Technical Considerations for Propulsion Systems of Future European Launchers

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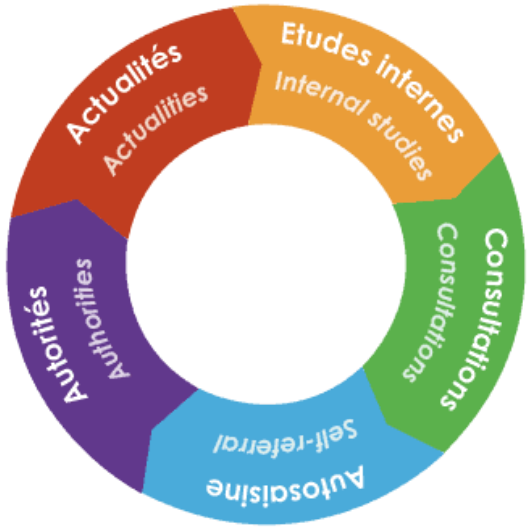


SAPIENZA
UNIVERSITÀ DI ROMA



Air and Space Academy (AAE)

A pool of knowledge unique in Europe for Air and Space



Who

Members of **all nationalities** who hold or have held **major responsibilities** in aeronautics and space from a wide variety of backgrounds

Engineers	Industrialists	Researchers
Managers	Pilots	Astronauts
Doctors	Lawyers	Economists
Journalists	Writers	Artists

… all working together

Mission

Promote and further high-quality scientific, technical, cultural and human activities in Air and Space

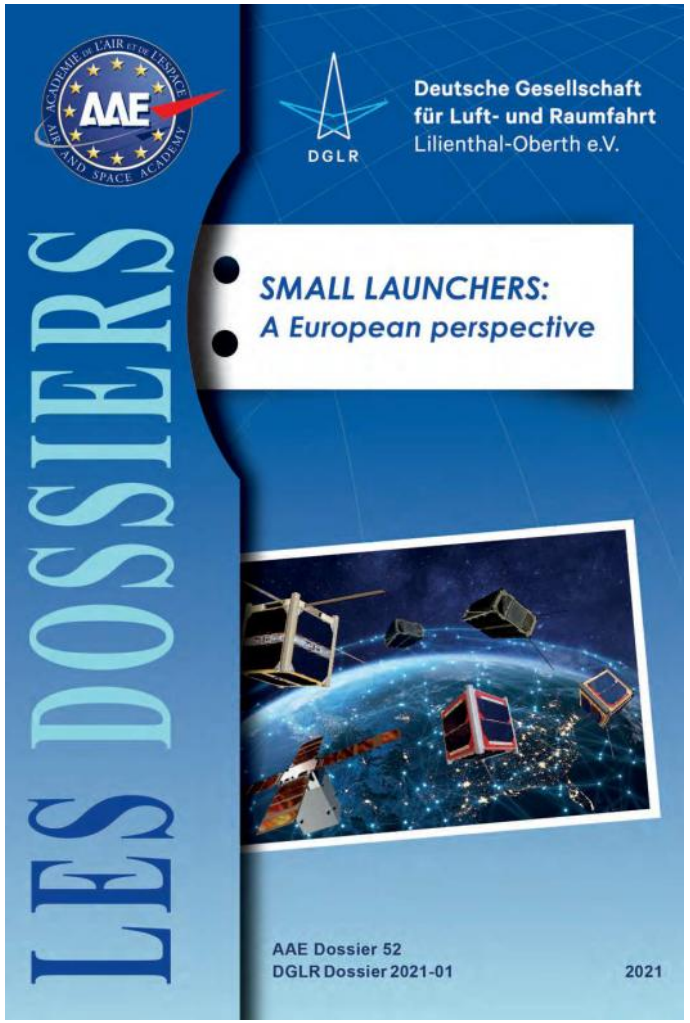
1. **Reflections**
   on general-interest, strategic or current topics, at the request of an authority or on its own initiative; food for thought for institutions and industry

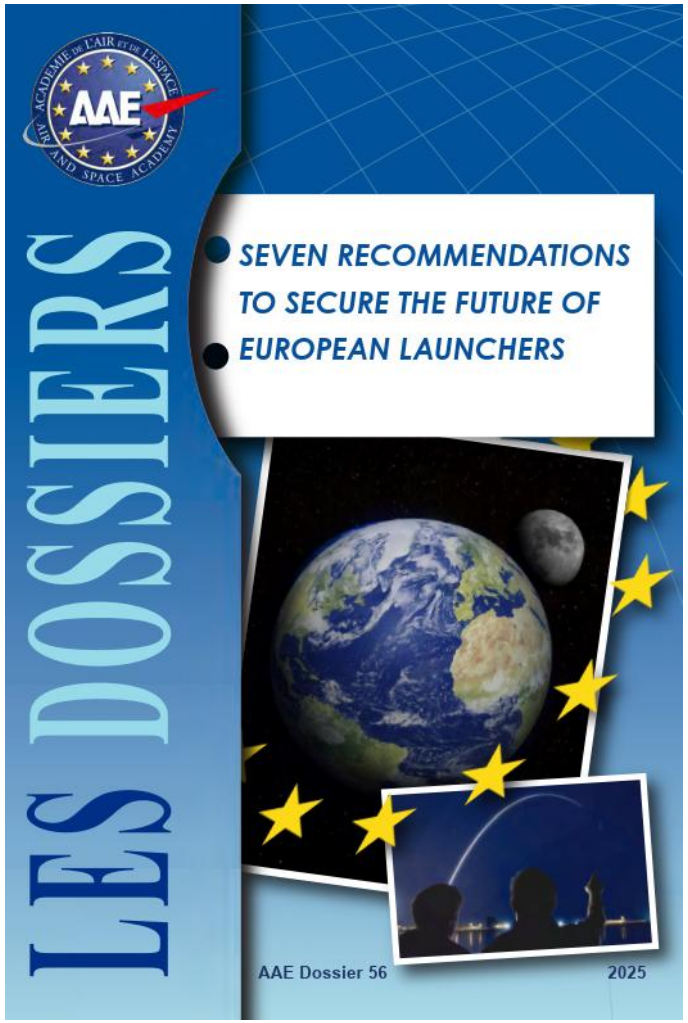
2. **Sections & commissions**
   multidisciplinary studies that identify the key issues

3. **Events & publications**
   reports, opinions, dossiers; events to compare viewpoints and keep close links with aerospace institutions and companies

https://academieairespace.com/

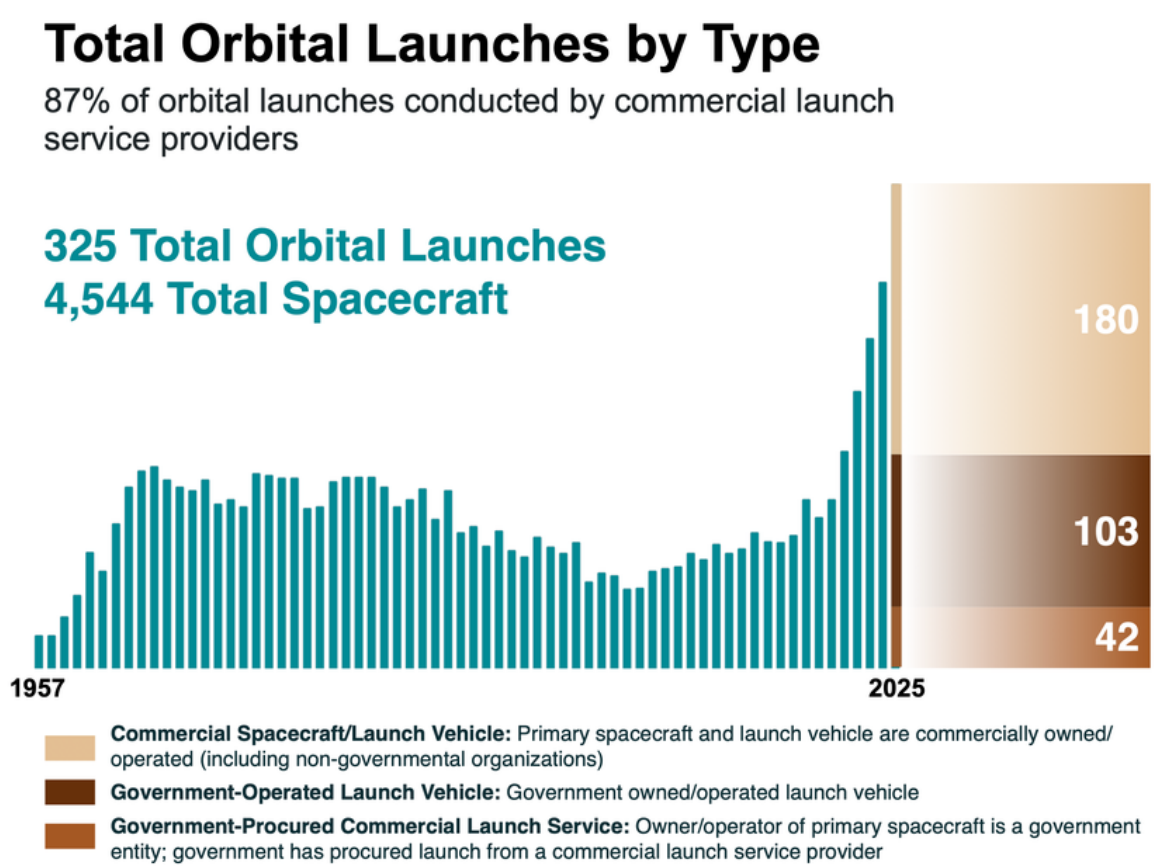
Future European Launchers: Dossiers of the Academy of Air & Space

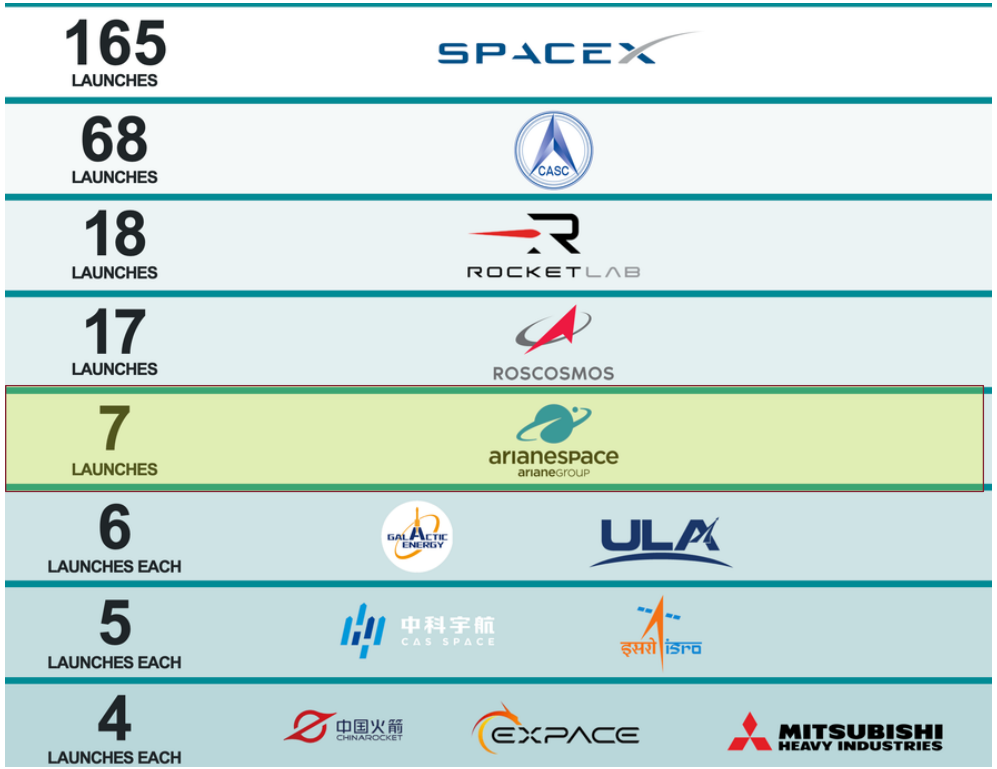




https://academieairespace.com/les-dossiers/

Space Launches 2025 Year in Review (Bryce Tech)





Credit: Bryce Tech

Past and Present European Access to Space

302 orbital launches since 1979 | **94.4 %** fully successful | **13** failures | **4** partial failures

Ariane 1–6 (ESA) | Vega / Vega-C (ESA) | Spectrum (Commercial)



Launcher	Period	Orbital launches	Fail.	Partial	Full success
Ariane 1	1979–1986	11	2	–	82 %
Ariane 2	1986–1989	6	1	–	83 %
Ariane 3	1984–1989	11	1	–	91 %
Ariane 4	1988–2003	116	3	–	97 %
Ariane 5	1996–2023	117	2	3	96 %
Ariane 6	2024–present	9	–	1	89 %
Vega	2012–2024	22	2	–	91 %
Vega-C	2022–present	8	1	–	88 %
Spectrum	2025–present	2	1	–	50 %
Total	**1979–present**	**302 orbital launches**	**13**	**4**	**94.4 %**

European Needs



Europe faces rocket launcher shortage by 2030, space agency chief warns

Demand for launches is growing faster than the region's capabilities

Financial times August 2026

OPINION

Launcher shortage threatens European New Space competitiveness

Without reliable, frequent access to orbit, Europe risks stalling startup innovation and compromising its technological sovereignty.

A rocket shortage gives SpaceX's competitors an opportunity

The firm may soon have little capacity to launch others' payloads

The Economist 1 October 2026

Andrius Kubilius Commissioner for Defence and Space at EC



"Europe overcame the launcher crisis. But now we face the next, maybe even bigger challenge."

50,000
satellites worldwide in the next 10 years

European satellites 2016–25 → 2026-35

Defence (national)
20 → **300** ×15

Government
70 → **630** ×9

Commercial
1000 → **2000** ×2

European launch demand

×6

demand will multiply by nearly six times

62 EU launches by 2034

Galileo | Copernicus | IRIS²

The launching gap

Ariane
10 per year planned
14 needed in 2031 alone

Vega
6 per year planned
8 needed in 2030 alone

- **Autonomous access to space**
- *Rockets used "again and again and again"*
- **The power of unity**

A. Kubilius, 2nd Access to Space Conference "Ready to Launch: Building Europe's Competitive, Resilient and Responsive Access to Space", 23 September 2026

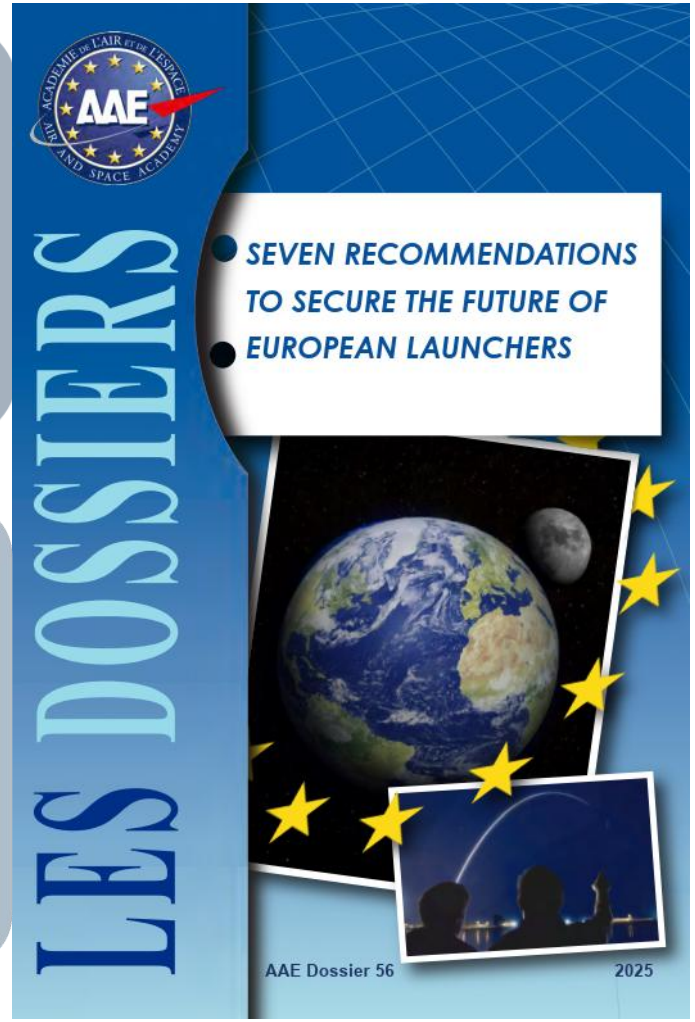
AAE Recommendations

RECOMMENDATION 1.

In the coming years, it is essential that European Union (EU) countries prioritise the use of Ariane 6 and Vega C and that the commonality between the two launchers is maintained. The Air and Space Academy (AAE) expresses its satisfaction at Europe's reaffirmed support for the Ariane 6 and Vega C programmes and the associated financial backing for their ramp-up until 2030.

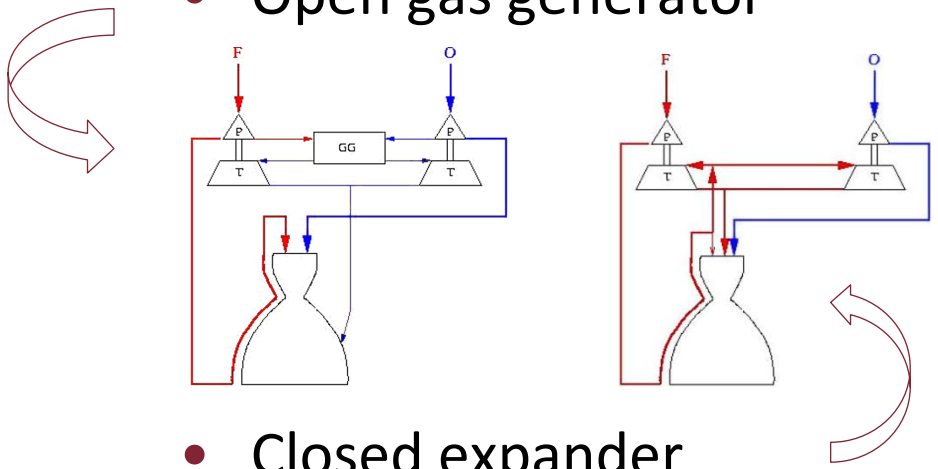
RECOMMENDATION 2.

Independent European access to space is essential for deploying and maintaining EU satellites (Galileo, Copernicus, IRIS², etc.), ESA satellites, Eumetsat meteorological satellites, EU Member State agencies' satellites (mainly defence satellites), satellites operated by European entities fulfilling strategic roles as well as those procured in Europe for international customers (i.e. export contracts).



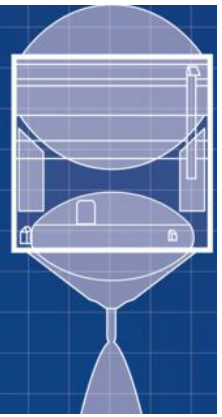
Present Propulsion Systems: Ariane 6

- Hydrogen/Oxygen
- Open gas generator

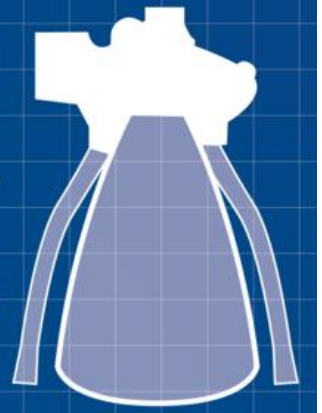


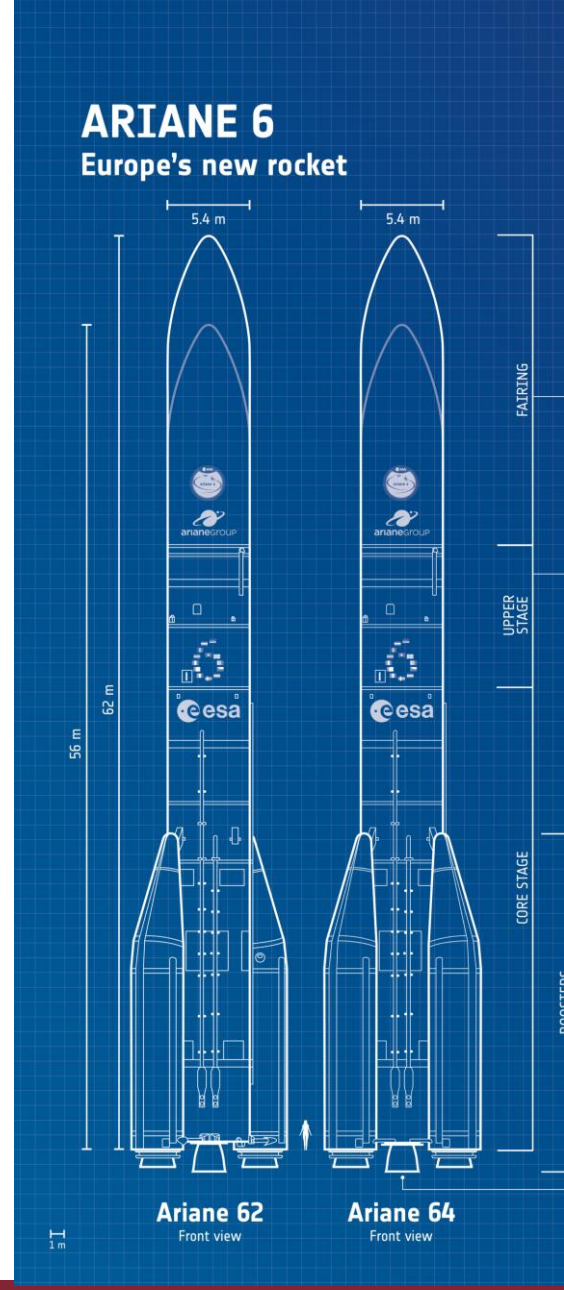
- Closed expander
- **State-of-the-art LRE**
- Heritage from Ariane 5

The Ariane 6 upper stage is powered by the restartable **Vinci engine**, fuelled by 30 tonnes of cryogenically cooled liquid oxygen and liquid hydrogen. The Auxiliary Propulsion Unit pressurises the fuel tanks and provides additional thrust on demand.



Vulcain 2.1 is the main stage engine, it provides 1370 kN of thrust and consumes 150 000 kg of liquid oxygen and liquid hydrogen in just under eight minutes. The liquid hydrogen turbopump used to fuel Vulcain 2.1 produces 15 megaWatts of power – more than a high-speed train engine!





Credits: ESA

Present Propulsion Systems: Vega-C

The P160C was driven largely by the Amazon constellation contract, but it pays off for the whole European fleet, as a common booster for Ariane 6 and Vega.

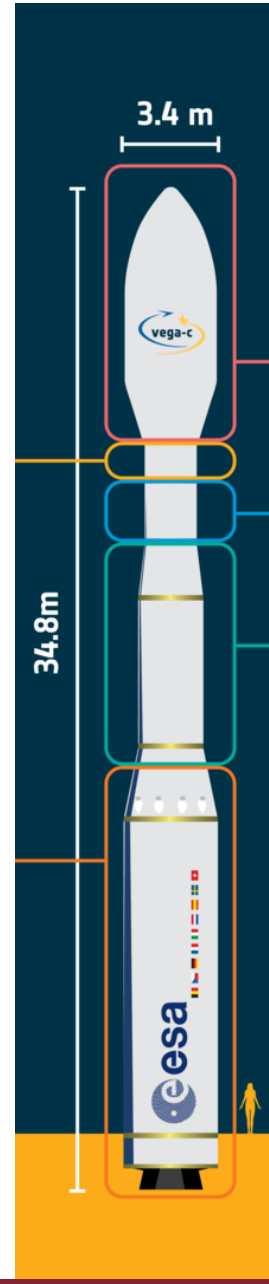
- **State-of-the-art SRM**
- Common P120/P160 with Ariane boosters
- Re-startable storable pressure-fed upper stage
- Heritage from Vega

The **fourth stage**, Attitude Vernier Upper Module or AVUM+, orients and positions the payloads in space allowing Vega-C to reach a range of orbits and deliver multiple payloads. It holds 740 kg of propellant and provides an average thrust of 2.45 kN.

The **third stage** Zefiro-9, was used on Vega-C's predecessor Vega and burns through 10 tonnes of solid propellant.

The **second stage** is powered by the new Zefiro-40 motor and uses 36 tonnes of solid propellant, providing an average thrust of 1100 kN.

The **first stage** P120C motor is one of the largest carbon-fibre solid-propellant rocket motors ever built in one piece. The P120C is also used as the boosters on the Ariane 6 rocket.



Credits: ESA

RECOMMENDATION 3.

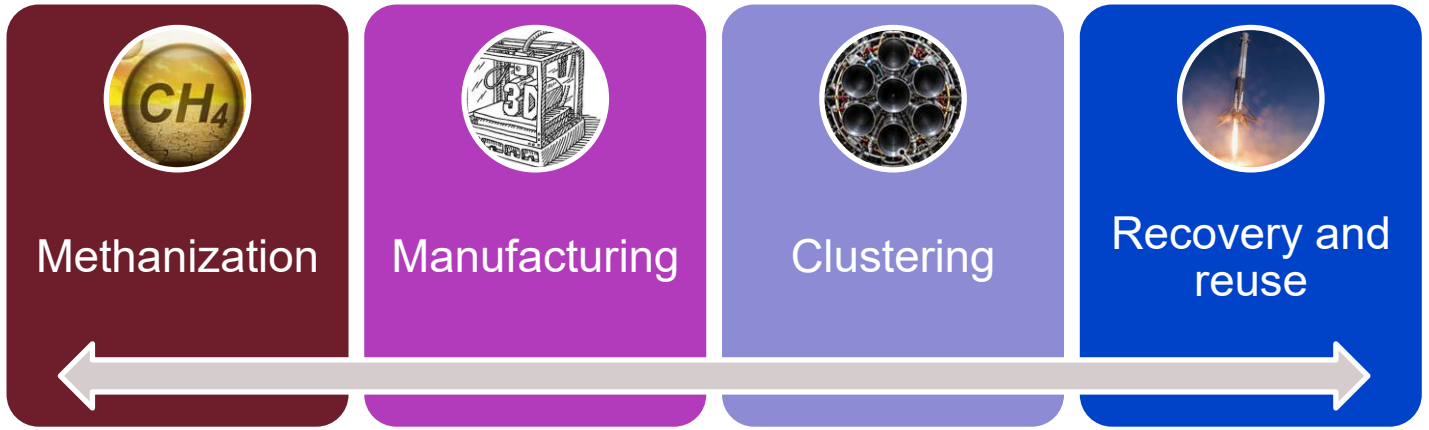
Ariane 6 and Vega C are strategic investments and must continue to operate beyond 2030: ending their exploitation after only five years would be a financial waste. In parallel, the objective for European industry is to commercialise its launcher services without increasing Member States' associated financial contributions beyond those agreed upon in Seville. This should be achieved through continuous improvements to competitiveness and organisational

Future European Launchers

RECOMMENDATION 5.

AAE recommends that ESA begins work on new launcher programmes, to be decided at the 2028 Ministerial Conference, as successors to Ariane 6 and Vega C.

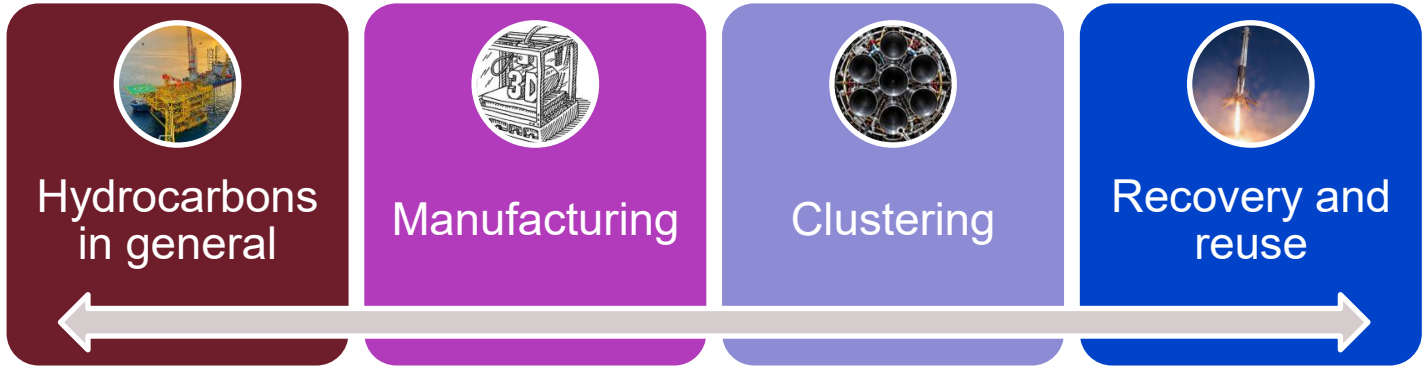
- Ariane Next
- Vega E
- Maia



RECOMMENDATION 4.

AAE recommends that, as a first step, the European Launcher Challenge should select launchers capable of carrying a one-tonne payload into Sun Synchronous Orbit, 550 km, complementing the existing Ariane 6 and Vega C launchers.

- RFA One
- Small launchers



Methanization

- No coking – reuse
- Perspective of in-situ availability (Mars)
- More pumping cycle options
- Easier to handle than hydrogen

Legacy challenges

Kerosene (RP-1)

- Coking and soot in cooling channels and turbines
- Limits reuse

Hydrogen (LH_2)

- Very low density (≈71 kg/m³): large tanks
- Deep cryogenic (20 K): insulation, leaks, complexity

Key advantages of CH_4

Rapid reusability

- Negligible coking: clean channels and turbines

Thermal properties

- Boils at 112 K, close to LOX (90 K): common bulkhead
- ≈420 kg/m³, six times denser than LH_2

In-situ resources

- Mars: $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$ (Sabatier)

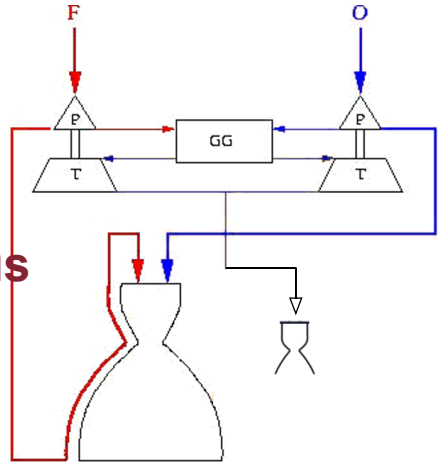
Methalox engines: who flew first

- **US** Apr 2023 **SpaceX Raptor 2**
  Starship, first integrated flight
- **CN** Jul 2023 **LandSpace TQ-12**
  Zhuque-2: first methalox to orbit ★
- **US** Jan 2024 **Blue Origin BE-4**
  Vulcan, then New Glenn (2025)
- **CN** Dec 2025 **TQ-12A, Longyun-70**
  Zhuque-3 and Long March 12A reach orbit
- **CN** Aug 2026 **Zhuque-3**
  first Chinese booster landing
- **EU** In dev. **Europe**
  Prometheus, MR10, MR60, LUMEN

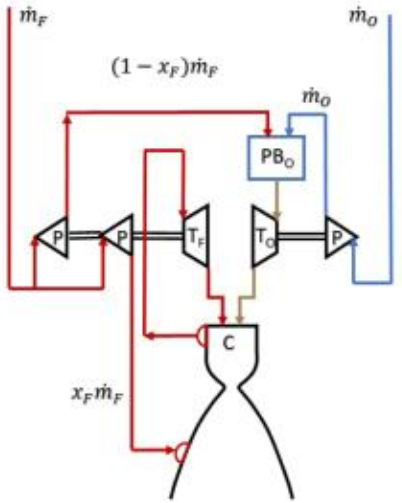
USA China Europe

Methanization: Pumping Cycle Options

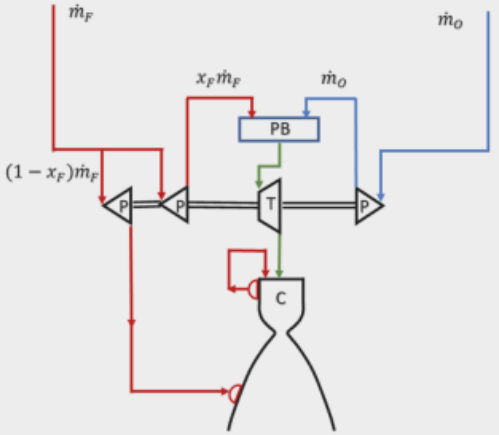
Prometheus
Gas
Generator
1000 kN



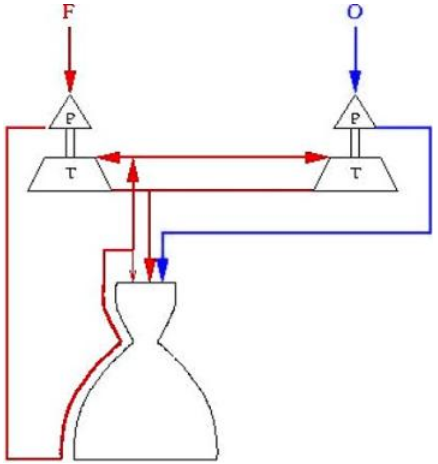
MR60
Full-flow
Hybrid
600 kN



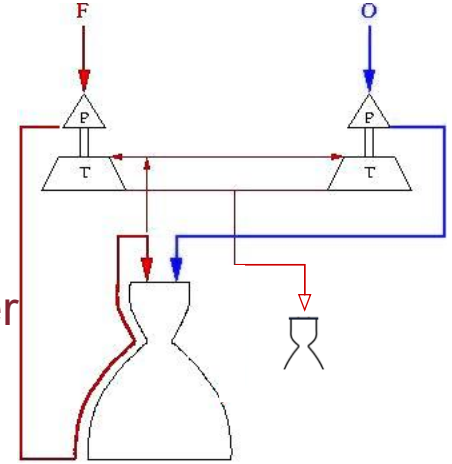
BE-4
Ox-Rich
Staged
2800 kN



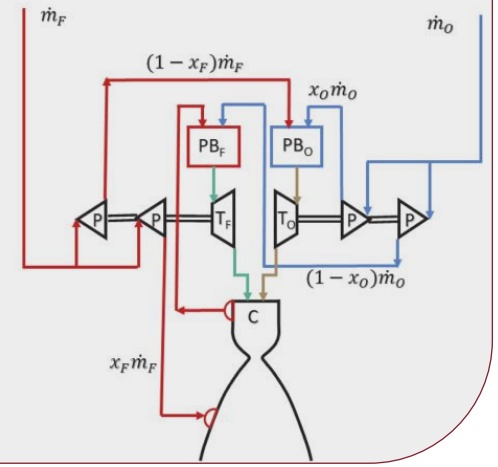
MR10
Closed
Expander
100 kN



Lumen
Expander
Bleed
25 kN



Raptor
Full-flow
Staged
2700 kN



Additive Manufacturing in Rocket Engines

International milestones

2014 — **SpaceX SuperDraco**
Inconel
regeneratively cooled chamber printed by DMLS; qualified May 2014

2014 — **SpaceX Merlin 1D**
alloy n/d
printed main oxidizer valve body flies (Falcon 9, Jan 2014): 2 days vs months of casting

2014→ — **NASA (LCUSP, RAMPT)**
Copper
GRCop copper alloys printed by laser powder bed fusion; >16,000 s of hot fire

2017 — **Rocket Lab Rutherford**
alloy n/d
chamber, injector, pumps and valves all printed; reaches space May 2017; 1,000 engines by 2026

2023 — **Relativity Terran 1**
Copper
nine Aeon engines with GRCop-42 printed chambers (NASA alloy)

Europe milestones

2018 — **Avio MR10**
alloy n/d
subscale 3D-printed thrust chamber hot-fired in Colleferro

2020 — **Avio MR10**
alloy n/d
full-scale chamber in 2 printed parts: 19 firings, 450 s at NASA Marshall

2020 — **ArianeGroup / ESA (ETID)**
Copper
chamber in 3 parts: printed copper liner, cold-spray jacket, printed injector head; DLR P8

2021 — **ArianeGroup Prometheus**
alloy n/d
up to 70 % of the engine 3D-printed, combustion chamber entirely printed

Why

- Fewer parts and joints: manifolds, injectors, cooling channels in one piece
- Lead time: weeks instead of months
- Lower cost, faster design iterations
- New alloys: GRCop-42 copper, superalloys

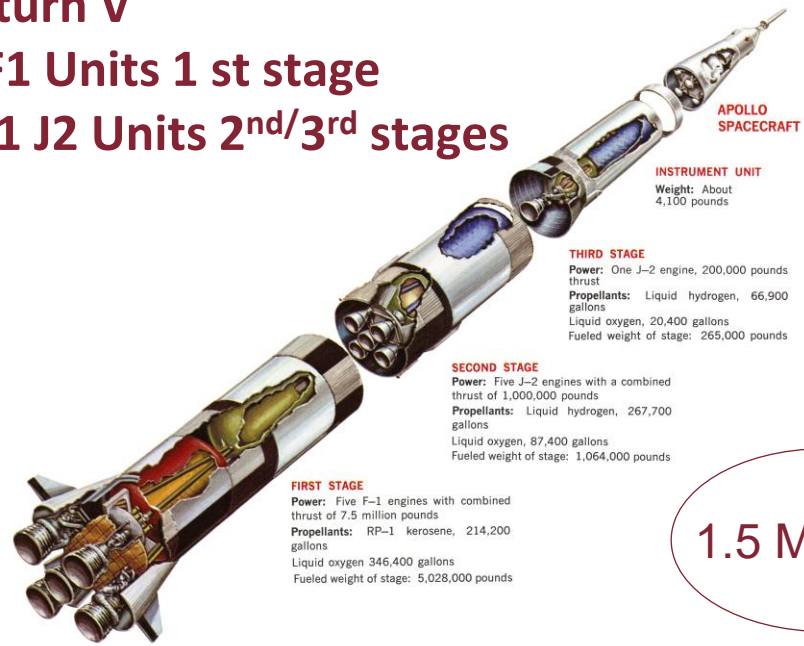
Challenges

- Surface roughness in cooling channels (pressure drop, heat transfer)
- Porosity, residual stress, anisotropy
- Powder removal, CT inspection, qualification
- Printer size limits (directed energy deposition for large nozzles)

Clustering: Should liquid rocket engines exploit it?

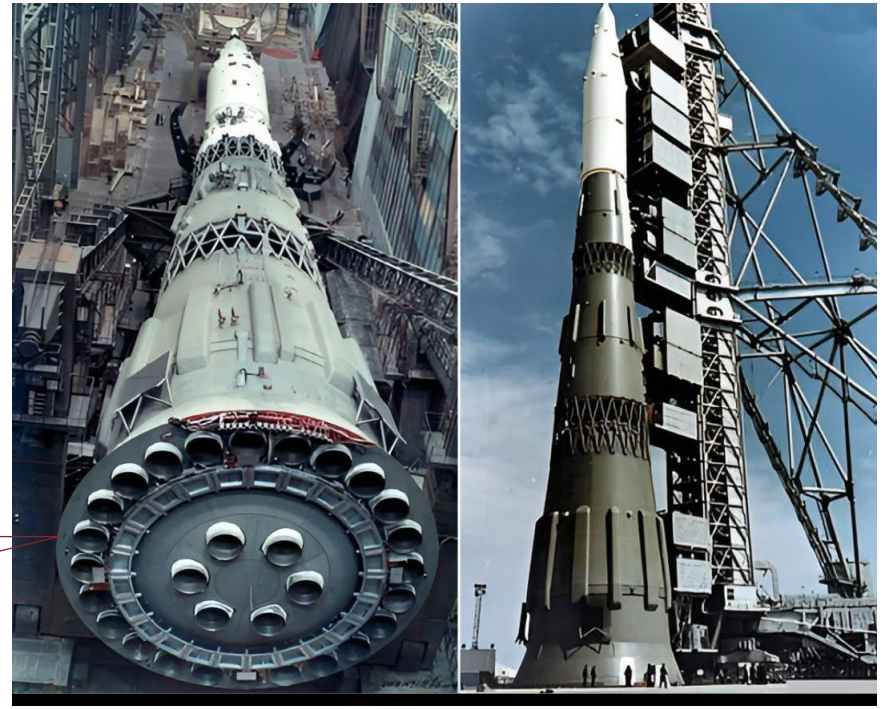
- The Soviet Union engine clustering approach
  - Clustering vs intensive clustering

Saturn V
5 F1 Units 1 st stage
5+1 J2 Units 2nd/3rd stages



7 MN each

N1
30+8 NK-15 Units 1st/2nd stages
4 Units 3rd stage



1.5 MN each

Image credits: NASA (left); RKK Energia archive, colorized (right)

Clustering of Engines

High thrust levels difficult to achieve with a single engine: you can consider few large or more small engines. Recent history:

- Western approach (Titan, STS, SLS in USA; Ariane 5-6 in Europe, H2 in Japan):
  - Liftoff high thrust levels are optimized using solid rocket boosters
- Eastern approach (no changes in the traditional approach):
  - Smaller units
  - Easier test
  - Production rate
  - Use in different stages



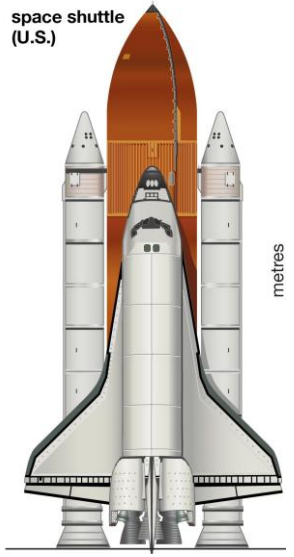


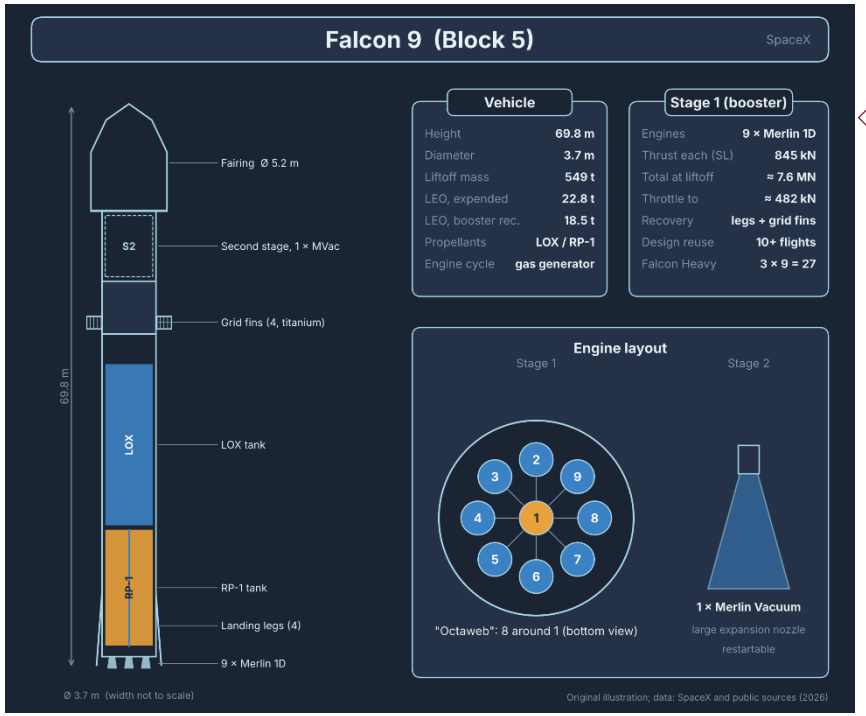




Image credits: NASA/ESA

Recovery and Reuse: SpaceX Reusable Launch Vehicles

- Back to Saturn V and especially N-1 to get throttling and reuse



Falcon 9
9(27)+1 Merlin Units
1st/2nd stages

Starship
33+6 Raptor Units
1st/2nd stages

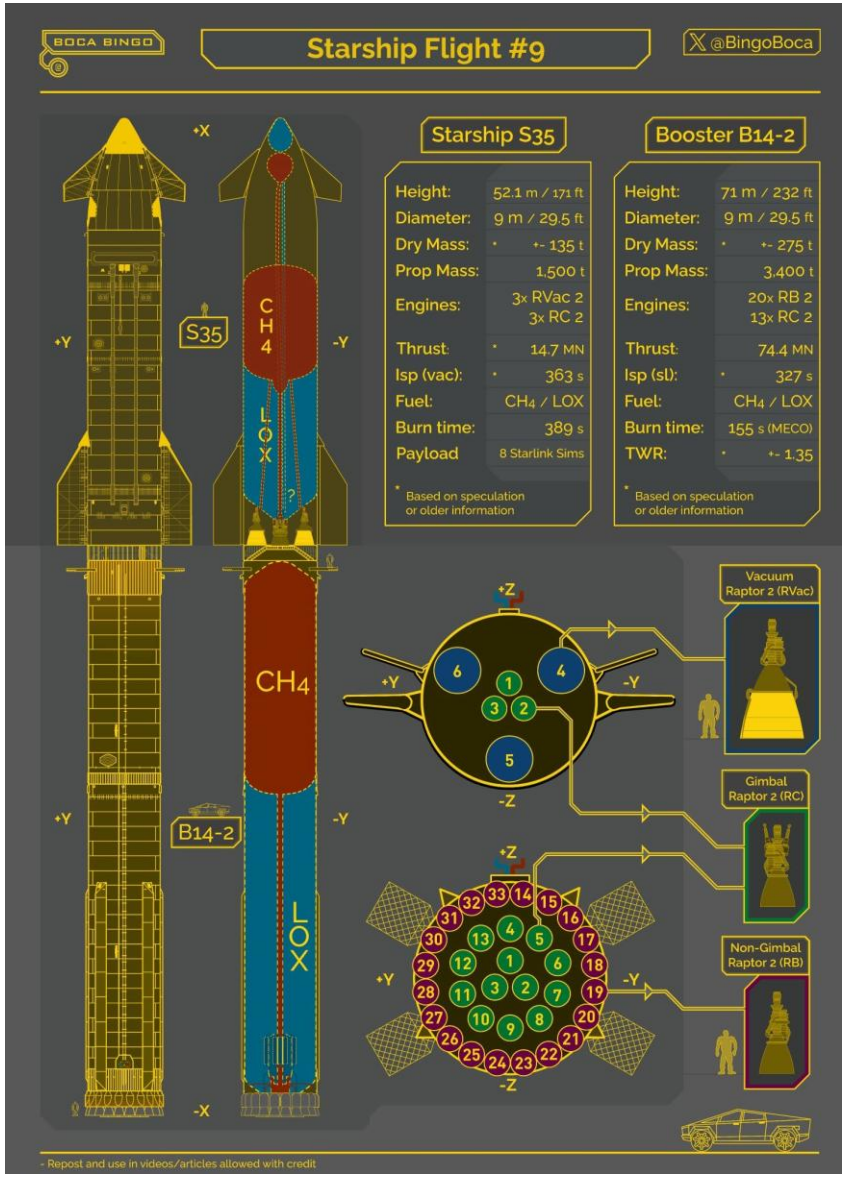


Illustration: AI generated

Credit: Boca Bingo (@BingoBoca)

ESA's Launchers Engine Developments

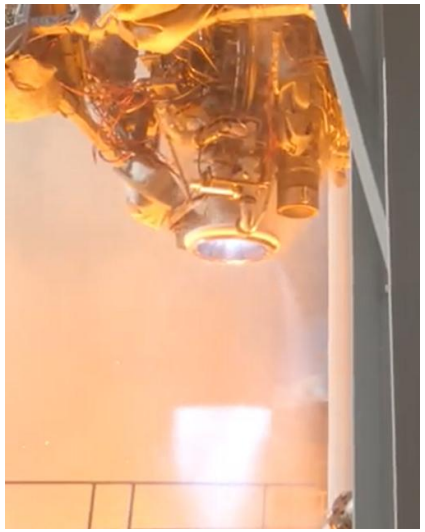
- Methane fuel (Prometheus, MR10)
- Reuse (Prometheus)
- …cost

- Pump-fed system evolution (MR10)
- Manufacturing (Prometheus, MR10)



MR10 / M10 — Avio / Vega-E

LOX/LCH_4
expander cycle
~98 kN
upper stage



Prometheus — ArianeGroup / ESA

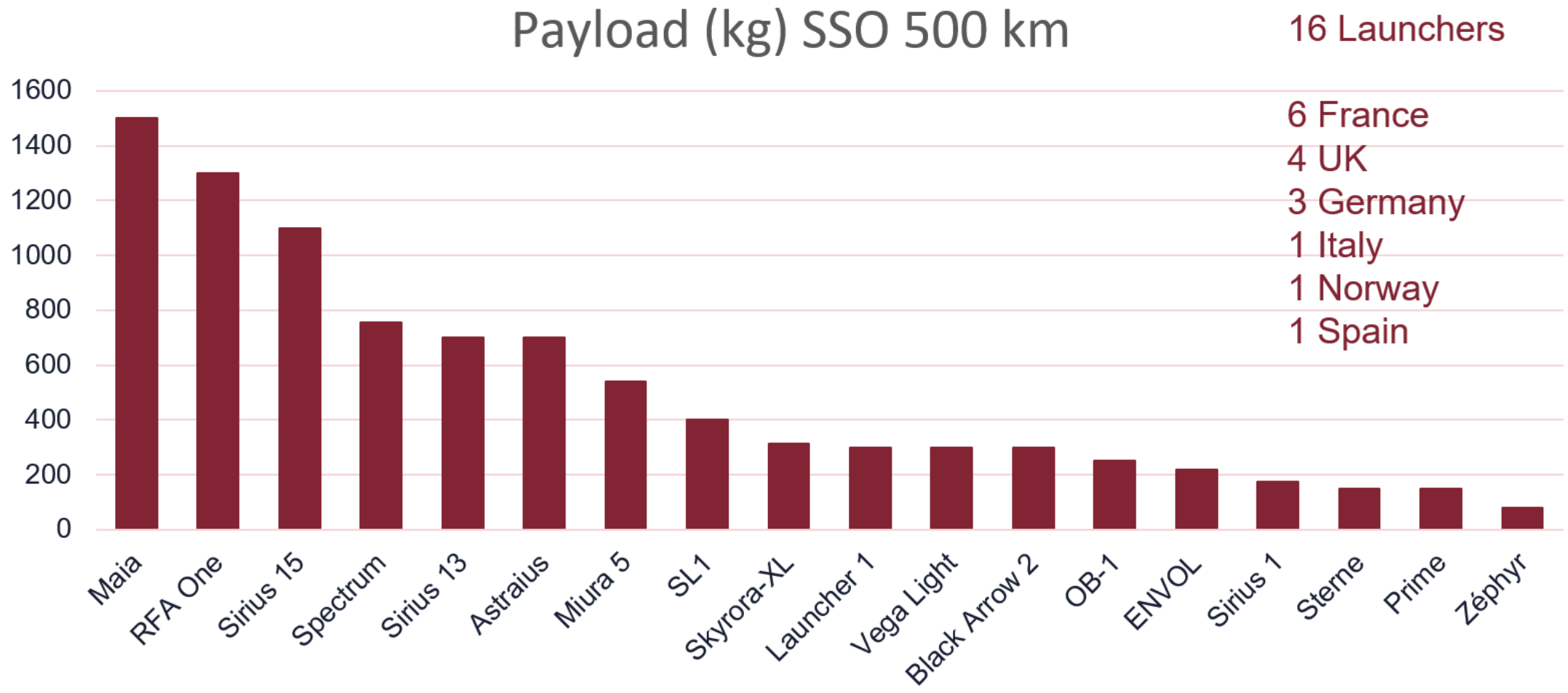
LOX/CH_4
gas-generator cycle
~1 MN
reusable first-stage technology



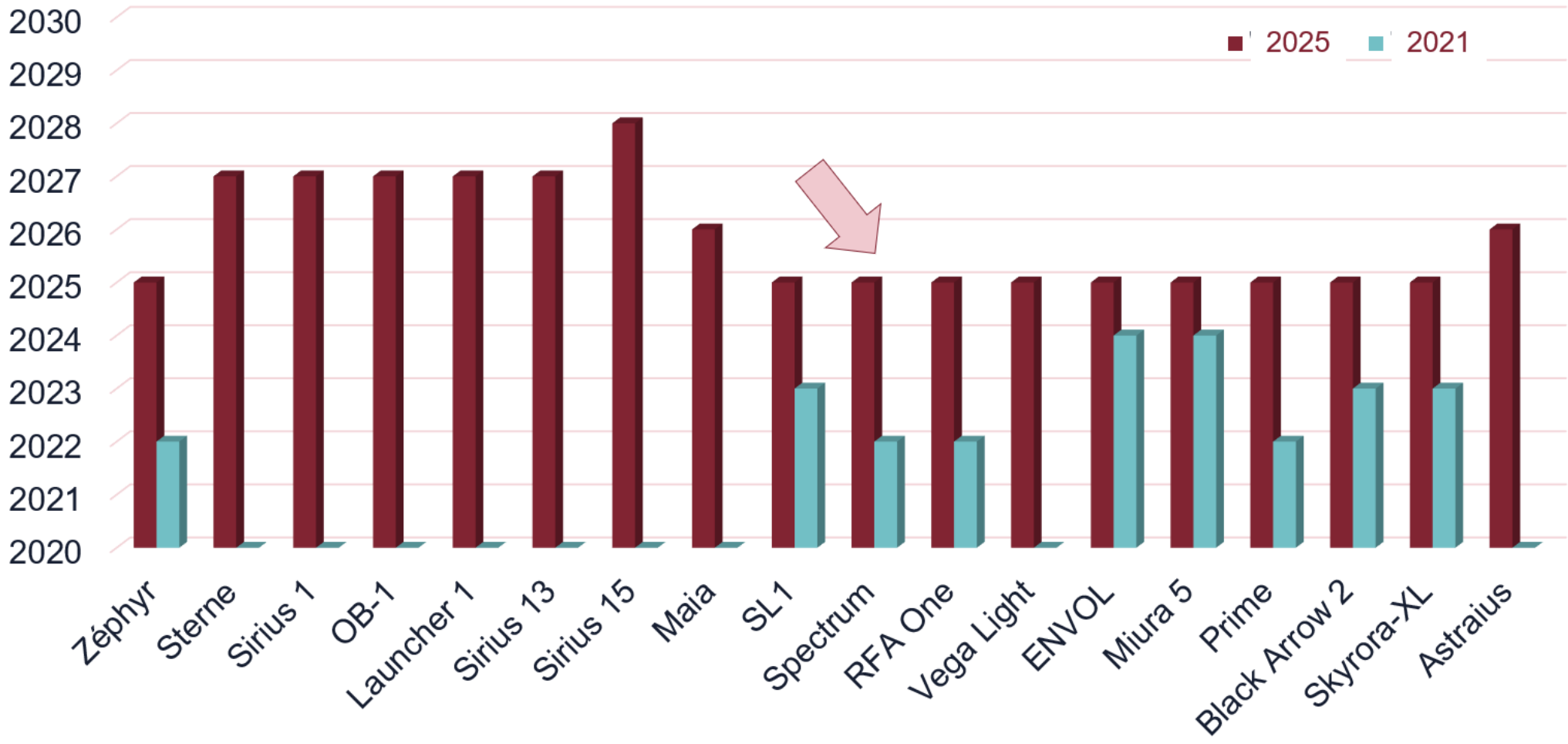
Ground-tested and undergoing advanced integrated system testing, with Themis having reached cryogenic wet-dress rehearsal and moving toward its first hop flight.

Image credits: Avio (left); ArianeGroup/ESA (centre); SSC Space – M. Forsberg/ESA (right)

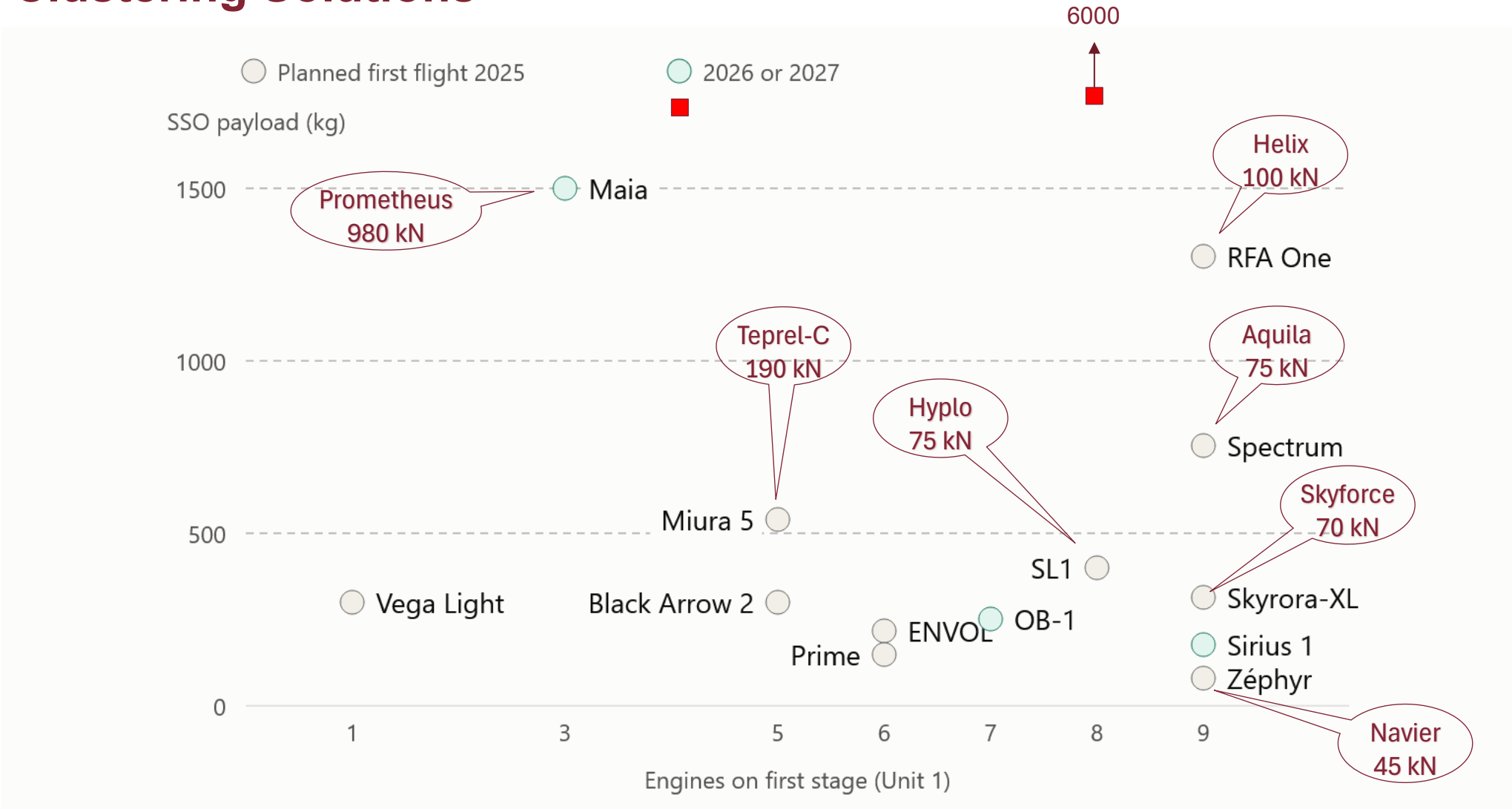
National and Commercial Launcher Developments in Europe (all except ESA's Ariane and VEGA)



First Launch Date



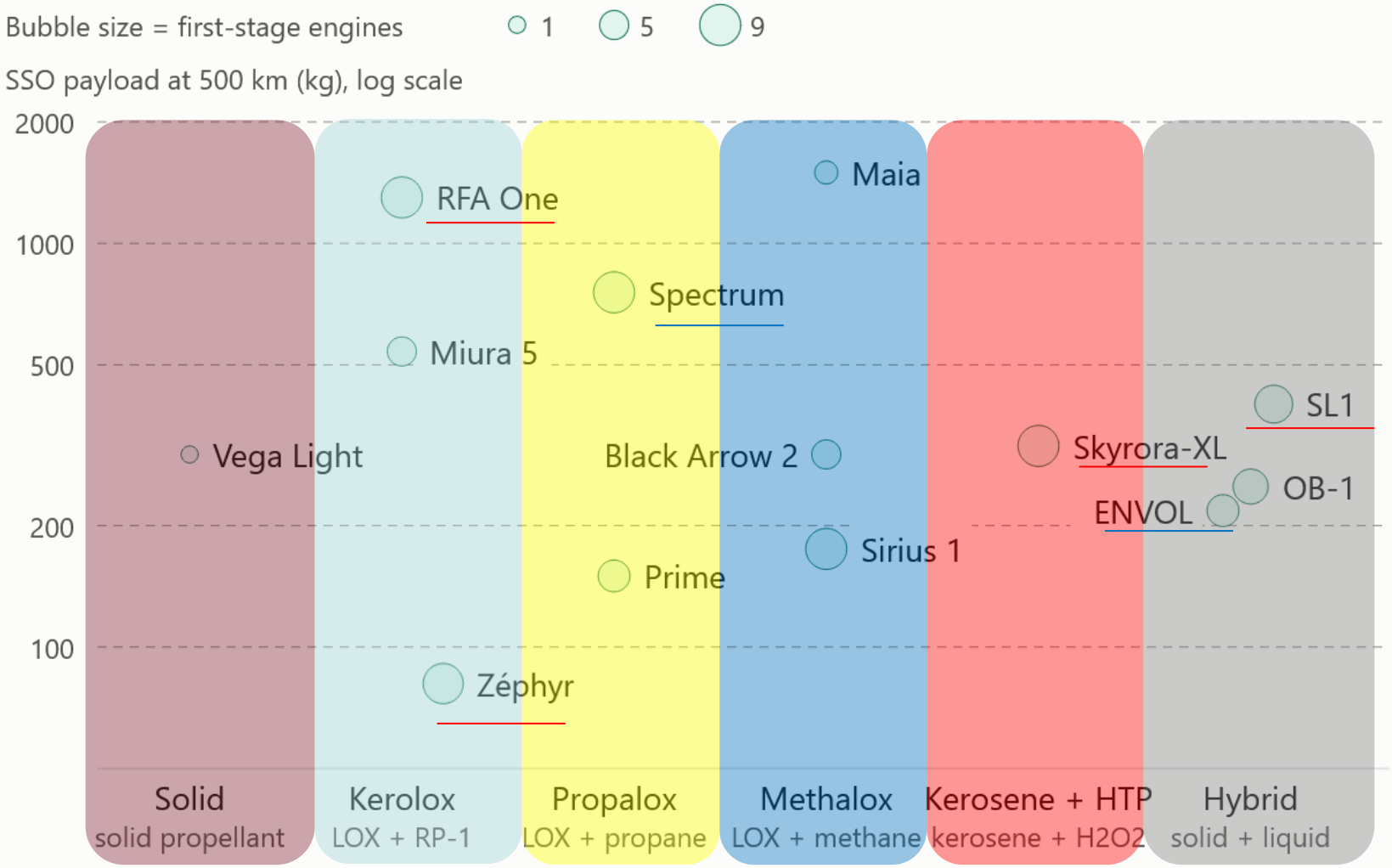
Clustering Solutions



Propellant Solutions

Andoya (Norway)

Saxavord (Scotland)



European Small-Launcher Engines at a Glance

Engine	Propellants	Cycle	Thrust	pc	Engines 1st + 2nd	Recovery	What is new
Prometheus Maia · MaiaSpace (FR)	LOX / CH_4	Gas generator	980 kN	100 bar	3 + 1	Landing on barge	Reusable European methalox, 30–110 % throttle
Aquila Spectrum · Isar (DE)	LOX / propane	Gas generator	75 kN	80–90 bar	9 + 1		First propane-fuelled rocket in orbit (Sep 2026)
Helix RFA One · RFA (DE)	LOX / RP-1	Ox-rich staged comb.	100 kN	n/d	9 + 1		First European ox-rich staged combustion
TEPREL-C Miura 5 · PLD Space (ES)	LOX / RP-1	Gas generator	190 kN	80–90 bar	5 + 1	Parachute + splashdown	First-stage recovery at sea
Skyforce Skyrora XL · Skyrora (UK)	HTP / kerosene	HTP-driven ox-rich SC	70 kN	n/d	9 + 1		Fully storable, no cryogenics
HyPLOX75 SL1 · HyImpulse (DE)	LOX / paraffin	Hybrid	75 kN	60 bar	8 + 4		Hybrid: throttling and re-ignition

Cycle · Propellant · Storable · Hybrid · Recovery

Sea-level thrust; pc = chamber pressure, company data where available (n/d = not disclosed)

What Each Engine Brings



Prometheus Maia · MaiaSpace (FR)

Reusable European methalox, 30–110 % throttle

LOX / CH_4 · Gas generator · 980 kN



Aquila Spectrum · Isar (DE)

First propane-fuelled rocket in orbit (Sep 2026)

LOX / propane · Gas generator · 75 kN



Helix RFA One · RFA (DE)

First European ox-rich staged combustion

LOX / RP-1 · Ox-rich staged comb. · 100 kN



TEPREL-C Miura 5 · PLD Space (ES)

First-stage recovery at sea

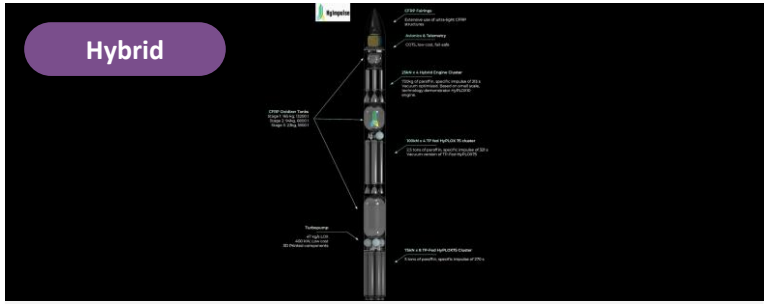
LOX / RP-1 · Gas generator · 190 kN



Skyforce Skyrora XL · Skyrora (UK)

Fully storable, no cryogenics

HTP / kerosene · HTP-driven ox-rich SC · 70 kN



HyPLOX75 SL1 · HyImpulse (DE)

Hybrid: throttling and re-ignition

LOX / paraffin · Hybrid · 75 kN

Image credits: ArianeGroup/ESA, Isar Aerospace, RFA, PLD Space, Skyrora, HyImpulse

Concluding Remarks

1 Europe needs more launches
First answer: raise the cadence of the ESA launchers (Ariane 6, Vega-C)

2 That will not be enough
Commercial small launchers will help meet defence, market and strategic needs

3 Small launchers are the testbed
Mostly private funding, new technologies and management: ideas to scale up to larger launchers

Remarkable technologies under development

Engine cycles

- **Ox-rich staged combustion** *Helix*
- **HTP monoprop. staged combustion** *Skyforce*
- **Methalox expander cycle** *MR10*

Propellants

- **Propalox** *Aquila*
- **HTP oxidizer, fully storable** *Skyforce*

Manufacturing

- **3D printing** *Prometheus, MR10, Helix…*
- **Composite cases / tanks** *Spectrum, SL1*

Recovery & reuse

- **Vertical landing on a barge** *Maia*
- **Parachute + splashdown** *Miura 5*

Europe is not starting from scratch – Progress must build on existing expertise

Acknowledgements



EASN european aerospace science network

AAE Academie de l'Air et de l'Espace – Air and Space Academy

Sapienza Università di Roma

Invitation

