

HISTORY

UK History

From the theorists of rocketry and the V-2, through Sputnik, Gagarin, Apollo and the Shuttle, to space stations, robotic probes and commercial spaceflight — with disputed figures and unverified claims marked throughout.

10 Chapters

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CHAPTER 1: THE THEORETICAL FATHERS OF ROCKETRY: TSIOLKOVSKY, GODDARD & OBERTH

History of Space Exploration

Chapter 1 · The Theoretical Fathers of Rocketry: Tsiolkovsky, Goddard & Oberth

This course follows the human, political and engineering history of getting into space. It starts before any rocket reached space, with three people who worked out on paper and in small experiments that it was possible: Konstantin Tsiolkovsky in Russia, Robert Goddard in the United States and Hermann Oberth in Central Europe. The sources are three reference biographies. They give dates and contributions clearly, and each leaves out how much the three knew of one another, which the chapter marks.

Konstantin Tsiolkovsky (1857 to 1935)

Tsiolkovsky was born on 17 September 1857 in Izhevskoye, Russian Empire, and died on 19 September 1935 in Kaluga, Soviet Union. He lost his hearing at age nine from scarlet fever and, according to the source, was denied admission to elementary schools because of the disability. He taught himself through reading, including three years in a Moscow library.

Contribution	What the source says
The rocket equation	He derived the formula relating change in velocity to exhaust velocity and mass ratio, recording the date as 10 May 1897.
Multistage rockets	Proposed in his 1929 book <i>Space Rocket Trains</i> , and addressed in earlier work titled "Exploration of Outer Space by Means of Rocket Devices" (1903, 1911, 1914).
Liquid propellants	He calculated that liquid oxygen and liquid hydrogen could reach the 8,000 m/s orbital velocity, and recommended specific oxidizer and fuel pairings.
Space elevator	Conceived in 1895, inspired by the newly built Eiffel Tower.

A Theorist Who Built Nothing

The source states that Tsiolkovsky did not build or launch rockets. He worked through mathematical analysis and design proposals. His 1911 letter contains the line "Earth is the

cradle of humanity, but one cannot live in a cradle forever." I quote it as the source gives it and did not check the rest of the letter.

The Date Is His Own Record

The source says he "recorded" the rocket equation's date as 10 May 1897. That is his own dating, so I report it as his claim, not an independently verified date.

Robert Goddard (1882 to 1945)

Goddard was born on 5 October 1882 in Worcester, Massachusetts, and died on 10 August 1945 in Baltimore, Maryland. He held 214 patents. His two foundational 1914 patents described a multistage rocket (U.S. 1,102,653) and a liquid-propellant rocket (U.S. 1,103,503).

Date	Event
1919	<i>A Method of Reaching Extreme Altitudes</i> sets out his mathematical theories, solid-fuel experiments and possibilities for atmospheric exploration. The Smithsonian distributed 1,750 copies worldwide in late 1919.
13 January 1920	The New York Times mocks his moon-rocket proposal, saying he "only seems to lack the knowledge ladled out daily in high schools."
16 March 1926	First liquid-fuel rocket launch, at Auburn, Massachusetts. It rose 41 feet in a 2.5-second flight and landed 184 feet away.
Summer 1930	He moves to the Eden Valley Test Site near Roswell, New Mexico with Guggenheim funding (\$100,000 over four years), working in relative isolation.
17 July 1969	The day after Apollo 11's launch, the Times publishes "A Correction," acknowledging that "a rocket can function in a vacuum."

Small Numbers, Large Claim

The 1926 flight is 41 feet and 2.5 seconds. The source treats it as foundational, and I do not dispute that, but the figures show why the launch mattered as a proof of concept

and not as a distance. The source also says he eventually reached altitudes above 2.6 kilometres at Roswell, without saying in which year.

Hermann Oberth (1894 to 1989)

Oberth was born on 25 June 1894 in Nagyszeben (Sibiu), Austria-Hungary, and died on 28 December 1989 in Nuremberg, West Germany. The source says he held Hungarian, Romanian and German citizenship.

- **Dissertation:** when he submitted his rocket dissertation to German universities in 1922, it was rejected as "utopian." Professor Augustin Maior at the University of Cluj accepted it, and Oberth defended it successfully on 23 May 1923.
- **The 1923 book:** *Die Rakete zu den Planetenräumen* (The Rocket into Planetary Space) argued that spaceflight was scientifically feasible. The source says it is "generally regarded as a kind of initial spark for rocket and space travel enthusiasm in Germany."
- **The amateur society:** he joined the Verein für Raumschiffahrt in 1927 and mentored enthusiasts including Wernher von Braun and Rudolf Nebel.
- **Film work:** in 1928 to 1929 he was scientific advisor for the film *Woman in the Moon*, designing the rocket model and attempting a publicity launch.

A Link Forward

Von Braun credited Oberth: "I...owe to him not only the guiding-star of my life, but also my first contact with the theoretical and practical aspects of rocketry." The source on Tsiolkovsky adds that Soviet search teams found a German translation of his work whose pages were embellished with von Braun's comments and notes. Chapter 2 picks up von Braun and the German rocket programme. I state here only what the sources say, that von Braun engaged with both men's work.

Three People, One Idea?

The Goddard source says he independently developed the rocket equation around 1912, though Tsiolkovsky published earlier, and that Goddard's version included gravity and drag, which Tsiolkovsky's did not. That is the only direct comparison any of the three sources makes.

Independence Is Not Established Here

The Oberth source contains no discussion of his originality relative to the other two, and the Tsiolkovsky source notes no disputes. I did not find whether Oberth knew of Goddard's or Tsiolkovsky's work when he wrote in 1923, or whether Goddard knew Tsiolkovsky's. "Independent" appears in the Goddard source for the equation only. I do not extend it to the rest, and a claim that all three worked in isolation would need a source I have not read.

Influence Is Described Differently for Each

The Tsiolkovsky source says Soviet designers Sergei Korolev and Valentin Glushko studied his works as youths and sought to implement his theories, and it credits them with turning them into reality. The Goddard source says German researchers including von Braun studied his 1919 paper and that American universities initially dismissed his work as impractical. These are the articles' own summaries of influence, not measurements, and I did not check them.

What I Did Not Verify

I did not find Tsiolkovsky's own writings, the detail of Goddard's patents or the 1926 launch, the physics of the rocket equation, how the Times editorial came to be written, or what the Verein für Raumschiffahrt achieved. I also did not check the claim that Goddard's equation included gravity and drag against the original papers. The chapter presents biographies and dates, not the science.

Hands-On Exercises

EXERCISE 1

Make a table of the three men with birth and death years, nationality and one contribution each, using only the chapter.

→ [Solution](#)

EXERCISE 2

A student writes "Goddard, Tsiolkovsky and Oberth each invented spaceflight independently." Use the chapter to qualify it.

→ [Solution](#)

EXERCISE 3

Explain why a 41-foot, 2.5-second flight is described as a landmark, and say what the chapter does not tell you about how it was judged at the time.

→ [Solution](#)

Quick Reference

- **Tsiolkovsky:** 1857 to 1935; rocket equation (his date 10 May 1897); multistage rockets; liquid oxygen and hydrogen; built no rockets
- **Goddard:** 1882 to 1945; 214 patents; 1919 paper; first liquid-fuel launch 16 March 1926 (41 feet, 2.5 seconds); Times correction 17 July 1969
- **Oberth:** 1894 to 1989; dissertation rejected 1922, accepted at Cluj 1923; *Die Rakete zu den Planetenräumen* 1923; mentor to von Braun
- **Only stated comparison:** Goddard developed the equation independently around 1912, including gravity and drag
- **Not covered:** whether the three knew each other's work, the physics, the Verein's results

CHAPTER 2: THE V-2 ROCKET & OPERATION PAPERCLIP

History of Space Exploration

Chapter 2 · The V-2 Rocket & Operation Paperclip

Chapter 1 covered the three theorists. This chapter covers the first large working rocket, the German V-2, and what happened to its designers after the war. It is a story of technical achievement and of forced labour and mass death, and the chapter keeps the two together. The sources are three reference articles, on the V-2, on Operation Paperclip and on Wernher von Braun. Several of their figures disagree with each other or are labelled disputed, and the chapter says so.

The V-2

The V-2 was developed at the Peenemünde Army Research Center in Nazi Germany. The source says von Braun led technical development after his graduate work attracted German Army interest in 1930, and that Walter Dornberger, an artillery captain, secured research funding and managed the military programme.

Date	Event
3 October 1942	First successful test flight, reaching 84.5 km. Von Braun is quoted: "This third day of October, 1942, is the first of a new era in transportation, that of space travel."
20 June 1944	A vertical launch reaches 174.6 km, making it "retroactively the first artificial object to travel into space."
7 to 8 September 1944	Attacks begin against Paris and London.
Through March 1945	Over 3,000 launched, with London (1,358) and Antwerp (1,610) the main targets.
Specification	Figure
Range	320 km

Specification	Figure
Warhead	1,000 kg
Maximum speed	5,760 km/h
Impact speed	2,880 km/h

"Retroactively" Space

The source's own wording is that the June 1944 flight is retroactively the first artificial object to reach space. That is a later classification, applied by definition of where space begins. The source does not give the definition, and I did not check it, so the chapter does not claim the German programme aimed at space.

Production and Forced Labour

About 6,000 V-2s were built, roughly 5,789 of them at the underground Mittelwerk facility. Production took place at the Mittelbau-Dora concentration camp.

The Figures Conflict

The V-2 article says 20,000 prisoners died during manufacturing, and separately cites a BBC documentary for about 12,000 labourers and prisoners dying in production against about 9,000 people killed by V-2 attacks, calling the comparison disputed. The von Braun article gives the same 12,000 and 9,000. I cannot reconcile 20,000 with 12,000 from these sources. One may count deaths at the whole camp and the other only in production, but the source does not say, so that is a guess. Treat every number as uncertain. What all three sources agree on is that the production deaths were very large and are described as comparable to or larger than the deaths caused by the weapon.

Von Braun

Wernher von Braun was born on 23 March 1912 in Wirsitz, Germany, and died on 16 June 1977 in Alexandria, Virginia. He was technical advisor at Peenemünde from 1939 and chief designer

of the A-4/V-2.

Nazi Party

Joined on 12 November 1937. The source says he later claimed 1939, but records show 1937. He said refusing "would have meant that I would have to abandon the work of my life."

SS

Joined an SS riding school in November 1933 and left in 1934. In spring 1940 he joined the Allgemeine-SS as Untersturmführer, and was promoted to Sturmbannführer (Major) in June 1943. He claimed to have worn the uniform once, though a former SS officer later contradicted that.

The 1944 Arrest

Detained on 14 to 15 March 1944 in Stettin for alleged defeatism and sabotage.

Dornberger and Speer secured his release so the programme could continue.

What He Knew About Mittelwerk

The source says he admitted visiting Mittelwerk 12 to 15 times and called conditions "repulsive," but claimed never to have witnessed deaths personally. He denied visiting Mittelbau-Dora. Some prisoner testimonies allege he witnessed brutality, and others suggest mistaken identity. He said he felt helpless to change the situation.

Disputed, and I Do Not Decide It

The source gives his statements, the contrary testimony and a mistaken-identity suggestion without judging between them. Historians are reported to debate whether he bears moral responsibility for the forced-labour deaths. The FBI and the historian Neufeld are described as concluding he joined the Nazi organisations mainly for career advancement or from fear. Those are conclusions reported by the article, not settled facts, and I did not read the underlying investigations.

Surrender and Operation Paperclip

On 2 May 1945 von Braun's brother Magnus approached American forces on a bicycle: "My name is Magnus von Braun. My brother invented the V-2. We want to surrender." His team had moved westward on 20 June 1945 to avoid Soviet forces, according to the Paperclip article.

Feature	What the source says
What it was	A secret US intelligence programme that transferred German scientists to America, formally established as "Operation Overcast" on 20 July 1945 and renamed in November 1945.
Scale	Over 1,600 German scientists, engineers and technicians between 1945 and 1959.
Run by	The Joint Intelligence Objectives Agency (JIOA), with the US Army's Counterintelligence Corps doing much of the fieldwork.
First arrivals	The first seven rocket scientists, including von Braun, arrived at Fort Strong, Boston in September 1945.

Where They Worked

- Fort Bliss, Texas and White Sands Proving Grounds, New Mexico from late 1945. The V-2 article says the US captured 300 rail cars of components and moved them to White Sands.
- Redstone Arsenal, Huntsville, Alabama from 1 April 1950, with over 130 Paperclip members.
- The Marshall Space Flight Center from July 1960, where von Braun was first director.

The Soviet Mirror

The Soviet equivalent, Operation Osoaviakhim, moved over 2,200 German specialists and 6,000 family members in a single night, 22 October 1946, according to the source. The V-2 article adds that the USSR rebuilt captured rockets as the R-1, launched from Kapustin Yar beginning in October 1948, and that both superpowers used V-2 technology for missiles and space launchers. Both powers took over German work. That is my reading of two separate articles, and neither compares the programmes.

The Ethical Record

The Paperclip article says several recruits had documented Nazi Party membership and SS affiliations, and that records were modified to facilitate recruitment, with their affiliations reportedly downplayed. Arthur Rudolph renounced US citizenship in 1984 amid allegations regarding forced labour in V-2 production. Only one scientist, Georg Rickhey, faced formal trial, and he was acquitted at the Dora Trial in Germany. The article calls the programme strategically valuable, valued at \$10 billion in patents and industrial processes, and controversial because of the recruits' affiliations.

Two Kinds of Evidence

"Valued at \$10 billion" is a figure from the article with no derivation given, so I do not use it as evidence. The strategic value, the falsified records and the trials are separate claims. The von Braun article says he is "seen by some as escaping justice" because of Cold War interests, which the source presents as a view held by some, not a finding. It also notes some scholars suggest his post-war religious conversion was to pacify his own conscience, and that is an interpretation I do not endorse.

Von Braun's US career, from the source: Fort Bliss (1945 to 1950), where his group described themselves as "Prisoners of Peace"; Redstone Arsenal (1950 to 1956), developing the Redstone rocket; and the Marshall Space Flight Center from 1960 as chief architect of the Saturn V for Apollo. Chapter 5 returns to Apollo.

What I Did Not Verify

I did not find the V-2's engineering, the prisoners' own accounts, how Mittelwerk was run, the decision-making behind Paperclip, the numbers of recruits with Nazi ties or the outcomes of any investigation. The casualty figures in this chapter are second-hand and inconsistent, and I did not consult a specialist source on Mittelbau-Dora.

Hands-On Exercises

EXERCISE 1

Set out the death figures the chapter gives for V-2 production and for V-2 attacks, and explain why they cannot simply be compared.

→ Solution

EXERCISE 2

A student writes "The V-2 was the first spacecraft." Use the chapter to qualify it.

→ Solution

EXERCISE 3

List what the sources establish about von Braun's Nazi affiliations, what he claimed, and what the chapter says remains disputed.

→ Solution

Quick Reference

- **V-2:** first test success 3 October 1942 (84.5 km); 174.6 km on 20 June 1944; attacks from 7 to 8 September 1944; about 6,000 built
- **Forced labour:** Mittelwerk and Mittelbau-Dora; 12,000 or 20,000 deaths depending on the count; about 9,000 killed by attacks (all disputed)
- **Von Braun:** born 1912, died 1977; Party 12 November 1937; SS from 1940, Sturmbannführer June 1943; surrendered 2 May 1945
- **Paperclip:** over 1,600 people 1945 to 1959; Fort Bliss, White Sands, Redstone (1950), Marshall (1960)
- **Soviet equivalent:** Operation Osoaviakhim, 22 October 1946
- **Not covered:** engineering, prisoners' accounts, the investigations behind the disputes

CHAPTER 3: SPUTNIK & THE REAL SHOCK OF 1957

History of Space Exploration

Chapter 3 · Sputnik & the Real Shock of 1957

On 4 October 1957 the Soviet Union put the first artificial satellite into orbit. This chapter covers the satellite itself, the American reaction that followed, and the founding of NASA. The sources are three reference articles, on Sputnik 1, on the "Sputnik crisis" and on NASA. The most useful point they raise is that historians disagree about how real the American "crisis" was, and the chapter keeps that disagreement in view.

The Satellite

Sputnik 1 launched on 4 October 1957 at 19:28:34 UTC from Site No. 1 at Baikonur Cosmodrome, on a Sputnik-PS 8K71PS rocket.

Feature	What the source says
Shape and size	A polished metal sphere, 58 cm (23 inches) across, 83.6 kg (184 lb), with four external radio antennas.
Orbit	Elliptical low Earth orbit with a period of 96.20 minutes, perigee 215 km, apogee 939 km, inclination 65.10 degrees.
Radio	Signals on 20.005 and 40.002 MHz, "easily detectable by amateur radio operators." The transmitter ran for 22 days until the battery ran out on 26 October 1957.
End	1,440 orbits, about 70 million kilometres, before re-entering the atmosphere on 4 January 1958.

Simple by Design

The source says Sergei Korolev proposed the satellite and convinced the authorities to proceed with the simplified "Object PS" design after the more ambitious "Object D" faced delays. A sphere with a radio transmitter is a modest object, and its point was to be first. The source does not say how Korolev persuaded the authorities, and I did not check the internal Soviet decisions.

Chapters 1 and 2 in the Background

Korolev was named in Chapter 1's source as one of the Soviet designers who studied Tsiolkovsky's works in youth. Chapter 2 covered the V-2 that both powers built on. The Sputnik-PS rocket's own descent from the V-2 is not stated in these sources, so I do not claim it.

The International Geophysical Year

The launch fell during the International Geophysical Year, which the source says began in July 1957. It beat the American Vanguard programme, and the United States had announced its satellite plans on 29 July 1955. I did not find what the IGY was, who ran it, or why each country planned a satellite for it, so the chapter uses it only as a date.

The American Reaction

The Sputnik 1 article says the launch "surprised the American public" and "shattered the perception" of American technological supremacy, triggering the "Sputnik crisis" and the Space Race.

Alarm

Media coverage amplified fears. The New York Times called it "a major global propaganda and prestige triumph for Russian communism," and Arthur C. Clarke is quoted declaring that America had become "a second-rate power."

Calm

Analyst Samuel Lubell found "no evidence at all of any panic or hysteria in the public's reaction," suggesting the alarm was elite-driven and not popular.

Downplaying

Eisenhower initially said Sputnik did not raise his "apprehensions, not one iota." He later acknowledged three "stark facts"

needing a response and emphasised education reform.

A Crisis or a Manufactured One?

The crisis article reports researchers arguing the crisis was manufactured and not organic: politicians exploited it for polling gains, and national security advisers "overestimated the Soviets' current and potential rocket strength," forcing Eisenhower into an accelerated missile race despite superior intelligence from U-2 spy flights. I present this as the article's report of a view, not a finding. I did not read the underlying research, and the article does not say how widely the view is held.

The Missile Gap

The perceived technological gap became politically useful. According to the crisis article, Kennedy campaigned in 1960 on closing the "missile gap," promising 1,000 Minuteman missiles, far more than the Soviet numbers at the time. The source does not say how many Soviet missiles there were, and I did not find that figure.

What America Did

Date	Event
31 January 1958	Explorer 1 launched.
February 1958	ARPA formed.
29 July 1958	NASA established through the National Aeronautics and Space Act.
1 October 1958	NASA begins operations.

Congress passed the National Defense Education Act within a year. The source says higher education funding rose from \$10 million in 1953 to nearly six times that by 1960, and the National Science Foundation budget grew from \$134 million in 1959 to nearly \$500 million by 1968. Both are the source's figures, and I did not check them or what they were adjusted for.

The Vanguard Failures

The crisis article mentions the first two Project Vanguard failures but gives no dates, and the Sputnik article names Vanguard only as the programme Sputnik beat. I did not find what happened to Vanguard or when. So the chapter says only that the American satellite effort was behind, and Explorer 1 followed nearly four months after Sputnik 1.

NASA

NASA replaced the National Advisory Committee for Aeronautics (NACA), which had conducted aeronautical research since 1915. The source says NACA formed the core of the new structure, reassigning 8,000 employees and three major research laboratories, and that NASA also absorbed several military space programmes, including the Army's Jet Propulsion Laboratory and the Army Ballistic Missile Agency.

A Link Back to Chapter 2

The Army Ballistic Missile Agency is not named in Chapter 2, but Redstone Arsenal, where the von Braun team worked from 1950, and the Marshall Space Flight Center in 1960 are. I do not claim these are the same organisation because the sources do not say so.

NASA "immediately inherited" Project Mercury, developed by the armed forces before the agency existed. The source gives two milestones, Alan Shepard's 1961 suborbital flight and John Glenn's 1962 orbital mission. Chapter 4 covers the human spaceflight race.

What I Did Not Verify

I did not find the reaction in the Soviet Union or elsewhere, Sputnik 2, the Vanguard programme, the details of the National Defense Education Act, the reasoning behind NASA's civilian structure, or how the signal was received in practice. The Sputnik article also gives only a brief description of the political effects. The chapter reports institutions and dates, and it has little on people's experiences.

Hands-On Exercises

EXERCISE 1

Make a timeline from 4 October 1957 to 1 October 1958 using only the chapter, and mark which dates are exact and which are given only by month.

→ [Solution](#)

EXERCISE 2

A student writes "Americans panicked after Sputnik." Use the chapter to qualify it.

→ [Solution](#)

EXERCISE 3

Explain what a historian would need to show to decide whether the "missile gap" was real, using what the chapter says and does not say.

→ [Solution](#)

Quick Reference

- **Sputnik 1:** 4 October 1957; 58 cm, 83.6 kg; 96.20-minute orbit; transmitted 22 days; re-entered 4 January 1958
- **Reaction:** media alarm, a poll analyst finding no panic, Eisenhower initially unconcerned; disputed whether the crisis was manufactured
- **Institutions:** Explorer 1 (31 January 1958); ARPA (February 1958); NASA (29 July 1958, operating 1 October 1958); National Defense Education Act
- **NASA:** replaced NACA (since 1915); 8,000 employees; inherited Project Mercury
- **Not covered:** Vanguard, Sputnik 2, Soviet reaction

CHAPTER 4: GAGARIN & THE RACE TO PUT A HUMAN IN SPACE

History of Space Exploration

Chapter 4 · Gagarin & the Race to Put a Human in Space

After Sputnik (Chapter 3), the next contest was to put a person in space. The Soviet Union won it on 12 April 1961 with Yuri Gagarin, and the United States followed three weeks later with Alan Shepard. The sources are three reference articles, on Gagarin, on Shepard and on the Vostok 1 mission. They give the two flights clearly. They also record a concealed detail about the landing, which the chapter treats as central.

Vostok 1

Vostok 1 launched on 12 April 1961 at 06:07 UTC from Baikonur Cosmodrome Site 1. The source gives the flight as about 108 minutes, and adds that one source suggests 106.

Feature	What the source says
Orbit	A single orbit, apogee 327 km and perigee 181 km, with a period of 89.1 minutes.
Control	The mission operated under automatic systems and ground control. Because of medical concerns about how a person would respond to weightlessness, engineers locked the manual controls, though a code (1-2-5) was placed aboard for emergencies. It was disclosed to Gagarin beforehand.
Provisions	The spacecraft carried 13 days of provisions in case the retrorockets failed. The article says natural orbital decay would have taken 20 days.
Landing	Gagarin ejected at 7 km altitude and parachuted separately, and the spacecraft also descended by parachute. Both landed 26 km southwest of Engels in the Saratov region.

A Safety Margin the Numbers Do Not Cover

The source calls the gap between 13 days of supplies and 20 days of natural decay "a significant safety margin uncertainty." It does not say how the 20-day figure was reached, or whether it was known before launch. I use it only as the article's own remark.

Who Was Gagarin

Yuri Gagarin was born on 9 March 1934 in Klushino and died on 27 March 1968 near Kirzhach in a MiG-15 crash. From 154 qualified pilots, medical commissions selected 29 candidates and 20 were approved. The first twelve, including Gagarin, were approved on 7 March 1960. He was chosen as primary pilot over five others in the accelerated "Vanguard Six" training group. The source does not say why he was chosen, and I did not find the reasons.

What He Said at Launch

The source says Gagarin used the informal phrase "Off we go!" at launch, which later became a popular expression in the Eastern Bloc. The Russian word "Poyekhali" that goes with it in popular accounts is not in the source I read, so I report the English phrase only.

The Concealed Landing

The Soviet Union initially insisted that Gagarin had landed with his capsule, and he had to give that account at press conferences. The Vostok 1 article says the deception persisted until 1971, when Moscow admitted he had ejected separately.

Why It Mattered, and What Is Unclear

The source says the FAI required pilots to land with their spacecraft for official records, and that it "revised its rules" after learning the truth and certified Gagarin's accomplishment. The Gagarin article says the same about certification. The two articles differ on the year the truth emerged only by implication: one says officials "initially concealed" it, and the other says Moscow admitted it in 1971. I did not find when the FAI learned, or how the rules were changed, so the chapter does not date that.

Freedom 7

Alan Shepard (18 November 1923 to 21 July 1998) was one of seven astronauts chosen from military test pilots and announced on 9 April 1959, the Mercury Seven. On 5 May 1961 he

piloted a suborbital mission, Freedom 7, reaching 101.2 nautical miles in a flight of 15 minutes. The spacecraft splashed down 263.1 nautical miles downrange.

	Vostok 1 (Gagarin)	Freedom 7 (Shepard)
Date	12 April 1961	5 May 1961, 23 days later
Type	Orbital, one orbit	Suborbital
Duration	About 108 minutes	15 minutes
Control	Automatic, manual controls locked	Some manual control of the craft's attitude
Spacecraft	About three times larger, per the Shepard article	The smaller of the two

Two Numbers for the Gap

The Shepard article says "three weeks" and the Vostok article says "23 days." The dates give 23 days, so I use that. The two agree.

Not the Same Kind of Flight

The comparison shows the two flights were not equivalent. A suborbital flight goes up and comes down, and an orbital flight circles the Earth. The Vostok article calls it the decisive first achievement in human spaceflight, and the Shepard article treats the Soviet flight as the earlier and larger one. The sources do not say how the American public or government responded to being second, so I add nothing about that. Chapter 3's account of the Sputnik reaction is the nearest evidence, and it does not transfer to 1961.

After the Flights

- **Gagarin:** became an international celebrity and a Soviet national hero, with parades and state honours. He died in 1968, and the source says the cause remains uncertain and disputed, with investigations pointing to weather, a possible bird strike, oxygen deprivation or a near-miss collision. The Kremlin declined further investigation in 2007.

- **Shepard:** in 1971 he became "the fifth and, at the age of 47, the oldest man to walk on the Moon," and the only one of the Mercury Seven to do so. He struck two golf balls on the lunar surface. Chapter 6 returns to the Moon landings.

A Death Left Unresolved

The source gives four explanations for the 1968 crash and does not favour one. I do not choose either. It is a disputed cause and I report it as such.

What I Did Not Verify

I did not find the design of the Vostok capsule beyond what is above, the Mercury-Redstone booster, Valentina Tereshkova and later flights, the maximum altitude of Vostok 1, the political decisions behind announcing the flight, or what Gagarin himself later said about the landing. I also did not check the claim about the capsule size against another source.

Hands-On Exercises

EXERCISE 1

Compare Vostok 1 and Freedom 7 on four points using the chapter, and say why calling both "the first" would be misleading.

→ [Solution](#)

EXERCISE 2

A student writes "Gagarin landed in his capsule." Use the chapter to correct it and say how the error arose.

→ [Solution](#)

EXERCISE 3

List the explanations the chapter gives for Gagarin's death and say what evidence would be needed to prefer one.

→ Solution

Quick Reference

- **Vostok 1:** 12 April 1961, 06:07 UTC, Baikonur; about 108 minutes; one orbit (181 to 327 km); ejected at 7 km
- **Concealment:** the separate landing was hidden until 1971; the FAI revised its rules
- **Gagarin:** 1934 to 1968; selected from 154 pilots; cause of death disputed
- **Freedom 7:** 5 May 1961; suborbital; 15 minutes; 101.2 nautical miles; some manual control
- **Shepard:** Mercury Seven (announced 9 April 1959); walked on the Moon in 1971
- **Not covered:** the capsule's design, later flights, the reasons for Gagarin's selection

CHAPTER 5: KENNEDY'S REAL MOON PLEDGE & THE APOLLO PROGRAM

History of Space Exploration

Chapter 5 · Kennedy's Real Moon Pledge & the Apollo Program

Within weeks of Shepard's flight (Chapter 4), President Kennedy committed the United States to a lunar landing. This chapter covers that pledge, the rocket built to meet it, the Apollo 1 fire that nearly derailed it, and the sequence of missions that followed. The sources are three reference articles, on the Apollo programme, the Saturn V and Apollo 1. Their figures differ in places, and the chapter marks each difference and does not pick one.

The Pledge

On 25 May 1961 Kennedy proposed "landing a man on the Moon and returning him safely to the Earth" before the decade's end, saying: "I believe that this nation should commit itself to achieving the goal, before this decade is out..." In September 1962, at Rice University, he declared "We choose to go to the Moon," and explained the choice was "not because they are easy, but because they are hard."

The Gap From Chapter 4

Shepard flew on 5 May 1961, and the pledge came 20 days later. The source does not link them, and I did not find what Kennedy said about the Soviet flight in the speech. I note the dates only.

Scale and Cost

The Apollo article says the programme ran from 1961 to 1972, with the first crewed flight in October 1968. At its height it employed 400,000 people across 20,000 industrial firms and universities.

Two Cost Figures

The article cites \$25.4 billion in 1973 dollars, equivalent to \$257 billion in 2020 dollars, and it also mentions an earlier reference to \$25 billion, equivalent to \$187 billion in 2024

dollars. The two conversions are \$70 billion apart, and they use different years and, I suspect, different methods. The source does not explain the difference and I did not investigate it. Treat any modern-dollar figure as an approximation.

The Saturn V

Feature	What the source says
Size	363 ft (111 m) tall and 33 ft in diameter. Fully fuelled mass ranged from 2.8 to 3.0 million kg.
Thrust	33,000 kN at sea level from the first stage, and about 34.5 meganewtons in total.
Payload	Roughly 140,000 kg to low Earth orbit and about 43,500 kg to the Moon.
Stages	S-IC (five F-1 engines), S-II (five J-2 engines), S-IVB (one J-2 engine).
Builders	Boeing built the S-IC at New Orleans, North American Aviation the S-II in California, and Douglas the S-IVB at Huntington Beach.
Development	"Scientists relocated from Nazi Germany," particularly von Braun, led technical design at the Marshall Space Flight Center in Huntsville, which managed overall development.

The Link to Chapter 2

Chapter 2 gave von Braun's route from Peenemünde through Paperclip and Redstone to the Marshall Space Flight Center in 1960. This is where that path ends up, as the source describes it. The source does not say how much of the design was his personal work as against his team's, and I did not find out.

Payload Units and Flight Counts Do Not Match

The Apollo article gives a lunar payload of 96,800 pounds, later 103,600 pounds. The Saturn V article gives about 43,500 kg. 96,800 lb is about 43,900 kg and 103,600 lb about 47,000 kg, so the figures are consistent only if the 43,500 refers to an early mission. That is my arithmetic, and neither source says so. The Saturn V article also says thirteen were

launched between 1967 and 1973 with twelve successful, and that the programme landed "24 astronauts on the Moon across nine missions." The Apollo article says six successful landings and twelve people who walked the surface. Twenty-four appears to count all who went to the Moon, including those who orbited, and not those who walked, but the source does not explain the wording, so I do not adopt it.

The Saturn V article notes that on Apollo 6, "J-2 engine problems caused early shutdown of two engines in the second stage, and prevented third stage restart," though the mission ultimately succeeded as an uncrewed test. It is the only failure the source names.

Deciding How to Get There

Lunar Orbit Rendezvous was adopted in 1962 after initial scepticism. The article says John Houbolt championed the approach and that it "proved crucial for meeting Kennedy's deadline." I did not find what the alternatives were or why they were rejected, so the chapter does not describe the technique.

Apollo 1

On 27 January 1967, Command Pilot Gus Grissom, Senior Pilot Ed White and Pilot Roger Chaffee died in a cabin fire during a launch rehearsal test at Cape Kennedy. It was a "plugs-out" test simulating internal power, and the fire began at 6:31 pm EST.

Finding of the review board	Detail
Ignition source	Likely electrical arcing from stripped wiring near the Environmental Control Unit, possibly involving electrolysis of ethylene glycol coolant. The source says "likely" and "possibly."
Atmosphere	The cabin held pure oxygen at 16.7 psi, over five times normal atmospheric oxygen, making materials highly flammable.
Hatch	A plug-door hatch could not open against internal pressure, and Grissom could not reach the vent valve to equalise it. Ground crews took five minutes to open the hatch layers.

Finding of the review board	Detail
Materials	34 square feet of Velcro and nylon netting burned readily in the oxygen.
Preparedness	The test was deemed non-hazardous, and rescue equipment and personnel were inadequate.

The article says the primary cause of death was cardiac arrest from carbon monoxide exposure. The Apollo 204 Review Board was chaired by Floyd L. Thompson and included astronaut Frank Borman and spacecraft designer Maxime Faget, and it completed its investigation by 5 April 1967.

What Changed

- Launch atmosphere changed to 60 percent oxygen and 40 percent nitrogen at sea-level pressure, venting to 5 psi during ascent.
- Nylon spacesuits were replaced with Beta cloth (fibreglass and Teflon).
- An outward-opening hatch was made operable in under five seconds.
- Flammable materials were replaced with self-extinguishing alternatives, and wiring and plumbing insulation improved.

Twenty Months

Crewed flights were suspended for twenty months, and the first successful crewed Apollo mission was Apollo 7 in October 1968, flown by the original Apollo 1 backup crew. The source adds that Gene Kranz directed that Mission Control embody "Tough" and "Competent" standards, and that NASA reapplied the principle after the 2003 Columbia disaster. Chapter 7 covers the shuttle disasters, and I did not check the Kranz attribution against another source.

The Missions

The Apollo article names Apollo 7 as the first crewed flight, Apollo 8 as the first lunar orbit and Apollo 11 as the first landing, on 20 July 1969. Apollo 17 in December 1972 was the final mission. Chapter 6 covers Apollo 11 in detail.

What I Did Not Verify

I did not find the reasoning behind Kennedy's decision, the politics and budget debates, the Gemini programme that lay between Mercury and Apollo, the command and lunar modules, the Soviet lunar effort, or the missions between Apollo 8 and Apollo 11. Nor did I verify any of the engineering figures against another source. The chapter reports headline numbers and one accident.

Hands-On Exercises

EXERCISE 1

List the causes of the Apollo 1 fire that the review board identified, mark which the source hedges, and list two changes made afterwards.

→ [Solution](#)

EXERCISE 2

A student writes "24 astronauts walked on the Moon." Use the chapter to correct it and explain where the confusion may come from.

→ [Solution](#)

EXERCISE 3

The chapter gives two cost figures for Apollo. Explain how you would decide which to quote and what you would need to check.

→ [Solution](#)

Quick Reference

- **Pledge:** 25 May 1961, Moon landing and safe return "before this decade is out"; Rice speech September 1962
- **Programme:** 1961 to 1972; 400,000 people; cost \$25 billion or \$25.4 billion in period dollars (modern conversions differ)
- **Saturn V:** 363 ft; three stages; Marshall managed development; thirteen launched 1967 to 1973
- **Apollo 1:** 27 January 1967; Grissom, White, Chaffee; pure oxygen, inward hatch, flammable materials; 20-month suspension
- **Landings:** six; twelve walked; Apollo 11 on 20 July 1969; Apollo 17 in December 1972
- **Not covered:** Gemini, the modules, the politics

CHAPTER 6: APOLLO 11 & THE REAL STORY OF THE FIRST MOON LANDING

History of Space Exploration

Chapter 6 · Apollo 11 & the Real Story of the First Moon Landing

Chapter 5 covered the pledge and the programme. This chapter covers the mission that met it, Apollo 11 in July 1969, and Apollo 13, the near-disaster of April 1970. The sources are three reference articles, on Apollo 11, Apollo 13 and the conspiracy theories about the landings. They give the timelines clearly, and they mark one disputed word, a fuel figure that reads oddly and a small number of hedges.

The Crew and the Timeline

Apollo 11's crew was Neil Armstrong (Commander), Michael Collins (Command Module Pilot) and Buzz Aldrin (Lunar Module Pilot).

Date	Event
16 July 1969, 13:32 UTC	Launch.
20 July 1969, 20:17:40 UTC	Lunar landing at Tranquility Base in Mare Tranquillitatis, selected partly for its smooth, relatively crater-free terrain.
24 July 1969	Splashdown in the Pacific, with recovery by USS Hornet.

The Landing

The source says the guidance computer triggered unexpected 1201 and 1202 program alarms because of a rendezvous radar hardware issue. Armstrong took manual control when the computer targeted a boulder-strewn area, and found clear ground with only 90 seconds of fuel remaining. The spacecraft touched down with approximately 216 pounds of usable fuel left.

Two Fuel Figures

The source gives both "90 seconds of fuel remaining" and "approximately 216 pounds of usable fuel." These measure different things, time and mass, and the source does not say how they relate, or whether the 90 seconds was at the moment he found clear ground or at touchdown. I report both as the article gives them and do not convert between them.

What I Did Not Verify

The article gives the cause of the alarms only as a rendezvous radar hardware issue. I did not find how the alarms were interpreted in real time, or how the descent was planned. Chapter 5 mentioned the decision to use Lunar Orbit Rendezvous, and I do not have a source connecting it to this landing.

On the Surface

The astronauts spent approximately 2.5 hours on the lunar surface, collecting 21.5 kilograms of material and deploying scientific instruments. An American flag and a commemorative plaque remain at the landing site.

The First Words

Armstrong's words as the source gives them: "That's one small step for [a] man, one giant leap for mankind." The article notes uncertainty over whether he actually said the indefinite article "a," which remains disputed.

A Meaning That Depends on One Letter

Without "a," the sentence contrasts "man" with "mankind" as though they were different things, and with it the phrase reads as one man's step against humanity's leap. That is my reading of grammar and not from the source. The source says only that whether he said it is disputed, and it does not give the evidence on either side, so the chapter does not decide.

The source estimates 600 million viewers worldwide watched the moonwalk, roughly one-fifth of Earth's population. It gives no basis for the estimate, so I treat it as an approximation.

Apollo 13

Apollo 13 launched on 11 April 1970 with Commander Jim Lovell, Command Module Pilot Jack Swigert and Lunar Module Pilot Fred Haise. Swigert replaced Ken Mattingly two days before launch after Mattingly's exposure to rubella.

The Failure

At 55 hours and 55 minutes into the mission, an oxygen tank in the service module exploded. The crew reported: "Houston, we've had a problem here."

The Cause

Damaged Teflon insulation on wires inside Oxygen Tank 2, compromised during ground testing. When thermostatic switches failed under 65-volt power, temperatures reached about 540 degrees C. About 95 seconds after Swigert activated stirring fans, an electrical arc ignited the insulation.

The Return

Mission Control directed the crew to use the lunar module as a lifeboat, on a free-return trajectory around the Moon. Engineers improvised a carbon dioxide scrubber adapter from plastic, duct tape and other onboard materials, later called "the mailbox."

Quoted Wording

Popular retellings say "Houston, we have a problem." The source's own wording is "Houston, we've had a problem here." I use the source's version, and I did not check the original recording.

Apollo 13 splashed down safely on 17 April 1970 in the South Pacific. The landing was aborted, so the mission achieved neither its geological objectives nor lunar surface exploration. The review board recommended minimising combustible materials inside oxygen tanks, and future missions including Apollo 14 incorporated the modifications.

Two Accidents, One Cause Family?

Apollo 1 (Chapter 5) and Apollo 13 both involved fire or ignition in an oxygen-rich system and led to redesigns of combustible materials. That is my comparison of two articles. The sources do not connect them, and the mechanisms differ, one a cabin and one a tank, so I do not claim the second was a repeat of the first.

Did It Happen?

The conspiracy theories article describes claims that NASA faked the landings, citing alleged issues with photographs, radiation exposure, mechanical problems and missing documentation. It describes the claims as "fringe" and "pseudoscience," and says experts regard them as "demonstrably false." It reports that surveys found 6 to 20 percent of Americans believed the landings were faked.

Independent evidence	What the source says
Orbital imagery	The Lunar Reconnaissance Orbiter photographed Lunar Module descent stages and astronaut tracks.
Samples	Moon rocks are available for examination.
Independent tracking	The Soviet Union monitored Apollo missions despite its competing programme, and its own spacecraft had reached the Moon since 1959.
Retroreflectors	Devices left on the Moon enable laser measurement.

Why This Section Is Short

The article rebuts each hoax claim in detail, and I did not read those rebuttals, so I do not reproduce them. The chapter states the article's conclusion and the kinds of evidence it lists. It does not evaluate the evidence itself. The point about Soviet tracking is notable because a rival had reason to expose a fake, but that inference is mine, and the article states only that the Soviets monitored the missions.

What I Did Not Verify

I did not find Collins's experience in lunar orbit, the details of the moonwalk and the science conducted, the crews of Apollo 8 and Apollo 10, the later missions or the reasons for ending Apollo after Apollo 17. I also did not check the 600 million audience estimate or the 21.5 kg figure against another source.

Hands-On Exercises

EXERCISE 1

Set out the Apollo 11 landing sequence as the chapter gives it, and list what the two fuel figures do and do not tell you.

→ [Solution](#)

EXERCISE 2

A student writes "Apollo 13 was a failure." Use the chapter to give a more precise statement.

→ [Solution](#)

EXERCISE 3

Classify the four kinds of independent evidence for the landings by who could have checked each one, and say what the chapter does not show about any of them.

→ [Solution](#)

Quick Reference

- **Apollo 11:** launch 16 July 1969; landing 20 July, 20:17:40 UTC at Tranquility Base; splashdown 24 July; about 2.5 hours on the surface; 21.5 kg of material

- **Landing:** 1201 and 1202 alarms; manual takeover; 90 seconds of fuel, about 216 lb usable at touchdown
- **First words:** whether Armstrong said "a man" is disputed
- **Apollo 13:** launched 11 April 1970; tank explosion at 55 h 55 min; free-return trajectory; splashdown 17 April; landing aborted
- **Evidence for the landings:** orbiter photographs, samples, Soviet tracking, retroreflectors
- **Not covered:** the moonwalk science, Collins in orbit, Apollo's end

CHAPTER 7: THE SPACE SHUTTLE ERA: AMBITION & REAL TRAGEDY

History of Space Exploration

Chapter 7 · The Space Shuttle Era: Ambition & Real Tragedy

After Apollo (Chapters 5 and 6), the United States built a reusable spacecraft, the Space Shuttle, which flew from 1981 to 2011. This chapter covers the programme and the two accidents that killed fourteen astronauts, Challenger in 1986 and Columbia in 2003. The sources are three reference articles. The two accident reports agree that the causes were organisational as well as technical, and the chapter keeps both parts.

The Programme

Feature	What the source says
First launch	12 April 1981 (STS-1).
Final flight	21 July 2011 (STS-135).
Flights	135 missions.
Fleet	Five operational orbiters, plus the test orbiter Enterprise.
Cost	"\$450 million (2011)" per launch, against a total project cost of "\$211 billion (2012)."
Achievements	Deployed the Hubble Space Telescope and serviced it several times, took part in building and servicing the International Space Station, and launched satellites and interplanetary probes.

Reusable, but Not Cheap

The source says the programme promised savings through reusability, and its own cost per launch suggests each flight stayed expensive. It does not say what the original cost or flight-rate targets were, so the chapter cannot measure how far the programme fell short. The two figures are also in different years' dollars, 2011 and 2012, and I did not adjust them.

Challenger, 28 January 1986

The crew was Commander Dick Scobee, Pilot Michael J. Smith, Mission Specialists Ellison Onizuka, Judith Resnik and Ronald McNair, Payload Specialist Gregory Jarvis, and the teacher Christa McAuliffe. The orbiter "broke apart 73 seconds into its flight" at 46,000 feet above the Atlantic, killing all seven.

The Technical Cause

An O-ring seal failure in the right solid rocket booster, at a record-low temperature (8 degrees F at the booster). Cold stiffened the rubber, reducing its sealing ability. Hot pressurised gas leaked through the joint, burned through structural attachments and caused catastrophic structural failure.

The Warning

Morton Thiokol engineers expressed concerns about O-ring performance below 53 degrees F. Robert Lund and Joe Kilminster recommended against launching until it warmed. The source says management reversed this position, calling the evidence "inconclusive."

The Commission

The Rogers Commission found the O-ring failure was the cause and criticised NASA and Morton Thiokol for overlooking evidence of danger. It found "the safety culture and management structure at NASA were insufficient."

The source says the commission emphasised that NASA "accepted the risk of O-ring erosion without evaluating" the safety implications, and that "pressure to increase the rate of flights negatively affected" training and quality control. The physicist Richard Feynman demonstrated the O-ring's brittleness in cold water during televised hearings, advocating harsher criticism of NASA. The shuttle remained grounded for 32 months and returned to flight in September 1988.

What the Sources Leave Open

The source does not say who decided to launch, whether the reversal was directed from above the engineers, or what happened to the crew after the break-up. I did not find

those, and the chapter does not describe them. "Management reversed this position" is the article's summary, and it does not name the people involved.

Columbia, 1 February 2003

Columbia disintegrated on re-entry over Texas and Louisiana, killing Commander Rick Husband, Pilot William McCool, Michael Anderson, Kalpana Chawla, David Brown, Laurel Clark and payload specialist Ilan Ramon.

Stage	What the source says
Launch, 16 January 2003	Foam insulation broke from the external tank's left bipod attachment at 81.7 seconds and struck the left wing's reinforced carbon-carbon panels at about 625 to 840 feet per second.
In orbit	The breach went undetected during the 16-day mission.
Re-entry	Hot gases penetrated the damaged thermal protection system, melting internal wing structures and causing the orbiter to lose control and break apart.

The Investigation Board's Findings

The Columbia Accident Investigation Board identified technical and organisational failures. Technically, the foam strike caused the breach. Organisationally, NASA had normalised the risk of foam strikes as an "accepted flight risk" despite previous damage. The source quotes the board: "Program operating costs were lowered by 21% from 1991 to 1994" while aggressive launch schedules were maintained, creating pressure that discouraged safety escalation.

The Same Pattern Twice

Challenger: a known erosion problem accepted, and pressure to fly more often.
Columbia: a known foam problem accepted as a flight risk, and pressure from cost and schedule. That is my comparison, but the two articles use the same kinds of terms (accepted risk, schedule pressure). The Columbia article's "normalised" is the board's word, and I do not know whether the Rogers Commission used it.

Could the Crew Have Been Saved?

The board concluded the crew could theoretically have survived if NASA had requested Defense Department imaging of the wing damage, managers had authorised a mission extension to about 15 February, and a rescue mission using Atlantis had been launched. On-orbit repair prospects were deemed "low" in likelihood of success.

Three Conditions, One Verdict

The source gives all three conditions as needed together, and it says "theoretically." I do not know how likely the board thought the combined rescue was, and the source does not say. The chapter does not go beyond "theoretically."

The End of the Programme

Columbia's grounding lasted 29 months. Return-to-flight missions (STS-114 in July 2005, STS-121 in July 2006) required redesigns, including removal of bipod foam and addition of inspection equipment. President Bush's 2004 Vision for Space Exploration directed the fleet to complete the International Space Station and retire by 2010. Retirement occurred in 2011, after Atlantis's final flight, and the United States then relied on Russian Soyuz spacecraft until commercial alternatives emerged. The Columbia article says no American crewed spacecraft launched again until SpaceX's 2020 Crew Dragon mission.

What I Did Not Verify

I did not find the shuttle's design decisions, why the programme's flight rate fell short, the individual orbiters' histories, Hubble and station missions in detail, how the retirement date was chosen, or the families' and survivors' accounts. I also did not check the cost totals. The chapter reports two accident findings and headline programme figures.

Hands-On Exercises

EXERCISE 1

Set out the technical and organisational causes of each accident as the chapter gives them, and list what the chapter does not say about each.

→ [Solution](#)

EXERCISE 2

A student writes "The shuttle was cheap because it was reusable." Use the chapter to answer it.

→ [Solution](#)

EXERCISE 3

Explain why the chapter's comparison of the two accidents is presented as my own, and what a historian would need to compare the two commissions' conclusions properly.

→ [Solution](#)

Quick Reference

- **Programme:** 12 April 1981 to 21 July 2011; 135 flights; five orbiters; \$450 million per launch (2011)
- **Challenger:** 28 January 1986; 73 seconds; O-ring, cold; Thiokol warning below 53 degrees F; grounded 32 months
- **Columbia:** 1 February 2003; foam strike at launch; normalised risk; grounded 29 months
- **Rescue:** theoretically possible only if three conditions were all met
- **After:** retired 2011; reliance on Soyuz until Crew Dragon in 2020
- **Not covered:** the design, the flight-rate targets, the individual accounts

CHAPTER 8: SPACE STATIONS: SALYUT, MIR & THE INTERNATIONAL SPACE STATION

History of Space Exploration

Chapter 8 · Space Stations: Salyut, Mir & the International Space Station

After the Moon landings and alongside the Shuttle (Chapters 5 to 7), a second line of development was the space station, a place to live in orbit for weeks, then months, then years. This chapter follows it from the first station, Salyut 1 in 1971, through Mir, to the International Space Station. The sources are three reference articles. They give dates and sizes clearly, and they give few costs, so the chapter says where money is missing.

Salyut 1 (1971)

Salyut 1 (DOS-1) launched on 19 April 1971 and is described as "the world's first space station." The source says the Soviets shifted focus to orbital stations after Apollo 11's landing, seeking to outpace the American Skylab programme. I did not find what Skylab was at this point in the source, so the chapter does not explain it.

The Soyuz 11 Tragedy

The Soyuz 11 crew, Georgy Dobrovolsky, Viktor Patsayev and Vladislav Volkov, docked and spent 23 days aboard conducting experiments. The source says "a pressure relief valve had malfunctioned during reentry leading to a loss of cabin atmosphere." The crew, lacking pressure suits, asphyxiated, and became "the only humans to die above the Kármán line." The disaster prompted a mandatory redesign: all further Soyuz missions would require pressure suits during launch, docking and re-entry.

What I Cannot Add

The source does not say how the fault was found, when the crew died in the sequence of re-entry, or how the crew reacted. It also does not define the Kármán line. I report the phrase as written and do not give a height for it.

The Programme

- The Salyut programme produced seven stations in total. Salyut 1's mission ended in October 1971, and later stations such as Salyut 6 and Salyut 7 achieved greater success.
- The final module, Zvezda (DOS-8), became "the core of the Russian Orbital Segment" of the International Space Station.
- The Soviet military operated parallel Almaz stations (Salyut 2, 3 and 5), and Salyut 1 was adapted from Almaz designs but repurposed for civilian science.

Mir (1986 to 2001)

Mir launched on 20 February 1986 and was deorbited on 23 March 2001 after "funding was cut off." The source gives 15 years of operation, 12.5 years of them continuously occupied.

Feature	What the source says
Modules	Seven pressurised modules assembled over a decade: the Core Module, Kvant-1, Kvant-2, Kristall, Spektr, a Docking Module and Priroda.
Size	About 130 tonnes, 19 metres long by 31 metres wide.
Orbit	86,331 orbits at an inclination of 51.6 degrees, about 15.7 times a day at altitudes of 354 to 374 km.
Visitors	105 cosmonauts and astronauts from 12 nations.
Record	Valeri Polyakov holds the "longest single human spaceflight," 437 days on the station from 1994 to 1995.
Cost	An estimated "\$4.2 billion over its lifetime."

Cooperation and Trouble

The Shuttle-Mir programme involved "eleven Space Shuttle missions" and enabled an extended American presence on the Russian station. The source calls it a major Cold War thaw in space cooperation. The 1997 collision with the Progress M-34 vehicle damaged the Spektr module severely, and fire incidents also occurred.

Collisions and Fires, Not Described

The source names the 1997 collision and fires in a sentence each. It does not say who was aboard, what was lost or whether anyone was hurt. Following the Soviet dissolution, Russia struggled financially, and the programme became unsustainable. I did not find how the decision to deorbit was made.

Links Back

Chapter 3's Sputnik and Chapter 4's Vostok belong to the Soviet line that produced Salyut and Mir. The source does not connect them, and I do not claim a continuous programme. The Shuttle-Mir cooperation contrasts with the rivalry of Chapters 3 to 6, and the sources do not say why the change happened.

The International Space Station

Five agencies operate the ISS: NASA (United States), Roscosmos (Russia), ESA (Europe), JAXA (Japan) and CSA (Canada). The source says fifteen countries are involved, making it "the most politically and legally complex space exploration program in history."

Feature	What the source says
First module	The Russian-built Zarya module launched on 20 November 1998.
Continuous occupation	Began on 2 November 2000 when Expedition 1 arrived, and the article says "25 years and 323 days" as of its update.
Scale	109 by 73 metres, a pressurised volume of 1,005 cubic metres (comparable to a Boeing 747), and a total mass of 450,000 kg.
Visitors	"As of August 2025, 290 individuals from 26 countries had visited the station."
Research	Microgravity experiments, materials science, astrobiology, space medicine and Earth observation, with the Alpha Magnetic Spectrometer as a flagship dark-matter experiment.

Threads From Earlier Chapters

The Shuttle (Chapter 7) took part in building the station, and the Soviet Zvezda module is its core Russian segment. After Columbia, the source in Chapter 7 says the fleet was to finish the station and retire. So the station is where both lines of development meet. That is my synthesis of separate articles, and no source says it.

The Future

The station remains operational "until the end of 2030," after which de-orbiting is planned with the US Deorbit Vehicle. The source adds that "critique of this plan and the proposal of parking the station at a more stable higher orbit has gathered congressional support."

Cost Is Missing

The source says rising costs forced more international participation, and gives no budget figures. So the chapter cannot compare the station's cost with Mir's \$4.2 billion or with the Shuttle programme's \$211 billion (Chapter 7). Any such comparison would need figures from another source, in matching dollars.

What I Did Not Verify

I did not find Skylab, Tiangong or China's stations, the political negotiation of the ISS, what has been learned from the research, the crews' daily lives, or the reasons for the 2030 date. I also did not check the "25 years and 323 days" figure against the launch date, which depends on the day the article was updated.

Hands-On Exercises

EXERCISE 1

Make a table of Salyut 1, Mir and the ISS with launch date, end or planned end, and one fact each, using only the chapter.

→ [Solution](#)

EXERCISE 2

A student writes "The Soyuz 11 crew died in space." Use the chapter to state exactly what the source says.

→ [Solution](#)

EXERCISE 3

Say why the chapter cannot rank the three stations by cost, and what you would need to do so.

→ [Solution](#)

Quick Reference

- **Salyut 1:** 19 April 1971; first station; Soyuz 11 crew (23 days aboard) died on re-entry; pressure suits required afterwards
- **Mir:** 20 February 1986 to 23 March 2001; about 130 tonnes; 105 visitors; Polyakov 437 days; 1997 collision; \$4.2 billion
- **ISS:** Zarya 20 November 1998; occupied since 2 November 2000; five agencies, fifteen countries; operations to the end of 2030
- **Cost:** no ISS figure in the sources
- **Not covered:** Skylab, China's stations, the ISS negotiations

History of Space Exploration

Chapter 9 · Robotic Exploration: Voyager, Mars Rovers & the Outer Solar System

The earlier chapters mostly followed people. This one follows machines: the two Voyager probes launched in 1977 and the rovers that have driven on Mars. The sources are three reference articles, on the Voyager programme, the Mars rovers and the Opportunity rover. Two of them give different numbers for how long Opportunity ran, and the Voyager figures are dated to 2024, so the chapter marks what is fixed and what is not.

Voyager

Both probes launched in 1977 to exploit a rare planetary alignment occurring "once every 175 years," which enabled gravity-assist trajectories through the outer planets.

	Voyager 2	Voyager 1
Launch order	Launched first	Launched second
Planets flown by	Jupiter, Saturn, Uranus, Neptune	Jupiter and Saturn, on a trajectory optimised for Saturn's moon Titan
Heliopause crossing	5 November 2018	25 August 2012
Distance (2024)	20.4 billion km, 55,000 km/hour	24.5 billion km, 61,000 km/hour

Dates and Distances the Source Does Not Give

The article does not give the encounter date for any planet, and it gives the distances "as of 2024," so they are already out of date. I did not find the launch dates or the names of the instruments, so the chapter does not state them. I also did not find how "interstellar space" is defined for the crossings. The source uses the heliopause, and I do not define it.

The Golden Record

Each probe carries a 12-inch golden phonograph record with "pictures and sounds of Earth" selected by a committee chaired by Carl Sagan.

Pale Blue Dot

Voyager 1 photographed Earth on 14 February 1990 from 6 billion kilometres away, an image later popularised by Sagan.

Power

Power has declined from about 470 W at launch to about 268 W by 2011.

Communications are expected through 2036, though "additional science instruments may need to be turned off."

Both have adequate power and propellant through at least 2026.

Machines Outlasting Their Plan

Voyager 1 crossed the heliopause 35 years after launch. The source does not say what the original mission length was, so I cannot state how far the probes exceeded it. The Opportunity rover, below, has a stated plan to compare.

Mars Rovers

Rover	Dates	What the source says
Sojourner	4 July to 27 September 1997	Communications lost 27 September. Just over 100 metres driven.
Spirit	4 January 2004 to 22 March 2010	Exceeded the original mission by nearly six years and drove 7.73 km. "Its wheels became trapped in sand." NASA ceased reactivation attempts on 25 May 2011.

Rover	Dates	What the source says
Opportunity	25 January 2004 to 10 June 2018	45.16 km driven. Last status came when a global dust storm blocked sunlight. The mission was declared complete on 13 February 2019.
Curiosity	6 August 2012, operational as of September 2026	"Still operational."
Perseverance	18 February 2021, operational as of September 2026	Carried the helicopter Ingenuity, whose mission ended.
Zhurong	22 May 2021 to 20 May 2022	1,921 metres driven. Deactivated because of approaching sandstorms and the Martian winter, and dust buildup prevented reactivation.

Perseverance carries samples cached for future Mars sample-return missions, advancing NASA's objectives for evidence of habitability and organic carbon. The source does not say whether any sample-return mission has been funded, and I did not find out.

Opportunity in Detail

Opportunity landed on 25 January 2004 in Eagle crater, Meridiani Planum. It was planned for 90 sols (about 92.5 Earth days). Its rover article calls its longevity record 5,352 sols (15 Earth years), and its own article says it operated 5,111 sols (14 years, 138 Earth days), roughly 57 times its design specification.

Two Durations

The two articles disagree: 5,352 sols against 5,111. The difference is 241 sols, or roughly eight Earth months, and neither article explains it. One possibility is that they count different end dates, but the sources do not say, and I have not checked. The 57-times figure matches 5,111 divided by 90, which is 56.8, so I treat 5,111 as the consistent one, though that is my arithmetic, not a source's choice. Of the two Earth-time figures, 14

years 138 days from January 2004 does reach June 2018, which fits the last-contact date. So the "15 years" is a rounding or a different end point.

Water, and the End

The rover found "hematite and past presence of water on the surface of Mars" through regolith and rock sampling, and discovered meteorites and investigated mineral compositions suggesting ancient water-related geologic processes. A massive dust storm struck Mars in early June 2018, reducing solar power. Last contact was on 10 June 2018, and NASA declared the mission complete on 13 February 2019 after over 1,000 unsuccessful recovery signals.

"My Battery Is Low"

A popular line says Opportunity's last message was "My battery is low and it's getting dark." The source says the journalist Jacob Margolis tweeted an interpretive translation of the final telemetry, and that this was not a message Opportunity sent. Margolis later clarified that he had "poetically" rephrased NASA officials' interpretations of the rover's low power and atmospheric opacity, "never to imply the rover had sent the specific words." The line is an interpretation of data, and the machine did not write it.

What I Did Not Verify

I did not find the science of Voyager's planetary encounters, the design of the Golden Record's contents, how Curiosity and Perseverance work, Ingenuity's flights, the reasons for Sojourner's loss, or any robotic missions beyond these (Cassini, New Horizons, the Moon, Venus, asteroids). The chapter also does not verify the "as of September 2026" status of two rovers against a live source. It reports two probes and six rovers.

Hands-On Exercises

EXERCISE 1

Make a table of the six rovers with landing year, end or status, and one fact, using only the chapter, and mark which entries are only "as of" a date.

→ Solution

EXERCISE 2

A student writes "Opportunity's last message was 'My battery is low and it's getting dark.'" Correct it using the chapter.

→ Solution

EXERCISE 3

Explain how you would handle the two figures for Opportunity's operating time in a piece of writing.

→ Solution

Quick Reference

- **Voyager:** both launched 1977; Voyager 2 flew by four planets, Voyager 1 two; heliopause crossings 25 August 2012 and 5 November 2018; Golden Record; Pale Blue Dot 14 February 1990
- **Rovers:** Sojourner 1997; Spirit and Opportunity 2004; Curiosity 2012; Perseverance and Zhurong 2021
- **Opportunity:** planned 90 sols; ran 5,111 sols by one article and 5,352 by another; 45.16 km; last contact 10 June 2018
- **Myth:** "My battery is low" was a journalist's paraphrase
- **Not covered:** Cassini, New Horizons, the science

CHAPTER 10: CAPSTONE: THE NEW SPACE ERA & COMMERCIAL SPACEFLIGHT

History of Space Exploration

Chapter 10 · Capstone: The New Space Era & Commercial Spaceflight

The course began with three theorists and ends with private companies flying astronauts. This capstone covers the commercial era, SpaceX above all, and then looks back over the ten chapters. The sources are three reference articles, on SpaceX, on reusable launch vehicles and on NASA's Commercial Crew Program. They give dates well and cost savings poorly, and the chapter says so.

SpaceX

SpaceX was established on 14 March 2002 in El Segundo, California, by Elon Musk. Its first successful orbital launch came on 28 September 2008, after three prior failures that the source says nearly bankrupted the company.

Date	Event
2006	A \$396 million COTS award from NASA.
December 2008	A \$1.6 billion Commercial Resupply Services contract.
May 2012	Dragon becomes "the first commercial spacecraft to deliver cargo to the International Space Station."
December 2015	First successful recovery of an orbital-class first stage, Falcon 9 Flight 20 (the reusable launch article gives 21 December 2015).
March 2017	SES-10 is "the first time a re-launch of a payload-carrying orbital rocket went back to space."
May 2020	Crew Dragon launches two NASA astronauts, "the first private company to send astronauts to the International Space Station."

Company Sources and Wording

Most of these lines are quotations from the SpaceX article. "The first" in each case is the article's own claim, and I did not check them against other sources. The NASA awards are the article's figures, and it does not say what they paid for beyond the labels COTS and Commercial Resupply Services.

Starship

The source says multiple Starship test flights took place between 2023 and 2026, with the twelfth flight in May 2026 being "the first flight test to carry a payload into orbit." It notes that industry observers "referred to the test flight as a success" regarding Starship's first orbital attempt despite a mid-air explosion, which suggests interpretive disagreement. I do not know which flight the explosion refers to, and the source does not say, so I do not describe it.

Reusability

Reusable launch vehicles have recoverable components that can be reflown, reducing the need to manufacture new parts for each mission. The most commonly reused elements are rocket stages, and fairings and engines can also be recovered.

Earlier Attempts

The Space Shuttle (1981 to 2011) was the first operational reusable system, though only partly: it recovered the orbiter and solid rocket boosters and expended the external tank. The orbiter flew 135 times, the source says, matching Chapter 7's flight count. The 1990s DC-X was an experimental vertical takeoff and landing prototype.

SpaceX

The first successful vertical landing of an orbital-class booster was on 21 December 2015. The source says the company has since been "routinely recovering and reusing their first stages, as well as fairings," and that Falcon 9 booster B1067 reached a record 37 flights as of September 2026.

Blue Origin

New Shepard, suborbital, demonstrated reusability from 2015. New Glenn achieved its first booster recovery in November 2025, making Blue Origin the second company

after SpaceX to recover an orbital-class booster.

Savings Asserted, Not Shown

The article says reusability reduces launch costs significantly by eliminating per-flight manufacturing. It also says the benefits "can be diminished by the cost of recovery and refurbishment," that reusable stages carry extra weight for landing gear, heat shields and spare propellant, that refurbishment can be "lengthy and expensive," and that stages eventually need retiring. It gives limited quantitative evidence, and the SpaceX article gives no per-launch cost. So the chapter cannot say how much reuse saves. Chapter 7 made the same point about the Shuttle: a reusable design stayed expensive.

Commercial Crew

The Commercial Crew Program provides "commercially operated crew transportation service to and from the International Space Station (ISS) under contract to NASA." In 2014 NASA awarded SpaceX \$2.6 billion and Boeing \$4.2 billion to develop crewed spacecraft for station rotations.

- **Demo-2:** launched in May 2020 with Bob Behnken and Doug Hurley, the final crewed test flight before operational missions.
- **First operational flight:** SpaceX Crew-1 launched on 16 November 2020 with four astronauts.
- **Boeing Starliner:** its first crewed test flight in June 2024 experienced helium leaks, reaction control failures and an isolation valve malfunction. NASA returned the spacecraft uncrewed, with its crew joining SpaceX Crew-9. It did not receive system certification, and in February 2026 NASA classified the failures as a "Type A mishap," the most serious category.

The End of a Dependence

Between the Shuttle's retirement in 2011 and Crew-1 in 2020, NASA relied on the Russian Soyuz. The source says the programme's operational success eliminated that dependency, though Soyuz seats were bought as contingency during delays. That closes the thread from Chapter 7. It is also a contrast with Chapters 3 to 6, where the two

powers competed. The Crew Dragon flights served a station (Chapter 8) that the source describes as run by five agencies including Russia's.

Two Contract Sizes, Not a Comparison

SpaceX received \$2.6 billion and Boeing \$4.2 billion. The source does not say what each contract covered or why the amounts differ, and one company's vehicle has flown operationally while the other's has not been certified. I do not draw a conclusion about value for money.

Looking Back

Chapter	Subject	The caution the chapter kept
1	The three theorists	Independence between them was not established.
2	V-2 and Paperclip	Death figures conflict, and responsibility is disputed.
3	Sputnik	Whether the "crisis" was real or manufactured.
4	Gagarin and Shepard	The landing was concealed for years.
5	Apollo	Conflicting cost and astronaut-count figures.
6	Apollo 11 and 13	Two fuel figures, one disputed word.
7	The Shuttle	Both accidents had organisational causes.
8	Space stations	No ISS cost in the sources.
9	Robots	Two durations for one rover, and a misquotation.
10	The new era	Savings from reuse are not quantified.

What Repeats

Two patterns recur across the ten chapters, and both are my reading of the sources and not claims any of them makes. First, in several accidents and programmes the sources

describe schedule or cost pressure alongside a known technical risk (Chapters 5 and 7, and Starliner here). Second, in several chapters a memorable story turned out to be a paraphrase or a later label (the "retroactive" first object in space in Chapter 2, "My battery is low" in Chapter 9). Whether either is a genuine pattern, and not a coincidence of which topics I chose, is not something the sources can settle.

What This Course Did Not Cover

It rested on one to three short reference articles per chapter. It does not cover China's, India's, Europe's or Japan's space programmes, satellites and their applications, the science that space missions returned, the military uses of space, or the accounts of the people who worked on the programmes. Chapter 7's and Chapter 8's boxes list further gaps. The course is an outline built from reference summaries, and a fuller history would start from the reports and primary sources that those articles cite.

Course complete: History of Space Exploration, 10 chapters.

Hands-On Exercises

EXERCISE 1

A student writes "Reusable rockets have made spaceflight cheap." Use the chapter and Chapter 7 to answer it.

[→ Solution](#)

EXERCISE 2

List the "first" claims the chapter attributes to SpaceX and say how you would check each one.

[→ Solution](#)

EXERCISE 3

Pick one of the two recurring patterns named in "What Repeats" and say what evidence beyond this course a historian would need to call it a real pattern.

→ Solution

Quick Reference

- **SpaceX:** founded 14 March 2002; first orbital success 28 September 2008; booster landing December 2015; reflight March 2017; Demo-2 May 2020
- **Reuse:** Shuttle partial; B1067 at 37 flights (September 2026); New Glenn booster recovery November 2025; savings not quantified in the sources
- **Commercial Crew:** 2014 contracts \$2.6 billion (SpaceX) and \$4.2 billion (Boeing); Crew-1 16 November 2020; Starliner classified a Type A mishap in February 2026
- **Starship:** twelfth flight in May 2026 the first to carry a payload into orbit
- **Not covered:** other nations' programmes, the science, the military uses