

To the Moon!

Astronomy 101
Syracuse University, Fall 2022
Walter Freeman

December 1, 2022

Orbiting Earth in the spaceship
I saw how beautiful our planet is.
People, let us preserve and increase this beauty,
not destroy it!

—Yuri Gagarin, first human in space,
upon landing from his first flight in 1961

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This quote, and others pertaining to the voyage to the Moon and the quest for the stars, were set by Christopher Tin in his oratorio “To Shiver the Sky”.

I discovered it just this morning, and listened to it while preparing for class today.

Give it a listen if you want:

https://www.youtube.com/playlist?list=PLMfqyskB8JL8fNbX2h_4h1zUKNMAH0iv3

Announcements: makeups/retakes

I am in the process of arranging the schedule for makeup labs. If you signed up to make up a lab, expect a note from me tonight or tomorrow morning.

I'll be in my office (215) or the Physics Clinic most of the day Friday. Come by if you want to chat about anything.

Announcements: final project submissions

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- **At the final exam (Tuesday, December 13, 3pm-5pm)**

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Remember that creative projects should include a brief artist’s statement linking your creative work to the stuff of astronomy or science.

The dream of flight / Il sogno di volare

Italian text: Leonardo da Vinci

Music by Christopher Tin

The Royal Philharmonic Orchestra, the Angel City Chorale, Prima Vocal Ensemble, and Lucis: London, July 2016

Una volta che avrai
spiccato il volo, deciderai
sguardo verso il ciel saprai:
lì a casa il cuore sentirai

Once you have taken flight
you'll decide
Gaze toward the sky: you'll know that
that is where your heart will feel at home

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Prenaderá il primoro volo
verso il sole il grande uccello
sorvolando il grande monte cereri
riempendo l'universo di stupore e gloria.

Once you have taken flight
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The first great bird
will take flight towards the sun,
sweeping over the great Mt. Ceceri,
filling the universe with wonder and glory.

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L'uomo verrá portato dalla sua creazione
come gli uccelli, verso il cielo...
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Man (sic) will be lifted by his own creation,
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Gloria!

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Glory!

The victory lap

We've studied what's up there,
how it works, and how we see it.

The victory lap

We've studied what's up there,
how it works, and how we see it.

You've learned some chemistry,
some physics, some geology, some
geometry, and – yes – some math,
and I'm proud of you.

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The dream of flight

People have dreamed of flying for ages, in all countries and since the earliest days of history.



- Often our dream of flight was a symbol of hubris: “mortals should know their place”
- Icarus and Daedalus...

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Leonardo da Vinci (Italian, 1452-1519):

- Embodied the humanist spirit of the Renaissance: “yes, we *can!*”
- Skilled at science, philosophy, engineering, and art
- ... and used them all to enhance each other
- Like so many others, dreamed of flying...
- Was a Ninja Turtle, or my childhood was a lie



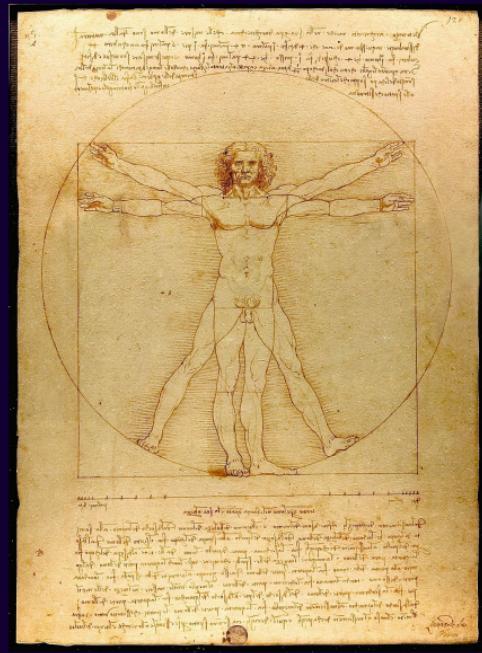
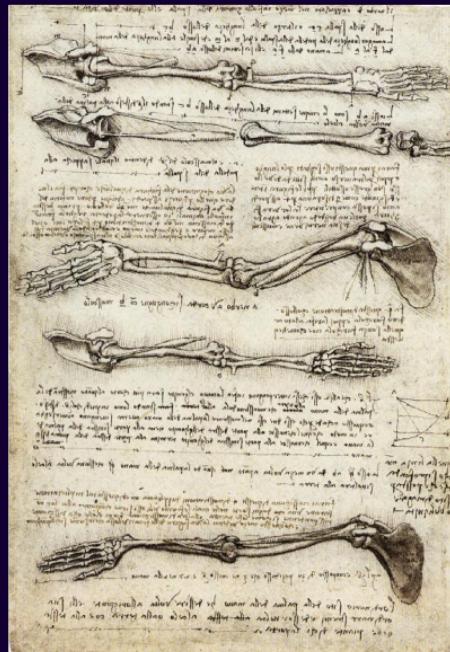
The “Renaissance man” (and woman!)

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Science as a liberal art

There's a reason this class is in the “College of Arts and Sciences”.

Understanding the world around us was once “natural philosophy” – another branch of the unified whole of learning.

Some of us will go on to become doctors – not of physics or literature or engineering, but *philosophy*.

“Science” just means knowledge: *Suos cultores scientia coronat...*

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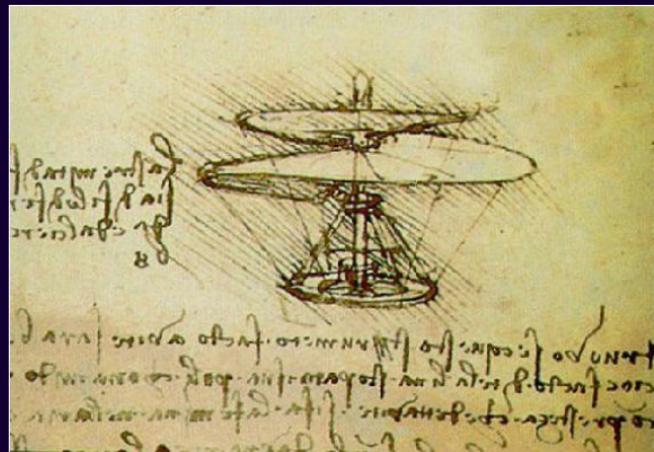
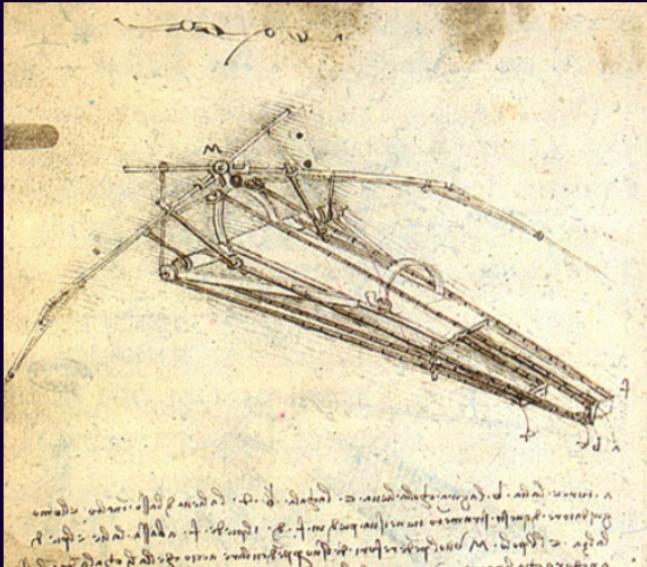
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When you can, be like da Vinci...

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.

(Human: 60 kg, 400 watts; duck, 1 kg, 100+ watts)

That's 14 times more power per gram for the duck!

Power + wings = flight!

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

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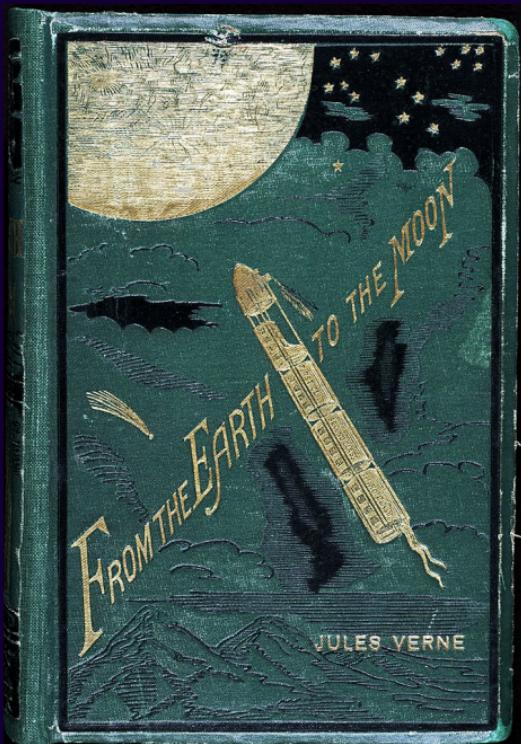
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In 1903 Wilbur and Orville Wright put an internal combustion engine on a winged machine, put a propeller on the front, added devices to steer, and invented the airplane.



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

Remember gravity?

$$F = \frac{Gm_1m_2}{r^2}$$

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

Rockets

Simple solution: 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”

Tsiolkovsky: making rockets precise

The Russian scientist Konstantin Tsiolkovsky (1857-1935) was the first to study the physics of rocketry in depth.

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

$$\Delta V = v_e \ln F$$

Here:

- ΔV 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 velocity of the rocket (how fast the gas comes out the back)
- F is how many times bigger the rocket is than its payload
 - Here "payload" means every part of the rocket that isn't fuel

We can make the math easier and rearrange this:

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

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 to orbit; 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...

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!)
- achieved exhaust speeds of 8600 km/hr

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- 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!)
- 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, as you saw on Exam 2:

[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=94T8Vx00vdI>

These rockets, designed by a team of German engineers led by Werhner von Braun, were fired across the English Channel at London. They were not very good weapons because they weren't accurate, but were terrifying.

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The widow of one of them lived across the street from me when I was a child. Another taught English at the local high school after retiring from NASA.

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.

Sputnik and Vostok

In 1957, the Soviets got there first, and launched the first satellite: Sputnik.

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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

In 1962 the American president John F. Kennedy called for a concentrated, devoted effort to travel to the Moon.

<https://www.youtube.com/watch?v=th5A6ZQ28pE> (excerpts – full text at
<http://bit.ly/2gB9L5q>)

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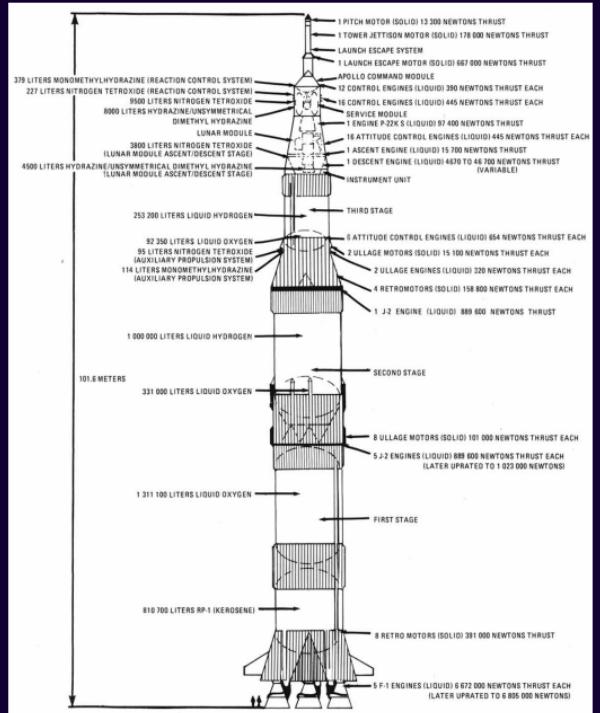
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The effort took seven years. Before embarking on the mission to build the Moon rocket, we undertook two other flight programs:

- 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”)

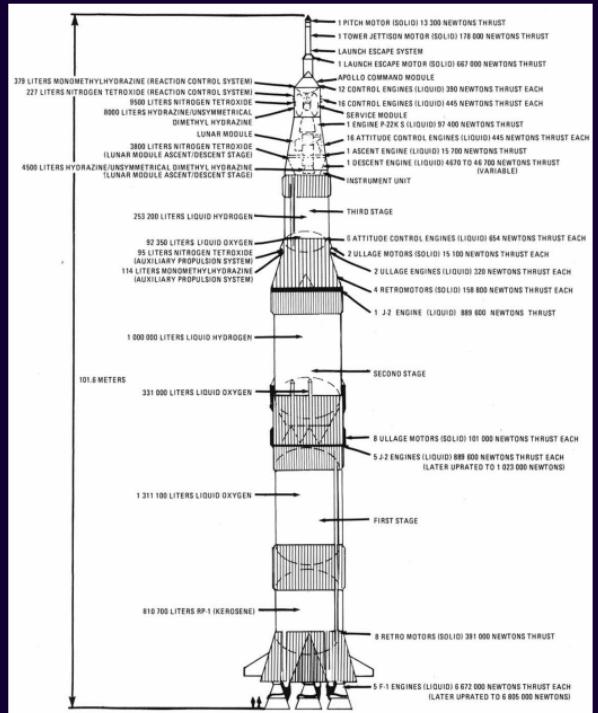
The Apollo program



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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<https://xkcd.com/1133/>

The first few flights

- Apollo I (1967): crew chamber pressurized with pure O₂
- 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”



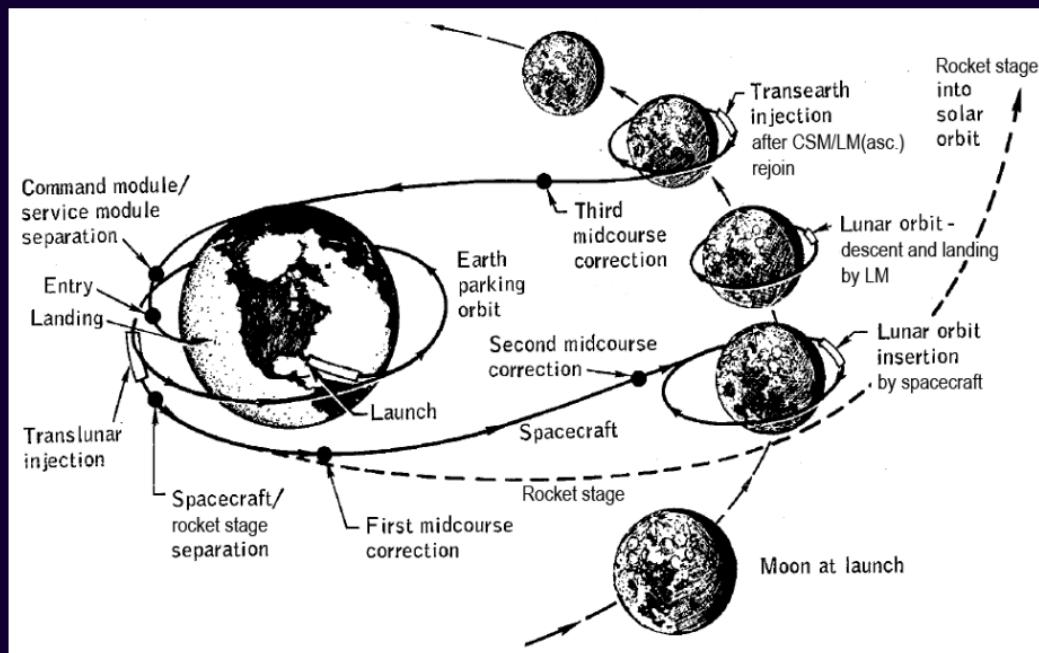
Margaret Hamilton, leader of the MIT team that developed the flight computer software for *Apollo*, who pioneered the field of software engineering

Apollo 11: the Moon, at last!

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

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<https://youtu.be/XisDvCTww4M?t=220>

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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







Forgotten weapons into long-remembered stories...



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