
LAUNCHERS
Elixir School program
ESTEC 19-20 May 2011
esa
European Space Agency

Overall design of a launcher

The design of a launcher is driven by its main mission features:

- The mass of the payload (for European launchers, from 1T to 20T) and its size
- The nature of the targeted orbit (LEO, GTO, SSO, MEO)
- The payload special requirements (shocks, vibrations, thermal during coasting phase, contamination, multiple satellites release, distancing, manned launch)
- The launch site and ground safety requirements (on site and downrange)

The main parameters for optimisation of the launcher are:

1. **The number of stages** : A launcher cannot (yet) carry its payload directly to orbit while remaining in one piece (SSTO) because 90% of its mass would have to be propellant, it would consist in huge tanks which would have to be carried to orbit, and those are dead weight when empty. It is preferable to empty a first stage using its dedicated tanks and propulsion, then get rid of it, and use the next stage to go on. Several stages are used (usually 3 or 4). A lower stage carries heavier mass (itself and everything above it) than the next, thereby it requires more thrust. Most often first stages are solid boosters.

Launchers parameters of optimisation (cont.)

2. The type of propellant: for each stage the type of propellant can be
   - Solid boosters (lower stage for high thrust, but lower performance)
   - Storable liquid, used for main and upper stages
   - Cryogenic (LOX/LH2) most beneficial for upper stages, used also in main stages
3. **The cycle of each liquid engine**: It drives its performance, but also its complexity and cost. (it will be explained hereafter)
4. **The staging velocities**: The task of accelerating the launcher to the orbiting delta V of around 8 km/s (for LEO) plus 1 km/s losses is shared between the stages. This sharing, plus the other above parameters, drive the size of each stage. Staging shall be consistent with the safety constraints (i.e. the stage fallout zone)

Main rocket propulsion tradeoffs

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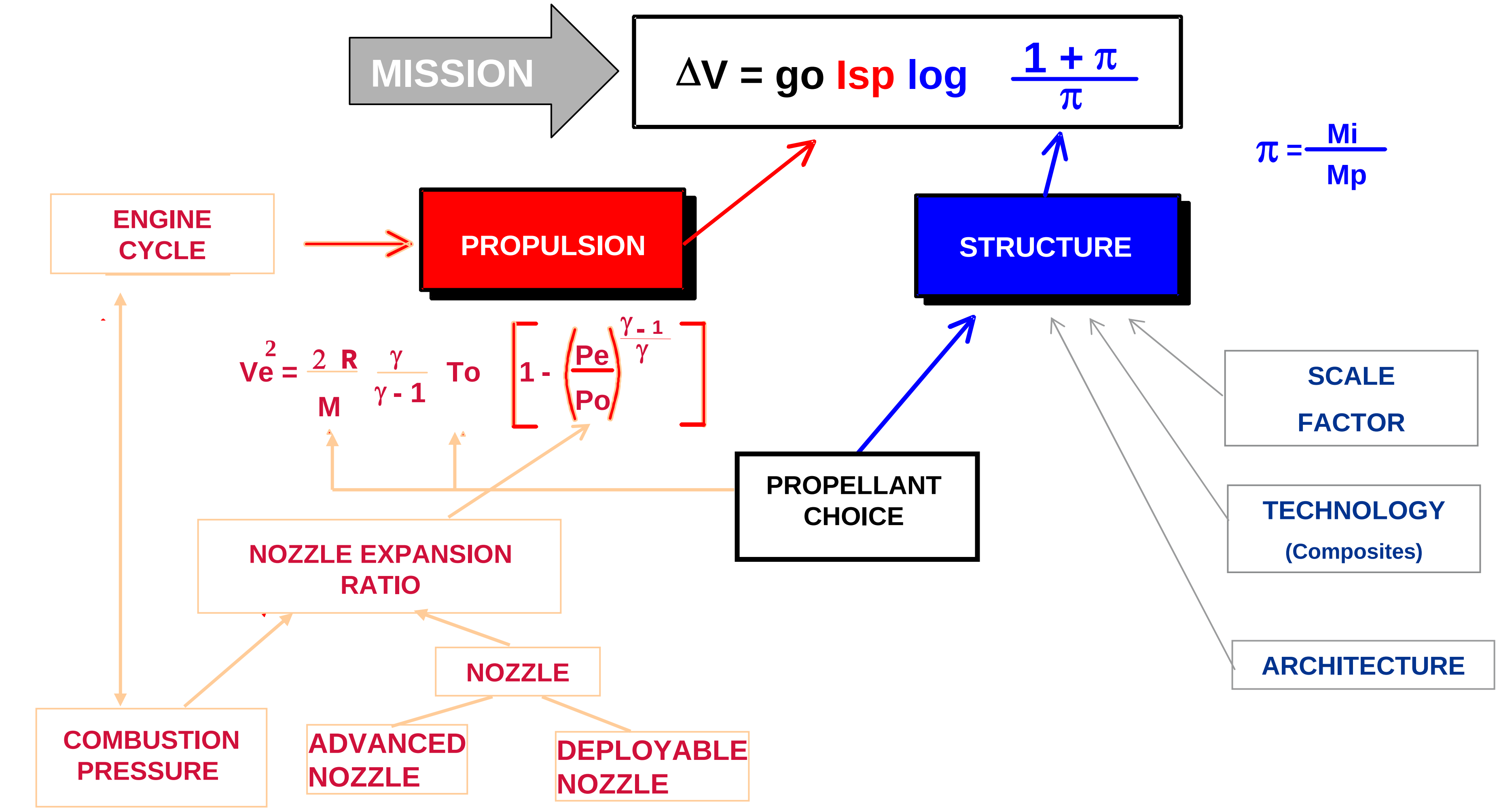

Liquid propulsion principle
(with a turbopump)

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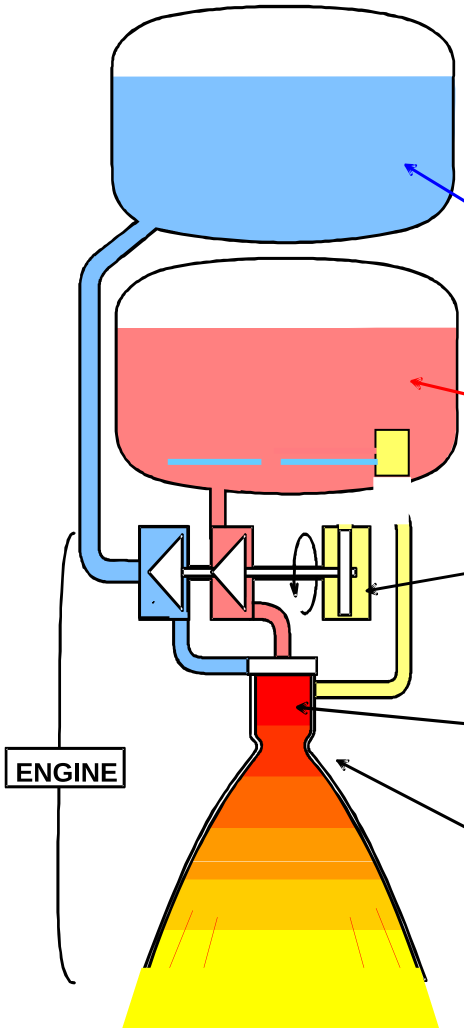

FUEL :
UDMH,MMH,Kerosene,
Liquid Hydrogen

OXYDISER :
Nitrogen Peroxide
Liquid Oxygen

TURBOPUMP:
10 000 à 200 000 rpm
0,5 à 50 MW

COMBUSTION
30 à 250 bar
2500 à 3500 K

NOZZLE (Acceleration):
Ejection speed :2500 to 5000 m/s
Mass flow rate :
10 à 400 T/min

Low density Propellant :
0,8 to 1,2 for storable
0,3 to 0,4 for cryogenic

INTRICATED FCNCTIONING DIAGRAMME : Many components

Combustion Time *: 3 à 20 min*

Consumption *: 130 (cryogenic) à 200 (storable) kg/tonne of thrust per minute*

	MASS (tonnes)	THRUST (tonnes)
Upper Stages	2 à 20	1 à 40
Lower Stages	70 à 700	50 à 800

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Major types of liquid propulsion cycles

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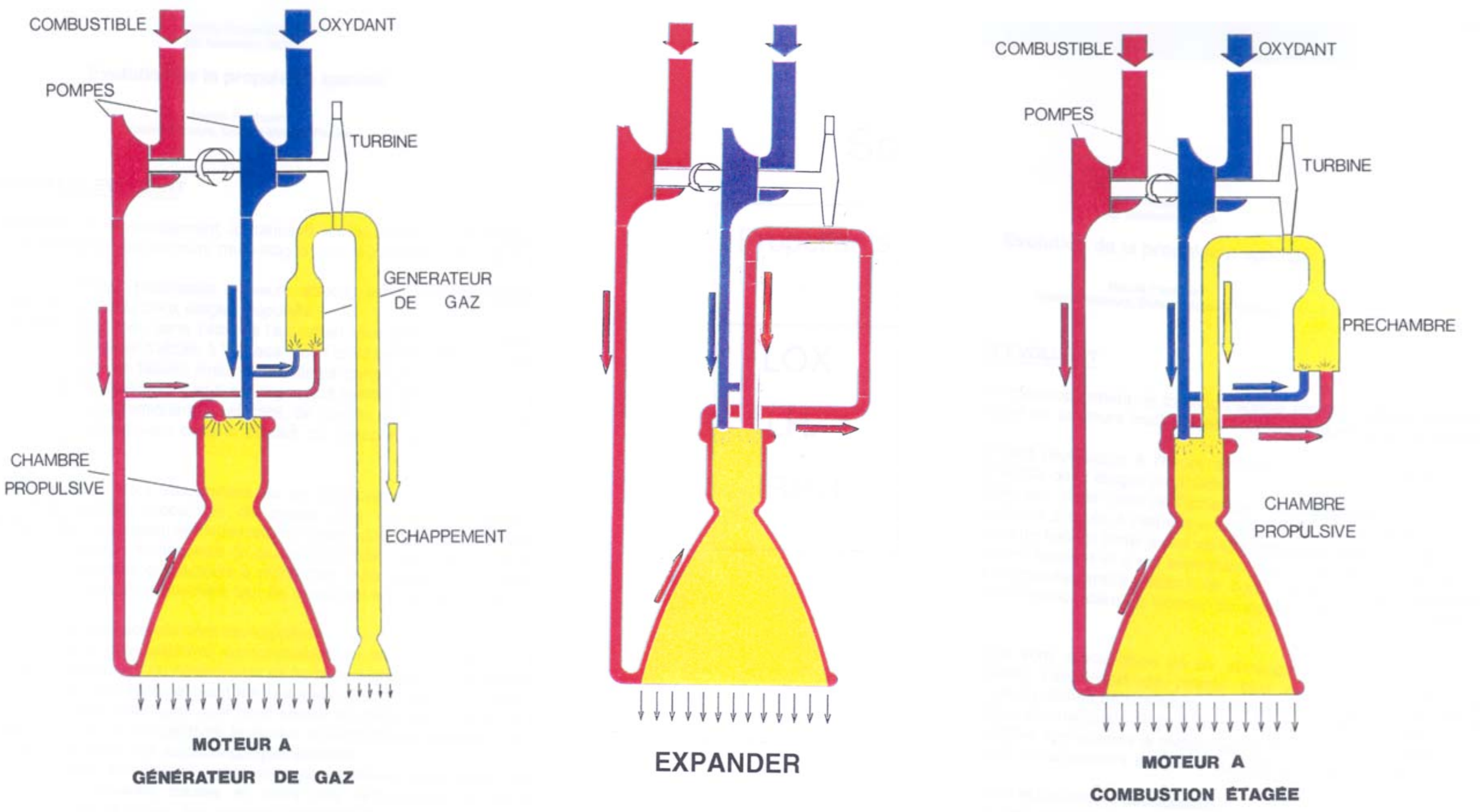

Cryogenic propulsion: the Vulcain example

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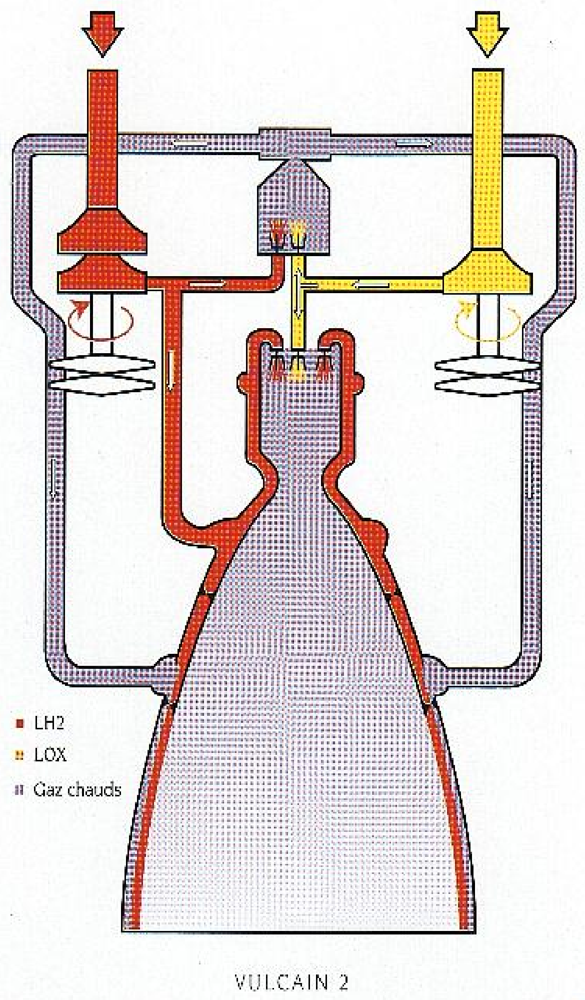
VULCAIN 2

Type	Cycle ouvert générateur de gaz
Poussée dans le vide	1 350 kN
Impulsion spécifique	434 s
Pression de combustion	115 bar
Rapport de section	58,5
Ergols	LOX - LH2
Débit d'ergols	320 kg/s
Rapport de mélange	6,10
Vitesse de rotation TP	LOX : 12 600 tr/min - LH2 : 35 500 tr/min
Puissance turbines	LOX : 5 MW - LH2 : 14 MW
Hauteur	3,60 m
Diamètre sortie tuyère	2,15 m
Masse totale	2 040 kg



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Storable propulsion: the EPS example

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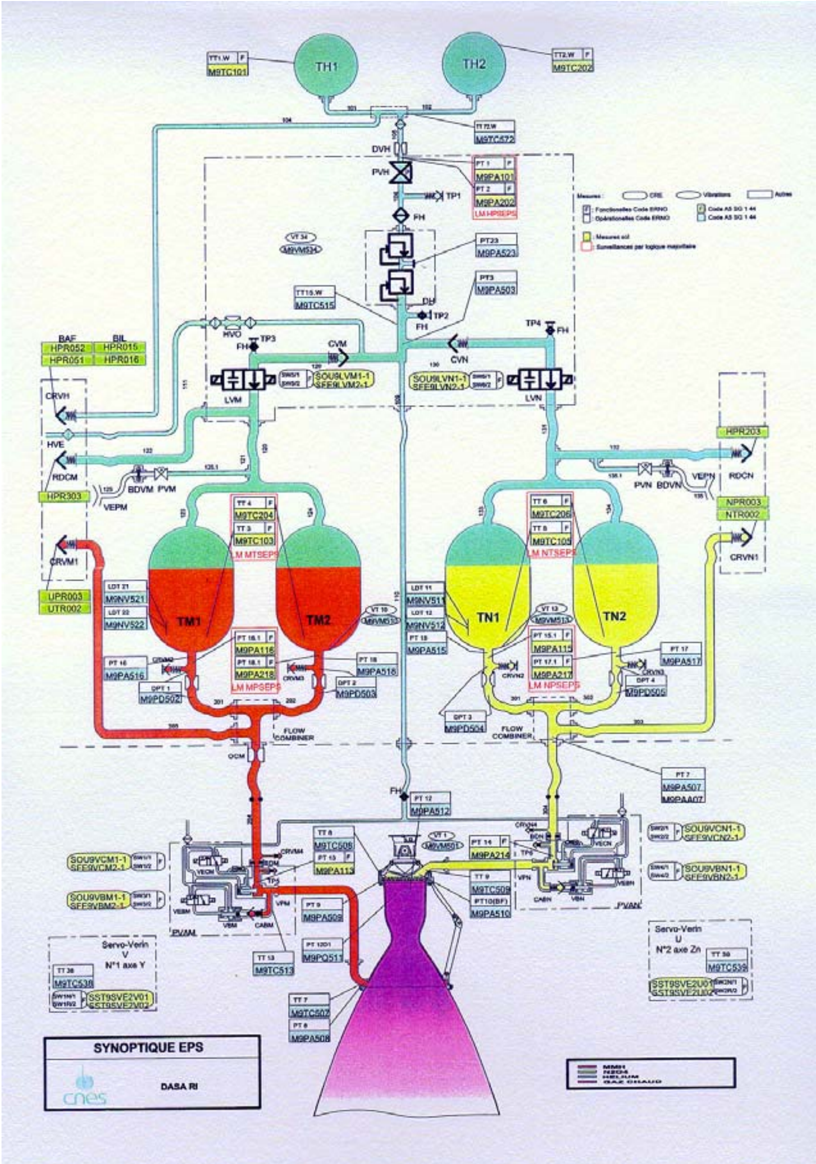

This type of stage features a blow-down cycle and uses hypergolic propellants (propellants which burns spontaneously together) :

- MMH (Mono methyl hydrazine)
- N2O4 (Peroxyde d'azote)

Simple engine, restart is possible, but:

It requires a pressurisation of the propellant tanks by Helium at a pressure higher than the combustion chamber pressure (this impacts heavily the tanks mass, which have to withstand the pressure. It limits the applicability of the blowdown storable propulsion to small to medium size stages)

Solid propulsion principle: the EAP example

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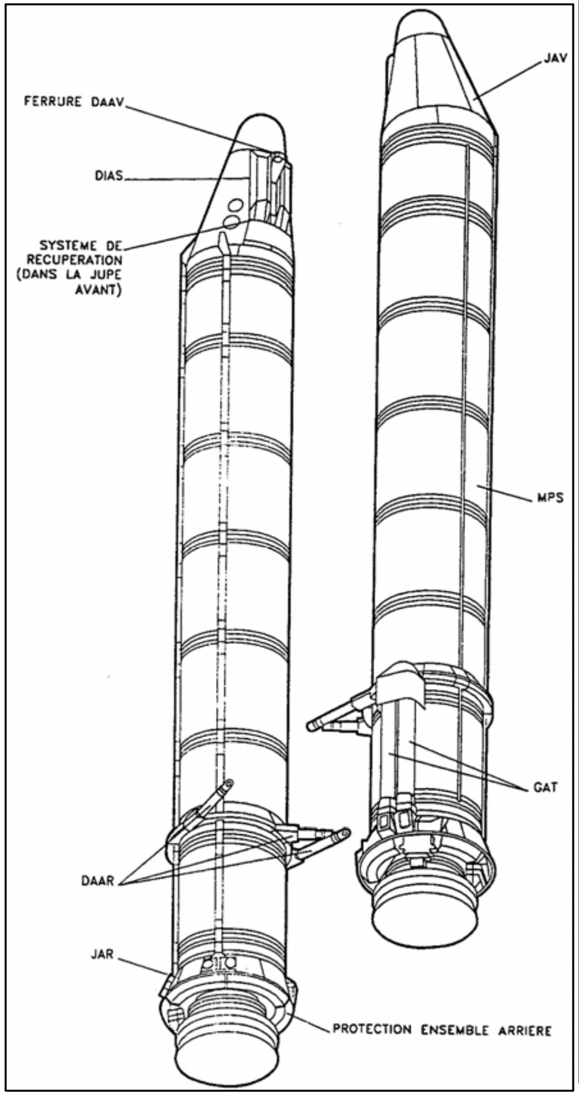

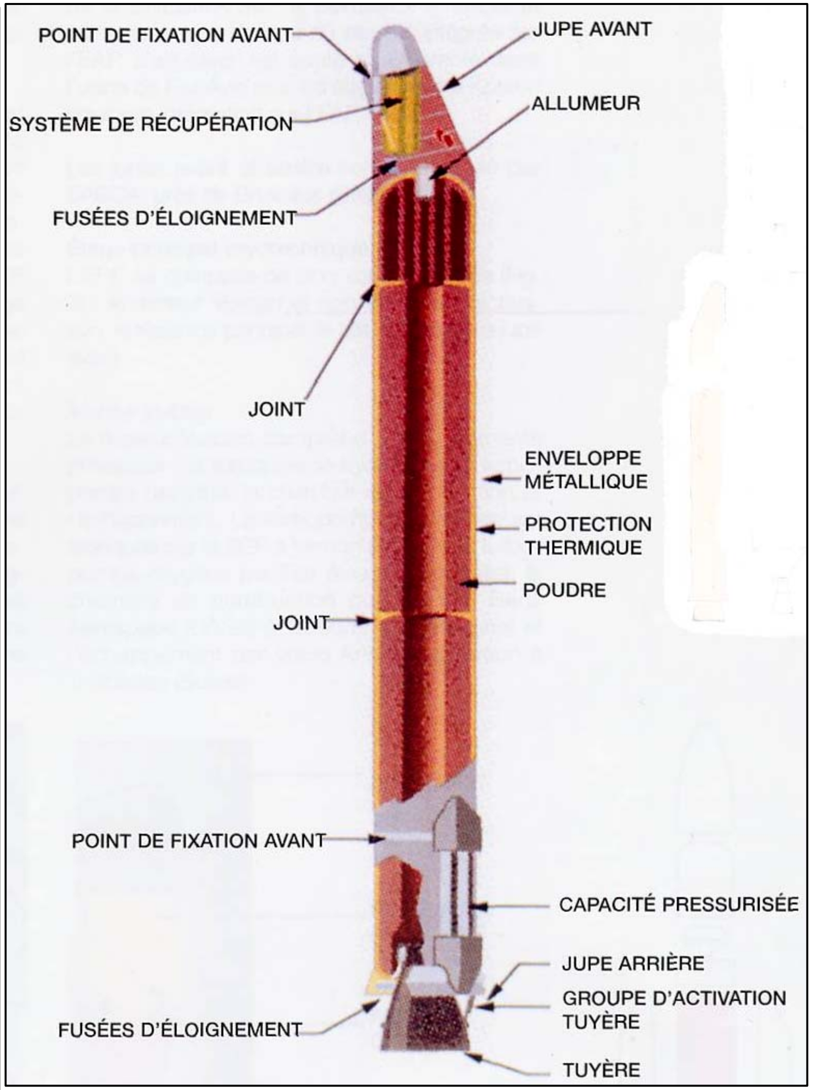

240T propellant
700T max thrust

Actuated nozzle
(using independent hydraulic system)

Reliable and comparatively cheap stage, but:

- Generates thrust oscillations
- Strict simultaneity of ignition needed
- Thrust tail off simultaneity requires pairing at production

Launcher design work

In the launcher design process, the following aspects need to be traded:

- Propulsion in steady phase, but also pre-conditioning, start-up and shut down
- Avoidance of engine and system instabilities (Pogo)
- Structural design (loads, mass minimisation, control of dynamic modes)
- Tanks pressurisation (mostly by pressurised Helium)
- Piloting (jacks, hydraulics), attitude control (thrusters)
- Guidance, Navigation, electronics, telemetry, EM compatibility, energy budget
- Flight software, hardware redundancy and swap criteria
- Stages separation (retrorockets), shroud separation (trajectory), pyrotechnics
- Internal environment (noise, separation shocks, boosters instability)
- External environment (aerodynamics, winds aloft, dynamic heating & pressure)
- Trajectories, tank filling strategy, propellant reserve, safeguard criteria
- Thermal status of tanks and systems throughout the flight
- Interfaces with the ground; operability; launch preparation process
- Costs minimisation, reliability maximisation
- And much more…

Main design features of Ariane 5 ECA

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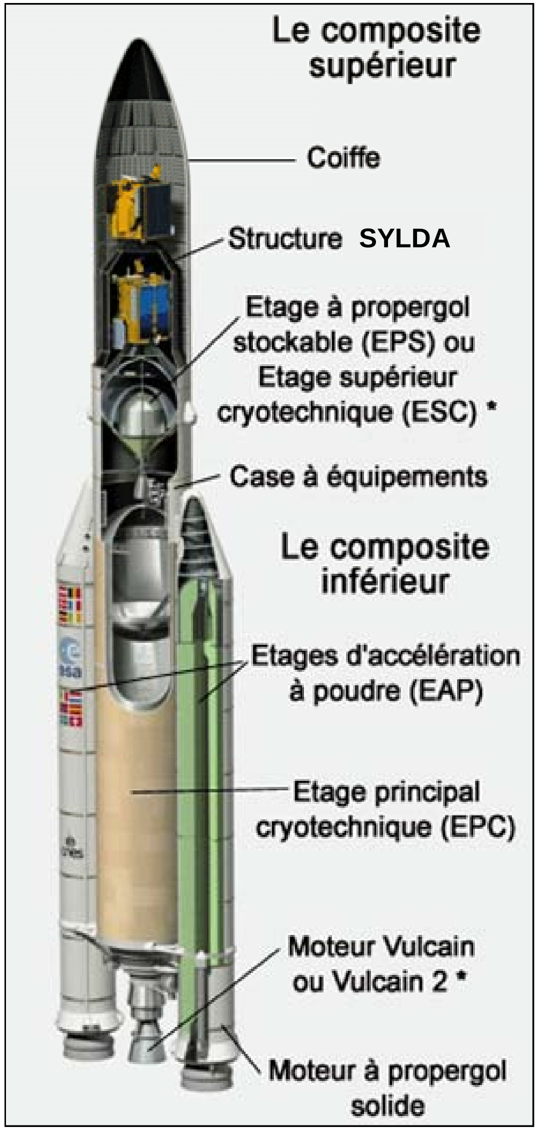
ARIANE 5 ECA LAUNCHER DATA

- *EAP Mass : 560 T*
- *Thrust : 2 * 650 T*

- *EPC Mass : 188 T*
- *Thrust : 135 T*

- *ECA+VEB : 20 T*
- *Thrust : 6.6 T*

- *LO Mass : 780 T*
- *LO Thrust: 1400 T*



ARIANE 5 ECA / GTO LAUNCH SEQUENCE

- *H0 : Vulcain2 Ignition*
- *H0 + 00:00:07*
  EAP Ignition

- *H0 + 00:02:21*
  EAP Separation

- *H0 + 00:03:09*
  Fairing Jettisoning

- *H0 + 00:08:53*
  EPC Separation

- *H0 + 00:08:57*
  ESC-A Ignition

- *H0 + 00:24:47*
  ESC-A Injection

THE 'FAMILY' OF ARIANE LAUNCHERS

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Main motivation:

ESA's launchers guarantee the independant European access to space.

The Ariane rocket wins more than 50% of the GTO payload launch market open competitions in the world. The European launch offer diversity will be broadened with Vega and Soyuz by the end 2011.

In order to further increase the available performance and launch flexibility of Ariane, the development of a new version called A5ME is ongoing. A5ME is scheduled to fly in 2016.

Ariane 5 ME Configuration

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ARIANE-5 ME

Extended Payload Fairing
Height: 20m (+3m w.r.t. current long fairing)
Very long Sylda (+ 3.1 m)

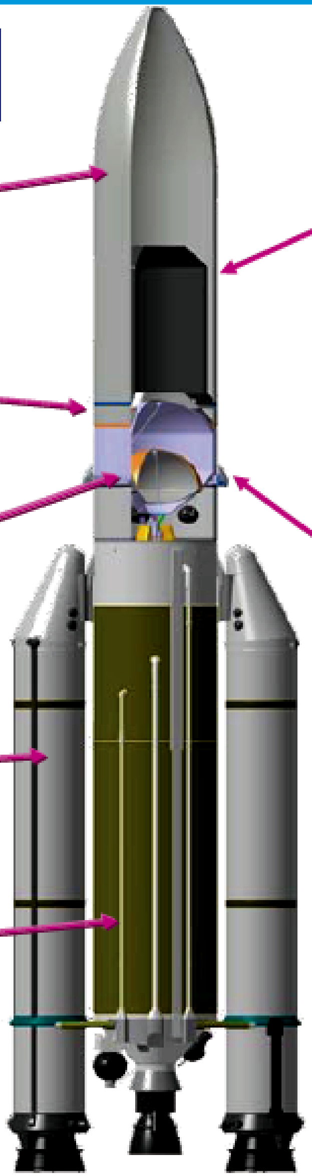
Electrical system
New generation On Board Computer (OBC)
Modernized avionics

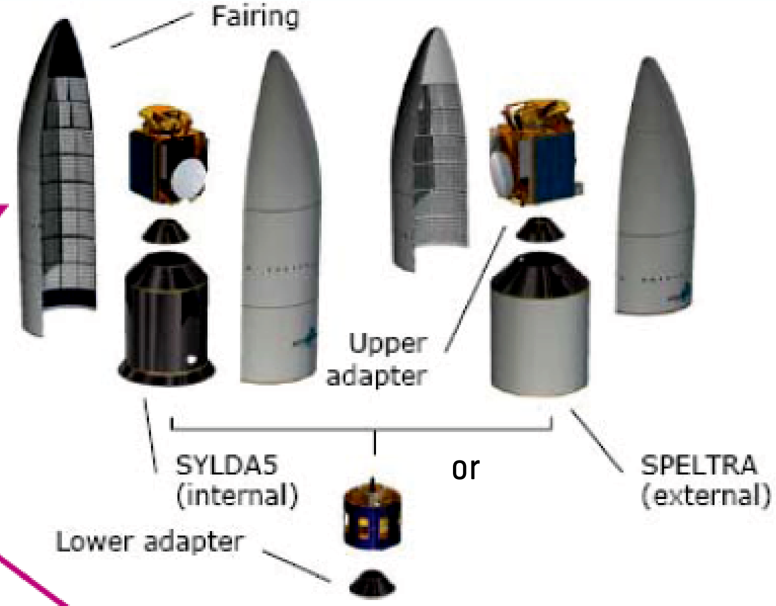
New Cryogenic Upper Stage (ESC)
Engine: Vinci 180 kN
Propellants: 28 t
Common bulkhead

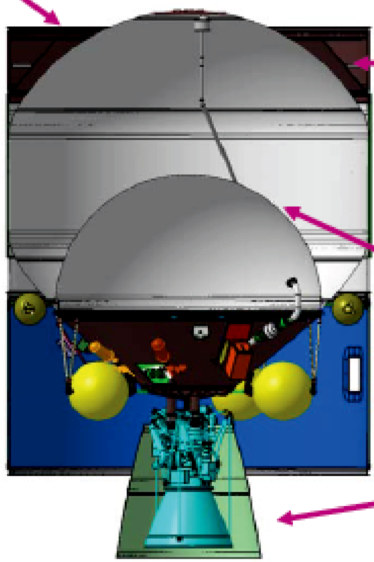
EAP Solid Propellant Boosters unchanged
Solid Propellants: 240 t each
Three segments metallic case with welded joints

EPC Cryogenic Main Stage mostly unchanged
reinforced JAVE

Launch Base
Reused ELA3 ground infrastructure







New OBC
Modernized avionics

LH2 / Lox Tank with Common Bulkhead

VINCI 160 - 180 kN
Expander Cycle
Deployable Nozzle

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Vega: the small launcher of the family

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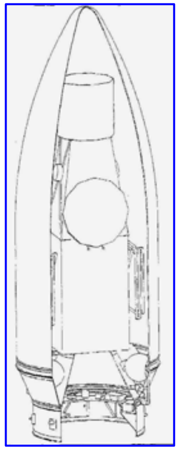

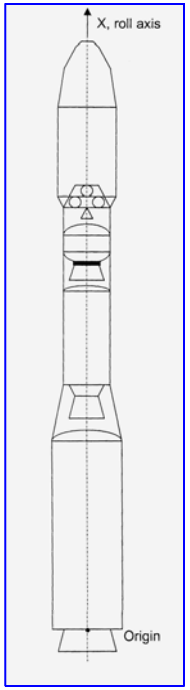

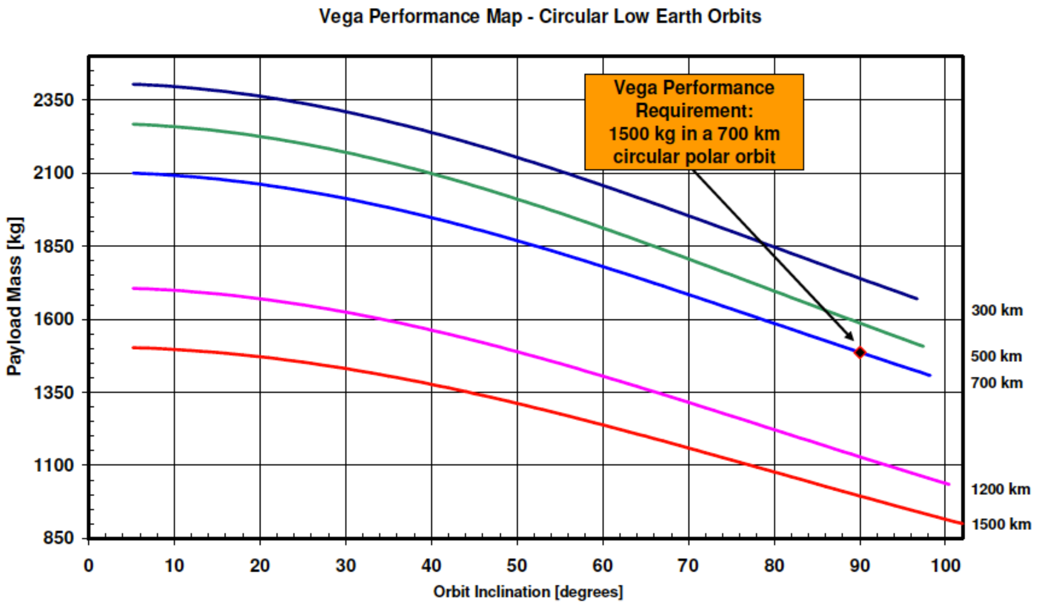

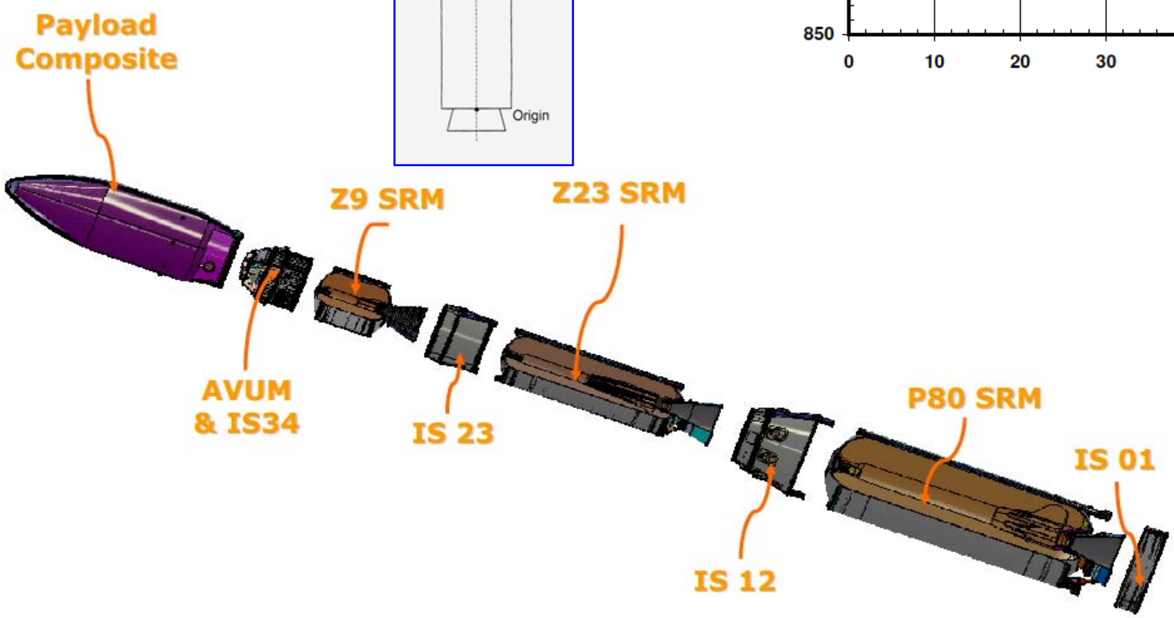

Characteristics and performances	
AVUM stage dry mass (kg)	615
Propellant loading (kg)	577
Pressuring (GHe) gas loading (kg)	4.1
Main engine thrust (N)	2450
LPS total impulse (kN s)	1634
Restart capability	5

Soyuz launcher at Kourou

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Today's operational launch sites worldwide

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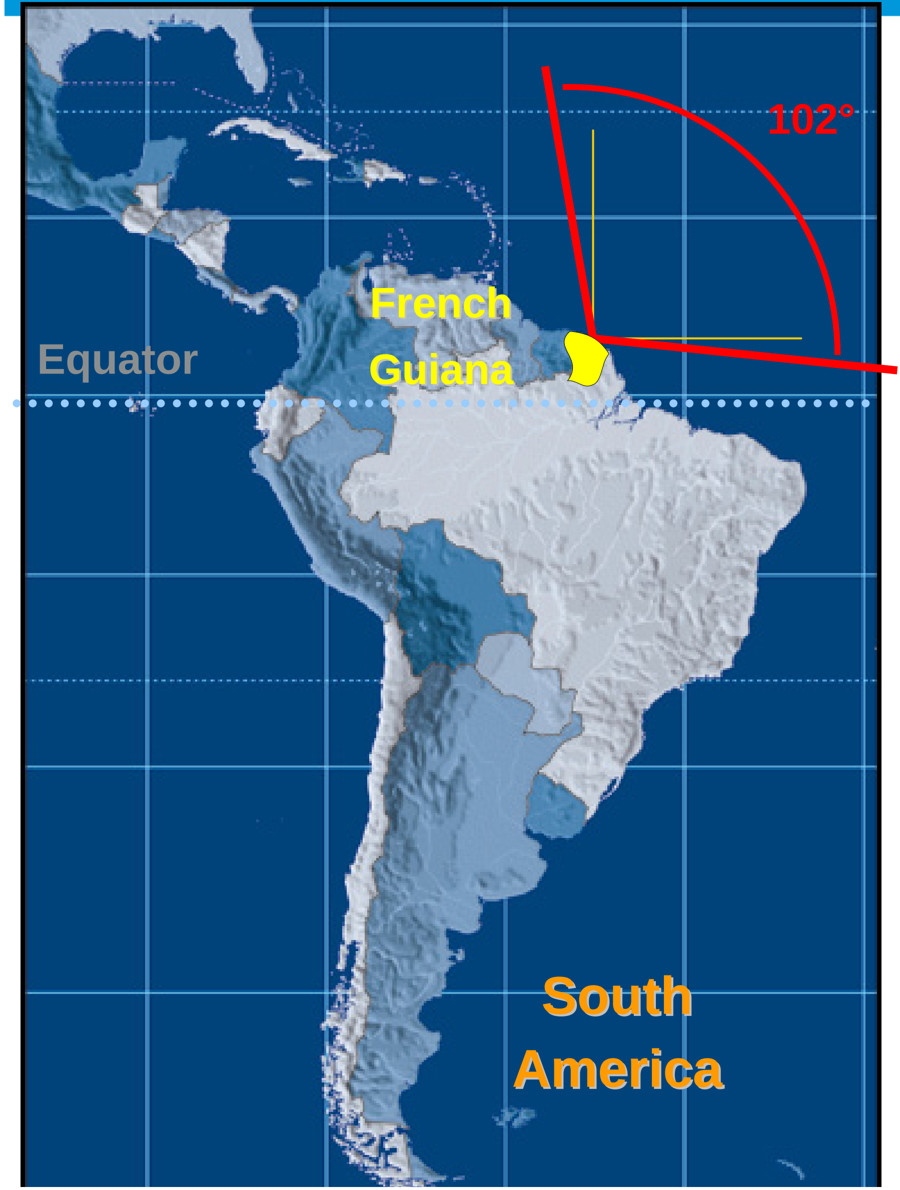

Kourou: An exceptional location

- **Closeness to the equator** (allows an improved performance for an identical launcher, e.g. Soyuz)
- **Extensive launch azimuth possibilities**
- **Cyclone and earthquake free**
- **Low population density**
- **Boosters fall back at sea**

Downrange telemetry stations

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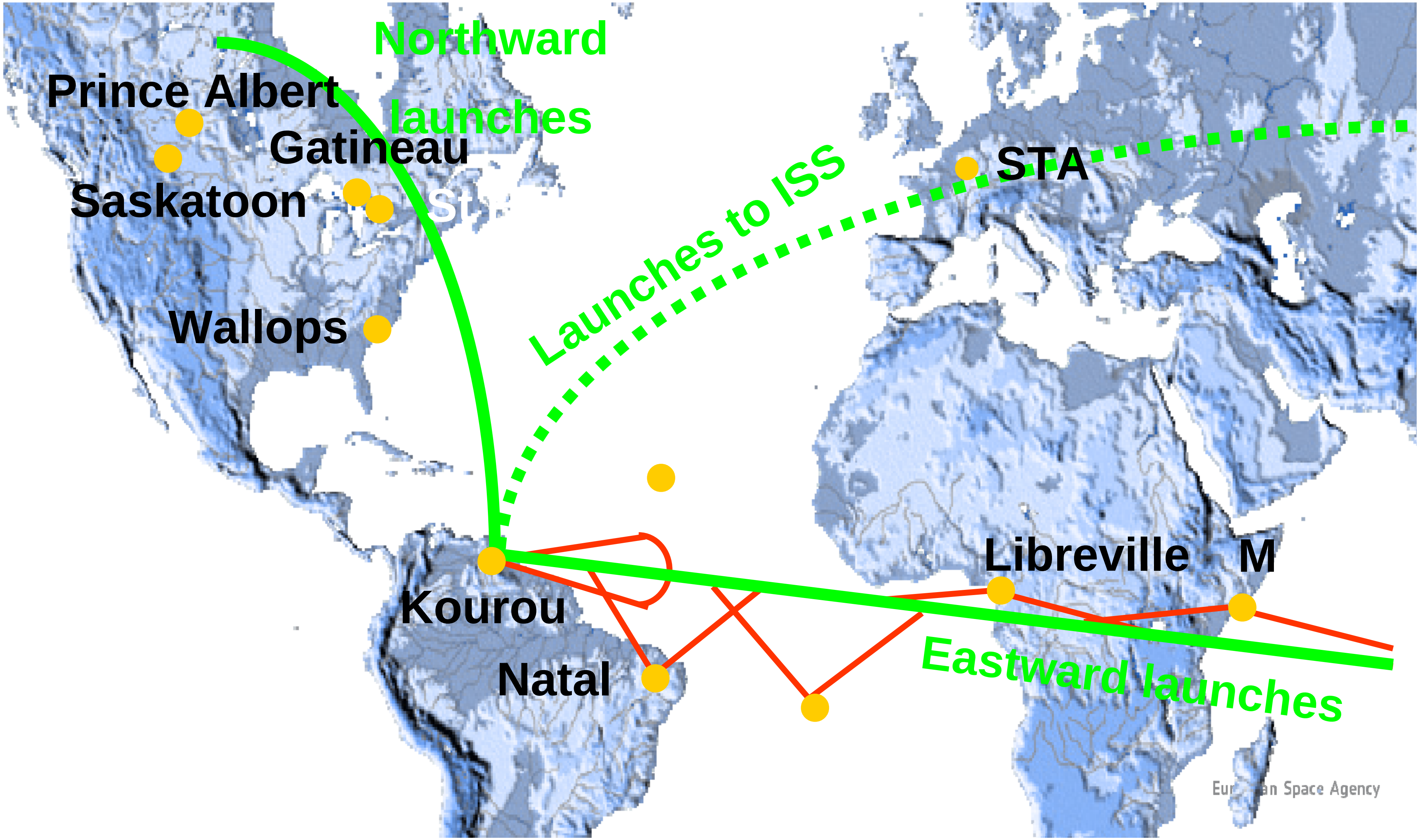

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