

What we learned from playing Kerbal Space Program

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Introduction

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

Technicalities

Orbit

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

Technicalities

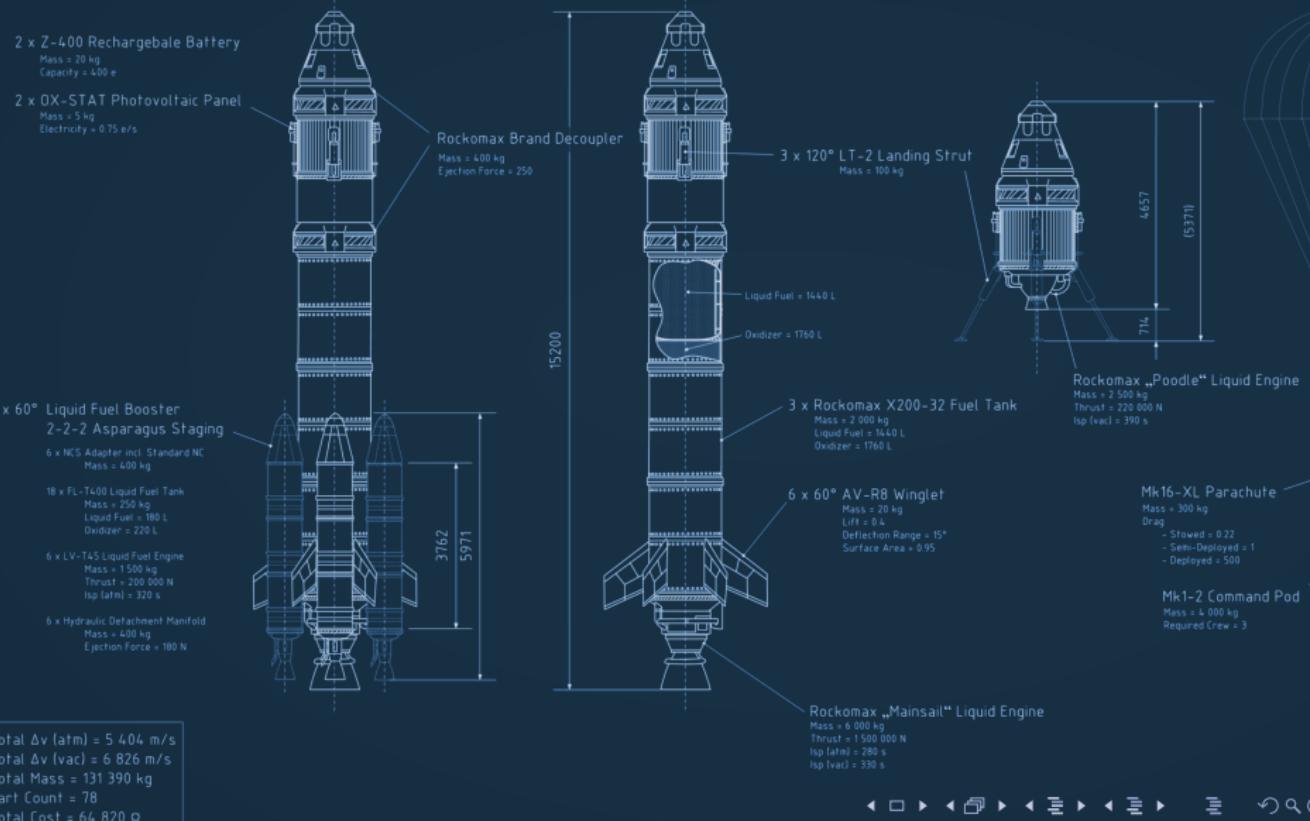
Delta-v

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



Prepare for launch!

Staging



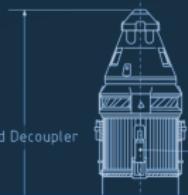
Staging

2 x Z-400 Rechargeable 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



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, transfer stage, landing stage, ...

6 x 60° Liquid Engine
Mass = 2 kg
Isp (atm) = 220 s
Isp (vac) = 320 s

6 x 18° Liquid Engine
Mass = 1.500 kg
Thrust = 200 000 N
Isp (atm) = 320 s

6 x Hydraulic Detachment Manifold
Mass = 400 kg
Ejection Force = 100 N



Rockomax „Mainsail“ Liquid Engine
Mass = 6 000 kg
Thrust = 1 500 000 N
Isp (atm) = 280 s
Isp (vac) = 330 s

Mk1-2 Command Pod
Mass = 4 000 kg
Required Crew = 3

Staging

2 x Z-400 Rechargeable 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 N



3 x 120° LT-2 Landing Strut
Mass = 100 kg



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 possible
- Throw away excess weight of unused engines and empty fuel tanks

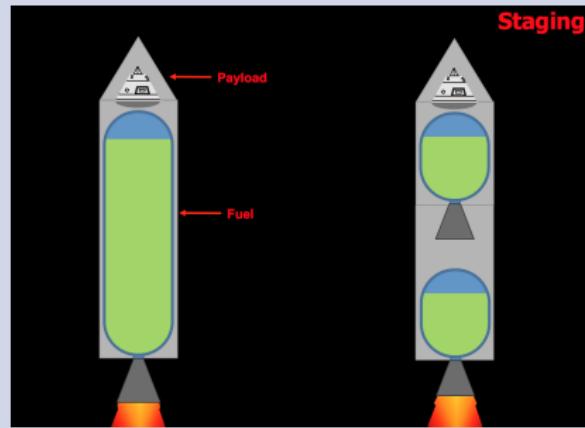
6 x 60° Liquid Engine
2 x 120° Liquid Engine
6 x 180° Liquid Engine
18 x 30° Liquid Engine
6 x 120° Solid Fuel Engine
6 x 180° Solid Fuel Engine



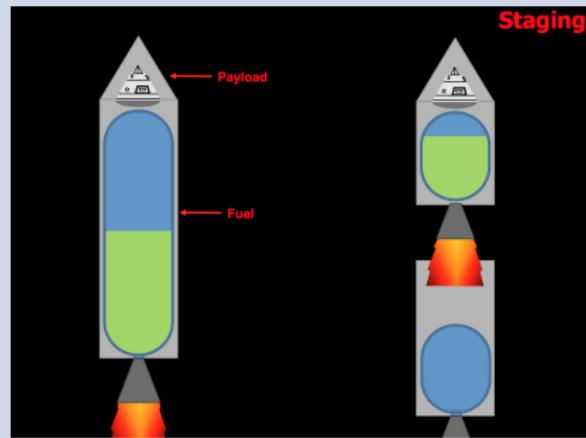
Rockomax „Mainsail“ Liquid Engine
Mass = 6 000 kg
Thrust = 1 500 000 N
isp (atm) = 280 s
isp (vac) = 330 s

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



Staging

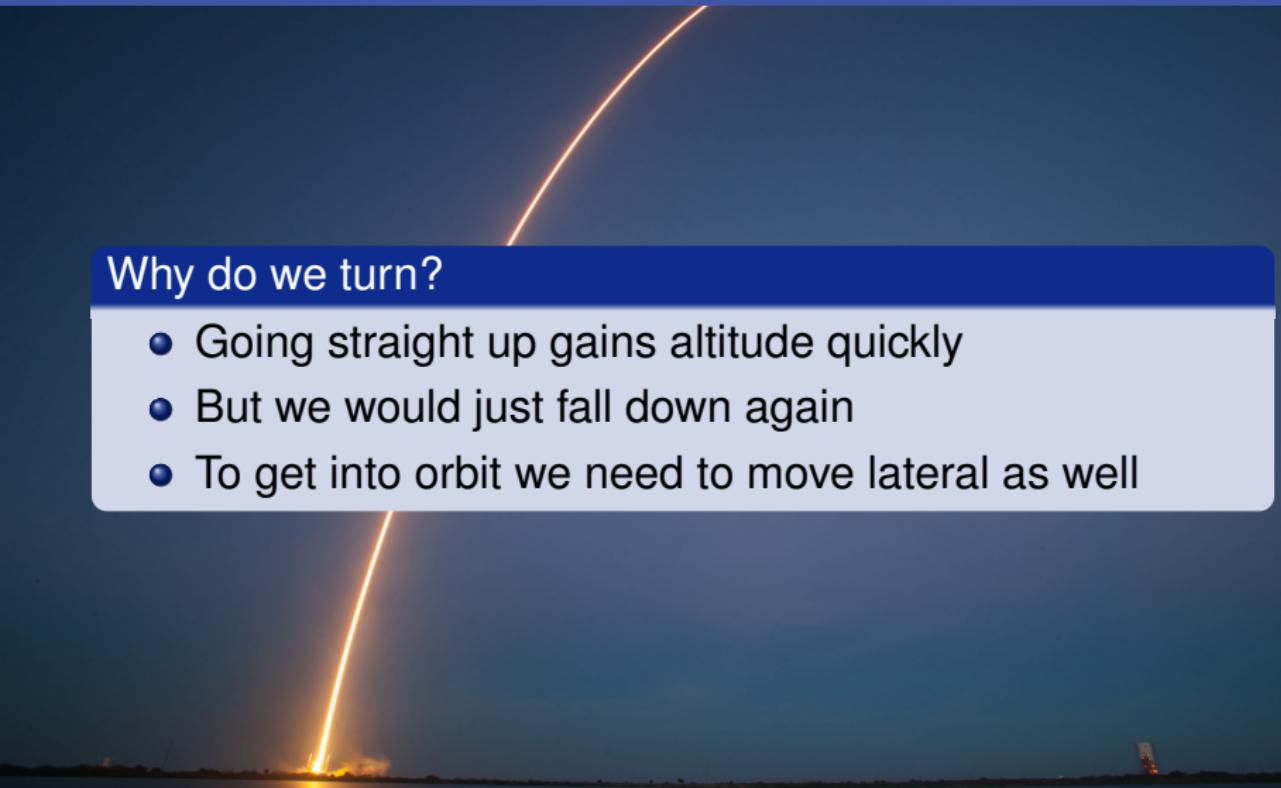


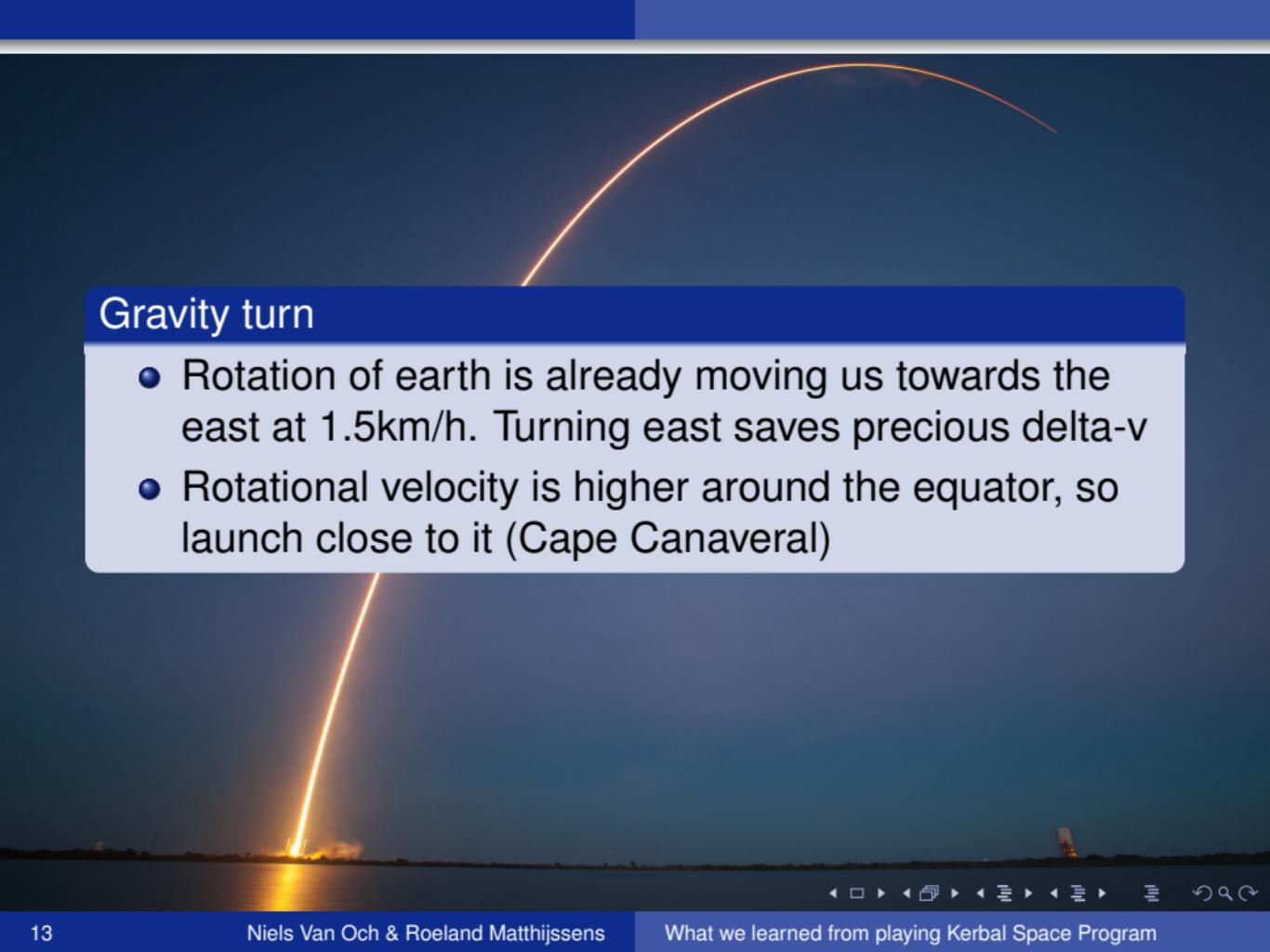


Getting into orbit

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)

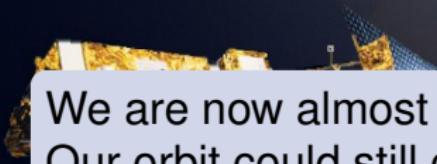
Let's launch!

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 not rocket science



About that circularizing



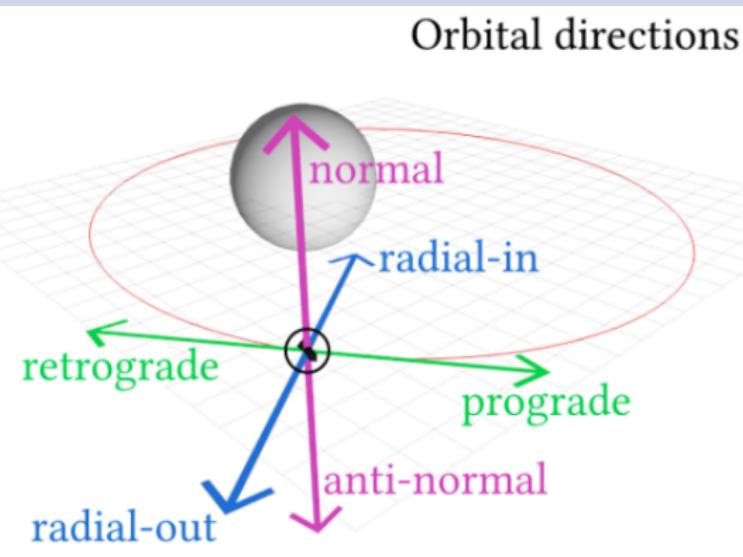
We are now almost in low earth orbit but still falling down. Our orbit could still cross the atmosphere. So we need to learn how to manipulate our orbit while in space.

Basics

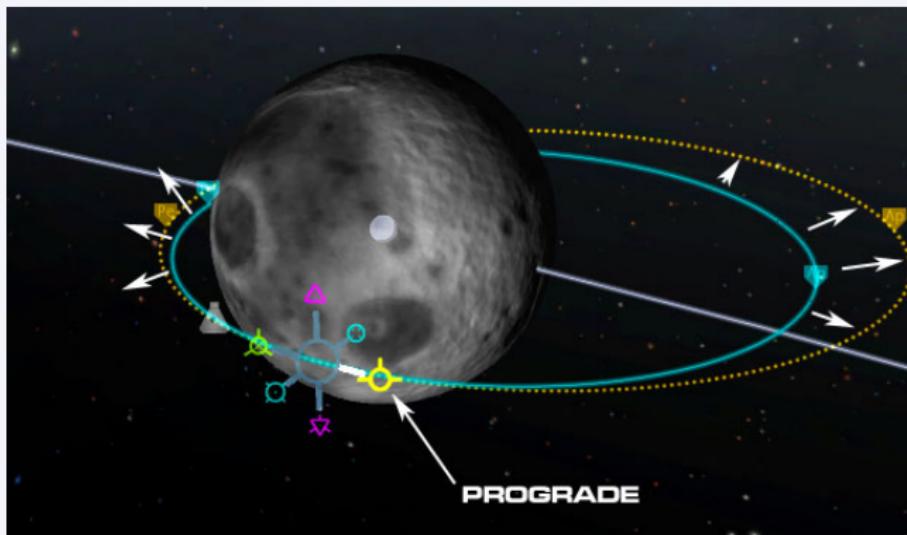
Movement on an orbit generally affects the opposite side of the orbit.

Adjusting orbits

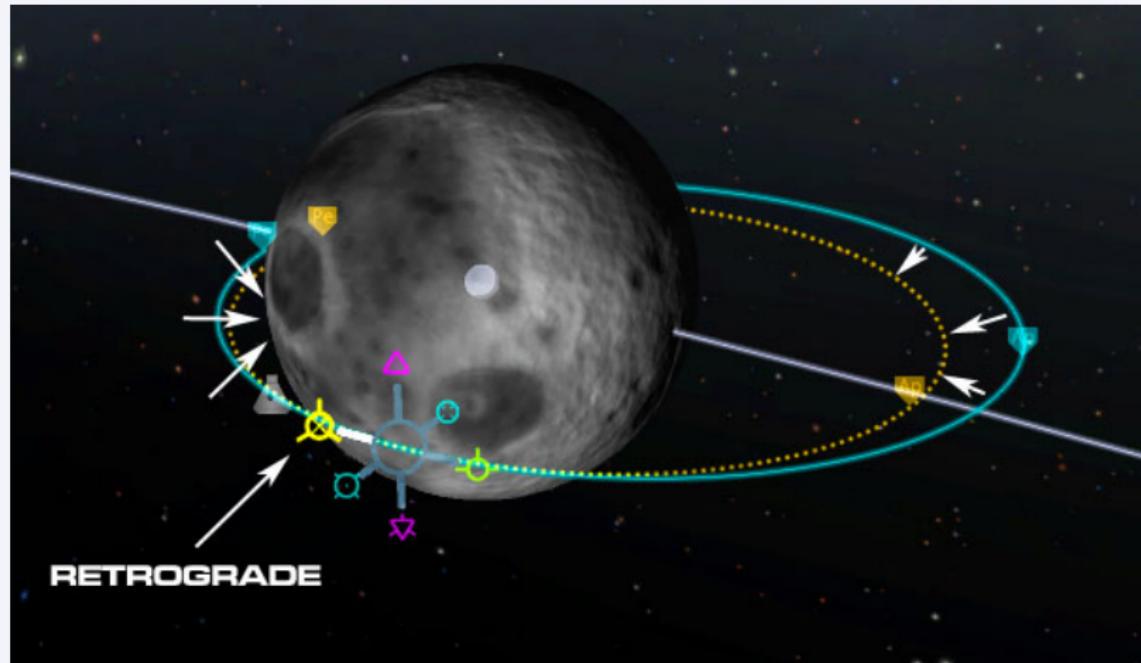
At any point on the orbit you can burn in 3 directions:
up/down, left/right, forwards/backwards



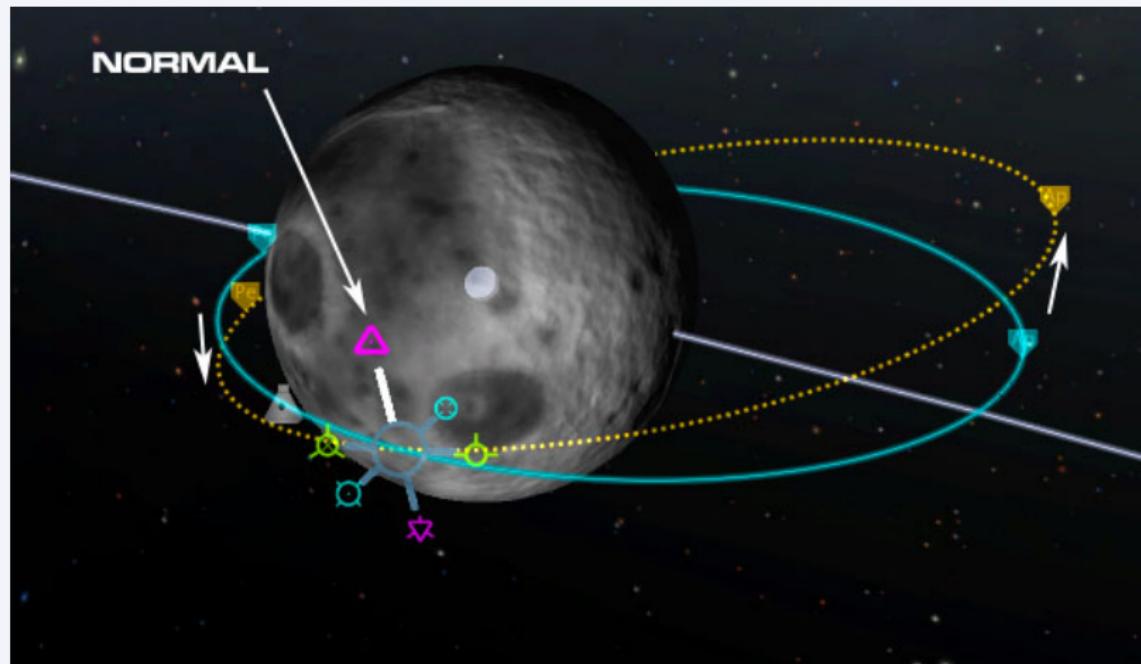
Prograde



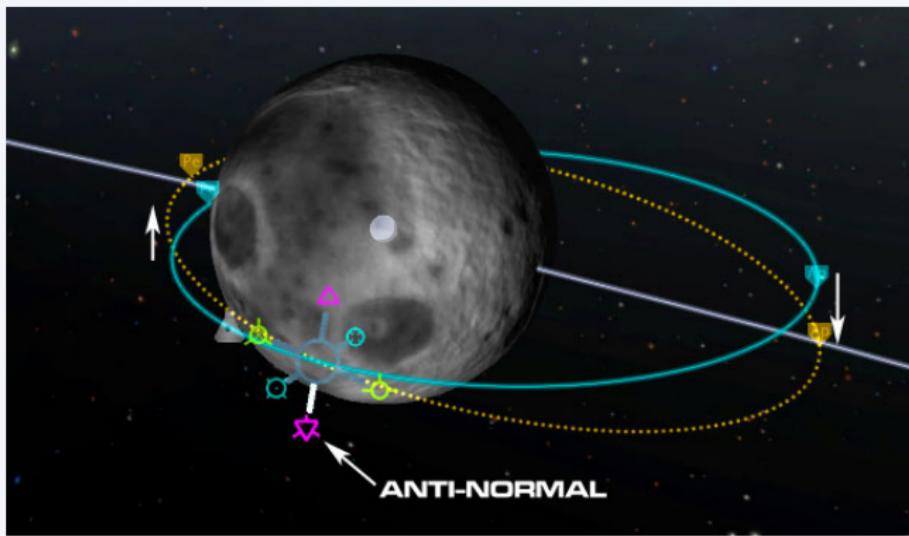
Retrograde

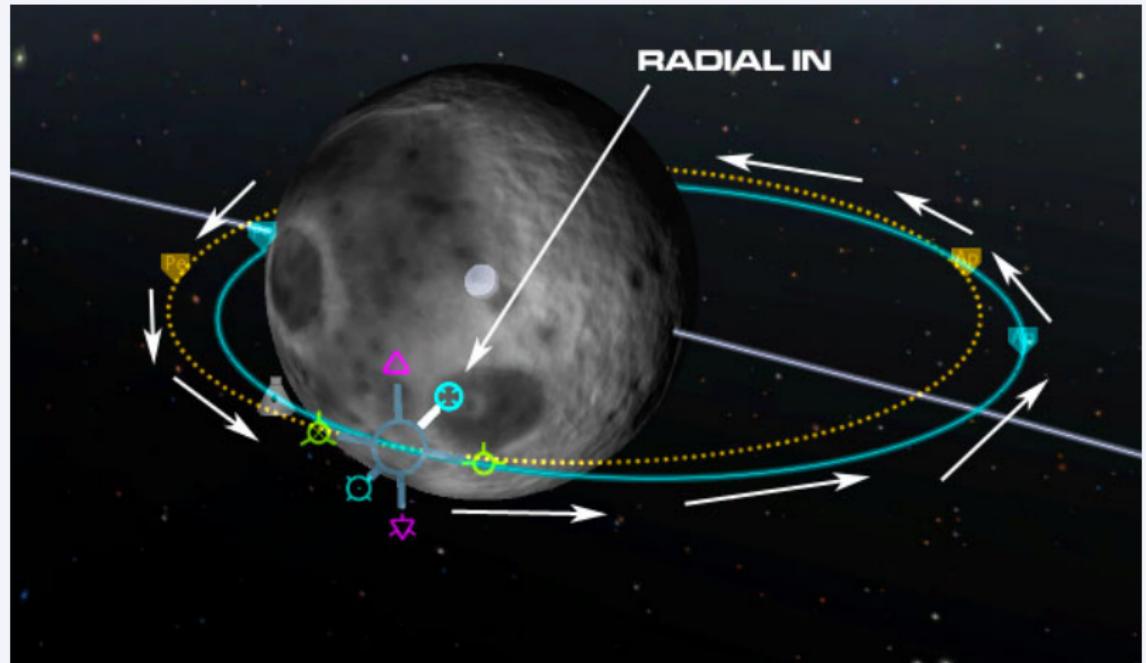


Normal

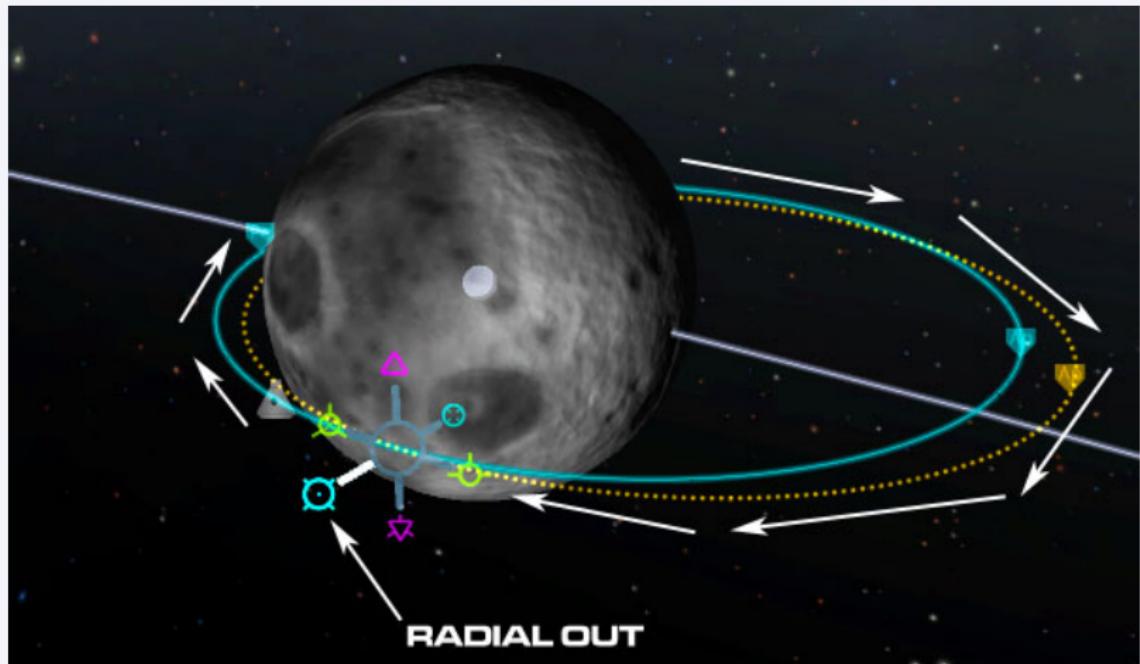


Anti-normal





Radial out



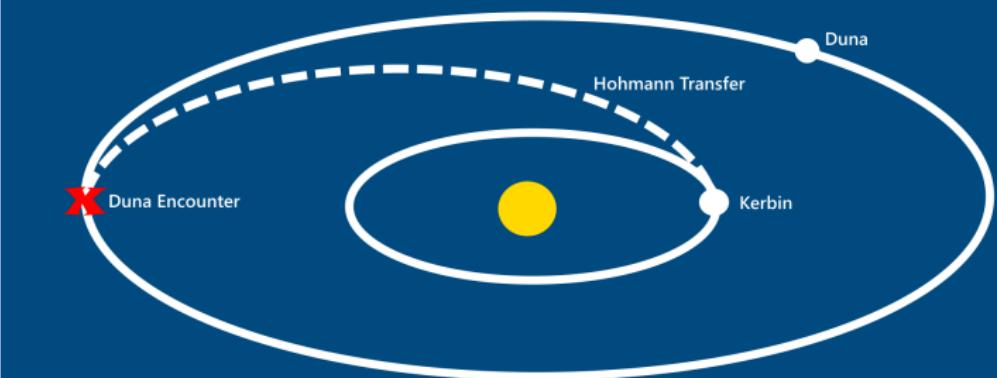
Planning transfer

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



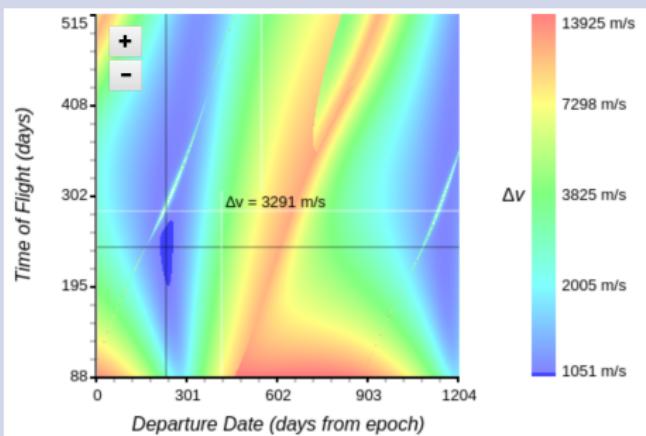
Hohmann transfer

Now that we know 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 possible, we need to launch when the target body is at an optimal position



Oberth effect

$$V = V_0 + at$$

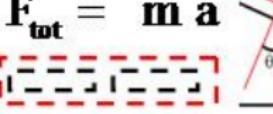
$$X = X_0 + V_0 t + at^2/2$$

$$V^2 - V_0^2 = 2a(X - X_0)$$

$$\bar{V} = \frac{V_f + V_i}{2}$$

$$\Delta X = \bar{V} \Delta t$$

~~$$\vec{F}_{\text{tot}} = m \vec{a}$$~~



$$W = F d_{\parallel} = F_I d$$

$$W_{\text{tot}} = \Delta(\text{KE})$$

$$\Delta U = -W_{\text{if}}$$

$$\frac{1}{2} kx^2$$

$$\omega = \sqrt{\frac{k}{m}}$$

$$p = m v$$

$$\vec{P}_{\text{int}} = \vec{P}_{\text{final}}$$

$$\left(\sum_i m_i \vec{v}_j \right) = \left(\sum_i m_i \vec{v}_j \right)$$

$$v_x = v \cos(\theta)$$

$$x \rightarrow x, y \quad x_0 \rightarrow x_0, y_0$$

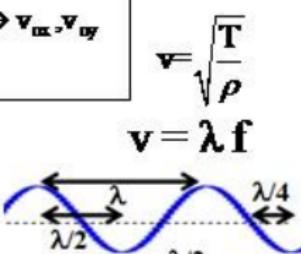
$$v \rightarrow v_x, v_y \quad v_0 \rightarrow v_{0x}, v_{0y}$$

$$a \rightarrow a_x, a_y$$

$$\mu N$$

$$a = \frac{v^2}{R}$$

~~$$a = \frac{v^2}{R}$$~~



$$v = \sqrt{\frac{T}{\rho}}$$

$$v = \lambda f$$

$$V = \omega r$$

$$a = \alpha r$$

$$\omega = \omega_0 + \alpha t$$

$$I = \sum_i m_i r_i^2$$

$$\theta = \theta_0 + \omega_0 t + \frac{1}{2} \alpha t^2$$

$$\omega^2 - \omega_0^2 = 2\alpha(\theta - \theta_0)$$

$$L = r_{\perp} p = m v r_{\perp}$$

$$L = I \omega$$

$$\tau = \frac{\Delta L}{\Delta t}$$

$$\tau = I \alpha$$

$$\frac{1}{2} I \omega^2$$

$$\sum_i \vec{F}_i = 0$$

$$\sum_i \tau_i = 0$$

$$\Delta S \geq 0$$

$$PV = nRT$$

$$\Delta Q = 1 \Delta (\text{quant.})$$

$$e = \frac{\Delta W}{\Delta Q}$$

$$e = 1 - \frac{T_L}{T_H}$$

$$P = \frac{F}{A}$$

$$M = \rho V$$

$$P_1 = P_2$$

$$\Delta P = \rho g \Delta h$$

$$B = \rho_{\text{liqu}} V_{\text{disp}} g$$

$$A_1 v_1 = A_2 v_2$$

$$p + \frac{1}{2} \rho v^2 = \text{const}$$

$$E = K + U$$

$$E_i = E_f$$

$$\frac{1}{2} mv^2$$

$$C_p = C_v + R$$

$$RT$$

$$\frac{1}{2}$$

$$\text{deg freedom}$$

$$x = A \cos(\omega t) = \{\text{or}\} A \sin(\omega t)$$

$$v = A \omega \sin(\omega t) = \{\text{or}\} A \omega \cos(\omega t)$$

$$a = A \omega^2 \cos(\omega t) = \{\text{or}\} -A \omega^2 \sin(\omega t)$$

$$\Delta Q = (\text{quant.})$$

$$C_{\text{cond.}}$$

$$\Delta T$$

$$\Delta W_{\text{by}}$$

$$C_p = C_v + R$$

$$RT$$

$$\frac{1}{2}$$

$$\text{deg freedom}$$

$$x = A \cos(\omega t) = \{\text{or}\} A \sin(\omega t)$$

$$v = A \omega \sin(\omega t) = \{\text{or}\} A \omega \cos(\omega t)$$

$$a = A \omega^2 \cos(\omega t) = \{\text{or}\} -A \omega^2 \sin(\omega t)$$

$$M_e = 5.97(10)^{24} \text{ Kg}$$

$$R_e = 6.37(10)^6 \text{ m}$$

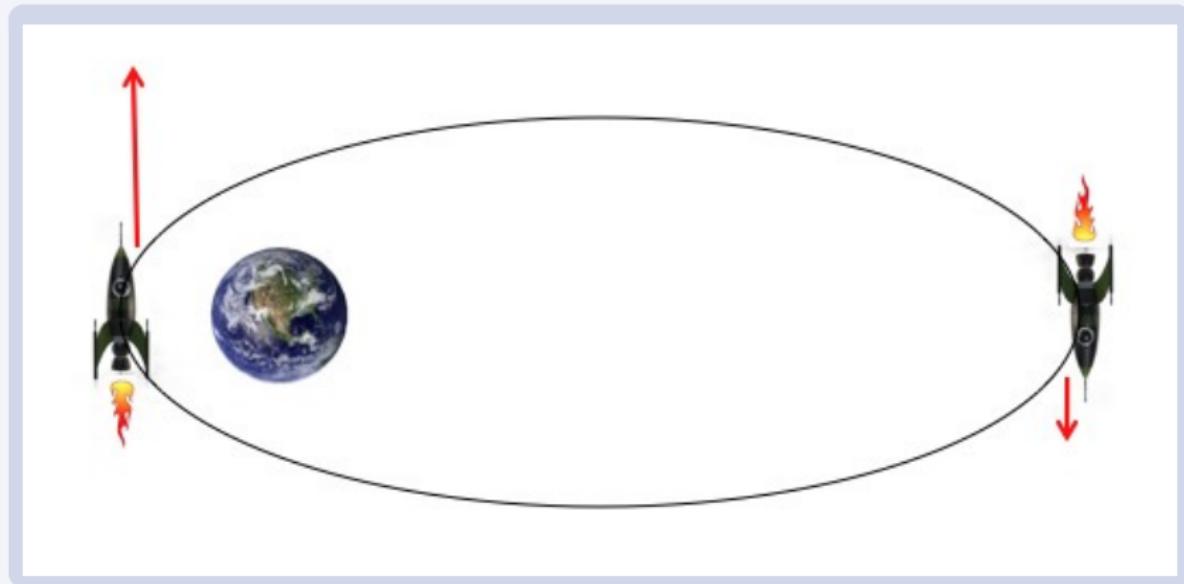
$$\frac{GM_e}{R_e} = g R_e$$

$$\frac{GMm}{r^2}$$

$$\frac{GMm}{r^2}$$

$$\frac{GMm}{r^2}$$

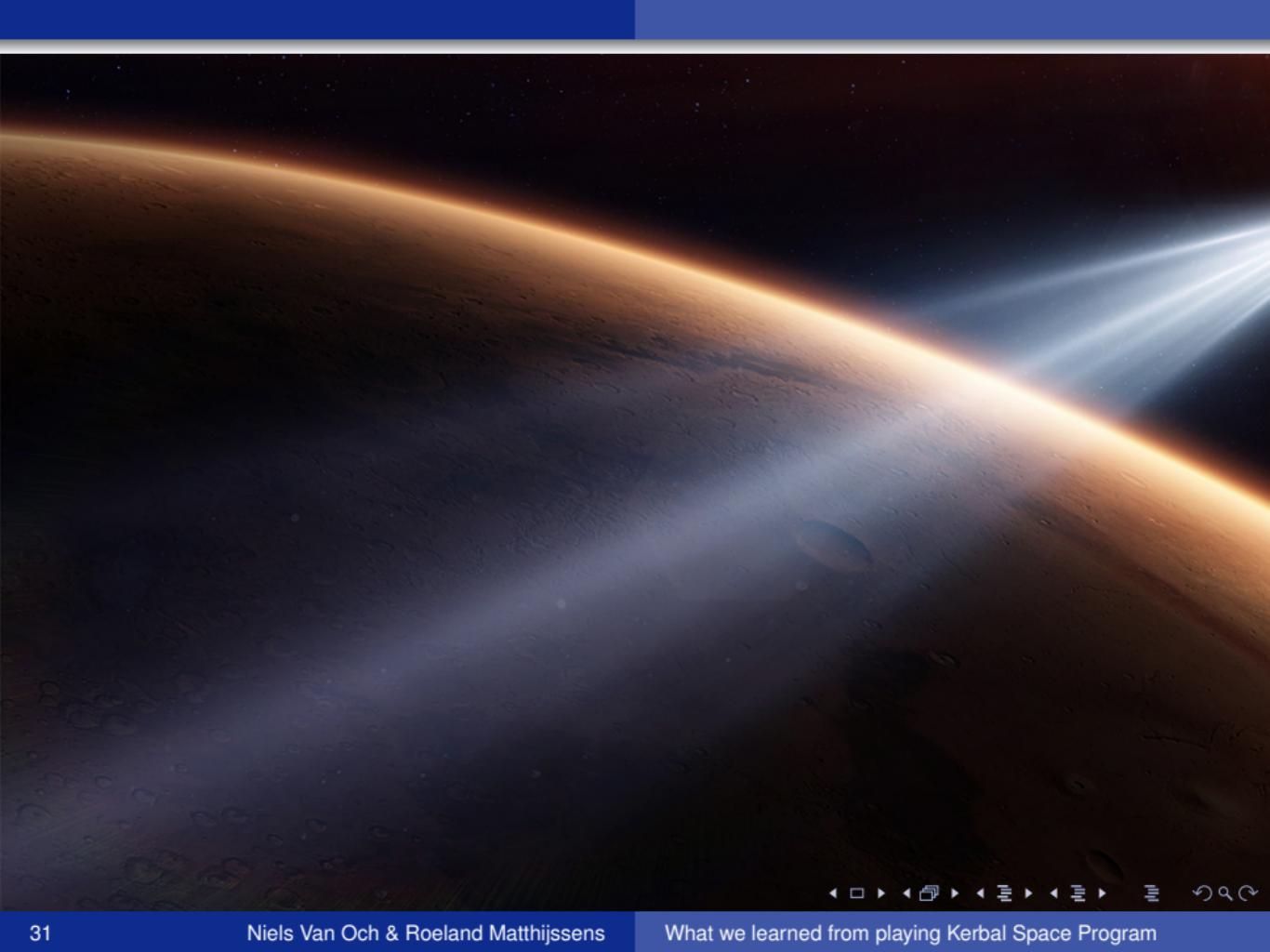
jk, Oberth effect



Escape

With the Oberth effect we can begin our escape burn and start our transfer orbit

- Decelerate 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 than any other.

- Earth is 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 make 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 until you fall into an highly elliptical orbit
- We want to circularize orbit

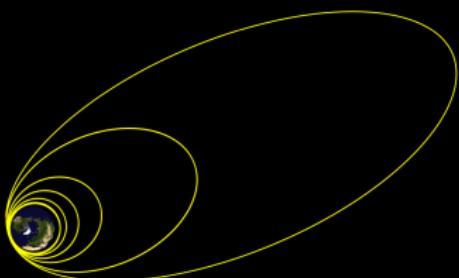
Intercept

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

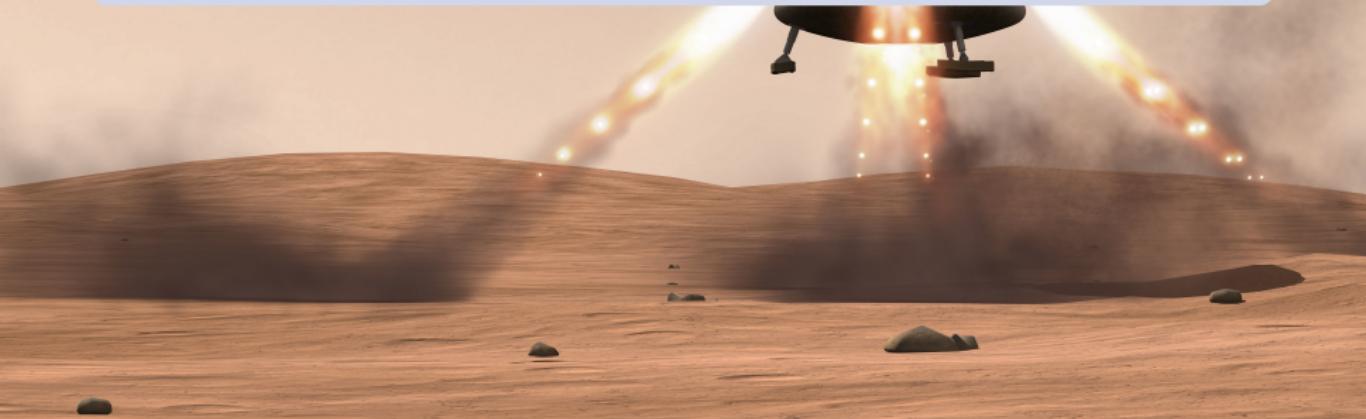




Landing

Determine entry angle

- Not to steep, because too much atmospheric 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 decelerating earlier gives gravity more time to accelerate us again
- So slowing down quickly uses less fuel

