How Was The Moon Formed?

(4.1 billion years ago)

Accretion

Collision + Accretion

Spawned
**Earth-Moon Orbit**

Orbital Period: 27-1/2 days

One side of Moon always faces Earth

There is no “Dark Side”

ALL SIDES are dark once a month

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**Fictional Lunar Voyages**

Lukian of Samosata, c. 160

A ship in a storm

Kepler, 1634

Carried by spirits

Godwin, 1638

Flying swans

Wilkins, 1638

Wings, springs, and gunpowder

Cyrano de Bergerac, 1656

Vials of morning dew and rockets

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**Early Russian Rocket Programs**

- Tsiolkovsky, Russian father of spaceflight
- Tsander, experimental rocket motors
- Kondratyuk, LOR, solar power, reentry
- Bolshevik governmental support of rocketry
  - Aerodynamics Institutes (1918, 1928)
  - Bureaus for Study of Rockets (1924, 1931)
- Technocracy, 5-Year Plans, Great Purge, Reign of Terror, Great Secrecy
  - Technologists imprisoned in Sharashkas (Gulag) or executed
  - Focus on short-range military rockets and airplanes
- Head start on ballistic missiles, nascent through WWII

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Chelomei

Glushko

Korolev
Early American Rocketry

- 1914-45: Goddard’s Papers, Patents, and Experiments
- US Army disinterested in Goddard’s research
- 1935: German and Russian agents obtain US Navy reports

Rocket clubs in 1930s

Robert Goddard (1882-1945)

Gyro Steering Control Vanes

Early German Rockets

1933
1934
1935
1938

1942
xx

A-1 A-2 A-3 A-4 A-4D A-5

German Army Rocket Team

- V-2 (A-4) Rocket
  - 6,000 built during WWII
  - 1000+ test flights
  - 3,000 launched in combat
  - Gyro Steering
  - Control Vanes

Post–World War II US Rocketry

US and USSR built on V-2 technology

- 1945–54: Von Braun team to US Army, Gröttrup team to USSR
  - (V-2 + JPL 2nd stage) to space
  - Satellite launch studies
  - Redstone missile based on V-2
  - Viking scientific sounding rocket [clean-sheet design]
  - R&D on IRBMs and ICBMs
- 1954: Recognition of need for military surveillance satellites

Project Paperclip

Satellite launch studies

Redstone missile based on V-2

Viking scientific sounding rocket [clean-sheet design]
Post-WW II Science Fact and Fiction
Catalyzed human imagination

Post-World War II US Rocketry

- 1955: Decision to launch "civilian" satellite during International Geophysical Year
  - Political implications of overflight
  - No concern in US to be first to orbit
  - Project Orbiter based on Redstone
  - Project Vanguard based on Viking

R-7: The First ICBM
(August 21, 1957)

- USSR launches 1st satellite for IGY with R-7 on October 4, 1957
- Solved the US overflight quandary
- ... unsettling for the American public

Russia launched Sputnik 2 carrying a dog on 11/3/57

October 4, 1957
**Project Vanguard (1957-1959)**

Vanguard 1 success, March 17, 1958 [still in orbit]

**Project Orbiter Resurrected**

(February 14, 1958)

Explorer 1 (Army/JPL)

Launched 84 days after approval

V-2 -> Redstone -> 4-stage Juno 1

**1958: NACA Becomes NASA**

**Vostok 1, April 12, 1961**

Yuri Gagarin
May 5, 1961

Vostok 2, August 6, 1961

February 20, 1962

Friendship 7
Mercury-Atlas

May 5, 1961

U.S. HURLS MAN 115 MILES INTO SPACE; SHEPARD WORKS CONTROLS IN CAPSULE, REPORTS BY RADIO IN 15-MINUTE FLIGHT

Vostok 2, August 6, 1961

Project Gemini [1965-66]

10 crewed missions

Titan II

US takes Space Race Lead

February 20, 1962

Friendship 7
Mercury-Atlas

US takes Space Race Lead

Lunar Missions

Friendship 7
Mercury-Atlas

Lunar Missions

Friendship 7
Mercury-Atlas
**JFK to LBJ, April 20, 1961**

**MEMORANDUM FOR VICE PRESIDENT**

April 20, 1961

In accordance with our conversation I would like for you as Chairman of the Space Council to be in charge of making an overall survey of where we stand in space.

1. Do we have a chance of beating the Soviets by putting a laboratory in space, or by a trip around the moon, or by a rocket to land on the moon, or by a rocket to go to the moon and back with a man. Is there any other space program which promises dramatic results in which we could win?

---

**LBJ to JFK, April 28, 1961**

Q. 1 - Do we have a chance of beating the Soviets by putting a laboratory in space, or by a trip around the moon, or by a rocket to land on the moon, or by a rocket to go to the moon and back with a man? Is there any other space program which promises dramatic results in which we could win?

A. 5 - We are neither making maximum effort nor achieving results necessary if this country is to reach a position of leadership.

Lyndon B. Johnson

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**John F. Kennedy’s Challenge to Congress**

May 25, 1961

[4 months after JFK took office]
Alternative Landers and Launch Vehicles

Saturn 1  Saturn 5  Nova (Saturn 8)

BUT ... Lunar landing technique was not decided until July, 1962

Intense competition among corporations to build rocket and spacecraft components through 1963

Apollo Guidance Computer (AGC) vs. iPhone 5S

- 16-bit computer
- Storage: 38,332 words
- Speed: 1 million "ticks" per sec
- Weight: 70 lb
- 1st integrated-circuit computer
- Plus Inertial Measurement Unit
- TWO per mission (CSM and LM)

- 64-bit computer
- A million times more storage
- 1,300 times faster
- Weight: 1/4 lb
- Including inertial measurements

This Image: 282,000 words
"We Choose to Go to the Moon ..."
Rice University, Texas, September 12, 1962

Saturn Launch Vehicles
Saturn 1B
Saturn 5

Propellant Tanks
V-2 -> Redstone
-> Jupiter

Saturn 5 in Princeton Stadium

Evolution of the Lunar Module
LUNAR LANDER—ONE MAN
The Apollo Modules

Command Module

Service Module

Lunar Module

Apollo 1 (AS-204) Fire, January 27, 1967

- Low-risk, “Plugs Out” test
- Combustible materials
- Pressurized pure oxygen
- Hatch opened inward
- Electric arc
- Lack of preparedness

First Manned Flight, Apollo 7
October 11, 1968

Eisele Schirra Cunningham

Apollo 8, December 21-27, 1968

- Planned to be an Earth-orbit mission
- A more ambitious mission was pursued
- Repurposed to 1st manned flight to the Moon
- 6-day mission duration

Free-return trajectory
No further propulsion after Trans-Lunar Injection
Apollo 8 Entered Lunar Orbit

- More daring alternative was pursued
- Rocket fired on far side for Lunar-Orbit Insertion; no free return
- Rocket had to fire again on far side to return to Earth

Why the change?

August 1968, CIA KH-8 GAMBIT Reconnaissance Satellite

N-1 Rocket: Russia was indeed racing for the Moon

Apollo 9
March 1969

Earth-orbit test of Lunar Module, rendezvous, and docking

Apollo 10
May 1969

2nd manned flight to Moon
No landing intended
LM descended to 50,000’

N-1 Launch for Lunar Fly-By, July 3, 1969

Oxygen pump explosion

29 of 30 engines automatically shut down
Rocket and launch pad destroyed
Apollo 11 Launch
July 16, 1969

Landing on the Moon
July 20, 1969

A Little AGC Digital Autopilot Code

Apollo LUMINARY 131 (1C)
Program Source Code Listing
Low Gate to Touchdown

Armstrong’s comment on manual control: “As anticipated, quick and responsive.”

Russian Proton-K Rocket Launches on July 13, 1969

Jodrell Bank, UK
Impact July 21, 1969

Apollo 12
November 1969
Pinpoint Landing

Pete Conrad, ’53 with Surveyor 3

Apollo 13
April 1970

Apollo 14
January 1971

Apollo 15
July 1971

Apollo 16
April 1972

2 EVAs
Lunar Rover “Genesis Rock”
Lunar Highlands 3-day stay

Apollo 17,
December 1972

Harrison Schmitt 1st Scientist on the Moon

Apollo 13
April 1970

Lunar Rover
“Genesis Rock”
First Digitally Controlled Aircraft Used Apollo Computer (1972)

2nd Digitally Controlled Aircraft
Princeton's Variable-Response Research Aircraft (1978)

SKYLAB, 1973-1974
America's 1st Space Station

- Two mission commanders from Princeton
  - Charles "Pete" Conrad, '53
  - Gerald Carr, '62

Apollo Applications Program
Manned Venus Flyby
Outpost on the Moon

Apollo-Soyuz Test Project, 1975

Space Race #1 comes to a close
What Did We Learn from the Moon Rocks?

- Apollo 15 “Genesis Rock” – 4 billion years old
- Materials in Earth and Moon rocks virtually identical
- Consistent with Giant Impact Model

What Did Jules Verne Get Right?

- Launch from Florida
- Cape Canaveral’s latitude
- Size of capsule
- Number of astronauts
- Required launch velocity
- Time of flight
- Weightlessness
- Capsule recovery at sea

USSR Perseveres and Succeeds with Robotic Spacecraft

- Lunakhod 1, 2 Rovers (1970-73)
- Luna 16, 17, 20, 24 Sample Return (1970-76)

The Legacy
108 Lunar Missions Since 1958

Resurgent interest in lunar missions

The Costs of Apollo

- 7 Astronauts (all test pilots) died
  - Apollo 1 fire (3)
  - T-38 aircraft crashes (4)
- No American lives lost in space

- $25.4B (1973 dollars)
- $144B (2019 dollars)
- Peak NASA funding: 4.4% of 1966 Federal Budget

The Benefits of Apollo

- 20,000 participating institutions
- 400,000 people engaged in the program
- Technology and Science
- Motivation and support for research and education
- Unchallenged leadership in spaceflight

- Achieving what was thought to be “impossible:"
- “If we can go to the Moon, why can’t we ..."

Apollo was a Keystone for Current Technology

- Spaceflight
- Electronics and Computation
- Manufacturing
- Chemistry and Biomedicine
Why Return to the Moon?

- Science: lunar geology and astronomy
- Technological Development
- Educational Benefit
- Economic Stimulus
- International Competition & Leadership

Robots?
- Preliminary exploration
- Search for WATER and raw materials

Humans?
- Long-term utilization of lunar resources
- Dealing with uncertainty

Where is the Water?

Valleys and craters near the North/South Pole

2019 Robotic Lunar Landers

Chandrayaan-2 (7/19)
SpaceIL Beresheet (2/21 Launch, 4/11 Crash)
Moon Express MX-1 (4th Q)

QueQiao, Chang’è-4, Yutu 2, and Chang’è-5, 2019

Chang’è-4
COMMUNICATIONS WITH THE FAR SIDE OF THE MOON

Chang’è-5
LUNAR SURFACE SAMPLING AND RETURN MISSION

Where is the Water?

Valleys and craters near the North/South Pole
Will Humans Return to the Moon?

Yes

NASA Exploration Missions 1 & 2

Space Launch System

NASA Orion Command Module, ESA Service Module

NASA Exploration Mission 1, 2020

Unmanned

- Launch date being reassessed
- SLS may not be ready
- Possible use of EOR with commercial rockets

NASA Exploration Mission 2, 2023

4-person crew

Schedule probably will slip
Will Humans Land on the Moon?

Perhaps

V. P. Pence calls for human return to the moon by 2024 using “any means necessary”
-- SpaceNews.com, 3/26/2019

- SLS delays
- Moon lander design unclear
- Training and infrastructure
- Concept of Operations TBD
- NASA Budget unclear
- Realistic?

2019 NASA ≠ 1969 NASA

Proposed Altair Lunar Lander

- Earth Orbit Rendezvous with Orion
- Would launch on SLS Block 2
- Crew of 4
- One-week on moon

Constellation Program
Cancelled in 2011
Inadequate NASA Budget

Pence Directive at Odds with NASA's More Measured Plan for Return to the Moon

Lunar Orbital Platform-Gateway

NASA Crewed Missions, EM3-10, 2021-2023
Returning to 1962 ...

That was 57 years ago!
Who will continue the journey?

America met the challenge of Sputnik, Vostok, and the N-1 in the 1960s

Should the US return to the Moon now?

The Human Impact of Apollo

The Blue Marble, Apollo 17

“To see the earth as it truly is, small and blue and beautiful in that eternal silence where it floats, is to see ourselves as riders on the earth together, brothers on that bright loveliness in the eternal cold -- brothers who know now they are truly brothers.”

— Archibald MacLeish, on the occasion of Apollo 8, December 25, 1968

To be continued...
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- Howard McCurdy, *Space and the American Imagination*
- Bernard Miller, *Ranger Missions*
- David Mindell, *Digital Apollo*
- Jules Verne, *From the Earth to the Moon and Around the Moon*
- Colleagues at
  - MIT Instrumentation Laboratory (Charles Stark Draper Laboratory)
  - NASA Wallops Flight Facility, Wallops Island, VA

Supplemental Material

Apollo Command and Service Modules (CSM)

- 3-person crew
- Autonomous guidance and control capability

Was the Moon Landing a Hoax?

No! Next question!

Want more proof? Mythbusters!
http://www.youtube.com/watch?v=Wym04J_3Ls0
http://www.youtube.com/watch?v=MtWMx51eL0Y
http://www.youtube.com/watch?v=MUJU935BC0

https://en.wikipedia.org/wiki/Third-party_evidence_for_Apollo_Moon_landings
http://en.wikipedia.org/wiki/Moon_landing_conspiracy_theories
The Earth and the Moon

Earth mass = 81.4 x Moon mass

Early Greek Astronomers

Pythagoras, 570-495 BCE
“The Earth is round”

Eratosthenes, 276-194 BCE
“The Earth’s circumference is 50 times the distance from Cyrene to Alexandria (~500 mi)”
He was wrong, of course ... by less than 1%

The Astronomical Revolution

Copernicus, 1473–1543
Planets move about the Sun

Galileo, 1564–1642
Constructed and used telescopes, 3x to 30x
Identified mountains and craters on the Moon

Concurred with Copernicus, but
Church canon decreed Earth was Center of Universe
Forced to recant heresy at Roman Inquisition (1633)
**The Astronomical Revolution**

*Kepler, 1571–1630*
- Planets move in ellipses
- "Magnetism" between Earth and Moon

*Newton, 1642–1727*
- Formalized the science of motion and gravitation

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**Rockets 101**
- **Initial mass:**
  - Payload
  - Structure, Systems
  - Rocket motors
  - Propellant
- **Final mass:**
  - Initial mass less propellant

*Konstantin Tsiolkovsky (1857–1955)*

Final velocity depends on ratio of initial to final mass

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**Rockets 102**

Final mass can be reduced by getting rid of structure when no longer needed

**Booster Staging**

Before Staging
- **Powered Ascent**

Parallel Staging
- **Sustainer Continues Firing**

After Staging
- **Uncarded Strap On**
**Pre-World War II Rocket Societies**

Verein für Raumschiffahrt

**Robotic Lunar Probes**

- **1958-1960**
  - Success | Failure
  - US 1 partial 8
  - USSR 2, 1 partial 6

- **1962-1965**
  - Success | Failure
  - US 3, 1 partial 3
  - USSR 1 9

- **1966-1967**
  - Success | Failure
  - US 11 2
  - USSR 5 4

**Precursors to Apollo**

Rangers 7, 8, & 9
Hard Landing
[Impact], 1964-5

Surveyor 3
Soft Landing, 1967

Bernie Miller,
RCA Astro Electronics
Program Manager

**Apollo was a Keystone for Current Technology**

- **Spaceflight**
  - Communications satellites
  - GPS
  - Space Shuttle
  - International Space Station
  - Cubesats

- **Electronics and computation**
  - Solar cells, fuel cells, energy storage
  - Computing hardware and software
  - Digital imaging (e.g., CT scanner)
Apollo was a Keystone for Current Technology

- **Manufacturing**
  - Cordless tools
  - Materials (e.g., insulation, fabrics, optics)
  - Welding, structures

- **Chemistry and biomedicine**
  - Automatic defibrillators
  - Chemical filtration (e.g., dialysis)
  - Fluid flow controls
  - Life support systems

Armstrong, Aldrin, and Collins
1969

Armstrong, Aldrin, and Collins
2009

SATURN IB
FIRST STAGE (S-IB)

- Propellant tanks from Redstone – after V-2

SATURN V
FIRST STAGE (S-IC)
**Soviet Manned Lunar Spacecraft**

Soyuz 7K-LOK, 2-man CSM

LK, 1-man Lunar Lander

**Space Tourism Fly-By**

Big Falcon Rocket #dearMoon FlyBy (2023)

Billionaire Yusaku Maezawa plus 6-8 artists
Crew of 1 or 2+

**Sub-Orbital (Sounding) Rockets 1945 - Present**

**Chang’e 5 Sample Return (12/2019)**

Chang’e-5
Lunar Surface Sampling and Sample Return

105

106

107

108
Lunar Orbital Platform—Gateway

SKYLAB reborn?
Easy access to lunar surface
NASA Crewed Missions, EM3–10, 2024–2033

Timeline to Lunar Gateway Platform

What Were the Russians Doing During the Apollo 11 Mission?

... but the Apollo Program was Not Quite Over