4. Lift-off!

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**GEO, LEO, MEO, and HEO Satellites**

**Geosynchronous Orbit (GSO or GEO):**
- Height: 23,000 nautical miles (36,000 km)
- Circular orbit in the equatorial plane
- Delay: ~260 ms

**Low Earth Orbit (LEO):**
- Height: 100 – 400 nautical miles
- Circular orbits
- Delay: ~10 ms

**Medium Earth Orbit (MEO):**
- Height: 1000 – 3000 nautical miles
- Circular orbits
- Delay: ~100 ms

**High Earth Orbit (HEO):**
- Height: ~23,000 nautical miles
- Delay: ~10 to 260 ms
Launchers: Expendable (Ariane 6)

- **135-tons 1st stage** (aka lower stage, liquid fuel)
- **Re-ignitable 2nd stage** (aka upper stage, liquid oxygen/hydrogen)
  - More mission/orbits in a single launch
  - Final ignition to place in decommissioning orbit
Launchers: reusable

- Expendable launchers are consumed during the launch process and fall into the sea or burn up in the atmosphere.
  - Ariane (Europe)
  - Soyuz (Russia)
  - Delta, Atlas (USA)
  - VEGA (Europe, Italy)

- Reusable launchers make a soft landing on Earth or at sea and can be refurbished for use on a future mission.
  - Space Shuttle (USA)
  - Falcon (USA)
Classification of Launch Vehicles

- Launch vehicles are classified by NASA according to Low Earth Orbit payload capability:[2]
  - Small-lift launch vehicle: < 2,000 kilograms (4,400 lb) - e.g., Vega
  - Medium-lift launch vehicle: 2,000 to 20,000 kilograms (4,400 to 44,100 lb) - e.g., Soyuz ST
  - Heavy-lift launch vehicle: > 20,000 to 50,000 kilograms (44,000 to 110,000 lb) - e.g., Ariane 5
  - Super-heavy lift vehicle: > 50,000 kilograms (110,000 lb) - e.g., Saturn V
# Heavy Launchers

<table>
<thead>
<tr>
<th>Launchers</th>
<th>Country</th>
<th>Height</th>
<th>LEO payload</th>
<th>GTO payload</th>
<th>TLI payload</th>
<th>MTO payload</th>
</tr>
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<tbody>
<tr>
<td>EU</td>
<td>USA</td>
<td>48 m</td>
<td>20 t</td>
<td>10.6 t</td>
<td>8.9 t</td>
<td></td>
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<tr>
<td>USA</td>
<td>USA</td>
<td>50 m</td>
<td>27.5 t</td>
<td>10.9 t</td>
<td>9.2 t</td>
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</tr>
<tr>
<td>EU</td>
<td>USA</td>
<td>56.1 m</td>
<td>21.7 t</td>
<td>11.5 t</td>
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<tr>
<td>USA</td>
<td>USSR</td>
<td>63 m</td>
<td>22.8 t</td>
<td>8.3 t</td>
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<tr>
<td>USA</td>
<td>USSR</td>
<td>70 m</td>
<td>100 t</td>
<td>38 t</td>
<td>32 t</td>
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<tr>
<td>USA</td>
<td>Russia</td>
<td>70 m</td>
<td>63.8 t</td>
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<tr>
<td>Russia</td>
<td>China</td>
<td>93 m</td>
<td>140 t</td>
<td>56 t</td>
<td>44 t</td>
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</tr>
<tr>
<td>China</td>
<td>USA</td>
<td>98.1 m</td>
<td>95 t</td>
<td>55 t</td>
<td>42 t</td>
<td></td>
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<tr>
<td>USA</td>
<td>USSR</td>
<td>105 m</td>
<td>95 t</td>
<td>28.1 t</td>
<td>23.5 t</td>
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<tr>
<td>USA</td>
<td>USA</td>
<td>110.6 m</td>
<td>140 t</td>
<td>57.8 t</td>
<td>48.6 t</td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>USA</td>
<td>111.3 m</td>
<td>130 t</td>
<td>55 t</td>
<td>46 t</td>
<td></td>
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<tr>
<td>USA</td>
<td>USA</td>
<td>120 m</td>
<td>150 t</td>
<td></td>
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<table>
<thead>
<tr>
<th>Launchers</th>
<th>Country</th>
<th>Height</th>
<th>LEO payload</th>
<th>GTO payload</th>
<th>TLI payload</th>
<th>MTO payload</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soyuz-2</td>
<td>Russia/EU</td>
<td>46.3 m</td>
<td>8.2 t</td>
<td>3.3 t</td>
<td></td>
<td></td>
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<tr>
<td>Atlas V</td>
<td>USA</td>
<td>58.3 m</td>
<td>20.5 t</td>
<td>8.9 t</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Titan IV</td>
<td>USA</td>
<td>62 m</td>
<td>21.7 t</td>
<td>5.7 t</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proton-M</td>
<td>Russia</td>
<td>58.2 m</td>
<td>23 t</td>
<td>6.9 t</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vulcan Centaur</td>
<td>USA</td>
<td>61.6 m</td>
<td>27.2 t</td>
<td>14.4 t</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delta IV Heavy</td>
<td>USA</td>
<td>72 m</td>
<td>28.8 t</td>
<td>14.2 t</td>
<td></td>
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</table>
1. The launch consists in an **initial period of powered flight** during which the vehicle is lifted above the Earth's atmosphere and accelerated to orbital velocity by a rocket – often with multiple thrust stages.

2. Powered flight concludes at **burnout of the rocket's last stage** at which time the vehicle begins its free flight.

3. During **free flight** the space vehicle is subjected only to the gravitational pull of the Earth (If the vehicle moves far from the Earth, its trajectory may be affected by the gravitational influence of the sun, moon, or other planets).
Different Launches for Different Orbits

- **LEO/MEO** – direct orbital insertion is common.
- **GEO** is more complicated
  - 1st phase: place in LEO
  - 2nd phase: kick into an elliptical GTO
    - Apogee is at GEO
    - Perigee is at LEO
  - 3rd phase: circularize orbit at GEO

- Some larger launchers can launch reduced mass payloads directly to GEO.
1. The initial approach to launching geostationary satellites is to place the spacecraft, with the final rocket stage still attached, into low earth orbit.

2. After a couple of orbits, during which the orbital elements are measured, the final stage is reignited and the spacecraft is launched into a geostationary transfer orbit (GTO). The GTO has a perigee that is the original LEO orbit altitude and an apogee that is the GEO altitude.

3. The apogee kick motor (AKM) fires at apogee and is used both to circularize the orbit at GEO and to remove any inclination error so that the final orbit of the satellite is very close to geostationary.
Sequence of Operations

1. Atlas-Centaur launch \( T_0 \)
2. Jettison fairing \( T_0 + 215 \) s
3. Transfer orbit injection \( T_1 = T_0 + 27 \) m
4. Centaur reorientation to orbit normal \( T_1 + 10 \) s
5. Satellite separation \( T_1 + 2 \) m
6. Spin up \( T_1 + 2 \) m + 2 s
7. TC&R line established \( T_1 + 20 \) m
8. Orbit and attitude determination \( T_1 + 30 \) m
9. Reorientation to apogee motor fire attitude \( T_1 + 2.8 \) h
10. Final attitude adjustment \( T_2 - 2.4 \) h
11. Apogee motor firing \( T_2 \)
12. TC&R antenna coverage reorientation \( T_2 + 30 \) m
13. Orbit and attitude determination \( T_2 + 20 \) h
14. Reorientation for drift orbit velocity correction \( T_2 + 20 \) h
15. Initiate drift orbit velocity correction \( T_2 + 23.75 \) h
16. Drift orbit velocity correction complete \( T_3 = T_2 + 24.25 \) h
17. Design \( T_3 + 5 \) m
18. Deploy solar arrays and antennas \( T_3 + 15 \) m
19. Sun acquisition \( T_3 + 1 \) h
20. Earth capture \( T_3 + 4.5 \) h
21. Station acquisition \( T_3 + 1 \) to 2 months

s: second
m: minute
h: hour
<table>
<thead>
<tr>
<th>Satellite</th>
<th>COSPAR ID</th>
<th>Location</th>
<th>Regions served</th>
<th>Launch</th>
<th>Comments</th>
</tr>
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<tbody>
<tr>
<td>Eutelsat 3B</td>
<td>2014-030A</td>
<td>3°E</td>
<td>Europe, Africa, the Middle East, Central Asia, Brazil</td>
<td>26 May 2014</td>
<td>Entered service in July 2014[24]</td>
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<tr>
<td>Eutelsat 5 West A</td>
<td>2002-035A</td>
<td>5°W</td>
<td>Europe, Americas, Africa</td>
<td>5 July 2002</td>
<td>Formerly named Atlantic Bird 3 until March 2012, was also called Stellat 5</td>
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<tr>
<td>Eutelsat 5 West B</td>
<td>2019-067A</td>
<td>5°W</td>
<td>Europe, North Africa</td>
<td>9 October 2019</td>
<td>Formerly named Eutelsat W3A until March 2012</td>
</tr>
<tr>
<td>Eutelsat 7A</td>
<td>2004-008A</td>
<td>7°E</td>
<td>Europe, Middle East, Africa</td>
<td>16 March 2004</td>
<td></td>
</tr>
<tr>
<td>Eutelsat 7B</td>
<td>2013-022A</td>
<td>7°E</td>
<td>Europe, Middle East, Africa</td>
<td>14 May 2013</td>
<td></td>
</tr>
<tr>
<td>Eutelsat 7C</td>
<td>2019-034B</td>
<td>7°E</td>
<td>Europe, Middle East, Africa</td>
<td>20 June 2019</td>
<td></td>
</tr>
<tr>
<td>Eutelsat 7 West A</td>
<td>2011-051A</td>
<td>7.3°W</td>
<td>Middle East, North Africa</td>
<td>24 September 2011</td>
<td>Formerly named Atlantic Bird 7 until March 2012</td>
</tr>
<tr>
<td>Eutelsat 8 West B</td>
<td>2015-039A</td>
<td>8°W</td>
<td>Africa, Middle East</td>
<td>20 August 2015</td>
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</tr>
<tr>
<td>Eutelsat KA-SAT[25][26]</td>
<td>2010-069A</td>
<td>9°E</td>
<td>Europe</td>
<td>26 December 2010</td>
<td></td>
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<tr>
<td>Eutelsat 10A</td>
<td>2009-016A</td>
<td>10°E</td>
<td>Europe, Africa, Middle East</td>
<td>3 April 2009</td>
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<tr>
<td>Eutelsat 12 West B</td>
<td>2001-042A</td>
<td>12.5°W</td>
<td>Europe, Americas</td>
<td>25 September 2001</td>
<td>Formerly named Atlantic Bird 2 until March 2012 and Eutelsat 8 West A until October 2015, when it was redeployed to 12.5° West.</td>
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<tr>
<td>Hot Bird 13C</td>
<td>2008-065D</td>
<td>13°E</td>
<td>Europe, Africa, Middle East</td>
<td>20 December 2008</td>
<td>Formerly named Hot Bird 9 until March 2012</td>
</tr>
<tr>
<td>Eutelsat 16A</td>
<td>2011-057A</td>
<td>16°E</td>
<td>Europe, Sub-Saharan Africa, Indian Ocean Islands</td>
<td>7 October 2011</td>
<td>Formerly named Eutelsat W3C until March 2012</td>
</tr>
<tr>
<td>Eutelsat 33C[38]</td>
<td>2001-011A</td>
<td>33°E</td>
<td>Europe</td>
<td>8 March 2001</td>
<td>Satellite is currently being redeployed at 33° East where it will be co-located with EUTELSAT 33B.</td>
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<tr>
<td>Satellite</td>
<td>Launch Date</td>
<td>Longitude</td>
<td>Regions</td>
<td>Operational Date</td>
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<tr>
<td>Hot Bird 13E</td>
<td>2006-007B</td>
<td>13°E</td>
<td>Europe, North Africa, Middle East</td>
<td>11 March 2006</td>
<td>Formerly named Eurobird 9A until March 2012; former Hot Bird 7A</td>
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<tr>
<td>Eutelsat 16A</td>
<td>2011-057A</td>
<td>16°E</td>
<td>Europe, Sub-Saharan Africa, Indian Ocean Islands</td>
<td>7 October 2011</td>
<td>Formerly named Eutelsat 9A</td>
</tr>
<tr>
<td>Eutelsat 21B</td>
<td>2012-062B</td>
<td>21.5°E</td>
<td>Europe, Middle East, North Africa, West Africa, Central Asia</td>
<td>10 November 2012</td>
<td>Fully operational since 19 December 2012. [37]</td>
</tr>
<tr>
<td>Eutelsat 33C</td>
<td>2001-011A</td>
<td>33°E</td>
<td>Europe</td>
<td>8 March 2001</td>
<td>Satellite is currently being redeployed at 33° East where it will be co-located with EUTELSAT 33B. Formerly named Eurobird 1 until March 2012 and Eutelsat 28A until July 2015.</td>
</tr>
<tr>
<td>Eutelsat 33E</td>
<td>2009-008B</td>
<td>33°E</td>
<td>Europe, South-West Asia</td>
<td>12 February 2009</td>
<td>Formerly Hot Bird 10 and Atlantic Bird 4A [39]</td>
</tr>
<tr>
<td>Eutelsat 36B</td>
<td>2009-065A</td>
<td>36°E</td>
<td>Europe, Africa, Middle East, Russia</td>
<td>24 November 2009</td>
<td>Formerly named Eutelsat W7 until March 2012.</td>
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<tr>
<td>Eutelsat 36C</td>
<td>2015-082A</td>
<td>36°E</td>
<td>Russia, Africa</td>
<td>2015</td>
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<tr>
<td>Eutelsat 48D</td>
<td>2008-065B</td>
<td>48°E</td>
<td>Afghanistan, Central Asia</td>
<td>20 December 2008</td>
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<tr>
<td>Eutelsat 65 West A</td>
<td>2016-014A</td>
<td>65°W</td>
<td>Americas</td>
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<td>Eutelsat 70B</td>
<td>2012-069A</td>
<td>70.5°E</td>
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<td>3 December 2016</td>
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<td>Eutelsat 113 West A</td>
<td>2006-020A</td>
<td>113°W</td>
<td>Americas</td>
<td>27 May 2006</td>
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<td>114.9°W</td>
<td>Americas</td>
<td>2 March 2015</td>
<td>Formerly named Satmex 8 until May 2014</td>
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<td>Eutelsat 117 West A</td>
<td>2013-012A</td>
<td>116.8°W</td>
<td>Americas</td>
<td>26 March 2013</td>
<td>Formerly Satmex 8 until May 2014</td>
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<tr>
<td>Eutelsat 172B</td>
<td>2016-038B</td>
<td>116.8°W</td>
<td>Americas</td>
<td>15 June 2016</td>
<td>Formerly Satmex 9</td>
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<td>Eutelsat 172B</td>
<td>2017-027A</td>
<td>172°E</td>
<td>Asia-Pacific</td>
<td>1 June 2017</td>
<td>Formerly EUTELSAT 172A, and GE-23 satellite</td>
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<td>Eutelsat 174A</td>
<td>2005-052A</td>
<td>174°E</td>
<td>Asia-Pacific</td>
<td>29 December 2005</td>
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<td>Eutelsat Konnect</td>
<td>2020-005B</td>
<td>7°E</td>
<td>Europe, Africa</td>
<td>17 January 2020</td>
<td>First satellite to use Thales Alenia Space's all-electric Spacebus NEO platform</td>
</tr>
<tr>
<td>Eutelsat Quantum</td>
<td>2021-069B</td>
<td>48°E</td>
<td>Middle East, North Africa</td>
<td>30 July 2021</td>
<td>First in-orbit reprogrammable satellite</td>
</tr>
</tbody>
</table>
How can you determine the Sat orbit when firing motor?

\( \gamma \) is the angle between the radius \( r \) and velocity \( v \) vector:

\( \gamma_0, r_0, v_0 \) are the parameter values when the motor is switched off (burnout) and are assumed to be known.

For any orbital point, the tangential velocity component \( \omega r = v \sin(\gamma) \); from Kepler’s second law,

\[
r v \sin(\gamma) = \omega r^2 = \text{CONSTANT}
\]

Let us focus on the perigee, at which point \( \gamma = \pi/2 \):

\[
r_p v_p = r_0 v_0 \sin(\gamma_0)
\]

On the other hand, we also have conservation of energy...
How can you determine the Sat orbit when firing motor?

\[
\begin{align*}
\begin{cases}
r_p v_p &= r_0 v_0 \sin(\gamma_0) \\
\frac{v_p^2}{2} - \frac{GM}{r_p} &= \frac{v_0^2}{2} - \frac{GM}{r_0}
\end{cases}
\end{align*}
\]

- Finding \( v_p \) from the 1\textsuperscript{st} equation and inserting in the second we get a quadratic equation for \( r_p \)

\[
\left( \frac{v_0^2}{2} - \frac{GM}{r_0} \right) \left( \frac{r_p}{r_0} \right)^2 + \frac{GM}{r_0} \left( \frac{r_p}{r_0} \right) - \frac{v_0^2 \sin^2(\gamma)}{2} = 0
\]

\[
(1 - \beta) \left( \frac{r_p}{r_0} \right)^2 + \beta \left( \frac{r_p}{r_0} \right) - 1 = 0 \quad , \quad \beta = \frac{2GM}{r_0 v_0^2}
\]
The 7 Subsystems of a Satellite

Power: Most satellites rely on a solar array to convert sunlight into energy.

Antennas: Satellite antenna systems are used to receive and transmit signals to and from Earth.

Transponders: Uplink and downlink signals arrive and depart at different frequencies. Transponders convert uplinked frequencies to downlink frequencies and then amplify the converted transmission for sending to Earth.

Housing: Housing is constructed from strong materials that can withstand the harsh space environment.

Command and Data Handling: The operational heart of a satellite, command and control systems monitor every aspect of the satellite and receive commands from Earth for operation.

Guidance and Stabilization: Sensors monitor the satellite’s position to ensure it remains in the correct orbit and is oriented toward the correct target. If necessary, thrusters and other maneuvers allow a satellite to fine-tune its position and orientation.

Thermal Control: Guards satellite equipment against extreme changes in temperature.

Marco Luise
4. Lift-off!
Telemetry, Tracking, and Control (TT&C)

- Sends downlink **data about status** (power, trajectory, faults etc.) as well as a **dedicated ranging signal** to perform tracking.

- Receives **uplink commands** to switch on/off devices, change trajectory etc.

- **NOTHING TO DO WITH THE (COMMUNICATIONS) PAYLOAD**
  - Different equipment, different bands, different antennas.
How to stabilize a satellite?

- Stabilizing a satellite means preventing it from revolving around its center of mass while following the desired orbit
  - If it’s not *stable*, cannot point antennas (or scientific instruments in science missions) to the desired objective

- Two main methods:
  - *Spin Stabilization*
    - exploits the “spinning top (trottola)” or gyroscope effect: the satellite is cylindrical and spinning around its main axis
  - *Body stabilization*
    - Needs three flywheels on the three main body axes $x,y,z$ – the satellite is in general “cubic” and stands still while orbiting
Spin stabilized (INTELSAT VI after repair by Space Shuttle STS-49)

- Stabilizing a satellite means that it does not revolve around its center of mass while following the desired orbit.
- If it's not stable, cannot point antennas or scientific instruments into the desired objective.
• Cylindrical satellites may be made to spin on their axis. Once the satellite is in proper orbit a jet thrusters is fired to begin spinning the satellite.

• A typical spin-stabilized satellite rotates between 30 and 120 rpm creating an inertial stiffness, which maintains the satellite spin axis perpendicular to the equatorial plane.

• The spinning causes a gyroscopic or flywheel effect that keeps the satellite spin action is north-south direction.

• The spin stabilization has the disadvantage that it requires the use of a de-spun antenna, so that the mounted antennas are constantly directed towards the Earth.

• In this type of stabilization a large flywheel is included at some point on the satellite body

• Once the satellite is in the position and its antenna, solar panels and sensors are oriented, the flywheel is put into motion.
EUTELSAT’s Quantum Satellite 48 E
Stabilizing a three-axis satellite

- Three-axis stabilization refers to the three main satellite motion axes called as *pitch* (beccheggio), *roll* (rollio) and *yaw* (imbardata) to achieve attitude control.

  - Yaw axis: Directed towards the earth’s centre.
  - Pitch axis: Normal to the orbital plane.
  - Roll axis: Tangent to the orbit.
Stabilizing a three-axis satellite

- Three heavy flywheels (one for each axis) rotate to provide gyroscopic effect
  - Alternatively, any of the axes is corrected by firing thrusters in proper direction controlling the flywheel motor speed.
- This technique is very accurate, but it needs embarking heavy flywheels and motors.
Super-precision DRS (Disturbance Reduction Systems) thrusters to control the spacecraft's position to within a millionth of a millimeter, in order to detect super-weak gravitational waves without noise.
Usual Hydrazine Thrusters (Arianespace)

1N  20N  400N