I Introduction
Outline
Rocket Pioneers

Jim Rauf

SPACEX

1 Introduction: topics , some basics and rocket pioneers

2 SpaceX founding , Musk’s vision, facilities, organization, personnel

3 SpaceX and NASA commercial funding

4 Falcon rockets and engines , Falcon 1, Falcon 9 and Falcon Heavy

5 Dragon spacecraft , Cargo Dragon and Crew Dragon

6 Super Heavy booster and engines and Starship spacecraft

7 Starship competition for Artemis Moon Human Landing System

8 Musk’s Mars vision , plans and challenges

Some Topics

- Rocket basics
- Orbits
- Escape velocity
- Some facts about space travel
- A little rocket history
- Rocket pioneers
- NASA space programs
- International Space Station (ISS)
- Reusable rockets – Space Shuttle
- Russian flights to ISS
- U.S. government support for commercial rockets
- "Private" commercial rocket companies
- Costs to reach space

- Elon Musk and SpaceX founding
- SpaceX's first rocket - Falcon 1
- Falcon 9 – reusable booster - lower costs to orbit
- Falcon 9 – SpaceX workhorse
- SpaceX advantages
- Falcon Heavy – SpaceX heavy lift booster
- SpaceX Starship and Super Heavy booster
- SpaceX facilities
- Artemis Moon program and SpaceX
- Starship HLS
- Musk's ultimate goal – Mars colony
- SpaceX Starlink business plan
- Mars challenges

Rockets and Isaac Newton

- Rockets operate according to **Newton's Third Law**
  - For every action there is an equal and opposite reaction
- The reaction (thrust) comes from ejecting large mass of gases from the rocket engine at high velocity (action)
  - Same principal as jet engines
- The thrust pushes the rocket in the opposite direction from the direction in which the exhaust gases flow
- Rockets and jet engines **do not** "push against" the ground or the air

- Rockets carry both **fuel** and **oxidizer** on board
  - Jet engines use the oxygen in the atmosphere oxidize their fuel
- As a rocket consumes its propellant it becomes lighter and accelerates faster and faster until all its propellant is used or its engine is shut off
  - **Newton's Second Law** F=MxA
- In space with engine off the rocket "coasts"
  - Newton's first Law –Body in motion stays in motion unless acted on by a force

Rocket Thrust Summary

Known:

p_t = Total Pressure

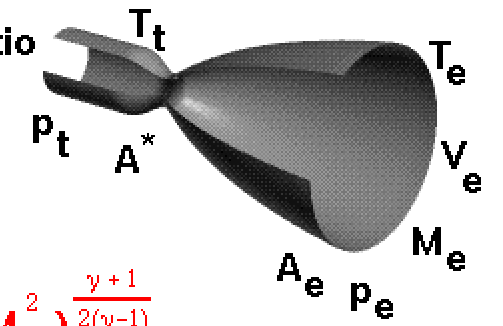
T_t = Total Temperature

p_o = Free Stream Pressure

γ = Specific Heat Ratio

R = Gas Constant

A = Area



Mass Flow Rate: $$\dot{m} = \frac{A^* p_t}{\sqrt{T_t}} \sqrt{\frac{\gamma}{R}} \left(\frac{\gamma+1}{2}\right)^{-\frac{\gamma+1}{2(\gamma-1)}}$$

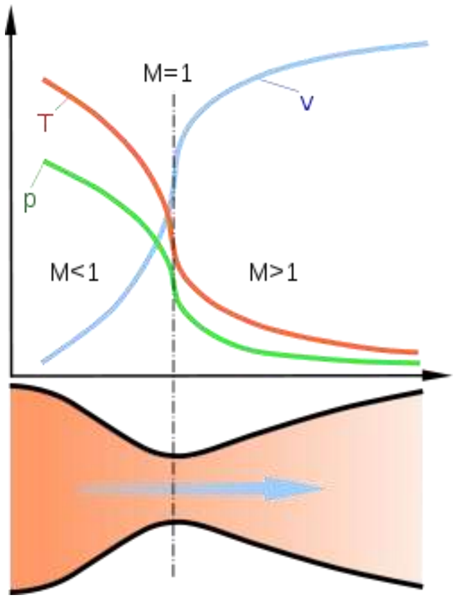
Exit Mach: $$\frac{A_e}{A^*} = \left(\frac{\gamma+1}{2}\right)^{-\frac{\gamma+1}{2(\gamma-1)}} \frac{\left(1 + \frac{\gamma-1}{2} M_e^2\right)^{\frac{\gamma+1}{2(\gamma-1)}}}{M_e}$$

Exit Temperature: $$\frac{T_e}{T_t} = \left(1 + \frac{\gamma-1}{2} M_e^2\right)^{-1}$$

Exit Pressure: $$\frac{p_e}{p_t} = \left(1 + \frac{\gamma-1}{2} M_e^2\right)^{-\frac{\gamma}{\gamma-1}}$$

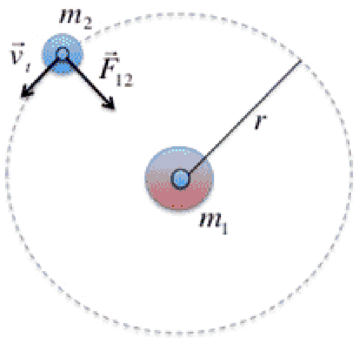
Exit Velocity: $$V_e = M_e \sqrt{\gamma R T_e}$$

Thrust: $$F = \dot{m} V_e + (p_e - p_0) A_e$$



$$\Delta v = v_e \ln(m_0/m_f)$$

Orbits Circular



$$F = ma$$

$$\frac{Gm_1m_2}{r^2} = m_2a_c$$

substituting in the equation for centripetal acceleration:

$$a_c = \frac{v_t^2}{r}$$

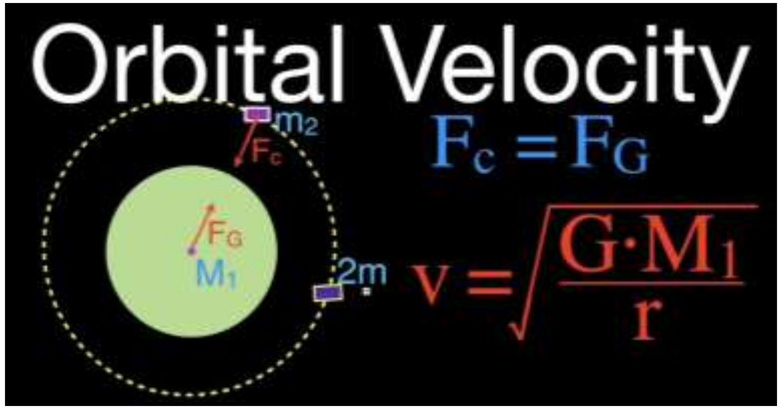
Then the equation becomes:

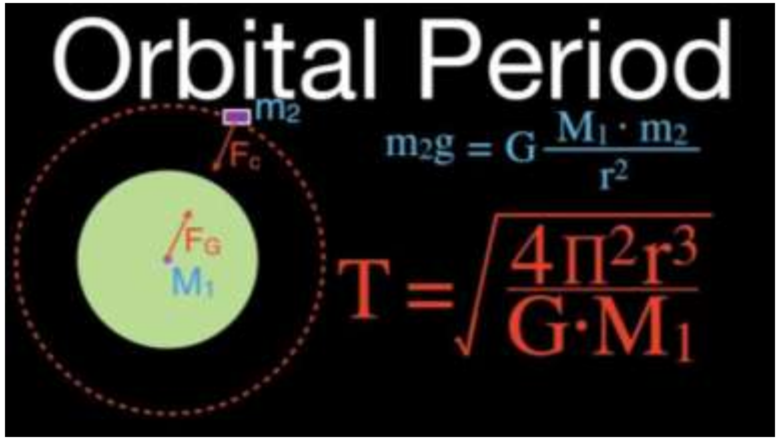
$$\frac{Gm_1m_2}{r^2} = m_2\left(\frac{v_t^2}{r}\right)$$

And finally, solving for the tangential speed:

$$v_t = \sqrt{\frac{Gm_1}{r}}$$

Low Earth Orbit (LEO) is orbit below an altitude of 2,000 km or 1,200 miles
ISS orbit 230miles by 290 miles altitude
Velocity ~7.66 km/sec or ~17,000mph





Leaving Earth's Gravitational Field   Escape Velocity

$$\frac{1}{2}mv^2 - \frac{GMm}{r} = 0 + 0$$

$$\frac{1}{2}mv^2 = \frac{GMm}{r}$$

$$\frac{1}{2}v^2 = \frac{GM}{r}$$

$$v^2 = \frac{2GM}{r}$$

$$v = \sqrt{\frac{2GM}{r}}$$

Kinetic Energy = Gravitational Potential Energy

M is Mass of planet
m is Mass of spacecraft
r is Radius of planet

Note:
Only the Mass of Earth(or planet) determines Escape Velocity

Ve ~11 km/sec or 7 mi/sec

Tsiolkovsky' Rocket Equation

$$\int_{V_o}^{V} dV = -V_e \int_{m_o}^{m} \frac{dm}{m}$$

$$\therefore [V]_{V_o}^{V} = -V_e [\ln m]_{m_o}^{m}$$

$$\therefore V - V_o = -V_e[\ln m - \ln m_o]$$

$$\therefore V - V_o = V_e[\ln m_o - \ln m]$$

$$\therefore V - V_o = V_e \ln\left(\frac{m_o}{m}\right)$$

•dm is the mass ejected

•dV is the increase in speed due to the ejected mass (dm)

•V_e is the exhaust velocity (ie. the velocity of the ejected mass relative to the rocket)

•m is the rocket mass (subscript 'o' denotes initial values)

In practice, drag reduces V_{max} by ~0.3 – 0.5 km s^{-1}.

Tsiolkovsky's Equation (the rocket equation).

Multistage Rockets

Consider the following extremely simplified model of a rocket: we have a three stage rocket with each stage having dry mass m_d and containing fuel m_f for a total mass of $3m_d + 3m_f$. The rocket equation is given

$$\frac{\Delta v}{v_e} = \ln\left(\frac{m_0}{m_1}\right)$$

where Δv is the change in velocity, v_e is the exhaust velocity, m_0 is the initial wet mass (dry mass + fuel) and m_1 is the final mass (dry mass).

First let's launch our rocket without staging. It starts with mass $3m_d + 3m_f$ and ends with mass $3m_d$. The rocket equation gives

$$\frac{\Delta v}{v_e} = \ln\left(\frac{3m_d + 3m_f}{3m_d}\right) = \ln(1 + \alpha)$$

with $\alpha = m_f / m_d$

Multistage rockets reach higher velocities than single stage rockets

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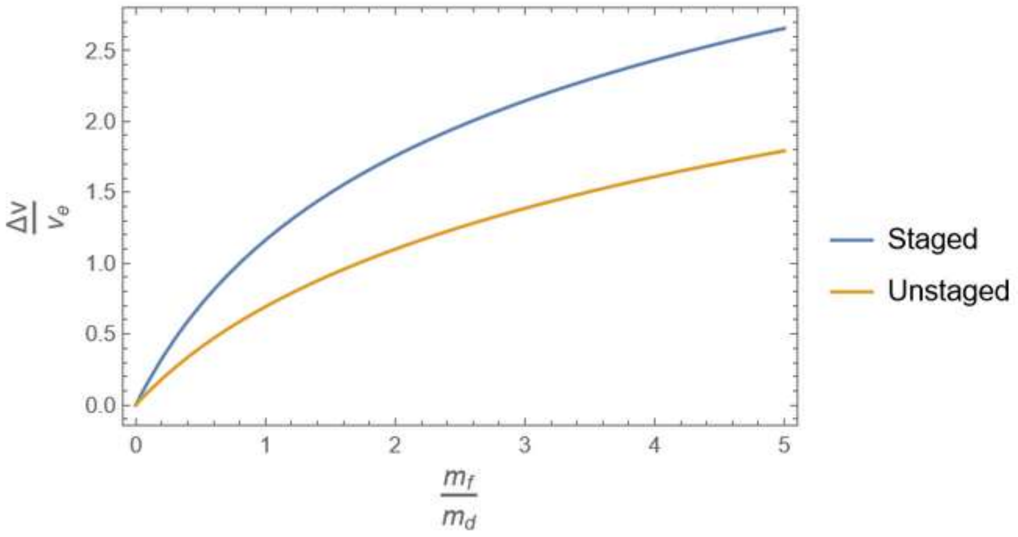
with $\alpha = m_f/m_d$

Now let's launch the rocket with staging. Each burn it loses mass m_f and during each separation stage it loses mass m_d without gaining Δv (it can be seen as a burn with $v_e = 0$). For the total Δv this becomes

$$\frac{\Delta v}{v_e} = \ln\left(\frac{3m_d + 3m_f}{3m_d + 2m_d}\right) + \ln\left(\frac{2m_d + 2m_f}{2m_d + m_f}\right) + \ln\left(\frac{m_d + m_f}{m_d}\right)$$
$$= \ln\left(\frac{3!(1+\alpha)^3}{(3+2\alpha)(2+\alpha)}\right)$$

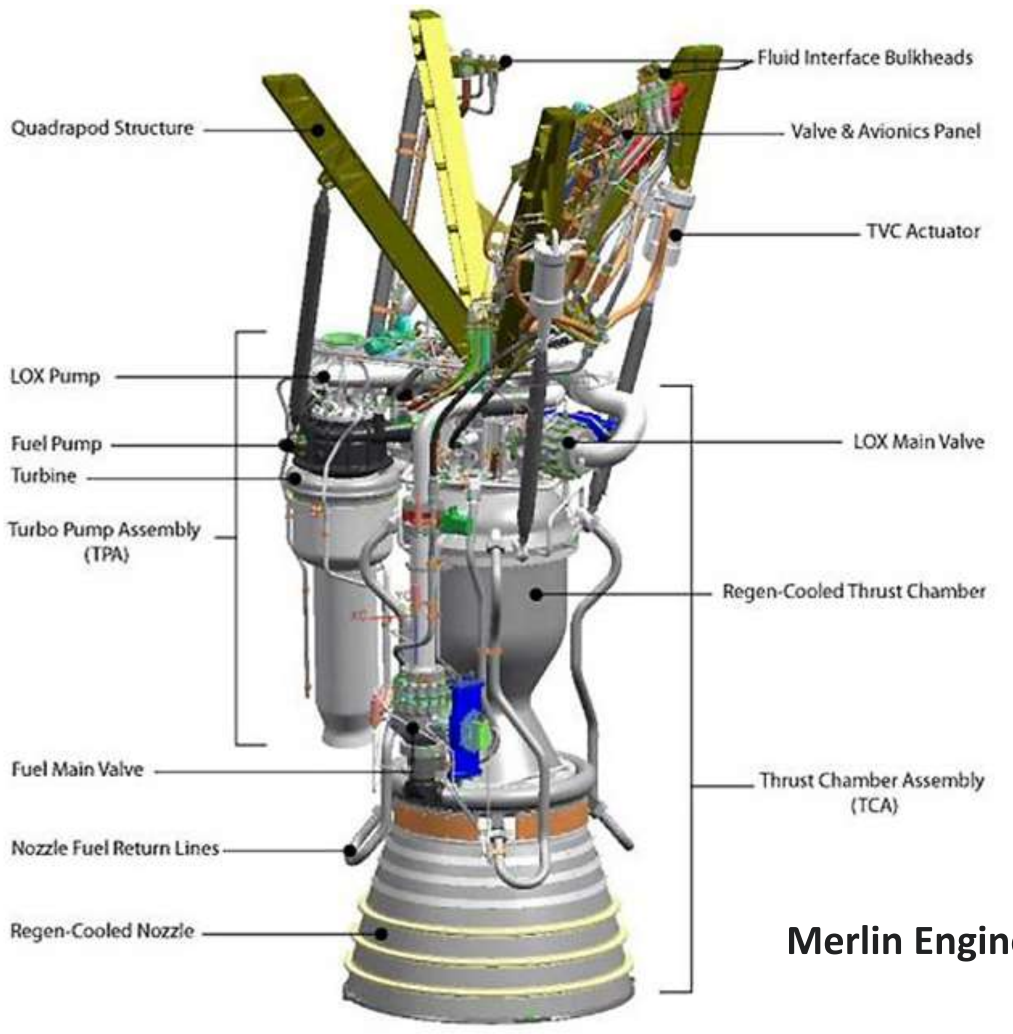
A quick plot shows that the staging always wins over the non staging



Multistage rockets reach higher velocities than single stage rockets

Rocket Engine Characteristics   SpaceX Merlin Engine

- Combustion chambers (**Merlin Engine**) typically operate at ~**1500 psi**
- Higher pressures give better performance
- High pressures cause the chamber to have very large hoop stresses
- **Merlin Engine** combustion temperatures up to ~**6000 F**
- High combustion temperatures tend to reduce material tensile strength
- Combustion chambers and nozzles require cooling, usually with fuel before it is injected into combustion chamber
- Significant temperature gradients in the walls of the chamber and nozzle create internal thermal stresses
- Rocket engines are designed to have minimum weight
- Rocket engines do not operate for long sustained periods



Merlin Engine

Early Rockets

- The earliest solid rocket fuel was a form of **gunpowder**, and the earliest recorded mention of gunpowder comes from China late in the third century BC
- By 1045 A.D. the use of gunpowder and rockets were applied to Chinese military tactics
- Rockets probably arrived in Europe around 1241 A.D.
- Arabs adopted the rocket and during the Seventh Crusade, used them against the French Army of King Louis IX in 1268
- Rockets found their way into European arsenals by 1300, reaching Italy by the year 1500, Germany shortly afterwards, and later, England
- Rockets (**Congrieve Rockets**) came to America during the War of 1812 ”…The rockets red glare…”
- Rockets were used in the Civil War
- The international whaling industry developed rocket-powered, explosive-tipped harpoons
- First World War - rockets were first fired from aircraft attempting to shoot down enemy hydrogen gas-filled observation balloons
- The principal drawback to early rockets was the type of fuel and lack of a guidance system
- In America and Germany experiments were under way to develop a more powerful, liquid-propelled rockets

Rocket Pioneers

KonstantinTsiolkovsky
1857-1935
Russian

The Exploration of Cosmic Space by Means of Reaction Devices --1903

Robert Goddard
1882-1945
American

A Method of Reaching Extreme Altitudes--1919

Hermann Oberth
1894 –1989
German

By Rocket Into Interplanetary Space 1923
Ways to Spaceflight 1929

Rocket Pioneers

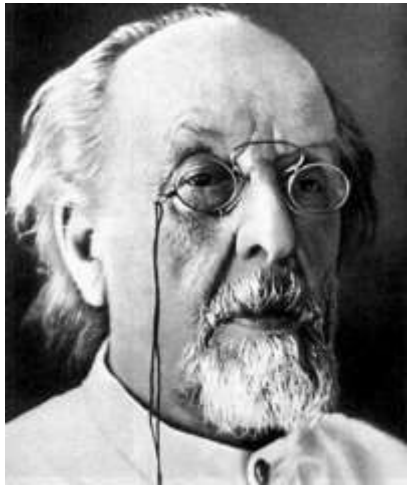
Wernher von Braun
1912 –1977
V-2
Redstone
Saturn I/IB
Saturn V

Sergey Korolyov
1907-1966
R-1 (V-2 Copy)
R-7 Semyorka (ICBM)

Konstantin Tsiolkovsky

- The first realistic proposal of space flight goes back to **Konstantin Tsiolkovsky**
- His most famous work, *"The Exploration of Cosmic Space by Means of Reaction Devices"*, was published in 1903
    - Hypotheses and calculations covered a broad spectrum of matters: gyroscopic stabilization; escape velocities from the earth's gravitational field; the principle of reactive action; and the use of liquid propellants for rockets; relationships between rocket speed, the speed of the gas at exit and the mass of the rocket and its propellant.
- Tsiolkovsky's work was scientifically sound but its influence on rocket development and space flight was delayed in Russia and elsewhere

"The Earth is the cradle of mankind, but mankind cannot stay in the cradle forever"



Tsiolkovsky "Rocket Equation"

$$\boxed{v_{bo} = u \ln \frac{m_o}{m_{bo}}}, \text{ where}$$

v_{bo} = rocket velocity at fuel burnout
m_o = initial rocket mass
m_{bo} = final rocket mass at burnout
u = effective exhaust velocity of expelled gasses, thus implementing Newton's 3rd Law of Motion

Robert Goddard

- Goddard's interest in rockets began in 1898 when, as a 16-year-old, he read the latest publication of that early science fiction writer, English novelist H.G. Wells "*War of the Worlds*“
- Goddard began his experiments in rocketry while studying for his doctorate at Clark University in Worcester, Mass
- He first attracted attention in 1919 when he published a paper titled, "*A Method of Reaching Extreme Altitudes.*"
    - In his paper he outlined his ideas on rocketry and suggested that a demonstration rocket should be flown to the Moon
    - The general public ignored the scientific merit of his 1919 paper and most dismissed Goddard as a "crank.“
        - The New York Times editorialized that he did not understand physics
- The experience taught Goddard a hard lesson -- one which caused him to shy away from future opportunities to publicize his work

- Both **Tsiolkovksy** and Goddard came to the conclusion that rockets needed to be liquid fuelled
- March 16, 1926 Goddard launched a liquid-powered rocket he had designed and built
- The rocket flew -- 152 feet
- The first flight of a liquid-fueled rocket in history.
- Only Goddard was working on rockets in America
- However, rocketry was beginning to develop

  a following in Europe

Robert Goddard

- Unlike **Tsiolkovsky**, **Goddard** was a technical man
    - He could and did build rockets
- By the time he died in 1945, **Goddard** held 214 patents in rocketry --
- Goddard's 1919 paper “*A method of Reaching Extreme Altitudes*” and his later work in designing and building rockets made space flight an engineering possibility
    - His application of the de Laval nozzle to liquid fuel rockets gave sufficient power for space flight to become possible
    - This paper was highly influential on **Hermann Oberth** and **Wernher von Braun**

Hermann Oberth

- **Hermann Oberth** was influenced by reading the great science fiction writers of the 19th century.
- For his Doctoral Degree at Heidelberg University, he wrote a comprehensive thesis on rocket development.
  - It was rejected as farfetched
- His dissertation became the now celebrated book "*The Rocket into Planetary Space"* published in 1923, in which he recognized and proposed solutions to a very wide spectrum of rocketry and space travel problems.
  - He addressed enormous fuel consumption, the hazards of solid propellants, handling of volatile fuels, and the effects upon the human body
  - This was more than 40 years before space flight became a reality

- It was his theories and writings which were to become a leading inspiration to the German rocket engineers of the 1930's and 1940's

Rocket Societies

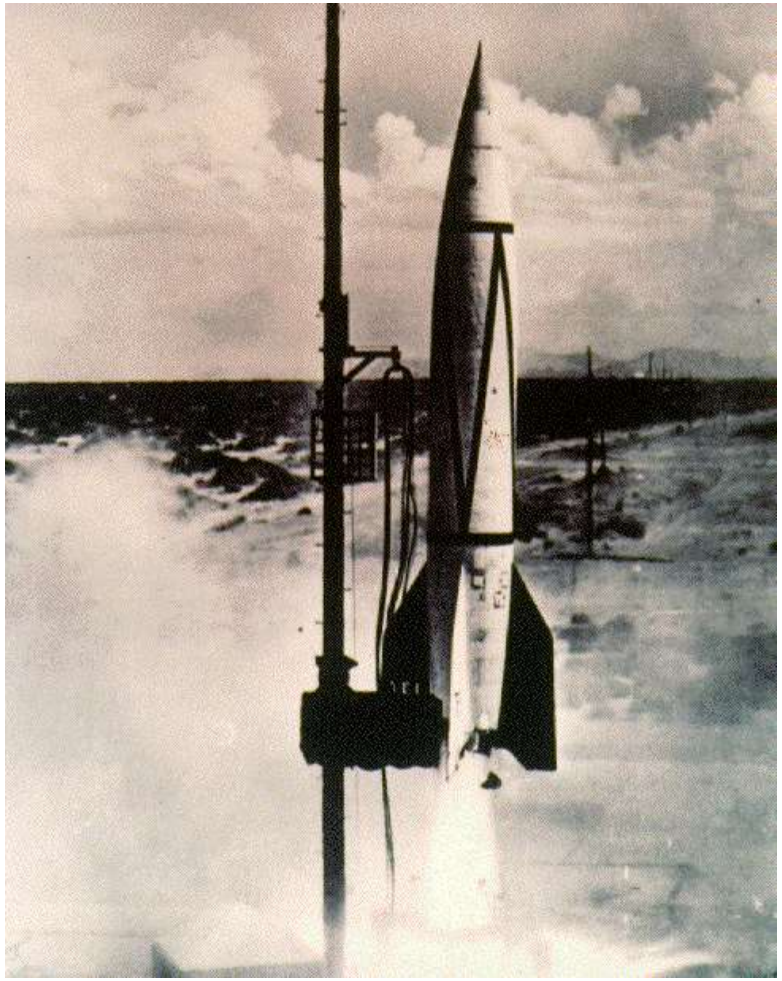
- In the late 1920s, spaceflight enthusiasts banded together into groups to advance their cause. These "rocket societies" especially flourished in Russia, Germany, and the United States
- Most quickly moved toward developing the one technology that pointed a way into space: the liquid-fuel rocket as proposed by **Tsiolkovsky**, **Goddard** and **Oberth**
- In 1927 the **German Society for Space Travel**, or VfR was founded
- Out of the VfR emerged the **Raketenflugplatz Berlin** , the world's largest, most active rocket group

Hermann Oberth (center, in profile) demonstrated his tiny liquid-fuel rocket engine in Berlin in 1930
Second from the right is 18-year-old student **Wernher von Braun**

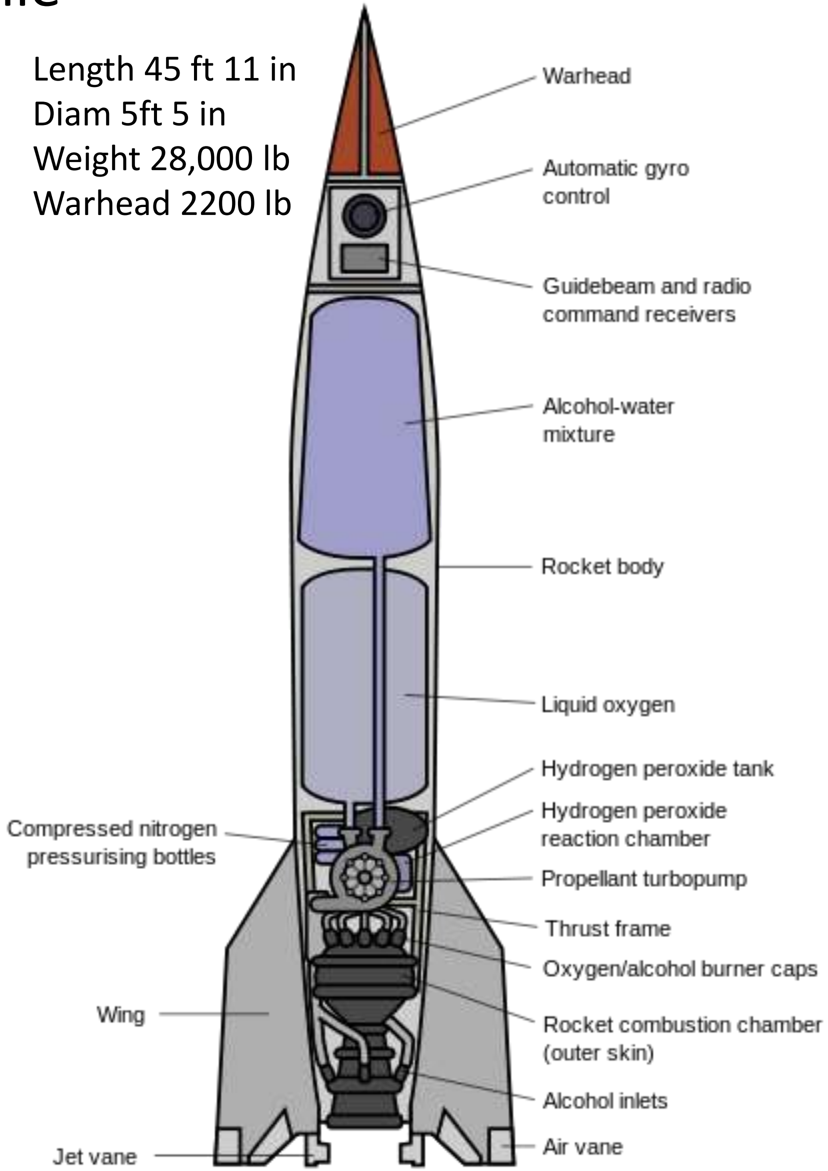
Wernher von Braun

- **Wernher von Braun** read Oberth’s the book "*The Rocket into Interplanetary Space.*" in 1925
- Five years later,1930, **von Braun** had joined **Oberth** and was assisting with rocket experiments in the ***German Society for Space Travel***
- By 1932, the German Army was beginning to show an interest in the German Rocket Society's efforts, and in July 1932, a "Mirak" rocket was launched as a demonstration for the head of the newly created German Army rocket research group, Captain (later Major General) **Walter Dornberger**
- The Mirak didn't impress **Dornberger Von Braun** did
- Three months after the demonstration flight, **von Braun** was engaged to work on liquid propelled rockets for the Army
- Most of the **German Rocket Society** followed **von Braun** into national service and the society disbanded
- By December 1934, **von Braun** and his team scored the first successes with an **A2** rocket powered by ethanol and **liquid oxygen**
- Two years later, as plans for the follow-on **A3** rocket were being finalized, initial planning began for the **A4** rocket –
    - In **Dornberger'**s words, a practical weapon, not a research tool
    - Most know the **A4** by another name -- the **V-2**
- Between 1937 and 1941, **von Braun's** group launched some 70 A3 and A5 rockets, each testing components for use in the proposed **A4** rocket
- The first **A4** rocket flew in March 1942
- The rocket barely cleared some low clouds before crashing into the sea a half mile from the launch site.
- The second launch in August 1942 saw the **A4** rise to an altitude of 7 miles before exploding

German WW II V-2 Ballistic Missile



Length 45 ft 11 in
Diam 5ft 5 in
Weight 28,000 lb
Warhead 2200 lb



German WW II V-2 Ballistic Missile

- On October 3, 1942, another A4 roared aloft from **Peenemuende**, followed its programmed trajectory perfectly, and landed on target 120 miles away
- This launch can fairly be said to mark **the beginning of the space age**
  - Space begins at between 62 to 76 miles above the earth
- The A4, the first successful ballistic rocket, is the ancestor of practically every rocket flown in the world today.
- Production of the A4 began in 1943 and the first A4s, now renamed **V2s**, were launched against London in September 1944
- The **V-2** offensive came too late to affect the course of the war
- On May 2, the same day Berlin fell to the Soviet Army, **von Braun** and his rocket team entered American lines and safety
- **von Braun** and his team were heavily interrogated and jealously protected from Russian agents

1912 –1977

- Most of **von Braun's** team began setting up shop at Fort Bliss, near El Paso, Texas.
- Piled up in the desert near Las Cruces, New Mexico, were enough parts to build 100 V2s.
- **Von Braun** and his team soon moved to nearby **White Sands Proving Ground** where work began assembling and launching V2s.
- By February 1946, **von Braun's** entire Peenemuende team had been reunited at White Sands and, on April 16, the first V2 was launched in the United States.
- The U.S. space program was under way!

V-2 Ballistic Missiles in U.S.

- 64 V-2s were launched at White Sands up to 1952
- A V-2 variant was the two stage rocket named Bumper-- V-2/WAC Corporal
- The need for more room to fire the rockets led in 1949, to the **Joint Long Range Proving Ground** at remote, deserted **Cape Canaveral, Fla**
- On July 24, 1950, a two-stage Bumper rocket became the first rocket to be launched from "the Cape."
- The transfer of launch operations to the Cape coincided with the transfer of the Army's missile program from White Sands to a post just outside a north Alabama cotton town called **Huntsville**
- **Von Braun** and his team arrived in April 1950 and worked to develop what was essentially a ***super-V-2*** rocket, named for the U.S. Army arsenal where it was being designed -- the **Redstone**

Mercury Redstone May 5, 1961
Alan Shepherd

Sergey Korolyov

- In 1931 a Russian rocket society , the **Group for the Study of Reactive Propulsion,** GIRD, was established.
- The group carried out early rocket experiments in Leningrad and at branches other Russian cities.
- On August 18, 1933, GIRD launched the first Soviet liquid-fueled rocket Gird-09
- The group's members included such pioneers as **Sergey Korolyov** -who dreamed of traveling to **Mars**
- He would be a leader later in the Soviet missile and space program

1907-1966

- During the 1930s Soviet rocket technology was
  comparable to Germany's, but Stalin's Purges
  damaged its development
- At the end of WWII Russian engineers who inspected the German rocket program's remains
  at Peenemunde were surprised at its advanced state
- Sergey Korolyov was one of the Russians
- The Russian rocket program greatly benefited from captured German records, engineers and drawings from V-2 production site
- **Korolyov** and others, helped by captured Germans built a replica of the V-2 called the R-1

Soviets

- The weight of Soviet nuclear warheads required a more powerful booster
- **Korolyov's OKB-1** design bureau was dedicated to the liquid-fueled cryogenic rockets he had been experimenting with in the late 1930s.
- Ultimately, this work resulted in the design of the **R-7 Semyorka (ICBM**) which was successfully tested in August 1957
- The **R-7** was the workhorse of the early USSR space program

R-7 ICBM

U.S. Space Program “Manned “ Launch Vehicles

Redstone IRBM

Mercury Suborbital

Army Missile

Atlas ICBM

Mercury Orbit

USAF Missile

Titan ICBM

Gemini Orbit

USAF Missile

Saturn IB

Apollo Orbit

NASA Rocket

Saturn V

Apollo Moon

NASA Rocket

Space Shuttle

LEO and ISS

NASA Rocket

Summary

- The early rocket pioneers were inspired by tales of space travel, especially trips to the Moon
- Pioneers in Europe and America begin theoretical and practical work on rockets with the ultimate goals of space flight
- Rockets were used by the military of many nations, but the **V-2** demonstrated the potential of the **ballistic missile**
- With the advent of the atom bomb warhead ballistic missile development moved to the "fast track" in the **USSR** and the **USA**
- Missiles that could deliver a warhead across the globe could be used to put a **satellite**, or a **manned space craft** into earth orbit
- Both the **USSR** and the **USA** based their early space program launch vehicles on their ballistic missile programs
- The **USSR'**s larger missiles, required by their larger atom bomb warheads, would give them ahead start in the "*space race*"
- **U.S**. responded to **USSR's Sputnik** satellite in 1957 with creation of **NASA** and a civilian space program
- **NASA** and its various aerospace company contractors ultimately "won" the race to the Moon in 1969 with the **Apollo Program**
- **U.S.** is now using ***commercial companies*** like **SpaceX** to support space exploration

Next Session

SpaceX founding , Musk’s vision, facilities, organization, personnel