Ingegneria delle Telecomunicazioni

Satellite Communications

4. Lift-off !

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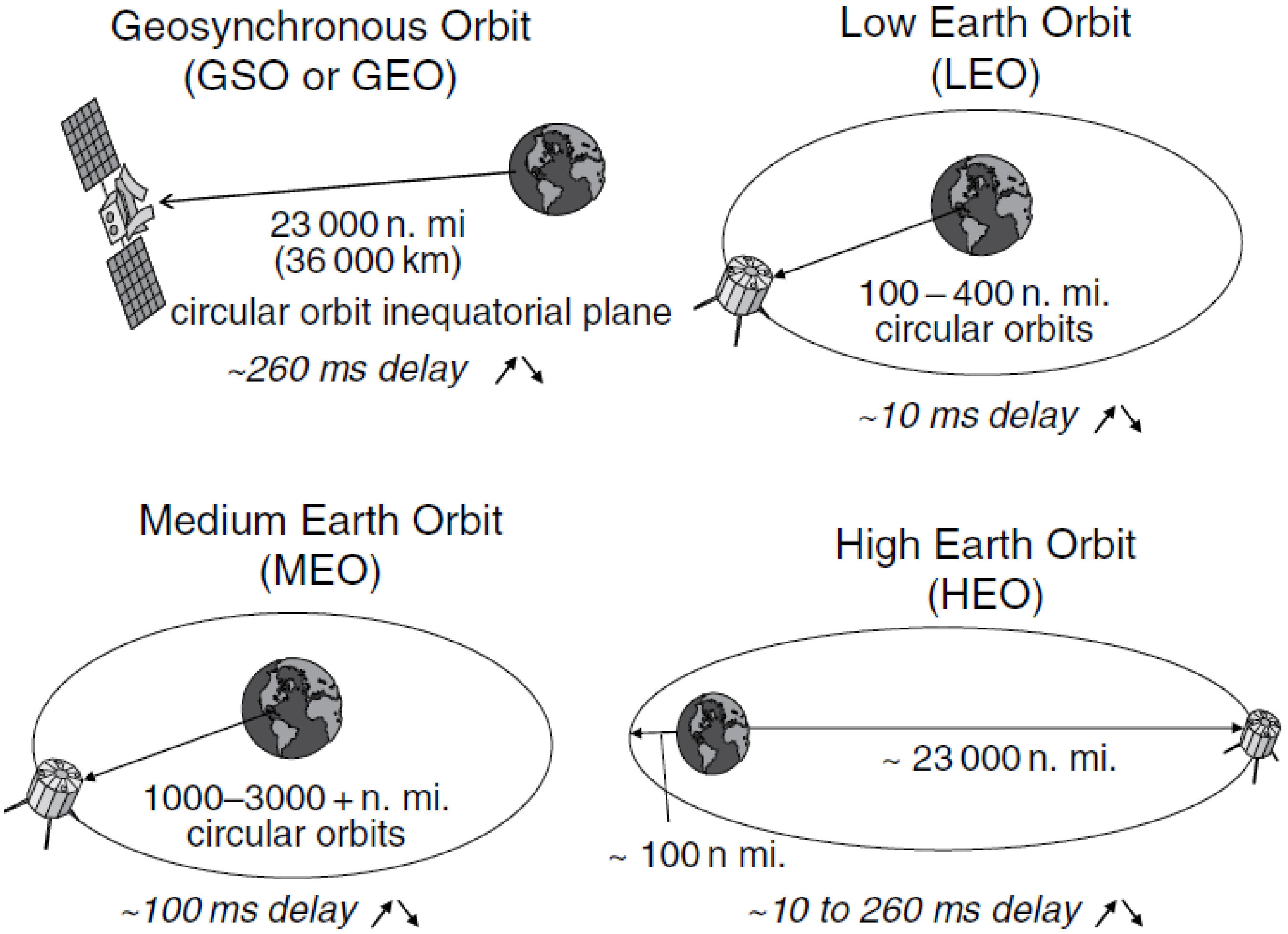
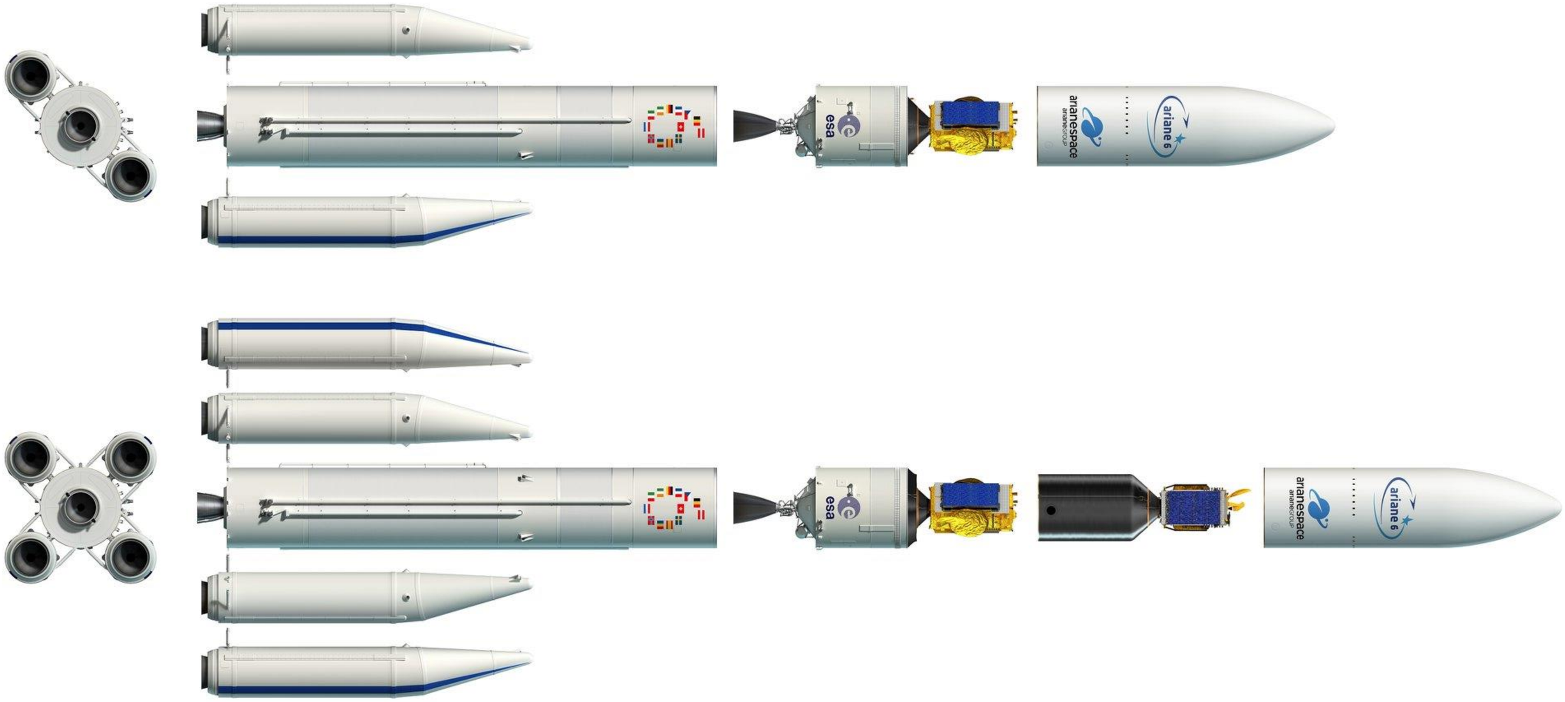
GEO,LEO, MEO HEO Satellites



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


USA

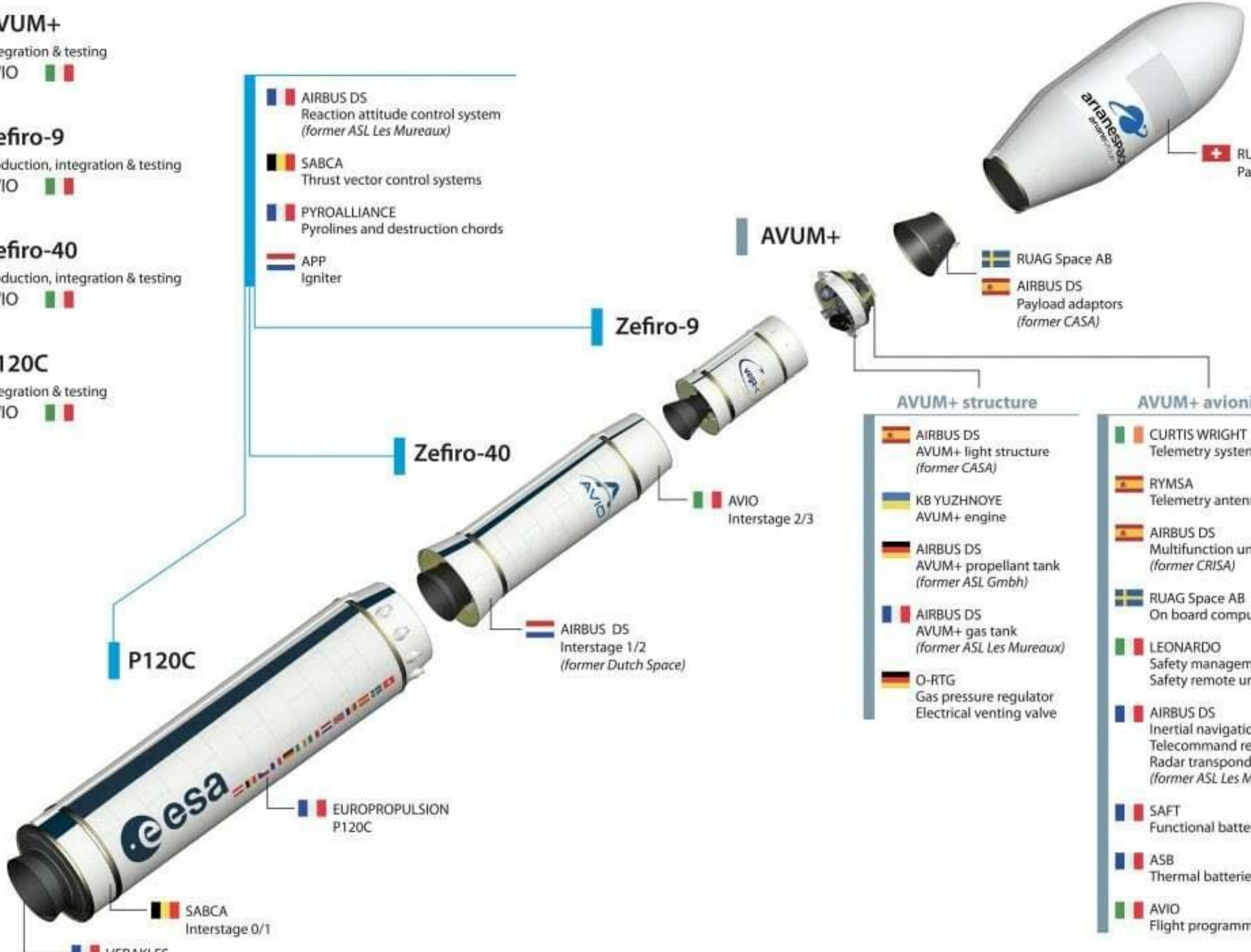
VEGA-C

AVUM+
Integration & testing
AVIO 🇮🇹

Zefiro-9
Production, integration & testing
AVIO 🇮🇹

Zefiro-40
Production, integration & testing
AVIO 🇮🇹

P120C
Integration & testing
AVIO 🇮🇹



🇫🇷 AIRBUS DS
Reaction attitude control system
(former ASL Les Mureaux)

🇧🇪 SABCA
Thrust vector control systems

🇫🇷 PYROALLIANCE
Pyrolines and destruction chords

🇳🇱 APP
Igniter

Zefiro-9

Zefiro-40

P120C

AVUM+

🇨🇭 RUAG Schweiz AG
Payload fairing

🇸🇪 RUAG Space AB
🇪🇸 AIRBUS DS
Payload adaptors
(former CASA)

🇮🇹 AVIO
Interstage 2/3

🇳🇱 AIRBUS DS
Interstage 1/2
(former Dutch Space)

🇫🇷 EUROPROPULSION
P120C

🇧🇪 SABCA
Interstage 0/1

🇫🇷 HERAKLES
P120C nozzle

AVUM+ structure

🇪🇸 AIRBUS DS
AVUM+ light structure
(former CASA)

🇺🇦 KB YUZHNOYE
AVUM+ engine

🇩🇪 AIRBUS DS
AVUM+ propellant tank
(former ASL Gmbh)

🇫🇷 AIRBUS DS
AVUM+ gas tank
(former ASL Les Mureaux)

🇩🇪 O-RTG
Gas pressure regulator
Electrical venting valve

AVUM+ avionics

🇮🇪 CURTIS WRIGHT
Telemetry system

🇪🇸 RYMSA
Telemetry antennae

🇪🇸 AIRBUS DS
Multifunction unit
(former CRISA)

🇸🇪 RUAG Space AB
On board computer

🇮🇹 LEONARDO
Safety management unit
Safety remote unit

🇫🇷 AIRBUS DS
Inertial navigation system
Telecommand receiver
Radar transponder
(former ASL Les Mureaux)

🇫🇷 SAFT
Functional batteries

🇫🇷 ASB
Thermal batteries

🇮🇹 AVIO
Flight programme software

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)

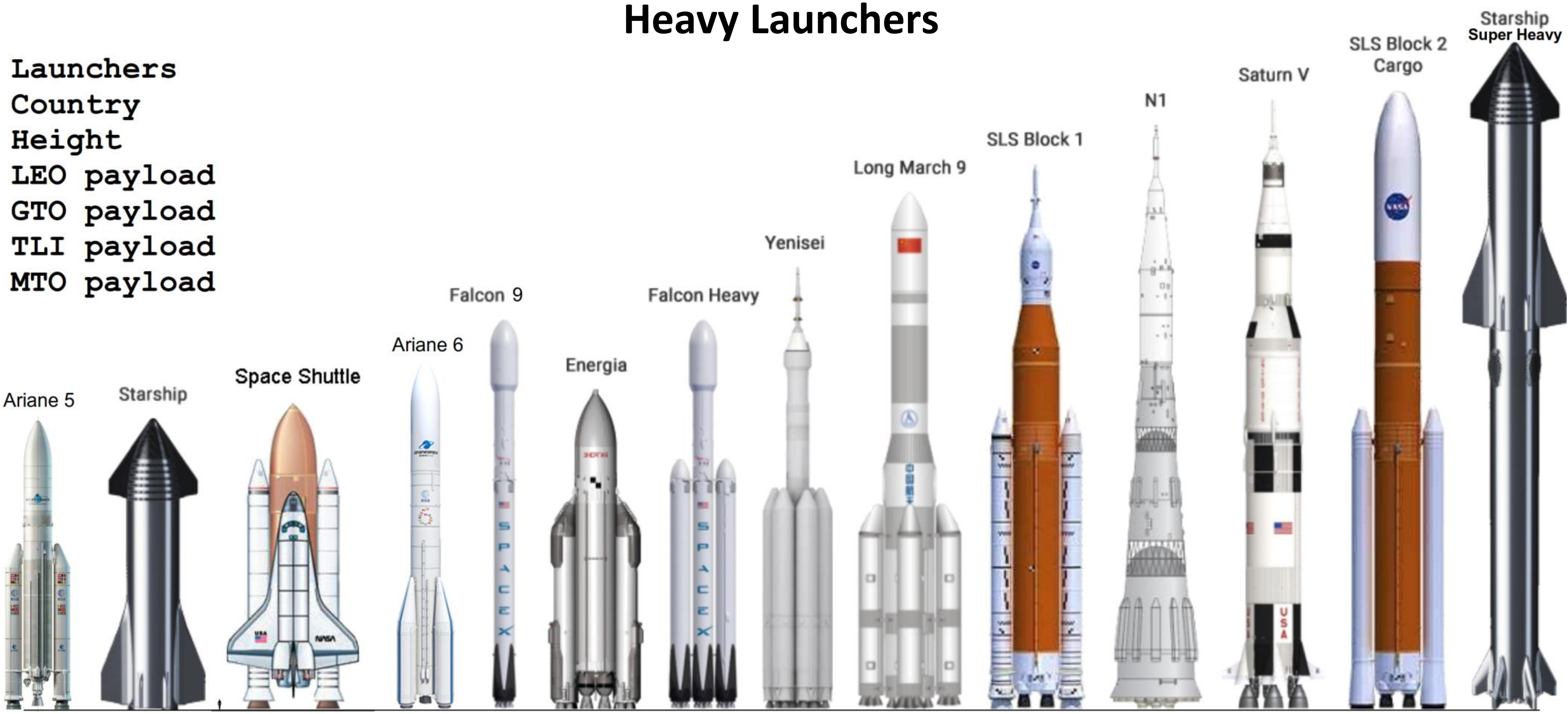
- **Reusable launchers make a soft landing on Earth or at sea and can be refurbished for use on a future mission.**
  - Space Shuttle (USA)
  - Falcon (USA)


HDNet

Classification of Launch Vehicles

- **Launch vehicles are classified by NASA according to Low Earth Orbit payload capability:**
  - 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 5/6
  - Super-heavy lift vehicle: > 50,000 kilograms (110,000 lb) - e.g., Saturn V

Heavy Launchers



Launchers	Country	Height	LEO payload	GTO payload	TLI payload	MTO payload
Ariane 5	EU	48 m	20 t	10.6 t	8.9 t	
Starship	USA	50 m	?? t	?? t		
Space Shuttle	USA	56.1 m	27.5 t	10.9 t	9.2 t	
Ariane 6	EU	63 m	21.7 t	11.5 t	9.7 t	
Falcon 9	USA	70 m	22.8 t	8.3 t	7.0 t	4.0 t
Energia	USSR	57.8 m	100 t	38 t	32 t	
Falcon Heavy	USA	70 m	63.8 t	26.7 t	22.4 t	16.8 t
Yenisei	Russia	~80 m	103 t			
Long March 9	China	93 m	140 t	56 t	50 t	44 t
SLS Block 1	USA	98.1 m	95 t	55 t	42 t	
N1	USSR	105 m	95 t	28.1 t	23.5 t	
Saturn V	USA	110.6 m	140 t	57.8 t	48.6 t	
SLS Block 2 Cargo	USA	111.3 m	130 t	55 t	46 t	
Starship Super Heavy	USA	120 m	150 t			
Soyuz-2	Russia/EU	46.3 m	8.2 t	3.3 t		
Atlas V	USA	58.3 m	20.5 t	8.9 t		
Titan IV	USA	62 m	21.7 t	5.7 t		
Proton-M	Russia	58.2 m	23 t	6.9 t		
Vulcan Centaur	USA	61.6 m	27.2 t	14.4 t	12.1 t	
Delta IV Heavy	USA	72 m	28.8 t	14.2 t		

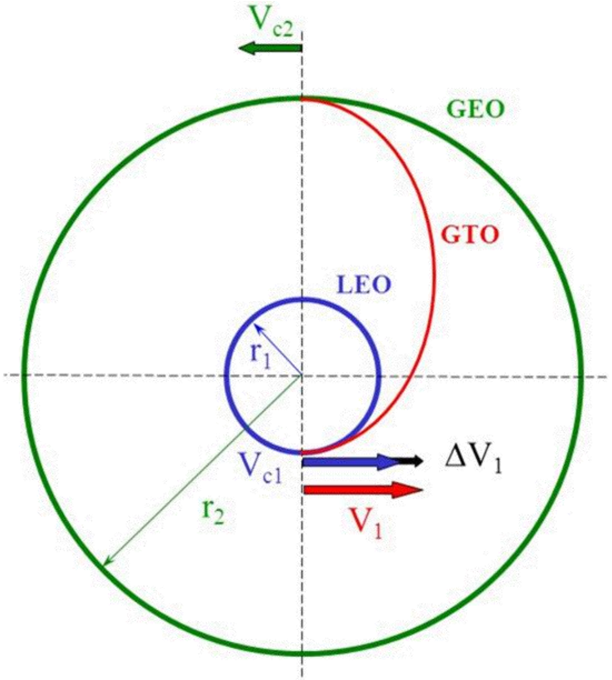
Launching a Satellite

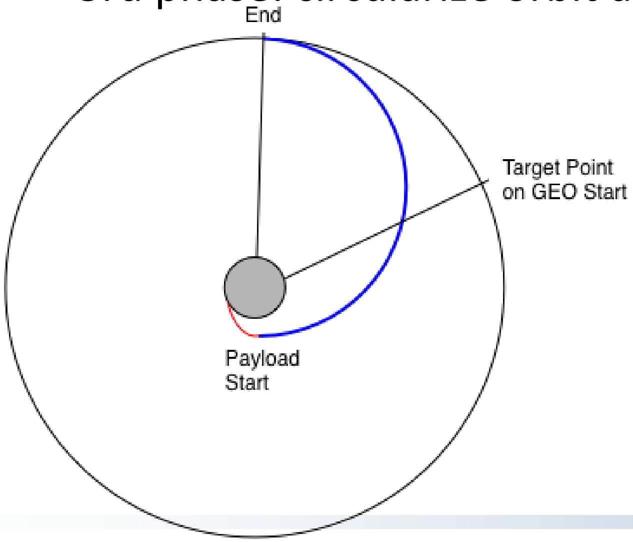
The launch consists in

1. 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 *Geostationary Transfer Orbit* (GTO)
    - Apogee is at GEO
    - Perigee is at LEO
  - 3rd phase: circularize orbit at GEO





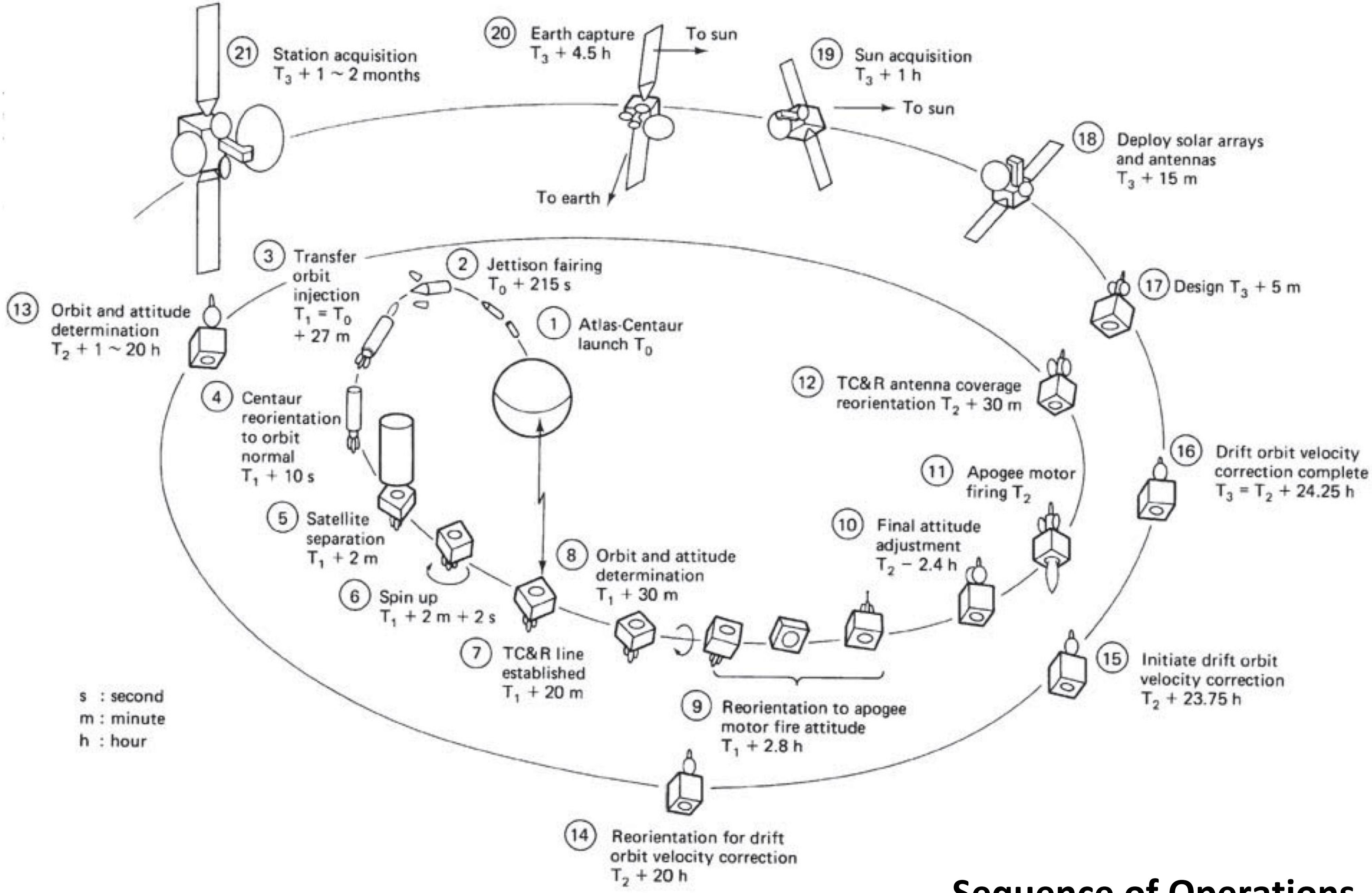
- **Some larger launchers can launch reduced mass payloads directly to GEO.**

Launching 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 re-ignited 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.

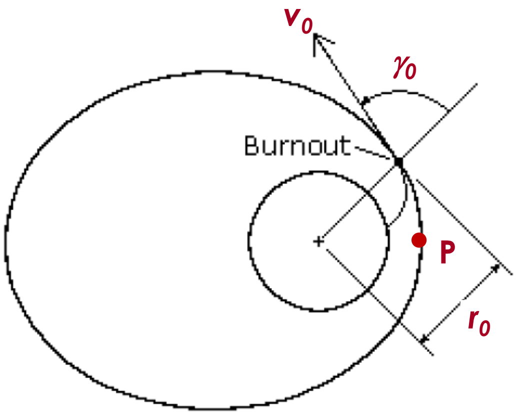


Sequence of Operations

Satellite	COSPAR ID	Location	Regions served	Launch	Comments
Eutelsat 3B	2014-030A	3°E	Europe, Africa, the Middle East, Central Asia, Brazil	26 May 2014	Entered service in July 2014[24]
Eutelsat 5 West A	2002-035A	5°W	Europe, Americas, Africa	5 July 2002	Formerly named Atlantic Bird 3 until March 2012, was also called Stellat 5
Eutelsat 5 West B	2019-067A	5°W	Europe, North Africa	9 October 2019	
Eutelsat 7A	2004-008A	7°E	Europe, Middle East, Africa	16 March 2004	Formerly named Eutelsat W3A until March 2012
Eutelsat 7B	2013-022A	7°E	Europe, Middle East, Africa	14 May 2013	
Eutelsat 7C	2019-034B	7°E	Europe, Middle East, Africa	20 June 2019	
Eutelsat 7 West A	2011-051A	7.3°W	Middle East, North Africa	24 September 2011	Formerly named Atlantic Bird 7 until March 2012
Eutelsat 8 West B	2015-039A	8°W	Africa, Middle East	20 August 2015	
Eutelsat KA-SAT[25][26]	2010-069A	9°E	Europe	26 December 2010	
Eutelsat 9B [27][28]	2016-005A	9°E	Europe, North Africa, Middle East	30 January 2016	
Eutelsat 10A	2009-016A	10°E	Europe, Africa, Middle East	3 April 2009	Formerly named Eutelsat W2A until March 2012; S-band payload not yet entered into service due to an anomaly.[29][30][31] Solaris Mobile filed the insurance claim and should be able to offer some, but not all of the services it was planning to offer.[32][33][34]
Eutelsat 12 West B	2001-042A	12.5°W	Europe, Americas	25 September 2001	Formerly named Atlantic Bird 2 until March 2012 and Eutelsat 8 West A until October 2015, when it was redeployed to 12.5° West.
Hot Bird 13B[35]	2001-011A	13°E	Europe, North Africa, Middle East	5 August 2006	Formerly named Hot Bird 8 until March 2012
Hot Bird 13C	2008-065D	13°E	Europe, Africa, Middle East	20 December 2008	Formerly named Hot Bird 9 until March 2012
Hot Bird 13E[36]	2006-007B	13°E	Europe, North Africa, Middle East	11 March 2006	Formerly named Eurobird 9A until March 2012; former Hot Bird 7A satellite / Eutelsat 9A
Eutelsat 16A	2011-057A	16°E	Europe, Sub-Saharan Africa, Indian Ocean Islands	7 October 2011	Formerly named Eutelsat W3C until March 2012
Eutelsat 21B	2012-062B	21.5°E	Europe, Middle East, North Africa, West Africa, Central Asia	10 November 2012	Fully operational since 19 December 2012.[37]
					Satellite is currently being redeployed at 33° East where it will be co-located with EUTELSAT 33B.

Hot Bird 13E[36]	2006-007B	13°E	Europe, North Africa, Middle East	11 March 2006	Formerly named Eurobird 9A until March 2012; former Hot Bird 7A satellite / Eutelsat 9A
Eutelsat 16A	2011-057A	16°E	Europe, Sub-Saharan Africa, Indian Ocean Islands	7 October 2011	Formerly named Eutelsat W3C until March 2012
Eutelsat 21B	2012-062B	21.5°E	Europe, Middle East, North Africa, West Africa, Central Asia	10 November 2012	Fully operational since 19 December 2012.[37]
Eutelsat 33C[38]	2001-011A	33°E	Europe	8 March 2001	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
Eutelsat 33E	2009-008B	33°E	Europe, South-West Asia	12 February 2009	Formerly Hot Bird 10 and Atlantic Bird 4A[39]
Eutelsat 36A	2000-028A	36°E	Africa, Russia	24 May 2000	Formerly named Eutelsat W4 until March 2012.
Eutelsat 36B	2009-065A	36°E	Europe, Africa, Middle East, Russia	24 November 2009	Formerly named Eutelsat W7 until March 2012
Eutelsat 36C	2015-082A	36°E	Russia, Africa	2015	
Eutelsat 36 West A	2002-040A	36.5°W	Europe, Middle East, Americas	28 August 2002	Formerly named Atlantic Bird 1 until March 2012, and Eutelsat 12 West A
Eutelsat 48D	2008-065B	48°E	Afghanistan, Central Asia	20 December 2008	Co-branded Afghansat 1. Formerly named Eutelsat 28B until January 2014, Eutelsat 48B until August 2012, W2M until March 2012.[40]
Eutelsat 65 West A	2016-014A	65°W	Americas	9 March 2016	
Eutelsat 70B	2012-069A	70.5°E	Europe, Middle East, Africa, Central Asia, South East Asia, Australia	3 December 2012	
Eutelsat 113 West A	2006-020A	113°W	Americas	27 May 2006	Formerly Satmex 6 until May 2014
Eutelsat 115 West B	2015-010B	114.9°W	Americas	2 March 2015	
Eutelsat 117 West A	2013-012A	116.8°W	Americas	26 March 2013	Formerly Satmex 8 until May 2014
Eutelsat 117 West B [41]	2016-038B	116.8°W	Americas	15 June 2016	Formerly Satmex 9
Eutelsat 172B	2017-027A	172°E	Asia-Pacific	1 June 2017	
Eutelsat 174A	2005-052A	174°E	Asia-Pacific	29 December 2005	Formerly EUTELSAT 172A, and GE-23 satellite
Eutelsat Konnect	2020-005B	7°E	Europe, Africa	17 January 2020	First satellite to use Thales Alenia Space's all-electric Spacebus NEO platform
Eutelsat Quantum	2021-069B	48°E	Middle East, North Africa	30 July 2021	First in-orbit reprogrammable satellite

How can you determine the Transfer Sat orbit ?



γ is the angle between the radius *r* and velocity *v* vectors

γ_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 is $\omega r = v \sin(\gamma)$; from Kepler's second law,

$$rv\sin(\gamma) = \omega r^2 = \text{CONSTANT}$$

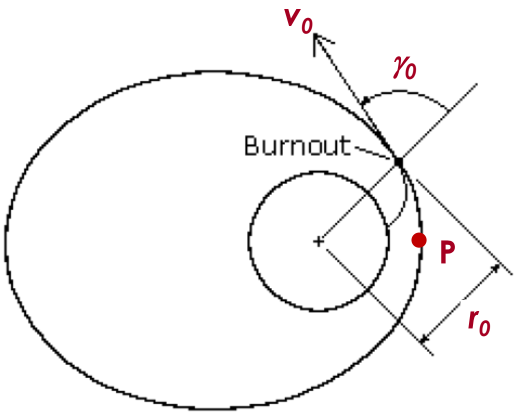
Let us focus on the perigee P, at which point $\gamma = \pi/2$:

$$r_p v_p = r_0 v_0 \sin(\gamma_0)$$

On the other hand, we also have conservation of energy…

How can you determine the Sat orbit when firing motor?

$$\begin{cases} r_p v_p = r_0 v_0 \sin(\gamma_0) \\ \dfrac{{v_p}^2}{2} - \dfrac{GM}{r_p} = \dfrac{{v_0}^2}{2} - \dfrac{GM}{r_0} \end{cases}$$

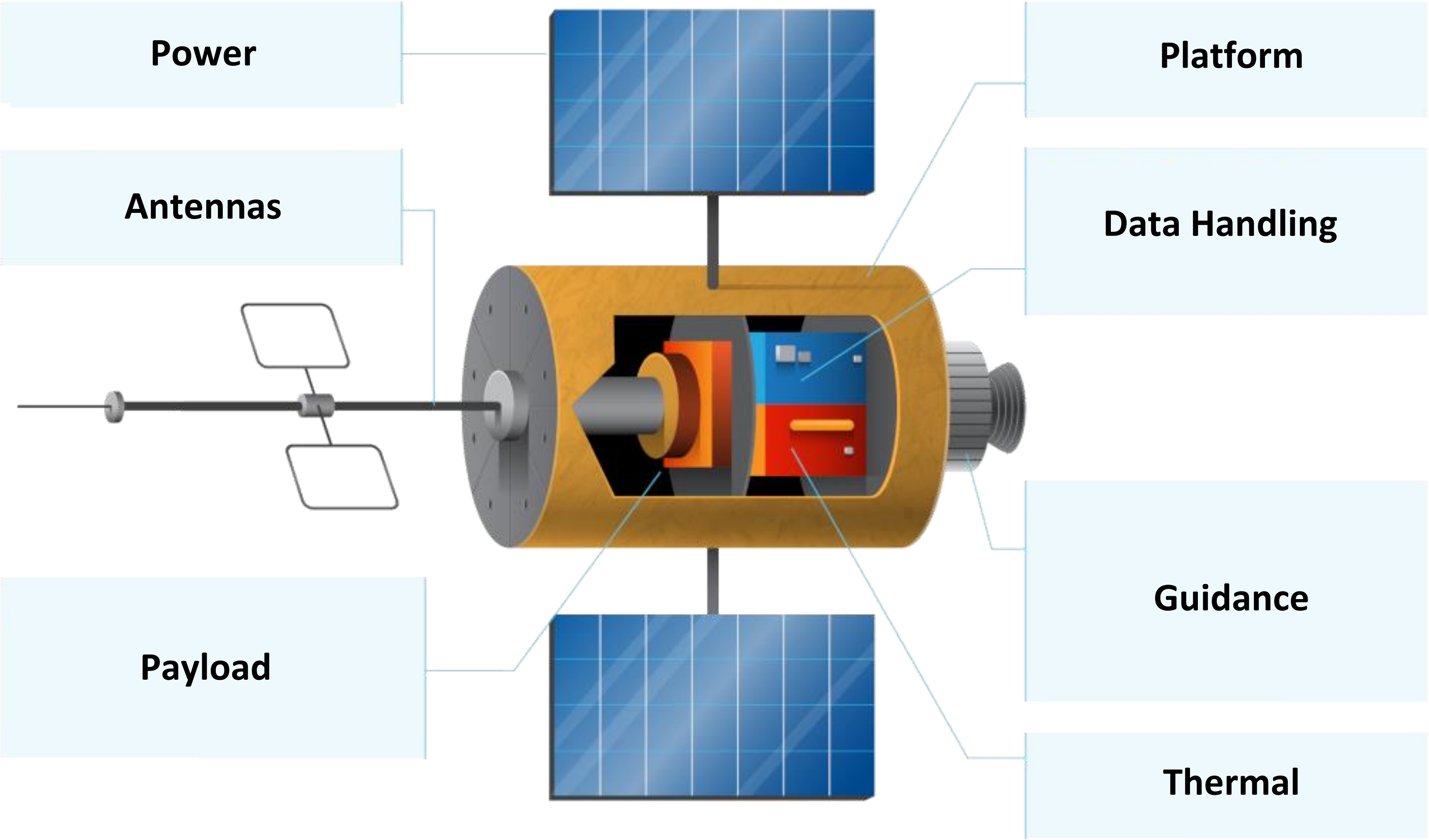


- **Finding v_p from the 1st equation and inserting in the second we get a quadratic equation for r_p**

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

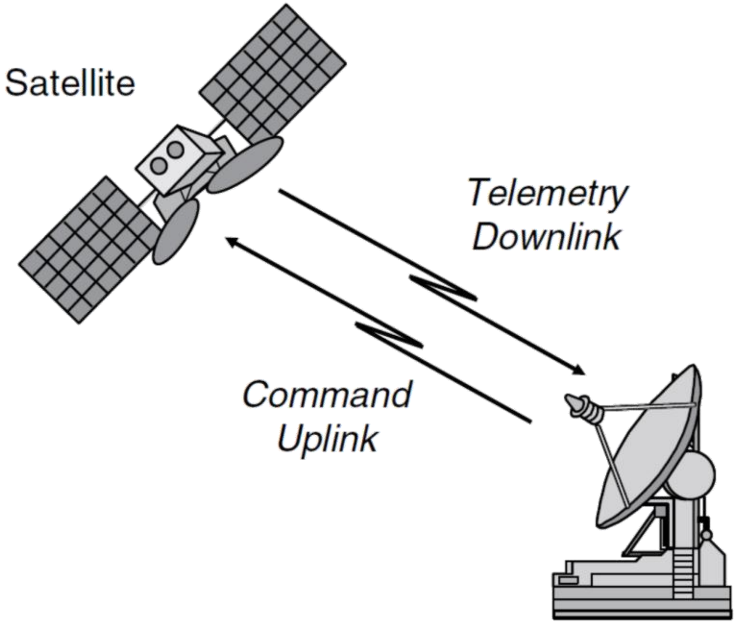
$$(1-\beta)\left(\frac{r_p}{r_0}\right)^2 + \beta\left(\frac{r_p}{r_0}\right) - 1 = 0 \quad , \quad \beta = \frac{2GM}{r_0 {v_0}^2}$$

The 7 Subsystems of a Satellite



Telemetry, Tracking, and Control (TT&C)

- Sends downlink **data about status** (power, trajectory, subsystems status/fault, etc.) as well as a **dedicated ranging signal** to perform tracking
- Receives **uplink commands** to switch on/off devices, initiate maneuvers to 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 spins 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

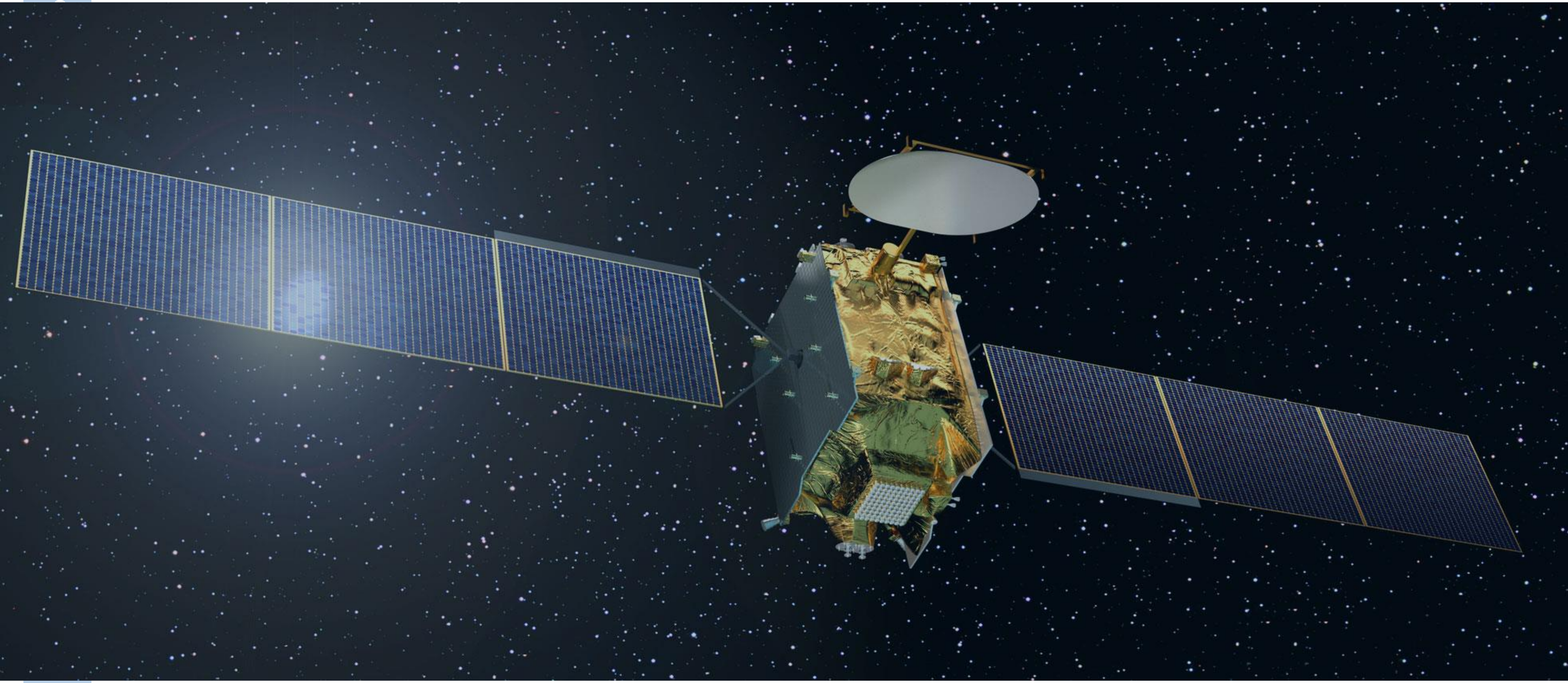
Spin stabilized (INTELSAT VI after repair by Space Shuttle STS-49)

- 

Stabilizing a cylindrical satellite

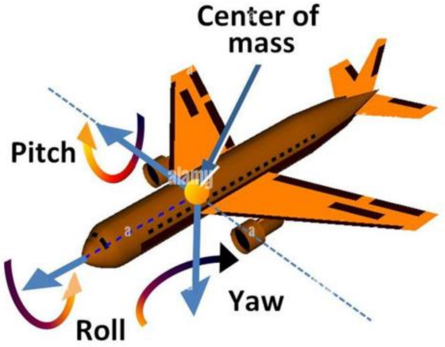
- Once the satellite is in proper orbit a jet thruster is fired to begin spinning the satellite.
- A typical spin-stabilized satellite rotates between 30 and 120 rpm creating an inertial “stiffness” by the *gyroscopic* or *flywheel* effect, which maintains the satellite spin axis perpendicular to the equatorial plane (north-south direction).
- Requires the use of a *de-spun* antenna, to make sure that the mounted antennas are constantly directed towards the Earth.
- 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.

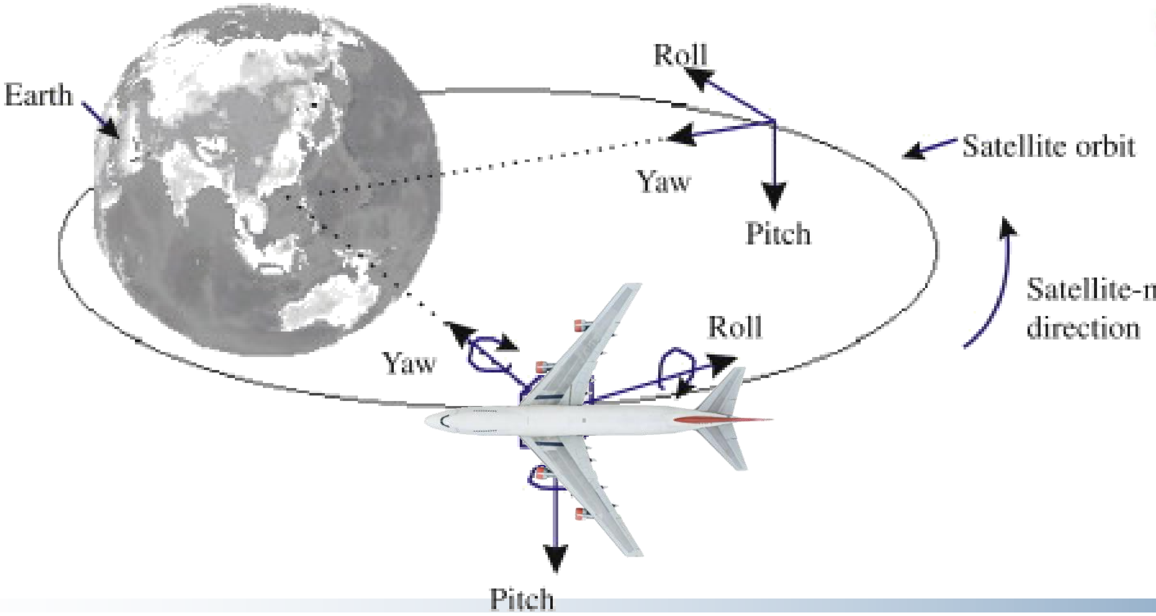
EUTELSAT’s Quantum Satellite 48 E



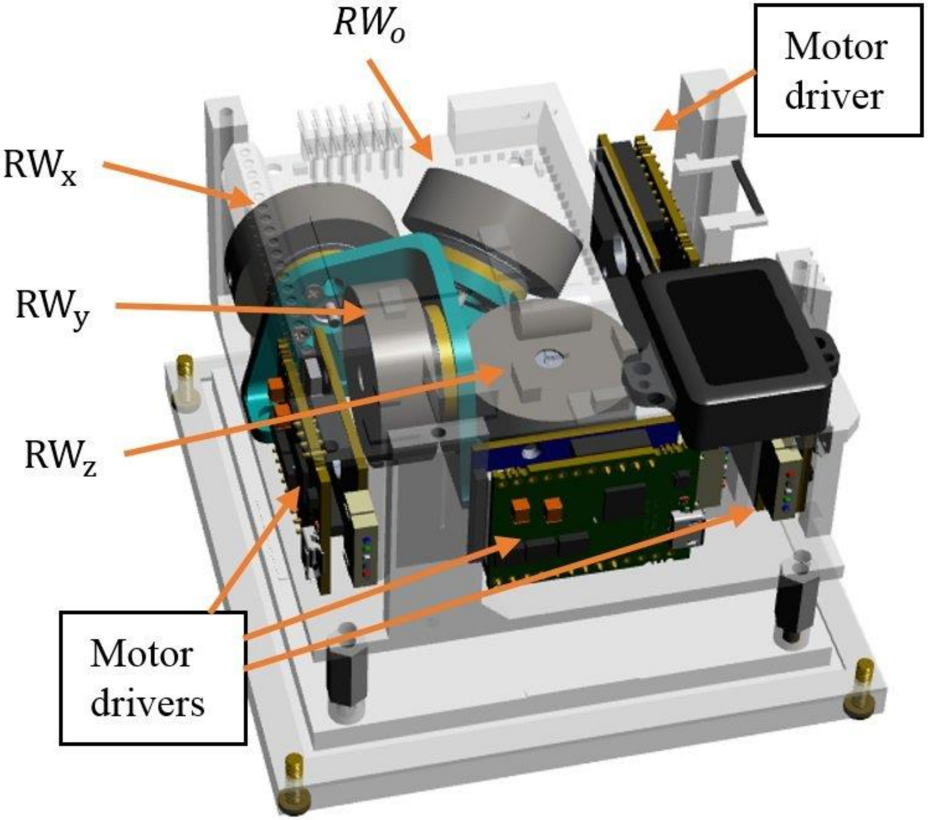
Stabilizing a three-axis satellite

- **Three-axis stabilization** refers to the three main satellite motion axes called *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.





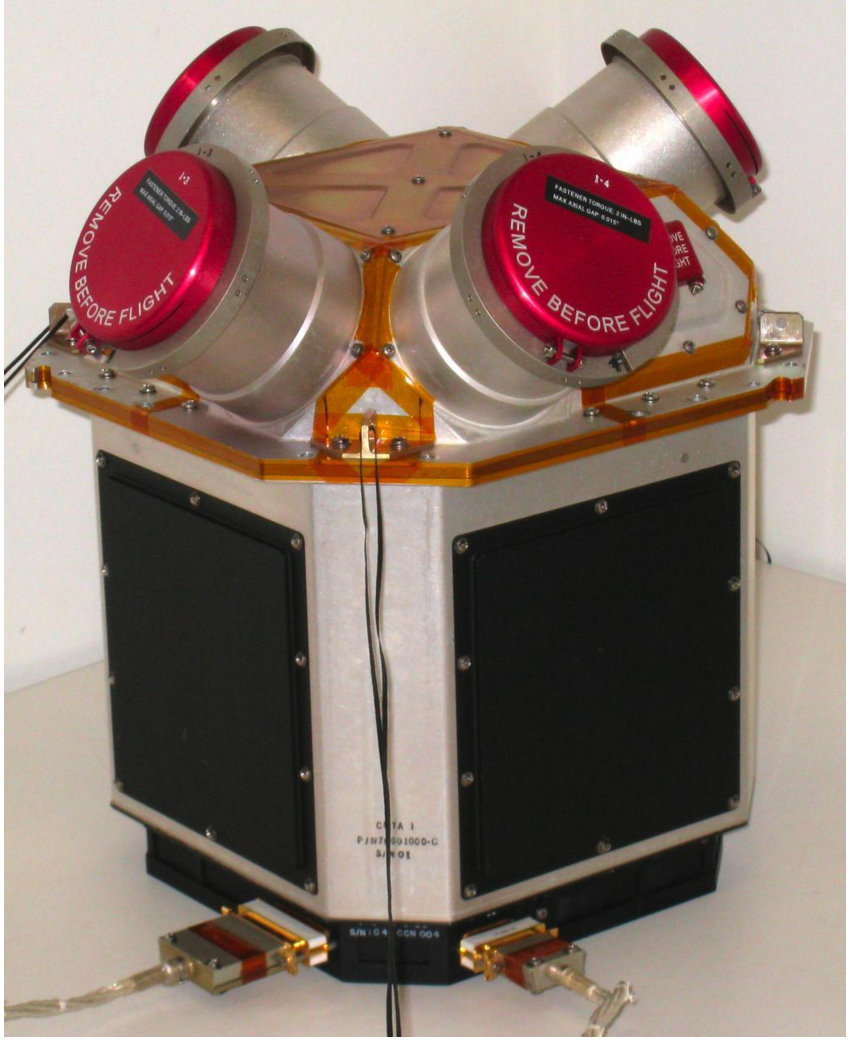
Stabilizing a three-axis satellite



- Three (heavy) flywheels (one for each axis) rotate to provide the gyroscopic effect
- This technique is very accurate, but it needs embarking heavy flywheels and motors.

ESA’s LISA Pathfinder

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)