Beyond Budgets

How Chandrayaan-3 Exemplifies Frugal Engineering

Group-2

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A Frugal Triumph in Lunar Exploration

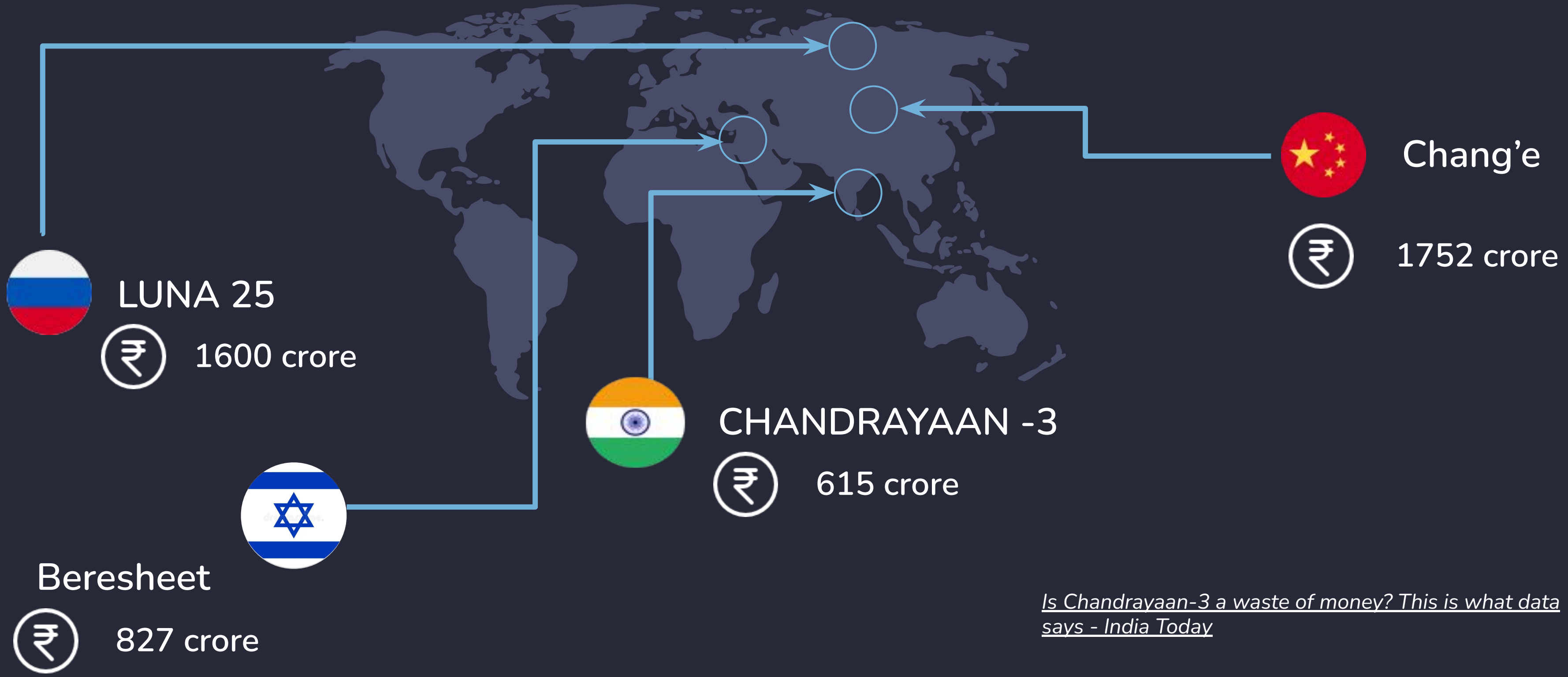
1. India became the **1st** country to land on south pole of moon

3.With **615 cr INR** budget it was one of the most frugal space missions

2. 4th country in world to land on moon surface successfully

4.Mission: To demonstrate safe landing and explore lunar composition

Chandrayaan-3 vs Global Lunar mission’s budget



[Is Chandrayaan-3 a waste of money? This is what data says - India Today]

A Longer Journey, Smart Fuel Savings

Trans-Lunar Injection

- It involves firing a spacecraft's propulsion system to accelerate it out of Earth's orbit and onto a trajectory that will take it to the Moon

- During TLI, the spacecraft's engines are fired at a specific point in its Earth orbit to increase its velocity and escape Earth's gravitational influence.

Hohmann Transfer

- The Hohmann transfer involves two main engine burns, one to increase the spacecraft's velocity at its initial orbit, and another to decrease its velocity at the destination orbit

- highly efficient as it takes advantage of the conservation of orbital energy

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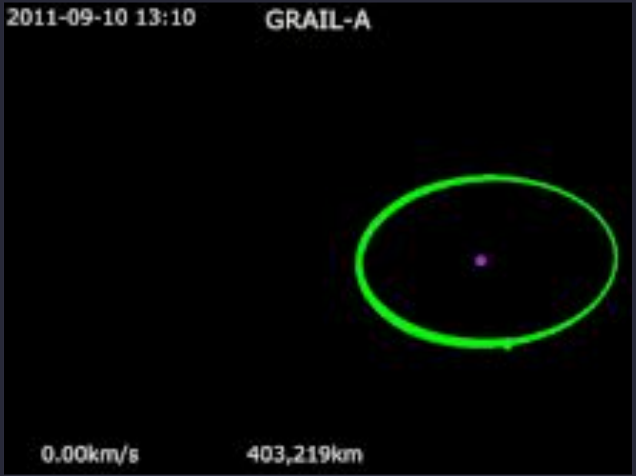
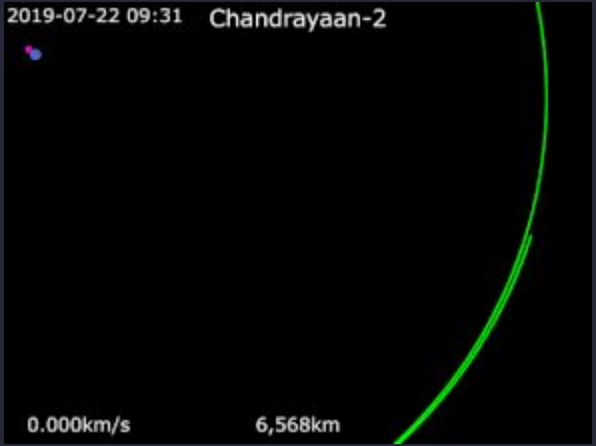


Trans-lunar injection



Hohmann Transfer

Walter Hohmann** was a German engineer who made an important contribution to the understanding of orbital dynamics. Hohmann demonstrated a **fuel-efficient path** to move a spacecraft between two different orbits, now called a **Hohmann transfer orbit.

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Other lunar mission

1. Used powerful launch vehicle like Soyuz-FG(Luna 25)with more fuel carrying capacity

   a. thrust (in vacuum):
      i. 1st stage: 4964 kN
      ii. 2nd stage: 997 kN
      iii. 3rd stage: 298 kN
      iv. 4th stage: (Fregat) 19.6 kN

   b. Payload to LEO : 5500kg

   c. Payload to GTO : 3060 kg

   d. liftoff weight: 304 tonnes

   e. (of which) propellant weight: 279.5 tonnes

   f. Propellant: LOX/RG-1

Chandrayaan-3

1. Used less powerful launch vehicle LVM3-M4 rocket (less fuel carrying capacity)

   a. thrust (in vacuum):
      i. 1st stage: 5150 kN
      ii. 2nd stage: 1598 kN
      iii. 3rd stage: 186.36 kN

   b. Payload to GTO: 4,000 kg

   c. Payload to LEO (Low Earth Orbit) : 8,000 kg

   d. Lift off mass: 640 tonnes

   e. Propellant: UDMH + H2O 115 tonnes +205 tonnes of HTPB+28 tonnes of LOX + LH2

Source : https://www.isro.gov.in/, https://www.nasa.gov/

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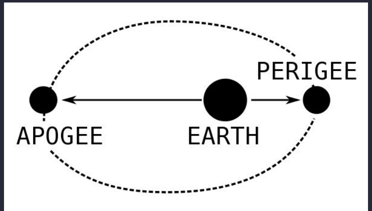
2. In this injection process we have power consumption ON throughout journey

3. This approach requires 4-5 days (Apollo 11: 4 days, LUNA 25: 5 days)

2. Engine firings at perigee for higher, elongated orbits, creating outward spiral with momentum gain



3. This approach requires around 41 days

We make a trade-off with lunar travel time by employing the Gravity Assist method, which results in substantial fuel savings and a significant reduction in overall mission costs.

Note:

Cost-Effective Launch Vehicles

LVM3-M4 vs LVM3-M1

- Shared components to save on development

Use of Vikas Engines

- Vikas engines used in multiple stages, reducing new development costs (explain the 3 stage launching process, and how it's cost effective)
- Proven reliability minimizes mission risk and expense

Cryogenic Upper Stage (CUS) Engine Efficiency

- CUS engine more efficient than previous solid rocket motors(comparative data add krdo..number data acha hoga)
- Less fuel needed, reducing overall mission costs

Launch Vehicle(LVM3-M4/GSLV MK-III)

Solid Rocket Boosters: S200

- LVM3 I use two S200 solid rocket boosters to provide the huge amount of thrust required for lift-off.
- The S200 was developed at Vikram Sarabhai Space Centre.
- Booster Height: 25 m
- Booster Diameter : 3.2 m
- Fuel: 205 tonnes of HTPB (nominal)

Core Stage: L110 Liquid Stage

- The L110 liquid stage is powered by two Vikas engines designed and developed at the Liquid Propulsion Systems Centre.
- Stage Height: 21 m
- Stage Diameter: 4 m
- Engine : 2 x Vikas
- Fuel: 115 tonnes of UDMH + H2O

Cryogenic Upper Stage: C25

- Engine: CE-20
- Designed and developed by the Liquid Propulsion Systems Centre
- Fuel : 28 tonnes of LOX + LH2

Source: Isro.gov.in

Comparison between the Launch vehicle of Chandrayaan-2 &3

Characteristic	LVM3-M4	LVM3-M1
Liftoff mass	640 tonnes	620 tonnes
Overall length	43.5 meters	43.0 meters
Payload fairing diameter	5 meters	5 meters
Maximum payload to LEO	8 tonnes	6 tonnes
Maximum payload to GTO	4 tonnes	3.5 tonnes
Solid rocket boosters	HTPB-SL propellant	HTPB-HC propellant
Cryogenic upper stage	CE-20 engine	L110 engine
Human-rated features	Yes	No
Cost	₹630 crores	₹500 crores
Frugality (cost savings)	20%	

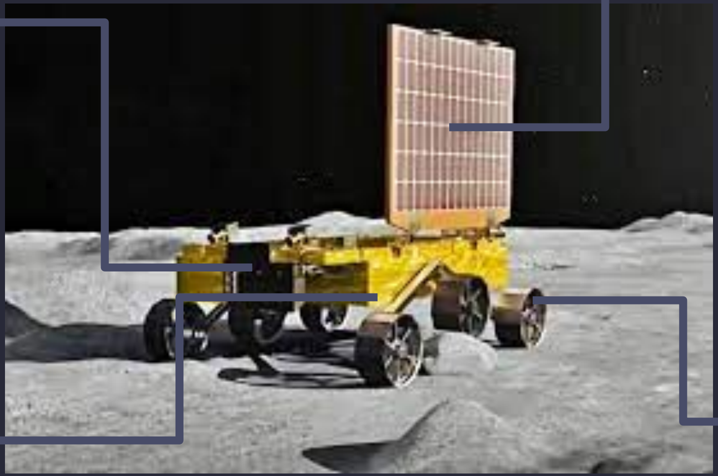
Comparison between liquid fuel used in Chandrayaan 3 &2

Characteristic	HTPB-SL	HTPB-HC
Propellant	Hydroxyl-terminated polybutadiene (HTPB) + solid oxidizer	Hydroxyl-terminated polybutadiene (HTPB) + different solid oxidizer
Efficiency	More efficient	Less efficient
Shelf life	Longer shelf life	Shorter shelf life
Reliability	More reliable	Less reliable
Safety	Safer	Less safe

Comparison of 3rd phase launcher of Chandrayaan 2 &3

Characteristic	CE-20	Previous engine
Thrust	200 kN	180 kN
Specific impulse	450 seconds	420 seconds
Cycle	Gas-generator	Staged combustion
Engine mass	2.5 tonnes	3.0 tonnes
Overall length	3.5 metres	4.0 metres

Frugal design of Pragyan



<u>Frugal Design Overview:</u>
They've designed it to function for **14** days, as the lunar night brings extreme conditions, without over engineering for prolonged survival

<u>Earth-Controlled Navigation</u>:
Navigation is mostly controlled from Earth, reducing the need for advanced onboard sensors

<u>Minimal Power Needs:</u>
Low power consumption (**50W**) due to its slow speed (**0.036 km/hr**) and solar panel reliance.

<u>Compact and Lightweight:</u>
Small size (**26** kg), reduces the need for heavy materials and lowers launch costs

ROVER

Rover payloads of Luna 17 (Lunokhod 2)

Weight = 840 kg

Payload

1. Cameras (three television and four panoramic telephotometers)
2. RIFMA-M X-ray fluorescence spectrometer
3. X-ray telescope
4. PROP odometer/penetrometer
5. RV-2N-LS radiation detector
6. TL laser retroreflector
7. AF-3L UV/visible astrophotometer
8. SG-70A magnetometer
9. Rubin 1 photodetector

Source : https://en.wikipedia.org/wiki/Lunokhod_programme

Rover payloads of Chandrayaan 3

Weight = 26 kg

1. LASER Induced Breakdown Spectroscope (LIBS)
   - Qualitative and quantitative elemental analysis & To derive the chemical Composition and infer mineralogical composition to further our understanding of Lunar-surface.
2. Alpha Particle X-ray Spectrometer (APXS)
   - To determine the elemental composition (Mg, Al, Si, K, Ca,Ti, Fe) of Lunar soil and rocks around the lunar landing site.

Reduced Testing & Prototypes

Vibration & Acoustic Tests

Fewer Iterations

- Chandrayaan-3 benefited from previous missions' data, requiring fewer vibration and acoustic tests
- Saved both time and resources, expediting the mission timeline

EMI/EMC Test

One Comprehensive Test

- Electromagnetic interference (EMI) and electromagnetic compatibility (EMC) tests consolidated into one
- Streamlined process, reducing testing period and cost

Flight Acceptance Hot-Test

Single Iteration

- Only one hot test needed for flight acceptance due to reliable design and engineering
- Decreases the risk factor and speeds up the mission readiness

Indigenous Components: Empowering the Mission

Middle nozzle, bucket flange, flight umbilical plates
(In Recent year L&T has provided $5.4 million worth parts and in total it supplied $240 millon worth parts to ISRO)

Provided the Ground System Antenna, Vikas engine, Thrustors
(Till Date it has provided ISRO around 175 engine

High quality battery for Chandrayaan-3 (By supplying it's 100th battery to ISRO)

Continued...

Critical booster in launch vehicle (Walchandnagar has participated in all the 48 launching mission of ISRO from 1993

Provided mechanical hardware

- Chandrayaan 3 Embraced '**Make in India**.' Our use of indigenous components not only champions self-reliance but significantly lowers import costs, exemplifying frugality in space exploration.
- Currently around 400 private companies actively working in space sector which is a great success for ISRO

Indigenous Components contd..

- The Vikram lander's legs are made of indigenously developed carbon fiber composites. The cost of these composites is estimated to be around ₹10 lakh per kilogram. The lander has six legs, so the total cost of the legs is estimated to be around ₹60 lakh.
- The Pragyan rover's wheels are made of indigenously developed titanium alloy. The cost of this alloy is estimated to be around ₹2 lakh per kilogram. The rover has six wheels, so the total cost of the wheels is estimated to be around ₹12 lakh.
- The propulsion module's engines are made of indigenously developed solid propellants. The cost of these propellants is estimated to be around ₹5 lakh per kilogram. The propulsion module has four engines, so the total cost of the engines is estimated to be around ₹20 lakh.
- In total, the use of indigenous components in the Chandrayaan-3 mission is expected to save about ₹92 lakh (US$110,000). This is a significant saving, considering the total cost of the mission

Indian salary

Salary Differences in ISRO

- Scientists at ISRO earn approximately one-fifth the salary of their counterparts in the developed world.
- Low salaries contribute to the overall cost-effectiveness of ISRO's missions.

ISRO's Culture of Dedication

- Scientists at ISRO are driven by mission objectives rather than financial incentives.
- This culture fosters an environment where efficiency and frugality are key, contributing to cost-effective space missions.

"They are not really bothered about the money but are passionate and dedicated to their mission. That is how we achieved greater heights" - G. M. Nair

Salary Comparison

COUNTRY	AVERAGE ANNUAL SALARY (INR)
India	**15.4 L**
USA	76.20 L
UK	75.3 L
Australia	54.18 L
Canada	69.77 L
Germany	62.40 L
Japan	49.35 L

Chandrayaan-2 vs Chandrayaan-3

ASPECT	CHANDRAYAAN 2	CHANDRAYAAN 3
Mission Approach	Success based approach	**Failure based approach**
Cost (in cr)	978	**615**
orbiter/propulsion module + lander + rover cost (in cr)	603	205
Launching costs (in cr)	375	365
Scientific Payloads	8 in orbiter	1 in propulsion module
Travel Time to Moon (days)	48	41
Rover Dimensions (mxmxm)	0.9 x 0.75 x 0.8	0.9 x 0.75 x 0.4
Orbiter Power Generation Capability (in W) Lander Power Generation Capability (in W)	1000 650	758 738

Chandrayaan-2 vs Chandrayaan-3 contd...

ASPECT	CHANDRAYAAN 2	CHANDRAYAAN 3
Orbiter / Propulsion Module Dry Mass (kg)	682	448
Orbiter/Propulsion Module propellant mass (kg)	1697 kg	1696.39
Landing area	Targeted 500m x 500m area	Expanded 4km x 2.4km area
Lander Physical Structure	Central thruster, standard legs	No central thruster, reinforced legs, more solar panels, increase attitude control, increased data frequency and transmission
Lander onboard computers	1 onboard computer	2 onboard computer
Duration of operation of experimental payload in orbiter/PM	7 years	5 - 6 months
Lander dimensions(m * m * m)	2.54 × 2 × 1.2	2 x 2 x 1.17

Metrics of Frugality

01

Indigenous Component Savings

- ➔ Utilizing locally-sourced materials and technologies minimizes costs by 92 lakh INR.
- ➔ Reduces dependency on imports and licensing

02

Lower Hiring Costs

- ➔ Work culture attracts mission-focused talent.
- ➔ Lowers overall workforce expenses.

03

Reduced Number of Prototypes

- ➔ Optimizing testing reduces physical prototypes.
- ➔ Cuts costs and speeds up project timelines.

04

Reusability of Components

- ➔ ISRO emphasizes on designing components that can be reused in future missions.
- ➔ This not only saves material costs but also the time and resources that go into new developments.

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Thank You