Introduction

- We'll take you through launching a rocket and landing it on a different planet
- Obviously: this is simplified

Technicalities

Jargon

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

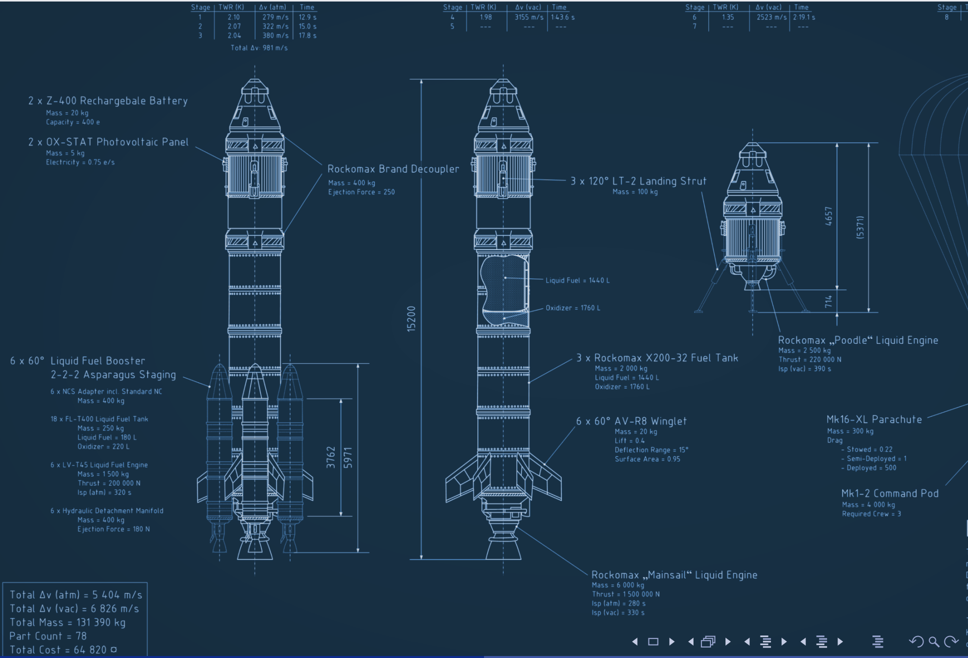
Inclined An orbit that is tilted relative to the plane of the parent body

Technicalities

Delta-v

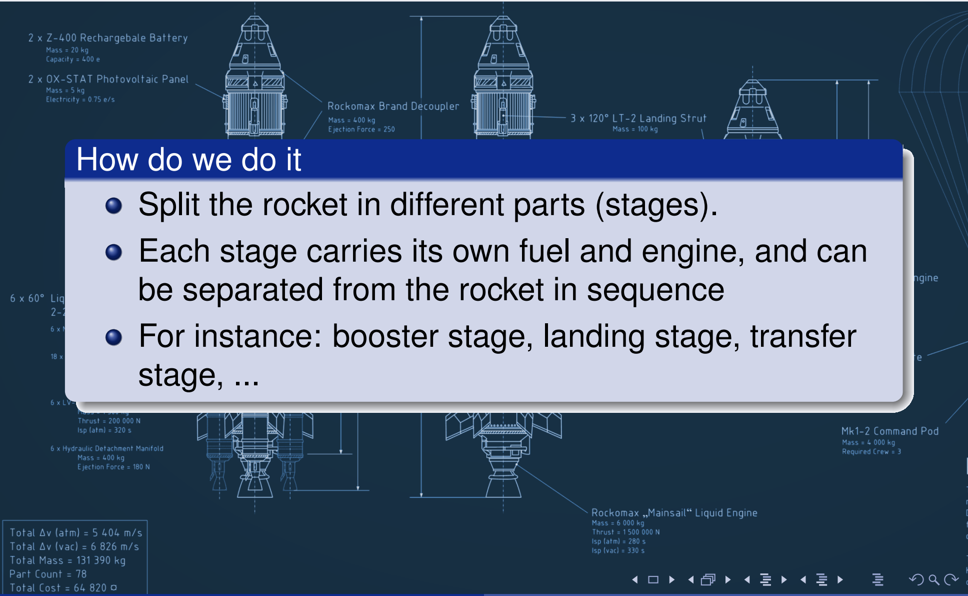
- Your fuel budget
- How hard can I accelerate/decelerate my rocket
- Depends on thrust to mass ratio

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 ¤

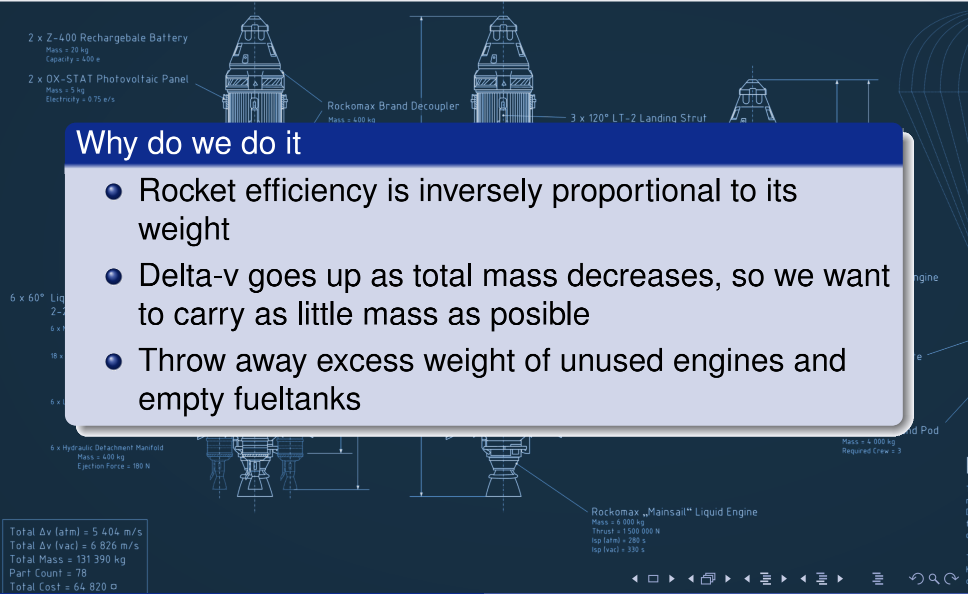
Staging



How do we do it

- Split the rocket in different parts (stages).
- Each stage carries its own fuel and engine, and can be separated from the rocket in sequence
- For instance: booster stage, landing stage, transfer stage, ...

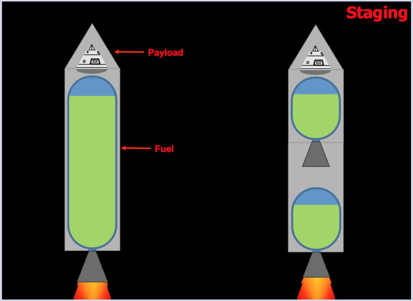
Staging



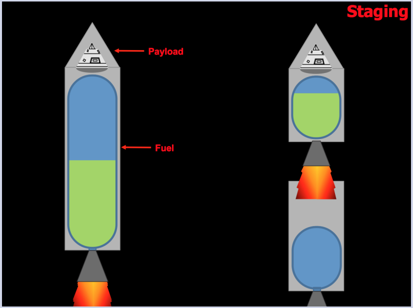
Why do we do it

- Rocket efficiency is inversely proportional to its weight
- Delta-v goes up as total mass decreases, so we want to carry as little mass as posible
- Throw away excess weight of unused engines and empty fueltanks

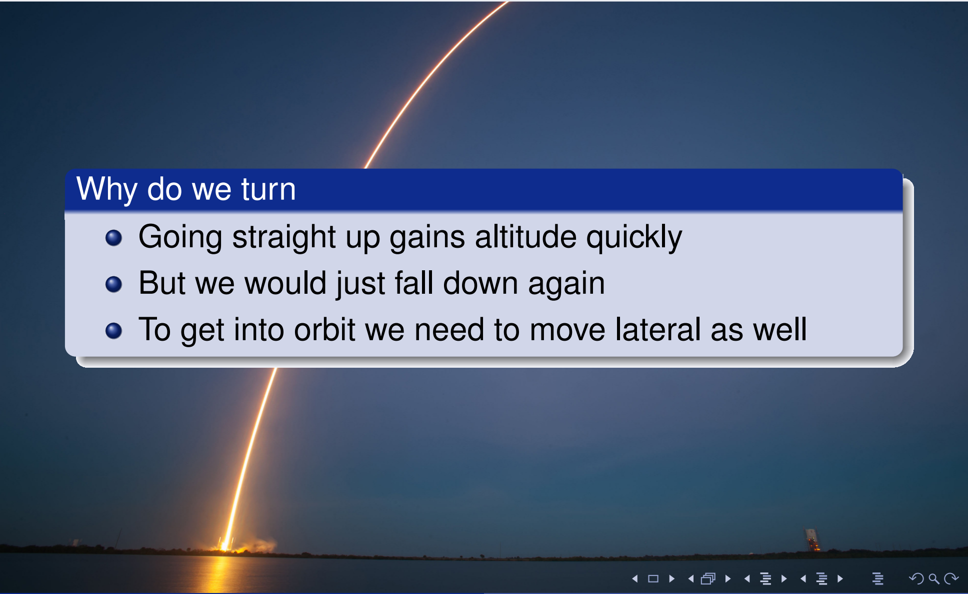
Staging



Staging

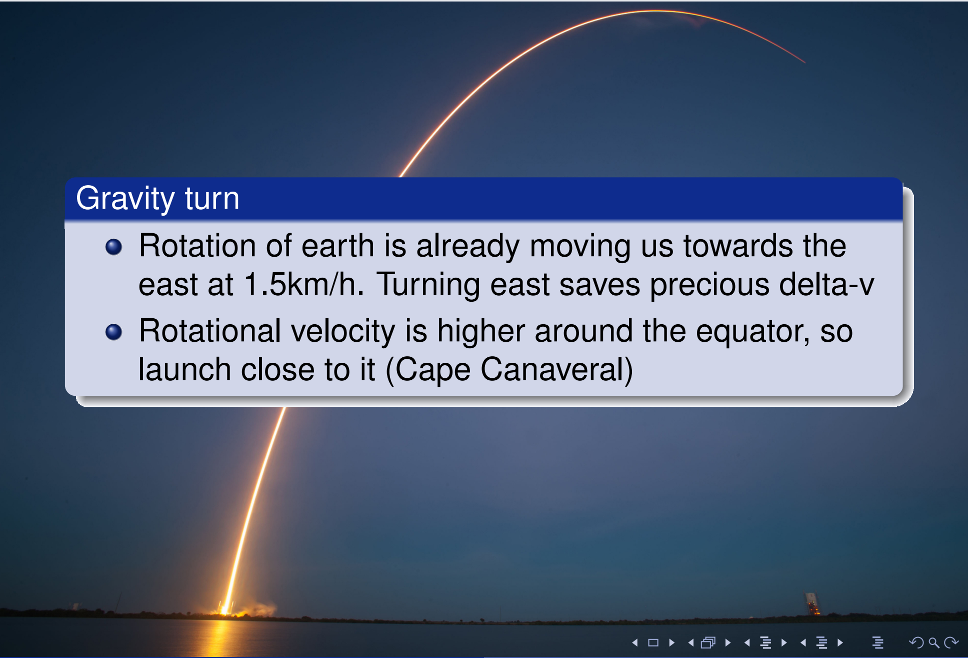


Getting into orbit



Why do we turn

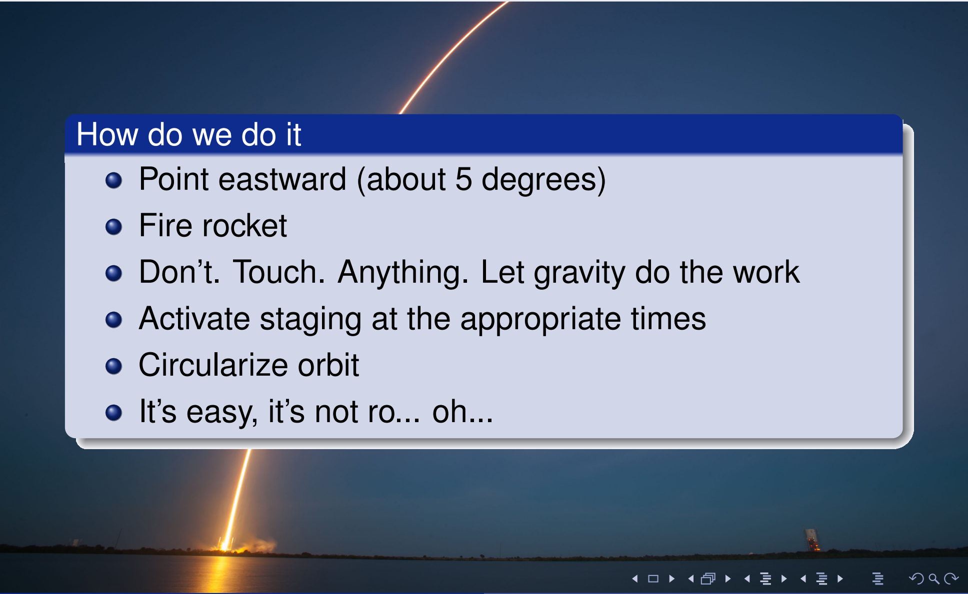
- Going straight up gains altitude quickly
- But we would just fall down again
- To get into orbit we need to move lateral as well



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, so launch close to it (Cape Canaveral)

Let's Launch



How do we do it

- Point eastward (about 5 degrees)
- Fire rocket
- Don't. Touch. Anything. Let gravity do the work
- Activate staging at the appropriate times
- Circularize orbit
- It's easy, it's not ro... oh...

About that circularizing

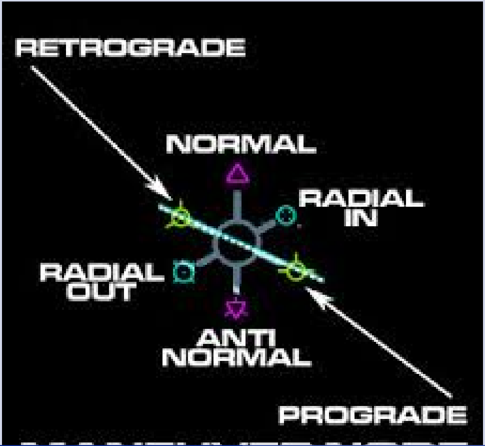
We are now almost in low earth orbit but still falling down. Our orbit could still cross the atmosphere. So we need to learn how to manipulate our orbit while in space.

Basics

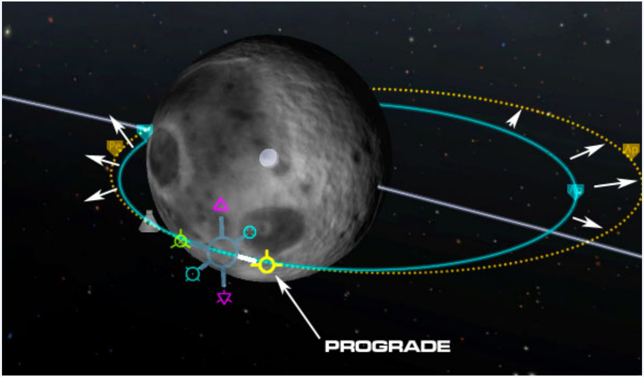
Movement on an orbit generally affects the opposite side of the orbit.

Adjusting orbits

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

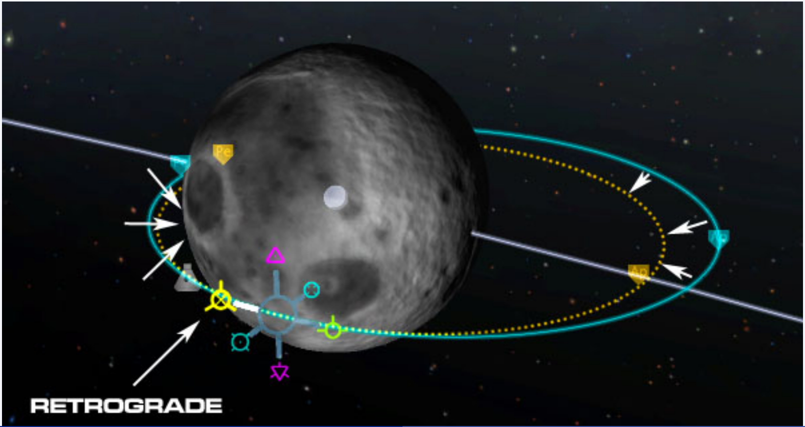


Burning in the prograde direction expands the size of the orbit, with the center of expansion at the current position.



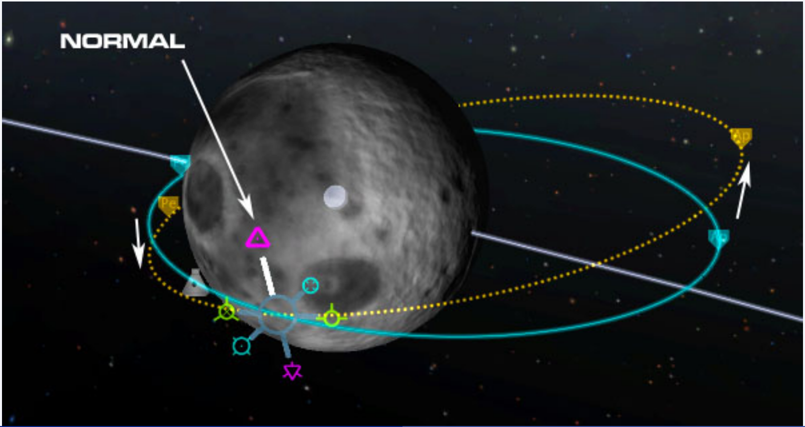
Retrograde

Burning in the retrograde direction contracts the size of the orbit, with the center of contraction at the current position.



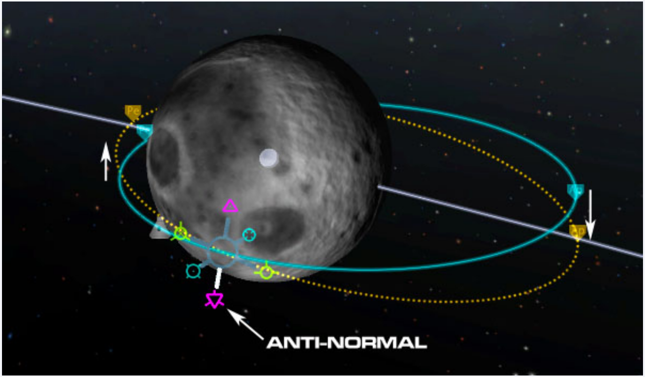
Normal

Burning in the normal direction tilts the orbital plane counterclockwise on the axis determined by the current position and the planet's center.



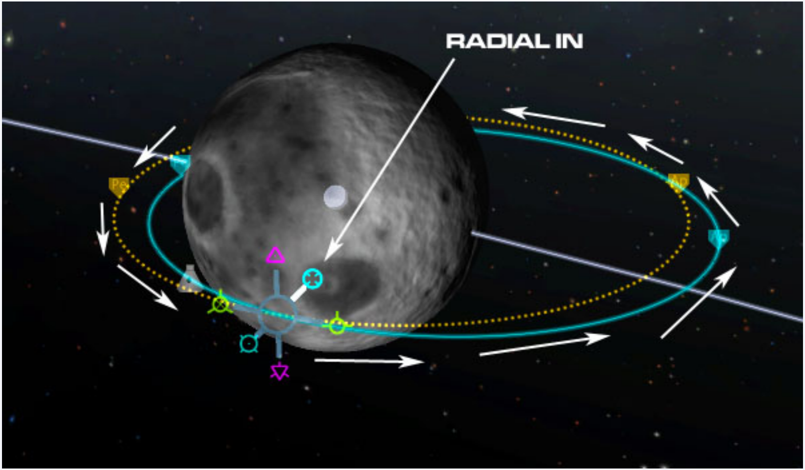
Anti-normal

Burning in the anti-normal direction tilts the orbital plane clockwise on the axis determined by the current position and the planet's center.



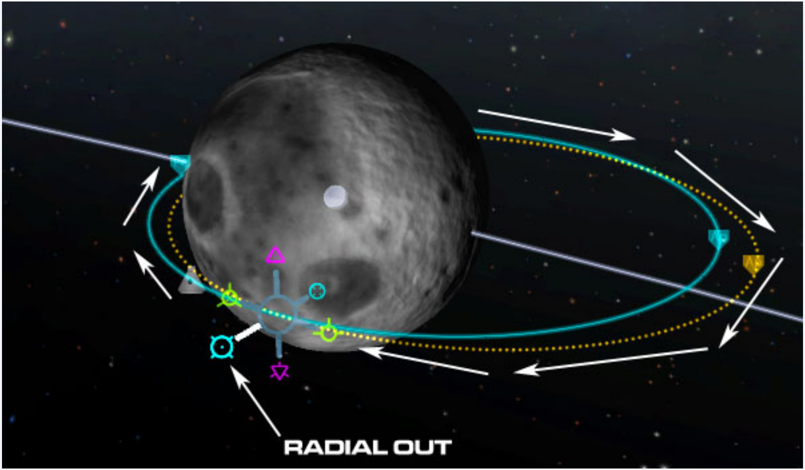
Radial in

Burning in the radial-in direction rotates the orbial plane counterclockwise.



Radial out

Burning in the radial-out direction rotates the orbial plane clockwise.



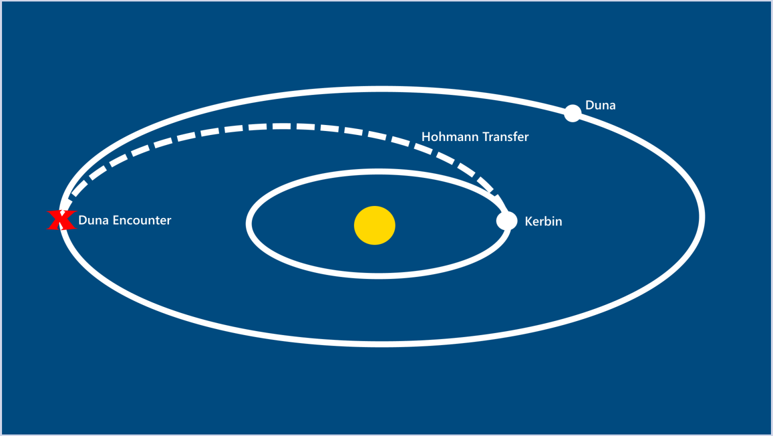
Planning transfer

We finally achieved a stable low earth orbit. We need to plan our transfer to our target body

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

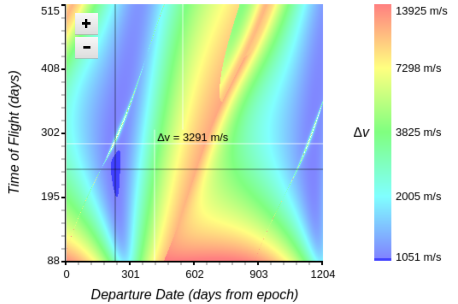
Hohmann transfer

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

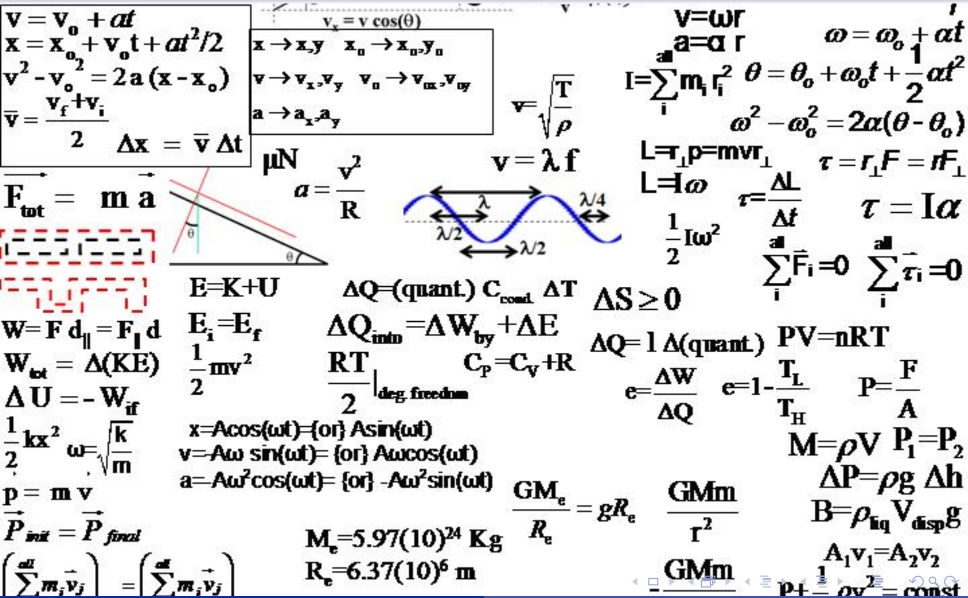


Hohmann transfer window

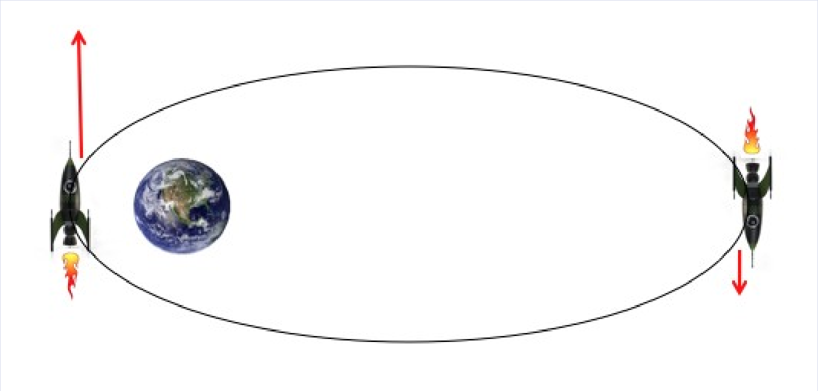
To be able to transfer with the least amount of delta-v possiblem, we need to launch when the target body is at an optimal position. If we are on a strict delta-v budget we need to wait for a good window



Oberth effect



jk, Oberth effect



Escape

Now that we can make optimal use of the Oberth effect we can begin our escape burn and start our transfer orbit

- Decelarate to drop orbit deeper into the gravity well
- Wait for lowest point of orbit (to make 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 larger any other.

- We are in the SOI of our sun
- The moon is also influenced by the gravity of the sun, but it's close enough to earth to makes its influence higher. So the moon is within the SOI of earth.

Intercept

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

- Burn retrograde to slow down
- Keep slowing down until you fall into an highly elliptical orbit
- Wait for lowest point of orbit

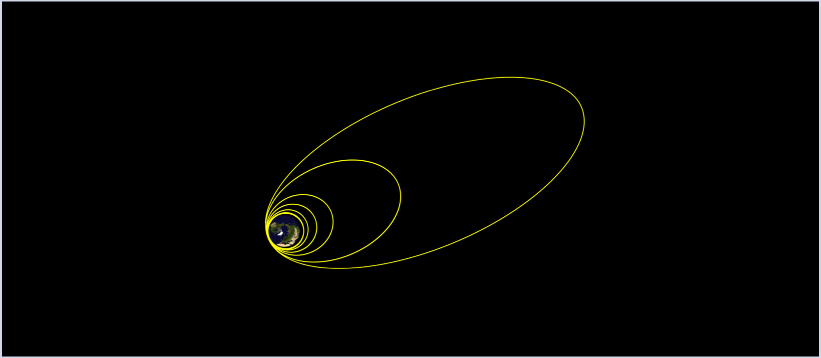
Intercept

Aerobreaking

Instead of having to circularize your orbit (which is expensive) we can make use of the body's atmosphere to slow down.

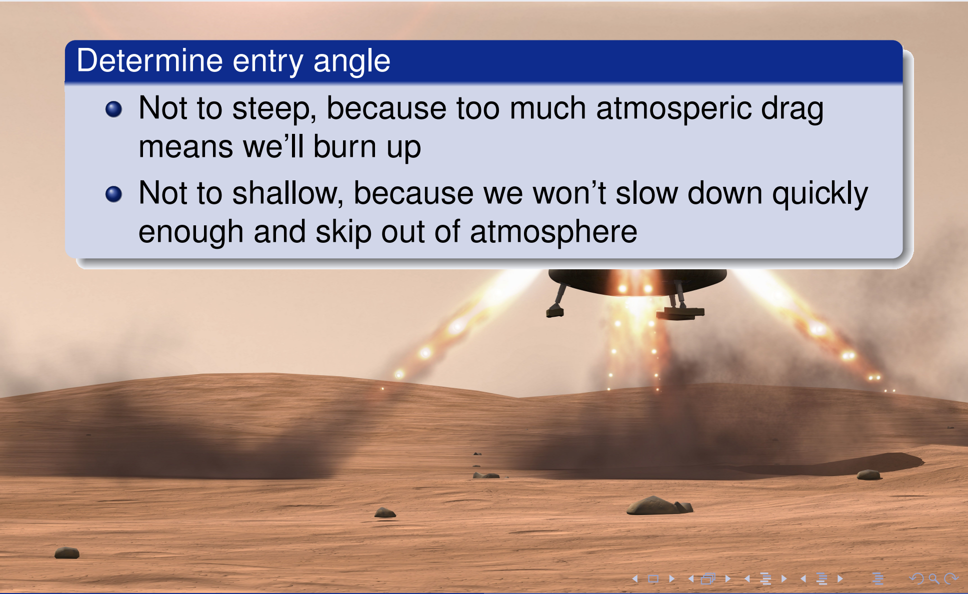
- Drop orbit just inside of the atmosphere
- Not too deep because you can burn up, not too shallow because it would take a very long time
- Wait a couple of orbits: you get closer every orbit because atmospheric drag slows you down

Aerobraking




SPACEX

Landing



Determine entry angle

- Not to steep, because too much atmosperic drag means we'll burn up
- Not to shallow, because we won't slow down quickly enough and skip out of atmosphere

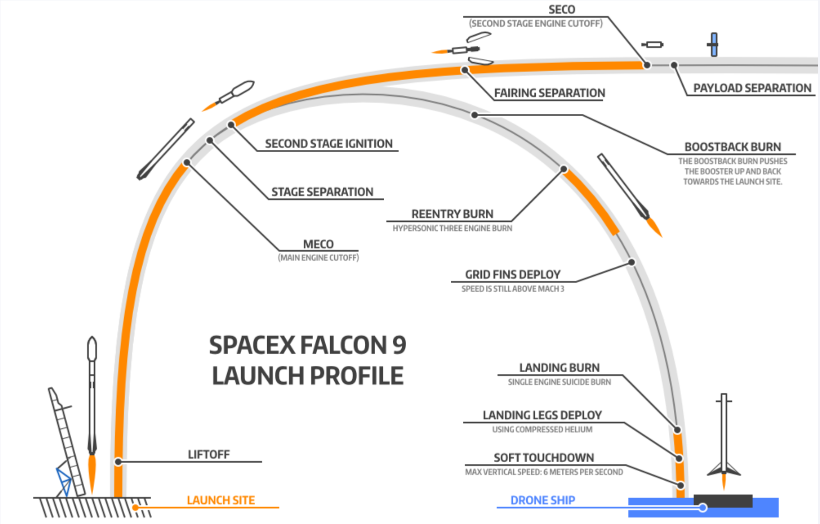
Landing

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 accelerating our fall, so decelarating earlier gives gravity more time to accelerate us again
- Slowing down quickly saves fuel.


SECO
(SECOND STAGE ENGINE CUTOFF)
PAYLOAD SEPARATION
FAIRING SEPARATION
BOOSTBACK BURN
THE BOOSTBACK BURN PUSHES THE BOOSTER UP AND BACK TOWARDS THE LAUNCH SITE.
SECOND STAGE IGNITION
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