Jean-Marc ASTORG - CNES/DLA

CNES FUTURE LAUNCHER ROADMAP

LA SAPIENZA – May 7th, 2019

cnes
CENTRE NATIONAL D'ETUDES SPATIALES

Content

Introduction: today's European Launchers

Coming soon : Ariane 6 & Vega-C

Global context & competition

CNES future launchers preparation roadmap

Conclusion

INTRODUCTION

The CNES invents the launchers of tomorrow

The European launcher fleet

3 systems, 3 missions

Vega

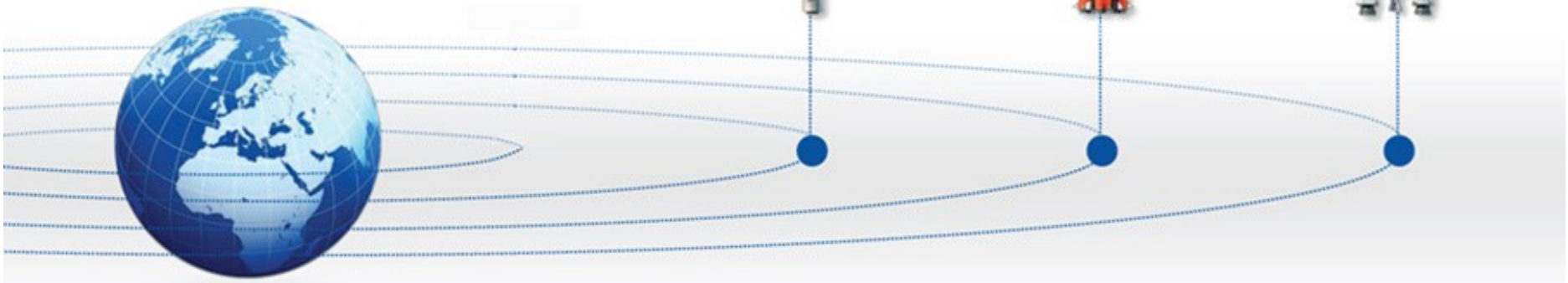
Launches small satellites up to 1.5 t into low or polar orbits

Soyuz
at the CSG

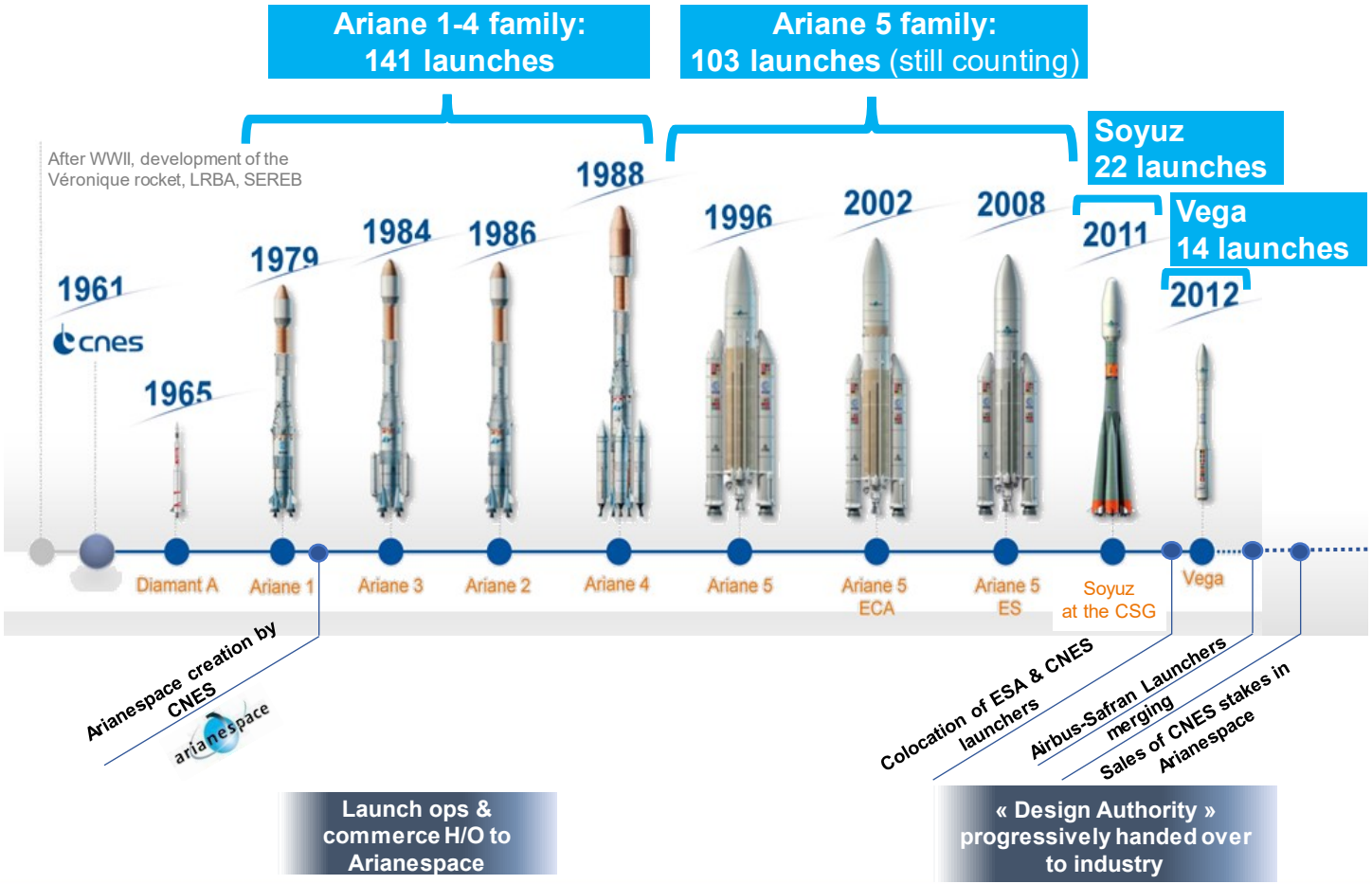
Launches intermediate payloads from 3t into GTO to 4.5 t into SSO

Ariane 5 ECA

Launches heavy payloads up to 10.8 t into GTO



European Space Transportation since 1961



2019 : a busy year

UPDATE: 04/25/2019 (Scale of launchers not respected)

	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
ARIANE 5 **5**		A5ECA 5 HELLASAT-4 GSAT-31 VA247				A5ECA 20 T16 EUTELSAT-7C VA248	A5ECA 24 INTELSAT-39 EDRS-C VA249			A5ECA GOV EGYPT GSAT-30 VA250		A5ECA 17 BB4A or GSAT-30 GX5 VA251
SOYUZ **3**		27 ONEWEB VS21		4 O3B-F5 VS22						15 COSMOS CHEOPS VS23		
VEGA **4**			21 FALCON EYE VV14				4 FALCON EYE-1 VV15		POC SSMS VV16		FALCON EYE-2 VV17	

3 = launch cadence/year

3 very different launchers

ARIANE 5

103 launches
89 success in a row

Net performance
10 t GTO

5 launches in 2019

SOYUZ

In French Guiana
22 launches
4,9 t SSO
1,62 t MEO

3 launches in 2019

VEGA

14 launches and success in a row
1.5 t PEO

4 launches in 2019

CSG : a key asset of the European independent Access to Space

An exceptional location

- Closeness to Equator
- Extensive launch possibilities
- Hurricane free area

Europe's spaceport for European launchers

1968

Véronique first launch

1970

Diamant first launch

1975

ESA-France agreement

1988

Ariane 4 first launch

1996

Ariane 5 first launch

2011

Soyuz first launch in Guiana

2012

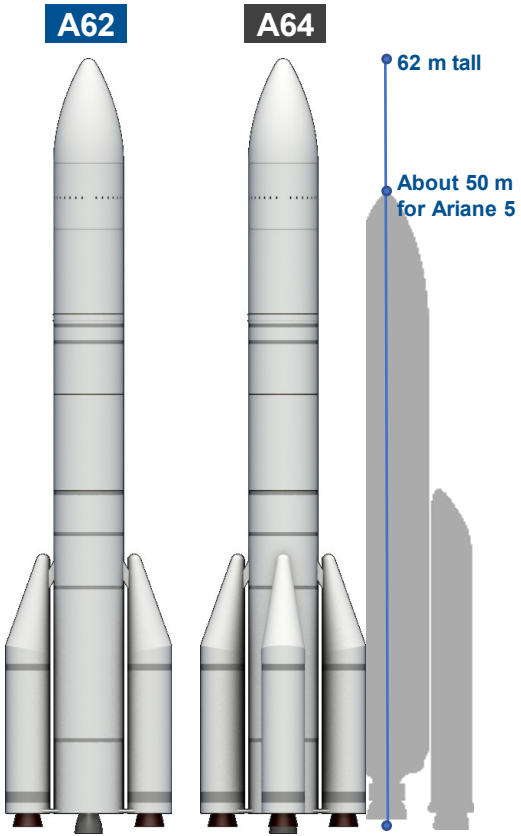
Vega first launch

ARIANE 6

&

VEGA-C

Ariane 6 main characteristics



Composition

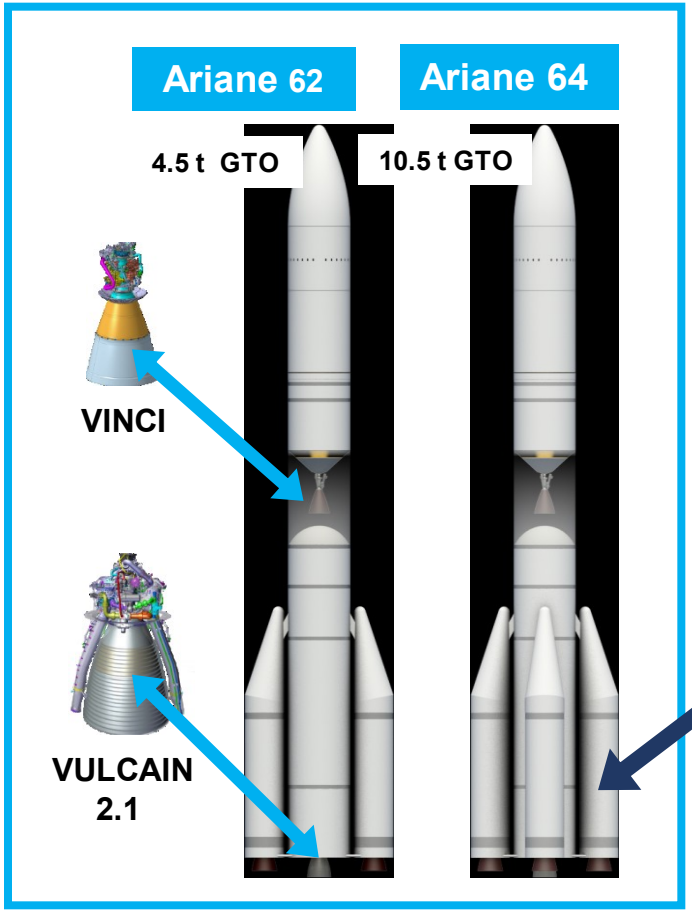
- P120C boosters including fuel: 141 t
- 1st stage: VULCAIN 2.1
- 2nd stage: VINCI
- Upper part: out of Autoclave fairing

	A62			A64
	GTO (Zp=250 km)	SSO	MEO	GTO (Zp=180 km)
HLRs	≥ 4.5 t net	≥ 4.5 t net	1.7 t	≥ 10.5 t

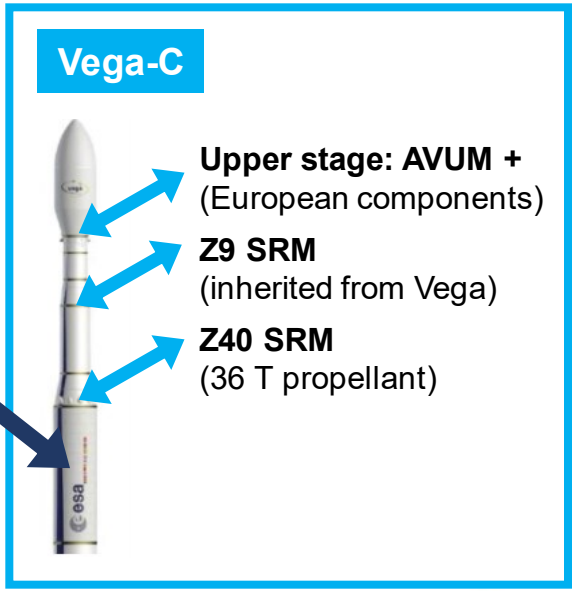
Maiden launch: 2020

Fully operational: 2023

P120C: the Ariane 6 & Vega-C common engine



P120C solid propellant booster



Ariane 6 Cost reductions

ARIANE 5

DESIGN FOR MANUFACTURING

INNOVATION

CADENCE

A62 A64

= 50% COST REDUCTION

6 launches/year
~20 k$/kg GTO

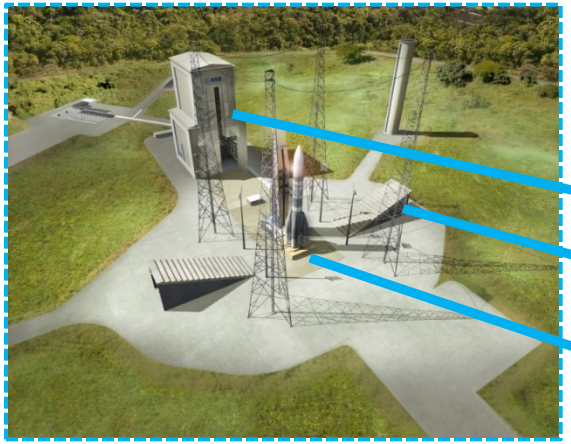
9 launches/year
~10 k$/kg GTO

ELA 4 recurring cost optimization

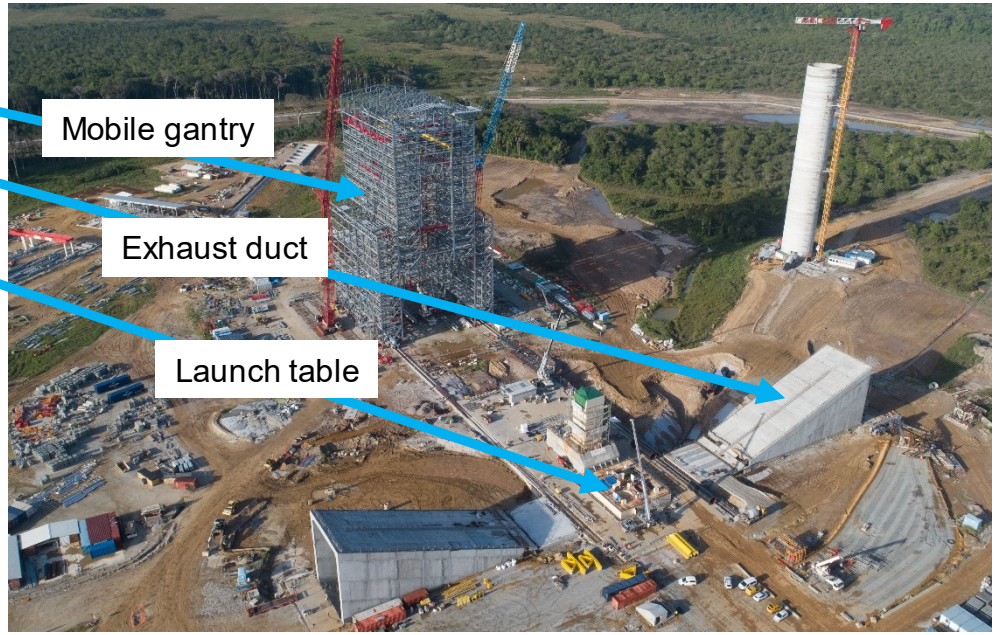
	ELA3	ELA4
Buildings	3	**2**
Launch rate (launches/year)	7 to 8	**9**
Integration	vertical	**horizontal**
Campaign duration	30 days	**15 days**
Revalidation duration	10 days	**5 days**
Air conditioning	All buildings	**As needed**

= 50% COST REDUCTION

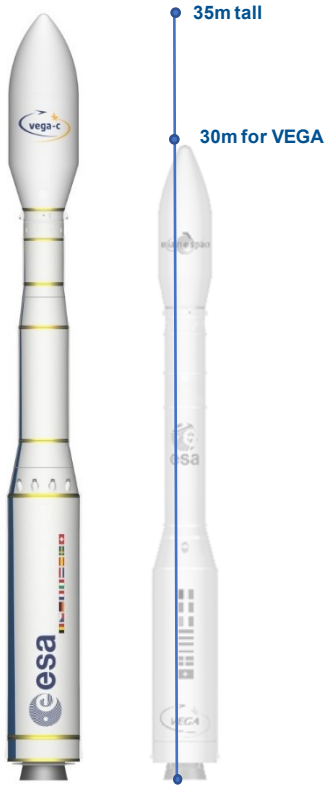
Ariane 6 launch pad (ELA4) & mobile gantry achievements



STATUS: BEGINNING 2019



Vega-C main characteristics



Composition

- P120C SRM (142 t propellant)
- Z40 SRM (36 t propellant)
- Z9 SRM (inherited from Vega)
- Upper stage: AVUM + (European components)

210 tonnes at lift-off

Performance

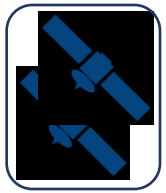
	VEGA-C	
	PEO (unconstrained)	SSO
MRD	> 2.4 t	> 2.0 t

Maiden launch: early 2020

Planned launch rate: 3 - 4

Vega-C targeted for institutional missions

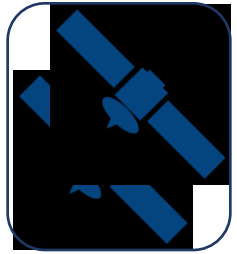
VEGA



Strong gain of performance

Fit for institutional missions

VEGA-C



2-3 launches/year

3-4 launches/year
Goal < 35 M€ per launch

GLOBAL CONTEXT

&

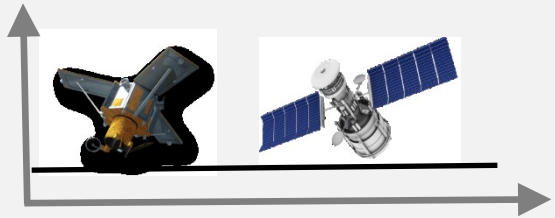
COMPETITION

Prospective look into next decade: commercial space evolution/revolution?

INSTITUTIONAL EUROPEAN MISSIONS

today → tomorrow

➡ A stable deman for the number of classical satellites



COMMERCIAL SPACE

20-2 per ye

today → tomorrow

COMMERCIAL SPACE

??? per ye

Global space services

Smallspace boom ?

Tourism/private infra ?

Orbital services ?

HTS/Obs in LEO / constel for > 10s of Tb/s ?

HTS in GEO > 2 Tb/s !

The current context

A fierce competition ahead

+ OMEGA NGIS NSSLV class vehicle NEW

NEW GLENN NEW
~ 7 to 13.6 t GTO
~ 50 M$ to 90 M$

Falcon 9 ✓
~ 3.5T to 8.3T GTO
~ 62 M$ to 85 M$

Falcon Heavy ✓
~ 8 to 26,7 T GTO
~85 M$ to 130M$

VULCAN NEW
~ 7 to 13 t GTO
~ 100 M$ to 200 M$

ARIANE 6 NEW
~ 3 to 10.5T GTO (dual launch)
~ Smart pricing ☺

PROTON ✓
6,3T GTO
~80-100 M$

GSLV Mk 3 ✓
~ 4-5 T GTO
~ 50-70 M$

ANGARA 5M NEW
~ 5 to 7T GTO
~ 70 M$ to100 M$

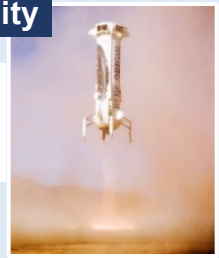
H-III NEW
~ 2 to 6 T GTO
~ 60 to 100 M$

CZ-5 NEW
~ 6 to 14 T GTO
launch price TBD

SPACEX

Reusability

BLUE ORIGIN



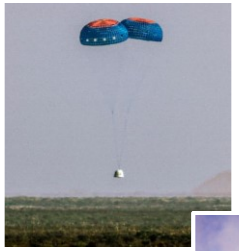
ULA

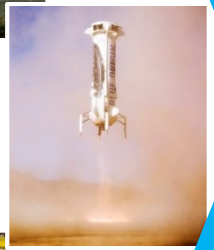
To remain competitive with new comers

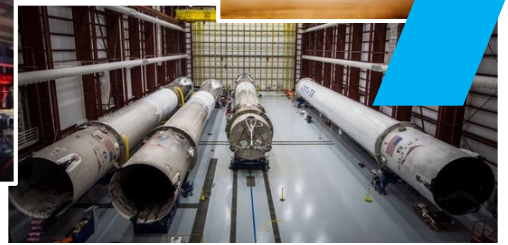
Private competitors jostle the whole sector

A NEW PARADIGM FOR THE LAUNCH SERVICES SECTOR:

- Reduced Supply chain
- Process Innovation
- Optimization of production facilities
- Simplicity in the design, cost oriented technologies choices
- spiral method and rapid prototyping







REUSABILITY

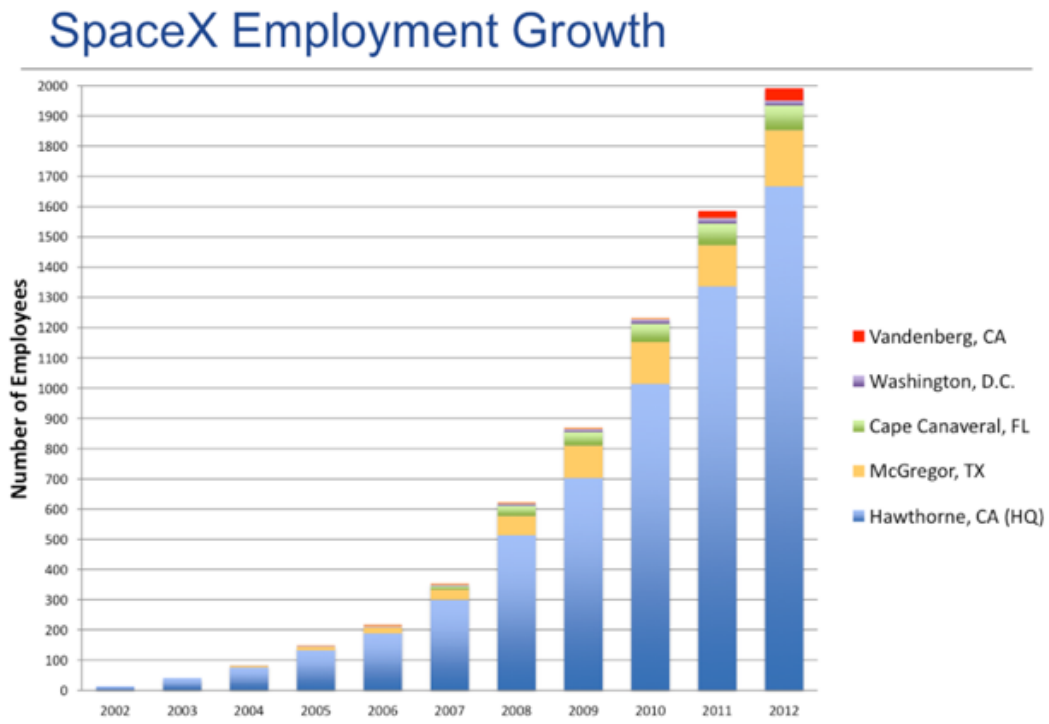
COST OPTIMIZATION

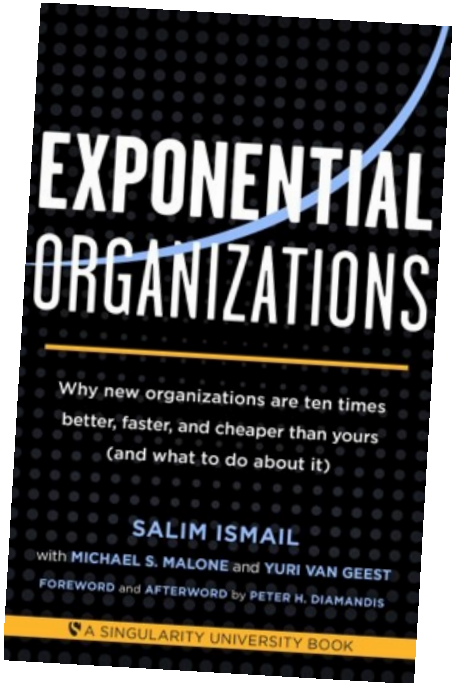
FAST DEVELOPMENT

MANNED FLIGHT

➡ A culture of cost awareness at all company levels
➡ Focus on technical and economic optimization of the entire system

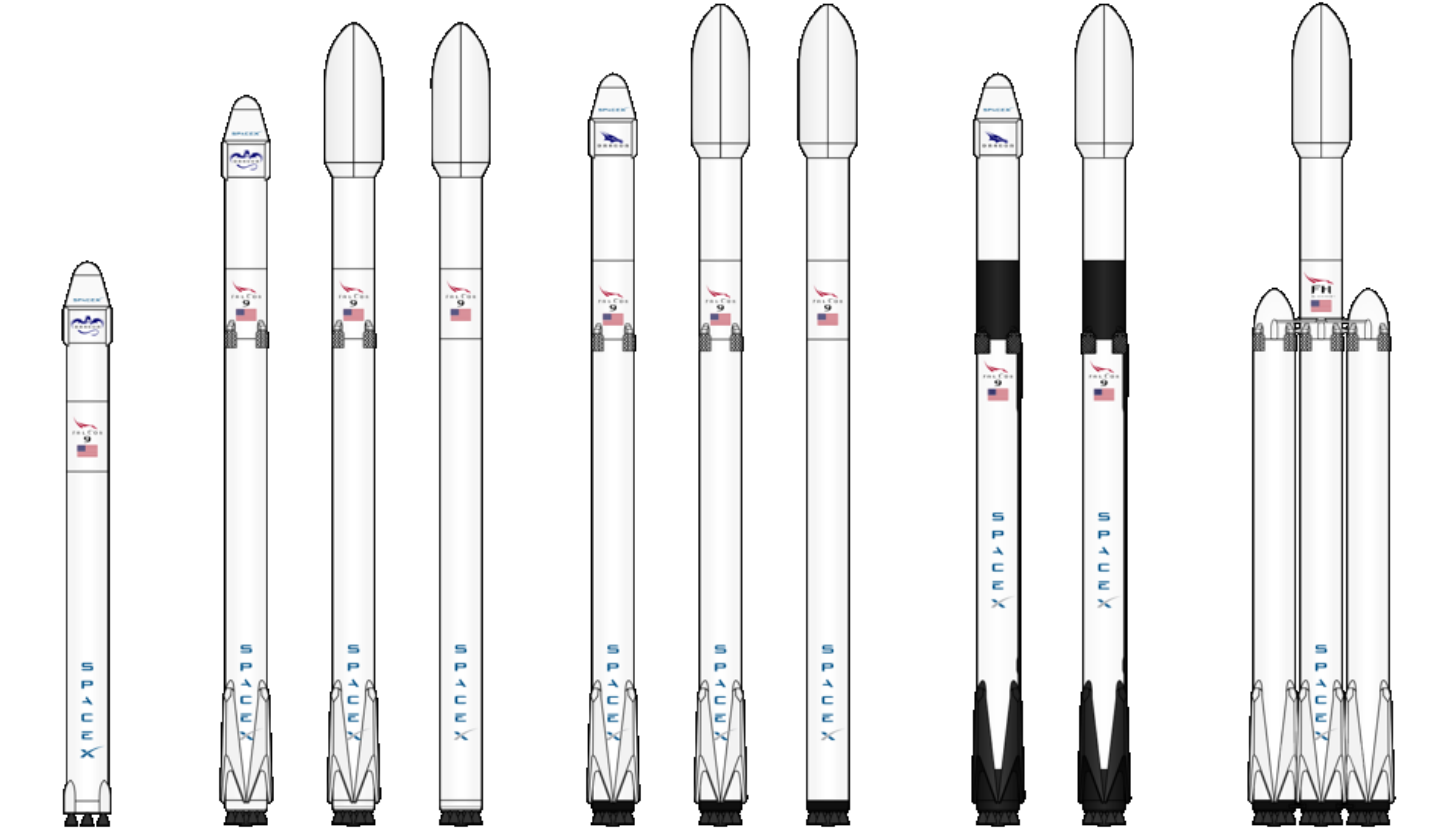
SpaceX: a typical Exponential Organization



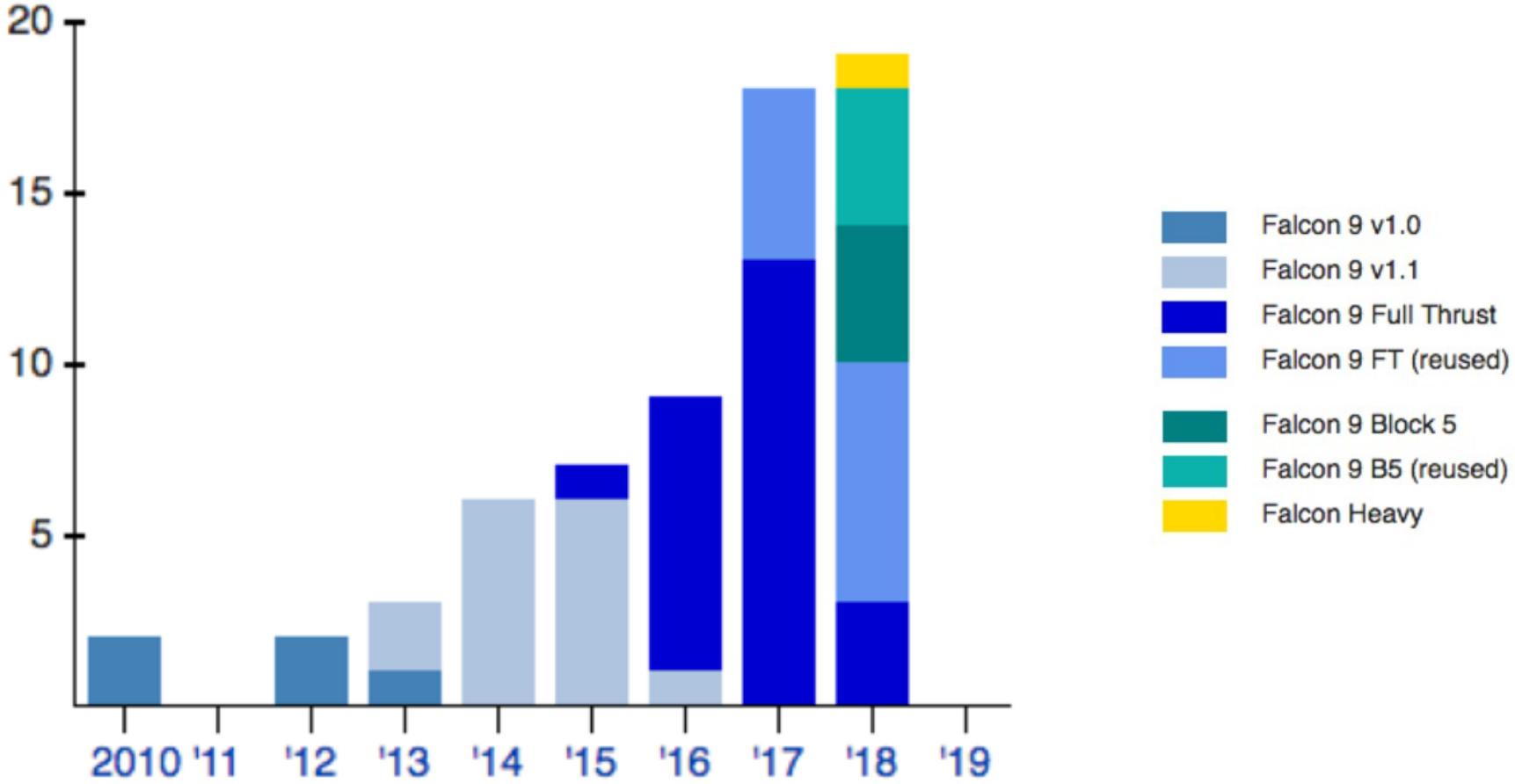


- SpaceX has been created in March 2002 by Elon Musk and had until 2017 exhibited an exponential growth of employees and revenues of the order of 40% per year. Since then growth has flattened and employment in March 2019 is about 6000 employees with a revenue which can be estimated around $2bn a year.
- It is a private company of which Elon Musk owns 50.5% at the beginning of 2019.

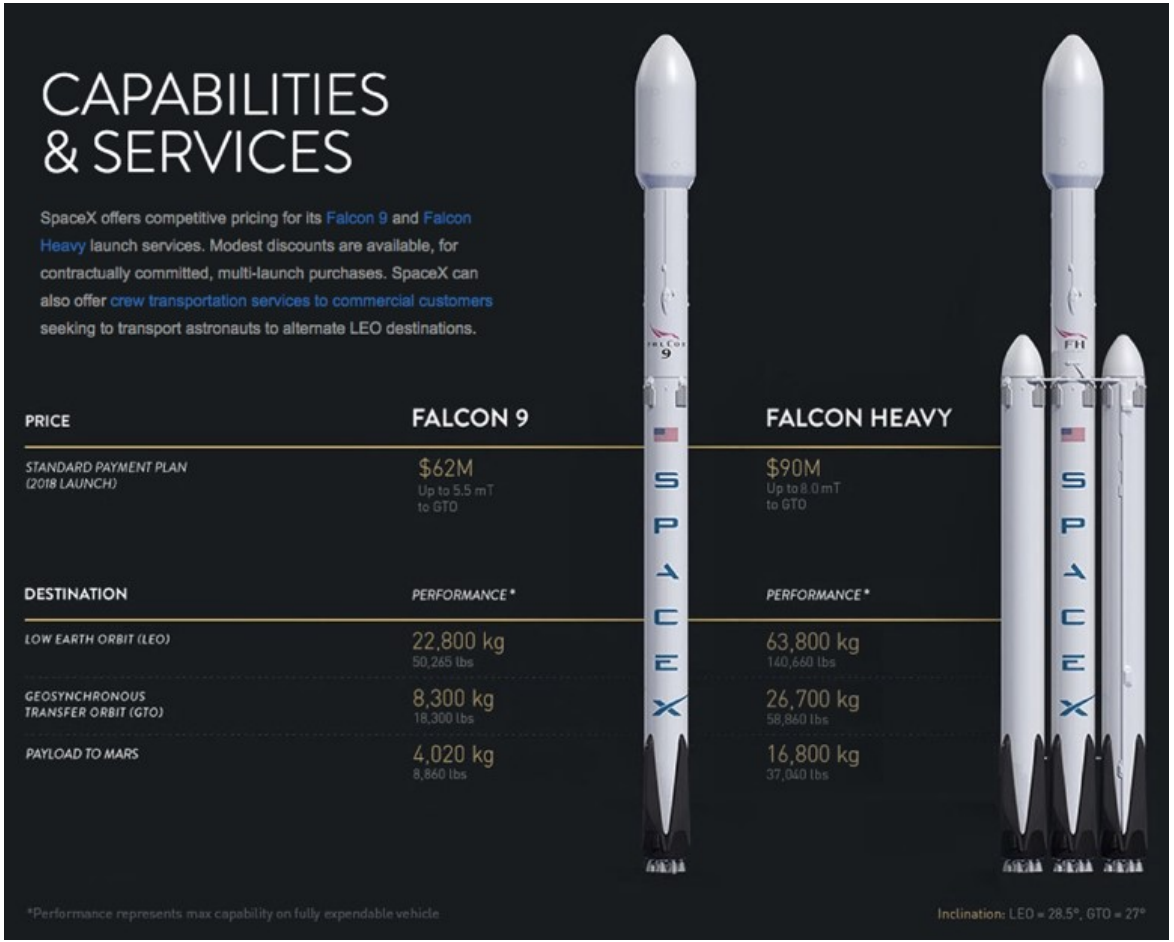
The Falcon launchers successive versions



Falcon 9 & Falcon Heavy launch history

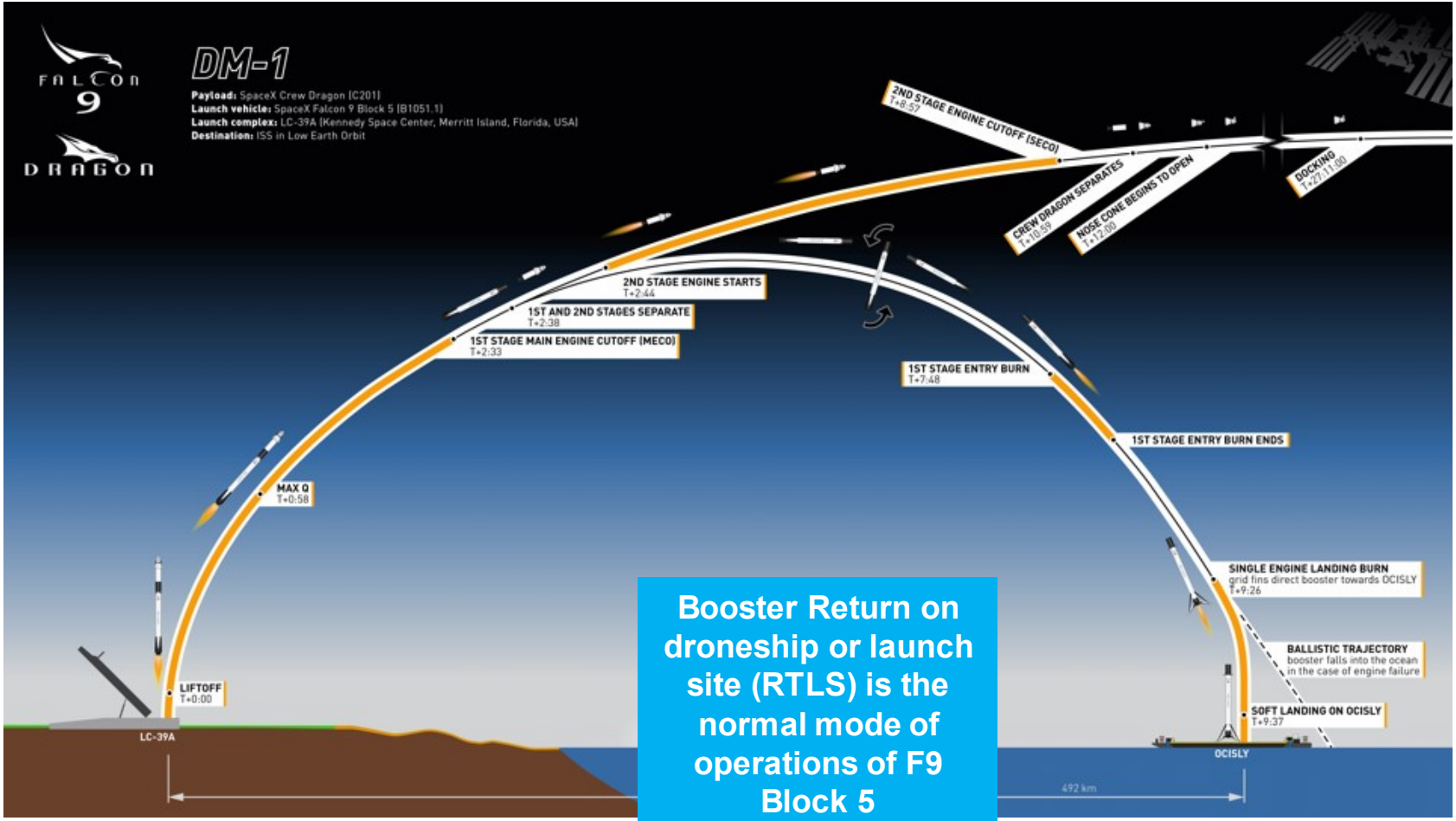


SpaceX current launchers performances and official prices



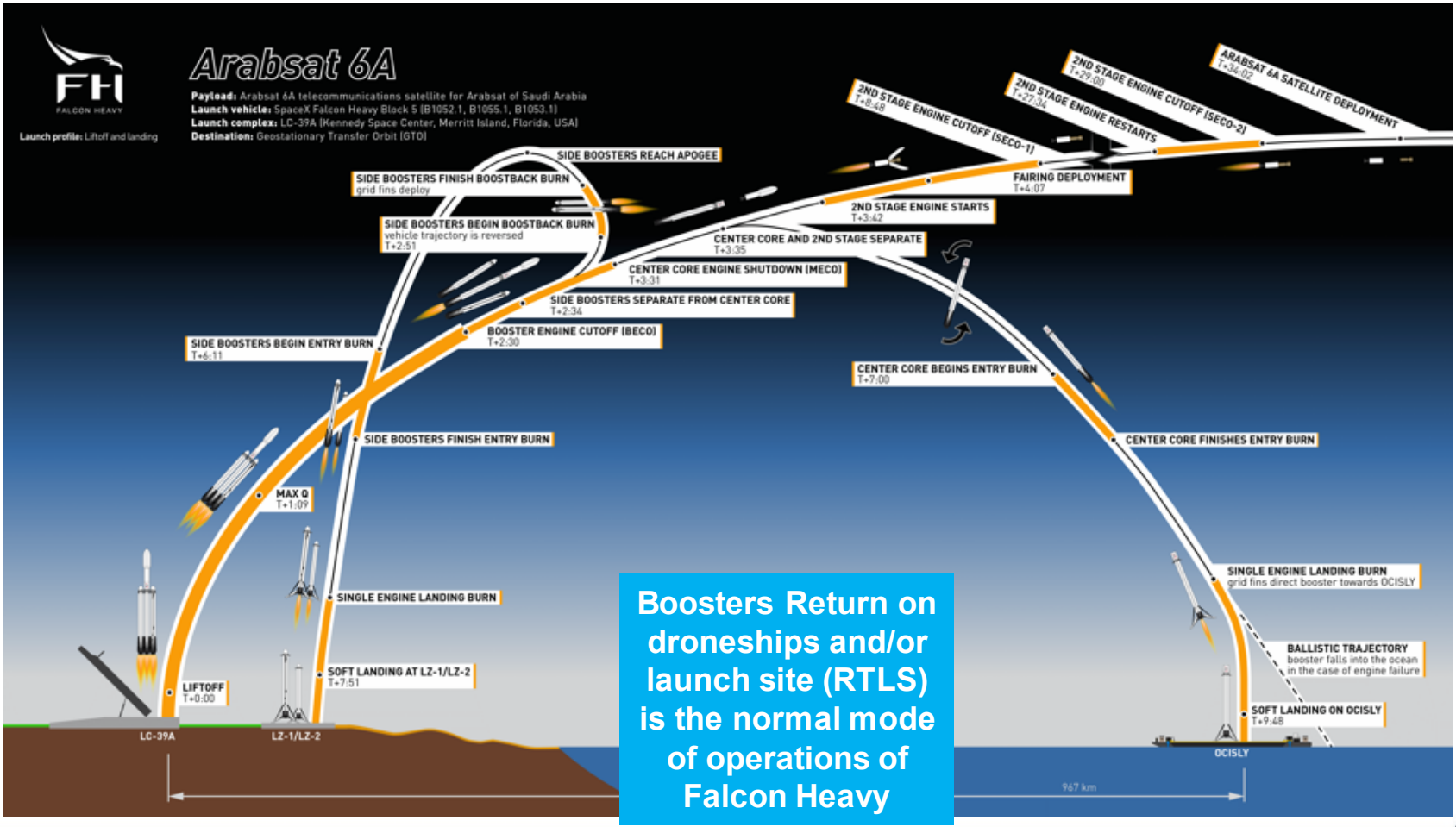
These performances are for use in expandable mode when the normal opearational mode is now boosters' return. The performance for the return and reuse mode in GTO 1500 of a F9 is 5.5 t only. Corresponding price seems to be $50m. Price for a full capacity FH seems to be $150m (performances assessed in following slides)

DM-1: typical F9 mission with Booster landing on DS



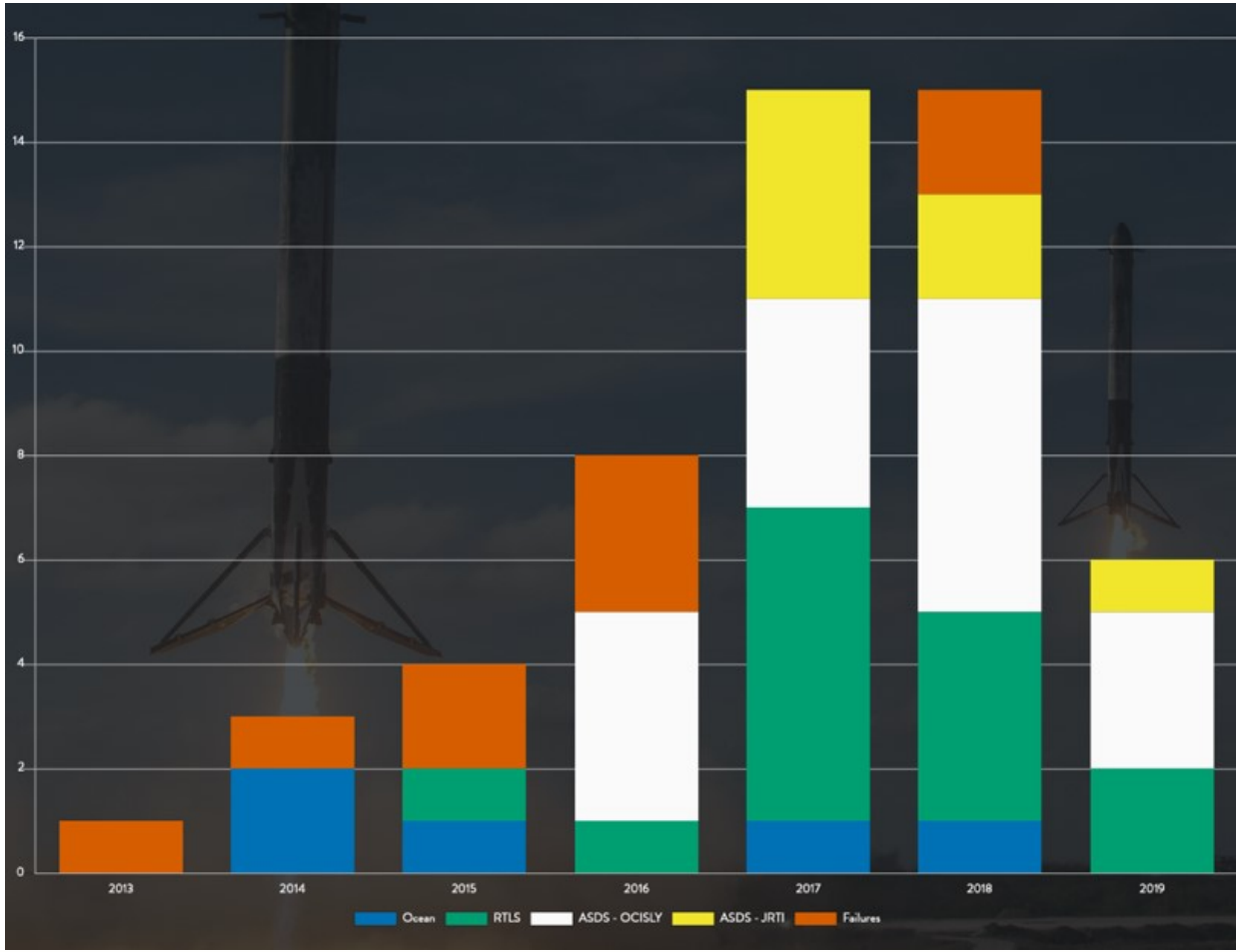
Booster Return on droneship or launch site (RTLS) is the normal mode of operations of F9 Block 5

Arabsat 6a: typical FH mission with Boosters RTLS



Boosters Return on droneships and/or launch site (RTLS) is the normal mode of operations of Falcon Heavy

SpaceX Booster Landing History (38 successful up to April 2019)



SpaceX: a bold strategy

SpaceX follows a bold strategy, leveraging public and commercial market opportunities to:

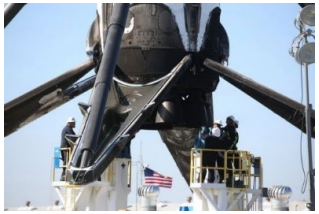
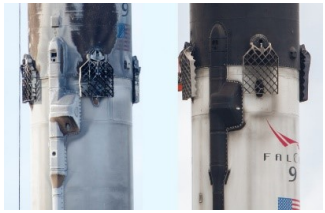
- Develop products in coherence with its own strategy, and adding, if possible, capabilities that are not strictly needed by the customers but are steps forward other more advanced products
- Work with high financial margins (typically in the 25-50 per cent range, which is unusual in the aerospace industry but not in the Silicon Valley - cf. Apple…but also Tesla Motors – another Elon Musk company, which works with 25 per cent margin)
- Reinvest all the profits in R&D and fund advanced development and new infrastructures

Globally the strategy of SpaceX could be summarized as:

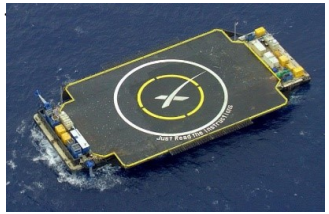
To develop reusable space transportation systems for automatic and human missions in the perspective of a strong growth of public and private space activities in the coming decades

Reusability costs

- Additional hardware(legs, fins, avionics, protections)

- Additional facilities & operations (landing site, drone ship, transport)barge et/ou site de récupération,



- Inspections means, storage



- propellants
- Losses in case of booster

Which refurbishments costs for reusability (Orbcom mission ex) ?

- Inspections
- HW change:
  - Aft bay thermal protection
  - 3 Merlin 1D engines
  - 30% of the tank equipments
  - 2 « landing legs »
  - Cabling &
- Refurbishment (cleaning & tests):
  - Propulsive system
  - Tank internal protection
  - Pressurization
  - Feed lines
  - Electrical equipments
- Ingineering & controls
- Final tests

Parametric estimation

A refursbished stage costs between 6% and 40% of a new one

Reusability pros and cons

Pros:

- 30% launch costs savings if the launcher is designed for reusability
- Flexibility to increase launch rate
- Less environment print

Cons:

- Big impact on performance (50% RTLS; 30% drone ship)
- Additional constraints and operations

To be assessed on the long term:

- Impact on reliability
- Capacity to reduced refurbishment costs

Jeff Bezos & Blue Origin => AMAZONED

Jeff Bezos is the fourth richest man on earth

Amazon stock market values reaches 1,000B$

Bezos wants to commercialize space activities

- **Space Tourism**
- **Launch commercialization**
- **Moon colonization**
- **Work and live in space**

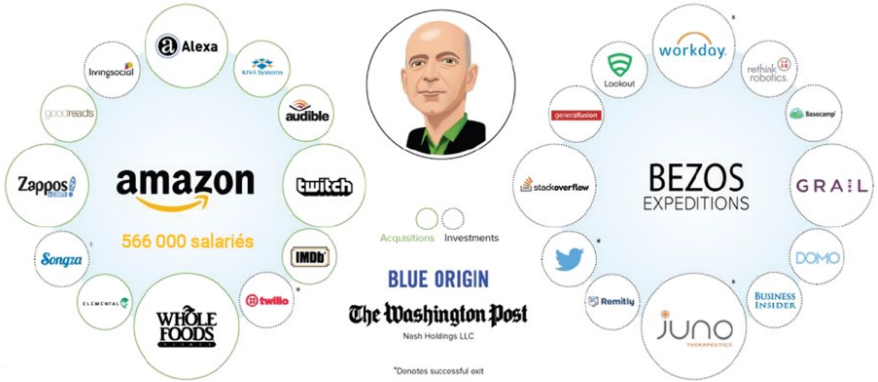
Blue Origin started in year 2000, more than **1500 employees today**

Wins numerous launch contracts (without any operational launcher!) and also get public funding

Amazon Web Services (AWS) currently hiring engineers for “big, audacious space project”: constellation

Announce of Kuiper Constellation, more than **3000 satellites to put into orbit with New Glenn**

Incredible powerful organisation, which wants to export amazon success to future space activities.



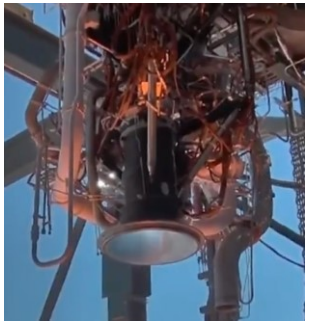
J. Bezos intends to inject 1B$ per year in Blue Origin during the first years, and then reach sustainable operations after ~ 5 launches

BLUE ORIGIN

Focus on Blue Origin: engines

Blue Origin Engine	BE-3	BE-3U	BE-4
Propellants	LOx/LH2	LOx/LH2	LOx/Methane (LNG)
Cycle	Tap-Off	Expander	Staged combustion
Thrust (kN)	490 (SL)	670 (Vacuum)	2 400 (SL)
Chamber pressure (kPa)	25 500		13 400
Life cycle	Reusable	Expandable	Reusable
Status	Operational	Under development	Qualification foreseen Q1 2019
Purpose	New Shepard	New Glenn Upper Stage (x2)	New Glenn & Vulcan First Stage (x7 & x2)

BLUE ORIGIN



Focus on Blue Origin: launch vehicles

NEW SHEPARD

10 Successful Flights

Space Tourism – Suborbital

1 Ticket ~200 000$

First commercial flight Q2-2019

NEW GLENN

First commercial flight 2021

Fairing 7m

- 1rst Stage reusable : 7x BE-4
- 2nd Stage : 2x BE-3U

PERFORMANCE (BO)

- 13 t @GTO
- 45 t @LEO

COSTS (not consolidated)

- 80M$, price 90M$
- Double launch GTO

Early contracts or agreements signed

eutelsat communications via satellite

OneWeb

mu Space Corp

SKY Perfect JSAT Holdings Inc.

Other Vehicles (project):

- Blue Moon: Lunar Lander
- New Amstrong: Super Heavy Launcher

Reusable / Diameter 15m

60 t on Cis-lunar Orbit

New ways of working

Blue Origin new launcher plant (Dec 2016)

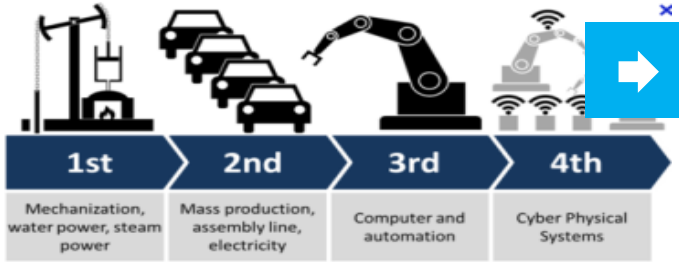
➡ Being reactive, working agile !

- New management & collaborative process
- Modular conception
- Launch flexibility

Falcon Transporter/Erector purchased for 37K$

➡ Frugal innovation and development

- Spin-in from other industry
- Quick prototyping (Additive Manufacturing)
- Development reduced from 10 to 5 years



➡ Digital revolution for rocketry !

- Industry 4.0
- Hardware empowered by software

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Main launchers coming on the market !









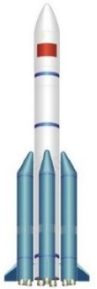
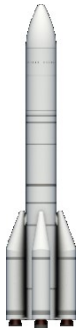
Launcher	New Glenn	Falcon 9	Falcon Heavy	H3	Vulcan	GSLV Mark III	Angara 5	Long March 5	Ariane 64
Industrial	Blue Origin	SpaceX	SpaceX	MHI	ULA	ISRO	Khrunichev	CALT	ArianeGroup
Country									
First launch	Q1 2021	03/12/2013	06/02/2018	Q2 2020	Q2 2021	05/06/2017	17/10/2016	03/11/2016	Q3 2020
GTO	13,6 t	8,3 t	8 t	6,5 t	7,4 t	4 t	7,5 t	14 t	10,5 t
Launch price	90 M$	62 M$	80 M$	50 M$	100 M$	62 M$	--	--	Smart price
Reusability	1st stage	Possible with GTO 3,5 t	1st stage + boosters	N/A	N/A	N/A	N/A	N/A	N/A

Launchers main characteristics







Launcher	New Glenn	Falcon 9	Falcon Heavy	H3	Vulcan	GSLV Mark III	Angara 5	Long March 5	Ariane 64
Tall	96 m	70 m	70 m	63 m	60 m	43,4 m	64 m	57 m	62 m
# Stage(s)	2	2	2	2	2	3	3	3	2
Booster (O/N)	N	N	O	O	O	= 1st stage	O	O	O
Thrust	17100 kN	7605 kN	22815 kN	11576 kN	8120 kN	10300 kN	9600 kN	10600 kN	15350 kN
ENGINES: Booster			18x Merlin	4x SRB-3	GEM-63XL	2x S200	4x RD191	8x YF-100	2x P120C
1st stage	7x BE-4	9x Merlin	9x Merlin	2x LE-9	2x BE-4	2x Vikas	1x RD191	2x YF-77	1x Vulcain 2.1
2nd stage	2xBE3U	1x Merlin V	1x Merlin V	1x LE-5B-3	2x RL-10C	1x CE-20	1x RD0124A	2x YF-75D	1x Vinci
3rd stage							BRIZ	1x YF-50D	

Towards a new paradigm?

2018 **2025** **2030**

Proton (Russia declining

Secondary actors
- Atlas / Delta IV (USA)
- H-II (Japan)
- GSLV Mk III (India)
- LM-3 (China)

Falcon 9 (USA): expandir

Development of partial reuse

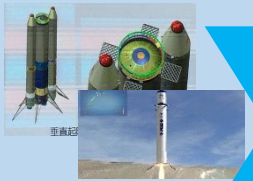
New conventional launchers

USA	China	Japan	India	Russia
Vulcan Omega	LM5 LM7 LM6	H3	ULV	Proton M Angara Soyouz 5

A

Low competitive potential but
- National autonomy (India, Japan often use of Ariane)
- Emerging markets (Africa, Asia)…

New partially reusable launchers



USA	USA	Chine
New Glenn	Vulcan Smart	Long March 8

➡ Fierce competition, price war...

B

New Paradigm?

- 100% reusable
- Intensive reuse (x 100)
- Extremely heavy (> 100t LEO)
- Launch cost < $10 million

- Cargo of satellites (GEO, LEO...)
- Lunar/martian missions,
- Inter-city manned flights...

Super heavy launchers 100% reusable

USA
BFR, New Armstrong

CNES FUTURE LAUNCHER

ROADMAP

Ariane: performance from 1979 to 2019

YESTERDAY

PERFORMANCE INCREASE

1979
Ariane 1

1,88
11 launches

1984
Ariane 3

2,17
6 launches

1986
Ariane 2

2,7
11 launches

1988
Ariane 4

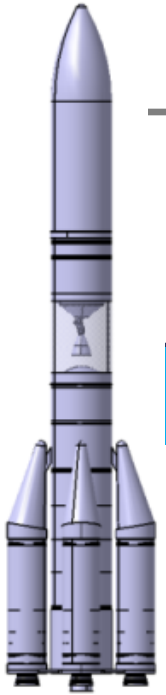
4,95
116 launches

1996
Ariane 5

10,8
103 launches

2019: 40 years of Ariane and it's just the beginning…

Todays driver: cost decrease !



2020

Ariane 6

Launc cost

- 50%

2030

Ariane Next

Launc cost

- 50%

COMING SOON

NEW LOGIC FOR FUTURE LAUNCHERS:

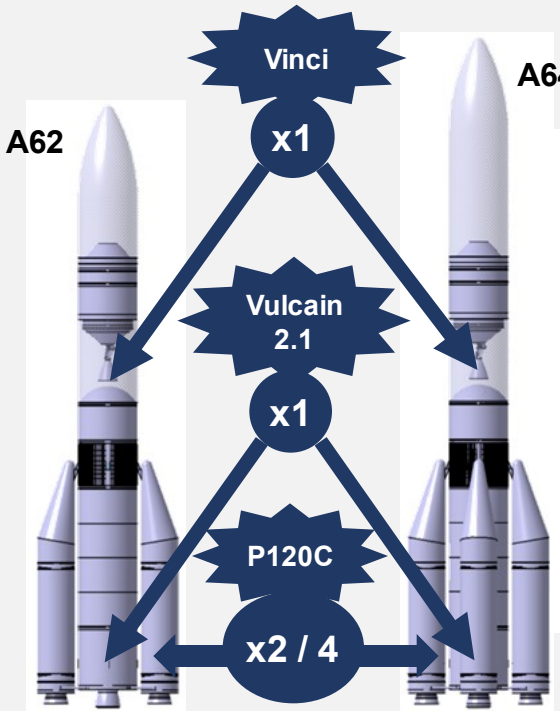
LAUNCH COST DECREASE

How to further reduce launch costs: main characteristics of a future launcher

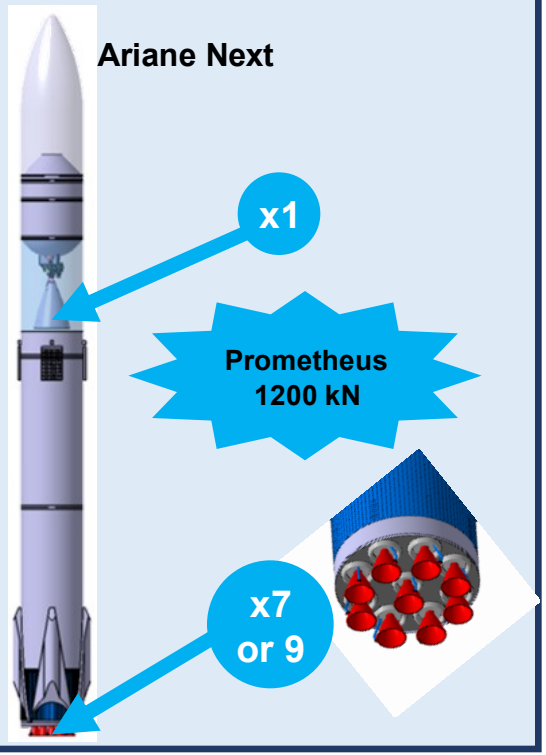
- **Simple** : two stage to orbit, one engine type
- Optimised for the **institutional missions**
- Compatible with **reusability**
- **Evolving** (heavy mission)

Ariane Next: launcher simplification

ARIANE 6 :
3 different engines
3 stages: LOX/LH2 & solid



ARIANE NEXT :
1 unique engine and propellant
2 stages



Reusability allows exploitation flexibility according to market evolution

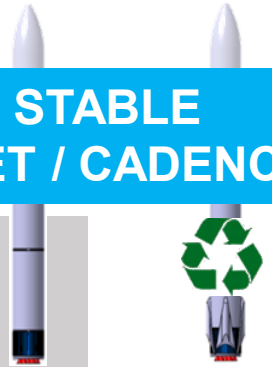
COMMERCIAL SPACE MARKET

MARKET EVOLUTION ?

↗ FLEXIBLE CADENCE WITH REUSABILITY

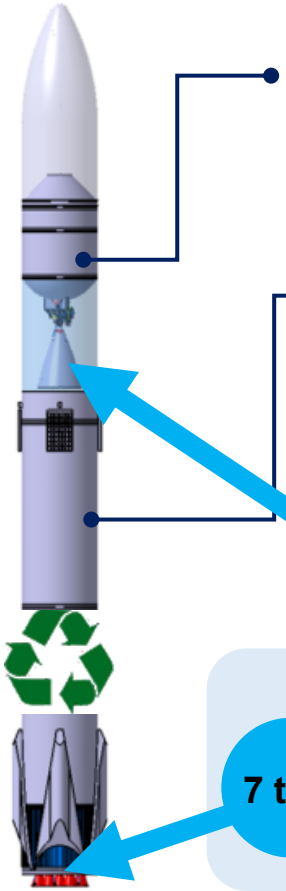
↗N (up to 25) launches/year

➔ STABLE MARKET / CADENCE



~10 launches/year

Ariane Next: a possible concept



- Satcom Telemetry
- Autonomous Flight Termination System
- « Pyro & helium free » architecture

~5 k$/kg GTO

- Reusable 1st stage architecture, toss back
- Standardized cryo tank
- Reconnectable connectors

Lower central core reused

- **Simple : 2 stages, 1 single engine type**
- **Reuse capacity, versatility (deep throttabillity, full electrical command,…)**
- **Low Cost 100 t class LOX/CH4 engine + mass production**
- **Evolutive (boosted version, exploration, manned flight)**

Ariane 6 / Ariane Next comparison

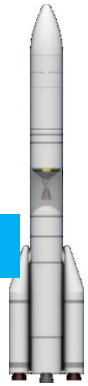
	ARIANE 6	ARIANE NEXT
Liquid Propulsion	1 Vinci & 1 Vulcain 2.1	**9 + 1 Prometheus**
Propellant	LOX/LH2	**LOX/CH4**
Mission modularity	2 or 4 P120C	**First stage recovery**
Tank	Specific for LOX and LH2	**Same for LOX and CH4**
Tall	62 m	**70 m**
GLOW	540 t (conf A62)	**790 t**
Launcher exploitation	Expendable	**Expendable / reusable**
Exploitation	Dual launch	**Single launch**
Launch cadence	Maxi 11	**Up to 25**
Performance	A62: 4,5 t GTO	**CC: 6,6 t GTO** 1500m/s
		CC-R : 4,5 t GTO 1800m/s
		CC-R : 5 t SSO
	A64: maxi 10,5 t GTO	

GAINS : **Mass production** **Cadence flexibility** **Low cost**

Major scale economy with Ariane Next
> through standardization and unification

DIVERSIFIED PRODUCTION

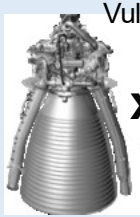
Ariane 6



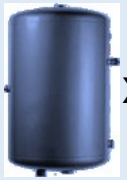
Central core

Vinci x10

Vulcain x10



LOX x10 LH2 x10



Upper stage tanks

LOX x10 LH2 x10

Lower stage tanks

~10 launches/year

STANDARDIZED PRODUCTION

Ariane Next

Central core

Prometheus x80 to x100

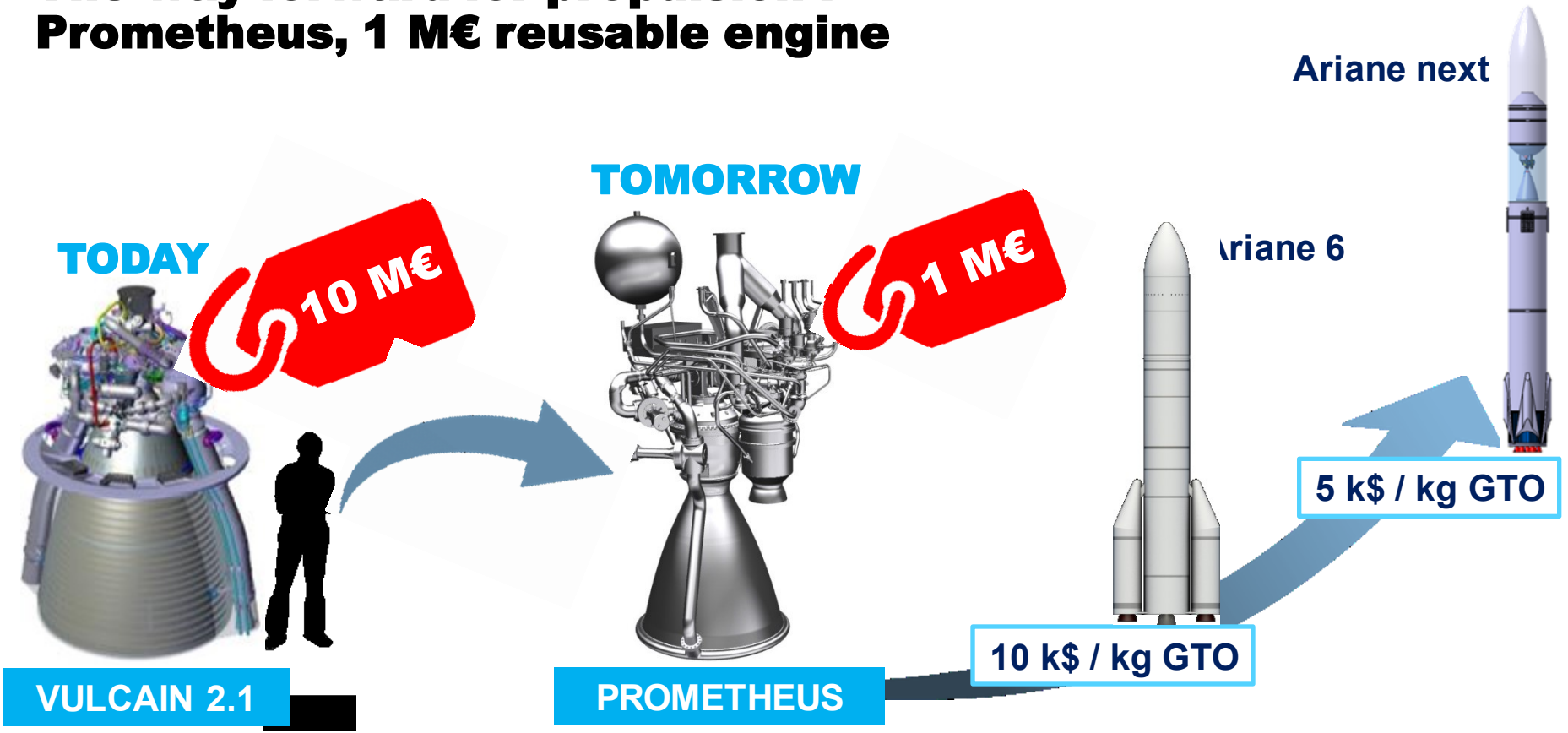
LOX or CH4 x20

Upper stage tanks

LOX or CH4 x20

Lower stage tanks

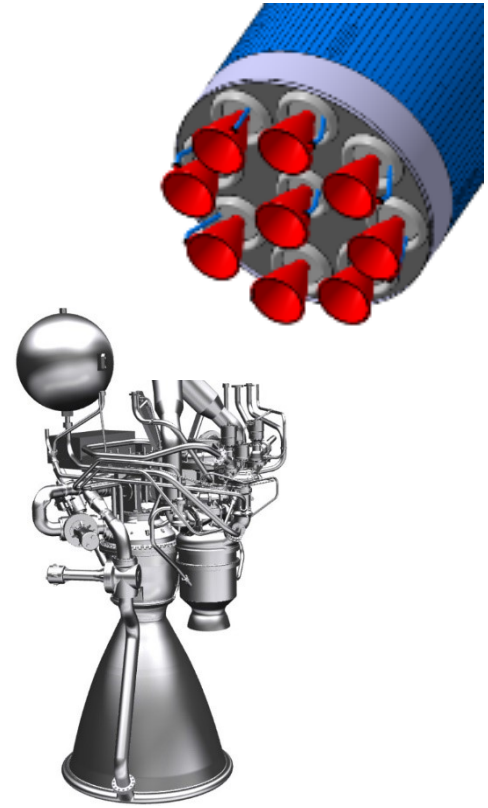
The way forward for propulsion : Prometheus, 1 M€ reusable engine



PROMETHEUS = **P**recursor **R**eusable **O**xygen **METH**ane cost **E**ffective Prop**U**lsion **S**ystem

Prometheus : An efficient versatile engine

Engine Characteristics	
Thrust (vacuum)	**1000 kN**
Engine Cycle	**Gas Generator**
ISP	**320 s (First Stage)** **360 s (Upper stage)**
Mass Target	**780 kg**
Fuel	**CH4 (methane)**
Oxidiser	**LOx (oxygen)**
Mixture Ratio	**3.4**
Chamber Pressure	**110 bars**
Throttling Capability	**30% to 110 % thrust**
Reusability potential	**Up to 5**
Additive Manufacturing	**Most of engine parts**



Roadmap: from techno bricks to launchers

Demonstrators and smart CSG:
➡ **to reduce cost and create options for launch system**

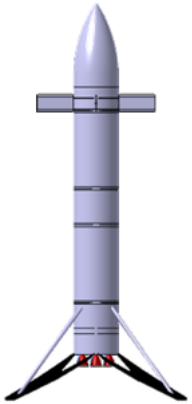
2019
Frog

2020-21
Prometheus

2021-22
Callisto

2022-25
Icarus

2022-25
Themis



2025 – 2030

Ariane Evolutio

Ariane Next

CSG NG

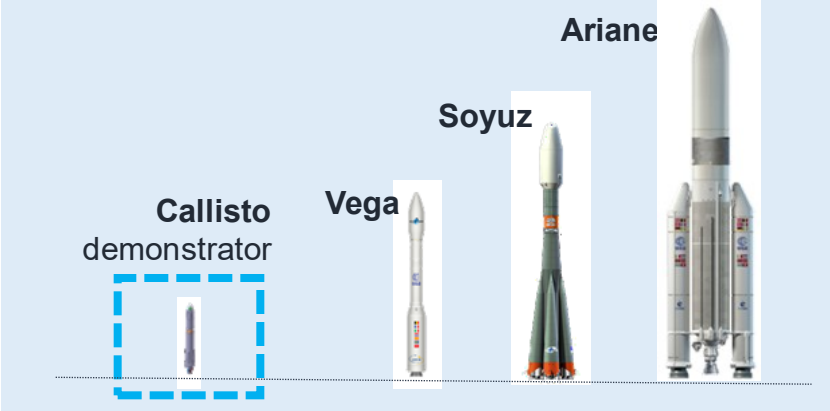
Why an in-flight system demonstration?

➔ Objective:
Acquire an experimental knowledge of the recovery and the reuse

- **Validate critical technologies/areas integrated into the system in representative environment**
- **Link technology performances to operational capability** in order to
  - **Validate** the concepts,
  - **Verify the cost model hypotheses**,
  - Identify **further enhancement**
- **Reduce risk of failure for the operational launch system**

CALLISTO

Cooperative
Action
Leading to
Launcher
Innovation in
Stage
Toss-back
Operations



Callisto mission (exemple)

> 5 FLIGHTS
with the same vehicle @ Kourou

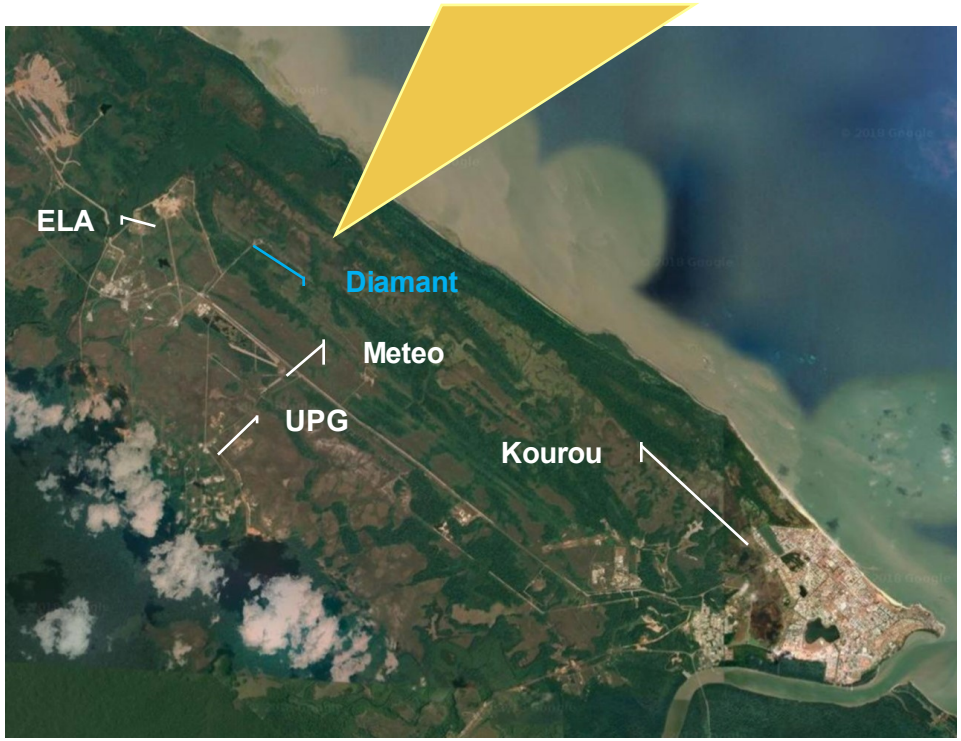
- Complex flight profiles
- Progressive increase of flight enveloppe

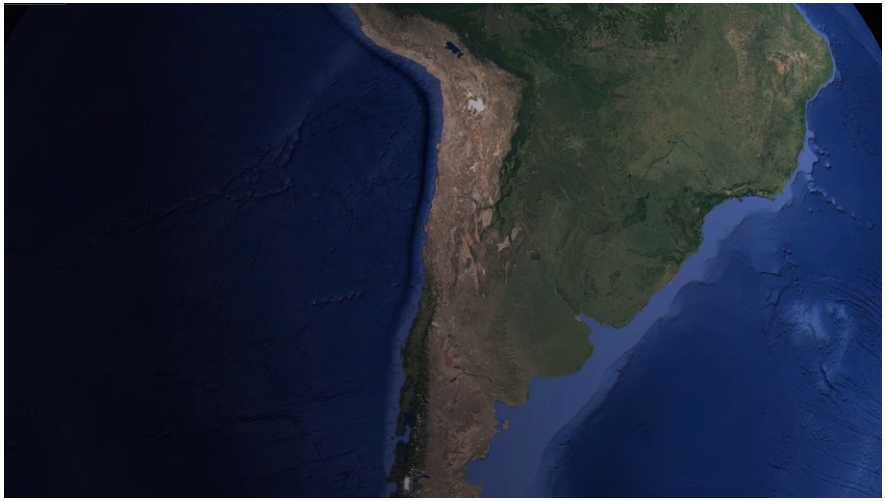
DIAMANT SITE

REFURBISHMENT

Diamant site will be used for demonstrator Callisto

- take-off site common to all trajectories
- envisaged landing site is a barge





The ArianeWorks acceleration platform

Scientific rocket, scout and humanist. All this mixed with an insatiable passion and curiosity, thanks to a young team from CNES and ArianeGroup to work on Themis.

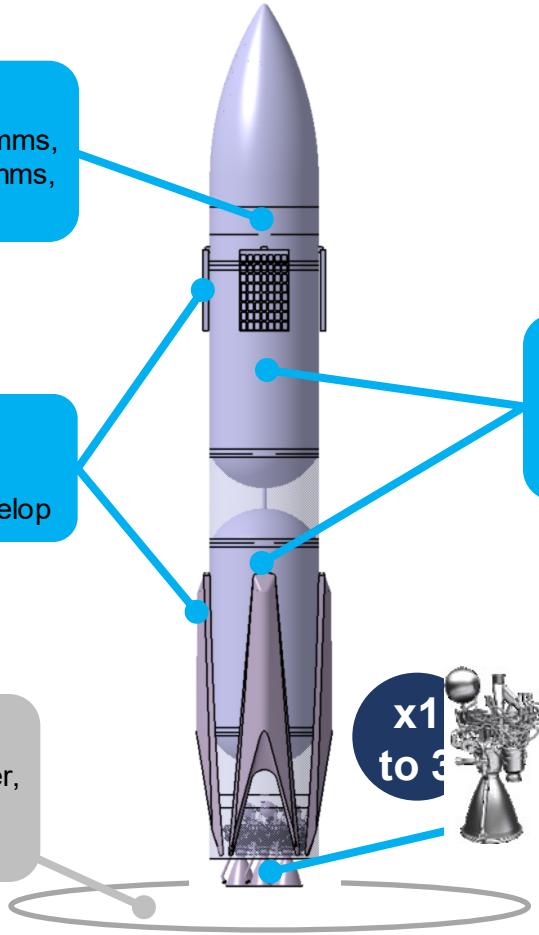
Themis single stage main elements and design

30 m tall

Avionics
Wireless interstage & ground comms, CALLISTO inherited flight algorithms, Health Monitoring System…

Recovery devices
Allowing Themis to explore a comprehensive 1st stage flight envelop

Ground segment
Launch from Kourou Space Center, Diamant or Fusée Sonde zone, Simplified Launch Ops



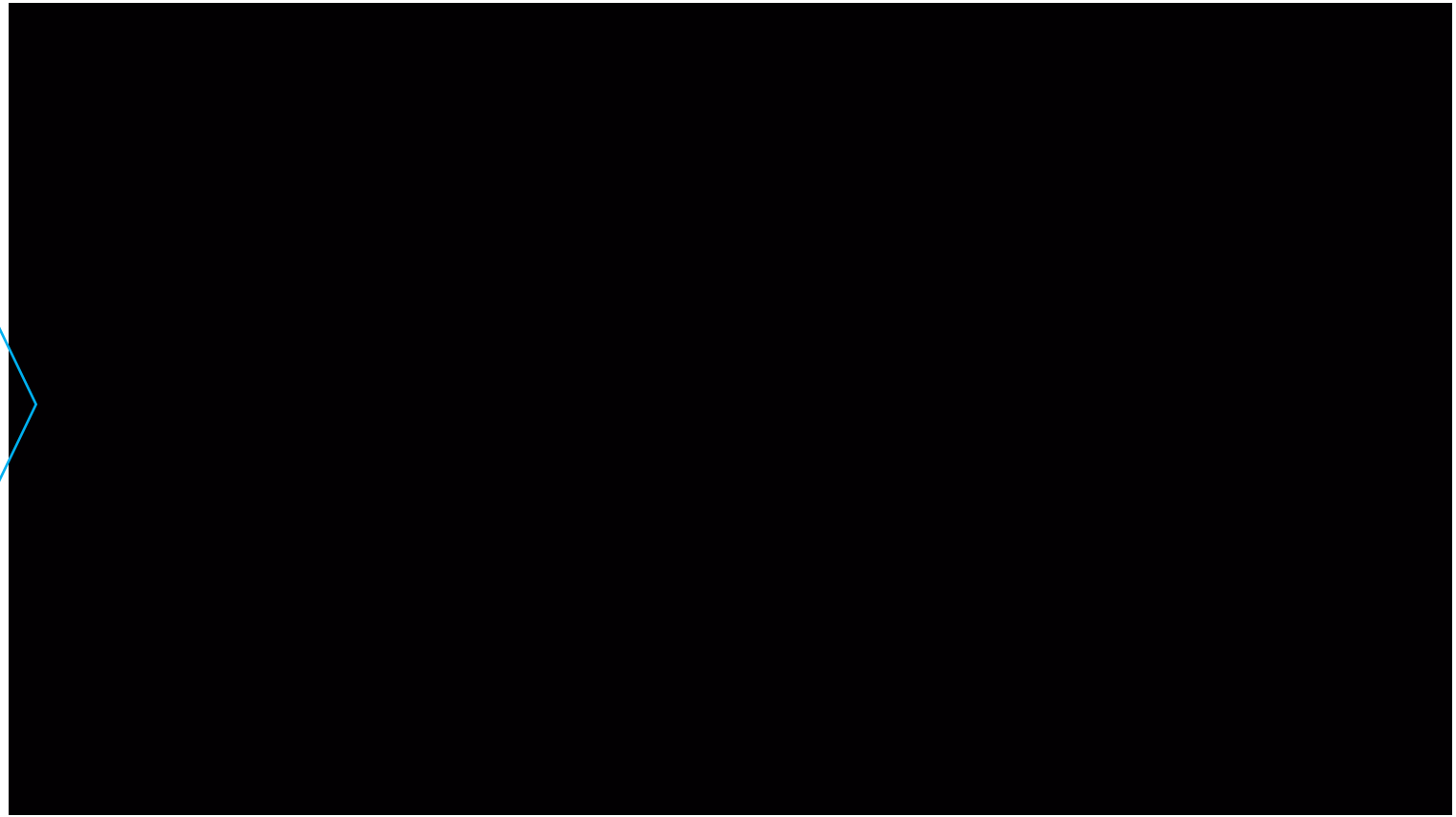
Oxygen & Methan tank
Standardized structures, featuring low cost next gen fluid equipments, and fueled by local BioCH4

x1 to 3

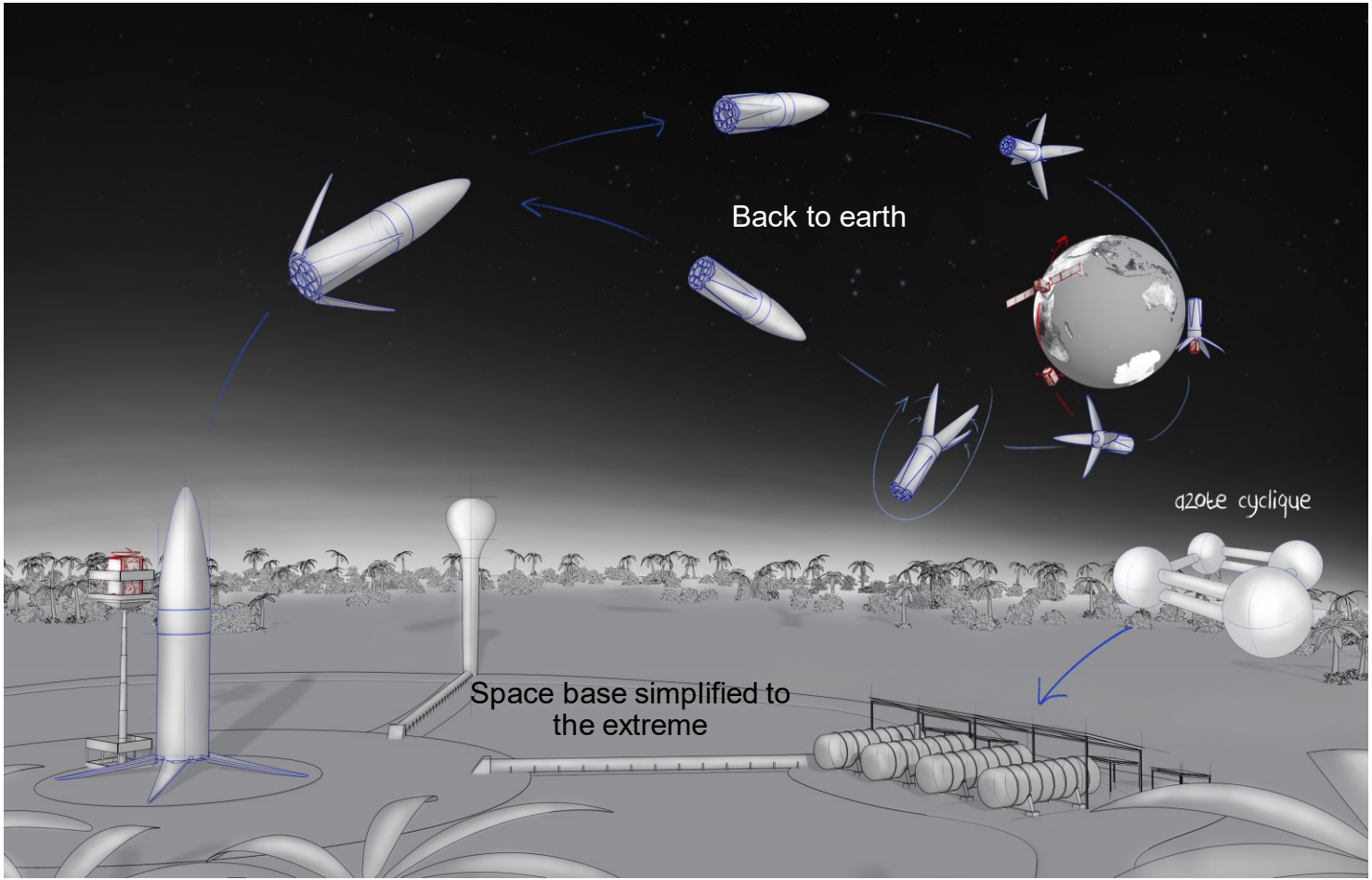
Prometheus low cost engine
1000 kN Oxygen/Methan

Toss-back demonstration flights : 2022-25

Themis demonstrator of reusable stage



Ariane Ultimate: year 2040…



- Single stage technology
- High performance fuel
- New materials
- New processors
- Flexible telemetry
- Robotics
- AI
- 3D printing
- Reusable protection components

CONCLUSION

Welcome in the world of launchers !