Final approach Apollo 11
July 20 1969
50 Years After Apollo: Revisiting the Race to the Moon

Jonathan McDowell

Center for Astrophysics
Imagine a stone.
Imagine a stone 2000 miles across. Hanging over your head.
Imagine a stone 2000 miles across. Hanging over your head.

Imagine you hadn’t grown up thinking that was normal!
Don’t be fooled by these diagrams and others like them… the Moon is not **that** close!
384,400 km
1.3 seconds at lightspeed

24x Boston-Sydney
July 1969
Half a century ago

Humans on another world
Artists in space...
First Earth Satellite: Sputnik  Oct 1957
First Earth Satellite: Sputnik Oct 1957

First Living Being in Orbit: Laika, Nov 1957

First Probe to Solar orbit: Luna-1 Jan 1959

First Probe to hit Moon: Luna-2 Sep 1959

First intact return to Earth from orbit: Discoverer 13 Aug 1960

First human in space: Yuriy Gagarin in Vostok-1 Apr 1961

Is America losing the Space Race? Time to up the stakes dramatically....
In this decade...

I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth.

John F Kennedy, address to Congress, May 25, 1961
JUNE 1962: Von Braun accepts John Houbolt's scheme for Lunar Orbit Rendezvous, so the enormous Nova rocket is not needed...
Voskhod 2
First Space Walk
March 1965
1965-66: Gemini rendezvous and docking
1961-1968
Test launches of the Saturn rocket:
Saturn I Block I
Saturn I Block II
Saturn IB
Saturn V
The Apollo AS-204 Fire ("Apollo 1")

January 27, 1967

Gus Grissom, Ed White, Roger Chaffee
November 1967: the first Saturn V, SA-501

0.11 km high
3000 tonnes
First stage thrust 35 MN
5 F-1 rocket engines – each with as much thrust as a Falcon 9
**SATURN V LAUNCH VEHICLE**

**CHARACTERISTICS**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (Vehicle)</td>
<td>86m</td>
</tr>
<tr>
<td>Length (Vehicle, spacecraft, LES)</td>
<td>111m</td>
</tr>
<tr>
<td>Weight (Total dry)</td>
<td>178,822 Kg</td>
</tr>
<tr>
<td>Weight (Total wet)</td>
<td>2,708,831 Kg</td>
</tr>
<tr>
<td>Weight (At liftoff)</td>
<td>2,903,000 Kg</td>
</tr>
<tr>
<td>Translunar payload cap</td>
<td>48,500 Kg</td>
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<tr>
<td>Earth orbit payload cap</td>
<td>96,000 Kg</td>
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**STAGES**

**FIRST (S-I C)**

- **Size**: 10 x 42 m
- **Engines**: 5 F-1
- **Thrust**: 3,470,000 Kg
- **Propellants weight (LOX)**: 1,497,856 Kg
- **Propellants weight (RP-1)**: 651,500 Kg

**SECOND (S-Ⅱ)**

- **Size**: 10 x 24.8 m
- **Engines**: 5 J-2
- **Thrust**: 526,176 Kg
- **Propellants weight (LOX)**: 379,339 Kg
- **Propellants weight (LH2)**: 72,387 Kg

**THIRD (S-Ⅳ B)**

- **Size**: 6.6 x 18.1 m
- **Engines**: 1 J-2
- **Thrust**: 104,328 Kg
- **Propellants weight (LOX)**: 86,000 Kg
- **Propellants weight (LH2)**: 19,700 Kg

**INSTRUMENT UNIT**

- **Size**: 6.6 x 0.91 m
- **Weight**: 2,038 Kg
- **Guidance system**: Inertial

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**MSFC-71-PM 1200-127**
New Orleans: Stage 1
Los Angeles: Stage 2 and 3; F-1 and J-2 rocket engines
Huntsville, Alabama: rocket design, some testing
Mississippi coast: rocket test firings

**SATURN V LAUNCH VEHICLE**

**CHARACTERISTICS**

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**THIRD (S-IVB)**

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| GUIDANCE SYSTEM | INERTIAL

MSFC-71-PM 1200-127
Los Angeles: Command/Service Module
Bethpage, NY: Lunar Module
White Sands, New Mexico: Escape tower tests
Houston, TX: astronaut training

Sacramento, CA: SM rocket engine
Cambridge, MA: Lunar module computer
Greenbelt, MD: Tracking
Cape Canaveral, FL: launch site
Saturn V three stage rocket places Apollo spacecraft on course for the Moon

Apollo consists of CSM (Command Module, with astronauts, and Service Module, with rocket) and LM (Lunar Module – consists of Ascent Stage, with astronauts, and Descent Stage, with rocket)

CSM/LM docked to each other, enter lunar orbit
2 of 3 crew go to LM, undock and land using Descent Stage engine
Walk on Moon, return to LM, Ascent Stage heads back to lunar orbit to rejoin CSM
LM discarded, CSM returns to Earth
Meanwhile, elsewhere...
Sergey Korolev's Program

At Podlipki, in the Moscow suburbs, Korolev's factory churns out rockets and satellites

- Sputnik
- Luna moon probes
- Vostok spaceships
- Mars and Venus probes
- Spy satellites
23 km east of Korolev-Podlipki:

“Zvozydniy Gorodok”
- “Starry Town”
Nauchno-Issledovatelskiy Ispitatel’niy Poligon-5

Scientific-Research Test Range No. 5, Kazakhstan
(nowadays “Kosmodrom Baykonur”)
Baykonur is HUGE - 65 km across.
Here it is compared in scale to Cape Canaveral
New spaceship design
Designed for lunar flight
Earth orbit test by test pilot Vladimir Komarov
Solar panel failed to open, spacecraft tumbling
Emergency reentry and crash landing
First fatality during a space flight
TORTOISES TO THE MOON! (AND BACK)
The Flight of Zond-5  Sep 14-21, 1968
First Return To Earth From Lunar Vicinity
First Terrestrial Creatures in Interplanetary Flight

- Launch into Earth orbit
- TLI (Trans Lunar Injection) rocket burn towards the Moon
- Fly around lunar farside (but not into a closed lunar orbit)
- Pass 1200 mi (1950 km) from lunar surface
- Coast back down towards Earth
- Reentry at 25000 mph over South Pole
- Splashdown in Indian Ocean, recovered by Soviet Navy
Space Complex L-1
With Spaceship 7K-L1 (Zond) and Booster Stage “Block D”

Compare 7K-L1 (above) with Soyuz (left)
Apollo 8, Dec 1968:
First humans to leave Earth's gravitational sphere of influence

First humans to orbit the Moon:
F. Borman  J. Lovell  W. Anders
Apollo/Saturn 3rd stage in Earth orbit 128 tonnes
Apollo/Saturn 3rd stage departing Earth orbit 59 tonnes
Apollo 8 spaceship is 10 tonnes dry plus 14 tonnes propellant
6h GMT, Wed Dec 25

TEI: Trans-Earth Injection

TRANSEARTH INJECTION
1969 – Soviet N-1 Moon Rocket
Jun 14, 1969

After an 11 day mission, a film capsule is ejected from the US NRO’s GAMBIT-3 Mission 4322. A rocket motor fires to drop it out of orbit; it is recovered in mid-air over the Pacific and flown via Hawaii to Washington, D.C.

It contains this picture: the N-1 moon rocket is on pad 110 at Baykonur ready for launch.
CORONA satellite photo of the same launch pad in August 1969: note blast damage
July 3, 1969
One engine catches fire at launch
14 seconds in, the first stage fails and falls back to the pad from a height of one hundred metres
Launch escape tower fires to pull the uncrewed Soyuz L1-S spaceship to safety
Rocket hits pad.
Boom
Estimated explosive force 7 kiloton (1/3 Hiroshima)
SUNDAY JULY 13, 1969

STATE TEST RANGE No. 5
KAZAKH SOVIET
SOCIALIST REPUBLIC

LAUNCH OF ROCKET
8K82K No. 242-01

SPACE PROBE E-8-5 No.
401 ON TRANSLUNAR
TRAJECTORY

TASS ANNOUNCES
LAUNCH OF “LUNA-15”
WHAT NEARLY HAPPENED:  LUNA-16, SEPTEMBER 1970
WED, JUL 16, 1969, 1:32pm GMT: APOLLO 11 LAUNCHES FROM KENNEDY SPACE CENTER, FLORIDA
Wed. July 16, 4:22pm GMT      TLI: Translunar Injection
Apollo spacecraft and Saturn S-IVB third stage reach near-escape velocity
Orbit 262 x 565954 km
Wed, Jul 16, 1969, 4:47pm GMT – Transposition and Docking
Columbia separates from rocket, turns around, docks with Eagle
Lunar module still attached to Saturn rocket stage
Seen from approaching command module
Wed, Jul 16, 1969, 5:49pm GMT: Columbia and Eagle docked, Apollo 11 spaceship backs out from the Saturn S-IVB stage
Sat. Jul 19, 1969, 5:27pm: Apollo 11 in orbit around the Moon
111 x 311 km elliptical path adjusted at 9:43pm to 100 x 122 km
Luna-15

Sun July 20, 2:16 pm

Luna-15 lowers orbit to only 16 km from the surface
Luna-15

Sun July 20, 2:16 pm

Luna-15 lowers orbit to only 16 km from the surface.
Sun. Jul 20, 5:45pm: Columbia undocks from Eagle Command and Service Module (CSM) and Lunar Module (LM) in separate lunar orbit.
Sun Jul 20, 1969:  8:05 pm: Powered Descent
15 km above the Moon
Sun Jul 20 1969, 8:17pm GMT: TOUCHDOWN

Houston: “30 seconds” [of fuel left]
Eagle: “Contact light.. OK, engine stop.....”
Houston: “We copy you down, Eagle”.
Eagle: “Houston, Tranquility Base here... the Eagle has landed.”
Monday July 21, 2:50am  Armstrong out the hatch and on the ladder

This photo actually from 3:12am, showing Aldrin coming down the ladder
“That's one small step for (a) man,
One giant leap for mankind”
Neil Armstrong aboard Eagle after the moonwalk
Mon Jul 21, 0800 GMT
Buzz Aldrin aboard Eagle after the moonwalk
Luna-15
July 21, 3:47 pm
Luna-15 begins descent to lunar surface towards Mare Crisium ("the Sea of Crises")
In England, Jodrell Bank radio observatory tracks the probe's signals, and deduces that Luna-15 landed on the Moon at a speed of 300 mph. The braking engines failed to operate...

The last-minute challenge to Apollo 11 is over!
Mon Jul 21, 5:54pm: Eagle's Ascent Stage lifts off, using Descent Stage as launch pad.
Mon Jul 21, 9:17pm:
Rendezvous with Mike Collins in Columbia
Tue Jul 22, 04:58 am
En route to Earth
Thurs Jul 24, 4:50pm
Splashdown in the Pacific

Apollo 17 – Dec 1972
Command Module “Columbia”
Pacific Ocean, 13 N 169 W
July 24, 1969: “… and returning him safely to the Earth”.
APOLLO 12 AT SURVEYOR 3 – NOV 1969
APOLLO 13 – APR 1970
APOLLO 14 AT FRA MAURO – FEB 1971
APOLLO 15 AT HADLEY – JUL 1971
APOLLO 16 AT DESCARTES – MAY 1972
APOLLO 17 AT TAURUS-LITTROW – DEC 1972
1969 – Soviet N-1 Moon Rocket

N-1 is a three stage rocket

Blok A, Blok B suborbital
Blok V puts the stack in Earth parking orbit and separates from the rest of the vehicle: the L-3 spaceship complex

L-3 consists of:
LOK (Soyuz) lunar orbiter and Earth return ship
LK lunar lander
Blok-G Earth escape stage
Blok-D lunar orbit insertion stage

2 crew members – one would descend to the lunar surface

Alexei Leonov was in training for the job..
L-3 spaceship

More complicated than Apollo/Saturn V – the deep space part plays out a bit differently

<table>
<thead>
<tr>
<th></th>
<th>N-1/L-3</th>
<th>Apollo/Saturn V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total crew</td>
<td>2 people</td>
<td>3 people</td>
</tr>
<tr>
<td>Earth orbit insertion</td>
<td>N-1 stage V</td>
<td>Saturn V stage 3</td>
</tr>
<tr>
<td>Translunar insertion</td>
<td>L-3 stage G</td>
<td>Saturn V stage 3</td>
</tr>
<tr>
<td>Lunar orbit insertion</td>
<td>L-3 stage D</td>
<td>Apollo service module</td>
</tr>
<tr>
<td>Descent and landing</td>
<td>Stage D + LK</td>
<td>Lunar Module Descent S</td>
</tr>
<tr>
<td>Crew on moon</td>
<td>1 person</td>
<td>2 people</td>
</tr>
<tr>
<td>Crew transfer</td>
<td>External spacewalk</td>
<td>Internal tunnel</td>
</tr>
<tr>
<td>Lunar takeoff</td>
<td>LK (same engine)</td>
<td>Lunar Module Ascent S.</td>
</tr>
<tr>
<td>Lunar orbit rendezvous</td>
<td>LK/LOK</td>
<td>LM/CSM</td>
</tr>
<tr>
<td>TransEarth insertion</td>
<td>LOK service module</td>
<td>Apollo service module</td>
</tr>
</tbody>
</table>
Fig. 1: Cosmonaut transfers from LOK to LK

Fig. 2: LOK and LK separate
Nov 1972
Final launch of N-1/L-3  Blew up 40 km above Kazakhstan

Dec 19, 1972: Apollo 17 splashdown
End of human exploration of the Moon – for now
Apollo Science Discoveries:

The moon has internal structure
- Small iron core? 100 km/ 60mi?
- Soft asthenosphere (mantle) 700 km / 450 mi
- Lithosphere 1000 km/ 600 mi
- Crust 60 km / 40 mi
- Regolith (`soil’) 10 m/ 3 feet

Craters are due to impacts

Moon rocks are old; 3.2 to 4.6 billion years
- Preserves early history of solar system lost on Earth due to geological processes
- No organic molecules
- Mare areas are lava (basalts)

About 4.5 billion years ago, the Moon was molten; lunar highlands have some of the rocks that cooled on its surface then
Afterwards (3-4 billion years ago) big asteroids hit the moon and made the basins (maria)
Later (about 3 billion years ago), lava filled the basins

Moon is lumpy - `mascons’ (mass concentrations) under large impact basins affect path of spacecraft in low orbit
50 years later:

**ARTEMIS**

NASA and Boeing build the core stage for the first SLS rocket

Plans still in flux for returning US astronauts to the Moon
Meanwhile, on the lunar farside:

嫦娥四号

玉兔二号