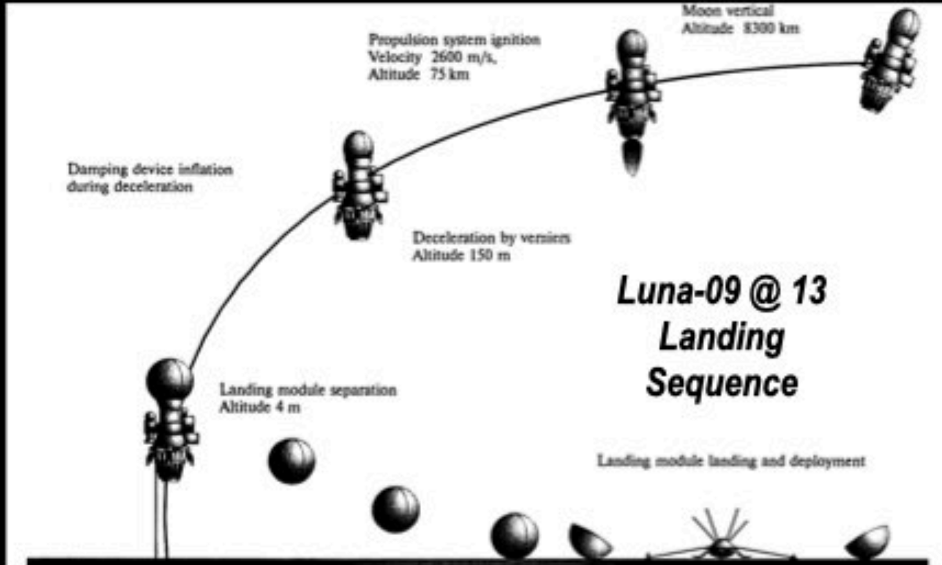
	LUNA 1 F 2	LUNA 3	LUNA 4 F 5 F 6 F 7 F 8 F 9 13	LUNA 10 11	LUNA 12 14	LUNA X 15 F XXX 16 18 F 20 23 F X 24	LUNA 17 21	LUNA 19 22
	1ST GENERATION		2ND GENERATION			3RD GENERATION		
YEARS	1959	1959	1963-1966	1966	1966-1968	1969-1976	1970-1973	1971-1974
LAUNCH VEHICLE	SL-3	SL-3	SL-6	SL-6	SL-6	SL-12	SL-12	SL-12
APPROXIMATE MASS (kg)	360-390	280	1400-1600	1600-1640	1600	5700	5700	5700
MISSION	IMPACT	FLYBY	LANDER	ORBITER	ORBITER	LANDER/RETURN	LANDER/ROVER	ORBITER

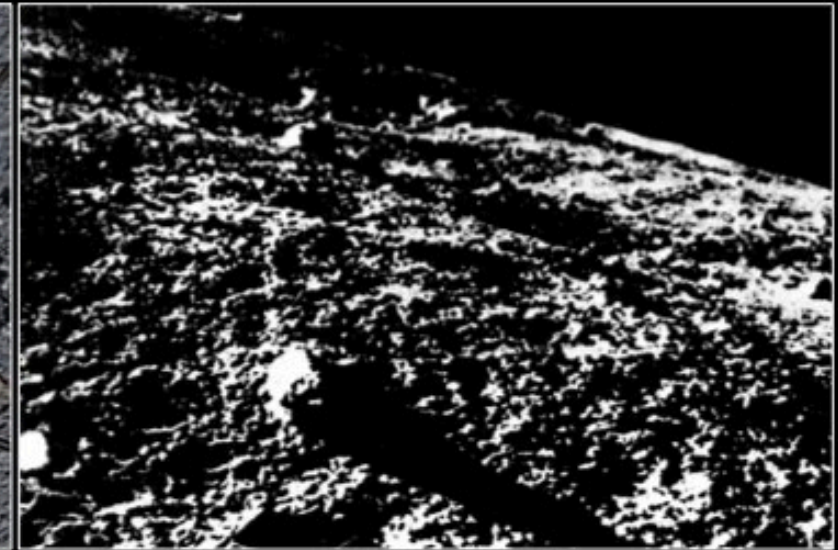


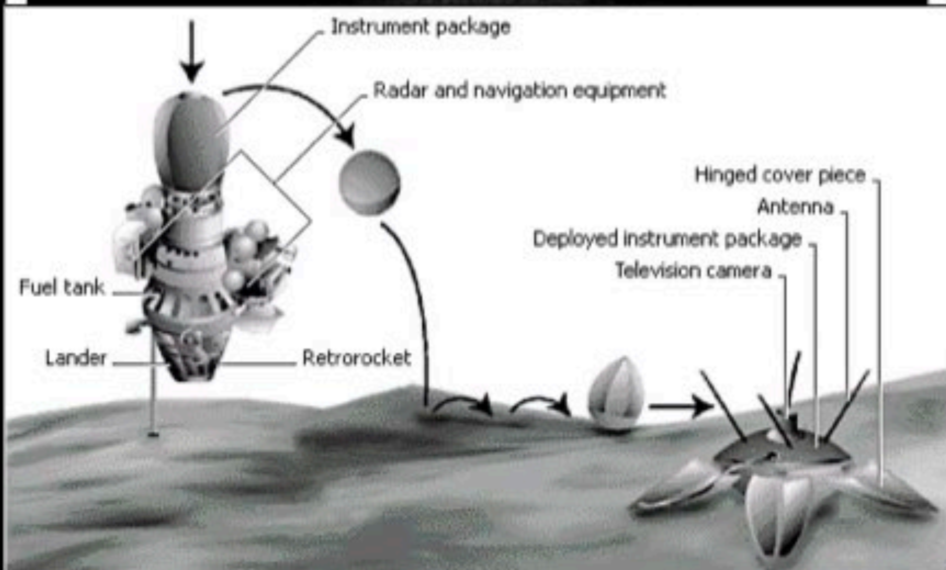

Luna-09 End-to-end Sequence
A. Launch 31/01/1966, 14h 41' 37"
B. Launched from LEO towards Moon
C. Initial Rocket Trajectory & Staging
D. LEO Parking Orbit
E. Release of Luna S/C
F. Near-Earth Trajectory Measurement
G. Trajectory Assessment
H. Orbit Correction Data transmission
I. Orientation & Trajectory Correction
J. Trajectory before Correction
K. Trajectory after Correction
L. Preparation of On-board Systems for Braking
M. Orientation of Engine wrt Lunar Vertical
N. Start of Engine Burn for Breaking
O. Moon Landing 03/02/1966, 21h 45' 30"


A. Construction of Lunar Vertical
B. Orientation of Engine Axis
C. Radio-altimeter Activation
D. Engin Activation (radio-altimeter)
E. Engine Activation Delay Time
F. Engine Activation
Attached Compartment Separation
G. Automatic Station Separation from Engine
Lunar Surface Soft (Bouncing) Landing
8300 км
75 км
Luna-09 Final Landing Sequence


6.735 m
2.3 m
1
2
3
4
5
6
7
8
9
10

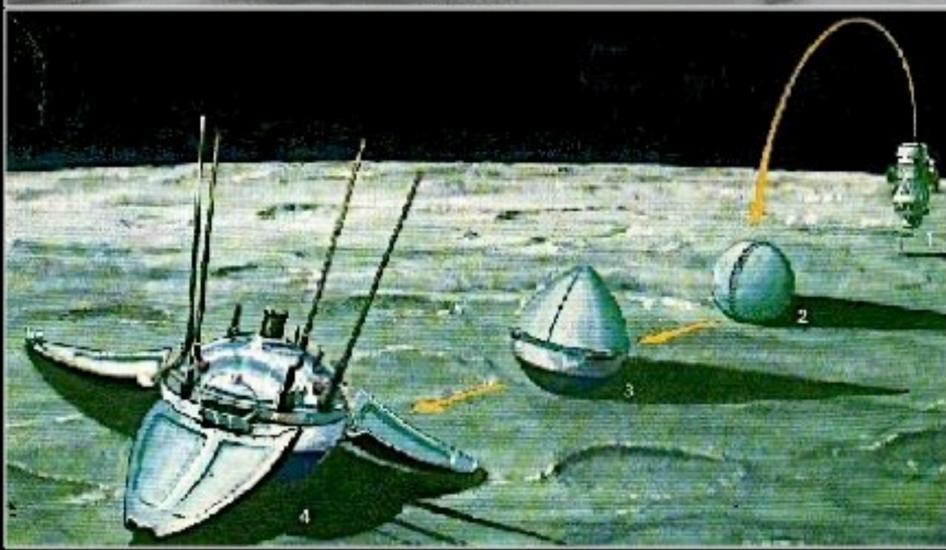


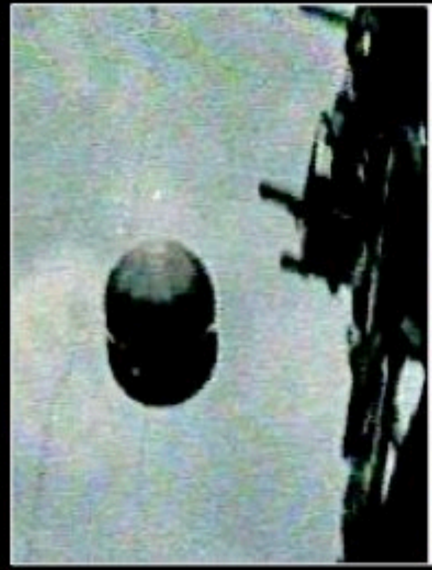


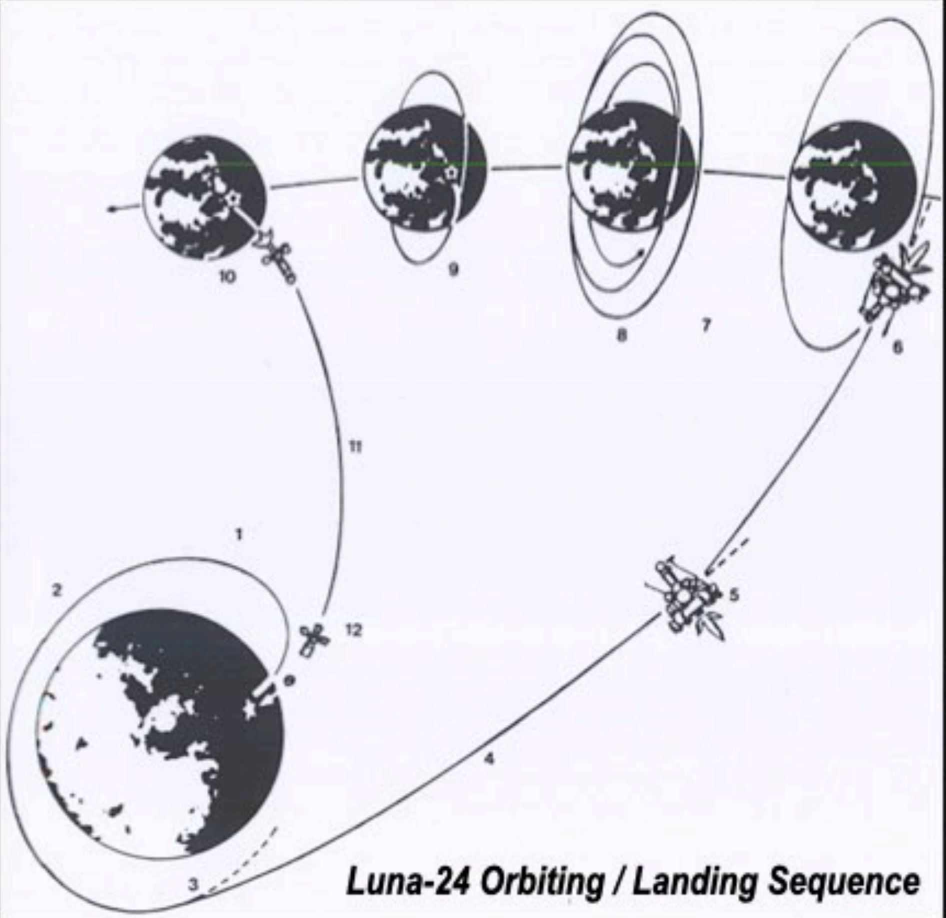


	Luna-13 Events (21-24.12.66)	Mass (Init./ Fin.)	DV	Comments
1	Separation from Upper Stage	1.620 Kg	—	Parking Orbit: H-200 Km @ 65°
2	Earth-Moon Traj. Correction	1.620 / 1.570 Kg	71 m/s	Accuracy: 0.1 m/s velocity & 1.0° angle
3	Modules Jettisoning ([a])	1.570 / 1.400 Kg	—	Last session: 15-20.000 Km from Moon
4	Deceleration before Landing	1.400 / 540 Kg	2600 m/s	Big Brake
5	Ejection of Lunar Lander	540 / 102 Kg	—	Inflatable Balloons (2 parts), 10 Kg mass Casing: Nylon (Extern.) & Rubber (Intern.) Helium Pressurized (0,068 - 0,090 MPa) External Belt Broken by Detonating Wire Internal Belt Tyre Broken by 2 Pyro-Locks
6	Landing on the Moon	102 Kg	—	
7	Shock Absorber Jettisoning	91.6 Kg	—	
8	Deployment of Instruments	91.6 Kg	—	

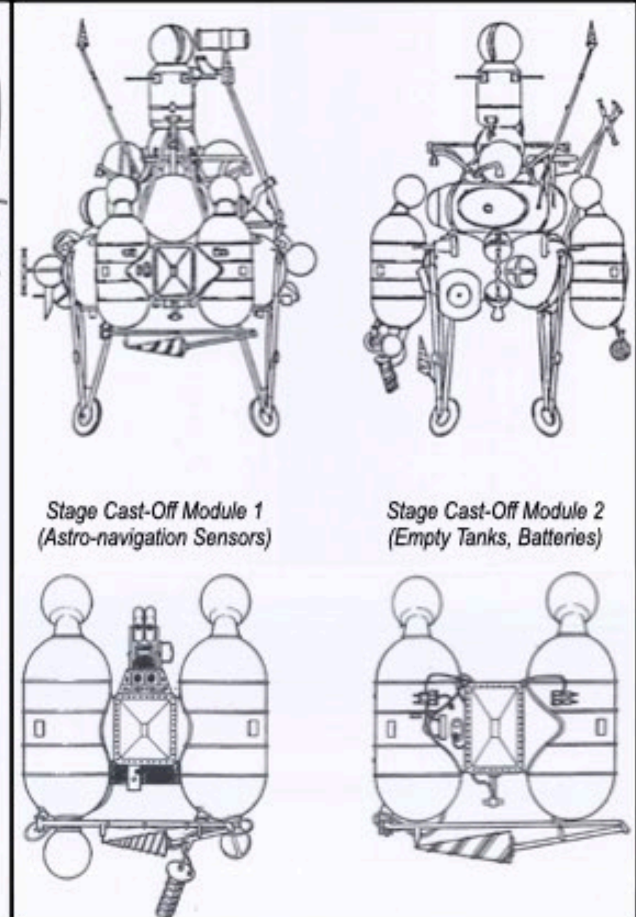
([a]): Astronavigation Instruments, Exhausted Batteries

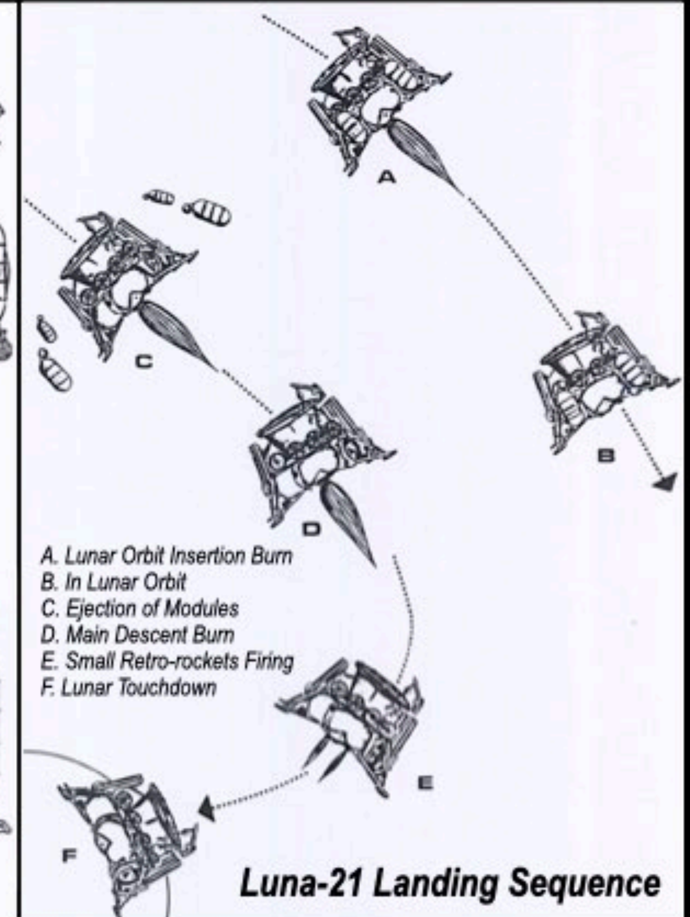




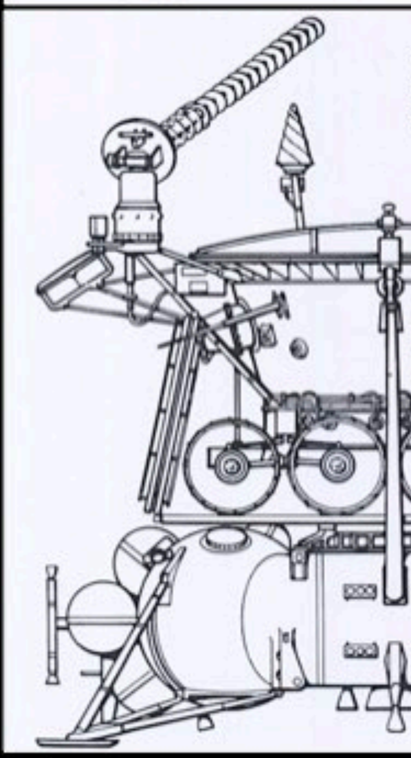


Luna-24 Orbiting / Landing Sequence





Luna-21 Landing Sequence

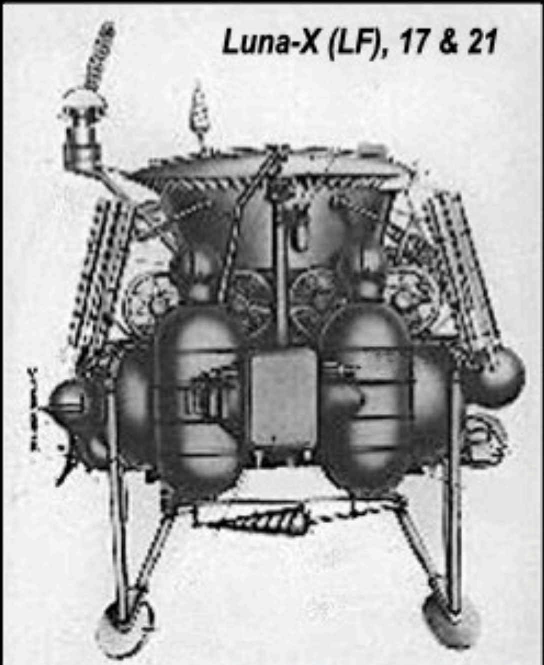


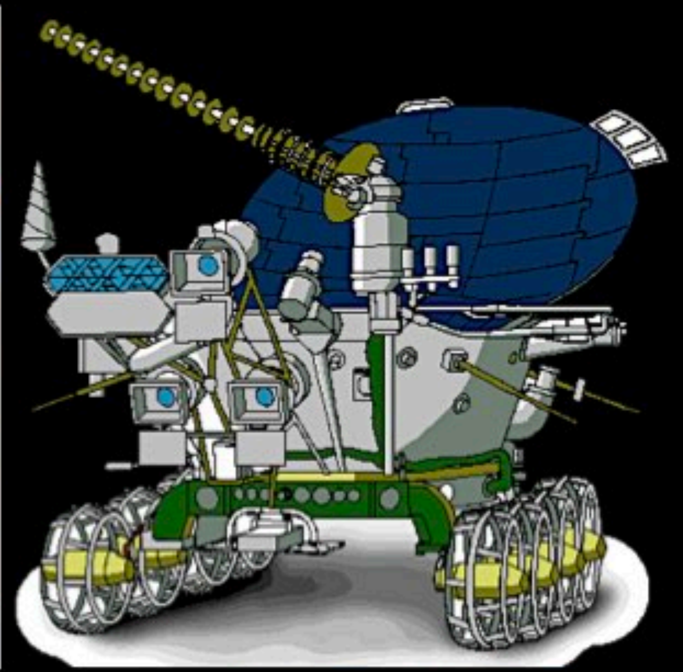
Luna 17: Lunokhod-1
Luna-21: Lunokhod-2

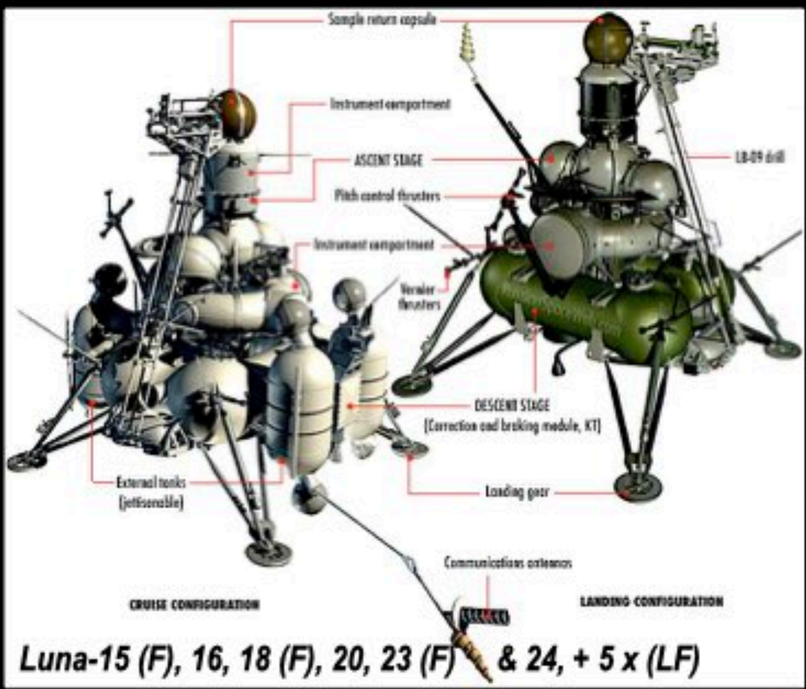
	Luna-24 Events	Date	Mass (Init./ Fin.)	DV (m/sec)	Comments
1	Separation from Upper Stage	10.08.1976	5.727 Kg	—	Parking Orbit: H-180 Km @ 51.6°
2	Earth-Moon Traj. Correction	11.08.1976		18	
3	Moon Orbit Insertion ([a])	14.08.1976		895	Moon Orbit: H-115 Km @ 120°
4	Lunar Orbit Correction #1	16.08.1976		21	
5	Lunar Orbit Correction #2	17.08.1976		5	Final Orbit: Ha-120 Km, Hp-12 Km
6	Modules Jettisoning ([b])		4.226 / 3.604 Kg	—	
7	Descent to the Moon ([a])	18.08.1976	3.604 / 2.018 Kg	1768	
8	Soft Landing ([c])		2.018 / 1.880 Kg	117	Mare Crisium: 62°12' E, 12°45' N
9	Lunar Soil Sampling		1.880 Kg	—	In case of Luna-21 (Lunokhod-2), rover mass on the Moon: 880 Kg
10	Return Rocket Launch	19.08.1976	495 / 196 Kg	2708	
11	Re-entry Module Separation		196 / 37 Kg	—	
12	Earth Landing	22.08.1976	32 Kg	—	Sample Mass: 170 gr

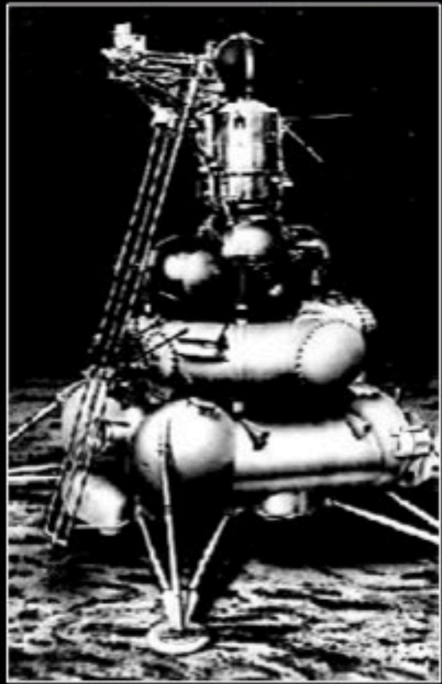
([a]): High Deceleration; ([c]): Precise Deceleration

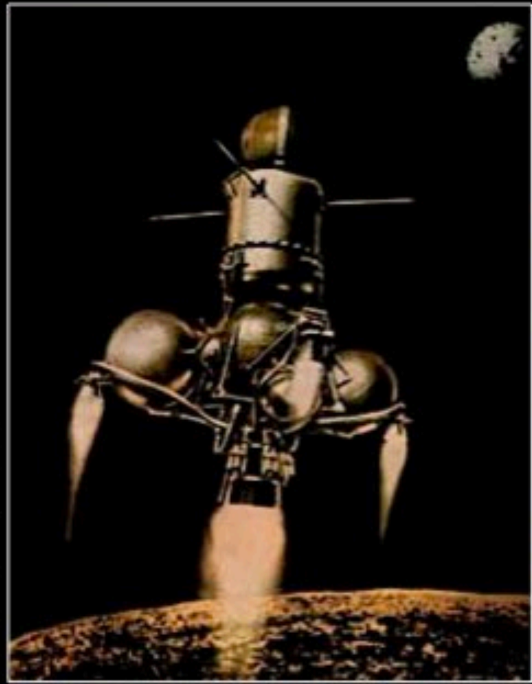
([b]): Astronavigation Instruments, Exhausted Tanks, Batteries

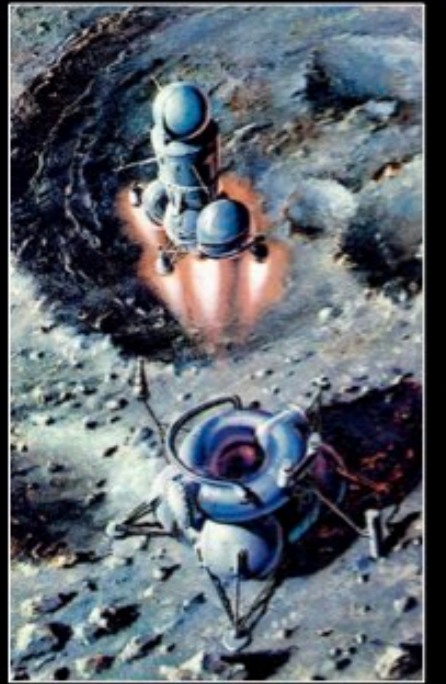

Luna-X (LF), 17 & 21




Sample return capsule
Instrument comportment
ASCENT STAGE
LB-09 drill
Pitch control thrusters
Instrument comportment
Vernier thrusters
DESCENT STAGE
(Correction and braking module, KT)
External tanks
(jettisonable)
Landing gear
Communications antennas
CRUISE CONFIGURATION
LANDING CONFIGURATION
Luna-15 (F), 16, 18 (F), 20, 23 (F) & 24, + 5 x (LF)

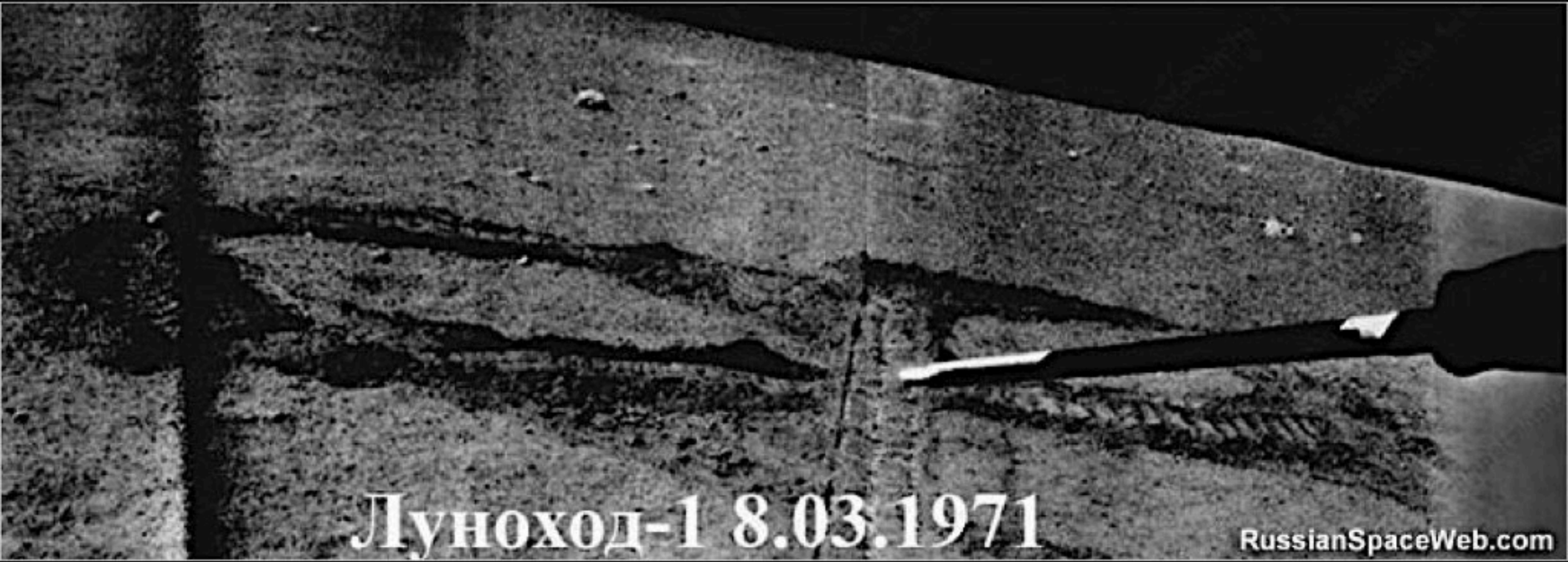







Luna-16, 20 & 24

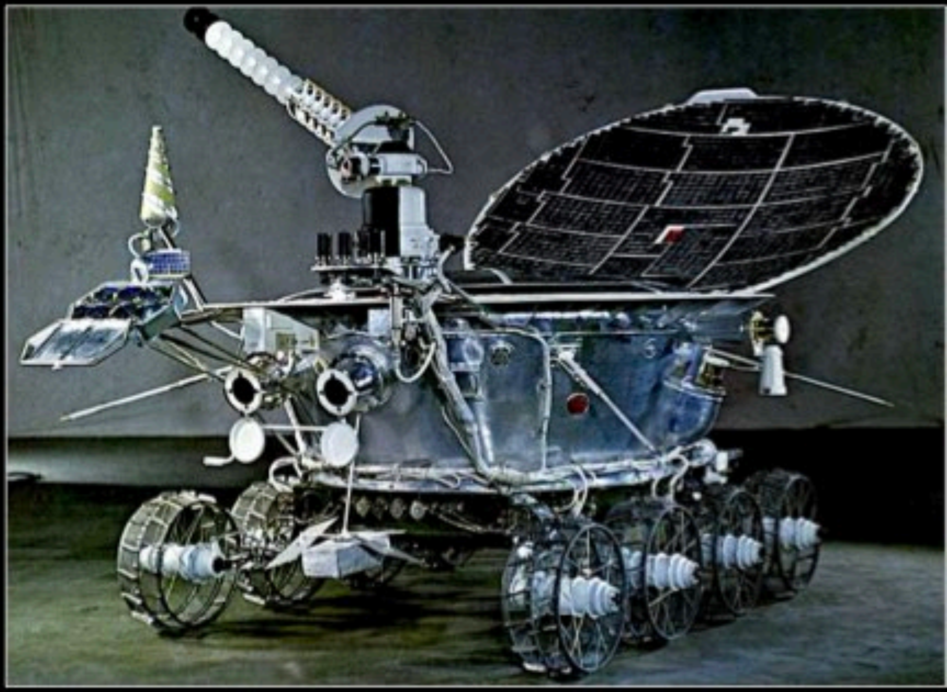
08.03.1971 Lunokhod-1 - Women Day Celebration



Real Picture ?

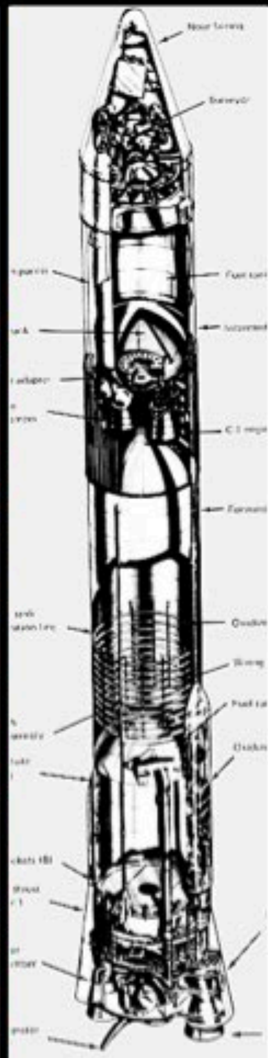
or

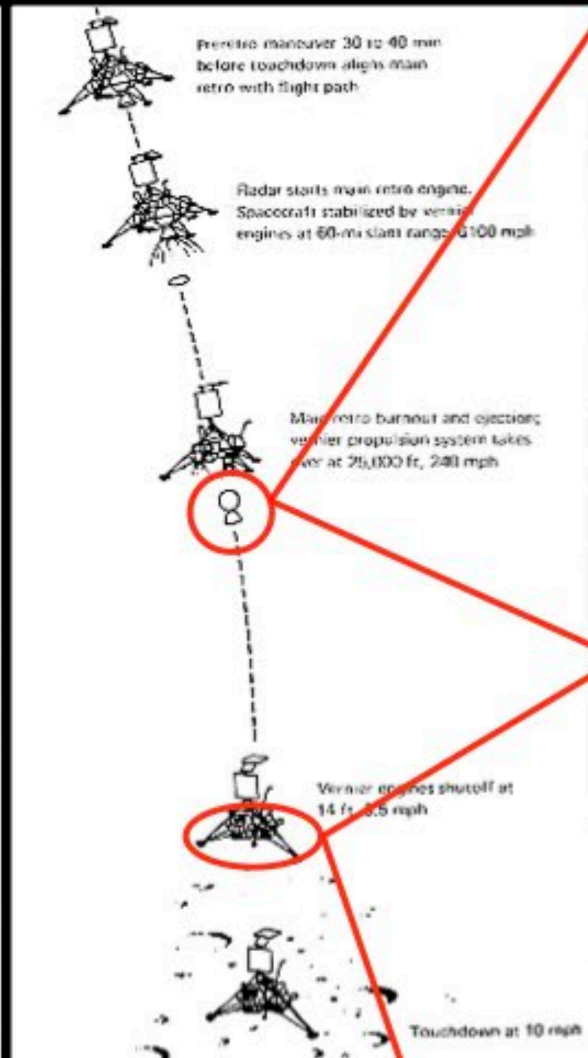
Usual Soviet Union Modified Picture ?

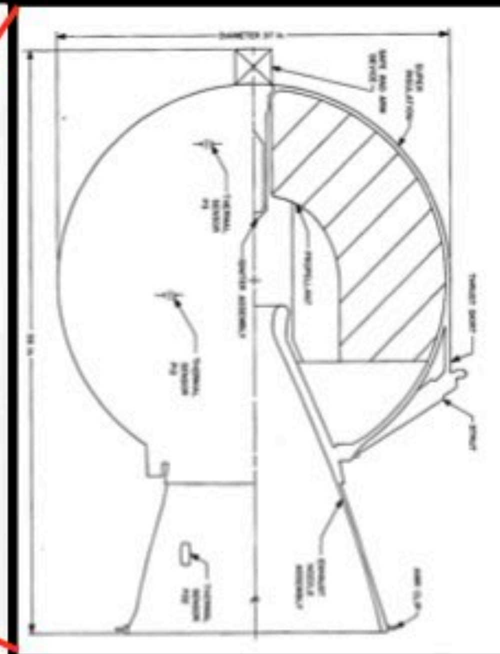


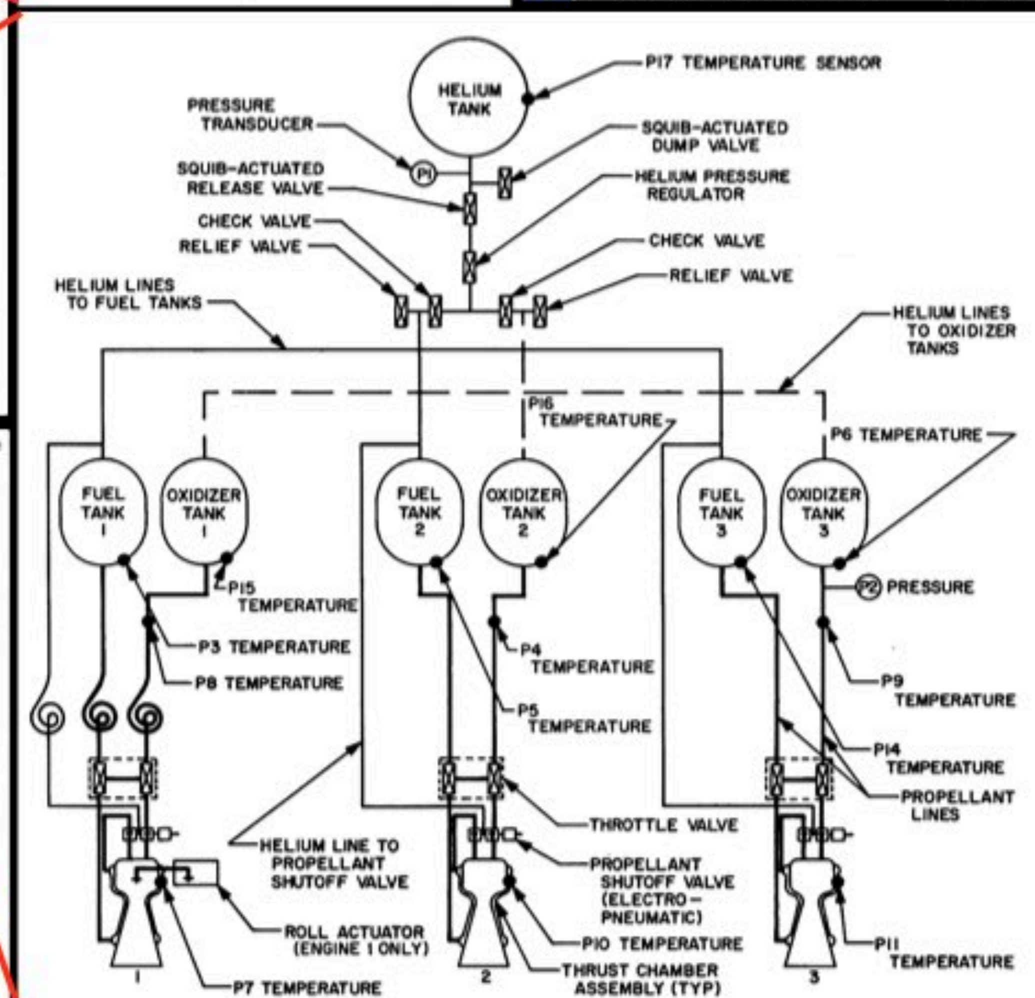
Surveyor Programme
Jun 1966 - Jan 1968
7 launches (2 Failures)
Total Mass: 995 < > 1036 kg

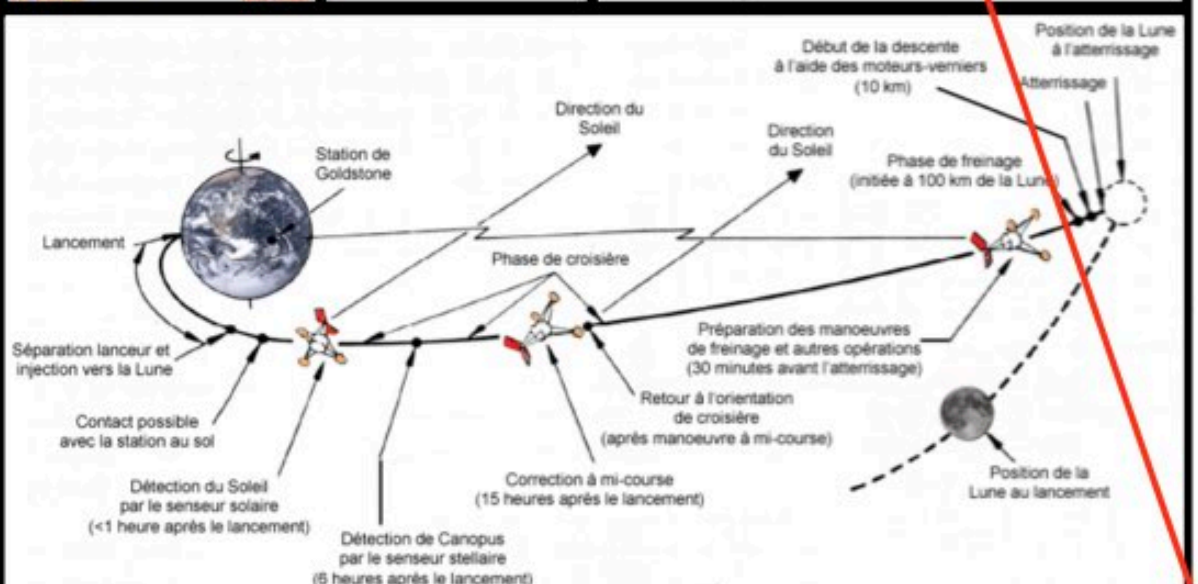
	Surveyor Fuel in Landing	Values
1	Propellant (solid), kg	564,3
2	Vernier Propellant, kg	
3	- Total Loaded, kg	83.4
4	- Consumed, kg	
5	- Midcourse Maneuv., kg	7.5
6	- Terminal Maneuv., kg	54.3
7	- Unusable, kg	1.0
8	- Remaining Usable, kg	20.6

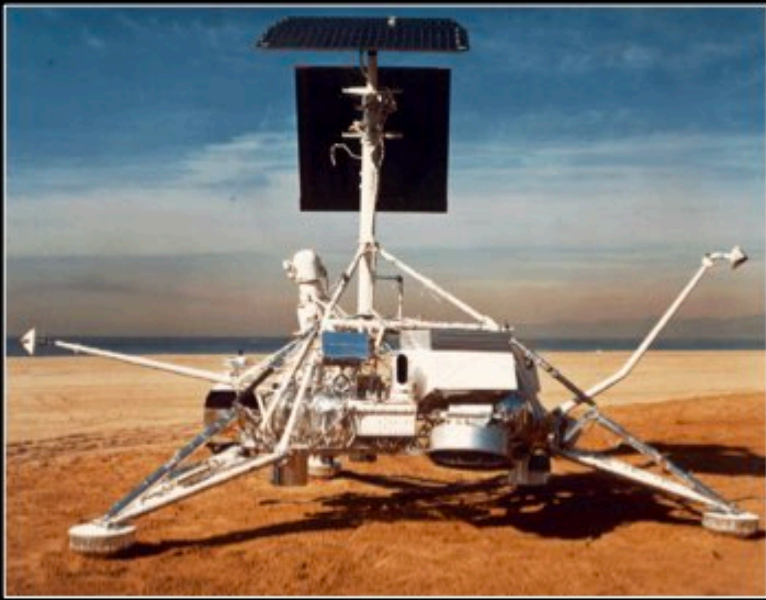


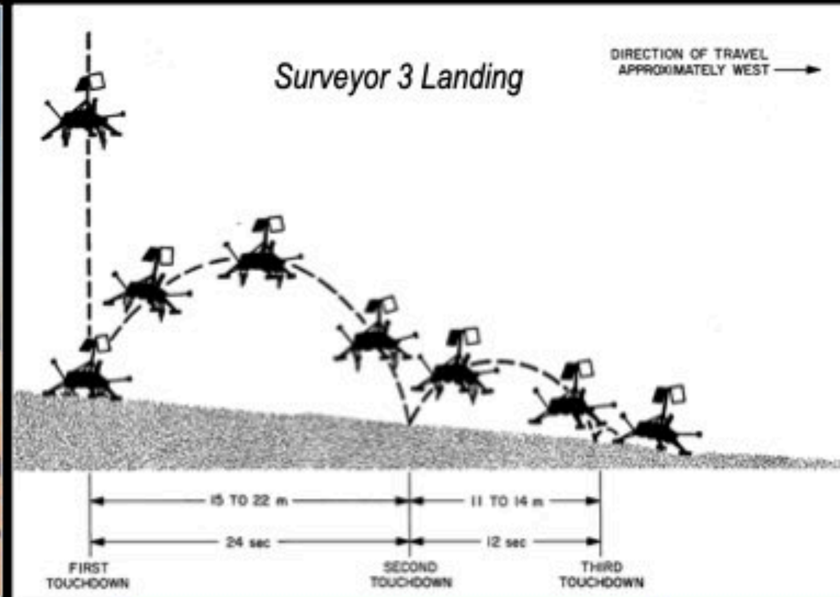


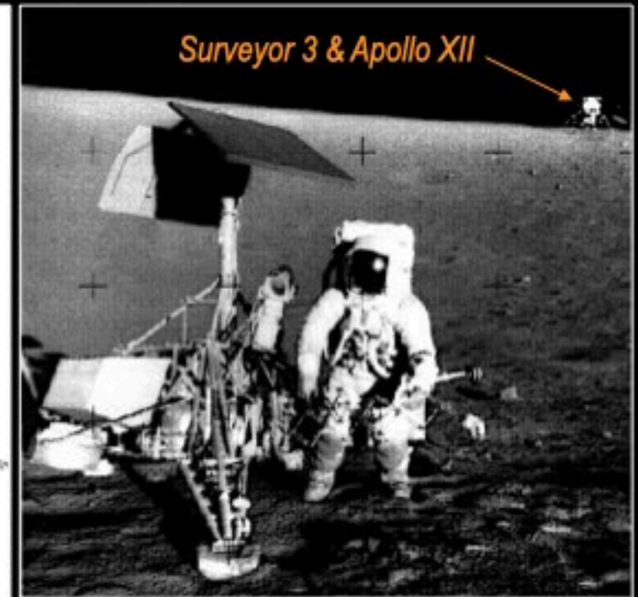


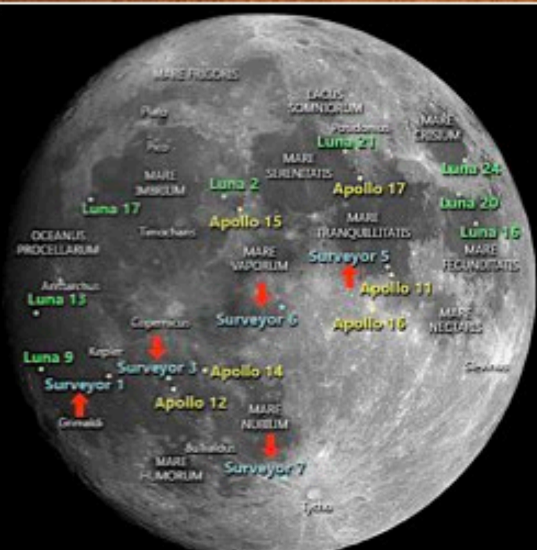






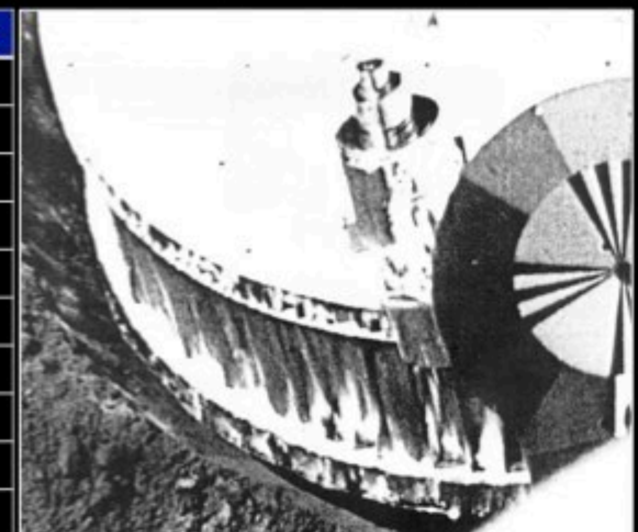


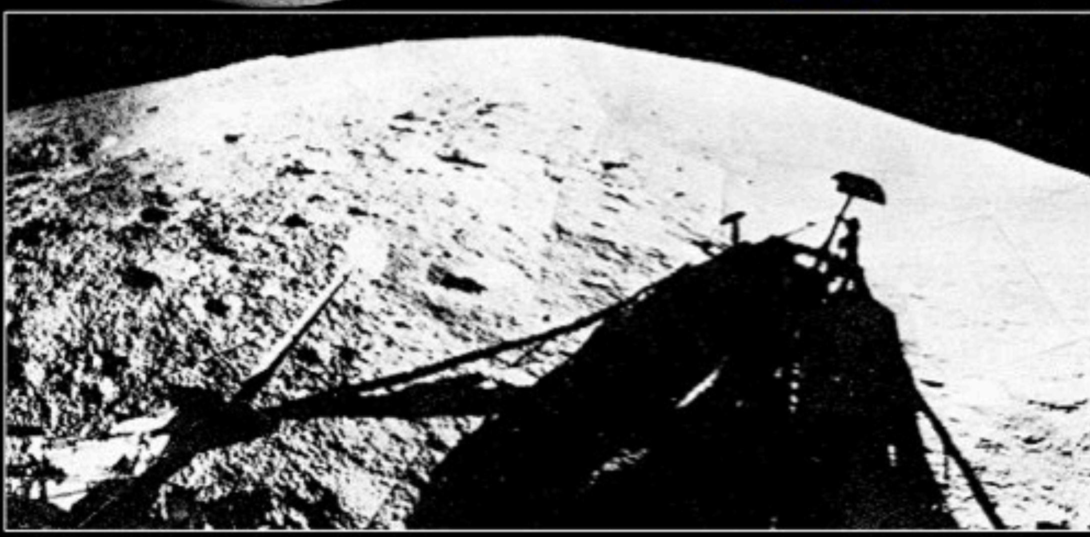




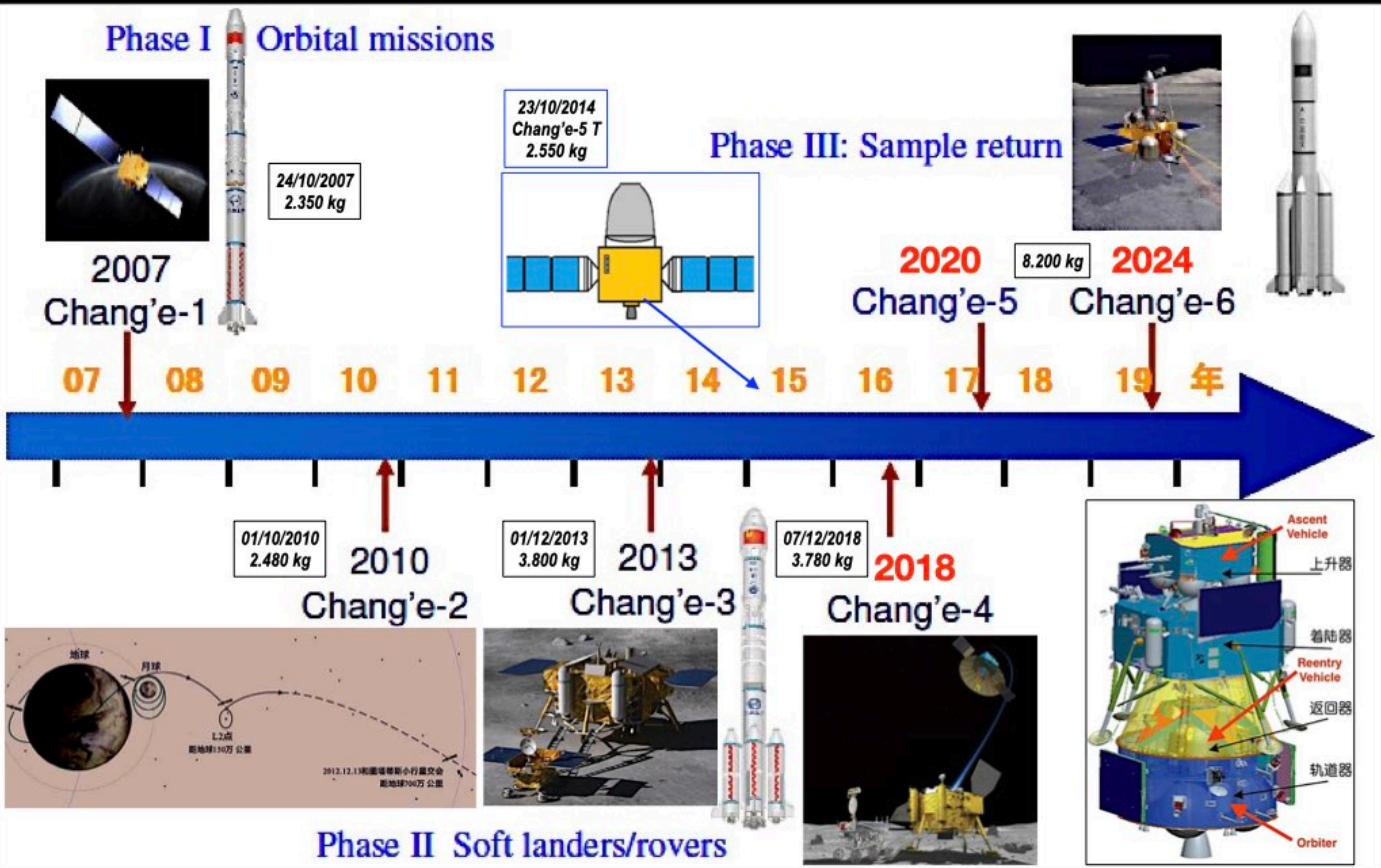
S#1: 02/06/66
S#2: Failed
S#3: 20/04/67
S#4: Failed
S#5: 11/09/67
S#6: 10/11/67
S#7: 10/01/68

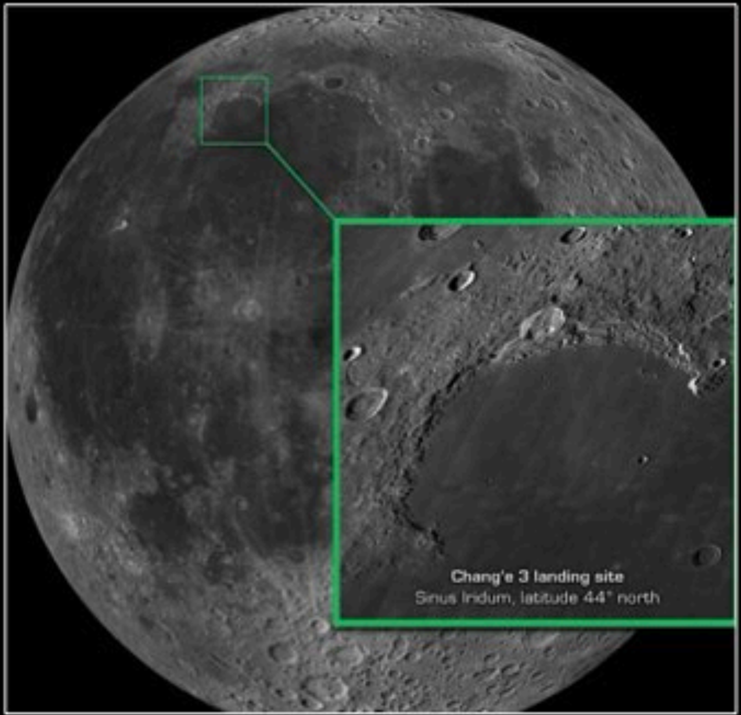
	Surveyor Landing (Nominal)	Actual values
1	Retro **Thrust** (average) kg	4175
2	Retro Burning Time, sec	38.9
3	Vernier **Thrust Levels**	
4	- Retro Phase, kg	90
5	- Retro Case Separation Phase, kg	125
6	- Low-Acceleration Descent, kg	45
7	- High-Acceleration Descent, kg	125
8	- Landing Maneuver, kg	45
9	Vernier Engine Burning Time, sec	165
10	Vernier Propellant Usage, kg	54

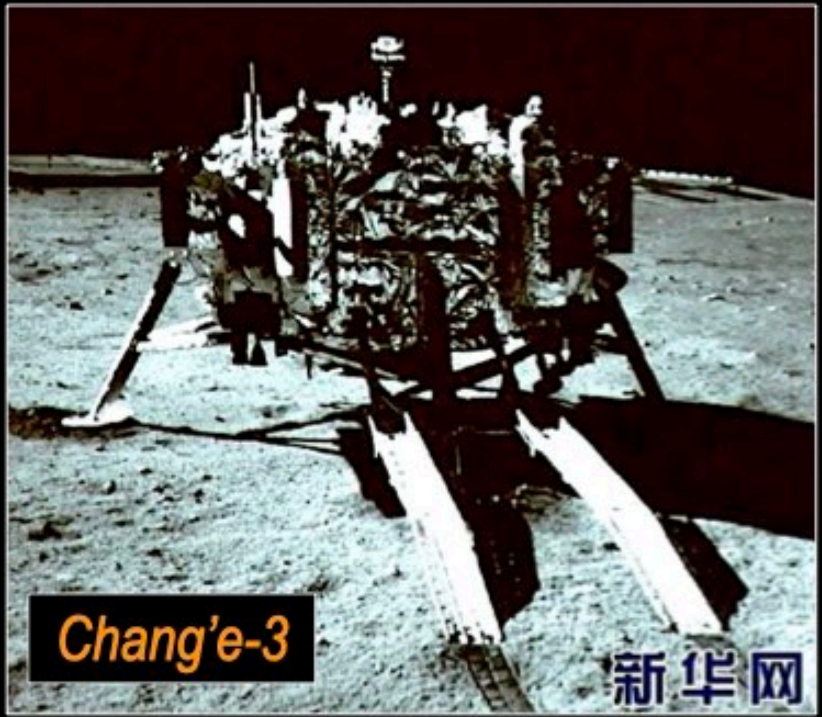


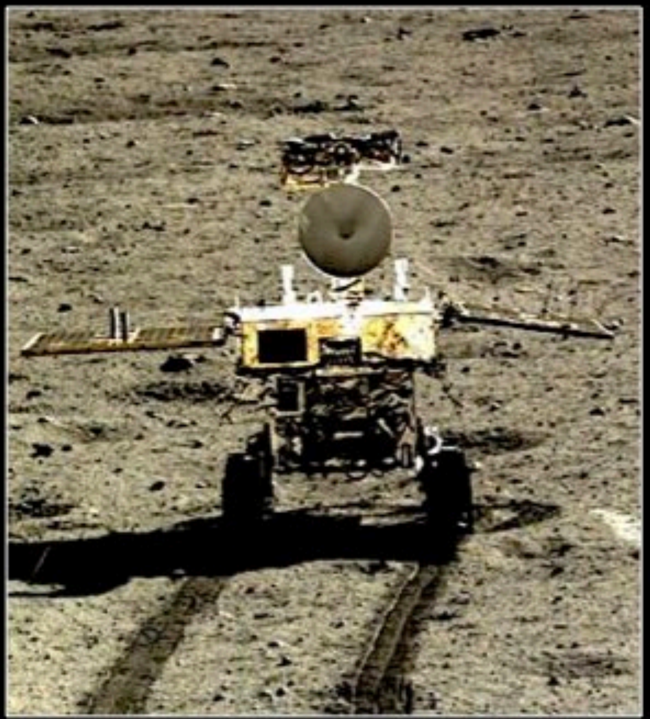


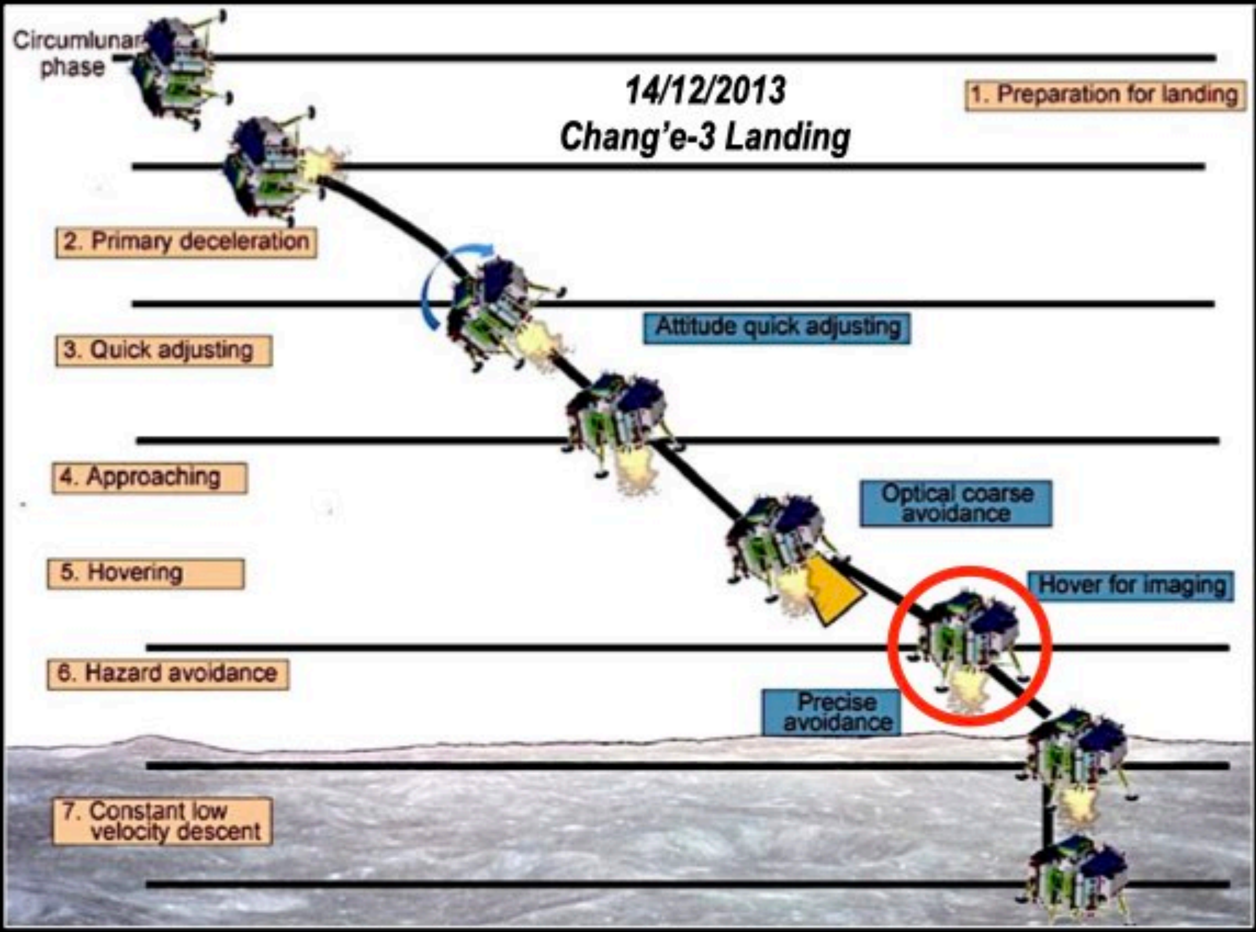
China Lunar Exploration Programme: Chang'e Missions

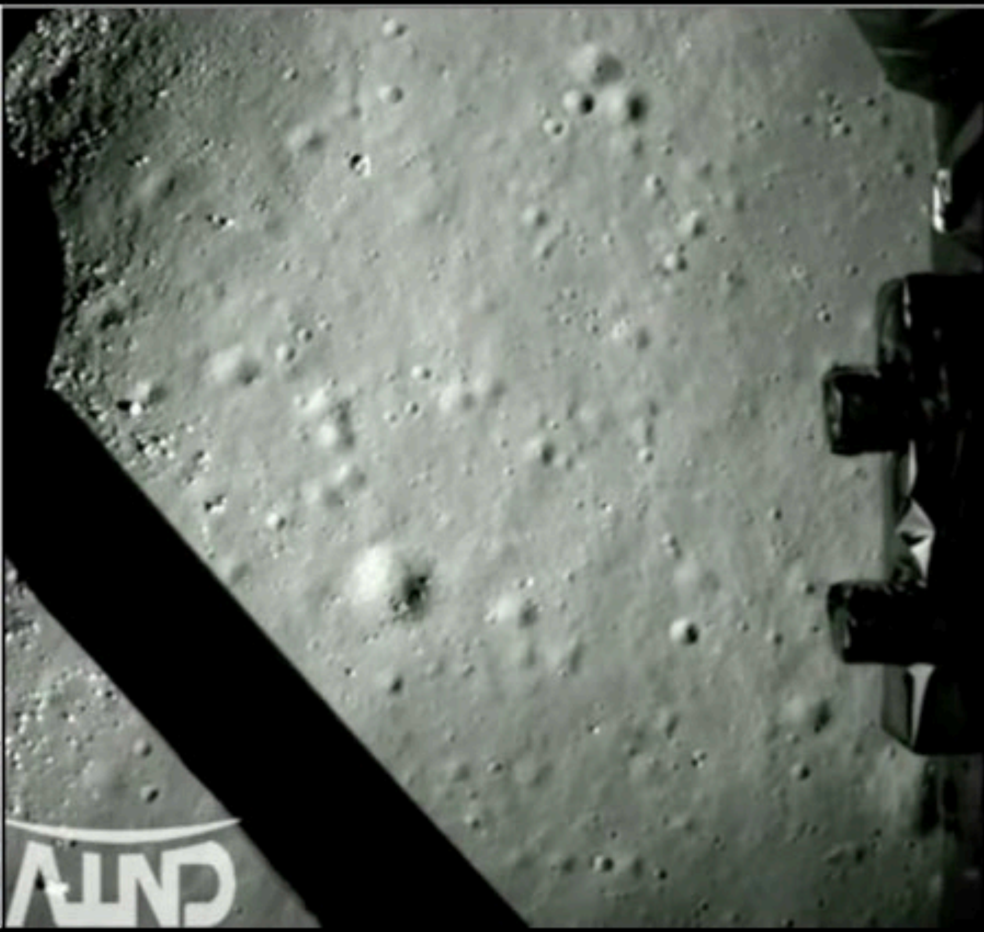



Chang'e 3 landing site
Sinus Iridum, latitude 44° north

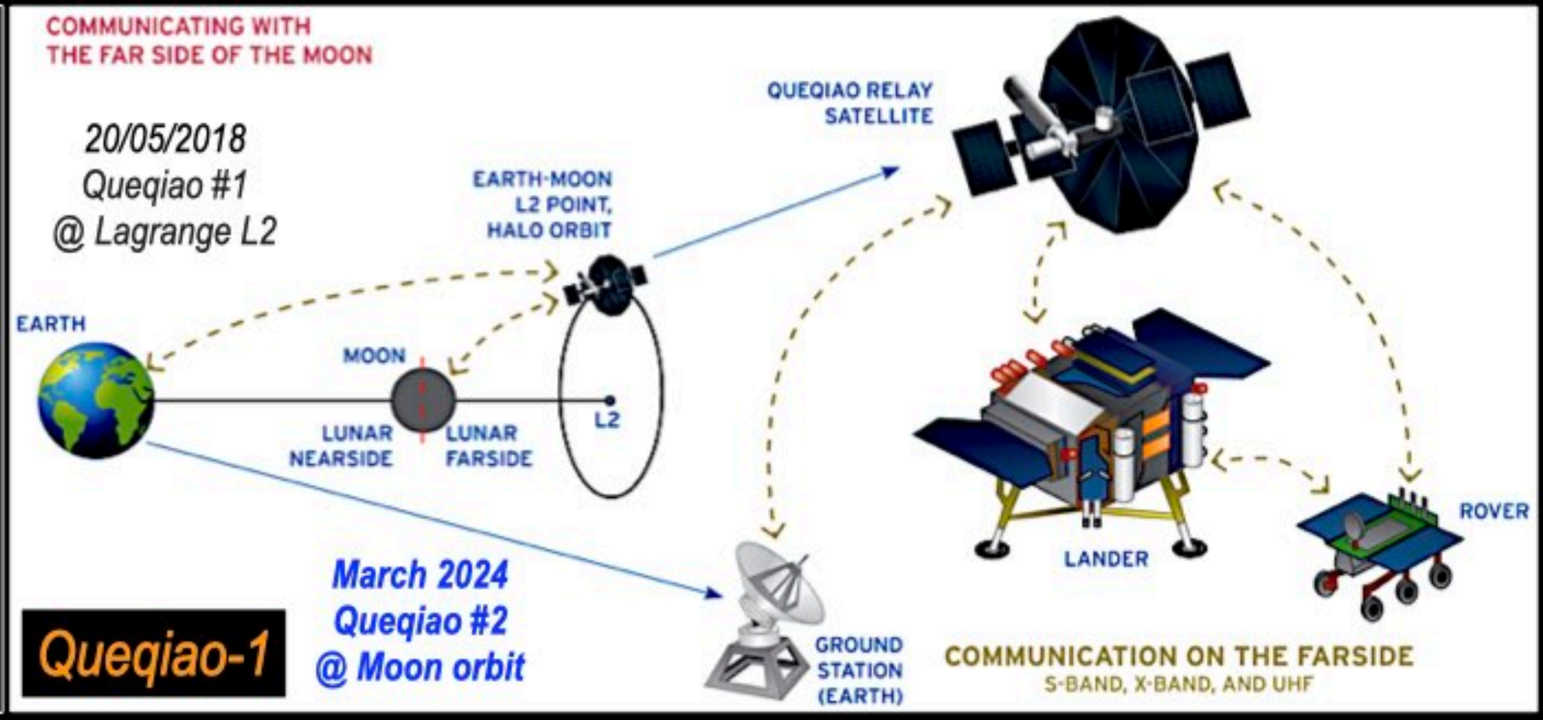

Chang'e-3
新华网

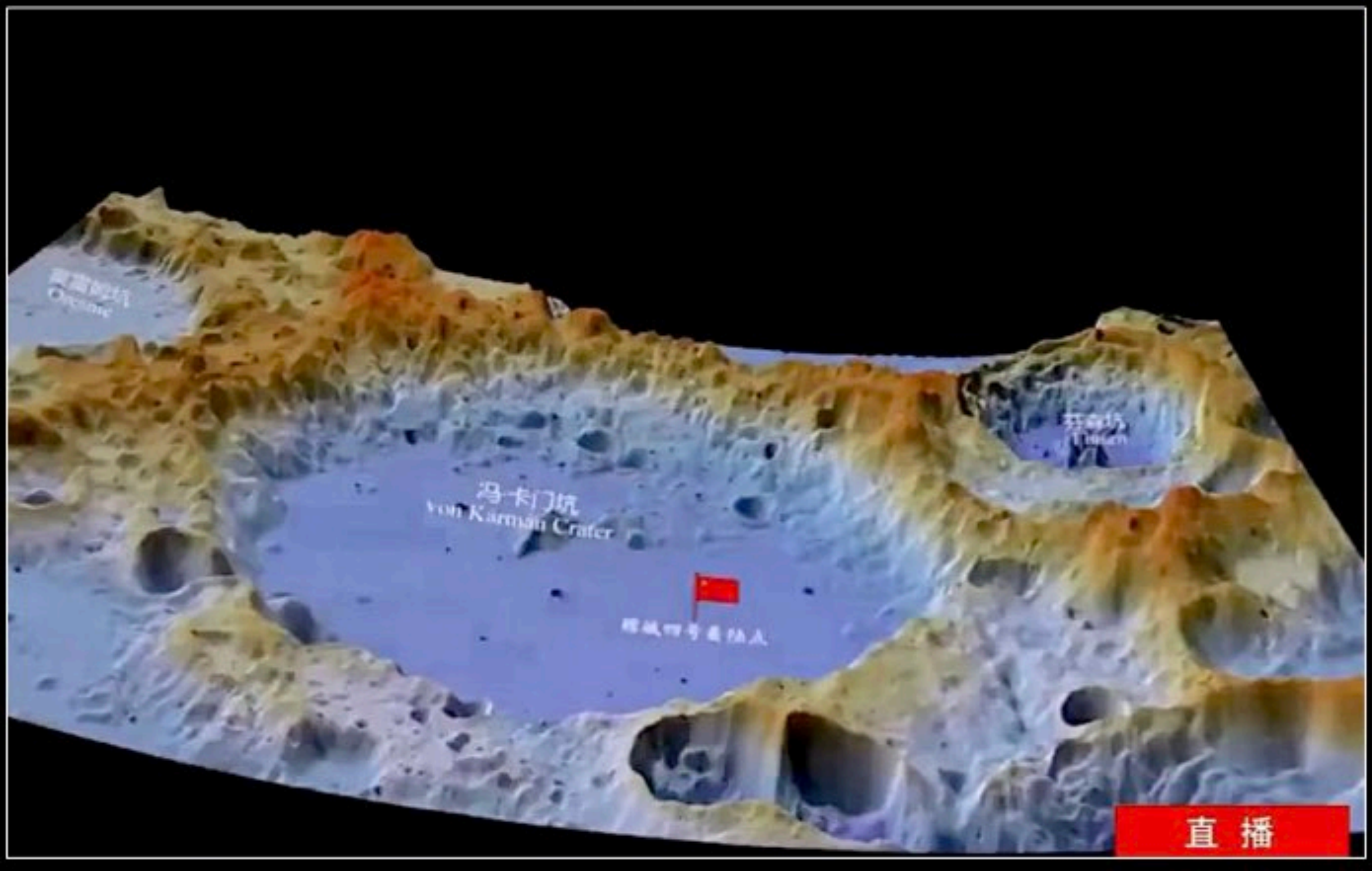



Circumlunar phase
14/12/2013
Chang'e-3 Landing
1. Preparation for landing
2. Primary deceleration
3. Quick adjusting
Attitude quick adjusting
4. Approaching
Optical coarse avoidance
5. Hovering
Hover for imaging
6. Hazard avoidance
Precise avoidance
7. Constant low velocity descent

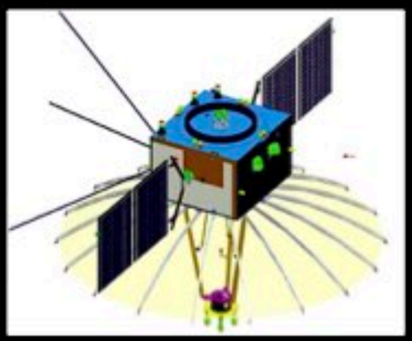


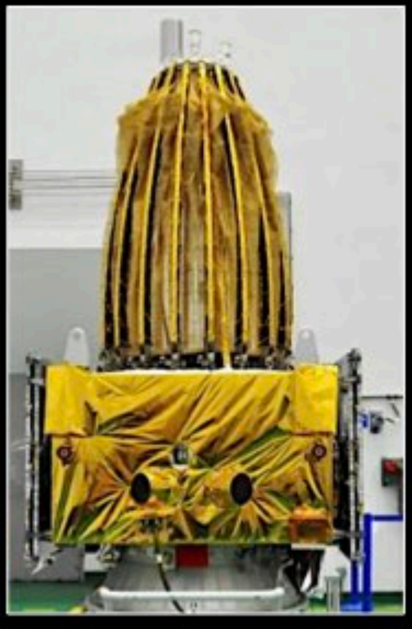

Von Kármán
crater

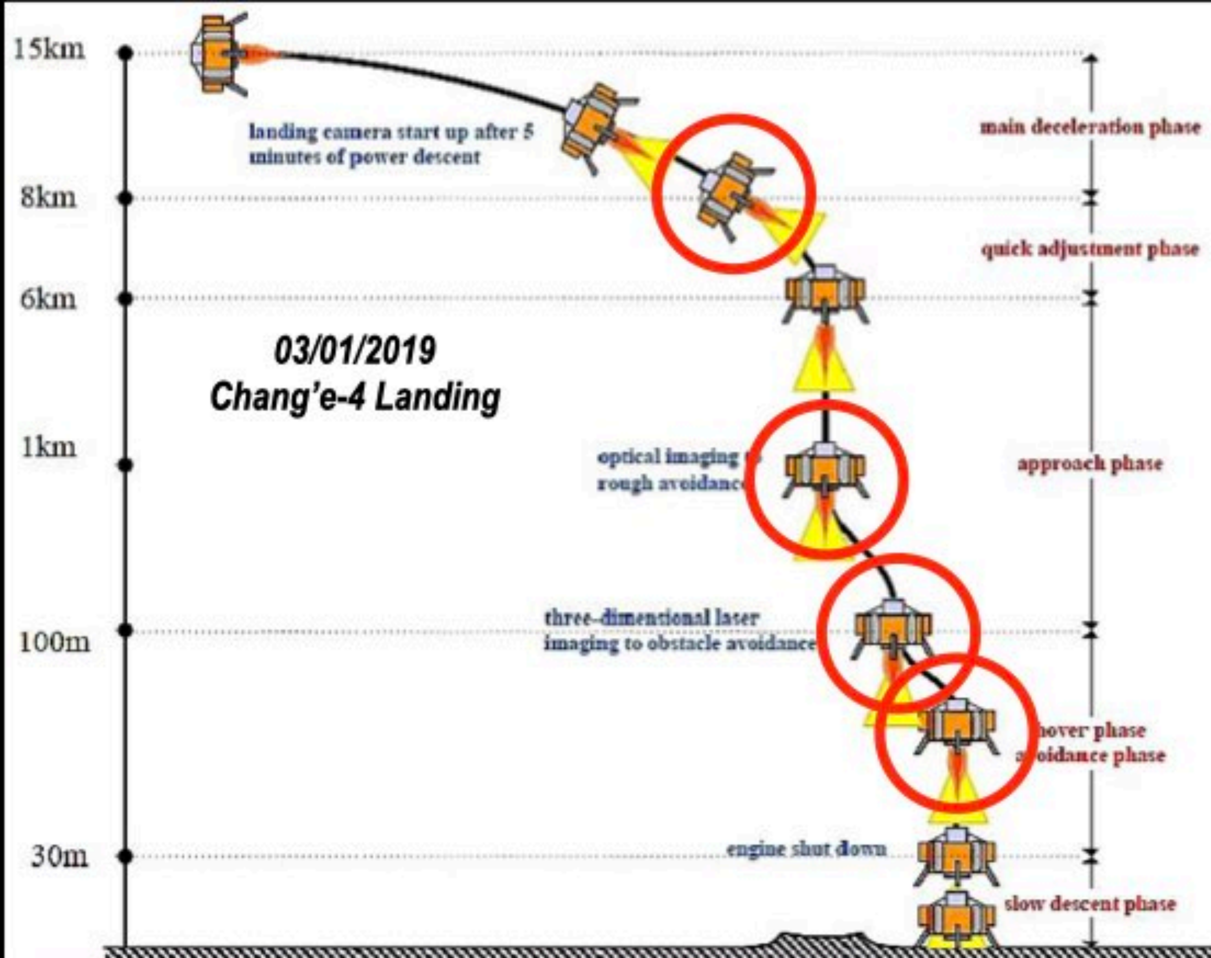

COMMUNICATING WITH
THE FAR SIDE OF THE MOON
20/05/2018
Queqiao #1
@ Lagrange L2
QUEQIAO RELAY
SATELLITE
EARTH-MOON
L2 POINT,
HALO ORBIT
EARTH
MOON
LUNAR
NEARSIDE
LUNAR
FARSIDE
L2
LANDER
ROVER
March 2024
Queqiao #2
@ Moon orbit
Queqiao-1
GROUND
STATION
(EARTH)
COMMUNICATION ON THE FARSIDE
S-BAND, X-BAND, AND UHF

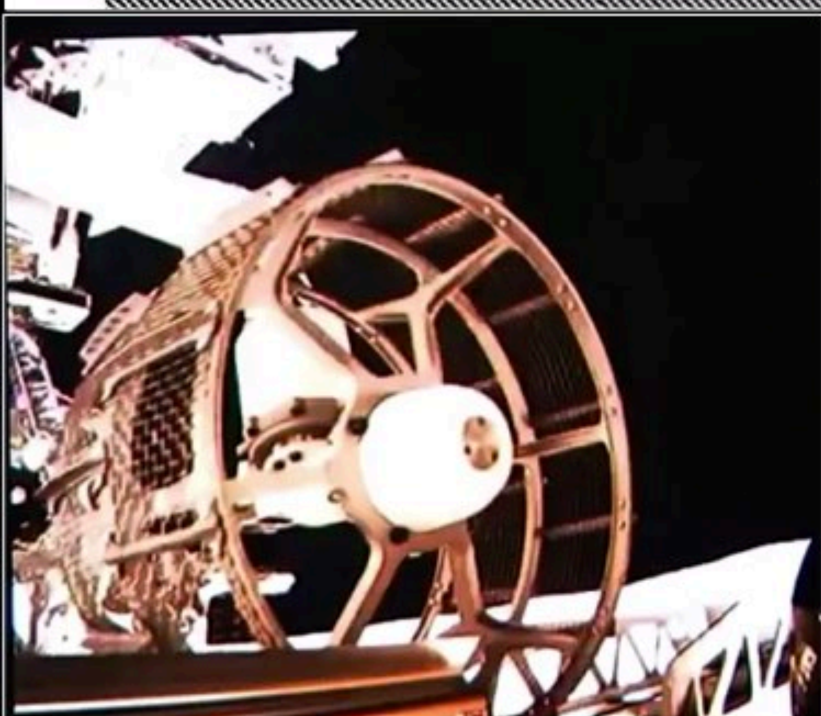

冯卡门坑
von Karman Crater
直播


LM-4C

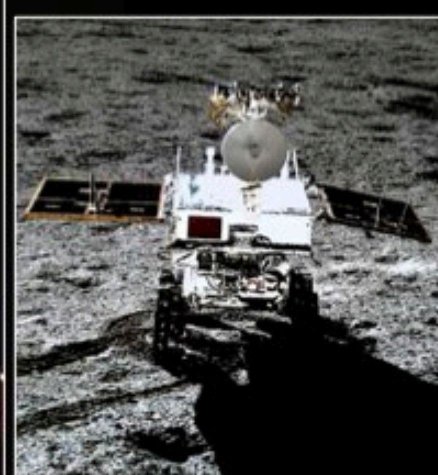


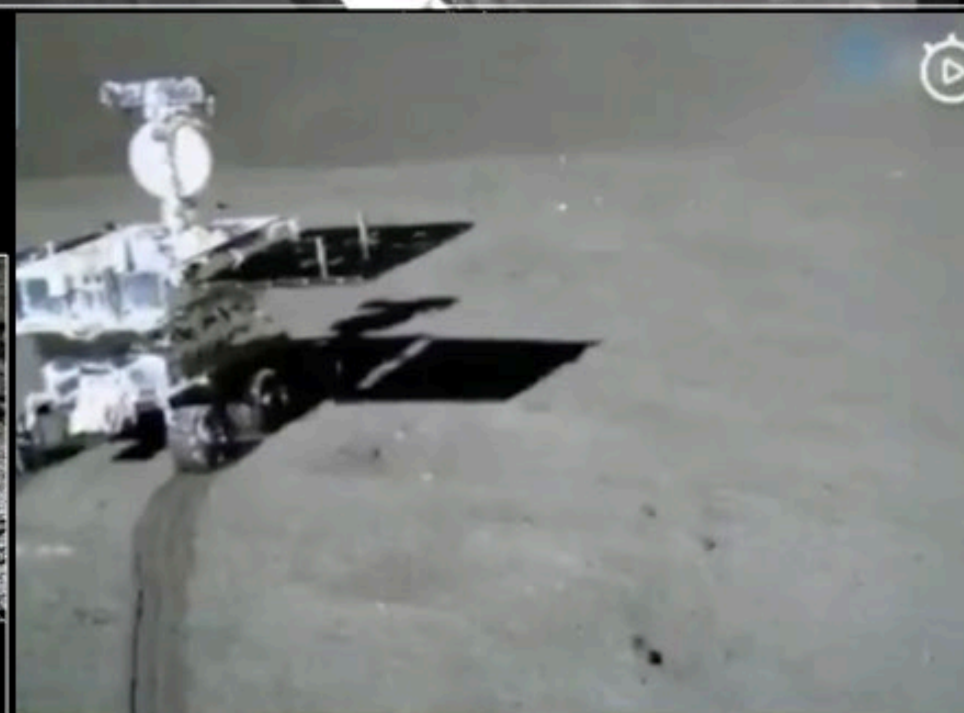


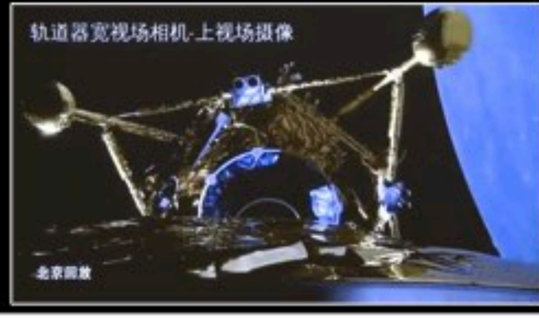


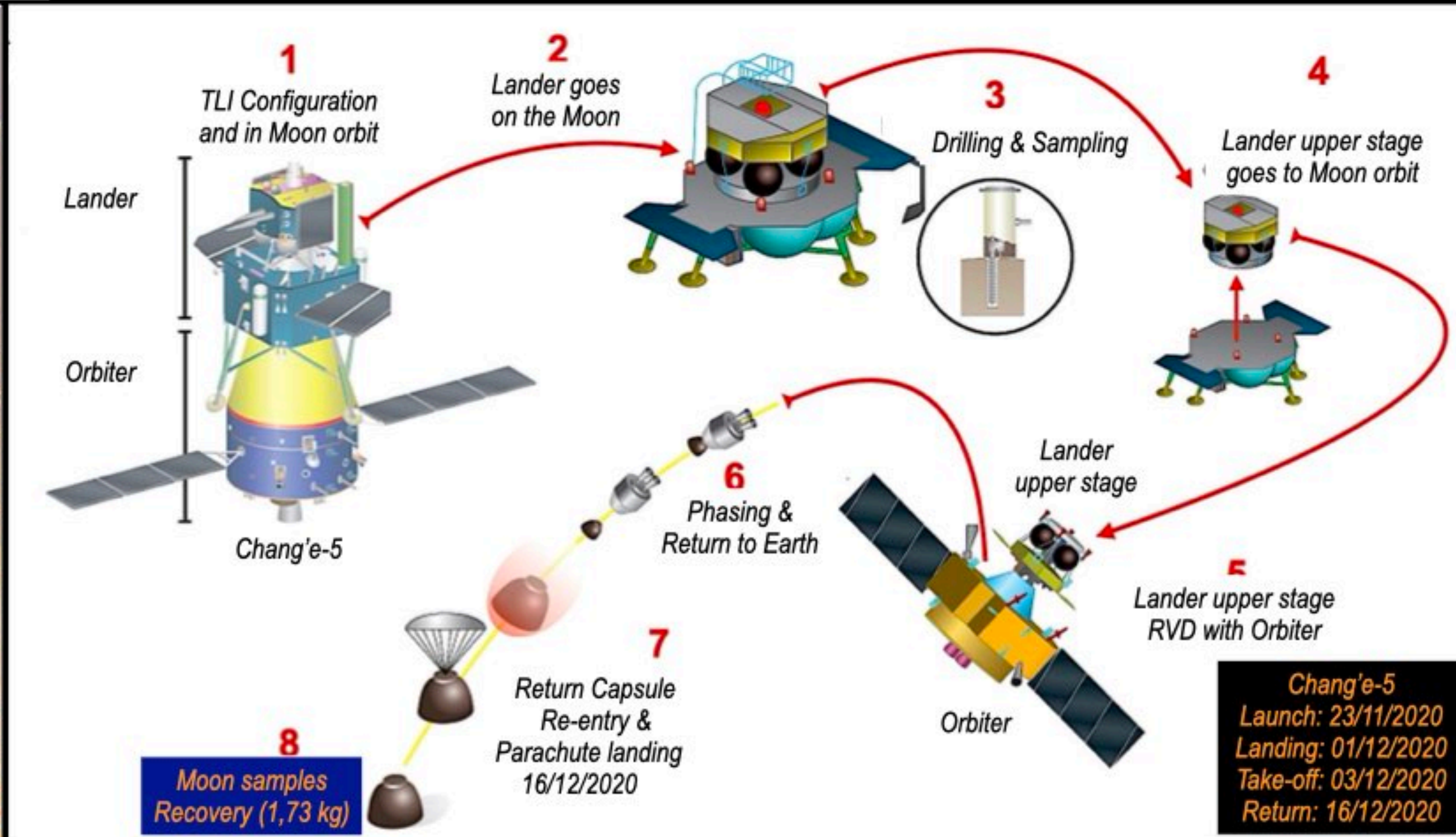


Chang'e-4 & Yutu-2
Launch: 08/12/2018
Landing: 03/01/2019

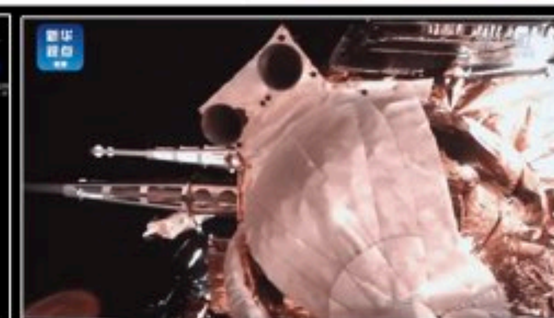





轨道器宽视场相机-上视场摄像

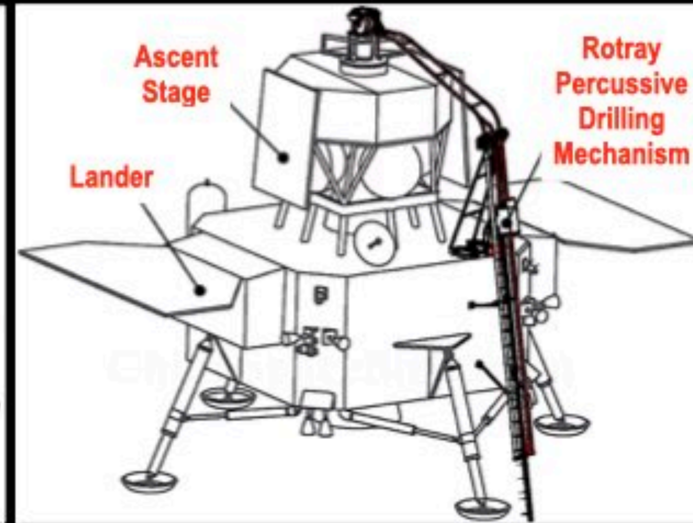

1
TLI Configuration
and in Moon orbit
Lander
Orbiter
Chang'e-5
2
Lander goes
on the Moon
3
Drilling & Sampling
4
Lander upper stage
goes to Moon orbit
Lander
upper stage
5
Lander upper stage
RVD with Orbiter
Orbiter
6
Phasing &
Return to Earth
7
Return Capsule
Re-entry &
Parachute landing
16/12/2020
8
Moon samples
Recovery (1,73 kg)
Chang'e-5
Launch: 23/11/2020
Landing: 01/12/2020
Take-off: 03/12/2020
Return: 16/12/2020

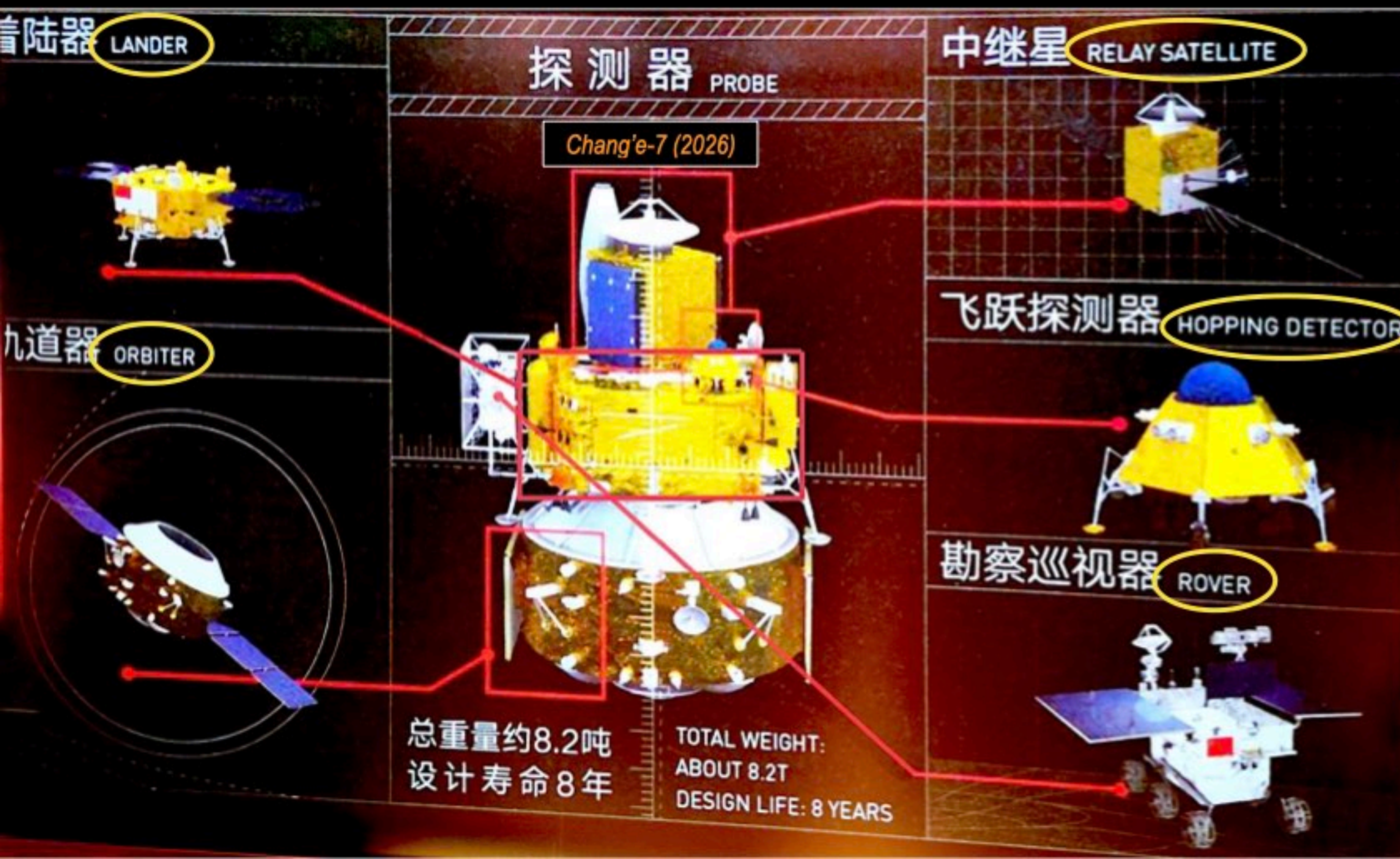

双谱段监视相机-可见光

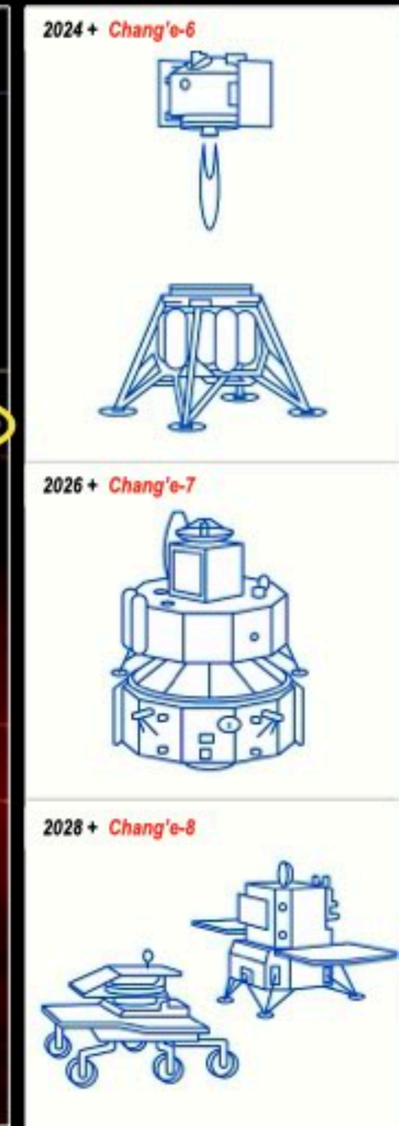


Chang'E-6 (03.05.2024)
(E-5 twin)
Far side on South pole
Launcher: LM-5;
S/C Mass: 8.2 T

Return: 25.06.2024
Sample Mass: 1.935 Kg
Drilling Depth: 1 m % 2
Capsule: 325 Kg





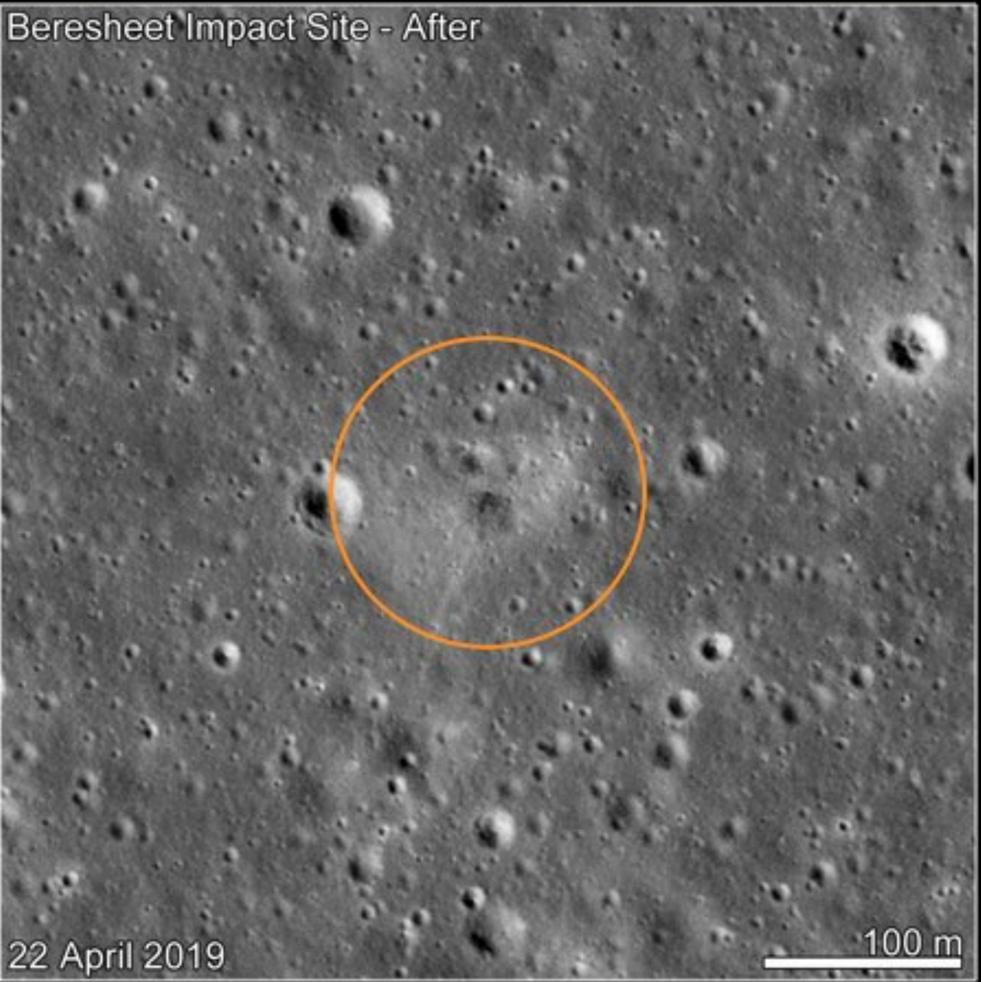


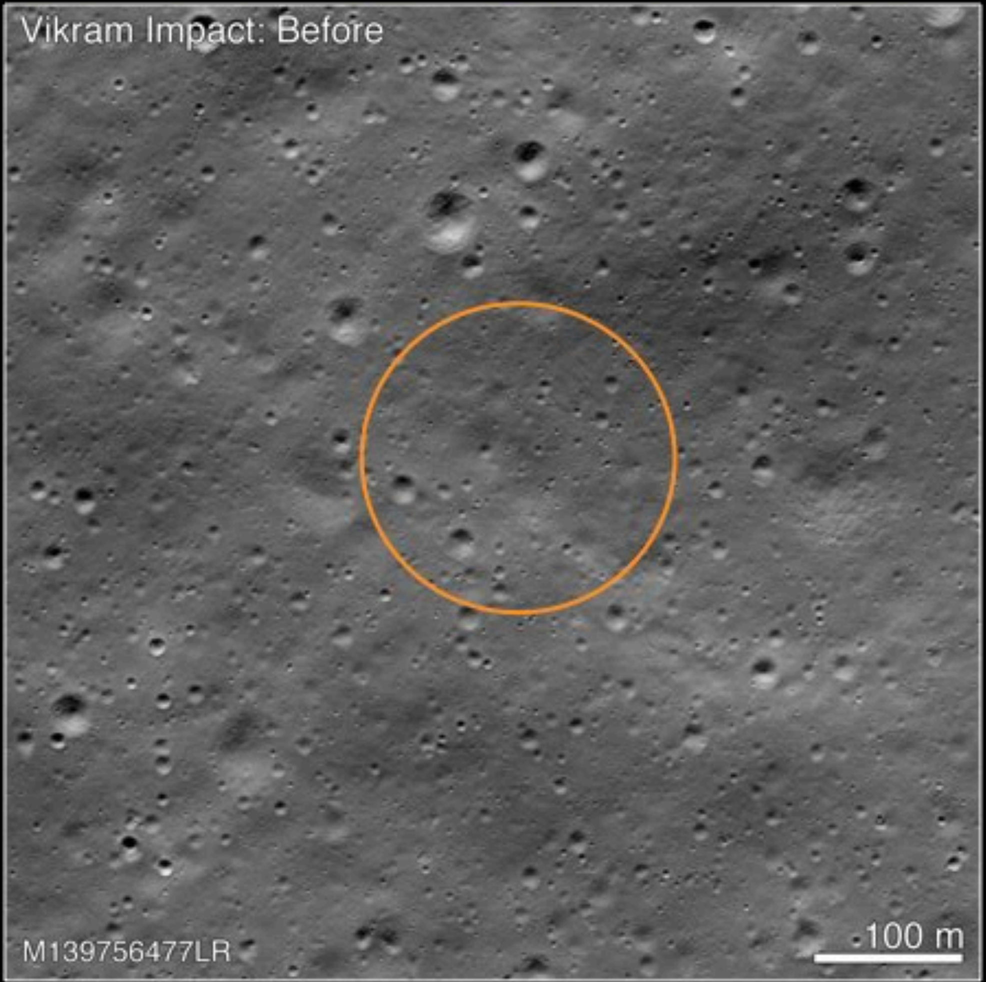
Beresheet

Launch: 22/02/2019
Landing: 11/04/2019

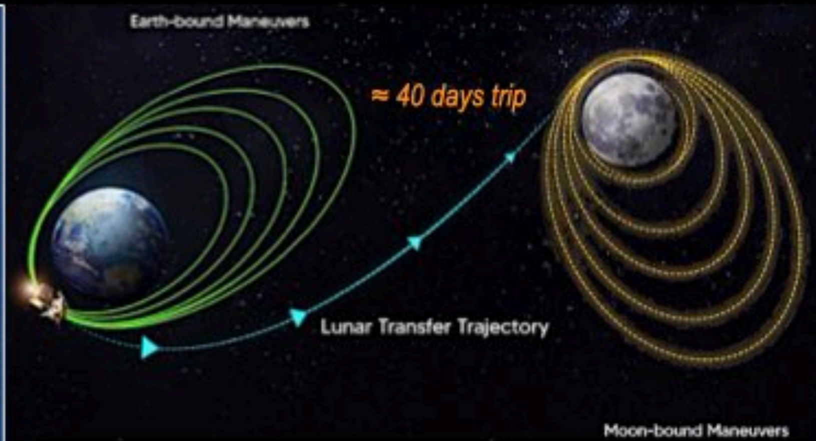
Chandrayaan-2

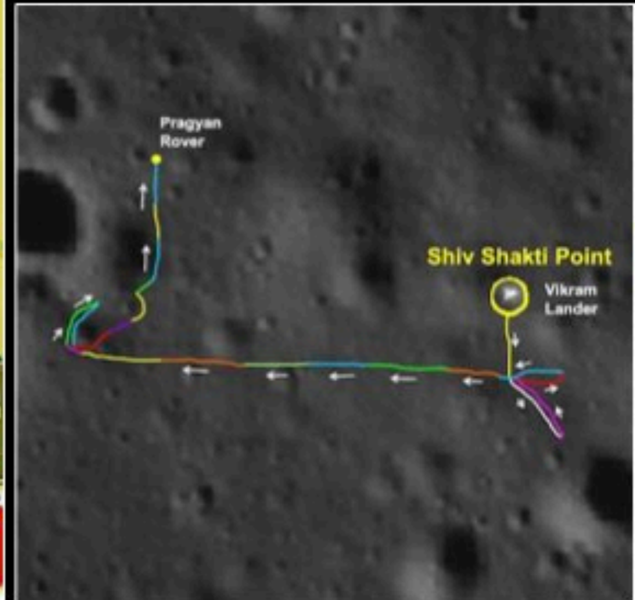
Launch: 22/07/2019
Landing: 07/09/2019





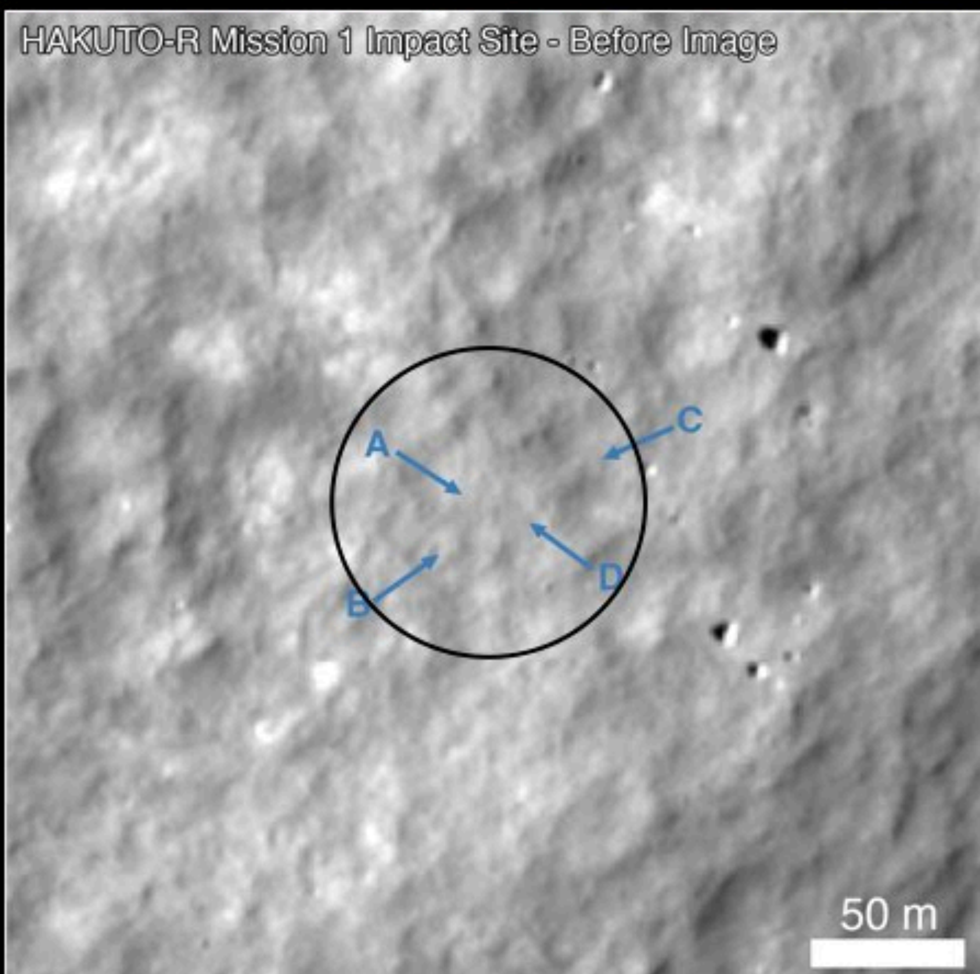
Chandrayaan-3 Lander & Rover Mission: to survive 1 Lunar day





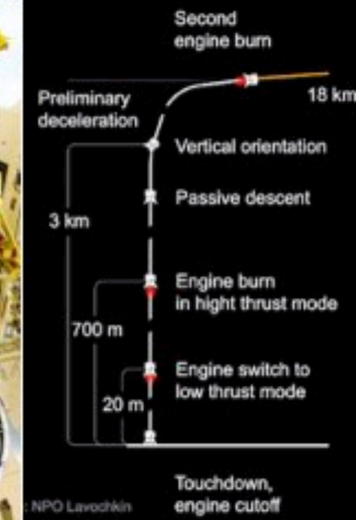
Hakuto-R

Launch: 11/12/2022
Landing: 25/04/2023



Luna-25

Launch: 11/08/2023
Landing: 19/08/2023

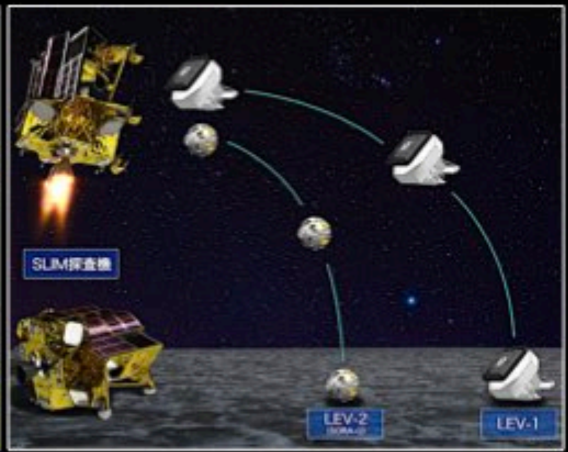


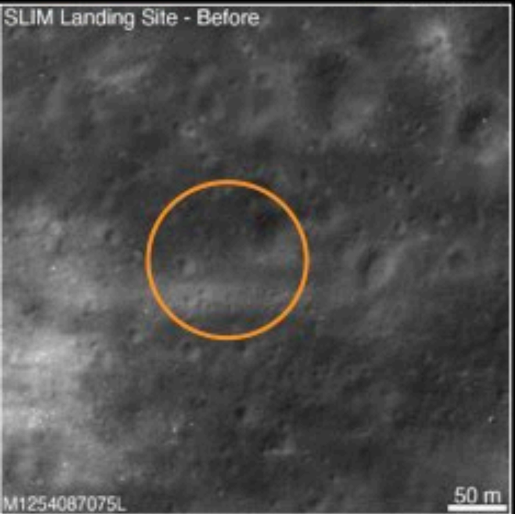
SLIM

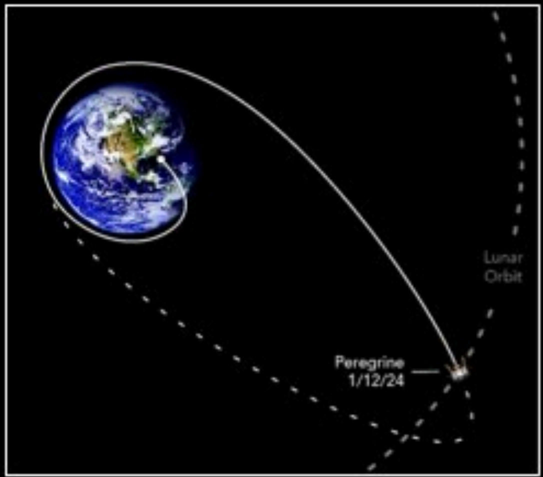
Launch: 06/09/2023
Landing: 19/01/2024

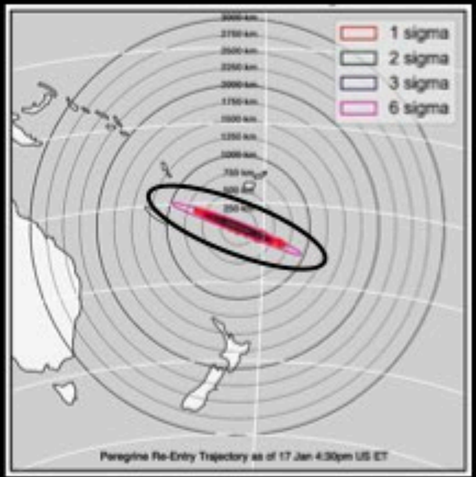
Peregrine M-1

Launch: 08/01/2024
Burning: 18/01/2024



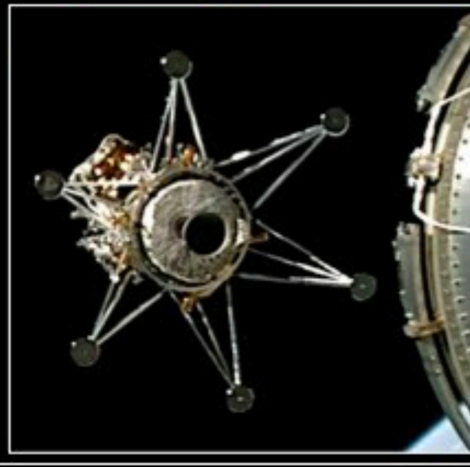


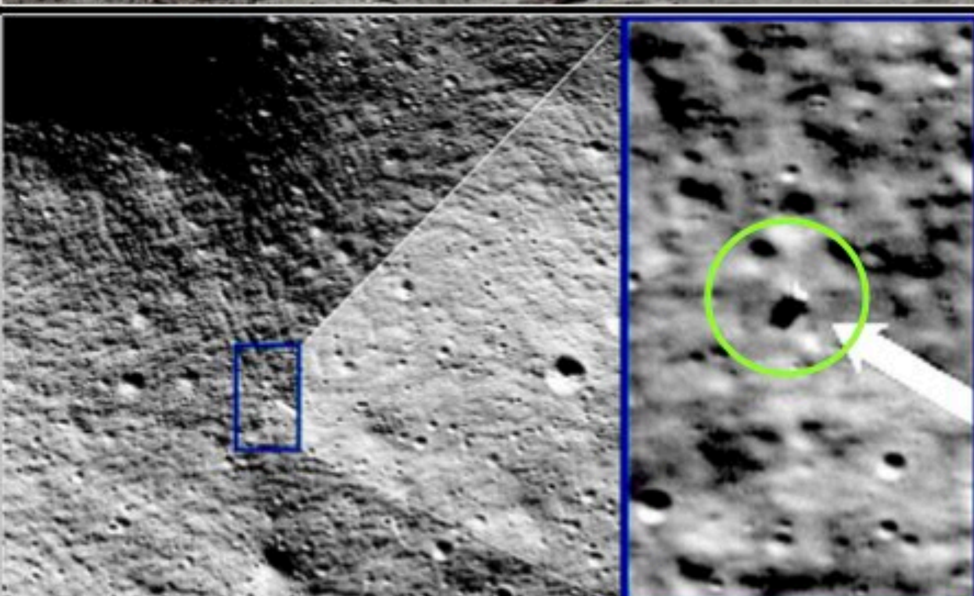




Intuitive Machine NOVA-C

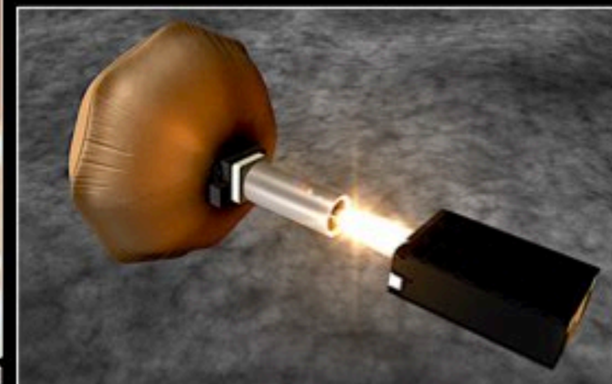
Launch: 15/02/2024
Landing: 22/02/2024

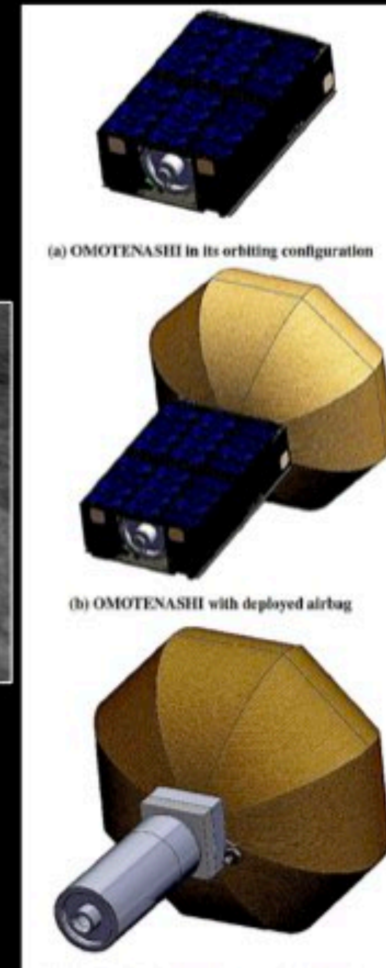




OMOTENASHI CubeSat

Launch: 16/11/2022
Missed the Moon

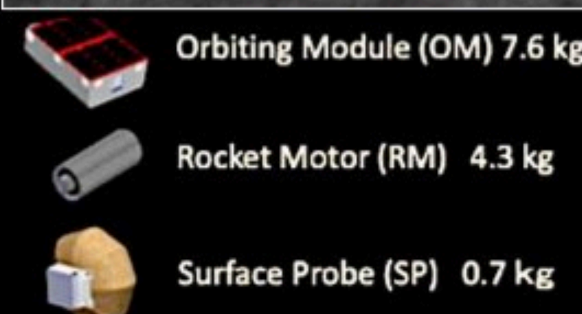


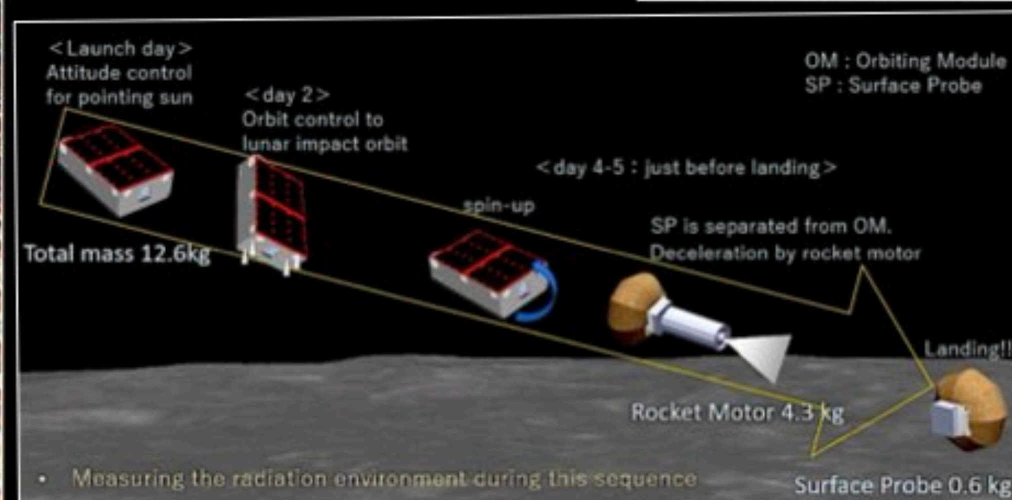


(a) OMOTENASHI in its orbiting configuration

(b) OMOTENASHI with deployed airbag

(c) OMOTENASHI after orbiting module detachment

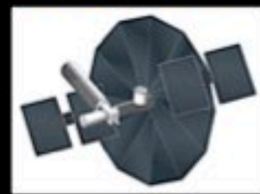




Last 15 years Lunar Exploration Missions

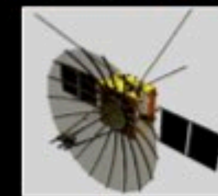
01/12/2013
Chang'e-3 & Yutu-1
3.800 kg

25/05/2018
Queqiao #1
@ Lagrange L2



23/11/2020
Chang'e-5
8.250 kg (sample return)

24/03/2024
Queqiao #2
300 x 8.600 km @ 54.8°



23/10/2014
Chang'e-5 T
2.550 kg (800 kg)

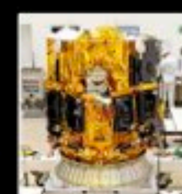
08/12/2018
Chang'e-4 & Yutu-2 Far side
3.800 kg

03/05/2024
Chang'e-6 Far Side
8.250 kg (sample return)

2013 → 2016 → 2019 → 2022 → 2025 →

22/02/2019
Beresheet
585 kg
R.W.. & Engine
Failure

11/12/2022
Hakuto-R
1.000 kg
GNC & Software
Failure

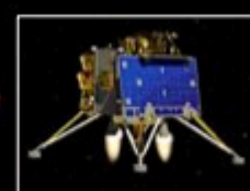


06/09/2023
SLIM
730 kg
Engine
Malfunction

15/01/2025
Firefly Blue & Hakuto-R
Ghost 1.9 T 0.34 T

22/07/2019
Chandrayaan-2
3.850 kg
GNC & Software
Failure

14/07/2023
Chandrayaan-3
3.900 kg



08/01/2024
Peregrine
1.283 kg
Propellant
Leak

26/02/2025
Intuitive
Machine
1.900 kg

11/08/2023
Luna-Glob #25
1.750 kg
GNC & Software
Failure

15/02/2024
Intuitive
Machine
1.900 kg
GNC Failure

Build your Project Group (min: 4, max: 6 (7) people)
Project Groups to be fixed by 10/03/2025, the latest

Imagine Mission, Lander & Rover Concepts (broad approach, sketches)
Imagine funding possibilities based on sponsoring ideas
Outline & Describe 3 Missions' Concept (avoid too complex options)
Explain with: Sketches / Drawings / Pictures / No computation

Define & Weight Evaluation Criteria (trace team's thinking process)
Make System Trade-offs (team's brainstorming)
Repeat the loop to get leading solution

Select & Define THE Group Best Concept (team's selection)

Portable: +33 (0) 6 73 53 05 09 email: marc.toussaint@epfl.ch

Facing challenges, one can identify 3 types of behaviors

Those who lead with temerity, guts and risks.
They take the 1st steps, inspiring others to follow.

Those who need a leader to show the way.
They gain confidence through examples.

Those who take time to assess, plan, re-think
and then adapt, before moving forward.

This is what you find in nearly all problem-solving teams.
Take advantage of culture & knowledge diversity to
strengthen your team and make it successful.