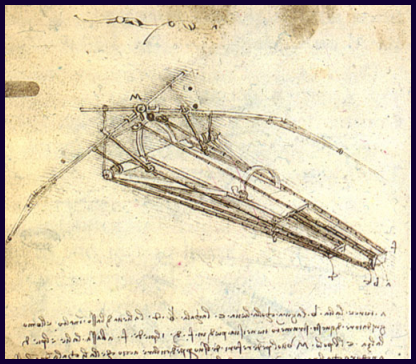
# To the Moon!

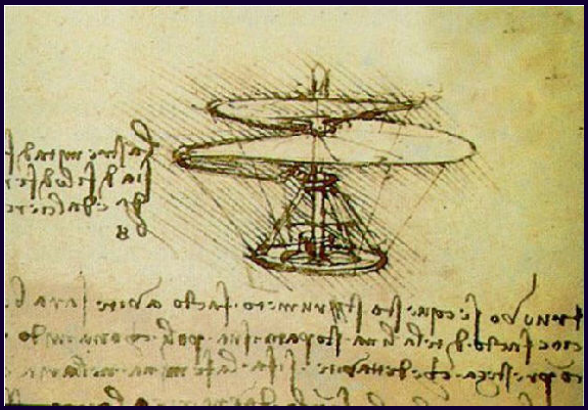
Astronomy 101
Syracuse University, Fall 2020
Walter Freeman

November 17, 2020

# da Vinci and flight

da Vinci dreamed of flying, and wrote a treatise on birds – and made diagrams for flying machines.





Unfortunately, people don't just lack wings – they lack enough power.

Nature gave birds incredible strength for their weight – but it gave *us* these brains!

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Push yourself forward, use wings to push downward on the air (flapping or not), and you can fly!

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In 1903 Wilbur and Orville Wright put an internal combustion engine on a winged machine, put a propeller on the front, added devices to steer, and invented the airplane.

# The dream of flight, in the waking world...


We can fly! Even before that, people were dreaming of going to the Moon and beyond.

- 1865: Verne wrote a book in which Baltimoreans shoot themselves to the Moon in a giant cannon
- Verne did the math for the size of the gun required and got it right
- It would have worked!
- ... the acceleration would have squashed the people, though...

A giant cannon won't work. Can we use Wilber and Orville's airplane to go to the Moon?

A: Yep!

B: Nope; it won't work at all

C: Sort of – you can propel yourself, but you can't steer

# Newton's third law

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(Forget that "action/reaction" stuff – "action" meant something specific to Newton that it doesn't mean today.)

# Rockets

Simple solution, first used in East Asia: carry gas (or anything else) with you, and push it out the back!

The Chinese had been using rockets in warfare as early as 1280, using the gunpowder also developed in China.

The Koreans and Mongolians quickly adopted the new weapon, and the technology spread around Eurasia in the next few centuries.

This works in space: "I push backwards on the gas I've brought with me; it pushes forwards on me"

# Making rockets precise

The Russian scientist Konstantin Tsiolkovsky (1857-1935) was the first to study the physics of rocketry in depth. (He also studied music and the problem of poverty.)

He discovered the *rocket equation*, which describes the performance of a perfect, ideal rocket:

$$\text{(total mass)} = \text{(payload mass)} \times \exp\left[\frac{\text{change in rocket's velocity}}{\text{exhaust speed of propellant}}\right]$$

("exp" is the exponential function: $\exp(x) = e^x$.)

This is the form of the rocket equation you'll use for Project 5.

# Making rockets precise

We can write this more compactly. If:

- $\Delta V$ is the speed that the rocket will be traveling after it burns its fuel
  - To escape Earth's gravity: about 11 kilometers/second (calculated by Tsiolkovsky)
- $v_e$ is the exhaust speed of the propellant
- $F$ is how many times bigger the rocket is than its payload
  - Here "payload" means every part of the rocket that isn't fuel

$$F = (2.719)^{\Delta V / v_e}$$

or

$$F = 10^{0.43 \frac{\Delta V}{v_e}}$$

# Tsiolkovsky: making rockets precise

Tsiolkovsky realized that rockets could take us to space, and wrote about this in 1903: "Exploration of Cosmic Space by Means of Rocket Devices"

But what kind of fuel is needed? Let's make a table here. Suppose we want to lift a ton of material away from Earth's gravity; how much fuel do we need?

| Fuel exhaust speed | Fuel needed |
|---|---|
| 1000 km/hr | 300 million billion tons |
| 2000 km/hr | 5.5 million tons |
| 3000 km/hr | 680,000 tons |
| 5000 km/hr | 3100 tons |
| 9000 km/hr (solid rockets) | 87 tons |
| 15400 km/hr (hydrogen/oxygen) | 13 tons |
| 104000 km/hr (ion thrusters) | 470 kilograms |

The problem with rockets: you have to carry your fuel with you. The less efficient your fuel is, the more fuel you need, so you need more fuel to carry that fuel...

And, if you want to come back from wherever you went, you need even *more* fuel... (Project 5)

# Robert Goddard: making rockets

Robert Goddard (American; 1882-1945) had a long-running interest in rocketry as a means to get to space. He:

- took Tsiolkovsky's ideas and put them into practice
- realized that a specially-shaped rocket nozzle could greatly increase exhaust speeds (remember how much this matters!)
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- realized that a specially-shaped rocket nozzle could greatly increase exhaust speeds (remember how much this matters!)
- achieved exhaust speeds of 8600 km/hr
- believed that a rocket could reach the Moon!

For the first time, we have a plan: a machine whose workings we understand that can get us to the Moon!

Not everyone was convinced.

*"[A]fter the rocket quits our air and really starts on its longer journey, its flight would be neither accelerated nor maintained by the explosion of the charges it then might have left. To claim that it would be is to deny a fundamental law of dynamics, and only Dr. Einstein and his chosen dozen, so few and fit, are licensed to do that.... That Professor Goddard, with his "chair" in Clark College and the countenancing of the Smithsonian Institution, does not know the relation of action and reaction [Newton's third law], and of the need to have something better than a vacuum against which to [push] – to say that would be absurd. Of course he only seems to lack the knowledge ladled out daily in high schools."*

–*The New York Times*, 1920

# Rockets as a weapon

Humanity's dream of flight to the Moon was interrupted by the Second World War, with rockets pressed into service to kill each other.

All sides in the war used rocket weapons, but the most famous and largest was the German V-2: `https://www.youtube.com/watch?v=94T8VxOOvdI`

These rockets, designed by a team of German engineers led by Werhner von Braun, were fired across the English Channel at London. They didn't do much damage, but were terrifying.

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One of them lived across the street from me when I was a child. Another one was my high school English teacher.

# The Cold War

Both Americans and Soviets lived in constant fear of nuclear war.

A rocket that could deliver a nuclear warhead was the ultimate weapon: an ICBM.

So rocket technology was key to "winning" the Cold War.

Both sides wanted to demonstrate their superiority. The Soviets, however, beat us: showing their mastery of the technology that could be used to kill tens of millions of Americans in a fraction of an hour.

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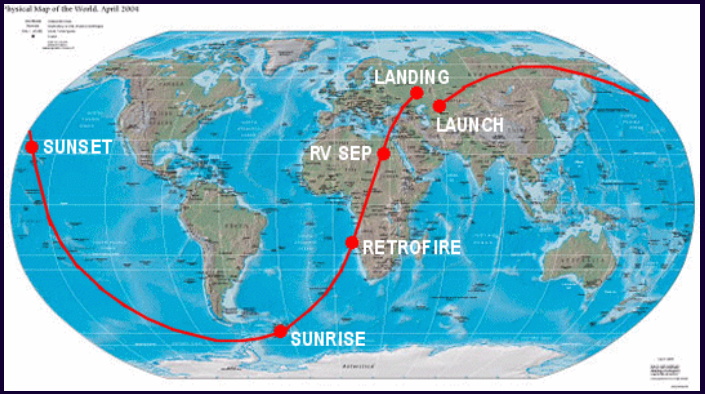
Then in 1961 the Soviets launched a human to space, Yuri Gagarin, who orbited the Earth and returned safely.



# The American response

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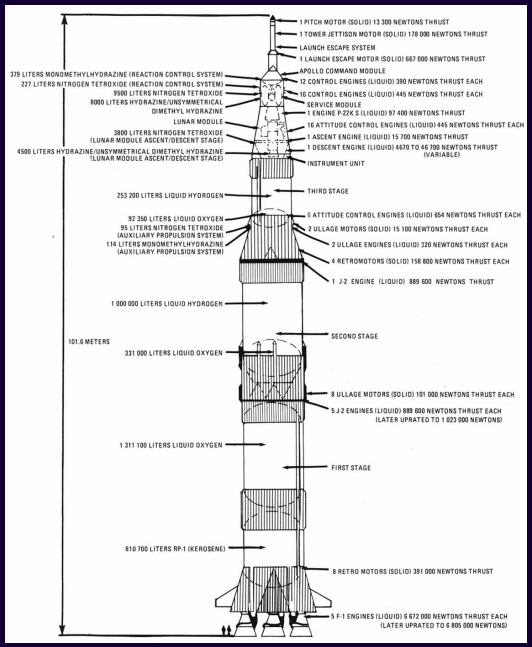
The effort took seven years. Before embarking on the mission to build the Moon rocket, we undertook two other flight programs:

- Project Mercury: small craft that carried one person, the first American in space Alan Shepard
- Project Gemini: two-person spacecraft in low-Earth orbit
  - Life support technology
  - Orbital maneuvering and docking
  - Extravehicular activity ("spacewalks")

# The Apollo program




NASA set out to build a large rocket, the Saturn V, that could reach the Moon.

- Three stages
- Designed to boost two spacecraft to the Moon
- ... a command module, designed to stay in lunar orbit
- ... and a lunar module, designed to land on the Moon itself

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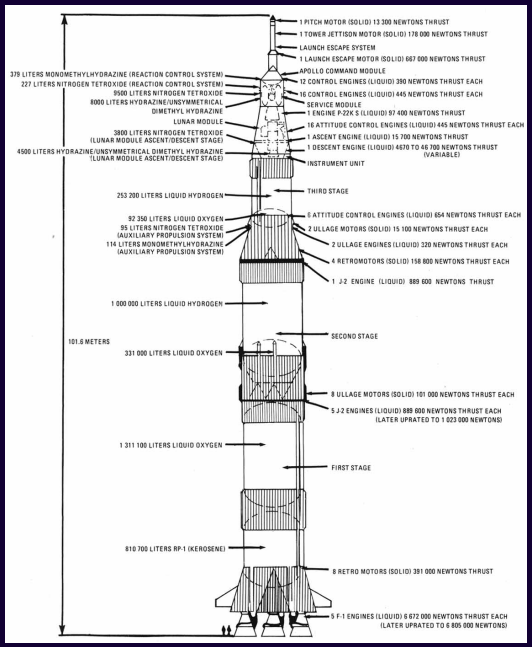


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`https://xkcd.com/1133/`

# The first few flights

- Apollo I (1967): crew chamber pressurized with pure $O_2$
- Caught fire; all three astronauts died – Chaffee, White, and Grissom.
- Seven flights in 1967-1969 tested various pieces of the equipment
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- "Software engineering"

Margaret Hamilton, leader of the MIT team that developed the flight computer software for *Apollo*

# Apollo 11: the Moon, at last!

Finally, it was time to go for the prize. `https://youtu.be/UExTN3_UOIY`

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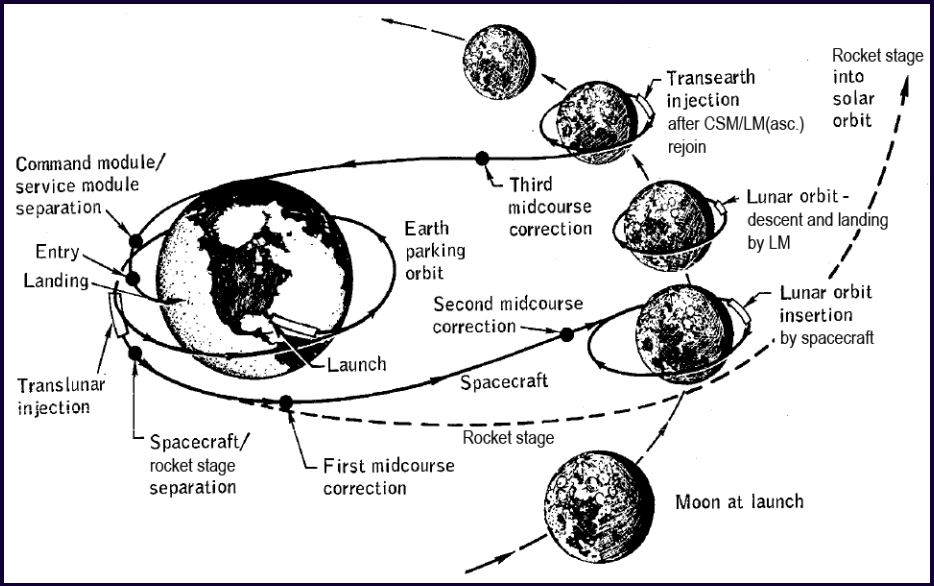


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"*Further investigation and experimentation have confirmed the findings of Isaac Newton in the 17th Century and it is now definitely established that a rocket can function in a vacuum as well as in an atmosphere. The* Times *regrets the error."*

–*The New York Times*, 1969

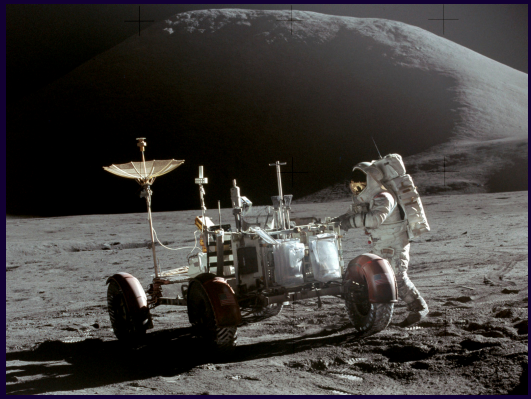
# Apollo 11: the Moon, at last!

On 20 July, 1969, humanity walked on another world for the first time.

- Neil Armstrong and Buzz Aldrin descended to the lunar surface
- Michael Collins stayed in lunar orbit in the Command Module
- They stayed on the Moon for nearly a day, walking on the surface for two and a half hours
- They brought back around fifty pounds of moon-rocks
- Gallery of images: `http://www.hq.nasa.gov/alsj/a11/a11_eva_thumbs.html`

# The remainder of Apollo

- The USA launched seven more *Apollo* missions to the Moon.
- Six of them made it; one, *Apollo 13*, suffered from an explosion en route.
  - Its story was made into a wonderful film of the same name
- 800+ pounds of moon rocks returned to Earth
- Dozens of hours spent on the lunar surface

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EXPLORATIONS OF THE MOON
DECEMBER 1972, A.D.
MAY THE SPIRIT OF PEACE IN WHICH WE CAME
BE REFLECTED IN THE LIVES OF ALL MANKIND
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RONALD E EVANS
ASTRONAUT
HARRISON H. SCHMITT
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Long after the specter of nuclear war that loomed over the middle part of the 20th century is forgotten, this is what people will remember:

Earth seen from lunar orbit, *Apollo 8 (December 1968)*