Introduction

- We will take you through successfully launching a rocket and landing it on a different body
- This is a simplified version based on our knowledge of KSP not real life per se

Technicallities

Jargon

Orbit An object rotating around another object is said to be in orbit

Inclined An orbit that is tilted relative to the plane of the parent body

Technicallities

delta-v

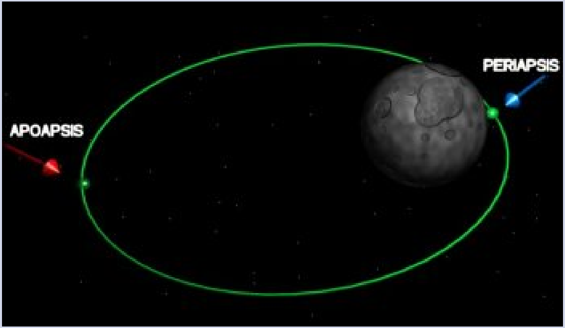
- aka: fuel budget
- how hard can i accelerate/decelerate my rocket
- dependent on:
  - fuel efficiency
  - thurst to weight ratio

Technicallities

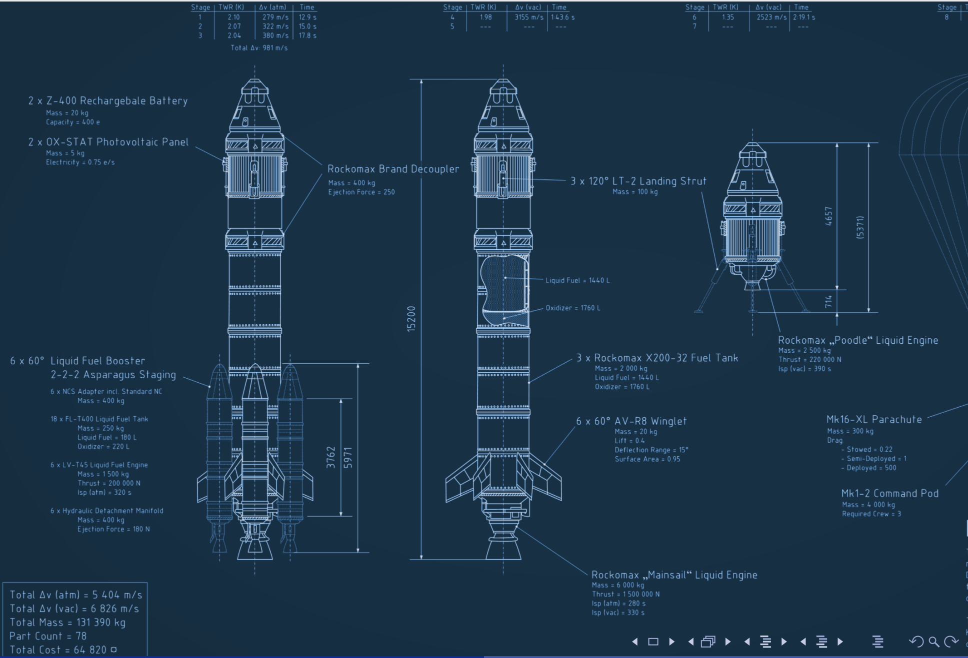
Points on orbit

apoapsis : highest point on orbit

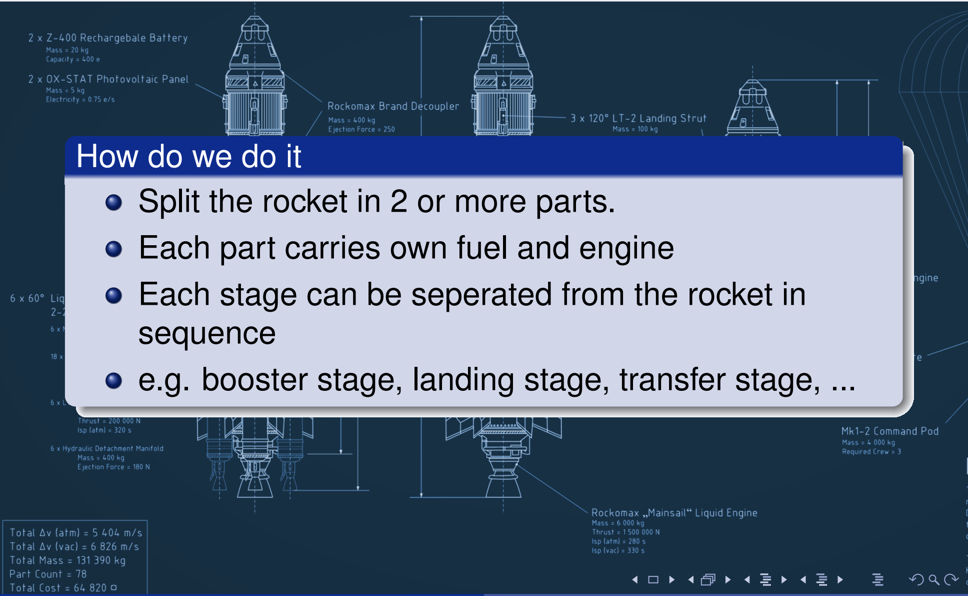
periapsis : Lowest point on orbit



Let’s prepare for launch


Stage | TWR (K) | Δv (atm) | Time
1 | 2.10 | 279 m/s | 12.9 s
2 | 2.07 | 322 m/s | 15.0 s
3 | 2.04 | 380 m/s | 17.8 s
Total Δv: 981 m/s
Stage | TWR (K) | Δv (vac) | Time
4 | 1.98 | 3155 m/s | 143.6 s
5 | --- | --- | ---
Stage | TWR (K) | Δv (vac) | Time
6 | 1.35 | 2523 m/s | 2:19.1 s
7 | --- | --- | ---
Stage
8
2 x Z-400 Rechargebale Battery
Mass = 20 kg
Capacity = 400 e
2 x OX-STAT Photovoltaic Panel
Mass = 5 kg
Electricity = 0.75 e/s
Rockomax Brand Decoupler
Mass = 400 kg
Ejection Force = 250
3 x 120° LT-2 Landing Strut
Mass = 100 kg
Liquid Fuel = 1440 L
Oxidizer = 1760 L
15200
4657
(5371)
714
Rockomax „Poodle“ Liquid Engine
Mass = 2 500 kg
Thrust = 220 000 N
Isp (vac) = 390 s
6 x 60° Liquid Fuel Booster
2-2-2 Asparagus Staging
6 x NCS Adapter incl. Standard NC
Mass = 400 kg
18 x FL-T400 Liquid Fuel Tank
Mass = 250 kg
Liquid Fuel = 180 L
Oxidizer = 220 L
6 x LV-T45 Liquid Fuel Engine
Mass = 1 500 kg
Thrust = 200 000 N
Isp (atm) = 320 s
6 x Hydraulic Detachment Manifold
Mass = 400 kg
Ejection Force = 180 N
3762
5971
3 x Rockomax X200-32 Fuel Tank
Mass = 2 000 kg
Liquid Fuel = 1440 L
Oxidizer = 1760 L
6 x 60° AV-R8 Winglet
Mass = 20 kg
Lift = 0.4
Deflection Range = 15°
Surface Area = 0.95
Mk16-XL Parachute
Mass = 300 kg
Drag
- Stowed = 0.22
- Semi-Deployed = 1
- Deployed = 500
Mk1-2 Command Pod
Mass = 4 000 kg
Required Crew = 3
Rockomax „Mainsail“ Liquid Engine
Mass = 6 000 kg
Thrust = 1 500 000 N
Isp (atm) = 280 s
Isp (vac) = 330 s
Total Δv (atm) = 5 404 m/s
Total Δv (vac) = 6 826 m/s
Total Mass = 131 390 kg
Part Count = 78
Total Cost = 64 820 ¤

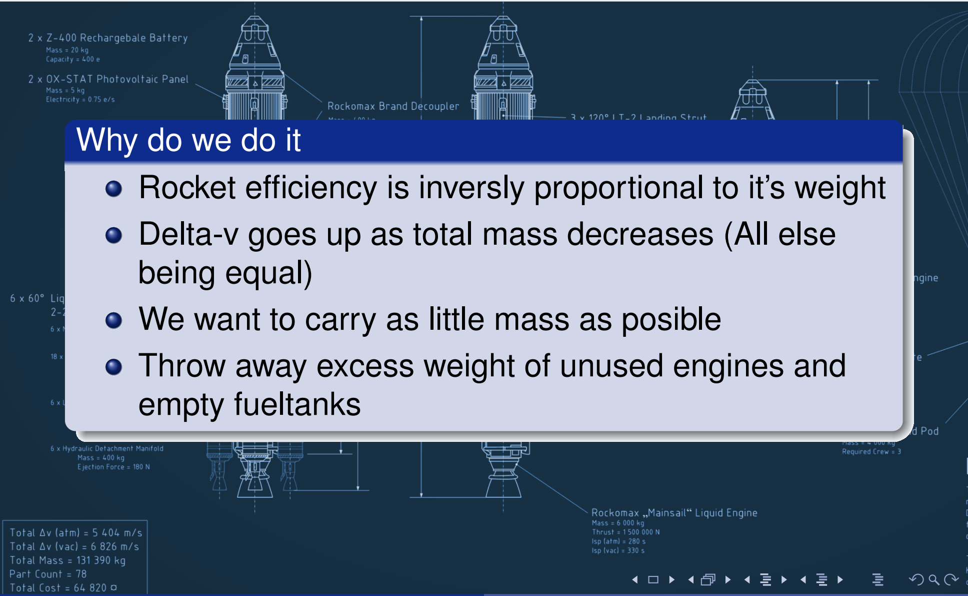
Staging



How do we do it

- Split the rocket in 2 or more parts.
- Each part carries own fuel and engine
- Each stage can be seperated from the rocket in sequence
- e.g. booster stage, landing stage, transfer stage, ...

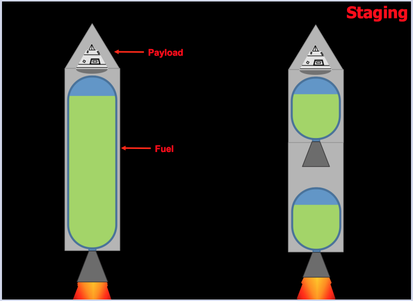
Staging



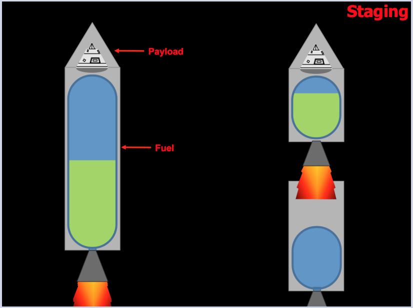
Why do we do it

- Rocket efficiency is inversly proportional to it's weight
- Delta-v goes up as total mass decreases (All else being equal)
- We want to carry as little mass as posible
- Throw away excess weight of unused engines and empty fueltanks

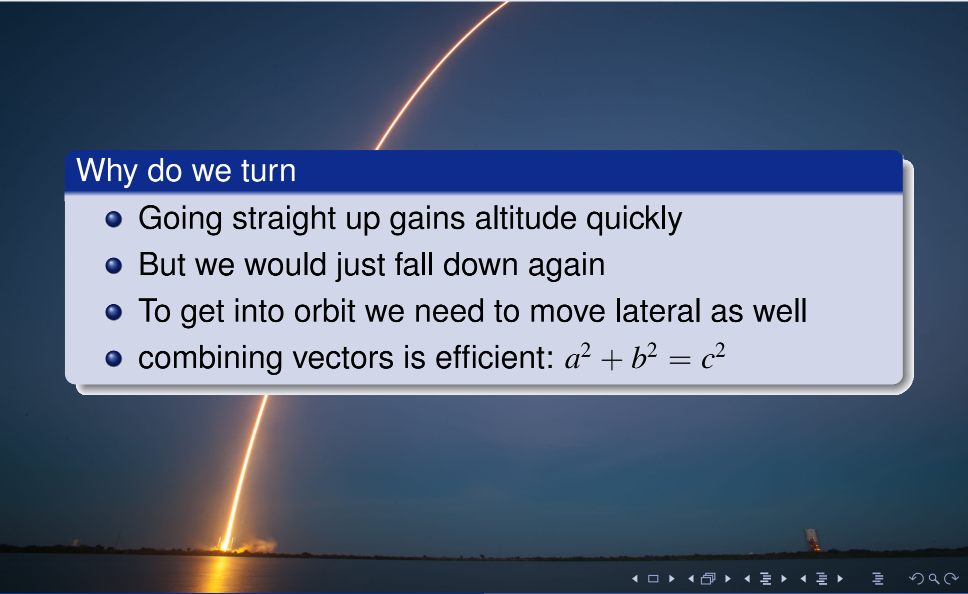
Staging



Staging

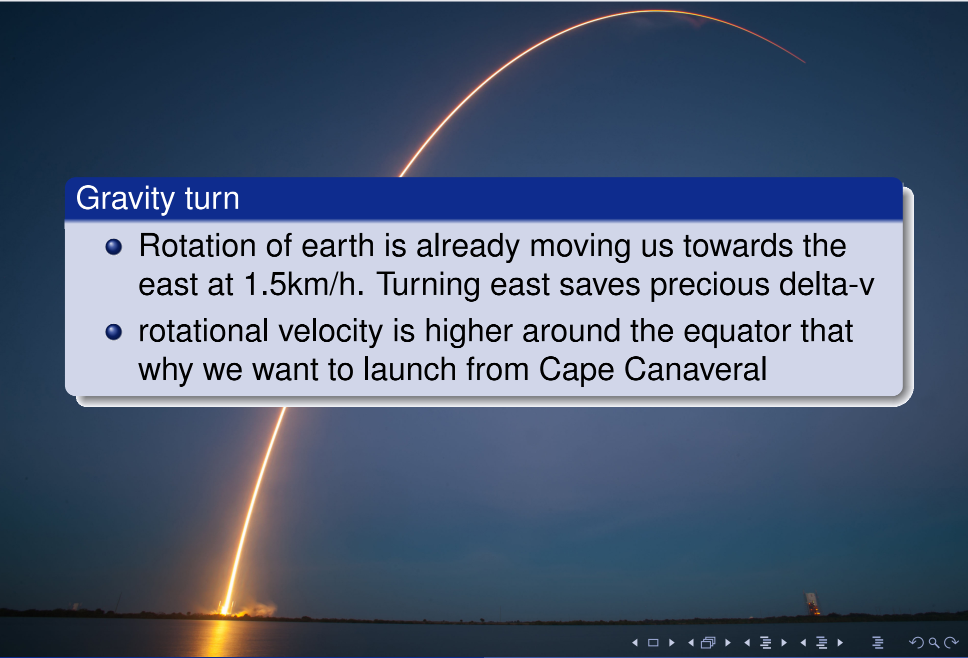


Getting into orbit



Why do we turn

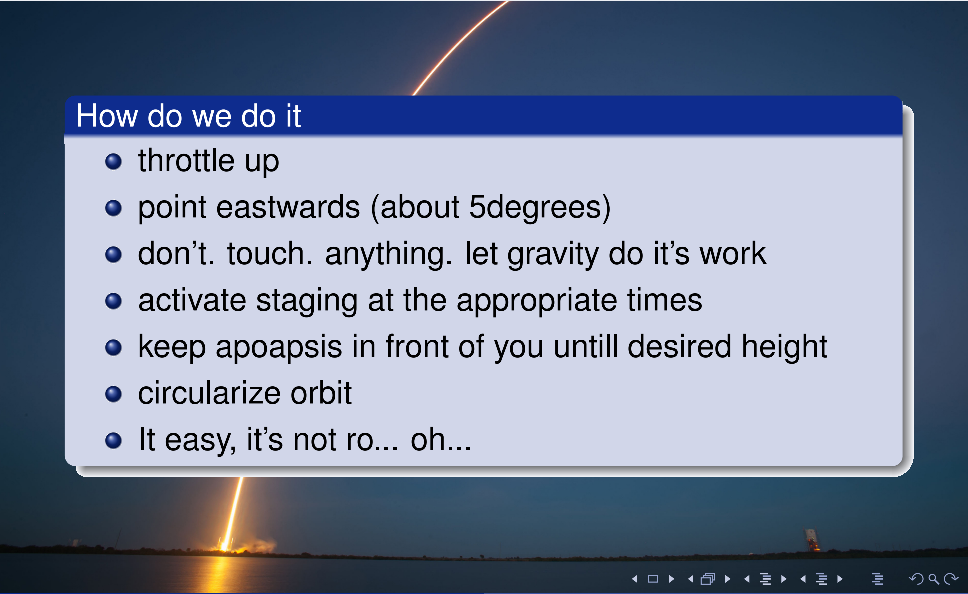
- Going straight up gains altitude quickly
- But we would just fall down again
- To get into orbit we need to move lateral as well
- combining vectors is efficient: $a^2 + b^2 = c^2$



Gravity turn

- Rotation of earth is already moving us towards the east at 1.5km/h. Turning east saves precious delta-v
- rotational velocity is higher around the equator that why we want to launch from Cape Canaveral

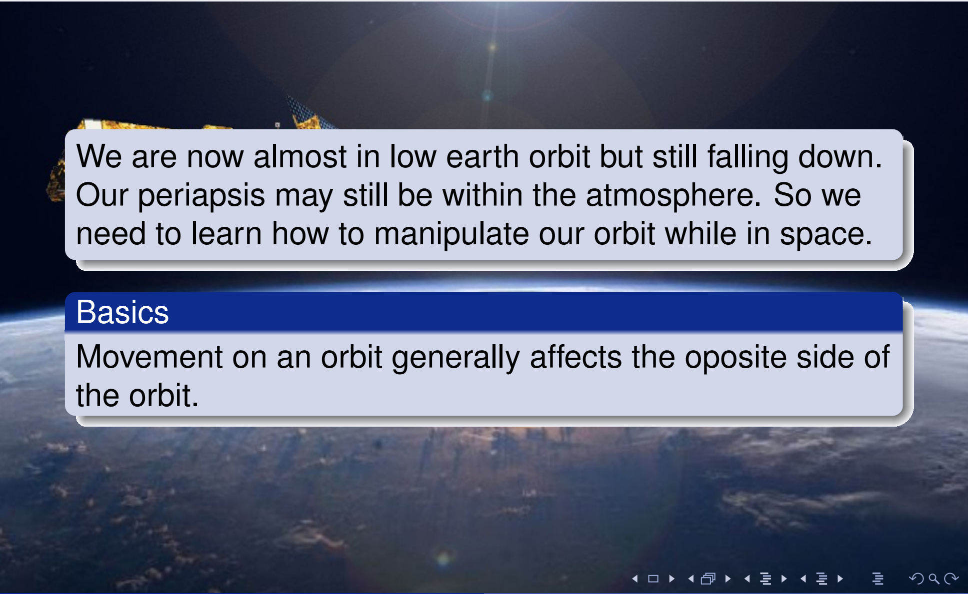
Let’s Launch



How do we do it

- throttle up
- point eastwards (about 5degrees)
- don’t. touch. anything. let gravity do it’s work
- activate staging at the appropriate times
- keep apoapsis in front of you untill desired height
- circularize orbit
- It easy, it’s not ro... oh...

About that circulizing



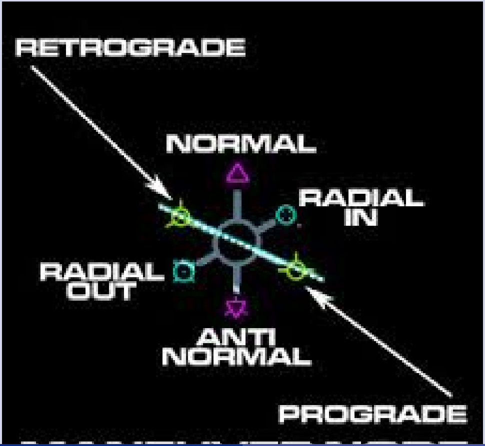
We are now almost in low earth orbit but still falling down. Our periapsis may still be within the atmosphere. So we need to learn how to manipulate our orbit while in space.

Basics

Movement on an orbit generally affects the oposite side of the orbit.

Adjusting Orbits

At any point on the orbit you can burn in 3 directions.
up/down, left/right, forwards/backwards



Low Orbit

Maveuvering in space

prograde Along your movement vector, used to increase orbit altitude

retrograde Oposite your movement vector, used to decrease orbit altitude

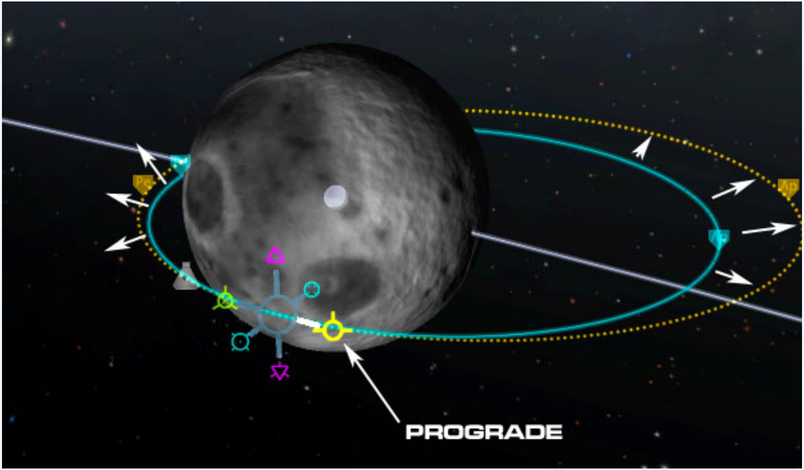
normal Perpendicular to orbit, used to increase/decrease inclination

anti-normal perpendiculat to orbit, used to increase/decrease inclination

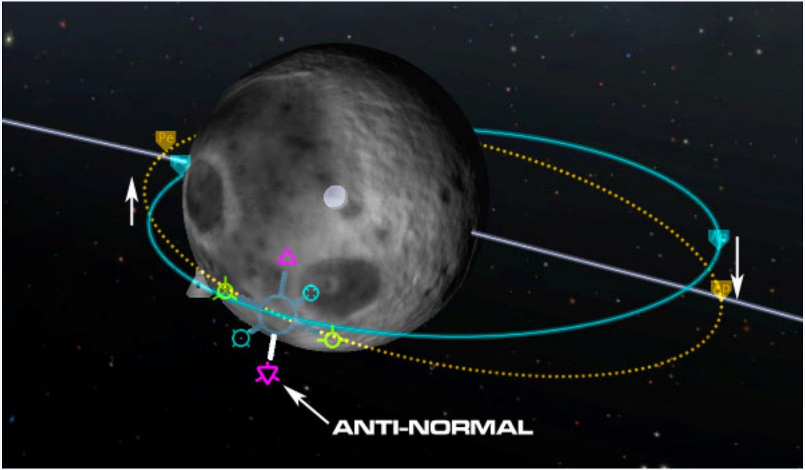
radial Towards parent body, Used to shift orbit around

anti-radial Away from parent body, used to shift orbit around

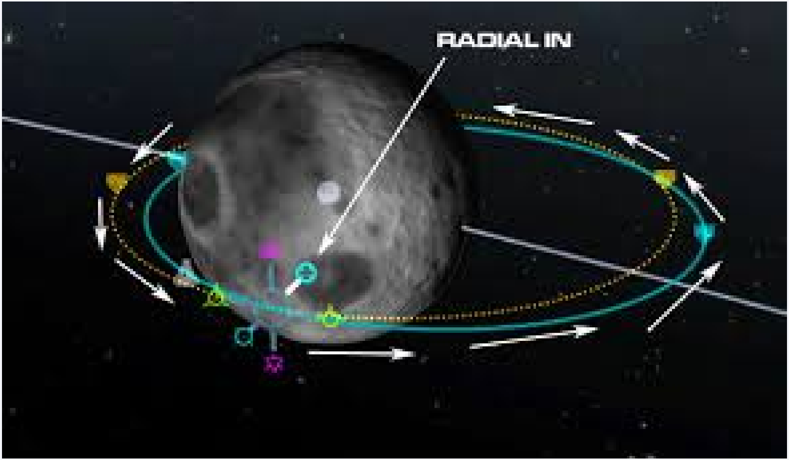
Prograde



Normal



Radial



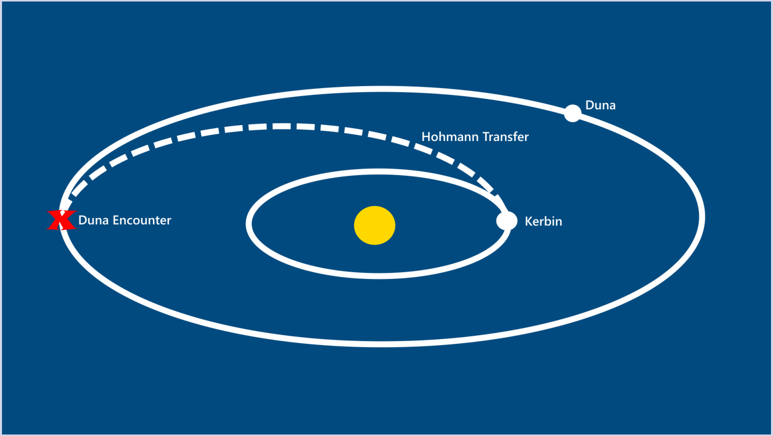
Planning Transfe

Finally achieved a stable low earth orbit. We need to plan our tranfer to our target body


Jupiter
Europa
Ganymede
1480
Low Orbit
(100 km)
580
Intercept
8890
45000
Low Orbit
(2000 km)
17200
1970
Low Orbit
(100 km)
790
Intercept
6700
Io
1850
730
Low Orbit
(100 km)
Intercept
10320
70
1760
Callisto
5140
Intercept
Low Orbit
(100 km)
Intercept
Deimos
4
2
Low Orbit
(1 km)
Intercept
990
Mars
3800
1440
Low Orbit
(200 km)
1060
Intercept
3360
Phobos
8
3
Low Orbit
(1 km)
Intercept
1280
Titan
660
7600
Intercept
Low Orbit
(1000 km)
3060
Saturn
10230
30000
Intercept
Low Orbit
(2000 km)
4500
Venus
27000
2940
Low Orbit
(400 km)
Intercept
640
Uranus
6120
18000
Intercept
Low Orbit
(1000 km)
5280
Mercury
3060
1220
Low Orbit
(100 km)
Intercept
8650
Neptune
6750
19000
Intercept
Low Orbit
(1000 km)
5390
Earth Intercept
Moon
1730
680
3260
Low Orbit
(100 km)
Intercept
3210
3910
Geostationary Orbit
Low Earth Orbit

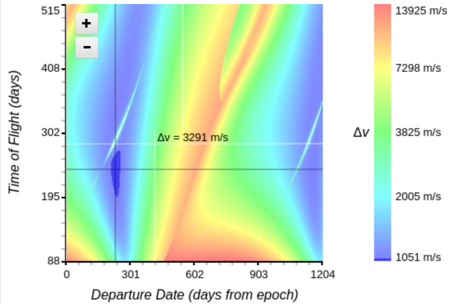
Hohmann transfer

Now that we now our target and know the delta-v required to get there we need to plan the encounter

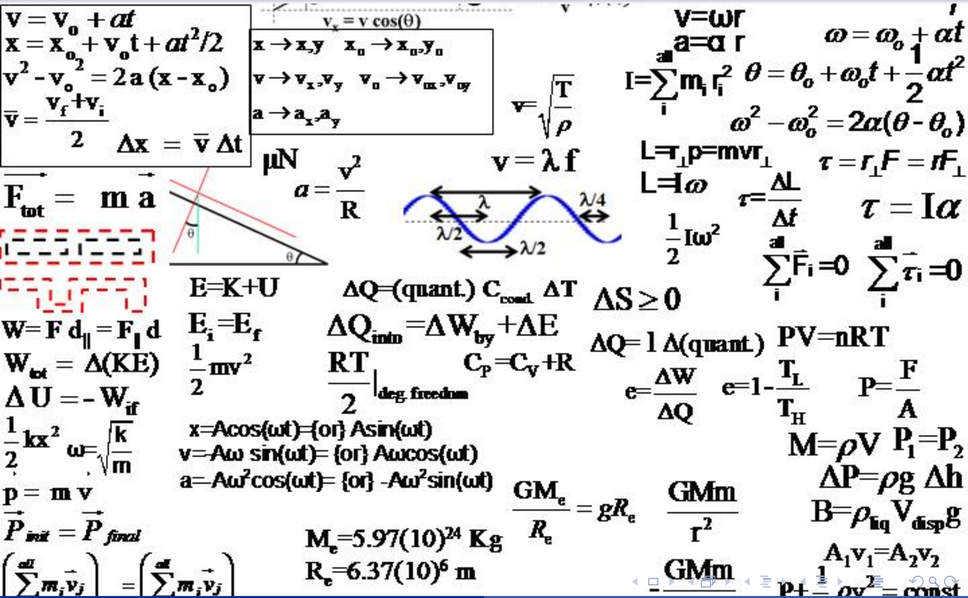


Hohmann transfer window

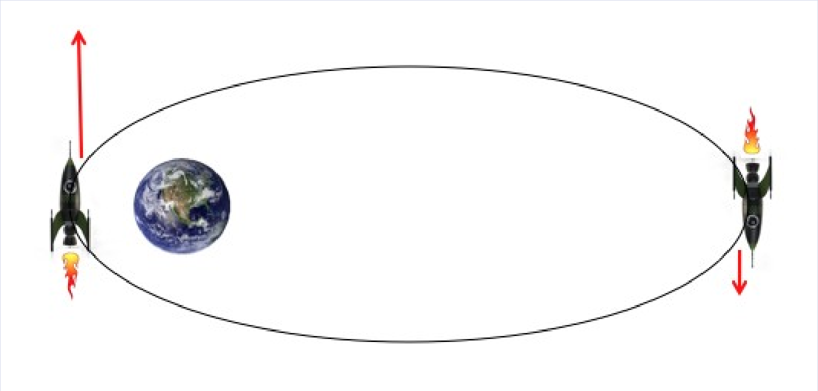
To be able to transfer with the least amount of delta-v as possible we need to launch when the target body is at an exact position relative to us. If we are on a strict delta-v budget we need to wait for a good window



Oberth Effect



JK, Oberth Effect



Oberth Effect explained

- things that go fast have higher energy
- $KE = 0.5 * m * v^2$

- mass is a form of energy
- $E = MC^2$

- Newton's third law
- $F_a = -F_b$

Dumping mass (fuel) while deep in the gravity well (going fast) gives more kinetic energy to the ship This is an oversimplification

Escape

Now that we know how to make optimal use of the Oberth effect we can begin our escape burn and start our tranfer orbit

- descelarate to drop periapsis deeper into the gravity well
- wait for periapsis (maximal use of Oberth effect)
- make transfer burn and coast to encounter

Sphere Of Influence

Sphere Of Influence(SOI) is the region around a planet in which the gravitational pull from the planet is bigger than any other body's gravitational pull. Which planet/body has the most gravitational influence on you

- We are in the SOI of the sun
- The moon is also influenced by the gravity of the sun
- but it is close enough to earth so that our gravitational influence is higher than the sun's
- therefor we say that the moon is within the SOI of earth

Intercept

When we are within the gravitational sphere of influence of the target planet we need to slow down to be captured by the planet.

- Burn retrograde to slow down
- Keep slowing down untill you fall into an highly eleptical orbit
- keep dropping periapsis to desired height
- wait for periapsis and then circularize orbit

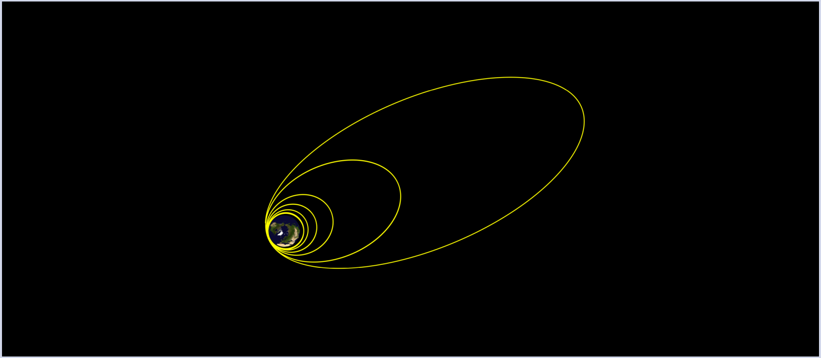
Intercept

Aerobreaking

Instead of having to circularize your orbit (which takes a fair amount of delta-v we can make use of the body's atmosphere to slow down to do this you need to

- drop periapsis just inside of the atmosphere
- not too deep because you can burn up
- not too shallow because slowing down would take a very long time
- just wait a couple of orbits
- the apoapsis should drop on every orbit because atmospheric drag slows you down while at periapsis

Aerobraking

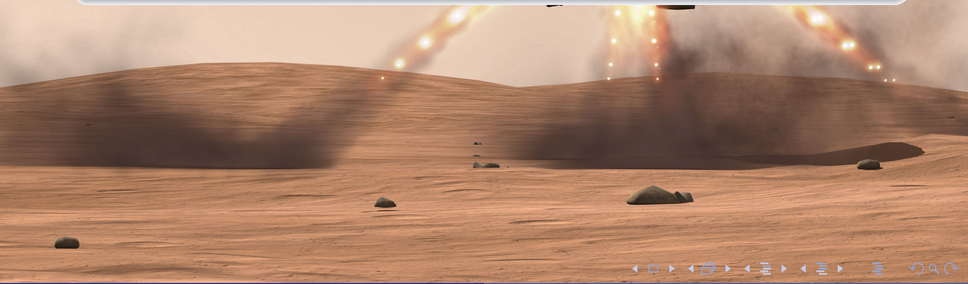



SPACEX

Landing

Entering atmosphere

- determine entry angle
- not to steep => to much atmosperic drag => burning up
- not to shallow => won't slow down quickly enough => skipping out of atmosphere



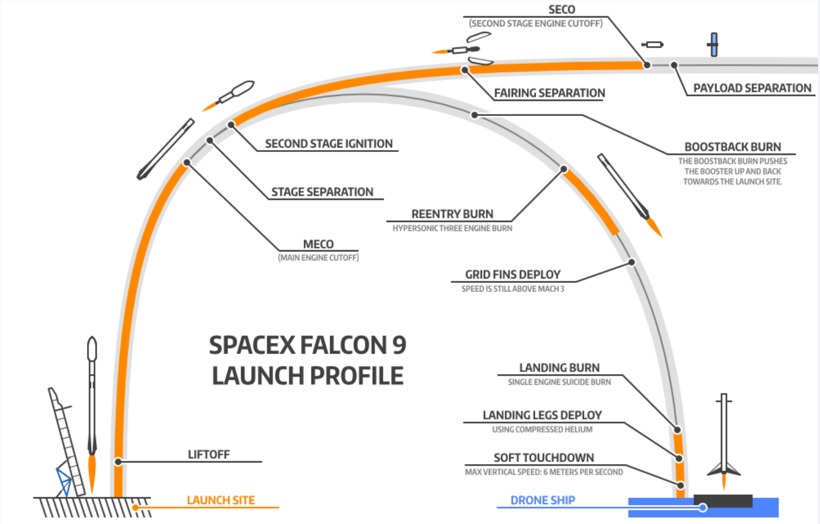
Landing

Suicide Burn

We need to slow down our descent before we hit the ground. At the last possible second we fire all engines at 100% throttle.

Why?

- Gravity is an accelerating force adding $\alpha m/s^2$
- Every second spend descelarating needs to be compensated for gravity
- Slowing down means burning an additional α delta-v every second
- Slowing down quickly saves fuel.


SECO
(SECOND STAGE ENGINE CUTOFF)
FAIRING SEPARATION
PAYLOAD SEPARATION
SECOND STAGE IGNITION
BOOSTBACK BURN
THE BOOSTBACK BURN PUSHES THE BOOSTER UP AND BACK TOWARDS THE LAUNCH SITE.
STAGE SEPARATION
REENTRY BURN
HYPERSONIC THREE ENGINE BURN
MECO
(MAIN ENGINE CUTOFF)
GRID FINS DEPLOY
SPEED IS STILL ABOVE MACH 3
SPACEX FALCON 9
LAUNCH PROFILE
LANDING BURN
SINGLE ENGINE SUICIDE BURN
LANDING LEGS DEPLOY
USING COMPRESSED HELIUM
LIFTOFF
SOFT TOUCHDOWN
MAX VERTICAL SPEED: 6 METERS PER SECOND
LAUNCH SITE
DRONE SHIP