Introduction to Aerospace Engineering

Lecture slides

Introduction to Aerospace Engineering AE1102

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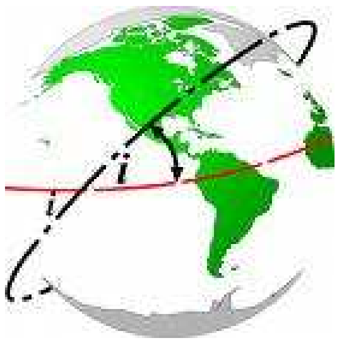

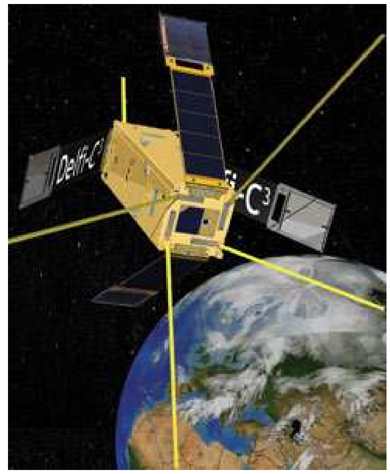

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How do we get in Space?

Development of rockets; enabling technologies

Launch vehicles

Typical launch profile

Part of the contents of this presentation originates from the lecture “Space Engineering and Technology I, Part I” (ae1-801/1), by R. Hamann.

Launch vehicles & space propulsion

- Learning goals
  - Understand the principles of rocket motion
  - Develop awareness of the historical development of launchers
  - Become familiar with the basic components of a launcher
  - Get acquainted with the physical characteristics of launchers
  - Become familiar with the nomenclature (jargon) of rocketry
  - Develop awareness of characteristic numbers and costs
  - Develop ability to make simple (back-of the-envelope) calculations

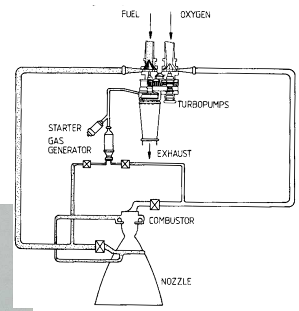
Why do we need rockets?

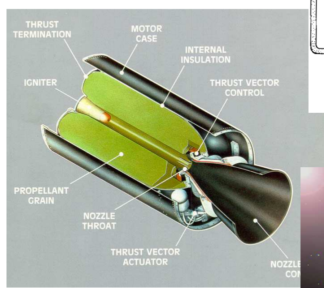
- Because jet engines and propeller engines do NOT work in space (no air / no oxygen)
- To provide brute force to lift the payload and the rocket itself against gravity (and cope with drag)
- To achieve the necessary extremely high orbital speeds (impossible in the atmosphere due to aerodynamic heating and drag)

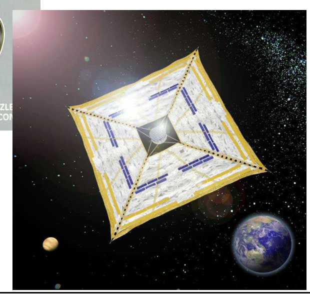
Launch of Friendship-7 (Glenn on board)

Types of space propulsion

- Liquid propellant rocket engine
- Solid propellant rocket engine
- Hybrid rocket engine
- Thermo-nuclear rocket engine
- Electro-magnetic propulsion (Ion-plasma)
- Solar radiation pressure (sail)







The principle of rocket motion

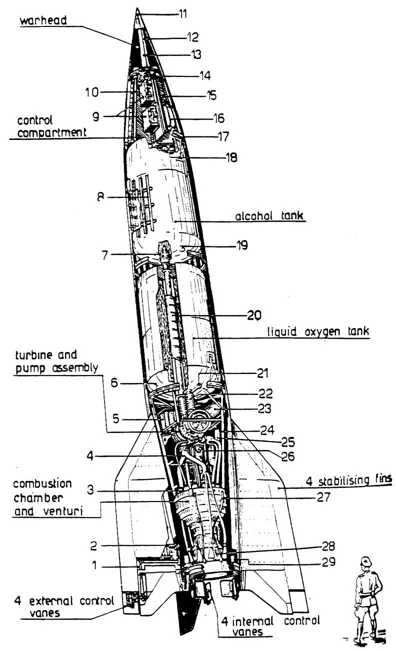
"ACTION = REACTION"

- What is the "action"?
  - The rocket engine expels mass at high speed ➔ "Thrust"
  - Thrust equals mass-flux times "exhaust" velocity:
  - T (N) = m (kg/s) * c (m/s)
- What is the "reaction"
  - The rocket accelerates ➔ "Motion"
  - Thrust equals *instantaneous* rocket mass times *instantaneous* acceleration:
  - T (N) = M (kg) * a (m/s2) ➔ a = T/M
- Theoretical rocket velocity (Tsiolkowski): $\mathbf{V = c * \ln (M_{start}/M_{empty})}$

NB Principle is the same for jet engines and propeller engines

The "mother" of all modern rockets (V2)

- The V2:
  - single stage
  - liquid propellants
    - alcohol
    - liquid oxygen (cryogenic)
  - steel structure
  - 12800 kg lift-off mass, 8800 kg propellants, 250 kN thrust
  - 68 s burn time
  - 1000 kg warhead
  - range several hundreds of kilometers



Example computation:

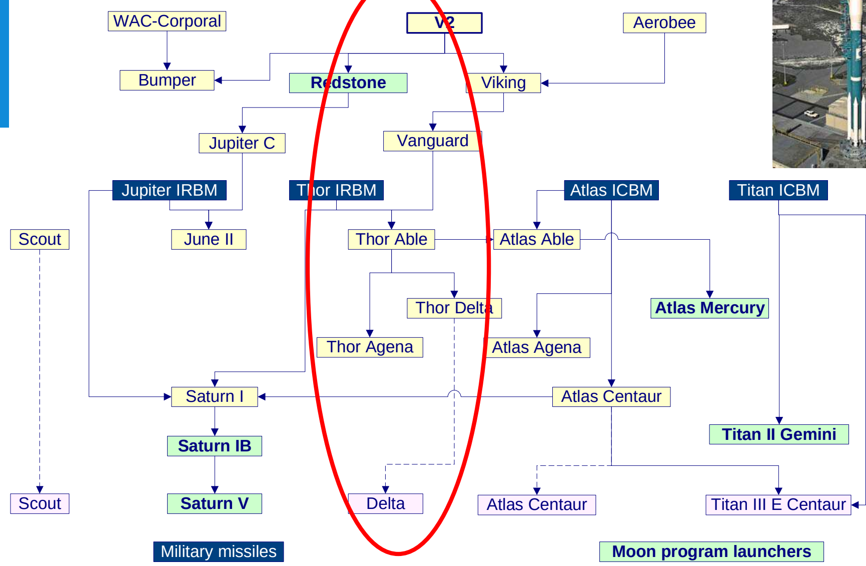
Calculate the theoretical end velocity of the V2 using Tsiolkowsky's equation.

Answer: Ve = 2247 m/s or 2.247 km/s

How much is this in km/hr?

Answer: 8089 km/hr

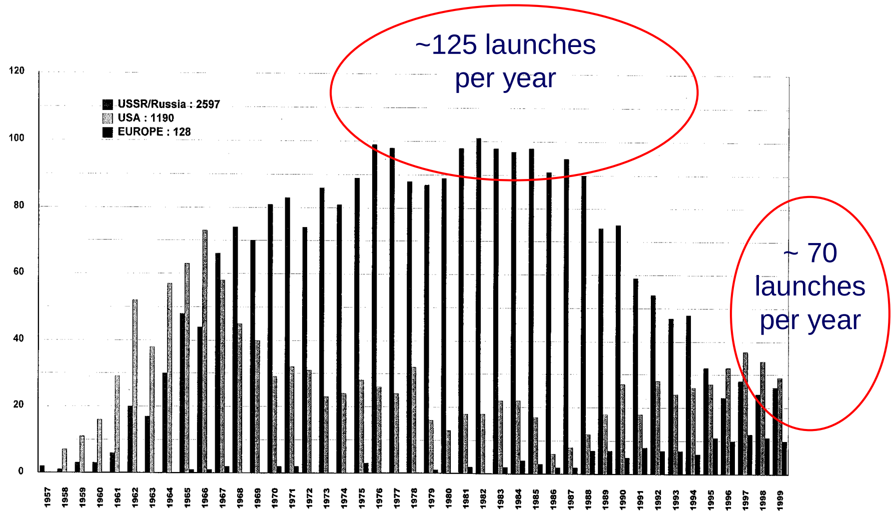
V2 Heritage - USA -



In the beginning it was not so easy….

http://www.youtube.com/watch?v=zVeFkakURXM

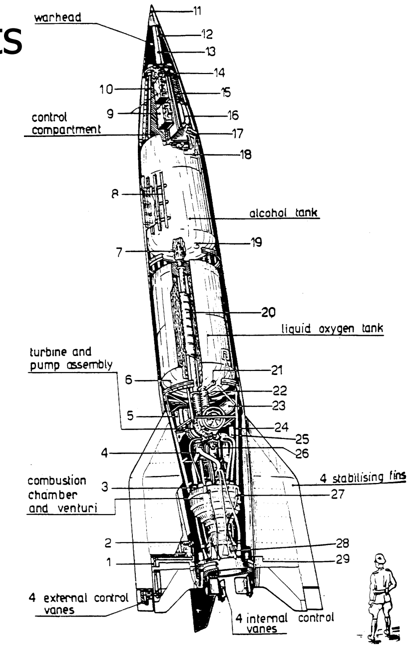
Successful launches 1957 - 1999



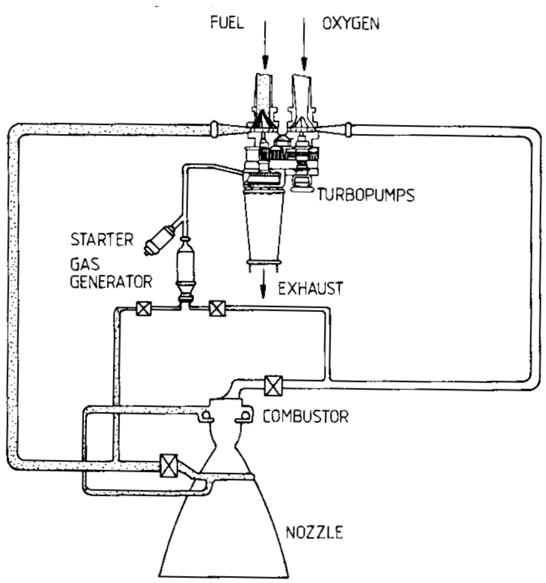
Source: Marc Toussaint

Main rocket components

- Structure (integral tank/skin)
- Propellants (liquid, solid or ?)
- Rocket engine
- Aerodynamic shape (drag)
- Control systems (e.g. TVC)
- Avionics
- Payload
- Payload fairing (shroud)



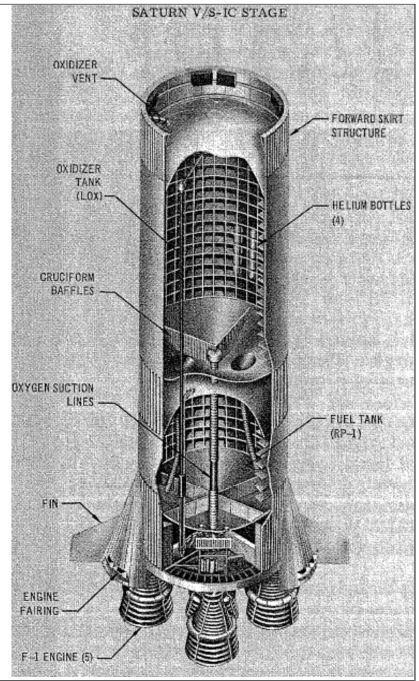
Schematic liquid propellant rocket engine



Source: Fortescue

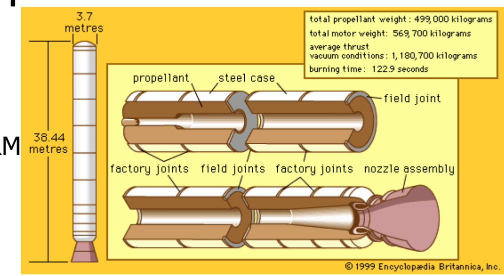
Example of liquid propellant rocket stage

- Saturn-V S-1C stage
  - Propellant tanks (RP-1 / LOX)
  - Engines (5 x F-1)
  - Aerodynamic control and streamline surfaces
  - Propellant (feed) lines
  - Tank pressurization system
  - Propellant management system
  - Forward skirt/inter- stage
  - Diameter: 10m
  - Length: 42m
  - Mass: 2,300,000kg (Dry: 133,000kg)
  - Thrust: 33,000,000N



Example of solid propellant rocket motor

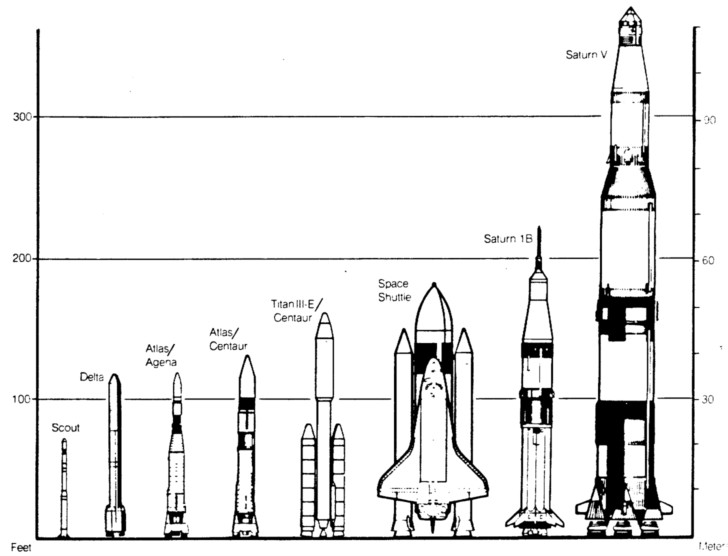
- Reusable Solid Rocket Motor (RSRM
  - Steel casing (segments)
  - Nozzle (gimbaling)
  - Hollow solid propellant grain
  - Igniter
  - Thrust vector control system (TVC)
  - Range safety destruct system
  - Parachutes
  - Diameter: 3.7m
  - Length: 38.5m
  - Mass: 570,000kg (dry: 70,000kg)
  - Thrust: 10,000,000N



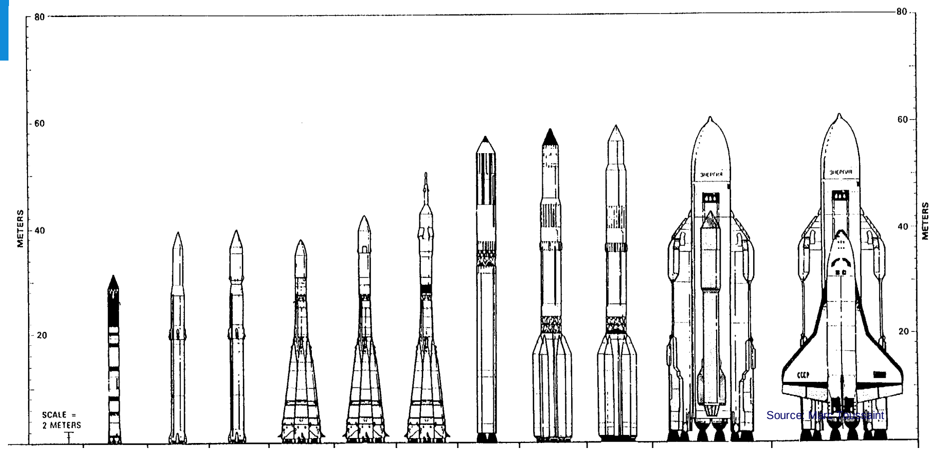
Payload fairing (shroud)

- **Payload fairing** is an important attribute of a launch vehicle. The fairing protects the payload during the ascent against aerodynamic forces and aerodynamic heating. More recently, an additional function is to maintain a "clean-room" environment for "sensitive" payloads.
- Fairing is affected by heat generated by friction – up to 600 degrees Celsius – during the launch phase
- Outside the atmosphere the fairing is jettisoned, exposing the payload. This causes a mechanical shock and a "spike" in the acceleration.
- Standard payload fairing is typically a cone-cylinder combination. Due to aerodynamic considerations, however, specialized fairing are in use as well.

Comparison of some US launchers



Some Russian launchers



Some approximate launcher data

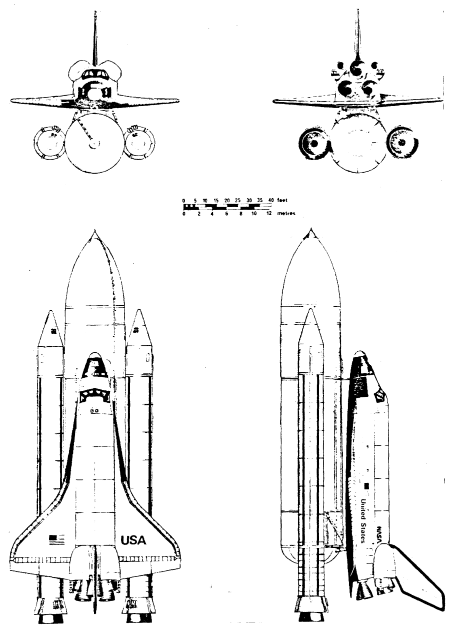
Launcher	mass x 1000 kg	thrust kN	payload (kg)		
			low orbit	geostationary orbit	escape velocity
Scout	21	490	200	-	-
Delta (2910-2914)	132	1715	2000	700	600
Atlas-Centaur	145	1865	4500	1800	1500
Titan IIIE-Centaur	650	10300	16000	-	5500
Saturn IB	650	7310	17000	-	-
Saturn V	2750	33350	110000	-	40000
Ariane V	746	6470 boosters	10800	6950 (G+)	
Soyouz launcher	310	4900	7000	-	-
Space Shuttle	2000	28450	30000	-	-

Some Russian launcher data

Launcher	*payload (kg)*			
	low orbit	*sun-synchronous orbit*	*geostationary orbit*	*escape velocity*
Kosmos	1500			
Tsyklon	4000			
Vostok	4730	1840		
Molniya			1800 (high latitude)	
Zenit	13740	11380		
Proton	20600		2500	5700
Energiya	105000		19000	32000
Energiya/Buran	30000			

Source: Marc Toussaint

The Space Shuttle launch configuration



External dimensions	
Wing span	23.79 m
Length overall	56.14 m
Length external tank	47.00 m
Length boosters	45.56 m
Height overall	23.35 m
Weights	
Shuttle complete	2010.6 t
Orbiter (empty)	74.8 t
External tank (full)	756.4 t
Boosters (2), each	589.7 t
Thrust	
Total, lift-off 28590 kN	
Orbiter,	
main engines (3), each	1670 kN
Booster (2), each	11790 kN

European launcher development efforts

- ELDO, founded in 1962
  - Europa; never reached orbit
    - first stage: "Blue Streak"
    - second stage: existing French rocket
    - third stage: new German design
- France
  - Diamant; some satellites launched
- UK
  - Black Arrow; one satellite launched
- ESA
  - Ariane 1 through 5; many launches

The main European launcher: Ariane 5

Development 10 yr, costs 7 B$

Payload:

- 6820 kg in 7^0 GTO
- 10800 kg in sun-synchronous orbit

Launch cost: 124 M$ ('00)

Success rate: 95% (end 2005)

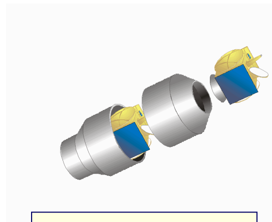
Number of stages: 2 + 2 boosters

Length: 51.4 m

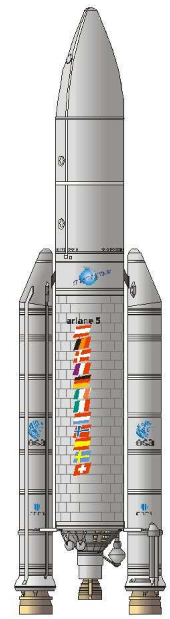
Diameter: 5.4 m

Start mass: 746 ton

Payload volume: ≈ 243 m^3

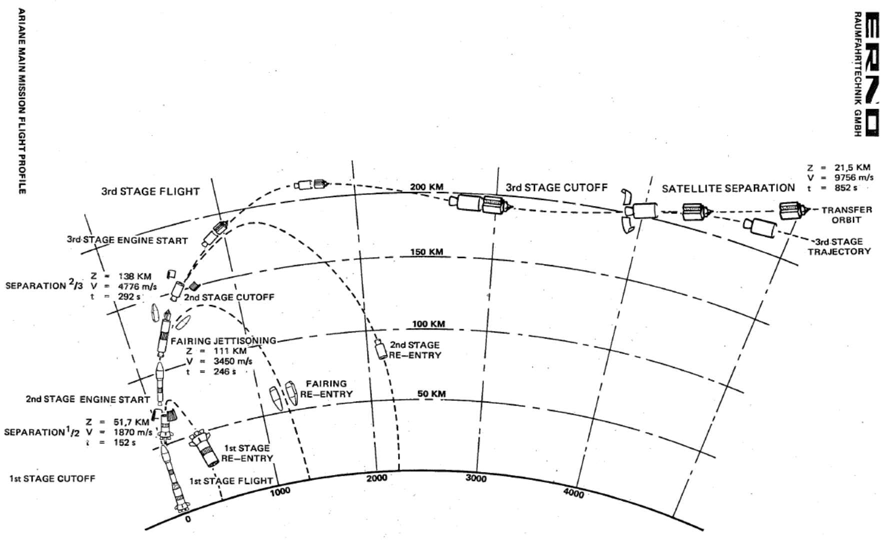


Speltra; launching two satellites together

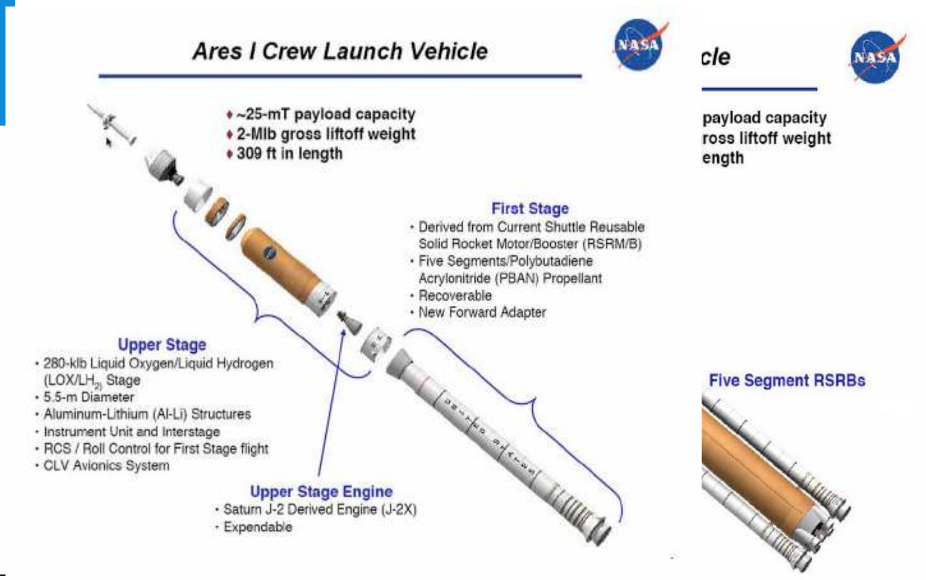


Source: Astrium

Example of a launch trajectory (Ariane 1)



NASA future (?): Ares launchers



Current challenges

- Decrease launch cost - Current launch costs are:
  - LEO $7000/kg
  - GEO $20000/kg
- Enhance reliability: Of the 4378 space launches conducted worldwide between 1957 and 1999, 390 launches failed (the success rate was 91.1 percent), with an associated loss or significant reduction of service life of 455 satellites (some launches included multiple payloads).

New commercial rockets

- SpaceX Falcon 9
- ???